Advancing the Aquaculture Agenda

WORKSHOP PROCEEDINGS

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Foreword

The aquaculture sector is uniquely placed to complement production from the stagnating capture fisheries sector and it has advantages in terms of controllable production characteristics. However, aquaculture poses undeniable economic, environmental and social challenges which may be poorly evaluated or inadequately addressed within current policy frameworks. In such cases, the sustainability of future operations may be compromised. Issues that may constrain the sector development and performance are among others the business environment (*e.g.* competing uses of land and water; introduction of new technologies to improve the overall economic efficiency of aquaculture to better exploit natural conditions) and administrative and regulatory structures that create constraints rather than underpin further aquaculture developments (*e.g.* regulation of access to resources; environmental prescriptions).

With a view to collect further evidence and analysis on aquaculture development the OECD Committee for Fisheries in collaboration with the French Ministry for Food, Agriculture and Fisheries hosted a Workshop on *Advancing the Aquaculture Agenda: Policies to Ensure a Sustainable Aquaculture Sector* on 15-16 April 2010 in Paris. The main objective of the workshop was to provide a platform for policy makers, technical experts, international organisations, the private sector and NGOs to examine policy challenges that OECD governments face in aquaculture development. The event informed policy makers, in particular in OECD countries, about critical economic, environmental and social aspects of the aquaculture sector as well as interactions with other sectors.

The two day Workshop was chaired by Professor Torger Børresen, Research Director of DTU Food at the Technical University of Denmark and brought together over 80 participants from 25 countries. Case studies and presentations on Day 1 concentrated on country case studies on governance, on managing aquaculture generated externalities and on managing externalities affecting aquaculture. A panel session on best practices in aquaculture management and development was chaired by Alistair Lane of the European Aquaculture Society at the end of Day 1. The sessions on Day 2 focused on enhancing economic conditions for aquaculture – from a private and a public perspective - followed by presentations on cross-cutting issues, including feed issues, trade and policy coherence. Courtney Hough from the European Aquaculture Technology and Innovation Platform chaired a panel that further discussed policy issues related to enhancing economic conditions for aquaculture. The Workshop concluded with a panel chaired by Philippe Ferlin from the French Ministry for Food, Agriculture and Fisheries that distilled lessons for policy makers from the event.

Acknowledgements

The Workshop *Advancing the Aquaculture Agenda: Policies to Ensure a Sustainable Aquaculture Sector* organised by the OECD Fisheries Polices Division was made possible through the generous support from the French Ministry for Food, Agriculture and Fisheries. The OECD expresses its appreciation to the Workshop Chair and the Panel Chairs for leading the discussions as well as to the presenters and authors of the papers, the panellists and all participants attending the event. The OECD would in particular thank the Member Economies and Observers of the Committee for Fisheries that submitted country case studies, presented and participated in workshop panels.

The Workshop was organised by Nicole Franz (OECD) and Carl-Christian Schmidt with constant support from Cécile Bigot, Phillipe Ferlin and Sébastien Goupil from the French Ministry for Food, Agriculture and Fisheries. Emily Andrews-Chouicha, Nathalie Elisseou and Janet Schofield provided substantial administrative support. The publication has been prepared and edited by Emily Andrews-Chouicha (OECD), Nicole Franz (OECD), Karine Ravet (OECD), Carl-Christian Schmidt (OECD) and Tracey Strange (Consultant).

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Acronyms

ACFA	Advisory Council on Fisheries and Aquaculture
AD	Anti-Dumping
ANEP	Spanish National Agency for Evaluation and Foresight
ASC	Aquaculture Stewardship Council
BMP	Best (Better) Management Practice
CCRF	(FAO) Code of Conduct for Responsible Fisheries
CEE	Central and Eastern Europe (as aquaculture production region)
CFP	Common Fisheries Policy
CGRFA	Commission on Genetic Resources for Food and Agriculture
CMO	Common Market Organisation
CMSP	Coastal and Marine Spatial Planning
COFI	Committee on Fisheries (FAO governing body)
CTC	Carbon Trading Credits
DIP	Dissolved Inorganic Phosphate
EAA	Ecosystem Approach to Aquaculture
EAS	European Aquaculture Society
EATIP	European Aquaculture Technology and Innovation Platform
EEZ	Exclusive Economic Zone
EFF	European Fisheries Fund
EIA	Environmental Impact Assessment
FAO	Food and Agriculture Organisation of the United Nations
FDA	Fisheries Dependent Areas
FEAP	Federation of European Aquaculture Producers

FIFG	Financial Instrument for Fisheries Guidance (now the EFF)
FTE	Full-Time Equivalent (employees)
FW	Fresh Weight
GCI	Global Competitiveness Index
GHG	Greenhouse Gas
GMO	Genetically Modified Organism
HABs	Harmful Algal Blooms
HACCP	Hazard Analysis and Critical Control Points
ICZM	Integrated Coastal Zone Management
IMTA	Integrated Multi-Trophic Aquaculture
JACUMAR	Spanish National Advisory Board for Marine Farming
LDC	Least (or Less) Developed Countries
LIFDC	Low Income Food Deficit Country
MA	Millenium Ecosystem Assessment
MARA	Turkish Ministry of Agriculture and Rural Affairs
MIP	Minimum Import Price
MSC	Marine Stewardship Council
MDG	Millennium Development Goal
MOU	Memorandum of Understanding
MSMEs	Micro, Small and Medium Sized Enterprises
NACA	Network of Aquaculture Centres in Asia-Pacific
NGO	Non Governmental Organisation
NTC	Nutrient Trading Credits
OIE	World Organisation for Animal Health
OMZ	Oxygen Minimum Zone
PD	Pancreas Disease
RAS	Recirculated Aquaculture System
RPD	Redox Potential Discontinuity
R&D	Research and Development
SAV	Submerged Aquatic Vegetation
SME	Small and Medium Sized Enterprise

SPS	(WTO) Sanitary and Phytosanitary measures
SWOT	Strengths, Weaknesses, Opportunities and Threats
TBT	Technical Barriers to Trade
TL	Total Length
UNCED	UN Conference on Environment and Development
UNCTAD	UN Conference on Trade and Development
USPs	Unique Selling Points
WEF	World Economic Forum
WFE	Whole Fish Equivalent (weight)
WTO	World Trade Organisation
WWF	World Wide Fund for Nature

Chair's summary[1]

The UN Millennium Development Goals include cutting the share of the global population suffering from hunger by half by 2015[2]. Progress was steady at first - before the rise in food prices in 2008 and the global recession wiped out many of the gains. This may turn out to be merely a temporary setback. However, there are fears for longer term food security, with some experts even warning of a 'perfect storm' as population is forecast to grow by 50% from now to mid-century, while agricultural land is lost to urbanisation and climate change introduces a number of uncertainties. This pessimistic outlook assumes it will not be possible to increase food supplies fast enough to keep up with demand.

Against this background, aquaculture can play a role in contributing to food security. With many stocks fully exploited, there is little scope for expansion of capture fisheries. Annual average per capita consumption of capture fish actually fell by 10.6% over 1995-2007, from 10.6 to 9.5 kg per person. Aquaculture on the other hand has shown great potential. Globally, aquaculture has been the fastest growing animal food producing sector for over half a century, with production (excluding aquatic plants) expanding at 8.1% per year since 1961, compared with 3% for terrestrial farmed meat production, 3.4% for egg production, and 1.5% for milk production. Per capita consumption of fish from aquaculture grew from 4.3 to 7.5 kg over 1995-2007, an increase of 74%. However, wide differences are seen geographically as to the potential of aquaculture development.

In 2007, aquaculture overtook capture fisheries and supplied more than 50% of aquatic products for direct food consumption. Although climate change and other factors might constrain developments, there are powerful drivers for expansion, including population and income growth fuelling demand for aquatic foods, coupled with supply limitations from capture fisheries. Global output from aquaculture may need to increase from 52 million tonnes in 2007 to 80 million tonnes or more by 2030 to meet demand. Success is not guaranteed though and the sector will have to manage biological risks such as disease; system risks such as equipment failures and water problems; economic and market risks such as price volatility of inputs and products, changing consumer preferences due to dietary considerations and perceptions about aquaculture products; and political risks affecting for example the legal context for production or trade.

The workshop

With a huge market plus a dynamic, innovative supply chain in OECD countries backed up by solid research capacities, aquaculture's future is promising. It does however have to address a number of challenges from both inside and outside the sector if it is to realise its full potential.

As a contribution to this process, the OECD's Committee for Fisheries organised a workshop entitled *Advancing the Aquaculture Agenda: Policies to ensure a sustainable aquaculture sector*, hosted by the French Ministry for Food, Agriculture and Fisheries at

OECD Headquarters in Paris on 15-16 April, 2010. Policy makers, technical experts, international organisations, the private sector and NGOs took part in the workshop and contributed to examining policy challenges that governments face in aquaculture development. Over 80 participants used this platform to discuss the critical economic, environmental and social aspects of the aquaculture sector and analysed interactions with other sectors.

The objectives of the workshop were to:

- Provide participants with information about the "state of the art" and trends in aquaculture;
- Encourage mutual learning by sharing best practices and experiences in aquaculture management and development, including intersectoral aspects;
- Identify key areas for improving the business environment for aquaculture – including perspectives from the private sector and from international organisations and NGOs;
- Understand the opportunities and challenges of aquaculture for OECD countries with regard to policy coherence for development and
- Outline innovative pathways for sustainable aquaculture for OECD countries.

In 2009 the OECD Meeting of the Council at Ministerial Level adopted the Declaration on Green Growth[3]. As outlined in this Declaration, the OECD can, through policy analysis and identification of best practices, assist countries in their efforts to respond to the growing policy demands to foster green growth and work with countries to develop further measures to build sustainable economies. The aquaculture sector is well placed to pioneer the Green Growth approach and the workshop built extensively on case studies from OECD member economies and on insights from well established experts to share important experiences and identify best practices.

This report is the Chair's summary of the key messages coming out of the two-day event. It is based on the discussions that took place among participants and the important messages that are contained in the various presentations given at the workshop. Some of these presentations built on papers and case studies compiled in the following chapters of the proceedings. Some papers that could not be presented at the workshop and the outcome of an OECD *Survey on Conditions for Establishing Aquaculture Production Sites* are also included in the proceedings. The publication concludes with the biographies of the speakers and authors, followed by the list of participants.

Summary of discussions

Best practices in aquaculture management and development

The workshop put aquaculture in the broader context of food security and Green Growth. Global aquaculture production in 2007 was valued at USD 94.5 billion, for a total of 65.2 million tonnes, produced for the vast majority in developing countries. Although most aquaculture production derives from fewer than a dozen species (fish grown in ponds or cages, shrimp or prawn in ponds, molluscs and seaweeds in beds or on suspended lines) biodiversity in aquaculture is high, with over 340 different species of farmed aquatic plants and animals produced in 2007.

Unlike capture fisheries, where the bulk of harvested species are carnivores high on the aquatic food chain, the mainstay of farmed fish production are omnivorous and herbivorous species positioned lower on the chain (*e.g.* carps, tilapia, catfish). However, in OECD and other more advanced economies, high value, high trophic level carnivorous fish species are favoured, both in terms of production and in terms of consumption (*e.g.* salmon, sea bass and bream), reflecting market demand for these species.

The paper entitled *Growing the wealth of aquaculture: perspective and potential* comprehensively explores the features of the sector's recent growth, its emerging opportunities and constraints, across major producing regions, species groups and production systems. It defines and examines the conditions of development for the sector, and considers potential features of growth and expansion, commercial structure, trade, supply and value chain development, and the implications of these at strategic investment and policy levels. Many of these topics are further illustrated and expanded in these proceedings.

Aquaculture can contribute substantially to food security. The nutritional quality of seafood from aquaculture may help reduce the number of people suffering from malnutrition, the number one killer today. The protein and lipid quality of aquaculture products also plays an important role in developed countries. Recent research results show that lifestyle diseases such as overweight and obesity may be reduced on a seafood-rich diet.

The workshop discussions benefited extensively from OECD country case studies on best practices in aquaculture management and development, in particular with regard to governance, to managing aquaculture-generated externalities and to managing externalities affecting aquaculture. The country case studies were complemented by presentations on the EU-financed CONSENSUS[4] project which developed a multi-stakeholder platform for sustainable aquaculture in Europe; a presentation on integrated multi-trophic aquaculture (IMTA) as a responsible practice providing diversified seafood products while rendering services to the ecosystem and a presentation on hypoxia and eutrophication in marine waters.

Many of the challenges in aquaculture production, such as environmental externalities, are common to the food industry as a whole, and indeed are just as important for capture fisheries as for aquaculture. There are parallels to the patterns of intensification in agriculture, for instance in terms of conflicts over access to space and increases in negative environmental externalities. Agricultural productivity has expanded remarkably in a very short time due to massive improvements in production technologies and the "industrialisation" of animal rearing – now also observable in aquaculture production. Seafood availability has increased and consumers have benefited considerably, but the environmental price is high (*e.g.* in terms of pollution; threats to biodiversity; diseases). Better information is vital to understand the interactions between aquaculture and the environment and to tackle negative externalities. While the knowledge base on the challenges in aquaculture has advanced significantly over recent years, communication of that knowledge has been somewhat lacking. However, policy makers and the aquaculture sector in general are increasingly conscious of the challenges and are taking steps to address these issues, through mitigation activities as well as through more comprehensive sector strategies.

Despite its long history, aquaculture at the current commercial scale is still a rather young industry and the coming years are likely to see it undergo a number of transformations common to other sectors. These changes will be driven by economic factors, such as consolidation with more competitive enterprises taking over rivals, but also by technical factors to optimise production. For example, there is currently surprisingly little standardisation of equipment except for modern cages and some aerators and feeding systems, and system technologies are often borrowed from other branches such as marine engineering. Public policy shows a similarly wide variety of approaches, ranging from almost total neglect to highly focused support and control of the aquaculture sector.

Yet one recurring theme is the need for policy coherence to allow the sector to achieve its potential and to minimize conflicts with other competing resource users. Spain for example is currently implementing 17 national plans for the promotion and development of marine aquaculture. The original aims of the plans were to introduce new species into aquaculture production and to improve technical production conditions, but in recent years more focus has been given to environmental and health aspects, analytical methodologies, product quality, technologies and management and planning. The national plans are important contributions to improve competitiveness through the optimisation of production systems and the incorporation of new technologies; to stimulate research; to improve administrative processes and to generate knowledge on environmental aspects. The French administration on the other hand has concentrated interventions around three priorities: access to space (in particular in coastal areas), increased investment in research and development and communication campaigns to improve the sector's image.

In Ireland, the unique Co-ordinated Local Aquaculture Management Systems (CLAMS) process is a nationwide initiative to manage the development of aquaculture in bays and inshore waters throughout Ireland at a local level. In each case, the plan fully integrates aquaculture interests with relevant national policies, as well as: Single Bay Management practices, which were initially introduced by salmon farmers to co-operatively tackle a range of issues, and have been extended to all aquaculture species; the interests of other groups using the bays and inshore waters; Integrated Coastal Zone Management plans, and County Development plans.

Recommendations from a Chilean programme on combating sea lice include among other to establish a national surveillance and control system applicable to the whole industry and to coordinate treatments in connected geographic production areas. Norwegian experience underlines the important role of the regulatory authorities, not just in setting technical standards, but in making reporting of escapes mandatory and in defining a mechanism to analyze and learn from the collected information. In addition, compulsory, technical assessments to determine the causes of large-scale, escape incidents have proved their worth.

Dutch finfish farms have adopted a radically different approach to controlling environmental impacts. The sector is based solely on recirculation aquaculture systems (RAS), *i.e.* land-based fish production systems in which water from the rearing tanks is re-used after mechanical and biological purification to reduce water and energy consumption as well as nutrient emissions to the environment. The water consumption in RAS is entirely based on water exchange to compensate for evaporation, incidental losses and to control water quality. However, RAS imply high capital and operational costs, specific disease treatments and intensive management and skill requirements.

Sustainable aquaculture should be ecologically efficient, environmentally acceptable, product-diversified, profitable and beneficial to society. Integrated multi-trophic aquaculture (IMTA) pursues these objectives by cultivating fed species (*e.g.* finfish fed sustainable commercial diets) with extractive species, which utilise the inorganic (*e.g.* seaweeds) and organic (*e.g.* suspension- and deposit-feeders) excess nutrients from aquaculture for their growth. Thus, extractive species produce valuable biomass, while simultaneously rendering biomitigating services. In this way, some of the externalities of fed monoculture are internalised, increasing the overall sustainability, profitability and resilience of aquaculture farms. It was argued that the economic values of the environmental and societal services of extractive species should be recognized and accounted for in the evaluation of IMTA to create economic incentives to further develop and implement IMTA. Seaweeds and invertebrates produced in IMTA systems could be considered as candidates for nutrient/carbon trading credits within the broader context of ecosystem goods and services and IMTA could become an integral part of coastal regulatory and management frameworks. While the technical feasibilities of introducing IMTA on a larger scale has been proved in Asia, in many other parts of the world the rapid expansion of such systems is challenged by reasons of social acceptance.

In terms of policy challenges, discussions identified the crucial role of appropriate spatial management (marine, coastal, inland) and of stakeholder participation in aquaculture planning processes. To enable progress, producer compliance with regulations, the sectors' acceptance by third parties and policy coherence are also crucial elements. Aquaculture is in competition with other uses for (access to) water and land resources. It is influenced by the activities of other user and, in turn, can have an impact on them. In this regards, many OECD countries have already implemented zoning policies and established forms of stakeholder consultation platforms but that these instruments need to be adaptive so as to deal with emerging issues (*e.g.* new production techniques like off-shore farming; disease management; social implications of aquaculture). Effective communication lines between the stakeholders and policy makers are needed for this purpose.

Workshop participants also called for the development of the sectors' capacity to attract investment. This capacity depends among others on the efficiency of the licence/permit allocation system (in terms of timeliness, complexity, duration and renewal) which represents a form of 'political' risk for investors that needs to be added to the natural, systemic and the economic risks. The development of improved farming technologies (*e.g.* IMTA, RAS) and the adoption of best practices for disease, escape and environmental impact management are additional instruments to increase the economic performance – and hence investment attractiveness - of the aquaculture industry.

Enhancing economic conditions for aquaculture

There are common challenges for the public and the private sector in terms of science and research: for example 'green' technologies serve public sustainability objectives but also accommodate private needs to cut energy costs in production and to comply with increasingly stringent environmental regulations. Reducing production costs through improved efficiency is for example achieved through better fishmeal/oil-based feed formulation, alleviating simultaneously pressure on capture fish stocks.

All farmed species are susceptible to stress factors (*e.g.* stocking density, grading, mixing of species, predators, handling, transport, removal of fish from water, temperature changes, inadequate light). Fishes' responses to stress include hormone imbalance, osmoregulation disruption and immuno-suppression, amongst others. As a result, the fish is more susceptible to disease, and possibly prone to bacterial carriage, with possible consequences for product safety. Animal welfare is increasingly incorporated in best aquaculture practices or guidelines developed by both, public and private entities, and needs to find its way into the production cost equation. The European Food Safety Authority has already produced a number of recommendations, based on a risk assessment methodology to derive a qualitative ranking and identify significant hazards. The scores indicate why the hazard achieved a high score and support recommendations to improve the welfare of fish.

Markets for aquaculture products are changing. There is a trend towards contract buying based on fixed prices as demand is increasingly concentrated, in particular with major retail chains. Faced with relatively stagnating prices and competition from third countries, European aquaculture producers react with improving production efficiency and increasing concentration as the traditional small medium enterprise (SME) model become risky. To progress and potentially preserve the SME structure, the industry calls for harmonization in regulation, privileged lending rates, accessible venture capital and fiscal reductions for efforts in environmental investments. Sustainability was however acknowledged as the most important attribute for ensuring a positive future for the aquaculture industry.

A more sustainable sector would also reinforce positive consumer perceptions. As to the sector's image, overall, seafood products have a neutral to positive image, while consumer awareness about aquaculture remains rather low. When asked people tend to express a preference for wild fish, while in practice shoppers pay little attention to origin when buying fish products. Partly, this is because consumers' knowledge of aquaculture and fisheries is limited and the surveys reveal no consistent opinions regarding the taste of farmed products. Aquaculture products however have the intrinsic advantage of a relatively stable supply and lower prices compared to captured species. Those positive features are counterbalanced by negative perceptions about the use of fish meal/oil, hormones and drugs, and the environmental implications of aquaculture production.

Risk and uncertainty issues in aquaculture production are important. The main causes for loss in aquaculture are diseases, algae blooms and adverse weather conditions. Models developed to capture uncertainties and risks are based on collected and elaborated data and are supposed to reduce some of the uncertainty by forecasting risk and its impact. Being insured can facilitate access to capital and the adoption of best practices can hugely reduce risk and hence the insurance premium.

One of aquacultures main environmental impacts is on marine capture fisheries through demand for wild fish for feed. Feed is the biggest cost factor in carnivorous aquaculture and also one of the most criticised areas in terms of sustainability. It is therefore important that aquaculture pays particular attention to the efficient use of feeds and the inclusion of responsibly sourced ingredients. However, the protein conversion ratio is much better in finfish than in other animal productions. As an example 100 kg of feed pellets may produce 110 kg of trout, while it only produces 20 kg of poultry - the land animal with the most efficient feed conversion ratio. Increased uses of plant proteins as substitutes for fishmeal and fish oil in feed are under development.

With respect to aquaculture in developing countries, the future industry structure is likely to see increasing differentiation between globally competing producers that will integrate into modern supply chains in major markets; nationally and regionally specialised commercial sectors - mainly for prosperous urban markets - and local development of small-scale production for rural markets or specialised niche supplies. The small scale sector could however play an important role in rural development, food security and poverty eradication, Experience from Malawi where fish ponds were added to smallholdings shows that total farm productivity improved and that total farm income increased by 61%. As Africa and Asia become increasingly urbanised, there are likely to be new markets for fish products from peri-urban aquaculture as there are already for agriculture.

Fish products generally are amongst the most traded foods internationally, and OECD countries import around 60% of their supplies. However, despite a flourishing international trade, WTO agriculture agreements exclude fish, and there are no separate tariff lines for aquaculture products in most WTO member countries, except for Iceland and Norway. This means that there are no global trade statistics tracing aquaculture products. With the increasing importance of aquaculture production in international seafood trade this may however have to change in the future.

One particular market development triggered by the increase in aquaculture production concerns the role of standards and certification for aquaculture products. The increasing commercial success of some farmed species translates, in some cases, into the establishment of trade barriers: domestic industries in the US for example filed cases against imports of farmed shrimp, salmon and more recently Vietnamese pangasius. The industry has developed its own quality standards for the production of the major species. In many OECD countries, full traceability on inputs and rearing practices is imposed for assuring food safety. The Global Aquaculture Alliance, WWF's Aquaculture Dialogues and the Aquaculture Stewardship Council are examples of standard-owning entities that have recognised the need to boost the overall reputation of the industry.

Key messages

The main policy messages can be summarised as follows:

How can the contribution of aquaculture to food security, climate change adaptation and Green Growth be optimized?

The aquaculture sector is an important contributor to the Green Growth Agenda – but political will needs to be harnessed to further support Green Growth in aquaculture. This calls among other for:

- Risk reduction to encourage sustainable long-term investment in the capital intensive aquaculture sector in OECD countries:
  - Encourage and recognise the use of better/best practices by producers;
  - Support adaptive innovation (*e.g.* improved water use, selective breeding, feed formulation).
- Ensure acceptance of sustainable aquaculture by limiting negative externalities on the (marine) environment:
  - Develop innovative solutions (*e.g.* IMTA);
  - Optimize management of escapes, disease, pollution and other externalities;
  - Implement monitoring and early-warning systems.

- Improve the image of the industry:
  - Develop pro-active information exchange with society and policy-makers.

How to translate lessons learned from best practices into specific policy action?

- Galvanize political will:
  - Develop clear and realistic national or regional plans for aquaculture development;
  - Include aquaculture in marine, coastal and inland spatial planning to minimize conflict among user groups;
  - Develop flexible regulatory frameworks with coordination across government agencies and levels of government (*e.g.* agriculture, fish, urbanization);
  - Support targeted research and development to promote:
  - Use of green technologies and promotion of sustainable aquaculture species (*e.g.* in terms of feed, nutritional value, GMO);
  - Market-oriented production; benefitting from changing consumption patterns (*e.g.* healthy diet, preference for Omega3-rich food).

Timely and effective dialogue between all stakeholders: how can it be achieved?

- Ensure that stakeholders are involved in developing aquaculture plans and in their implementation;
- Consider commercial perspectives to serve public and private interests;
- Conduct information campaigns to make sure sustainable products and production methods are valued by the market and accepted by consumers.

Dealing with emerging issues: how to keep regulatory frameworks flexible?

If the aquaculture sector is to be sustainable, a holistic approach is needed in which profitability, environmental risk and social acceptability are defined and targeted, and where aquaculture is seen as part of a wider picture incorporating not only food supply, but also broader ecosystem services that either contribute to it and/or depend on it.

All workshop presentations are available on the OECD website – www.oecd.org/document/3/0,3343,en_2649_33901_44041283_1_1_1_37401,00.html#Presentations.

Notes

[1] By Professor Torger Børresen, DTU Denmark.

[2] Compared to 1990 values.

[3] www.oecd.org/dataoecd/58/34/44077822.pdf.

[4] www.euraquaculture.info.

Résumé du président[1]

Les objectifs du Millénaire pour le développement prévoient de réduire de moitié la proportion de la population qui souffre de la faim d'ici 2015[2]. Des progrès réguliers ont été accomplis dans un premier temps – avant que l'envolée des prix des produits alimentaires, en 2008, et la récession mondiale annulent une grande partie des bénéfices produits. Cette régression pourrait n'être qu'un simple incident de parcours. La sécurité alimentaire à long terme suscite toutefois des inquiétudes, certains experts craignant même une « véritable tempête » puisque les prévisions annoncent un doublement de la population d'ici le milieu du siècle alors que le territoire agricole diminue sous l'effet de l'urbanisation et que le changement climatique introduit de nombreuses incertitudes. Dans ce scénario pessimiste, l'offre alimentaire ne pourra pas progresser suffisamment vite pour répondre à la demande.

Dans ce contexte, l'aquaculture peut jouer un rôle important en faveur de la sécurité alimentaire. De nombreux stocks sont aujourd'hui pleinement exploités, c'est pourquoi la pêche n'offre guère de possibilités d'expansion. La consommation annuelle moyenne de poissons de pêche par habitant a reculé de 10.6 % entre 1995 et 2007, tombant de 10.6 à 9.5 kg par personne. L'aquaculture en revanche s'est révélée très prometteuse. A l'échelle mondiale, l'aquaculture est le secteur de production animale qui affiche les meilleurs chiffres de croissance depuis plus de cinquante ans, sa production (hors plantes aquatiques) progressant au rythme de 8.1 % par an depuis 1961, contre 3 % pour la production de viande d'animaux d'élevage terrestre, 3.4 % pour la production d'œufs, et 1.5 % pour celle de lait. La consommation par habitant de poissons d'élevage est passée de 4.3, à 7.5 kg entre 1995 et 2007, ce qui correspond à une hausse de 74 %. Toutefois, le potentiel de développement de l'aquaculture est très variable selon les régions.

En 2007, l'aquaculture a dépassé la pêche de capture en produisant plus de 50 % des produits aquatiques destinés à la consommation alimentaire directe. En dépit du changement climatique et des autres facteurs qui pourraient freiner son développement, certaines évolutions appuient fortement sa croissance, notamment l'augmentation de la population et des revenus qui stimule la demande de produits aquatiques, et la limitation de l'offre de la pêche de capture. Pour répondre à la demande, la production aquacole mondiale devra passer de 52 millions de tonnes en 2007, à 80 millions de tonnes voire plus en 2030. Cependant, la partie n'est pas gagnée et le secteur devra gérer un certain nombre de risques : biologiques (maladies, par exemple) ; systémiques (défaillances des équipements et problèmes d'eau) ; économiques et commerciaux (volatilité des prix des intrants et produits, évolution des préférences des consommateurs pour des raisons diététiques et de perception des produits d'élevage ; et politiques (modification du contexte juridique de la production ou des échanges, par exemple).

L'atelier

L'aquaculture, qui représente aujourd'hui dans les pays de l'OCDE un énorme marché et une filière dynamique et innovante, basée sur de solides capacités de recherche, est un secteur d'avenir. Toutefois, pour tenir ses promesses, il lui faudra relever un certain nombre de défis internes et externes,

Dans ce contexte, le Comité des pêcheries de l'OCDE a organisé un atelier intitulé *Faire progresser le dossier de l'aquaculture : Actions publiques pour un avenir durable de l'aquaculture*, qui a été accueilli par le ministère français de l'Alimentation, l'Agriculture et la Pêche au Siège de l'OCDE à Paris, les 15 et 16 avril 2010. Ont participé à cet atelier des dirigeants, des experts techniques ainsi que des représentants d'organisations internationales, du secteur privé et d'ONG, qui ont examiné ensemble les défis que pose aux gouvernements le développement de l'aquaculture. Plus de 80 participants ont utilisé cette plateforme pour passer en revue les aspects économiques, environnementaux et sociaux qui conditionnent l'aquaculture, et analyser les interactions avec les autres secteurs.

L'atelier avait pour objectifs :

- fournir aux participants des informations sur l'état actuel de l'aquaculture et ses évolutions ;
- encourager les acteurs à tirer des enseignements mutuels de leurs pratiques exemplaires et de leurs expériences dans le domaine de la gestion et du développement de l'aquaculture (sans omettre les aspects intersectoriels) ;
- identifier des domaines clés pour améliorer l'environnement économique de l'aquaculture – notamment du point de vue du secteur privé et des organisations internationales/ONG ;
- comprendre les opportunités et les enjeux de l'aquaculture pour les pays de l'OCDE s'agissant de la cohérence des politiques au service du développement ; et
- définir des pistes innovantes pour une aquaculture durable dans les pays de l'OCDE.

En 2009, le Conseil de l'OCDE réuni au niveau des ministres a adopté la Déclaration sur la croissance verte.[3] Comme l'indique cette Déclaration, l'OCDE, au travers de l'analyse des politiques et du recensement des pratiques exemplaires, peut soutenir les efforts déployés par les pays pour satisfaire aux exigences croissantes de politiques favorisant une croissance verte, et œuvrer avec les pays à l'élaboration de mesures complémentaires destinées à bâtir des économies durables. Le secteur de l'aquaculture est bien placé pour ouvrir la voie au projet de croissance verte, et l'atelier s'est largement appuyé sur les études de cas des économies membres de l'OCDE et sur les avis d'experts reconnus pour mettre en commun les expériences utiles et recenser les pratiques exemplaires.

Le présent rapport est le résumé du Président, qui récapitule les messages clés de ces deux journées de réflexion. Il rend compte des échanges de vues entre les participants et des principaux messages contenus dans les différents exposés présentés à l'atelier. Certains exposés se sont appuyés sur des rapports et études de cas qui ont été réunis dans les chapitres suivants des actes de l'atelier. Certains documents qui n'ont pu être présentés à l'atelier, de même que les résultats de l'*Enquête de l'OCDE sur les conditions de création de sites de production aquacole,* ont également été inclus dans ces actes. La publication comprend enfin les biographies des intervenants et des auteurs, suivies d'une liste des participants.

Résumé des débats

Pratiques exemplaires en matière de gestion et de développement de l'aquaculture

L'atelier a envisagé l'aquaculture dans le contexte plus large de la sécurité alimentaire et de la croissance verte. En 2007, la production aquacole mondiale était évaluée à 94.5 milliards USD, pour un total de 65.2 millions de tonnes produites principalement dans les pays en développement. Bien que le gros de la production aquacole repose sur moins d'une douzaine d'espèces (poissons élevés en bassins ou en cages, crevettes cultivées en bassins ou en étangs, mollusques et algues élevés en culture à plat ou suspendue), la biodiversité de l'aquaculture est élevée puisque qu'elle comptait en 2007 plus de 340 espèces de plantes et animaux aquatiques.

Contrairement à la pêche, où les captures sont essentiellement des espèces carnivores marines situées à un échelon élevé de la chaîne alimentaire aquatique, la production aquacole est essentiellement constituée de poissons omnivores et herbivores situés aux niveaux inférieurs de la chaîne alimentaire (carpe, tilapia et poisson-chat, par exemple). Toutefois, dans les pays de l'OCDE et d'autres économies plus avancées, les espèces carnivores de grande valeur situées en haut de la chaîne trophique (saumon, bar et dorade, par exemple) sont privilégiées par les producteurs mais aussi par les consommateurs, comme le montre la demande de ces produits.

Le document intitulé *Growing the wealth of aquaculture: perspective and potential* propose une étude très complète des caractéristiques de la croissance enregistrée récemment dans le secteur, ainsi que des nouvelles opportunités et contraintes auxquelles il doit faire face, en s'intéressant aux principales régions productrices, groupes d'espèces et systèmes de production. Il définit et passe en revue les conditions nécessaires au développement du secteur, et examine quelles pourraient être les caractéristiques de la croissance et de l'expansion, de la structure commerciale, des échanges, de l'offre et de l'évolution de la chaîne de valeur, et ce qu'elles impliquent du point de vue de l'investissement stratégique et de l'action publique. Bon nombre de ces questions sont illustrées et développées dans les actes de l'atelier.

L'aquaculture peut jouer un rôle important en faveur de la sécurité alimentaire. Les qualités nutritionnelles de la production aquacole pourraient permettre de réduire le nombre de personnes victimes de la malnutrition, première cause de décès aujourd'hui. La qualité des protéines et des lipides contenus dans les produits aquacoles joue aussi un rôle important dans les pays développés. Selon des recherches récentes, les régimes riches en aliments d'origine marine pourraient contribuer à faire reculer les maladies liées au mode de vie, telles que le surpoids et l'obésité.

Les débats de l'atelier ont largement mis à profit les études de cas des pays de l'OCDE sur les pratiques exemplaires de gestion et de développement aquacoles, notamment en matière de gouvernance et de gestion des externalités produites par l'aquaculture et des externalités affectant ce secteur. Les études de cas nationales ont été complétées par des exposés sur le projet CONSENSUS[4] financé par l'UE qui a mis en place une plateforme multipartite pour l'aquaculture durable en Europe ; une présentation sur l'aquaculture multitrophique intégrée (IMTA) en tant que pratique responsable alliant fourniture de produits de la mer diversifiés et services écosystémiques, et une présentation sur l'hypoxie et l'eutrophisation des eaux marines.

Beaucoup des enjeux auxquels se trouve aujourd'hui confrontée l'aquaculture, notamment les externalités environnementales, rejoignent ceux que l'on rencontre dans l'industrie agro-alimentaire, et concernent tout autant la pêche que l'aquaculture. Un parallèle peut être fait avec l'intensification de l'agriculture, si l'on considère par exemple les conflits d'accès à l'espace et l'accroissement des externalités environnementales négatives. La productivité agricole a fait en très peu de temps des progrès remarquables grâce à l'amélioration massive des technologies de production et à « l'industrialisation » de l'élevage – phénomène que l'on observe également aujourd'hui en aquaculture. L'offre de produits de la mer a augmenté, au grand bénéfice des consommateurs, mais le prix environnemental à payer est élevé (pollution, menaces sur la biodiversité, maladies, par exemple). Il est indispensable d'améliorer l'information pour comprendre les interactions entre l'aquaculture et l'environnement et s'attaquer aux externalités négatives. Si les connaissances accumulées ces dernières années permettent de mieux comprendre les enjeux de l'aquaculture, la communication de ces connaissances n'a pas été suffisante. Les responsables des politiques et le secteur de l'aquaculture en général sont néanmoins de plus en plus conscients des enjeux et prennent des mesures pour s'y attaquer en cherchant à atténuer les effets de leurs activités ou en adoptant des stratégies sectorielles plus globales.

Bien que pratiquée depuis des siècles, l'aquaculture à son stade de développement commercial actuel reste une industrie relativement jeune et devrait, à l'instar des autres secteurs, subir de nombreuses transformations dans les prochaines années. Ces changements résulteront de facteurs économiques (fusions-acquisitions au profit des entreprises les plus compétitives) mais aussi techniques (optimisation de la production). Ainsi à l'heure actuelle, les équipements, à l'exception des cages modernes et de certains systèmes d'aération et d'alimentation, sont étonnamment peu standardisés et les technologies sont souvent empruntées à d'autres branches d'activité, notamment la mécanique navale. De même l'action publique revêt des formes très diverses, qui vont du laisser-faire presque total à des mesures d'aides et de contrôle très ciblées visant spécifiquement le secteur aquacole.

Cependant, la nécessité d'assurer la cohérence des politiques pour permettre au secteur d'exploiter pleinement son potentiel et de limiter au minimum les conflits avec les autres candidats à l'utilisation des ressources fait partie des thèmes récurrents. L'Espagne, par exemple, applique actuellement 17 plans nationaux de promotion et développement de l'aquaculture marine. Ces plans visaient initialement à introduire de nouvelles espèces en aquaculture et à améliorer les conditions techniques de production, mais depuis quelques années, ils mettent davantage l'accent sur les aspects environnementaux et sanitaires, les méthodes d'analyse, la qualité des produits, les technologies et la gestion/planification. Ces plans nationaux jouent un rôle important pour améliorer la compétitivité en optimisant les systèmes de production et en introduisant de nouvelles technologies ; stimuler la recherche ; améliorer les procédures administratives et produire des connaissances sur les aspects environnementaux. L'administration française a, quant à elle, concentré son action autour de trois axes prioritaires : accès à l'espace (dans les zones littorales notamment), investissement accru en faveur de la recherche et développement et campagnes de communication pour améliorer l'image du secteur.

Les recommandations d'un programme chilien de lutte contre le pou de mer prévoient entre autres la mise en place d'un système national de surveillance et de contrôle applicable à tout le secteur et une coordination des traitements dans les zones de production géographiquement liées. L'expérience de la Norvège met en évidence le rôle important des autorités de réglementation, non seulement pour établir les normes techniques, mais aussi pour imposer l'obligation de notifier les fuites de poissons d'élevage et établir un mécanisme permettant de les analyser et de tirer les enseignements des informations collectées. Les évaluations techniques obligatoires pour déterminer les causes d'échappements massifs se sont également révélées très précieuses.

Les éleveurs de poisson néerlandais ont choisi une voie radicalement différente pour réduire leur impact sur l'environnement. Tout le secteur utilise des systèmes piscicoles en circuit recirculé c'est-à-dire des systèmes de production installés à terre dans lesquels l'eau des bassins d'élevage est réutilisée après épuration mécanique et biologique afin de réduire la consommation d'eau et d'énergie ainsi que les rejets d'éléments nutritifs dans l'environnement. La consommation d'eau de ces systèmes est entièrement basée sur le renouvellement de l'eau pour compenser l'évaporation et les fuites accidentelles et pour maîtriser la qualité de l'eau. Ces systèmes impliquent toutefois des dépenses d'investissement et des coûts d'exploitation élevés, des traitements vétérinaires spécifiques, une gestion intensive et des compétences.

L'aquaculture durable devrait être écologiquement efficace, acceptable pour l'environnement, source de produits diversifiés, rentable et bénéfique pour la société. L'aquaculture multitrophique intégrée (IMTA) vise justement ces objectifs en associant la culture d'espèces d'élevage (poissons nourris avec des aliments commerciaux durables) et celle d'espèces extractives qui utilisent pour se nourrir les matières inorganiques (algues, par exemple) et organiques (sous-produits en suspension et dépôts) issues de l'aquaculture. Les espèces extractives produisent ainsi une précieuse biomasse tout en assurant simultanément des services de biomitigation. De cette façon, les externalités de la monoculture aquacole sont en partie internalisées, ce qui améliore la viabilité, la rentabilité et la résilience générales des fermes aquacoles. D'aucuns ont fait valoir que la valeur économique des services environnementaux et sociétaux des espèces extractives devait être reconnue et prise en compte dans l'évaluation de l'IMTA afin de créer des incitations économiques propices à son développement et sa mise en œuvre. Les algues et les invertébrés produits dans les systèmes d'IMTA pourraient être comptabilisés dans les systèmes d'échange de crédits éléments nutritifs/carbone dans le contexte plus large des biens et services fournis par les écosystèmes et l'IMTA pourrait devenir partie intégrante des cadres de réglementation et de gestion côtières. Si la faisabilité technique à grande échelle de ces systèmes a été prouvée en Asie, dans de nombreuses autres régions du monde, leur expansion est freinée par le fait qu'ils ne sont pas toujours acceptés par la société.

S'agissant des défis à relever par les pouvoirs publics, les participants ont appelé l'attention sur le rôle déterminant d'une bonne gestion de l'espace (marin, côtier, continental) et de la participation des acteurs concernés à la planification des activités aquacoles. Il est également indispensable, pour pouvoir progresser, de veiller au respect de la réglementation par les producteurs, à l'acceptation du secteur par les tierces parties et à la cohérence des politiques. L'aquaculture est en concurrence avec d'autres activités pour utiliser l'eau et les ressources terrestres (y avoir accès). Elle est influencée par les activités des autres utilisateurs et peut avoir elle-même des effets sur ces activités. A cet égard, de nombreux pays de l'OCDE appliquent déjà des politiques de zonage et ont mis en place divers types de plateformes de consultation des parties prenantes mais ces instruments doivent pouvoir être adaptés en fonction des problèmes qui se font jour (nouvelles techniques de production comme l'élevage en mer ; gestion des maladies ; implications sociales de l'aquaculture, par exemple). Les acteurs concernés et les pouvoirs publics doivent disposer de circuits de communication efficaces à cet effet.

Les participants à l'atelier ont aussi constaté qu'il était nécessaire de renforcer l'attrait du secteur pour l'investisseur. L'attrait exercé dépend notamment de l'efficience des systèmes de délivrance de licences/permis (rapidité, complexité, durée et renouvellement) qui représentent pour les investisseurs une forme de risque « politique » qui s'ajoute aux risques naturels, systémiques et économiques. Le développement de techniques d'élevage améliorées (IMTA, élevage en circuit recirculé, par exemple) et l'adoption de pratiques exemplaires de gestion des maladies, des fuites de poissons et des impacts sur l'environnement peuvent permettre aussi d'améliorer la performance économique – et partant l'attrait pour l'investisseur – du secteur aquacole.

Améliorer les conditions économiques de l'aquaculture

Le secteur public et le secteur privé se trouvent confrontés à des enjeux communs dans le domaine de la science et la recherche : pour citer un exemple, les technologies « vertes » répondent aux objectifs publics de durabilité mais également aux besoins des acteurs privés qui cherchent à réduire le coût énergétique de la production et respecter des normes environnementales de plus en plus contraignantes. Il est ainsi possible de réduire les coûts de production par des gains d'efficacité obtenus grâce à l'amélioration de la composition des aliments à base de farine/d'huile de poisson, amélioration qui permet aussi d'alléger les pressions sur les stocks de poissons sauvages

Toutes les espèces d'élevage sont sensibles aux facteurs de stress (densité de la population, tri, mélange des espèces, prédateurs, manipulations, transport, retrait des poissons de l'eau, variations de température, éclairage inadéquat, par exemple). Les situations de stress provoquent chez le poisson diverses réponses : déséquilibre hormonal, troubles de l'osmorégulation et immuno-suppression, pour n'en citer que quelques unes. Le poisson est alors plus exposé aux maladies et, dans certains cas, au portage bactérien, ce qui peut avoir des conséquences pour la sécurité des produits. Les considérations de bien-être animal sont de plus en plus souvent intégrées dans les pratiques exemplaires ou lignes directrices pour l'aquaculture établies par les instances tant publiques que privées, et doivent trouver leur place dans les calculs de coûts de production. L'Autorité européenne de sécurité des aliments a déjà publié plusieurs recommandations, et établi, à l'aide d'une méthodologie d'évaluation des risques, une échelle qualitative des dangers permettant de mettre en évidence les dangers importants. La notation indique pourquoi le danger atteint un niveau élevé et renvoie à des recommandations visant à améliorer le bien-être des poissons.

Les marchés des produits aquacoles évoluent. Les achats contractuels basés sur des prix convenus semblent avoir actuellement le vent en poupe, en présence d'une demande de plus en plus concentrée, émanant en particulier des grandes chaînes de distribution. Face à la relative stagnation des prix et à la concurrence des pays tiers, les aquaculteurs européens tentent d'accroître l'efficience de la production et s'orientent vers une plus grande concentration, le modèle traditionnel des PME devenant risqué. Pour progresser et préserver si possible la structure des PME, le secteur souhaite voir la réglementation harmonisée, bénéficier de taux de prêt avantageux, avoir accès au capital-risque et obtenir des réductions d'impôt en échange des investissements consentis en faveur de l'environnement. La durabilité apparaît cependant comme le principal atout sur lequel l'aquaculture doit miser pour assurer son avenir.

Miser sur la durabilité permettrait en outre d'améliorer la perception du secteur par les consommateurs. Les produits de la mer, tout comme l'ensemble de la filière, ont une image neutre à positive, mais les consommateurs connaissent assez mal l'aquaculture. Lorsqu'on les interroge, ils disent plutôt préférer le poisson sauvage, mais dans la pratique, les acheteurs accordent assez peu d'attention à l'origine du poisson qu'ils choisissent. Cette situation s'explique en partie par le fait que les consommateurs ne savent pas grand-chose de l'aquaculture et de la pêche et les enquêtes ne révèlent pas d'opinion marquée en ce qui concerne le goût des produits d'élevage. Les produits aquacoles ont toutefois pour atout le maintien d'une offre relativement stable et des prix plus bas que ceux des espèces pêchées. Ces avantages sont toutefois contrebalancés par la façon négative dont sont perçus l'utilisation de farines/huiles de poisson, d'hormones et de médicaments et les incidences de l'aquaculture sur l'environnement.

Les questions de risques et d'incertitudes occupent une place importante en aquaculture. Les causes de pertes dans ce secteur sont principalement les maladies, la prolifération d'algues et les mauvaises conditions météorologiques. Les modèles mis au point pour tenir compte des incertitudes et des risques, qui s'appuient sur l'ensemble des données collectées et traitées, sont supposés réduire une partie des incertitudes en anticipant les risques et leurs impacts. Le fait d'être assuré peut faciliter l'accès au capital et l'adoption de pratiques exemplaires peut considérablement réduire les risques, et partant les primes d'assurance.

L'un des principaux impacts environnementaux de l'aquaculture s'exerce sur la pêche marine qui doit fournir le poisson sauvage nécessaire pour produire les aliments de pisciculture. L'alimentation est le premier facteur de coûts des élevages de poisson carnivores et également l'un des éléments les plus critiqués en termes de durabilité. L'aquaculture doit donc s'efforcer d'utiliser les aliments de façon efficiente et d'y inclure des ingrédients issus de pratiques responsables. Cependant, le rendement protéique du poisson est bien plus élevé que celui des autres productions animales. Par exemple 100 kg de granulés peuvent produire 110 kg de truite, mais seulement 20 kg de volaille (espèce terrestre présentant le meilleur rendement protéique). L'utilisation accrue de protéines végétales pour remplacer les farines et huiles de poisson dans l'alimentation des poissons d'élevage est actuellement étudiée.

Dans les pays en développement, la structure de l'aquaculture devrait évoluer vers une plus grande différentiation entre les producteurs rivalisant sur le marché mondial qui intégreront les filières d'approvisionnement modernes sur les grands marchés ; les secteurs commerciaux spécialisés au plan national et régional –principalement sur les marchés urbains prospères – et le développement d'entreprises à petite échelle fournissant les marchés ruraux ou des niches spécialisées. Le secteur des petites entreprises pourrait toutefois jouer un rôle important dans le développement rural, la sécurité alimentaire et l'éradication de la pauvreté, L'expérience du Malawi où des étangs d'élevage ont été installés dans les petites exploitations indique une amélioration de la productivité totale des exploitations et une hausse de 61 % de leurs revenus totaux. A mesure de la progression de l'urbanisation en Afrique et en Asie, de nouveaux marchés devraient voir le jour pour les produits de l'aquaculture périurbaine comme c'est déjà le cas pour les produits agricoles.

Les produits halieutiques figurent généralement en bonne place dans les échanges internationaux de produits alimentaires et les pays de l'OCDE importent près de 60 % de leurs approvisionnements. Cependant, bien que le commerce international soit florissant, les accords agricoles de l'OMC excluent le poisson, et il n'existe pas de ligne tarifaire séparée pour les produits de l'aquaculture dans la plupart des pays membres de l'OMC à l'exception de l'Islande et de la Norvège. Cela signifie qu'il n'existe pas non plus de statistiques du commerce mondial pour les produits aquacoles. Compte tenu de l'importance de ces produits dans les échanges internationaux de produits de la mer cette situation devra changer.

L'une des évolutions commerciales résultant de l'essor de la production aquacole concerne le rôle des normes et de la certification des produits aquacoles. Le succès commercial croissant de certaines espèces d'élevage se traduit, dans certains cas, par la mise en place d'obstacles aux échanges : aux États-Unis, par exemple, des entreprises ont dénoncé l'importation de crevettes et de saumons d'élevage et plus récemment de pangasius vietnamien. Le secteur a établi ses propres normes de qualité pour les principales espèces produites. De nombreux pays de l'OCDE exige l'entière traçabilité des intrants et des pratiques d'élevage afin d'assurer la sécurité des aliments. L'Alliance mondiale pour l'aquaculture, les Dialogues aquaculture du WWF et le Conseil pour une bonne gestion de l'aquaculture (Aquaculture Stewardship Council) sont des exemples d'entités émettrices de normes qui ont reconnu la nécessité d'améliorer la réputation générale du secteur.

Principaux messages

Les principaux messages pour l'action peuvent se résumer comme suit :

Comment optimiser la contribution de l'aquaculture à la sécurité alimentaire, à l'adaptation au changement climatique et à la croissance verte ?

Le secteur de l'aquaculture occupe une place importante dans le dossier de la croissance verte – mais une réelle volonté politique est nécessaire pour l'engager sur cette voie. Il conviendra pour cela de :

- Réduire les risques pour encourager les investissements durables à long terme dans l'industrie aquacole des pays de l'OCDE, qui est un secteur à forte intensité de capital :
  - Encourager et reconnaître l'utilisation de pratiques plus satisfaisantes/exemplaires par les producteurs ;
  - Favoriser l'innovation adaptative (meilleure utilisation de l'eau, élevage sélectif, composition de l'alimentation, par exemple).
- Faire accepter l'aquaculture durable en limitant les effets externes négatifs sur l'environnement (marin) :
  - Mettre au point des solutions innovantes (IMTA, par exemple) ;
  - Optimiser la gestion des fuites de poissons, des maladies, de la pollution et des autres externalités ;
  - Mettre en œuvre des systèmes de suivi et d'alerte précoce.

- Améliorer l'image du secteur :
    - Mettre an place un système dynamique d'échange d'informations avec la société et les responsables des politiques.

Comment transposer les enseignements tirés des pratiques exemplaires dans l'action publique ?

- Galvaniser la volonté politique :
    - Élaborer des plans nationaux ou régionaux clairs et réalistes en faveur du développement de l'aquaculture ;
    - Inclure l'aquaculture dans la planification des espaces marins, côtiers et terrestres afin de limiter au maximum les conflits entre groupes d'utilisateurs ;
    - Établir des cadres réglementaires souples en veillant à la coordination entre les différents organismes gouvernementaux et niveaux d'administration (agriculture, pêche/aquaculture, urbanisation) ;
    - Soutenir la R-D ciblée afin d'encourager :
        - L'utilisation de technologies vertes et la promotion d'espèces aquacoles durables (en termes d'alimentation, de valeur nutritionnelle, d'OGM, par exemple ;
        - Une production répondant aux besoins du marché ; mettant à profit l'évolution des modes de consommation (alimentation saine, préférence pour les aliments riches en omégas-3, par exemple).

Assurer un dialogue efficace adapté aux besoins du moment entre les parties prenantes : comment procéder ?

- Veiller à ce que les acteurs intéressés soient associés à l'élaboration et la mise en œuvre des plans concernant l'aquaculture ;
- Étudier les perspectives commerciales dans le souci des intérêts publics et privés ;
- Mener des campagnes d'information pour assurer la valorisation des produits et méthodes de production durables sur le marché et leur acceptation par les consommateurs.

Faire face aux nouveaux problèmes qui se font jour : comment maintenir la souplesse des cadres réglementaires ?

Il importe, pour engager le secteur de l'aquaculture sur la voie de la durabilité, d'adopter une approche intégrée dans laquelle la rentabilité, le risque environnemental et l'acceptabilité sociale sont définis et ciblés, et l'aquaculture envisagée dans une optique plus large comprenant non seulement l'offre alimentaire, mais aussi toute la gamme des services écosystémiques qui contribuent à assurer cette offre ou qui en dépendent.

Toutes les présentations faites à l'atelier peuvent être consultées sur le site Web de l'OCDE à l'adresse : www.OCDE.org/document/3/0,3343,en_2649_33901_44041283_1_1_1_37401,00.html #Presentations.

Notes

[1] Par le Professeur Torger Børresen, Université technique du Danemark (DTU).

[2] Par rapport aux valeurs de 1990.

[3] www.oecd.org/dataoecd/58/34/44077822.pdf

[4] www.euraquaculture.info.

Opening remarks

Mario Amano

OECD Deputy Secretary General

Dear Delegates, Dear Chair,

It is an honour for me to come here and open the Workshop on *Advancing the Aquaculture Agenda: Policies to Ensure a Sustainable Aquaculture Sector*. The OECD's Fisheries Committee has for a long time recognised that the aquaculture sector is uniquely placed to complement production from the stagnating capture fisheries sector. Aquaculture has certain advantages in particular in terms of controllable production characteristics. Put simply, it is easier for man to produce fish in controlled conditions than in a hunter/gathering activity such as is the case in wild capture fisheries.

When adopting its last program of work the Fisheries Committee decided, with financial support from France which I would like to acknowledge, to host this Workshop on *Advancing the Aquaculture Agenda: Policies to Ensure a Sustainable Aquaculture Sector.*

An ever increasing world population, changing consumption patterns and a growing middle class with more disposable income and with a strong preference for healthy diets motivates consumers to demand more fish and seafood. With capture fish production stagnating, aquaculture is a part of the answer to this challenge.

Aquaculture is rapidly growing and is widely recognised as critical to increasing seafood supplies. In 1970, aquaculture provided 3.9% of the *total* global supply of fish and seafood. By 2006 this had increased to 36%. Considering the global fish supply for direct human consumption, the contribution from aquaculture is even larger at around 50%. However, among the world top ten producers only three OECD countries feature - namely Chile, Norway and Japan.

The OECD has a strong emphasis on Green Growth: in 2009, a Declaration on Green Growth tasked the OECD with developing a Green Growth Strategy bringing together economic, environmental, technological, financial and development aspects into a comprehensive framework. At the same occasion, the Ministers declared that they will strengthen their efforts to pursue green growth strategies acknowledging that "green" and "growth" can go hand-in-hand. Within this context, it is imperative that the OECD examines how to mitigate the environmental problems associated with aquaculture, while concurrently enabling the sector to prosper and ensure economic growth, jobs and food in a world where global food security is a concern.

This workshop is therefore a timely and important contribution to better understand the policy challenges for a competitive and sustainable sector which can contribute to the supply of important aquatic protein in OECD countries and beyond. In particular, it is important to introduce new clean technologies to improve the overall economic efficiency of aquaculture to better exploit natural conditions and to develop administrative and regulatory structures that enable further sustainable aquaculture developments. This workshop will contribute to the objectives of both Green Growth and food security which are high on the OECD agenda.

I wish you all the best in your endeavour.

Key messages by the French Minister for Food, Agriculture and Fisheries

Mr. Bruno Le Maire, French Minister for Food, Agriculture and Fisheries, opened the OECD Workshop on the development of aquaculture *Advancing the Aquaculture Agenda – Policies to Ensure a Sustainable Aquaculture Sector.*

The Minister stressed the major role that aquaculture could play in feeding the world population, as fish consumption had doubled in the space of 30 years. He called for the development of this sector to be a priority in the challenge to ensure food security, at a time when most of the world's fisheries have reached or exceeded their sustainable harvesting limits.

The Minister called for aquaculture development, both sea- and land-based, along the following lines:

- At the European level, aquaculture should become a pillar of the Common Fisheries Policy (CFP), along with fishery resource management and the organisation of the markets. The European Union's aquaculture development strategy, launched during France's Presidency of the EU and adopted under the Czech Presidency in 2009, was a first step. The forthcoming reform of the CFP, to be completed by 2012, should be an opportunity to build a genuine aquaculture policy for the EU.
- At the national level, the Agriculture and Fisheries Modernisation Bill, debated in the French Senate from May 2010, provides for new regional marine-aquaculture plans to foster dialogue and set aside areas for expansion of the sector.
- Funding for research on effluent treatment and fish feed improvement is needed. As environmental concern grows, it is crucial to implement good farming practice and there is still room for improvement in effluent management and feed (less fish meal/fish oil and more plant proteins).
- Funding for public relation campaigns to enhance the industry's image and highlight the nutritional value and quality of aquaculture products should be made available.

Chapter 1

Growing the wealth of aquaculture

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Abstract

Aquaculture, the farming of aquatic organisms, has grown markedly in recent decades, with an ever-widening production base. In 2007, for the first time, it supplied more than 50% of aquatic products used for direct food consumption. With growing demand, it is expected to expand further and in many markets, it will increasingly dominate the supply of aquatic foods.

However, prospects and opportunities for growth have been by no means certain, and the industry has at times suffered reverses. Major losses from disease have caused catastrophic failures and loss of investment confidence, and there are continuing concerns about environmental impacts. Expectations of profitability linked with technical opportunities have caused some sectors to expand very rapidly without corresponding market capacity, and falling prices have resulted in business failures and major restructuring. To understand more realistically the nature and potential characteristics of the sector's development a range of issues needs to be considered.

This review explores the features of the sector's recent growth, its emerging opportunities and constraints, across major producing regions, species groups and production systems. It considers key issues including: drivers of growth: demand, technology (production, breeding, feed, disease etc.); resources: land, water, feed; risks and their management; trade and its development, and governance. It addresses their implications, and offers recommendations at strategic investment and policy levels.

Executive summary

Growth and resources

Globally, aquaculture continues to have strong drivers for growth and although key transforming processes such as climate change might constrain or realign development, population and income growth, growing demands for aquatic foods and supply limitations from capture fisheries all contribute to positive prospects for expansion. Depending on demand assumptions, global production of 52 million tonnes in 2007 may need to reach 80 million tonnes or more by 2030. Many countries and regional economic entities expect to contribute to this growth, with corresponding aims of facilitating technology development, resource access, investment, market development and trade.

The sector is remarkable for its diversity, with a wide range of environments, species and production systems, though most production derives from less than a dozen species, fish grown in ponds or cages, shrimp or prawn in ponds, molluscs and seaweeds in beds or on suspended lines. A very small amount is grown in intensive tanks, sometimes with water treatment and reuse and except for limited trials, nothing in open seas. Some 58% of current output, 47% of value, is produced in inland waters and 42% by volume and 53% by value in coastal (brackish and marine) waters. An increasing share of production derives from hatcheries, with life-cycle control opening prospects for genetic improvement, with notable performance impact already in a small number of species. However, a sizeable part of production is still based on wild seed, which is usually a more critical constraint for fish and crustaceans than for molluscs and seaweeds. Although considerable research interest is devoted to species diversification and full life-cycle control of a wider range of species, future expansion of aquaculture production is likely to build primarily around better commercially performing stocks of a small number of more domesticated species.

Resources for aquaculture development are a critical issue and concerns arise for impacts on land and water resources, demand for wild seed stock and raw materials for fertilisers and feeds. A considerable part of recent growth in output has been based on intensification and yield gain, but factor productivity constraints and rising input costs are likely to limit the extent to which intensification is feasible and future increases in production may need sizeable area expansion as well as yield gains. However, in many systems there appear to be substantial ‘yield gaps’ and technology development and management improvements will be key factors in improving resource use efficiency and overall performance. The integration of aquaculture with other activities, sharing resources and recycling wastes, will also have a stronger potential at strategic and local levels, subject to system viability and acceptability amongst resource sharers.

As with many other food production sectors, externalities have not been widely factored into costs and benefits, though nutrient dispersion, genetic interactions, biodiversity impacts and unaccounted embodied energy are encountered in many systems. These elements and related concepts of carbon footprints and sustainability indicators are likely to come into far wider currency, and driven by policy evolution and consumer demand will influence choices made in aquaculture systems, locations and operating principles. The valuation of ecosystem services and potential payment for their provision or protection are also likely to influence aquaculture options, and the use of concepts such as the ecosystem approach to aquaculture is likely to grow further.

Risks and their management

Aquaculture is intimately connected with the aquatic medium and its environmental drivers, whose characteristics and variability impose a range of potential hazards on both, aquaculture stocks and the containment/management system. Increasing variability and changing trends may bring about new or more extreme risks with unpredictable occurrence or consequence and these will need to be understood and managed effectively. Risk areas can be classified as: *biological* - aquatic diseases, predation, ecosystem instability, food safety and environmental/biodiversity impacts; *system* – water supply, holding unit or other component failure; *market/economic* – changes in factors affecting costs and returns, or business viability; and *political* – affecting security, policy environment, legal context, trade options. To date, apart from a small number of politically derived cases, biological risks have been the most significant in impact and continue to be problematic. Market risks associated with rapid supply expansion have also been notable, but are potentially less significant now that more realistic expectations are common, at least in mainstream commercial sectors. Technologies have in many cases matured, and risks reduced, but new rounds of species diversification and more complex systems may increase these.

A range of practical responses to risk can be identified. For aquatic diseases, improved diagnostics, vaccine and other protective technologies and better understanding of the genetic and immunological basis for resistance are significant in reducing risks. However, poor preparedness or response to new diseases remains a significant problem and many countries are still ill-equipped to address this. Even if diagnostic capacity is developed, it needs to be connected with effective responses as both strategic and specific levels. For system and technology risks, better materials, design and testing procedures, greater use of information and communication technologies and cumulative build-up of experience, more proven designs and best practices have usefully reduced risks in mainstream sectors. However other sectors, with new species and systems, or intensifying production on an *ad hoc* basis, continue to be vulnerable. The issue of food quality and contamination has been containable in most cases, but increasing eutrophication, particularly in coastal areas, inadequate controls on industrial development and on input raw materials will put much more pressure on the sector to ensure food safety. Apart from the issues of over-expansion, market and financial risks are increasingly manageable through more professional management at larger commercial scales and through capacity building amongst smaller producers. The role of insurance in commercial production has also been very important in managing production risks and in driving the selection of better and less vulnerable systems. However, major systemic risks associated with vectors such as climate change are likely to require much more strategic approaches for the sector.

Consumers and markets

A key feature of aquaculture output is that apart from some low food chain species such as molluscs and phytoplankton eating fish, such as silver carp or milkfish, most species occupy mid to high levels within the price range for aquatic protein. This is broadly related to the food chain position; with carnivorous species both costing more to produce and attaining higher market prices. By comparison, many traditional fisheries products, more independently of food chain position, have had much lower first sale values. Viability of fisheries operations depend primarily on stock available and the potential to catch them, though very high landings may result in unprofitably low prices.

By contrast, aquaculture, and the investment for its expansion, depends on its margins over production cost. For this reason, though potential demand may be very positive, the opportunity to supply desired species at prices which are acceptable to many markets may limit production potential. Reduced capture fisheries supplies will tend to increase real prices, but the extent to which this will offer sufficient margins remains to be tested.

An increasing division may also be seen between major aquaculture sectors with globally competing producers, feeding into modern supply chains in major markets, nationally and regionally specialised commercial sectors, mainly for prosperous urban markets and local development of smaller-scale production for rural markets or specialised niche supplies. Most attention for aquaculture market development has been given to the first of these, in both domestic consumption and food service sectors, though a substantial part of current supply and a sizeable element of future production are likely to be retained in the other sectors.

A particularly important element of development in the modern market sector is that of traceability, variously defining origin, production inputs and conditions and other key attributes. Labelling and certification and an increasing focus on ethical aspects – fish welfare and the social and environmental conditions of production, are becoming more common. However, the costs and complexity of more specialised compliance and the uncertainty of widespread consumer demands for higher criteria may act to settle specifications for most production to simpler levels. For larger producers or co-operatives that have been able to establish brand identities, the maintenance and extension of these may be the primary focus.

Location, structure, competition and trade

Systems, environments, economic and market conditions vary widely within and across regions, and will be further subject to changes due to comparative wealth and market power and to climate change impacts. However a number of comparative production characteristics can be defined and thematic areas of regional potential identified. Major delta areas, large lakes and sheltered coastal margins in subtropical latitudes have significant capability and potential for producing lower-cost, lower food chain species with potential for serving both regional and global markets. In temperate latitudes, near major high value markets, coastal production from more intensive higher cost fish systems and mollusc culture based on high seasonal productivity will have preferential opportunities. Where transport, processing and distribution infrastructure is available, together with an existing sectoral presence, specific regions are likely to have strong advantages, subject to environmental capacity. If demand increases, new areas with low cost access to natural resources and labour and potential for reaching regional and global markets will become more significant. At this stage, expectations are strengthening for Africa to serve regional, European and Western Asian markets and for Latin America, particularly Brazil, to serve regional and North American markets. However, developments in existing supply centres are likely to maintain competitive pressures in the short to medium term.

In terms of industry structure, much of the expansion in the commercial sector has been accompanied in the last decade by sector consolidation and varying degrees of integration. More notably in modern food supply chains, companies adding value to raw material have increased market power and their influence over sourcing and potential investment. However, particularly in developing countries and also in more widely rural communities, smaller scale producers continue to hold important market shares and are considered to have valuable social roles. A mix of private capital and smaller scale credit is important for the support and growth of this sector. Arguments for consolidation and for small scale community enterprise are likely to continue and the strategic value of having a diverse industry structure will need to be further evaluated. This is specially the case in developing countries where aquaculture is promoted for employment and local food supply, typically as a subsistence or rural farm enterprise.

The trade in aquatic products is already recognised for its scale and diversity and geographical imbalances between supply and markets will ensure that aquaculture trade will remain at significant levels. Regional trade in aquaculture products, particularly for growing urban economies in Africa and Asia will be increasingly important. However, concern for 'food miles' carbon footprints and LCA (life cycle assessment) evaluations will increase focus on transport distances and resource uses. Practices such as the shipping of whole fish from Northern Europe to China for processing and resupply in added value format to European markets are likely to be less common. Rising fuel costs may also shift balances from air freighted fresh product to middle-distance refrigerated supply or wider use of freezer containers using surface transport. With respect to terms of trade, continuing attention will be required to ensure equality of market access and reduction of non-tariff barriers such as over complex aquatic health and food safety requirements. Capacity building at various levels will continue to be important.

Research, innovation and knowledge

The sector has benefited from a range of research and development activities, both endogenous and deriving from other sectors. The primary focus has been on biotechnologies, including identifying and managing life–cycle requirements, genetic improvements, use of genomics, proteomics for disease diagnosis and control and potentially for stock selection. Feed metabolism, digestive efficiencies, feedstock development and formulation and delivery also have high priorities. Issues such as behavioural interactions and welfare requirements are also being more widely considered. System technologies are often borrowed from other sectors, such as fisheries, marine engineering, water treatment, materials sciences and electronics and communications. With the exception of modern cages and some aerators and feeding systems there are few standardised products or common performance criteria, though the diversity of technical approaches has tended to reduce. Future directions for technologies include more focused component design, remote sensing of stocks and environments, and multiple component integrated data at strategic/large scale or more localised levels.

With some exceptions, there has been little appreciation of the role of innovative approaches, nor of strategic and cost-focused research and development strategies. Research station-based biological research is often pursued along classical lines, though industrial research, particularly in feeds and disease treatments is more focused. There are concerns, as in other sectors, that knowledge differentials will increase and will disadvantage poorer countries and smaller businesses. In response to this, the role of public-private partnerships in creating strong processes of knowledge sharing is likely to become more important.

Policy and governance

The policy and governance context for aquaculture is an essential feature of its development and potential. Currently, its significance in national policy ranges from relative disregard to highly developed and focused support and control. A better balanced perspective may be required. A primary requirement is that the aquaculture sector and its features are understood, its value is recognised and its connections with other sectors realised. The development of various valuation approaches and their application will become increasingly important, allowing integrated tradeoffs across sectors to be better defined.

Key areas of policy and governance include: resource allocation and the protection of its quality, control and management of environmental and disease risks, determination and control of food safety, qualified areas of trade support, selective promotion of regional co-operation's management, development of shared water bodies and catchment area protection of specific interests, including social objectives. The implications of these are discussed further in the review.

Conclusions

National and regional development strategies for aquaculture need to be based on sound market and economic understanding linked with knowledge of the impacts of innovation, technological change and human and institutional capacity building. This is an essential requirement for sound and effective sectoral growth. To date, many national plans and strategies are based primarily on simple biotechnical issues – ability to rear aquatic organisms, land areas, theoretical availability of water or feedstuffs, without adequate consideration of practical enterprise issues or of impacts of aquaculture supplies on national or other markets. Practical issues such as resource rights, availability of capital and the time needed to develop supply chain components such as seed, feed and services also need to be considered.

Climate change will be a major driver in most regions, with increasingly important adaptation and risk management requirements. Current work to develop iterative concepts of the type, scale and location of risks, potential impacts, policy and management strategies and investment responses will be critical in defining the viability of future growth for the sector. As with equivalent approaches for agriculture, climate change adaptation will need to be integrated into planning processes rather than considered as a simple modifying factor. There is also the potential for aquaculture to play a mitigation/ecosystem quality enhancement role and these functions are likely to become more important. The potential for creating a market for protecting or enhancing aquatic ecosystem services is yet to be specified, but may have a role in rural economies.

Inland area production will continue to be significant, in particular in greater areas and with more intensive use of pond systems and a wider development of lake or reservoir based cage culture. There will be a greater need for integration with other functions as water demand from agriculture, power generation, water and sanitation and industrial uses increases. Coastal areas are likely to become more important for a range of aquaculture production systems and in cases where land-based enrichment occurs, as is increasingly the case in major delta zones, integrated systems are likely to become more common, with plants, molluscs and lower food chain fish species taking up a nutrient removal role as well as generating additional production.

Changes in feed design and formulation are likely to play a major role in future change, shifting dependence on marine-based oils in particular, and widening access to terrestrial raw materials to reduce production costs, expand production opportunities and ensure sustainability. Genetic modification of feedstuffs could become a key factor in widening feed availability, together with a greater focus on lower food chain species. However, food value of some of these species may be lower than those assumed for typical capture fisheries products and nutritional impacts less significant. This could particularly be the case for lower-income groups with fewer protein alternatives.

The importance of good sectoral data cannot be underestimated, as is the need to link this effectively with other data sources to develop higher order measures and indicators. Links between production, resources, social and economic attributes need to be improved and made more consistent. Approaches which integrate data acquisition with analysis and feedback will be much preferred over systems which offer little development purpose. Knowledge exchange, through private sector interests and in wider public sector arenas will become more significant and more necessary. Features of this will include a wider range of partnerships; greater use of objective-defined approaches; the use of ICT for a wider range of interactive purposes, linking aquaculture production within wider supply and value chains.

Introduction

Aquaculture, the farming of aquatic organisms[1], has over recent decades been one of the fastest growing and most nutritionally significant global food sectors. Unlike capture fisheries, its production is not defined by primary natural resources, but through management and technical skills linked with investment choices in system capacity, seed and feeds. These primary inputs can be produced from an increasing range of sources. While feed raw materials, water, energy and other system inputs have limitations, as does the environmental capacity for receiving production wastes, the scope for increased aquaculture output is considerably greater than that available for capture fisheries. Aquaculture also has important features of controllable production volumes and timing of supply to meet market and supply chain demands. Against a backdrop of overfishing and increasing demand from a growing population, many governments consider aquaculture as high opportunity sector, both in terms of food supply and in terms of economic impact.

However, while aquaculture has grown throughout many parts of the world, this has not been a uniform development, in spite of apparent opportunity. Evidence suggests that aquaculture poses economic, environmental and social challenges which may be poorly understood or addressed within current policy frameworks. In such cases, the sustainability of future operations may be compromised. Issues that may constrain the sector development and performance are among others the business environment (*e.g.* competing uses of land and water; insufficient adoption of new technologies to improve the overall economic efficiency of aquaculture to better exploit natural conditions;) and administrative and regulatory structures that create constraints rather than underpin further aquaculture developments (*e.g.* regulation of access to resources; environmental prescriptions).

Over the last decade, global aquatic animal production rose from 28.6 million tonnes in 1997 to more than 51.6 million tonnes in 2006 (Table 1.1), an annual growth rate of around 5%. Production is dominated by Asia, accounting for more than 88% of total production and 76.3% of total value in 2006.

Table 1.1: Global and regional aquaculture production and value, 1974-2006

Area	Million tonnes 1997	Million tonnes 2006	Average annual % change	USD billion 1997	USD billion 2006	Average annual % change
Total	28.61	51.65	4.96	44.10	78.76	4.89
Asia	25.21	45.96	5.02	35.51	60.08	4.54
China	19.32	34.43	4.88	20.36	38.42	5.22
Latin America	0.40	1.23	7.51	1.18	5.43	8.70
Europe	1.36	1.93	3.29	3.37	6.44	5.30
North America	0.52	0.64	2.03	1.01	1.69	4.49
Africa						
Egypt	0.09	0.60	9.51	0.18	0.95	8.96
Oceania						
New Zealand	0.08	0.11	3.17	0.05	0.23	8.82
Other countries	0.95	1.19	2.24	2.80	3.94	3.21

Source: FAO, 2009a

In 2006, China was the largest aquaculture producer with 49.9% of global output and 66.5% of Asian production, with a value of USD 38.4 billion, 49% of the global total. According to FAO (2009a), it produces 77% of all carps (*cyprinids*) and 82% of all oysters (*ostreids*). It is also noted however that China is revising its aquaculture statistics, with a downward revision in 2008 of more than 10%, more than 3 million tonnes of production. The Asia–Pacific region as a whole accounts for 98% of carp, 95% of oyster, and 88% of shrimp and prawn (*penaeids*) acquaculture production. Over the decade to 2006, global average annual growth rates of aquaculture volume and value were 5% and 4.9% respectively. The highest output growth was in Latin America, at 69.6%, followed by Asia at 48.8% and Europe and North America, both at 29%. Latin America also had the highest growth rate of value, 75.7%, followed by North America and Europe, both 42%, and Asia at 35.8%. Average reported first sale value was highest in Latin America, followed by Europe, North America, and lowest in Asia. With respect to ecosystem, production in inland water and coastal/marine waters[2] grew by 44.7% and 44.4% over the decade, by 2006 reaching 31.5 million and 20 million tonnes with values of USD 41.4 and 37.3 billion, and average prices of USD 1.31 and USD 1.86 per kg, respectively.

The particular dominance of China has a strong influence on regional and global sectoral indicators and it is considered separately in some analyses, to give clearer focus to the characteristics and trends of other producers. Table 1.2 shows equivalent trends in key producing countries, and higher growth rates associated with particular species in countries such as Vietnam (*Pangasius* catfish), Chile (salmon) and Egypt (tilapia). It is also notable how unit values have changed; Thailand, Indonesia, and the Philippines record substantial falls, Bangladesh and Myanmar moderate falls, India, Vietnam and Egypt having slight falls, while China, Chile, Norway and the Republic of Korea all show gains. Only Japan showed a decline in output and in value.

Table 1.2: Trends in major producing countries (>500 000 t), 1997-2006

Producer	Production, million tonnes		% annual change	Value, USD billion		% annual change
	1997	2006		1997	2006	
China	19.32	34.43	4.9	20.36	38.42	5.2
India	1.86	3.12	4.5	2.13	3.43	4.2
Viet Nam	0.32	1.66	9.0	0.68	3.32	8.8
Thailand	0.54	1.39	6.8	1.91	2.22	1.6
Indonesia	0.66	1.29	5.4	2.05	2.25	1.0
Bangladesh	0.49	0.89	5.1	0.97	1.36	3.2
Chile	0.27	0.80	7.3	0.92	4.43	8.8
Japan	0.81	0.73	-1.1	3.52	3.10	-1.5
Norway	0.37	0.71	5.3	1.05	2.72	6.8
Philippines	0.33	0.62	5.3	0.89	0.98	1.0
Egypt	0.09	0.60	9.5	0.18	0.95	9.0
Myanmar	0.08	0.57	9.5	0.83	1.79	6.0
Korea Rep	0.39	0.51	2.6	0.92	1.42	3.9

Source: FAO, 2009a

Table 1.3 shows recent national aquaculture growth rates. Among countries with the highest recent growth rates (2004-06) only Mexico, Pakistan and Nigeria are significant producers, though Cambodia and particularly Uganda appear to be gaining ground. During 2006-07, five significant producers (>100 000 tonnes annually) - Vietnam, Norway, Philippines, Republic of Korea and the Islamic Republic of Iran, recorded double digit growth rates. Growth in Vietnam, mainly based on *Pangasius* catfish of almost 500 000 tonnes over one year is particularly remarkable. By contrast, some larger producers showed small declines in output, while others such as Greece and the Russian Federation had zero growth. At regional levels (FAO, 2009a) growth over 1997-2006 has not been uniform, with Latin America and the Caribbean region showing highest average annual growth (22%), followed by the Near East (20%) and Africa region (12.7%). China's production increased at an average rate of 11.2%, despite a decline to 5.8% from 14.3% in the 1990s. Since 2000, output growth in Europe and North America has slowed to about 1% per year.

Table 1.3: Key aspects of national growth rates

Highest growth rate, 2004-06			Large producers with high growth rates 2006-07		
	2006, '000 tonnes	% per year		2007, '000 tonnes	% per year
Uganda	32.4	141.8	Vietnam	2156.5	30.1
Guatemala	16.3	82.2	Iran, Islamic Republic of	158.8	22.4
Mozambique	1.2	62.2	Korea, Rep of	606.1	18.0
Malawi	1.5	43.1	Norway	830.2	16.6
Togo	3.0	40.7	Philippines	709.7	13.9
Nigeria	84.6	38.7	Large producers with falling production 2006-07		
Cambodia	34.2	28.6	Spain	281.2	-4.0
Pakistan	121.8	26.1	Canada	168.8	-1.3
Singapore	8.6	25.9	Thailand	1390.3	-1.2
Mexico	158.6	23.3	France	337.6	-0.2

Source: Developed from FAO, 2008a, 2009b

These simple production trends overlie a sector which is remarkable for its diversity, with a wide range of environments, species, production systems and producer entities. However, the major part of total production derives from only a few dozen species of fish grown in ponds or cages, shrimp or prawn in ponds, molluscs and seaweeds in beds or on suspended lines. A very small part of production is grown in intensive tanks, sometimes with water treatment and reuse, and except for limited trials, nothing in open seas. Tables 1.4 and 1.5 summarise the 25 key species (excluding aquatic plants) at the global level.

Table 1.4: Most significant species (>1 million tonne annually), volume and value

	Output, tonnes	% change		Value, '000 USD	USD per kg	% change	
	2007	1 year	10 years	2007	2007	1 year	10 years
Pacific cupped oyster	4 233 829	3.2	4.1	3 054 108	0.72	5.9	-3.9
Silver carp	3 662 810	-4.3	1.9	3 572 719	0.98	12.6	1.1
Grass carp(=White amur)	3 610 318	4.1	3.6	3 522 354	0.98	16.7	0.7
Japanese carpet shell	3 044 057	12.0	9.4	3 044 091	1	7.5	-2.9
Common carp	2 872 874	1.8	3.4	3 094 050	1.08	12.5	-0.4
Whiteleg shrimp	2 296 630	9.8	29.5	8 815 854	3.84	4.1	-3.3
Catla	2 274 411	68.3	14.4	2 961 539	1.3	5.7	3
Bighead carp	2 160 627	4.4	4.1	2 134 203	0.99	11.2	0.8
Nile tilapia	2 121 009	12.3	11.6	2 632 978	1.24	10.7	0.2
Freshwater fishes nei	1 994 687	-1.0	4.5	3 095 026	1.55	-1.3	3.3
Crucian carp	1 939 280	7.2	9.2	1 612 717	0.83	13.7	-0.9
Atlantic salmon	1 433 708	7.9	8.3	7 578 273	5.29	5.0	5.2
Yesso scallop	1 412 896	16.1	1.7	2 016 103	1.43	2.9	0.5

Source: Developed from FAO, 2009b

Table 1.5: Mid-range species groups (0.4 - 1 million tonnes annually)

	Output	% change		Value	Unit value	% change	
	2007	1 yr	10yr	2007	2007	1 yr	10yr
Pangas catfishes nei	901 655	59.4	36.6	1 351 763	1.5	0.7	-0.6
Marine molluscs nei	849 514	-24.4	-2.3	559 665.4	0.66	11.9	3.2
Roho labeo	690 731	-48.6	-0.2	1 030 711	1.49	28.4	-3.2
Milkfish	667 508	14.0	6.2	787 737.5	1.18	7.3	-4.1
Constricted tagelus	667 058	12.3	7.2	593 681.6	0.89	4.7	-0.1
Sea mussels nei	658 741	-25.3	1.6	190 460.1	0.29	11.5	1.9
Rainbow trout	604 695	11.4	3.5	2 588 782	4.28	8.1	3.3
Giant tiger prawn	589 888	-7.5	2.1	2 890 482	4.9	2.7	-4.1
White amur bream	576 341	12.4	3.6	726 189.7	1.26	5.9	0.5
Chinese mitten crab	489 479	19.4	18	2 599 458	5.31	2.3	-1.2
Channel catfish	466 017	13.2	6.9	638 837.3	1.37	-4.2	-1.3
Blood cockle	423 502	7.7	8.3	488 976.7	1.15	10.6	1.3

Source: Developed from FAO, 2009b

Here it can be noted that three out of the 13 top output species are molluscs, one a crustacean, and of the remaining fish species, six are either Chinese or Indian carp species. Only Nile tilapia, Atlantic salmon and White shrimp are ‘modern’ aquaculture species whose culture has been developed specifically in recent decades. All the molluscs and crustacean are produced in coastal water while all the fish except Atlantic salmon are grown in fresh water. In the next group, four are molluscs and two are crustaceans. Four species, *Pangasius* catfish, Rainbow trout, Tiger prawn and Channel catfish are of more recent development, though of the molluscs, Tagelus and mussels are playing a growing role in integrated systems. Except for milkfish, often grown in intermediate salinities, the fish species are mostly produced in fresh water; all other species are grown in coastal areas.

At the global level, approximately 58% of current production and 47% of value is produced in inland waters and 42% by weight and 53% by value in coastal (brackish and marine) waters. There has been a gradual trend of increase in coastal aquaculture production, particularly for higher value species, but expansion of output in inland waters has also continued. An increasing part of global output derives from hatchery produced seed stock, with better life-cycle control opening out the potential for genetic improvement. This has already had notable performance impact in a small number of species, though the extent to which it will extend to others remains to be determined. A sizeable part of global production is still based partially or completely on wild seed, which in terms of impacts on wild stocks is usually more critical for fish and crustaceans than for molluscs and seaweeds. Concerns have been focused on eels, marine fish as groupers and more recently on bluefin tuna. Hatchery technologies for many marine species are relatively expensive and unreliable, and though positive developments have recently occurred in spawning and early rearing of tuna, bringing this to routine commercial realisation is likely to take many years more. Although considerable research interest is devoted to species diversification and full life-cycle control of a wider range of species, future expansion of aquaculture production is likely to build primarily around a small number of commercially better performing domesticated species.

If capture fisheries is sustained at current levels, aquaculture production will need to rise to approximately 70 million tonnes by 2025 to maintain current consumption levels with assumed population increases, and to 91 million tonnes if per capita consumption continues to climb. However, the required growth rate for most expansion scenarios is less than the historic growth rate of aquaculture of 8.8% between 1970 and 2004. This was the fastest growth rate in the animal food protein sector as terrestrial meat production only increased by 2.8% per year.

Drivers for growth and development

Introduction

The complex processes of change in the sector are indicative of changing balances of opportunity and constraint across different producer regions and species/production systems. Notable areas of development include the strong expansion of aquaculture of Atlantic salmon, penaeid shrimp – particularly White shrimp, which is increasingly overtaking other species due its superior disease resistance - Nile tilapia of various improved strains, and most markedly, *Pangasius* catfish. However each of these species has seen setbacks in various locations, primarily due to disease and also due to short-term environmental variability. Most of these subsectors have exhibited falling real prices as output expanded, but more organised production, control over input costs and more efficient production processes have retained sufficient profitability for further investment. Major carp production sectors have also continued to expand in output, though in some cases being substituted with tilapia or catfish. Smaller production sectors have also seen variable performance with a mix of technical improvements, market price uncertainties and gradually changing risk conditions.

Table 1.6 summarises the commonly recognized factors underlying the growth of aquaculture in recent decades. The relative importance of these varies with location and context, though each has a definable influence and positive features for all are required. A notable issue in regions such as sub-Saharan Africa has been that although technologies and natural resources potentially exist for aquaculture, repeated failed development approaches have confirmed the need for a sound commercial context. The developments of urban markets and improvements in export infrastructure, together with technology access have now started to bring about growth.

Table 1.6: Factors in the development of the aquaculture sector

Factor	Implications
Market demand	Good demand and high prices for selected species in traditional markets offering initial targets for producers; steadily growing developed markets for major species
Environments	Initial availability of inland waters, lagoons, sheltered bays, with suitable water quality, production temperatures, nutrient supply for shellfish and other systems
Infrastructure	Available or improving transport, power, communications, access to major markets, good information system; scientific support structure
Technical capability	Emerging and rapidly establishing techniques for hatchery production, husbandry, feeds, ponds, cage and other culture systems; improvements to traditional systems
Investment	Local, national and regional private, commercial and institutional investment; incentives and support schemes for development, and technical research
Human resources	Initial nucleus of primary technical skills, developed through pioneer companies and development centres; increasing level of management skills in core groups
Institutional system	Generally positive and proactive environment, providing strategic research inputs, adapting to changing needs of industry, development of legal and regulatory systems

At subsector level, simple SWOT (strength, weakness, opportunity and threat) analyses can also be used to explore the potential growth conditions and their constraints. Table 1.7 outlines a recent example for salmon culture, in this case within the EU, but applicable more widely (STAQ, 2009). SWOT analyses of other major sub-sectors show a number of recurring themes. Production technologies and markets are generally well established, although weaknesses in industry structure, uneven investment and lack of marketing frequently contribute to financial instability. Disease is an inherent threat to all sectors, as to any animal production systems but mature sectors with high stock levels are especially vulnerable. Environmental risk associated with extreme short-term weather conditions is also more notable.

Table 1.7: Example of SWOT analysis for the EU salmon aquaculture sector

Strengths	Weaknesses
Technical know-how; positive image Diversity of salmon based products Large local and regional markets Successful certification schemes Range of research outputs available to producers Restructuring and efficiency gains accomplished Vertical integration – hatchery to processing Relative stability in relations between producers and distributors etc.	Smaller scale than some international competitors Heavy regulatory burden for obtaining site licenses Marginal sector relative to national economy compared to main competitors Relatively high production costs (labour, feed, economies of scale) by international standards Constraints in access to credit
Opportunities	**Threats**
Growing consumption, and development of new consumption opportunities Development of niche markets (branding) New export markets *e.g.* Russia, Ukraine Advantage for local markets for fresh product Technical developments; novel vaccines, improved production systems	Diseases and parasites Competition with external countries: Norway, Chile Competition from other species/products Adverse NGO campaigns v farming practice Confusing proliferation of labels Growing relative transport costs (esp. islands)

Source: Developed from STAQ, 2009

While positive driving forces remain to varying degrees, potentially constraining factors, cross-sectoral and intra-sectoral, have emerged as aquaculture has grown, as outlined in Table 1.8.

Table 1.8: Current issues for global aquaculture

Issue	Features/implications
Cross-sectoral	
Policy and planning	Opportunities for aquaculture to access resources, operate effectively and securely in conjunction with other sectors; plan and develop strategically
Internationalisation	Increased competition from imports/substitutes, reduced local identity for production, possibly reduced/altered quality standards
Disease management	Identification, control and transmission management; substantial loss potential in most species, costly control measures
Environmental quality	Maintenance of suitable environments as production increases and/or in conjunction with other resource users; cost of environmental management
Wildlife/conservation	Increasing value placed on natural habitats/key species and their preservation; reduced access to sites and/or restriction on operations
Intra-sectoral	
Market prices	Profitability, security, investment potential
Seed supply	Potential for expansion, production scheduling, diversification, quality improvement, cost reduction
Feed supply	Production costs; problems of ingredient quality/costs, availability
Technical capacity	Reliability and cost of production systems; efficient operation, access to new resources
Local environments	Critical interactions with other uses; impacts of overloading
Land availability	Increased pressure on traditional inland and coastal areas
Public health issues	Accumulation of toxic materials, algal/bacterial toxins, pathogenic bacteria
Traditional livelihoods	Difficulty of maintaining simple, low profitability practices

Source: Developed from Muir and Young, 1998

A number of these issues will be highlighted in subsequent sections of this review.

Consumption and markets

Reported world per capita consumption of aquatic foods has risen steadily over past decades from an average 11.5 kg during the 1970s, 14.4 kg in the 1990s to 16.7 kg in 2006, when according to FAO (2008a), 51.7 million of the global consumption of 110.4 million tonnes derived from aquaculture. Forecasting population to reach 8.32 billion in 2030 and with capture fisheries (92 million tonnes) and non-food uses of fish (33.3 million tonnes) remaining constant, aquaculture would need to produce 80.5 million tonnes by 2030 to maintain current per capita consumption. In more direct terms, *ceteris paribus* each extra billion of population would require an extra 16.7 million tonnes of annual aquaculture output at these levels. A number of scenarios have been developed for future demand and supply for aquaculture, much depending on expectations of population growth, income levels and drivers of preference. Table 1.9 shows recent trends in regional consumption, and projections for 2020 (Delgado *et al.*, 2003). In scenarios of declining capture fisheries supply, dependent in turn on the resilience of major stocks, fishing pressures and management, aquaculture demand may be further increased.

Table 1.9: Projections of per capita consumption

Country/region	Per capita/year		% growth/year
	2020	1985-1997	1997-2020
China	35.9	10.4	1.3
South East Asia	25.8	1.3	0.5
India	5.8	2.3	0.9
Other South East Asia	6.1	0.9	0.1
Latin America	8.6	-1.2	0.4
West Asia and North Africa	6.4	0	0.2
Sub Saharan Africa	6.6	-2.6	0
US	19.7	0.5	0
Japan	60.2	0.2	-0.2
EU 15	23.7	1.3	0
Eastern Europe/CIS	11.6	-6.1	0.4
Other developed	14	0.8	-0.2
Developing world	16.2	3.8	0.6
Developed world excluding China	9.9	-0.1	0.3
Developed world	21.5	-1	0
World	15.7	1.7	0.4

Source: Delgado *et al.*, 2003

More specific analyses are carried out at national level and with respect to particular aquaculture species and products. A key issue for aquaculture is the likely price at which its products will clear in various markets. In reviewing the demand elasticity for fish, Asche *et al.* (2005) found considerable variations due to local markets, cross substitution, income, temporal, and value chain effects, but concluded that overall, the market for seafood is probably elastic. Bjorndal (pers. comm. 2007) noted such studies had mainly concerned salmon and that values observed may also change over time. Some seafood products such as canned tuna appear inelastic. In general, elasticity is lower at the consumer end of the value chain and highest at the primary producer point of first hand sale in capture fisheries.

Delgado *et al*. (2003) suggested values of own-price elasticities for modelling purposes of between -0.8 to -1.5 and cross-price elasticity values between poultry and fish of 0.3. The degree of separation between aquaculture and fisheries is less well studied. A review by Asche *et al.* (2005) found frozen wild Pacific salmon to be in the same market as fresh and frozen farmed Atlantic salmon, whereas a more subjective assessment by the UK Competition Commission found the market for farmed salmon to be separate from that of wild (Atlantic or Pacific) salmon (STAQ, 2009). As aquaculture supplies increase, the distinction between captured and farmed product is likely to be increasingly influenced by the product positioning strategies adopted within the chain.

It is usually assumed that aquaculture can substitute for capture fisheries if it can supply broadly similar products at similar prices. However, a recent review (STAQ, 2009) noted that the average first sale value (whole fish equivalent) of farmed fish produced in the EU25 in 2005 was EUR 3.25/kg, while UK capture fisheries landings had an average value of EUR 0.96/kg. The issue of production cost and market sector sizes is likely to be critical in the practical realization of the potential for future aquaculture development, whether at regional and national level, or in serving specific markets.

Social objectives

While food supply and economic output are primary drivers for development, the role of aquaculture in employment and income generation is an important theme, with significant policy implications. This is particularly the case for developing countries with growing challenges of rural employment and livelihood options (see Box 1.1). In 2006 some 43.5 million people were estimated (FAO, 2009a) to be directly engaged, part or full time, in fishing or aquaculture, with a further 4 million involved occasionally. The rate of growth of employment in the sector over the last three decades had been higher than growth in global population or in employment in traditional agriculture. Regionally, China accounts for 86% of global employment, including some 4.5 million fish farmers; other countries with significant sectoral employment included India, Indonesia, the Philippines and Viet Nam. In fishing, most people are at small-scale, artisanal level and in many countries, aquaculture is at similar scale. Aquaculture can also be an important source of employment for women. While global employment in capture fisheries declined by 12% over 2001-06, aquaculture has provided important gains, with some 9 million people employed in 2006, 94% of which in Asia. However, while aquaculture is often proposed as an alternative livelihood for those facing declining incomes in fishing, or denied access through regulatory change, it is not always a viable option, and employment transfers often occur from the wider rural population, *e.g.* agriculturalists adopting aquaculture or recruitment from rural labour pools.

Box 1.1: Bangladesh's aquaculture – a hidden triumph

In two decades Bangladesh has gone from an almost total dependence on wild fisheries to generating almost half its inland fish production through aquaculture. This development has taken numerous forms, rapidly embracing new species and production systems, but often remains poorly known outside the country. Although aquaculture ranks as the second largest source of export earnings for Bangladesh, its greatest impacts may actually be less obvious. Two introduced species, silver carp and Pangasius, have become the most important fish among consumers in lower income brackets by virtue of their relatively low market value and high productivity. Small sized silver carp produced in low input, yet often commercial smallholder systems have to a large extent substituted for wild fish species in rural diets, whilst Pangasius produced in an intensive manner on an almost industrial scale sells in huge volumes and at low cost in urban and peri-urban markets. Culture based fisheries now also produce higher value major carps in large volumes, stimulating output from the seed supply sector. Backward and forward linkages, particularly those associated with more commercially oriented systems of production, have also generated entrepreneurial niches and labour opportunities in input supply, marketing, and other ancillary services, driving up agricultural wages rates and providing alternative livelihood options for fishers in areas with high concentrations of aquaculture. It is these often forgotten multiple linkages that account for the bulk of economic value associated with aquaculture in Bangladesh.

Table 1.10 provides an outline of a small range of recorded employment levels, their change over recent years and the equivalent production and value levels per person. The two extremes can be seen for Indonesia, with substantial numbers of people and low output/value levels compared to Norway, where highly mechanized production of relatively high value product gives more than 300 times the output and 600 times the value person employed. The values for China are more similar to global averages, though the recorded annual growth in employment is higher.

Table 1.10: Examples of aquaculture employment, output and value

Location	Employment, '000		Growth % per year	Aquaculture, 2006		Output, tonnes/person	Value, USD/person
	2000	2006		Million tonnes	Billion n USD		
World	7 671.6	8 662.6	2	51.65	78.76	5.96	9 092
China	3 722.3	4 502.8	3.2	34.43	38.42	7.65	8 532
Indonesia	2 142.8	2 275.0	1	1.29	2.25	0.57	989
Norway	4.6	4.4	-0.8	0.71	2.72	161.22	617 620

Source: Developed from FAO, 2009a

With 2% global increase per year and production growth of around 5% annually, average labour productivity would appear to be increasing by around 3% annually. Indonesia's production growth rate for 2006-07 was 6.4%, suggesting annual productivity gains in the order of 5%, which might be expected from a low productivity base, commonly also associated with small producers, possibly rationalising towards larger unit sizes. Norway's production growth over the period was a 16.6%, and productivity gains correspondingly higher, reflecting also the ability to invest in productivity enhancing technologies.

Table 1.11: Employment and value outputs by species group

Species group	Turnover Euro/kg	Labour tonnes/person	Value, '000 USD/person
Salmon, trout and other salmonids	2.78	89.5	360.8
Sea bass, bream & similar	4.65	20	134.9
Halibut, turbot, sole etc	6.26	40	363.1
Cod, haddock, hake etc	4.82	50	349.5
Carp, tilapia, catfish	1.92	12	33.4
Eels, sturgeon, perch, zander etc.	4.44	40	257.5
Tuna	11.94	120	2 077.6
Mussels	0.83	15	18.1
Oysters and scallops	2.29	11	36.5
Clams, cockles etc.	3.34	5	24.2
New non-fish aquaculture sp.	11.68	10	169.4
Aquatic plants	0.29	3	1.3

Source: Developed from STAQ, 2008 - unit values calculated from FAO FishStat data, 2007

Table 1.11 provides a similar breakdown for a range of species groups, showing the marked difference in labour and output value associated with more more labour intensive high value species – tuna being a particular example, and the lower food-chain, less labour intense species such as molluscs and warmer water freshwater fish. Connections may also be made with value addition and wage rates; in many simpler systems with low levels of inputs, much of turnover can be represented as returns to labour, and in many cases, income from aquaculture can represent an important part of individual or household level income. Analyses in Bangladesh (FSRFD, 2004), using closer estimates of full time equivalent (FTE) labour levels demonstrated an important range of earning potential for a range of aquaculture enterprises.

Employment multipliers are also significant. FAO (2009a) suggests that for each person employed in the primary fishery sector, four might be employed in related activities, including processing, marketing and service industries, indicating further employment associated with aquaculture of some 35 million people. However, some of this will overlap with capture fisheries and other sectors, and also needs to be assessed on an FTE basis. As will be noted later, the organisation of production, the scale of entities involved, and the social context in which they are placed, has a strong influence on the potential for aquaculture for wider social development objectives. Thus community based enterprises – *e.g* producing molluscs or seaweeds in extensive systems will tend to have relatively high levels of social impact, contributing modest levels of income into wider livelihoods networks, while large commercial enterprises will provide wages into local economies but possibly little other secondary benefits.

Production efficiency drivers

At various levels and across a range of systems and locations, the viability, performance and reliability of aquaculture has been improved by technical and operational gains. These have been based on a mix of improved scientific understanding, innovation and improvement at practical levels and the spread of improves approaches across various sectors. In broad terms these drivers can be grouped as biotechnology – based around the farmed organism and its environmental interactions, system technology – with improved production system performance, and more generic sectoral level efficiency changes. In modern aquaculture sectors, biotechnology has been a particular focus and might be expected to have increasing impact in the future.

Breeding and genetics

Selective breeding programmes, originally developed for Asian carp, are in place for major species such as salmon, trout, catfish, sea bass and bream, tilapia and shrimp, though with varied impact as strains and production environments are not always perfectly compatible. Desired characteristics include growth rate, feed conversion efficiency, disease resistance, environmental tolerance and flesh fat content and colour (Utter and Epifanio, 2002). Average performance for specific traits can be improved by up to 20% per generation (Table 1.12), though simple approaches to improve single characteristics may have negative impacts on others. A multi-trait breeding programme is possible but more complex to manage. Traits also vary with respect to heritability; if this is low, discerning the genetic effect from environmental influences is more difficult. The current range of quantitative trait loci (QTL) and genome mapping should ultimately provide much greater levels of information and hence control.

Table 1.12: Genetic gain from selective breeding

Species	% gain per generation
Channel catfish	12-20
Pacific salmon	10
Atlantic salmon	11-14
Rainbow trout	13
Tilapia	14-23

Source: Sturrock *et al.*, 2008

For major commercial species such as Atlantic salmon there have been substantial performance gains over recent decades, associated with strain and family selection processes. In the UK, the average harvest weight of a two sea-winter salmon rose from 3 kg in 1980, to 4.3 kg by 1995 and to 4.4 kg by 2005, while early maturing fish (grilse) dropped from around 30% in 1980, to 18% in 2005. In this case, photoperiod management also played a role. Total yield per smolt rose from 1.67 kg for 1990 smolts to 3.43 kg for 2003 year class smolts, though this also reflects other management gains. In Norway, gains were shown of 4.6% per generation in feed efficiency ratios and 8-10% per generation for growth rate, age at maturity and flesh pigmentation. In Canada, economic benefits of improvements of an Atlantic salmon stock were quantified as USD 1.43 per fish marketed, or USD 1.23 per smolt used if sold early at the same weight as unimproved stock, or USD 3.66 per fish marketed and USD 3.07 per smolt if grown for the same period to a greater weight (Sturrock *et al.*, 2008).

On an annual basis, species with shorter breeding cycles can be advanced at a faster rate. Salmon generation time is approximately four years, while that of tilapia can be as little as nine months. The Norwegian company GenoMar claims a 15% annual genetic gain for growth rate (GIFT-strain). At a more basic level, the breeding and hatchery phase is the most technically complex one of most aquaculture production processes and is key in developing any new aquaculture species. Improvements in efficiency and performance achieved through breeding and in production of healthy seedstock can have substantial economic benefits throughout the production process and hence on viability and competitiveness. Particular impacts are expected from the increasing use of genomics and proteomics in selective breeding, diagnostics, vaccine development and nutrition research. For many species there are significant productivity gains still to be exploited if survival and growth rates can be improved.

The use of genetically modified aquaculture species has also received attention. Whilst the technology is yet to be stabilized, genetic modification (GM) offers the possibility of reducing chemical usage, growth efficiencies, fishmeal substitution and better quality of product with the chance to lower production costs. However public and consumer acceptability is highly questionable, although more precise and closely targeted technologies and approaches such as autotransgenesis (using genetic materials only from the species produced) may in the future accelerate gains without the same focus of concern. GM developments of feed materials are also likely to be more widely encountered and have the potential for important technical and cost improvements.

Feeding

As a primary cost input, the performance of feed is highly significant in defining production efficiency, cost and sustainability. Feed may also have a significant effect on the amount and type of wastes deriving from an aquaculture system. Advances in early rearing feeds include nutrient enrichment of live feeds, development of microalgae and copepod production techniques, reducing labour requirements by using commercially available algal paste, manufactured artemia systems, automated feed delivery systems and artemia replacement diets. Compound diets for grow out have been steadily improved, with significant advances including improvements in fishmeal quality through lower-temperature processing, finer milling and the use of extrusion technology and the better tuning of diet formulation to meet species and life stage requirements or reduce environmental impacts. Current issues include the widening of raw material options, reducing dependence on fishmeal and fish oil and reducing net costs of feeding. At the technology level, linking better feeds with improved feed manufacturing and delivery systems, particularly using stock behavioural monitoring to optimize feed offer and conversion efficiency, has brought about steady improvements in performance. However, gaps between potential methods and practical farm-level systems are still quite substantial and across many aquaculture sectors feeding performance varies widely. Likewise, except in well-developed and highly competitive conditions, standards of feed manufacture can often be much improved.

Disease diagnosis and management

Disease is a continuing and highly serious threat to the output and viability of aquaculture across all systems and species. Losses of more than 20-30% can occur in serious outbreaks and almost complete mortality can occur in sensitive stocks or life-cycle stages. Surviving stocks may be physically damaged or reduced in market quality, generating further loss. Diagnosis methods and effectiveness vary widely, depending on pathogens, technical resources and skills and the ability to define and communicate effective responses. This is a particular problem in developing countries. Treatment varies considerably with species, disease status and husbandry conditions, from simple measures to improve water quality and reduce stress, eliminating contaminants or disease agents, to the application of drugs and other chemicals, orally, by immersion or injection, with specific or general control of pathogens and increasingly, vaccination. Complete eradication and sterilisation may be required for particularly dangerous pathogens and processes of slaughter, with or without compensation, may be initiated.

Amongst many advances, immunology has delivered significant impact, in the key areas of diagnosis and vaccine development. Antibody probes to pathogens are now widely used for rapid diagnosis for a range of conditions. Vaccination has proved highly effective in preventing infection, an optimal strategy for disease control. The development of vaccines against vibriosis and furunculosis in the late 1980s was crucial in facilitating the growth of the Norwegian salmon farming industry. This moved from using some 50 tonnes of antibiotics in 1987, with huge mortalities, both dropping close to zero in ten years with the introduction of multivalent vaccines, while more than tripling in output. However, as the development costs for vaccines are high, use has focused only on the most common disease problems in high value species like salmon and trout. The effectiveness of vaccination also varies with the type of disease, being particularly effective against bacterial diseases such as vibriosis, furunculosis, ERM, while much more variable in effectiveness against viral diseases (IPN, Pancreas disease, ISA, VHS).

A range of technical approaches, including sub-unit recombinant vaccines and direct DNA vaccination is now being developed (see *e.g.* Renault, 2009). The latter appears to be cheap and effective and is being developed commercially for ISA virus in salmon.

In the less intensive and lower-value aquaculture sectors, disease management has been much more difficult. Apart from routine disinfection and preventative treatments for hatchery stock, limited attempts to control and quarantine introduced stocks and separation or harvesting of affected stocks management has had much less impact. This has been a significant challenge, as a great part of production risk and productivity loss could be associated with non-existent or poor health management and a number of epidemic conditions such as White Spot virus in marine shrimps and Epizootic Ulcerative Syndrome (EUS) in freshwater fish have caused substantial losses and driven out significant numbers of producers. Recent epidemiological work has shown some potential and there is some prospect of moving from traditional focus on pathogen diagnosis with very limited effective feedback to more solution and outcome driven approaches.

Technology developments

A range of technology introductions or improvements can be identified in aquaculture. Many of these have been ‘borrowed’ from other sectors, such as fisheries, marine engineering, water treatment, materials sciences and electronics and communications. A primary constraint in many cases has been that the sector or specific subsectors have not been large enough to justify specifically targeted technology research and development approaches. With the exception of modern cages and some aerators and feeding systems there are few standardised products or common performance criteria, though over time, the diversity of technical approaches has tended to reduce, with more focus on better established systems of proven reliability. Current technical areas include the further development of closed recirculated water systems and their components, more robust and mostly mechanised cage and related systems for more exposed marine locations and progress on specific technical aspects of rearing new species. Future directions for technologies include more focused component design, remote sensing of stocks and environments, and multiple component integrated data at synoptic or local level.

The use of computers, microprocessors, various sensors and information technology has also enabled increased control in many aquaculture sectors, from fish production to monitoring market trends and consumption. The use of sensors linked to computer control allows for more efficient use of resources and a higher level of monitoring, avoiding losses. There are also potential welfare gains in controlling feeding and rearing environments to optimise husbandry conditions, picking up early disease signs and protecting stocks more effectively from predators. As farms become bigger and more cost-focused such control is likely to become more commonplace. Improved communication links (including ready data transfer, video conferencing and streaming) also enables large enterprises to manage many functions at remote sites from a single centre, potentially saving personnel and travel costs.

Market information and access is also improved through information and communications technology (ICT) and opportunities for widening product sourcing and comparing market prices should improve the function of markets and the efficiency of supply chains. ICT is also employed increasingly as a marketing and consumer assurance tool associated with higher levels of traceability of products (Bostock, 2009). Products can be tracked through the distribution chain using small sensors (*e.g.* monitoring temperature, physical shock and other relevant parameters) held in the packaging to help assure traceability, assure quality and improve logistics management. GPS receivers can be used to update geographic positions and mobile phone modules, to relay data to a central internet-based tracking application. This allows for distribution efficiency increases and better safety along the supply chain.

Other drivers

In more developed aquaculture markets, drivers associated with energy, carbon footprint, resource use and protection are likely to take a greater place in future global supply options and market sourcing decisions. This is closely matched with growing concerns for food safety and for ethical or welfare standards, linked with increasing pressures for sound environmental practices. Resource costs and risks – addressed in the next sections, will interact with these and though ethical consumption drivers may have less impact in traditional subsistence and local markets, access and costs of resources may act to have similar effects. Current and emerging technologies are critical in addressing such demands and where applied could confer competitive advantages to producers, market intermediaries and retailers alike. Energy, carbon and other resource-related drivers in supply choice will also become more clearly defined, moving away from cruder food miles debates to incorporate accurate assessments of consumption, including how food is purchased and prepared locally. Amongst other impacts, this has potentially positive implications for local small scale aquaculture production. However there will be notable challenges for smaller enterprises to access these advantages.

Resource and development interactions

Introduction

As with many other primary food industries, aquaculture is heavily dependent on natural resources. Their availability and cost are an important determinant for its size and expansion potential and their quality is critical for supporting sustained output. The impact of aquaculture on resources is also critical in determining access and in defining requirements for management and protection. It is clear that demand for expanding aquaculture will have significant resource implications, and that even if productivity and efficiency is improved, quantitative changes in resource use are likely to be involved. There is limited data on the extent to which resource use efficiency has changed across the sector, but an average global growth rate of some 5% annually is likely to exceed total factor productivity gains. In other respects, tradeoffs will be required; thus intensifying production to gain output from given land and water resources will commonly require greater feed and energy inputs and may also add to downstream environmental loading. Optimising the efficiency envelope across a range of input factors depends closely on species, system and local site conditions, as well as on resource and system variability during the production cycle. Until more detailed typologies can be developed it is therefore more common to use simpler conceptual descriptions, based on nominal intensity of production per culture area or volume. A number of reviews (Muir 2005; FAO 2009a) have noted the significance of land, water, feeds and energy as constraining resources for sectoral development and these are the focus of the next sections. Table 1.13 outlines typical relationships with these resources for a range of common aquaculture species.

Table 1.13: Typical aquaculture resource demands by species

	Land or water tonnes/ha	Water '000 m^3/tonnes	Input:output energy ratio	System features
Salmon, trout and other salmonids	1 750	2 260	50	Intensively fed cage/ponds
Sea bass, bream and similar	1 125	2 500	40	Intensively fed cages
Halibut, turbot, sole etc	2 676	2 000	45	Intensive onshore tanks
Cod, haddock, hake etc	1 200	2 500	45	Experimental cage systems
Carp, tilapia, catfish	2	5	30	Fertilised ponds
Eels, sturgeon, perch, zander etc.	190	0.1	35	Extensive stocked water bodies
Tuna	300	3 000	50	Intensively fed cages
Mussels	76	3 000	10	Raft or longline systems
Oysters and scallops	25	2 000	5	Rafts or longlines - lanterns
Clams, cockles etc.	0.5	2 000	5	Extensive coastal beds
New non-fish aquaculture sp.	150	0.2	20	Range of systems
Aquatic plants	1	2 000	1	Coastal beds/stakes and lines

Note: Protein energy per tonne for all fish/shellfish species = 4.73 GJ;for aquatic plants = 3.55GJ

Source: Sturrock *et al*. (2008),

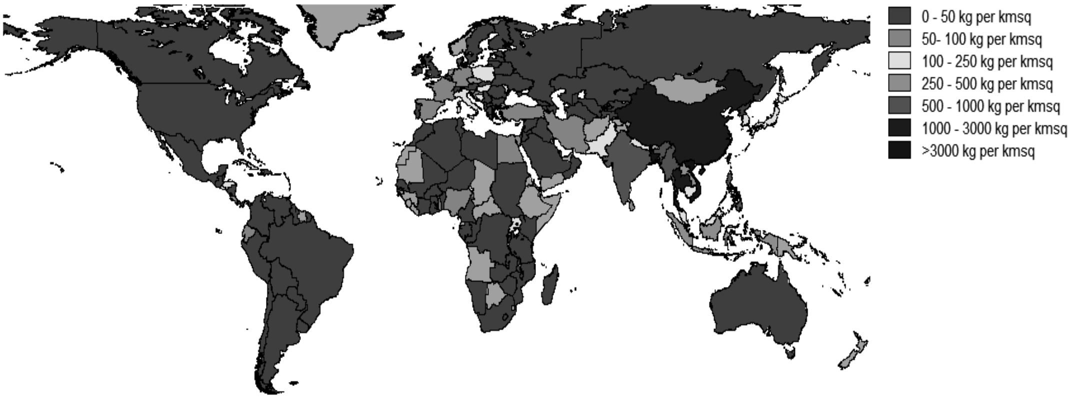
Land and water demands

The combination of land and water availability is the primary determinant of aquaculture development potential in both inland and coastal areas. Apart from availability and cost of land, its configuration and agro-ecological characteristics are key features of suitability. Although GIS-based reviews have been carried out to define strategic/regional potential (*e.g.* Nath *et al.*, 2000; Ross *et al.*, 2009), more localised suitability depends on specific features including access, development cost and potential security (Corner *et al*., 2006). However, more strategically, inland aquaculture, primarily based on ponds, is most easily developed in low-lying deltaic zones in lower latitudes, with substantial inputs of photosynthetically driven productivity. Secondary options are for cages in lakes and reservoirs, normally using supplementary of complete feeds, while a small amount of production originates from pumped or gravity flow intensive tanks in a range of locations and topographies. For coastal areas, low-lying deltaic/lagoonal zones in low latitudes are common for ponds and shellfish beds, while deeper embayments in low and higher latitudes are used more intensively for cages and shellfish rafts or lines. These categorizations determine strategic suitability and allow resource capacity and its utilization to be considered at regional, national and local levels.

Aquaculture water demands are rarely consumptive, as most of it is returned to the environment, commonly slightly enriched with nutrients, organic wastes and sometimes lower in oxygen content. Capacity limitations in assimilating wastes are common constraints. In inland areas, particularly with more heavily competing water demands this tends to limit the size and clustering of individual units and discourages intensification. Coastal developments have had less immediate constraints, allowing higher levels of production from individual sites and greater opportunities for consolidating central services and facilities. However, though expansion of sites or operations could generate further efficiency gains, local or area level regulatory resource limits are increasingly a constraint.

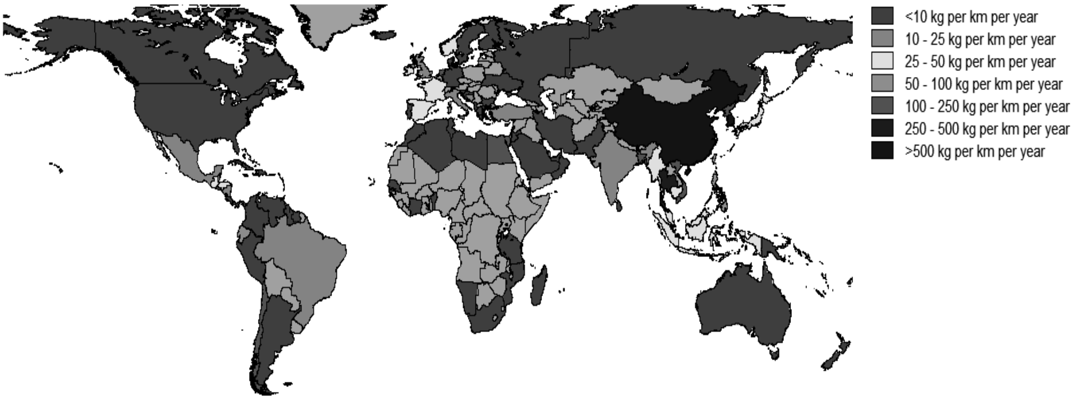
The broad scope for aquaculture development can also be defined by the comparative loadings (production per unit of resource) at regional, national or local levels, as outlined in the following figures. These relate reported output with national land areas (Figure 1.1), coastline length (Figure 1.2), and available water (Figure 1.3), (Handisyde and Ross, 2009 in prep.).

Figure 1.1: Production intensity, total aquaculture in inland areas, kg/km2 per year



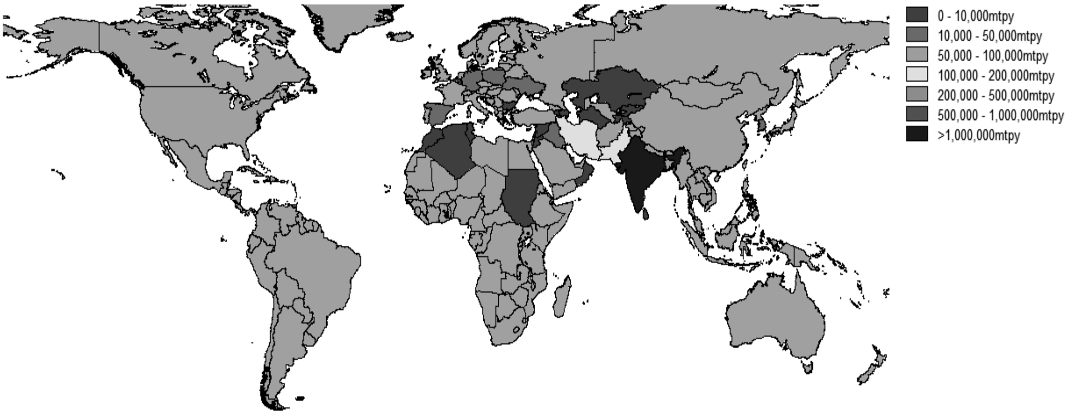
Mean freshwater aquaculture production, 2005-07 as a function of land area (kg/km^2 per year)

Figure 1.2: Production intensity. total aquaculture in coastal areas, kg/km annually



Mean coastal aquaculture production, 2005-07 as function of coastline length (kg/km per year)

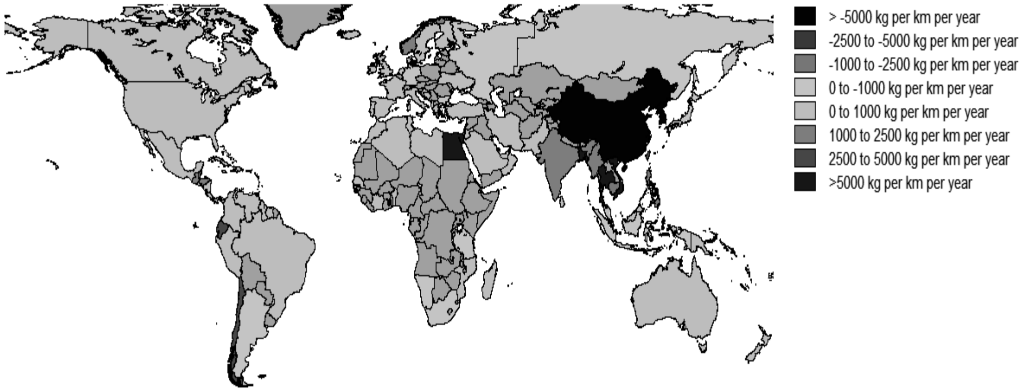
Figure 1.3: Aquaculture output levels in higher stressed fresh water zones, tonnes per year



Mean inland aquaculture production, 2005-07 in countries where freshwater withdrawal as a percentage of total renewable water resources is greater than 25%.

As expected, higher loading levels are commonly to be found in South and East Asia, while regions such as Africa and Latin America are much less heavily loaded and theoretically have much greater capacity. To illustrate other implications, Fig. 1.4 shows the theoretical nitrogen output from aquaculture into coastal waters, based on simplified assumptions for nitrogen output according to system intensity (Muir, 2005). However, more detailed analysis for all these is required at local level, to determine interactions with other resource users, specific quality issues, management contexts and the extent to which highly loaded systems are approaching critical thresholds.

Figure 1.4: Aquaculture waste production - nitrogen output into coastal waters, kg/km per year



Estimated total output of nitrogen from coastal aquaculture systems as a function of coastline lengths (kg per km per year) based on production figures for the years 20-0705

While highly loaded systems are potentially nearer to safety margins (where definable), the availability of existing production and infrastructure may mean that marginal costs of expanding capacity and output up to those margins may often be lower than for developing new areas. Nonetheless, these give useful indications of where aquaculture is likely to become more constrained or where further growth is likely to be relatively cost-effective.

Box 1.2: Vietnam: Is pangasius production sustainable?

In the last decade a small area of Vietnam's Mekong delta has undergone the most remarkable growth in export oriented aquaculture output for a single species recorded anywhere in the world, generating well over USD 1 billion in foreign exchange and rivalling farmed salmon in terms of quantity produced. Locations are concentrated along the banks of main river channels which supply the large volumes of water required by this exceptionally intensive production system. Although concerns have been raised about the environmental outcomes of such rapid development and local declines in water quality have been reported, recent studies suggest that overall impacts on the ecology of delta may not be severe. Of potentially greater concern with respect to the industry's long term sustainability is the open nature of the production system and the highly clustered pattern of production units which may leave it highly vulnerable to disease should a virulent new pathogen of Pangasius emerge. Very slim margins, exceptionally high production costs, and the unpredictable nature of export markets also combine to make production a high risk business. Recent drives to certify Vietnamese Pangasius farms may intensify these pressures, particularly for producers at the smaller-scale end of the spectrum, but may also represent opportunities for larger operators to consolidate their market position and improve management. A national institution, the Vietnamese Association of Seafood Exporters and Processors (VASEP), which has a strong record for proactively and effectively promoting Pangasius in international markets has been particularly effective in supporting the industry's development, may also have an important role to play in helping to direct its course in future.

Feed materials

After land and water, feed is the next most critical productive input. For mollusc and seaweed culture and some extensive fish and crustacean farming this is closely associated with the water supply and with fertility of associated soils and sediments. For more intensive aquaculture, feed is supplied externally, with a significant component (fishmeal and oil) derived from industrial capture fisheries of which aquaculture is using an increasing share. Although sometimes described as the 'fishmeal trap', where further expansion might be constrained by the limited availability of fishmeal, particularly if capture fisheries are placed under further pressure, the use of fish oils is in fact a greater constraint; these are also important in providing good fatty acid profiles in the aquaculture product, an important consumer and market issue. The production of fishmeal and oils is a global industry with major dependence on anchovy and other pelagic fisheries in South America (Table 1.14). Supplies have been reducing slightly, but are in any event linked with South American El Niño and La Niña events. More strategically, if other high value uses become available for the resource – particularly for direct human consumption, competition and prices will increase.

Table 1.14: Global sources of fishmeal and species used

Country/region	Fishmeal production		Species
	tonnes*	%	
Peru	1 714 000	30.0	Anchovy
Chile	798 000	14.0	Jack mackerel, anchovy, other, sardine
Iceland	224 000	3.9	Capelin, blue whiting, herring (including trimmings)
Norway	198 000	3.5	Blue whiting, capelin, sandeel, trimmings, others
Denmark	246 000	4.3	Sandeel, sprat, blue whiting, herring, other
Other EU*	210 000	3.7	Trimmings, sandeel, sprat, blue whiting, herring, other
China	348 000	6.1	Various
Thailand	402 000	7.0	Various
USA	300 000	5.2	Menhaden, Alaska pollack
South Africa	103 000	1.8	Anchovies, pilchard
Others	1 176 000	20.6	Mainly anchovy
TOTAL	**5 719 000**	**100**	

Source: International Fishmeal and Fish Oil Organisation (IFFO) mean of 2002/2006 production

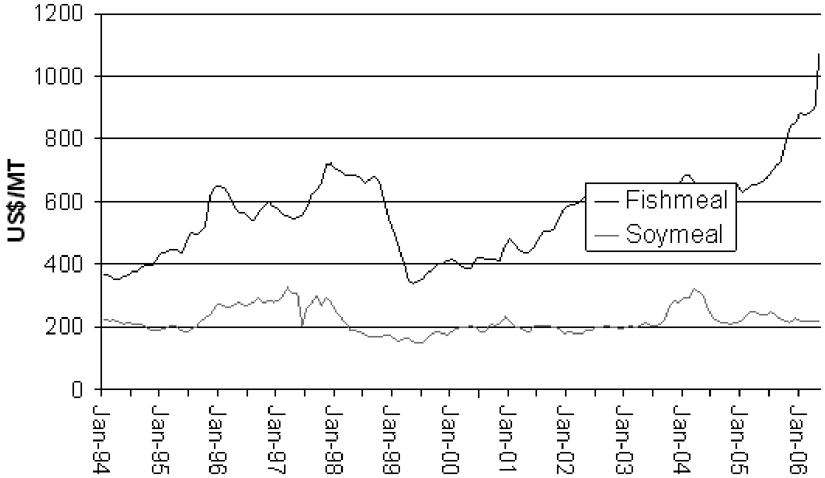
Common early estimates for fish input-output (FIFO) for aquaculture, typically 10:1, are still used to emphasise the potential unsustainability of aquaculture and its undesirable ecosystem impact (Naylor *et al.*, 2000). These ratios roughly resemble the ecological conversions from one trophic level to another. However, on the basis of a worldwide review involving some 800 industry respondents, Tacon and Metian (2008) estimated that in 2006 the sector used 3.72 million tonnes of fish meal (68.2% of global production) and 0.84 million tonnes of fish oil (88.5% total production). Assuming a wet fish to fish meal yield of 22.5% and a yield to oil of 5%, this was equivalent to 16.6 million tonnes of forage fish. At species-group level there was a steadily decreasing input fish to output aquaculture ratio from 1995 to 2006, most dramatically for carnivorous fish species such as salmon (from 7.5 to 4.9), trout (6.0 to 3.4), marine fish (3.0 to 2.2) and shrimp (1.9 to 1.4). Herbivorous and omnivorous finfish and some crustacean species showed net gains in output, with ratios in 2006 of 0.2 for non-filter feeding Chinese carp and milkfish, 0.4 for tilapia, 0.5 for catfish, and 0.6 for freshwater crustaceans. While these probably understate the less formalized feed sources, they provide very useful baselines for further development, with the prospects for national or species subsector performance indicators. In a further update, Jackson (2009), using a more refined methodology and allowing also for the use of process wastes from aquaculture itself, suggested that the overall FIFO level for global aquaculture was around 0.52, with salmon the highest at 1.68.

In production cost terms, real prices for qualities suitable for inclusion in aquaculture diets (with concerns for persistent organic contamination) have in most cases been rising. However, much of the current and immediate prospective requirement could be substituted with terrestrially derived proteins and oils, and with a different mix of species and systems, shifting from higher food-chain species to others such as tilapia, carp and catfish produced in partially or fully fed conditions, substantial sector, growth could be sustained. For species such as salmonids, a solution may also be to use diets high in vegetable oils during most of the production cycle, switching to a high fish oil diet in the period prior to harvest. Data is yet to be developed on the most effective timing for this, as well as ensuring appropriate baseline fish oil levels to ensure stock health and welfare.

For other species and systems there is still substantial scope for improvement, particularly those dependent on 'trash fish' based diets, usually bycatch or locally caught small pelagics, often mixed with local agricultural materials to provide a moist diet, which though inexpensive by weight produced, commonly gives unreliable nutritional content, poor food conversion, contamination risks and significant waste levels and polluting potential in receiving waters.

However, while a growing terrestrial dependence is likely for aquaculture, the broader context of supply is now under increasing scrutiny, *e.g.* with potential impacts from the growing demand for bioenergy, and with concerns about major soil systems and the sustainability of agricultural water supplies (Molden *et al.*, 2007; FAO, 2009c). Although earlier price comparisons with alternative protein sources such as soymeal (Figure 1.5) suggest good opportunities, vegetable proteins such as soya can lack sufficient essential amino acids, sometimes contain anti-nutritional factors, and have poorer digestibility resulting in the production of more solid wastes. Research is under way on amino-acid supplementation and processing technologies to improve digestibility (Hassan *et al.*, 2007). Other alternative protein sources are also under investigation for aquaculture, most notably and controversially, krill, for which fishing levels are projected to nearly 5 million tonnes. While the technical potential to incorporate krill into diets is reasonably established, its practical use will depend much on the costs of supply (energy costs of capture are high) and the market acceptability of tapping into what many consider to be the world's last major unexploited aquatic biomass. The challenges of combining flexible substitution with containable prices are greatly increasing for all aquaculture systems, and further research effort is required.

Figure 1.5: Fish meal and soymeal prices (USD/tonnes)



Source: Fish Information Network Market Report: *March 2006* and www.eurofish.dk

Energy

Energy use in aquaculture is highly variable, depending on the type of farming system and its operating conditions. Concerns arise both from the direct costs of using fuels and other energy sources, and for the strategic issue of energy subsidies and future sustainability under impending supply shortages. Distinctions need to be made between direct energy use, where the total of fuel, electricity and other sources of energy input are defined, usually in energy units relative to the specific activity or output, and other more comprehensive measures. Industrial energy use includes the energy required to produce or manufacture all the capital and operating inputs in the process, *e.g.* steel, timber, synthetic fibres, plastics in vessels, gear, aquaculture facilities and processing equipment, and including inputs such as fish feeds, chemicals and treated water. Embodied energy (emergy) is more holistic, adding to industrial energy the photosynthetic energy input into the biological processes of ecosystem support, food chain supply and uptake of process and consumption waste. Further distinctions can be made between renewable and non-renewable energy use – in any of the above categories.

Table 1.13 summarises typical total ratios of energy input to protein energy output. Table 1.15 shows typical embodied energy levels and ratios for different production systems, with seaweed and mussel culture requiring much more modest input levels. However in this example, seaweed culture has a high percentage input of non-renewable energy, associated with the physical facilities involved.

Table 1.15: Total embodied energy relationships, for equivalent area

Quantity	Seaweed culture	Mussel culture	Cage salmonid culture
Energy inputs (kcal x 10^5)			
Solar/renewable (%)	0.30 (4.5%)	0.75-2.05 (71.4-85.4%)	470-830 (81.0-87.4%)
Fossil/non-renewable (%)	6.35 (95.5%)	0.30-0.35 (28.6-14.6%)	110-120 (19.0-12.6%)
Total energy	6.65	1.05-2.40	580-950
Protein output, kcal	6 605	255-440	22420
Input/output ratio	100	410-545	2 585-4 235

Source: developed from Muir, 2005

When subject to life cycle analysis (LCA), the most significant energy input is in the production and delivery of feed. According to Tyedmers *et al.* (2007) energy dependence varies with intensity, typically a consequence of the high energy cost of providing feed inputs to intensive culture systems. However, direct on-farm consumption of energy also varies widely, from virtually zero up to about 3 kWh per kg in farms with comprehensive water exchange and treatment. For land based farms, most of the power is likely to be provided by electricity, usually generated centrally from fossil, nuclear or renewable energy sources. Cage-based farms will normally require boats and vehicles using diesel or other fossil fuel. While generic figures can be developed for most systems, it is important to establish reliable comparative bases and for this reason, LCA approaches are increasingly being used (Ayer and Tyedmers, 2009). At a strategic level, total aquaculture energy use measures and that for significant subsectors are currently being developed (FAO, 2009 in prep.). In conjunction also with various forms of footprint analyses and assessments of carbon budgets these will become increasingly important in defining comparative performance (Kautsky *et al.,* 1997; Bunting and Pretty, 2007).

Risks and their management

Introduction

The issue of risk is a significant factor in the development of the aquaculture sector, affecting both the specific performance and outcomes of individual operating activities and the confidence for further investment and development. By definition, aquaculture is intimately connected with the aquatic medium and its environmental drivers, whose characteristics and variability impose a range of potential hazards on both stocks and the containment/management system (Bondad-Reantaso *et al*., 2008). Increasing variability and changing trends due to climate change and other factors may bring about new or more extreme risks with unpredictable occurrence or consequence, and these will need to be understood and managed effectively. A range of other risks may also impact on the sector – some more generic and common to other activities; others more specialised and focused. The common approach in addressing risk is to define the nature and sources, the potential likelihood (or in some cases the graded probability related to the severity), the consequences, and the means (and potential costs) of reducing risks to definable levels. Based on this, various judgements can be made as to the continued viability of an activity or proposal, or the extent of action or investment necessary to bring the consequences of risk within workable levels. As appropriate, tools such as risk-adjusted financial returns and net present values (NPVs) can be used for investment decisions. The main 'business as usual' areas of risk and their management are considered here, together with the specific issues associated with climate change and the potential adaptation approaches.

Key areas of risk

Though more complex categories can be used, risk areas for aquaculture can be simply classified according to system/process groupings as:

- *biological* - aquatic diseases, predation, ecosystem instability, food safety and environmental impacts including biodiversity;
- *system* – water supply, holding unit or other component failures;
- *market/economic* – unexpected changes in factors affecting costs and returns, or business viability; and
- *political* – affecting security, policy environment, legal context, trade options.

To date, apart from a small number of politically derived cases (*e.g.* security problems, interference with business activities) environmental and biological risks have been the most significant in impact and continue to be problematic across almost all aquaculture sectors. Extreme climatic events such as typhoons, hurricanes and flooding are particular problems in some areas. Thus typhoon Chebi in June 2001 was estimated to cause direct losses to aquaculture in the Fujian Province of China of around USD 270 million, with 203 800 marine cages and more than 2 000 ha of shrimp ponds destroyed or heavily damaged with total compensation, including many thousands of fishing boats, of only USD 0.6 million.

It was estimated that in China in 2004 annual direct loss to the fishery sector (including aquaculture) by natural disasters was around USD 600 million. As noted earlier (see also Box 1.3), diseases constitute a major risk in many systems.

Box 1.3: A Chile wind – lessons from ecosystem risk

Salmonid farming has been one of the major economic success stories in Chile over the past ten years. Production climbed steadily since the mid 1990s reaching 485 000 tonnes from 800 farms in 2006, with export earnings around USD 2.2 billion (*Globefish*, 2009). However, since 2007 the industry has suffered a major outbreak of the viral disease Infectious Salmon Anaemia (ISA) resulting in the collapse of some companies and major disruption of the industry. Official statistics indicate a modest reduction in production in 2007 to 475 000 tonnes and an increase in 2008 to 488 000 tonnes. However, this is reportedly due to many companies harvesting early to clear sites and production in 2009 is expected to fall to around 320 000 tonnes (almost a 35% reduction). Statistics for the first half of 2009 show a decrease of only 17% over the same period in 2008, but greater falls are expected in the second half (Intrafish, 2009). The impact on jobs has been substantial, with an estimated 15 000 to 20 000 job losses and damage to the industry's public image and reputation will also affect value.

ISA is not the only disease problem affecting the salmon industry. Sea lice (parasites), a variety of bacterial diseases and other viruses are also a chronic problem. Buschman *et al.* (2009) and others argue that problems are not confined to the salmon farms, but that adverse impacts can also be found in the wider environment with significant changes to local ecosystems due to the release of organic solids, inorganic nutrients, chemicals, antibiotics and fish themselves from the sea cages. Lack of proper regard for ecosystem function and the consequences of stress are considered to have precipitated the current industry crisis. Addressing individual problems only when they arise has for instance led to high use of antibiotics in Chile – approximately 350 to 800 times as much as in Norway (TheFishSite, 2009). There were warnings of poor practices and their likely consequences well in advance of the current crisis but little incentive to heed these as long as operations were profitable. Over the past year, the industry has admitted that self-regulation has not provided the stability required and stricter regulation added to the existing General Fisheries and Aquaculture Law is now being implemented. The key element is the creation of areas of sanitary management or "neighborhoods" which can be more easily monitored and controlled. This falls short of the wider eco-system based Integrated Multi-Trophic Aquaculture (IMTA) approach advocated by Buschman *et al.* (2009). However, the feasibility of IMTA within the current economic system remains to be proven, and this area-based approach is a potentially useful initial step.

Market risks associated with rapid supply expansion have also been notable for a number of cases – *e.g.* salmon, seabass/bream, but are potentially less significant now that more realistic expectations are common, at least in mainstream commercial sectors. Technologies have in many cases matured, and risks have reduced as a consequence, but new rounds of species diversification and more complex systems may increase these. This is particularly the case when more than one major parameter is being changed at any one time, for example if a new species is being developed in an untried system.

Responses to current areas of risk

A range of practical responses to risk can be identified. For aquatic diseases, improved diagnostics, vaccine and other protective technologies and better understanding of the genetic and immunological basis for resistance are significant in reducing risks. However, poor preparedness or response to newly developing diseases remains a significant problem and many countries are still ill-equipped to manage aquatic diseases. In some cases diagnostic capacity is developed but needs to be connected with effective responses as both strategic and specific levels.

For system and technology risks, a range of better materials, design and testing procedures, with a greater use of ICT (information and communication technologies) together with cumulative build-up of experience, more proven designs and best practices have done much to reduce risks in mainstream sectors. However other sectors, with new species and systems or intensifying production on an *ad hoc* basis continue to be vulnerable.

The issue of food quality and contamination has been broadly containable in most cases, but increasing eutrophication, particularly in coastal areas, inadequate controls on industrial development and on input raw materials are likely to put much more pressure on the sector to ensure food safety (Bell and Waagbo, 2008). Apart from the issues of over-expansion, market and financial risks are increasingly manageable through more professional management at larger commercial scales and through capacity building amongst smaller producers. More widely, the role of the insurance industry in commercial production has been very important in managing production risks and in driving the selection of better and less vulnerable systems. However, major systemic risks associated with vectors such as climate change are likely to require much more strategic approaches for the sector.

An important area of risk management and a common prerequisite for investment is that of insurance (see Table 1.16). This is based not on protecting average and internally manageable risks within the system, but for covering impacts of more unexpected exposure. The coverage available, its costs, and the cumulative experience of insurance agents and brokers in addressing aquaculture risk can be a critical element in the investment viability of aquaculture ventures, particularly those moving outside the conventional species or system boundaries. While the EU zone has a relatively well developed insurance sector, with considerable international experience, access to insurance and the terms available can be important competitive elements. Risks of various kinds are equally if not more important in developing country contexts, but insurance markets are commonly underdeveloped and transaction costs for engaging with smaller enterprises can be too high for access. While proposals have been made for insurance instruments to cover small crop and livestock farmers against critical areas of risk, this has not so far extended to aquaculture. An exception to this may be for financial and trade transactions, particularly for larger and internationalised companies, for which credit insurance and other instruments may be available.

Table 1.16: Aquaculture in selected European countries

Country	Insurance companies	Coverage
France	Groupama (mainly provides insurance services to Asia)	Limited insurance available from local companies
Italy	n/a	Only a small number of farms insured, mostly directly through London market, or via UK insurers
Norway	Gjensidige Insurance Co.; IF Forsikring AS; Industrie Forsikring AS; NEMI Norway Energy & Marine Insurance ASA; Uni Storebrand Insurance Co.; Vesta Forsikring AS	Well developed specialist market for insurance – also covers Norwegian companies overseas
Spain	Spanish Insurance Group for Multi-Peril Crop Insurance (pool of >40 insurance companes) + Consortium for Compensation of Insurance (governmental agency	Insurance for aquaculture stock is highly regulated in Spain, but premiums are also subsidised by the Ministry of Agriculture, Fisheries and Nutrition.
UK	Sunderland Marine Mutual Insurance Company Ltd; Aquarius Insurance Services/Royal & Sun Alliance; and SBJ Nelson Steavenson Ltd.	Well developed insurance market, with major companies also insuring aquaculture operations overseas

Source: Adapted from Anrooy *et al.*, 2006.

Climate change and its implications

The specific and potentially transcending issues of climate change and its impacts are as fully relevant to the aquaculture sector as they are to other natural resource based processes. Moreover wider social, economic and political impacts will bear on governance, market, investment and organisational decisions (IPCC, 2007). Impacts will be spatially and temporally diverse and could be positive or negative. At a natural resource level these will arise from direct and indirect impacts, primarily on water, land, seed, feed and energy. Effects on capture fisheries will also influence significant feed and seed inputs. The vulnerability of aquaculture-linked communities will derive from resource dependency and exposure to extreme weather events. Changing physiological stress on cultured stocks could affect productivity and raise vulnerability to diseases and environmental stressors, in turn imposing higher risks and reducing net returns. Risks of damage to structures and other facilities will increase. Other fisheries and aquaculture interactions could include stock escapes following extreme weather events, compromising genetic diversity of wild stock, affecting biodiversity more widely.

These impacts will be combined with other aspects affecting adaptive capabilities, such as the increased pressure that growing or displaced populations place on resources, any rigidity of political, institutional and management response, deficiencies in monitoring and early-warning systems or in risk and emergency planning together with any non-climate factors such as poverty, inequality, food insecurity, conflict and disease. However, new opportunities and positive impacts (*e.g.* changes in species, better production conditions, new markets) could also arise. Such opportunities are not specifically defined at this stage but ability to benefit will depend on adaptive capacity. At present, higher risk/impact regions have been outlined (Handisyde *et al.,* 2006; FAO 2009d) on the basis of theoretical features. Asia is by far the major aquaculture producer, with large populations and production zones in low-lying areas, and is the most vulnerable region. However given the potential of Africa, Latin America and other regions, implications for future developments may also need to be considered. Deltaic areas in Asia and elsewhere are also critical for agricultural livelihoods and food security, and the loss of agriculture productivity due to salination from sea level rise and seawater intrusion could have an important impact. This could reduce availability of agricultural by-products, but could lead to aquaculture taking a major compensatory role, providing income and some aspects of food supply.

Longer term approaches

In most cases and for most climate change-related impacts, improved management and better aquaculture practices would be the best and most immediate form of adaptation, providing a sound basis for production which could accommodate possible impacts. Tools such as ecosystem approaches to aquaculture (EAA) management could be valuable in defining contexts, functional links and potential sensitivity and resilience features. Reactive or anticipatory responses would range across public, NGO and private sector. Over longer periods and based on earlier stage lessons, considerable structural and operational responses may be required, as outlined in Table 1.17.

Table 1.17: Climate change related impacts and potential adaptation measures

Climate change element/ impacts on aquaculture or related function	Potential adaptive measures
Warming	
Raise above optimal range of tolerance of farmed species	Better feeds; more care in handling; selective breeding and genetic improvements for higher temperature tolerance (and other related conditions)
Increase in growth; higher production	Increase feed input, adjust harvest and market schedules
Eutrophication & upwelling; mortality of farmed stock	Better planning; sitting, conform to CC predictions, regular monitoring, emergency procedures
Increase virulence of dormant pathogens and expansion of new diseases	Better management to reduce stress; biosecurity measures; monitoring to reduce health risks; improved treatments and management strategies; genetic improvements for higher resistance.
Limitations on fish meal & fish oil supplies/ price	Fish meal & fish oil replacement; new forms of feed management; genetic improvement for alternative feeds; shift to non-carnivorous species; culture of bivalves and seaweeds wherever possible
Sea level rise and other circulation changes	
Salt water intrusion	Shift stenohaline species upstream; introduce marine or euryhaline species in old facilities
Loss of agricultural land	Provide alternative livelihoods through aquaculture: capacity building and infrastructure
Reduced catches from coastal fisheries, seedstock disruptions, reduced options for aquaculture feeds; income loss to fishers	Greater use of hatchery seed, protection of nursery habitats, develop/use formulated pellet feeds- (higher cost but environmentally less degrading), alternative livelihoods for suppliers
Increase of harmful algal blooms- HABs	Improve monitoring and early warning systems, change water abstraction points where feasible
Acidification	
Impact on calcareous shell formation/ deposition	Adapt production and handling techniques, move production zones,
Water stress and drought conditions	
Limitations for freshwater abstraction	Improve efficacy of water usage; encourage non-consumptive water use in aquaculture, *e.g.* culture based fisheries; encourage development of mariculture where possible
Water retention period changed (reduced in inland systems, increased in coastal lagoons)	Use different/faster growing fish species; increase efficacy of water sharing with primary users *e.g.* irrigation of rice paddy, change species in lagoons
Availability of wild seed stocks reduced/ period changed	Shift to artificially propagated seed (extra cost), improve seed quality and production efficiency, close the life cycle of more farmed species
Extreme weather events	
Destruction of facilities; loss of stock; loss of business; mass scale escape with the potential to impacts on biodiversity	Encourage uptake of individual/cluster insurance; improve siting and design to minimize damage, loss and mass escapes; encourage use of indigenous species to minimize impacts on biodiversity, use non reproducing stock in farming systems

Source: FAO (2009d)

Biological and system technologies will need to be improved and made more secure, and new technologies developed. Genetic knowledge and management is likely to be more critical, including genetic improvement for more efficient feeding and diet specificity, and improved species resistance to wider temperature ranges, salinity changes, lower oxygen and to a wider range of pathogens. New aquatic pathogen risks may require biosecurity and prevention measures to be more closely applied (Gatesoupe, 2009). Early identification and detection mechanisms may need to be improved, and treatment strategies and products developed.

There may also be drivers for changing system and species priorities, including shifts around salinity and temperature tolerance, locations in salinising coastal zones and possibly high-security enclosed systems. The aquaculture of extractive species (using nutrients and carbon directly from the environment) such as bivalves and macroalgae may merit further focus for their positive ecosystem characteristics and potential food security benefits (Ferreira *et al*., 2008). Most importantly for feed-based aquaculture is its dependence on capture fisheries for fish meal and oil and growing competition for terrestrial raw material. Feeding materials and formulation strategies will be particularly important in maintaining and expanding output while containing costs and energy inputs and improving resilience to climate change. Adaptations include changing to less carnivorous species, genetic improvements, feed source diversification, better formulation, quality control and management.

Integrating aquaculture with other practices, including agro-aquaculture, multitrophic aquaculture and culture-based fisheries could also potentially recycle nutrients and use energy and water more efficiently (Little and Edwards, 2003; Bunting, 2007; Neori, 2008). These could also include capture fisheries and could assist riparian and coastal communities in general (Lorenzen, 2007). Short cycle aquaculture may also be valuable, using new species or strains and new technologies or management practices to fit into differently defined seasonal opportunities. Aquaculture could be a useful adaptation option for other sectors, *e.g.* coastal agriculture under salinization threats and could also have a role in biofuel production, *e.g.* algal biomass, using of processing fish discards and by-products.

Sector structures, trade and competition

Big fish in big ponds? Setting the scene

The context of structures and competitiveness can be recognised not just in the primary aspect of competition within and across the aquaculture sector and between regions, but also in terms of access to primary resources and in terms of the relationships and commercial impacts within the broader supply and value chain for aquatic foods. Linkages can be seen in the way that sector structures – the nature, size and relationships between aquaculture enterprises provide the basis for defining viability, efficiency and comparative performance. Trade conditions define the means by which comparative advantages and market opportunities can be realised and consumers can improve access to aquaculture products. More broadly, global and more localised competition for factors of production, particularly site area, water and feeds can be critical, as is competition in food markets and price-supply conditions. Here, the role of aquaculture in providing raw material for value-added products is different from that for whole fresh or live product as is the potential size and value of markets involved. Further complexities arise in less tangible product attributes such as environmental and ethical provenance. Though value-based ‘quality’ definers provide opportunities for niche products, cost leadership remains the basis of competition for much of the sector. In this context technical innovation commonly becomes subordinate to productivity gains via basic efficiency factors/ scale economies etc. as the primary driver of competition.

Evolution of commercial structures

Globally, the aquaculture sector remains highly fragmented, ranging from smallholder ponds or cages providing a few kilos of fish per year, to international companies with annual turnover in excess of USD 1 billion. However, commercial production is clearly consolidating, especially for products that are internationally marketed. This is the case for the fisheries and food sector more general and in many cases aquaculture production is being incorporated within wider structural change. To date, the greatest consolidation has occurred in the salmon sector where for instance 4 companies now account for 70% of UK (Scottish) production, with two accounting for over 50% of industry value. In Europe, the top 25 seafood companies accounted for EUR 14.6 billion in sales in 2008, up 22.4% on 2006, with five having turnovers greater than USD 1 billion. The sector has not previously been a target for institutional equity investors, but this is changing with consolidation and growing appreciation of growth potential. Companies such as FoodVest and Birds Eye Igloo have come under the ownership of private equity companies which has significantly strengthened their performance. Stock exchange financing has also been important, especially for larger Norwegian and Greek aquaculture companies (Table 1.18).

Table 1.18: Stock exchange listed aquaculture companies in Europe

Company	Capitalisation (EUR million)	Company	Capitalisation (EUR million)
Oslo stock exchange		Athens stock exchange	
Marine Harvest	1 626.0	Pescanova S.A.	78.0
Leroy Seafood Group	611.2	Nireus S.A.	56.0
Austevoll Seafood	598.6	Dias Aquaculture S.A.	38.7
SalMar	489.3	Selonda Aquaculture S.A.	24.6
Cermaq	479.3	Galaxidi Fish Farming S.A.	8.9
Marine Farms	52.6	Hellenic Fishfarming S.A.	6.1
AKVA Group	49.5	Interfish Aquaculture S.A.	4.9
Domstein	17.3		
Codfarmers	16.1		

Source: STAQ, 2009 - Norwegian data converted to Euro at rate of EUR 1=NOK 8.68386

Consolidation trends are also apparent in Asia, for example in the Thai shrimp sector, where agro-industrial companies such as CP are increasingly also developing a major regional presence. This is also occurring in the rapidly growing Vietnamese catfish industry, mainly driven by the implementation of western quality standards initially in processing, but increasingly stretching into production.

The number of small and medium enterprises (SMEs), sole traders and artisanal producers nevertheless remains very high, especially in some shellfish and freshwater fish sectors, and particularly in developing countries. In the EU, Framian (2009) identified over 13 139 aquaculture companies with an average of 2.6 FTE staff and turnover of around EUR 270 \ 000 (Table 1.19). For many participants, aquaculture is one of a more limited range of economic activities available in the specific coastal or rural location. In some cases, the location is self-selected and aquaculture may be more a livelihood choice than driven by purely business objectives. For those with deep social roots to specific areas, aquaculture can be one of the few economically viable livelihood options. Similarly, at global levels, as earlier noted, numbers of people are substantial, a large part of which linked with small-scale, household level activities (see *e.g.* FSRFD, 2004).

There are critical linkages between market chain structure and viable company size. In Europe, the smallest entities tend to market directly to consumers and to local food service outlets, gaining a premium on wholesale market or larger scale contract prices. This is not an option for slightly larger producers who would saturate local markets. Scale economies become more important when producers are competing in larger markets and when larger buyers impose minimum purchase quantities. More widely, producer cooperatives have sometimes enabled smaller enterprises to work with more consolidated market chains, most frequently when consolidation of sites is not physically possible.

Table 1.19: Profile of EU aquaculture (55 segments representing 95% of production)

	Number of segments	**Total turnover (EUR million)**	**Gross value added (EUR million)**	**Number of employed persons**	**Full time equivalents (FTE)**	**Number of firms**	**Volume (‘000 tonnes)**
Czech Republik	1	37	18	1 961	1 301	570	21
Denmark	5	131	40	679	498	187	42
Finland	4	70	24	na	423	434	12
France	2	477	241	na	6 389	2 285	177
Germany	2	133	87	1 872	1 599	3 343	39
Greece	3	619	na	11 982	6 628	418	na
Hungary	1	33	24	1 891	1 203	321	21
Ireland	5	114	35	1 950	1 052	na	na
Italy	6	512	263	7 307	4 859	636	218
Lithuania	1	7	3	349	315	18	4
Netherlands	4	127	63	na	405	180	68
Poland	2	94	41	2 610	2 587	870	35
Portugal	4	64	30	1 322	415	1 006	11
Spain	6	433	248	14 445	4 461	2 365	368
Sweden	4	26	7	277	277	132	8
United Kingdom	4	667	173	2 569	2 096	465	176
TOTAL	55	3 544	1 297	49 214	34 508	13 139	1 200

Source: Framian 2009 (segment = combination of species and on-growing technique)

Table 1.20 outlines some of the common drivers for expansion or aggregation in aquaculture. Their application in specific circumstances depends much on the local site and management contexts, as well as the extent to which markets are consolidating. Generally, within traditional markets defined and characterised for example by capture fisheries based supply chains, the potential for smaller enterprises to remain competitive is likely to remain for longer. Equally where margins are high enough to allow a diversity of investment and profitability conditions, there may be less pressure for consolidation. Finally, where commercial or resource capacity regulations restrict individual site size or scope of ownership, consolidation is less likely to occur. However, issues of external competition may need to be considered.

Table 1.20: Scale economy/aggregation factors in aquaculture

Factor	Implications/effects
Site locations	Impose a natural constraint on unit scale, but technical change may act to increase outputs - *e.g.* better growth, survival, environmental control, productivity
Direct/indirect cost structures	Demonstrate significant efficiency gains towards the upper scale limits of individual sites and management structures
Fiscal/financial Integration	Taxation and reinvestment incentives tend to stimulate increased capacity and productivity; regional development support promotes expansion
Markets	Efficiency gains through, *e.g.* linking hatcheries, ongrowing, joint marketing initiatives
Acquisition	Demands for uniform supply and product quality in larger-scale markets drive suppliers to increase management control, scale and/or co-ordination Different management, finance and site conditions leading to varied commercial performance, and hence opportunities for takeover and capital write-down
Management systems	Development of effective management systems and staff teams increasing investor confidence in good performers, increasing opportunities for growth/acquisition

Source: Developed from Muir (1995)

Whilst there is a global trend for increasing consolidation along the market chain, this has not yet deeply affected many areas in Asia where highly complex chains involving many small companies still exist. Efficiency comes through specialisation and competition on flexibility and quality of service. A key example of this is the production of live marine fish for restaurants and specialist markets in Korea, Hong Kong, China and many other parts of Southeast Asia. However, Dasilva and Davy (2009) note that co-operative approaches have also been developed in Asia, linking smaller scale marine fish, shrimp, seaweed and other producers together to meet their respective markets, and gain wider access and better revenue.

Trade and its development

Fishery products are the most traded of foods. In 2006, 194 countries reported exports to the value of USD 85.9 billion (up 9.6% compared to 2005 and 62.7% compared to 1996) and imports reached USD 89.6 billion (10% over 2005 and up 57% since 1996). A total of 97, mainly developing countries are net exporters of fishery products. Some 38% of all production by volume enters international trade, of which over half originates in developing countries (Valdimarsson, 2009). Given its high perishability, more than 90% of international trade volume is in processed form, though 10% by quantity, live, fresh or chilled fish accounted for more than 18% by value. According to STAQ (2009) high-income countries (83% of current GNI, 59% of real income - GDP at PPP) and 17% of population currently account for 88% of fish imports. In 2005, the EU accounted for 36.4%, Japan 22.3% and USA 16.4% of internationally traded seafood volume. However, in the longer term income growth in the developing world will generate new trade. For example, although China's share of world seafood imports remains modest, since 1990 it has grown from 0.5% to nearly 4%, with an increasing rate of growth. Much of the resultant trade is likely to be regional (FAO, 2009c) but this also impacts on availability and price of materials for wider trade flows.

Aquaculture products are tightly bound with this global market and with a plateau in capture fisheries production a substantial proportion of increased trade has been in aquaculture. Anderson and Valderrma (2009) estimate it now to account for around 50% of internationally traded seafood for human consumption. Key trends include a decrease in species diversity, but increase in product diversity through value-added processing and labelling. Although major capture fisheries groups such as tuna, pollack, cod, small pelagics and squid are likely to remain the primary trade for the sector, aquaculture products are likely to increasingly dominate the commodity market. For species such as salmon (Table 1.21), trout and penaeid shrimp, increasingly for tilapia and catfish and for more regionally traded species such as Japanese sea bass and yellowtail, aquaculture output is already predominant. However there will be increasing opportunities for wild fisheries products in upper-end segments and niche markets. Retail markets, which are becoming increasingly important in driving trade, are also demanding improvements in standards and standardization. However, intra-regional trade, common for many capture fisheries products, is also developing strongly for aquaculture product.

Table 1.21: Simplified trade matrix for farmed Atlantic salmon

Producer	Output 2007	Market source percentage		
	‘000 tonnes	EU25	Russia	USA
Norway	736.2	70	92	5
Chile	379.5	9	3	51
UK	130.1	19	3	6
Canada	117.3			34
Other/re-export		2	2	4
Other producers (‘000 tonnes): Australia 25; Faroes 22.3; USA 11; Ireland 9.9; Iceland 1.2; France 1.1				
Other markets for Norwegian salmon (2006-07 increase): Thailand 181%; Ukraine 110%; Hong Kong 27%; China 103%; ROK 75%; Chinese Taipei 217%; Vietnam 100%				

Whilst there is trade in all directions, the major import markets are the EU, North America and Japan. The trade deficit is particularly acute in North America and also substantial in Europe. At this stage, China is a net exporter, but the rest of Asia also has a trade deficit in fish products. Regions with higher exports than imports include Latin America, Africa and Oceania.

Developing countries play a particular important role in aquaculture. FAO figures (FAO, 2009) show that of the total world production of 65 million tonnes in 2007, some 60.6 million tonnes (93%) originate in developing countries. In consequence, developed country markets are heavily dependent on aquaculture product from developing countries, including tilapia, pangasius, (Table 1.22) and shrimps. For these and a number of species, developing countries may have competitive advantages, including production environments and labour costs, and this has also stimulated regional and inter-regional investment.

Table 1.22: Trade destinations for Vietnamese pangasius

Country	Export, tonnes
EU	224 300
Russia	118 200
Ukraine	74 400
ASEAN	34 000
China/Hong Kong	18 500
USA	24 200
Mexico	23 200
Egypt	26 600
Others	97 600

Source: STAQ (2009)

The processing of aquaculture product close to the place of production, especially in low-labour cost countries, also has substantial benefits for overall cost of production and can be an important factor in benefit for exporting countries. Anderson and Valderrama (2009) report that this trend is accelerating, with the prime example of pangasius production and processing in Vietnam. Links may also be made for product from developed countries, such as the recent rise of processing of Norwegian Atlantic salmon in China. Here, low labour costs made it feasible to hand-fillet farmed salmon, the improved yields from this more than compensating for the additional handling and transport costs.

Closely linked with trade development is an element in the FAO Guidelines for Responsible Fish Trade (FAO, 2009c) stating that "international trade in fish and fishery products should not compromise the sustainable development of fisheries and the responsible utilization of living aquatic resources". Artisanal fisheries can be rapidly over-exploited with increasing trade opportunities driven by higher prices (Kurien, 2005). There are potentially similar concerns for aquaculture, as earlier illustrated by the rapid development of commercial shrimp farming in tropical coastal regions, with subsequent environmental and social problems. However, a number of reviews (*e.g.* FAO, 2008b, 2009c; Dasilva and Davy, 2009) have noted the significance of trade in opening up income and employment opportunities, particularly if production standards or certification requirements provide effective safeguards.

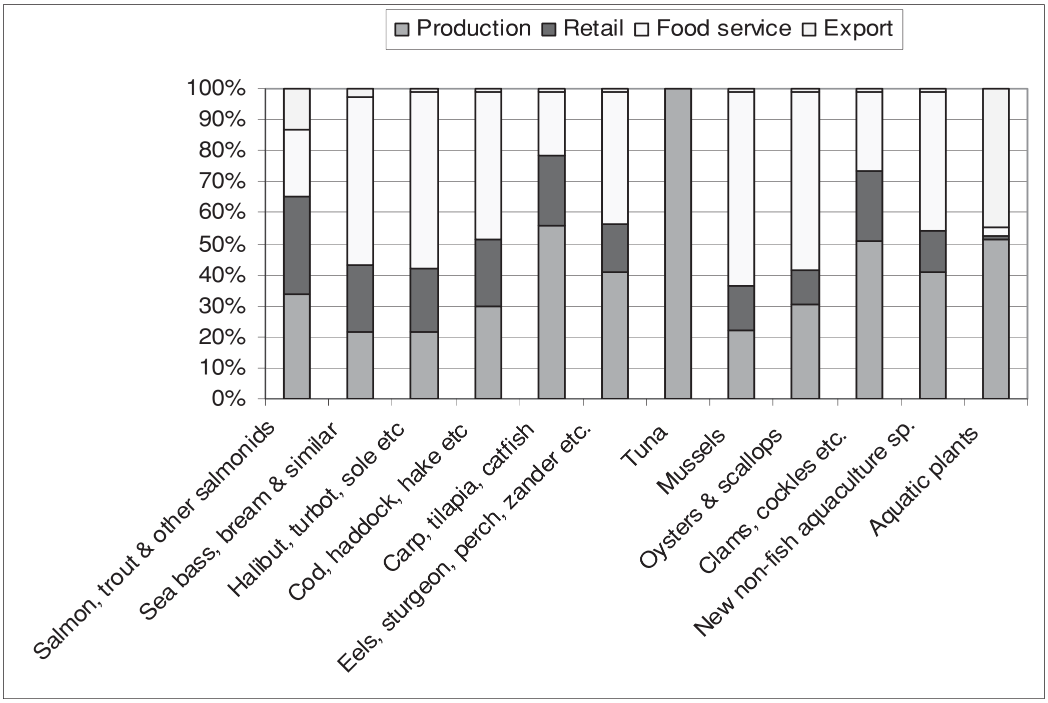
More strategically, the development of trade in fishery and aquaculture products is very closely dependent on terms and conditions of trade and whether access to key markets is sufficiently free of tariff or non-tariff barriers. Many developing countries including China, Vietnam and Turkey already benefit from full tariff elimination under various bilateral free-trade agreements. However compliance costs for adhering to Rules of Origin ensuring traceability still typically range from 2-5% of import value. While terms of trade for fisheries products, including those for aquaculture, have generally been improving under successive WTO processes, a number of contestable anomalies remain and under the current more defensive economic conditions there are concerns that protectionism may become more common. Anti-dumping (AD) measures imposed on goods sold at less than 'fair price' (below cost price in the exporting country) are particularly featured, such as the Minimum Import Price (MIP) imposed in 2006 on Norwegian salmon entering EU markets, revoked in 2008 by the WTO. The USA has notably used these to protect its farmers, with duties imposed on Norwegian salmon

(1990), Chilean salmon (1997), Chinese crayfish (2003) and shrimp for six countries (2003). Earlier in 2009 the AD duty of 64% imposed on Vietnamese frozen catfish fillets in 2003 was renewed. Vietnamese seafood businesses also find it difficult to penetrate the (second largest) Russian market due to its higher tariffs. WTO based health and sanitary (SPS) measures and those of the OIE concerning aquatic pathogens are also invoked to create practical constraints for export from various sources, and while concern for food safety and the protection of aquatic environments are very legitimate, the measures to address them may in practice add to the risks and costs for those attempting to reach key markets. The additional requirements for private sector certification, increasingly entering market requirements in more prosperous regions may add to these constraints (FAO, 2009c; STAQ 2009). However, where significant downstream commercial interests exist in the importing countries, competition for good quality raw materials may strengthen demands for tariffs to be reduced.

Competition issues

A range of competition factors will bear on the development and characteristics of the aquaculture sector whether they are global or local levels. At the level of the individual enterprise, of whatever type and scale, trends towards growth in output and an adjustments resulting from the shift away from capture fisheries tend to create pressures on margins and drivers for specialisation or more efficient production. Changes in supply and value chains and the steadily increasing strength of value addition and retail sectors create strong competitive pressures within the chain, addressed by cost competition or more efficient (and often more dependent) market relationships. A recent review of EU aquaculture production (STAQ, 2009) provided the baseline breakdown shown in Figure 1.6. For internationally traded products, particularly from small scale producers, downstream value addition may be more pronounced; thus the distribution of benefits from small-scale pangasius producers in Vietnam to European retailers shows that for a final sales price of EUR7/kg, 10% goes to the farmer, 10% to the fish collector, 20% to the processor, 20% to the trader and 40% to the retailer.

Figure 1.6: Production, retail, food service and export values - EU aquaculture (2005)



At the national and regional level, competition can also be seen for sector performance and profitability and for the food sector, the ability to contribute to national or regional demands. Thus for the EU, the European Commission issued a strategy for the sustainable development of aquaculture (EC, 2002), recognising its role in meeting expanding regional demand for seafood, but also the need to meet rising standards and aspirations for food safety and environmental sustainability. This envisaged an increase in EU production of 4% per year to meet expected demand, though in fact production has since been relatively static, contributing some 1.3 million tonnes to an estimated 12 million tonnes of annual demand. The EC Lisbon agenda (2000) provides the context for sector competitiveness, aiming for Europe to be the most competitive and dynamic knowledge-based economy in the world. This was relaunched in 2005 with a stronger focus on growth and jobs following a review recommending action based around three main areas:

- Better analysis of competitiveness as a foundation for action;
- Getting the regulatory framework right and
- Increasing efforts to foster research, innovation and entrepreneurship.

Competition was further embedded into the wider Lisbon strategy framework in 2007 with the launch of the new cycle (2008-2010) (European Commission, 2009). Recent reviews (STAQ, 2009) have analysed the sector's competitiveness across these and related criteria, identifying areas for further growth, while recognising that other regions were likely to continue supplying aquaculture raw materials, but that significant value, and important competitive position was to be derived from developing products to meet EU and other markets. More broadly, the World Economic Forum Global

Competitiveness Report (WEF, 2008) describes twelve pillars of competitiveness within three economic competitiveness classes. Table 1.23 outlines these and notes the respective issues for aquaculture.

Table 1.23: Applying WEF competitiveness criteria to aquaculture

Competitiveness elements	Issues for aquaculture
Basic factors	
Institutions	Governance framework, policy development and implementation
Infrastructure	Efficient access for inputs and markets, efficient communication
Macroeconomic stability	Sound conditions for investment, reduced risk and transaction costs
Health and primary education	Availability and quality of human and social capital, basic skills and motivations
Efficiency enhancers	
Higher education and training	Availability of specialised skills, generation and commercialisation of new knowledge
Goods market efficiency	Means by which raw materials/products are made available to aquaculture particularly seed and feeds, also technologies – in accessible, timely and cost-effective manner.
Labour market efficiency	Flexibility of access to labour, potential to build key skills; transparency of wage/contract/other conditions
Financial market sophistication	Range of financial instruments, risk management, access to capital, R&D and other incentives, cost of financial services
Technology readiness	Preparedness to take up and gain competitive advantage through new technologies; positive environment for interface
Market size	Market presence and power; scale advantages; investment potential for new products, market development
Innovation and sophistication factors	
Business sophistication	Extent of development of specialised products and services, access to wider value addition potential
Innovation	Understanding of process and value; context for support of innovation; public-private partnership options

According to this definition, most commercial aquaculture sectors can be defined as efficiency-driven, while in some developing country contexts, factor-driven elements are more important. ‘Market size’ is a particularly important in this designation, *i.e.* growth in global value chains for seafood along with consumer demand. This is linked with the potential to exploit resources more efficiently through economies of scale, and the use of vertical and horizontal integration for efficiency gains. This is most clearly seen in consolidation trends in growing segments of the industry.

Notable issues in competition are the increasing vertical integration of larger companies in the fishery product sector, the increasing power of major multiple retailers and the growing importance of developing effective and innovative product forms. Aquaculture products hold distinct advantages in their potential regularity of supply and ability to deliver on order. With the wider adoption of HACCP and other quality/traceability systems, farmed product is also more favourably placed. Eco-labelling and other market discriminants have also become much more important as a competitive element in key markets (see Box 1.4), though as noted earlier, there are concerns about the extent to which smaller producers, particularly those in developing countries, can access such systems.

Within these markets, representing a growing share of global supply, and with a particular role in developed country market blocs, an increasing targeting of reliable, uniform quality and adaptable aquaculture product is likely to result. Here, species origin and primary characteristics may become far less significant. Competition at both enterprise and regional level is increasingly likely to be defined by the ability to build efficient supply chains and to meet emerging requirements. To do so shifts the emphasis from competence in raw material production towards a more holistic performance and competitive advantage. However, while considerable attention has been given in the last decade to value addition and supply chain development, investment needs will continue for effective and sustainable primary production.

Box 1.4: Ecolabels – Communicating sustainability information in aquaculture products

The communication of sustainability information has become increasingly prominent in markets for products from both capture fisheries and aquaculture. A variety of instruments both nationally and supra-nationally share a common goal of seeking to promote a market-based response to concerns over fish stocks, production techniques and their impacts. Concerns surrounding the ineffectiveness of formal controls to meet key aims have encouraged a variety of schemes from a diverse range of organisations including the private sector, NGOs and governments. These may be categorised as certification schemes (some of which appear as an ecolabel) or recommendation lists. These co-exist, sometimes overlapping, with a raft of measures including guidelines, codes of conduct, and best practice guides which suggest working practices for improving environmental, welfare, social, ethical and other issues.

Certification schemes are voluntary assessments of the status of a specific aquaculture operation and its related production practices and impacts. Assessment of compliance is undertaken by a third party and may result in permission to use a designated ecolabel. A charge is commonly made for this endorsement of the product. The ecolabel is intended to communicate to the retail consumer, or less commonly the seafood diner that the product meets the requirements of the scheme. However because of the diversity of such schemes and varied criteria, consumers may become confused and ultimately uninfluenced. .

Recommendation lists offer another communication approach and commonly attempt to provide advice about the sustainability of a particular species and hence it desirability to purchase. Traffic lights or similarly abbreviated messages can simplify potentially complex communications. Lists are favoured by NGOs such as Greenpeace, Marine Conservation Society and WWF, but also by some governmental agents (e.g. NOAA) and other bodies. Listing agents tend to choose their own focus and do not necessarily consult with the sector involved. They are commonly part of wider campaigns and may also introduce confusion to the buyer through the more generalised, and potentially less accurate, nature of the information conveyed.

The market-based approach of such schemes has received criticism for its potential to exclude some producers from certain markets for reasons of cost. Concerns have been expressed for their possible effect as a trade barrier and for potential manipulation by large buyers such as supermarkets to exert yet more control over their suppliers. Confusions may however lessen over time as schemes become more convergent and as some gain market dominance. FAO (2009) are also promoting integration of aquaculture within established codes for fisheries and the EU is also moving towards incorporating fish within wider eco-labelling schemes. However market-based measures alone, though they will impact producers, are unlikely to be either an effective or efficient means of ensuring aquaculture sustainability.

Diversification strategies

One of the significant issues in competition in the aquaculture sector is that of diversification with the aim of creating new frontiers of market opportunity and the potential for improving margins over sectors which become increasingly cost-driven. A range of strategies for production or value chain development can be identified at global or more localized levels, including:

- Increasing variety of output from the same species; including different sizes, product form or quality, and different production times; this could also include genetic diversification - colour morphs, changed body configuration, single sex species, etc. These approaches could have implications for production and capacity planning, operational management, market targets, costs of production and there might also be increasing competitive overlap across species, *e.g.* large rainbow trout versus Atlantic salmon; *Pangasius* versus tilapia.
- Diversifying species within similar groups; relying on similarities in system and operational requirements. So far these have most commonly involved salmonids - Atlantic salmon, rainbow trout, brown (sea) trout and Arctic charr, though Mediterranean marine fish could follow a similar pattern. There are implications for production efficiency - adapting to less than optimal conditions for new species, operational management, as well as disease and ecosystem risks (which may sometimes limit the opportunity to introduce other stocks).
- Diversifying production systems; using cheaper or less site-constrained methods for the same species, widening flexibility of operation, product timing etc. The simplest step is usually through intensifying existing systems; other options include offshore cages and highly intensive recycle units, which both remove site constraints, but have higher capital and operating costs. A further prospect is to integrate production (*e.g.* intensive tank systems with extensive ponds in coastal areas, combining mollusc culture with cage culture, etc.).
- Diversifying species and production system; *i.e.* completely new production concepts, with if necessary radical departures from current approaches; costs and risks of technical development may be substantial, though some may be developed through reassessing earlier approaches which had not been followed up.

Muir and Young (1998) noted that while diversification is a rational objective, species diversification is not necessarily the best goal; that risks and returns of making new species available on aquaculture markets need to be compared with the creation of new products from existing species. They also described a range of aquaculture species identifying key attributes, determining their potential to become ‘universal products’ (Table 1.24).

Table 1.24: Comparative development features of aquaculture and other fish sources

Features	Salmon	Seabream	Block white fish	Channel catfish	Tilapia	Mussels
External appearance	Medium-large, powerful, long, deep, silvery, clean	Small, short, stubby, flat, silvery bright, clean - 'marine''	N/a – sourced from range of species	Small, slender, blue/grey, unprepossessing	Short, stubby, silvery, grey or red, bright	Black/green shells clean to crusted - marine'
Internal appearance	Pale-deep pink/ orange, distinct flakes varying fat levels	Pale/creamy, close-textured, lean	White or white-ish, close-textured, flakes, lean	White(ish), quite close-textured, neutral	White(ish), close-textured, quite lean	Light-deep orange, single nugget
Flavour/ Texture	Distinct, firm, soft to well-textured, can be coarse, fatty	Mild, succulent, fine textured low-medium fat	Neutral, well-textured	Mild, soft-well textured, can be muddy	Mild, well textured, can be muddy	Distinct, soft to well-textured, can be gritty
Connota-tions	Good quality, associations with clean, cold waters	Very good quality, linked with coastal/city restaurants	Widely accepted though not always recognised	Poor- neutral, but improving widely due to marketing	Neutral but improving strongly	Popular; occasional public health concerns
Availability	Increasingly available year-round, in range of sizes and product forms	Seasonal availability gradually extending, limited sizes and product forms	Generally ubiquitous in wide range of quality and form.	Seasonal, but widening access; mainly whole and fillets	Wide sourcing for year-round supply; whole and fillets	Seasonal availability supplemented by imports v. limited size/ product form
Production costs	Moderate costs, reducing but above 'bulk fish prices	High costs, red-using; may have constraints	Baseline product costs; target for other supplies	Low-moderate costs, margins being reduced	Low-moderate costs, potential to reduce	Low cost, increasing due to environmental limits
Distinctiveness	Medium-high in most forms, but can be varied	High if fresh/ whole; otherwise limited	Low-medium, depending on source	Medium, but can be varied *e.g.* with husbandry	Medium, can be varied either way	High in most forms; also ingredient
Adaptability	Very adaptable - whole, steaked, portioned, fresh, cured smoked, in value-added foods	Currently limited - whole, split, filleted fresh/frozen	Adaptable; portions, nuggets, fillets, in value-added foods	Moderate, improving; fillets, nuggets, value added products	Moderate but potentially improving; fillets, value-added products.	Moderate – whole, shelled, fresh, pickled, smoked, in value added foods

This concluded that large fish, easily and rapidly grown, with good consumer attributes and potential product versatility, could offer good opportunities for expanding markets through diversifying product form. Based on a review of typical aquaculture product characteristics, they concluded that product modifications based around existing aquaculture stocks could have considerable potential, while the commercial opportunities of diversification to specialised high unit value species might be more limited, particularly as multiple retailers are able to source widely on a global basis for other species. Amongst current species, while seabream and similar species may be developed more widely, there will be basic constraints, while catfish and tilapia and possibly salmon may have considerably greater potential. Though Asian and Indian carps have the potential to be produced relatively cheaply, their disadvantages of texture and bone structures make their widespread incorporation in major traded commodity flows unlikely.

Positioning for the future

In all but the most extreme risk conditions, the prognosis for growth of the aquaculture sector, globally, regionally and across species and systems, appears very positive. Demand projections suggest greater output and value in most subsectors. The value of the sector is such that many enterprises are likely to wish to strengthen their positions and in changing economic, trade and environmental conditions, national interests in competing in wider markets are also likely to increase. As outlined in Box 1.5, there is considerable question as to whether new centres of production and market power are likely to arise.

In this context also the role of various support functions may also be significant. As discussed in the next section, broad issues of governance are critical in ensuring that a positive environment exists for the sector, that resources are accessible, investments can be made and that markets can be accessed in an effective and profitable manner. The specific competitive policy of governments deserves scrutiny and while a range of support measures can be noted, ranging from infrastructure development, human and organisational capacity building, scientific and technical facilitation, marketing and trade information and brokerage, credit insurance and other measures, there is strategic concern that uncompetitive measures are avoided. Arguments against these include unfair trading practice and the economic costs and market distortions created by subsidising specific sectors or activities within them. However, such are the current pressures for food self-sufficiency, strategic positioning in key markets, protecting or developing poorer regions or communities, that the avoidance of explicit support incentives becomes difficult. For poorer countries in particular, where foreign exchange holds a particular importance and external investment a major target, incentives for development can be substantial. Where for example, land and coastal margins are held in national ownership, low cost site concessions, combined with generous taxation allowances can create very favourable conditions for commercial development. In the past, incentives for aquaculture had also been provided in some Middle Eastern countries to subsidise costs of key inputs such as international staff, broodstock and feeds, as well as substantial grants on capital investment, but this is now largely past. However, low energy costs and the provision of major infrastructure can still make a substantial difference to capital and operating costs for aquaculture enterprises.

Box 1.5: Who are the new aquaculture powerhouses and why?

Norway has led the development of cage-based aquaculture, especially salmonids, over the last 30 years. Its companies also play a major role in the industries of Chile, Scotland and Canada. Key elements have been the traditional importance of marine resources to Norway, priority at policy level and strong strategic investment flowing from the successful Norwegian oil industry. So far, diversification of Norwegian interests into other species and geographic regions have been relatively limited, but some companies are active, and through NORAD the country is involved in aquaculture development globally. Ultimately, Norwegian interests may not be large enough to power massive global expansion, but it remains a technology leader and if it maintains current levels of commitment, could retain its position for the foreseeable future.

Norwegian aquaculture production is dwarfed by China, with around 50 times the output from a far more diverse industry. Although growth is slowing, its annual increase in production is still 2-3 times the entire production of Norway. Key strengths have been access to natural resources, a very large and industrious population and a willingness to innovate (although often with imported technology). Natural resources and population are limited, so the industry might be expected to weaken, except that China is increasing investments in overseas aquaculture projects and has a major role in global fish trade, both as a producer and as a processing country; which could power it to even greater prominence in the future.

In recent years, Vietnam has emerged as growth leader in South East Asia, following earlier expansions in Thailand, Indonesia and The Philippines. These may be followed by Cambodia if inward technology transfer combines with strengthening economies and civil society. Global competitiveness however, has depended on high utilisation of natural resources and low labour costs, which may not last. Similar patterns are apparent in some African countries such as Nigeria, Ghana and Uganda, which with proper governance and greater inward investment and technology transfer could become key producers. Arguably closer however is much of Latin America. Strong growth has occurred across the continent from Chile to Mexico and the sheer size, natural resource base and growing economic strength (e.g. of Brazil) suggest it could become a major powerhouse for future aquaculture.

If however the future of aquaculture depends on technology development more than natural resource exploitation, opportunities for leadership remain with the traditional technology leaders of the USA, Europe and Japan.

The most significant development in competition and trade is however that of corporate power, whether in the form of private or publicly owned enterprises operating in modern capital markets, or in public-private entities typical of the liberalising command economies, where local and provincial managers have significant strategic power and access to investment. The linkage of these enterprises with major markets and with increasing levels of vertical integration is likely to take up an increasing share of the growing aquaculture sector.

Governance, management systems and strategies

Initial concepts

The policy and governance context for aquaculture is an essential feature of its development and potential. Its significance in national policy ranges from relative disregard – particularly if it is an undeveloped or minor economic sector, to a level of highly developed and focused support and control. In some cases, optimistic expectations, often linked with the enthusiasm of external development agencies, may generate elaborate sectoral policy and planning exercises without the benefit of tangible production, or the means of bringing it in to reality. A primary requirement for effective governance and management is that the sector and its features are understood, its value is recognised, both in terms of costs and benefits, and its connections with other sectors realised. In this last respect, the development and application of various valuation approaches will become increasingly important, allowing integrated tradeoffs across sectors to be better defined.

Key areas of policy and governance include; resource allocation and the protection of its quality; identification, control and management of environmental and disease risks, determination and control of food safety; qualified areas of trade support and possibly selective protection; promotion of regional co-operation; management and development of shared water bodies and catchment areas; protection of specific interests – such as social objectives; sectoral diversity; and wider representation and policy exchange with other parties. A recent summary of current aquaculture governance issues has been provided by FAO (2008b). This section therefore highlights specific issues and offers further commentary on their likely directions.

Significance of the aquaculture sector

An essential consideration for aquaculture, as for the fishery sector more widely, is the role it plays in national and local economies. As with most food primary production sectors its contribution to GDP is usually small. Table 1.25 shows examples of the range involved for a selection of countries, based on first sale values. Though this will be increased in many cases, typically 2-4 times, by downstream added value and economic impact, the sector's role is usually relatively modest, though examples can be seen where with strong export markets in particular, limited alternative GDP sources or with particular livelihood support for key groups, it has a more valuable position.

Table 1.25: Estimates of aquaculture sector contribution to GDP in 2007 (*OECD countries)

Country	Value USD million	GDP USD billion	Value as % GDP	Notes
Asia				
China	39 684.8	2 278.8	1.74	Major producer and economy
Japan*	3 172.9	5 333.9	0.06	Domestic markets, modern economy
India	4 383.5	730.3	0.60	Shrimp, other exports
Viet Nam	4 525.8	51.8	8.74	Major exporter
Indonesia	2 461.9	231.7	1.06	Shrimp, other exports
Thailand	2 432.8	173.2	1.40	Active exporter, modern economy
Bangladesh	1 522.6	66.5	2.29	Domestic markets and shrimp, other exports
Chinese Taipei, ROC	991.5	391.4	0.25	Domestic markets, modern economy
Korea	1 576.9	708.1	0.22	Domestic markets, modern economy
Myanmar	1 862.4	14.7	12.70	Shrimp, other exports in poor economy
Philippines	1 234.2	101.8	1.21	Exports and domestic markets
Malaysia	369.7	125.1	0.30	Wealthy resource based economy
Europe				
Norway*	2 977.7	191.5	1.56	Diverse and wealthy economy; salmon
France*	757.2	1 488.2	0.05	Large diverse economy, domestic demand
Italy*	757.4	1 142.6	0.07	Large diverse economy, domestic demand
United Kingdom*	927.9	1 695.3	0.05	Large diverse economy, aquatic exports
Greece	533.3	146.5	0.36	Smaller economy, seabass/bream exports
Spain	384.1	719.4	0.05	Large diverse economy, domestic demand
North, Central and South America				
Chile	5 277.3	103.6	5.09	Salmon aquaculture and exports
United States of America*	944.6	11 925	0.01	V large, diverse economy, aquatic imports
Brazil	598	721.8	0.08	Diverse growing economy, minor aquatic role
Ecuador	763	21.7	3.51	Shrimp exports
Canada*	788.2	875.1	0.09	Salmon exports but diverse economy
Other				
Russian Federation	325.8	389.9	0.08	Growing economy, minor aquatic role
Iran (Islamic Rep. of)	451.1	145.8	0.31	Domestic markets, expanded aquaculture
Turkey	604.6	269.5	0.22	Diverse economy, bass/bream exports
Egypt	1 192.6	135.9	0.88	Substantial aquaculture; domestic supplies

Particularly for countries developing PRSPs (poverty reduction strategy programmes) a recent development initiative has been to increase awareness of the GDP, employment and food supply significance of the fisheries sector and where appropriate, that of aquaculture. As a result, an increasing number of countries are recognising the sector within policy frameworks.

Commercial environments

According to FAO (2008b), good governance for the aquaculture sector can be defined by offering predictable, transparent, equitable and easily enforceable legislative frameworks and simple regulations covering all aspects of aquaculture and its value chain. Where appropriate these would be complemented by economic incentives to encourage best practices, supporting producers to develop and apply self-regulating management codes and sustainable production systems. In a broader sense of the policy and institutional environments comprising the governance context, Muir (1995) summarised the following elements (Table 1.26).

Table 1.26: Institutional/policy factors in aquaculture development

Institutional/ policy factor	Effects	Notes and issues
Overall framework	Legislative structure, definition, certainty, basis for contracts, leases, property rights, protections, obligations; infrastructures	Provides the basic context in which aquaculture can operate; legislative factors commonly need to be developed; rights often difficult to establish
Economic policy	National economic strength, income distribution, market conditions, investment opportunity and structures, trading conditions	Aquaculture sector usually the recipient of policy, as relatively small scale; may affect international competitive environment
Fiscal structures	Business entities, investment opportunity and structures; development and re-investment, internationalisation	Positive and negative aspects for aquaculture; financing delayed-payoff projects may require special instruments; small-scale credit may be a constraint
Social policy	Development targets, objectives; poverty focus, investment priorities, availability of support structures/ development services	Aquaculture commonly seen as a possible socially effective activity, but targeting may be difficult because of need for resources, security
Environmental policy	Environmental objectives, resource assessments, protection and conservation, development constraint, resource pricing, rehabilitation	Increasing impact on aquaculture, possible over-reaction; aquaculture can contribute to environmental gain - needs good management
Other	Consumer protection, public health, resource development and management, employment regulation, liability, personal property, wealth	Various issues affect aquaculture development, cost of production, security, market issues, etc.

Many countries have developed legislation to govern the licensing, monitoring and control of aquaculture. These aim to ensure that development is appropriately located, ventures are sustainable and adequately protected and meet standards of environmental protection. Most frameworks cover a number of production-related aspects including, location and resource planning, resource access provision, water sourcing and wastewater management, supply, sourcing or standards for seed and feed, and biosecurity issues such as stock movement and disease control. Financial and market provisions and as appropriate, investment instruments and other incentives may also be established (FAO, 2008b), with governments promoting and supporting investment by small-scale producers through economic incentives including subsidized credit and collateral-free loans. Fiscal incentives reducing or eliminating income tax, land taxes, sales taxes or import duties may also be available to domestic and foreign investors. Targets for foreign direct investment (FDI) have at times been contentious, even if ownership levels are sometimes capped, with instruments such as capital and profit repatriation encouraging rapid developments with insufficient social or environmental safeguards.

Amongst existing or emerging producers, self-policing is becoming more common and is being promoted by a number of representative bodies, notably the Global Aquaculture Alliance and other sectoral interests, increasingly linked with certification schemes of various kinds. International assistance has sometimes been given to support and promote private sector quality assurance, for example with USAID and the Bangladesh shrimp industry (FSRFD, 2004). The FAO Code of Conduct for Responsible Fisheries (CCRF) (FAO, 1995) is being used in some cases as a framework for self-regulating management codes. By empowering small-scale producers in complying with voluntary codes, it has been possible to improve environmental practice and improve access to international markets (FAO, 2009c). However, self-regulation through voluntary codes of practice may be ineffective in the absence of binding legal obligations to enforce rules, though with processes such as the WWF Aquaculture Dialogues, building industry support for definable good practices, linking with formal regulation and definable international standards, efficient and trustworthy self-regulation may become more viable.

Here, as in the fisheries sector, the international dimension of governance can also be noted. Thus EU legislation on aquaculture and its value chain governs food additives, animal diseases, environment, labelling and packaging, marketing, research, sanitary and hygiene measures, structures and third countries. These regulations are binding in all EU Member States without the need for any national parallel legislation. Import standards extend the impact of these regulations tom exporting countries. An extensive array of international agreements, standards and procedures is similarly in place elsewhere. To participate in international trade, compliance with some of these agreements, standards and procedures is mandatory, and competent authorities are defined and empowered to verify compliance. However, for internal markets and some regional markets, this level of interlinking standards and compliance is not so well developed, absent or more arbitrary.

Overall though, there have been important changes. As the sector has grown, its governance at various levels is still beset with practical and conceptual problems. Some are the inevitable consequence of highly technology and market driven activities quickly moving outside of societal boundaries, others relate to regulatory over-reactions or imbalanced responses with insufficient protection in some themes co-existing with strong focus on relatively insignificant issues. In some circumstances, particularly in developing countries, there is specific concern that some forms of aquaculture can cause environmental damage at the expense of society and that local communities are not sufficiently aware or empowered to call producers to account, or to realise local resource potential to produce more equitable results in their own hands. FAO (2008b) notes the possible risk of "environmental or societal dumping" as the sector grows and countries compete for foreign investment.

FAO (2008b) propose the key reasons for deficient governance to be the failure to i) distinguish between private and public sector roles and responsibilities, ii) establish a predictable framework of laws and iii) provide transparent and consistent decision-making in application of laws and rules. A significant number of problems is still connected with the need for public sector agencies to disengage from direct involvement with production and having the confidence and capacity to move to a sector enabling role, while reserving sufficient regulatory control to be able to bring excesses into line. At the same time is noted the lack of financial and skilled human capacity to establish, monitor and enforce regulations and the particular challenges of doing so where there are large numbers of small producers. Issues of over-regulation and administrative delays are also noted. A strategic problem is also that traditional governance agencies – commonly fisheries departments, lack the capacity to address aquaculture across the broader range of relevant policy issues. Although attempts continue to be made to widen linkages with other public sector agencies, the practical consequences are in most cases very limited.

Resources and ecosystems

A range of laws and regulations commonly address access to key resources, their use and the obligations to address the consequences of use (*e.g.* resource quality degradation, deprivation of other users, wastes). In most countries, permits are required to put up structures in open water areas, such as fish traps and cages, or to dam or divert flowing water for private use. Access to groundwater is also increasingly under control as resources become more heavily loaded. Similarly, conditions are set for the discharge of water and wastes, continuously or periodically into receiving areas. However, laws can be difficult to enforce because of the limited capacity to monitor, particularly for resource quality parameters. These are in any case often related to generalised targets rather than useful and relevant levels for local contexts. In some cases, communities or producer associations manage water resources and resolve conflicts. Multiple uses of water have also been encouraged to resources more efficiently and reduce potential conflicts, but the criteria for these, the administrative context, and the rights and responsibilities of shared users can be problematic to define and manage.

For planning and resource access, some countries apply zoning regulations, in which aquaculture of various forms is spatially delimited. This commonly also provides some level of protection for aquaculture operators from other activities and is sometimes linked with provision of specific infrastructure, such as power, water supplies or waste channels. A management and monitoring regime is also often established. Normally this is accompanied by a licensing system with associated fees and penalties. While this can be very effective in newly developing allocations of resources, retrospective application, particularly for small producers, can be problematic, though where associations can be developed to participate in the zoning process, there may be better outcomes. In some cases also, the definition and application of rights to resources can be problematic, particularly where customary use rights and allocation mechanisms clash with more modern and formalised legislative structures. A further issue for land and water allocations is that of restitution; potentially, zoning and related approaches can enforce obligations to restore sites which have been used for aquaculture but no longer applied. However, this requires well designed regulation to ensure the financial and other responsibilities can be addressed. To date, and usually in the absence of zoning/licensing provisions, restitution, *e.g.* for salinised soils around abandoned shrimp farms, has been impossible to enforce.

Other biological resources and ecosystem features related to aquaculture are also commonly subject to regulation, though its focus and enforcement can also be problematic. Key issues are biodiversity and biosecurity – associated with impacts of aquaculture via change of habitat, species introductions, escapes, disease interactions, and predator control. Seed production and seed quality are also becoming a focus for governance, at one level regulating stocks and their source and quality and at another, creating incentives for producers to target good quality seed of desired species. As this develops certification of seed producers, quality standards and other elements can be established and monitored via national and local seed agents. For biosecurity and disease risk reduction many countries have provisions to control movement of stock, including quarantine, export controls and other measures. However in practice, particularly for developing countries with long terrestrial or coastal borders, monitoring and enforcing these can be extremely difficult and in many locations stocks move freely, without inspection or certification.

Other areas of regulation include feeds and ingredient quality, with associated licenses for feed, additives and/or premixes produced domestically or imported. However, monitoring is commonly constrained by capacity and resources and in many cases small farmers make feeds on site or obtain supplies from artisanal producers, without any reference to quality standards. However, as evidenced by the recent issues of adulteration of raw materials, with Chinese feed producers incorporating melamine to artificially enhance measured protein levels, concern is increasing, and more organised approaches are being introduced. This is particularly the case for exporting countries targeting international markets.

At a wider level, a range of governance issues concerns the management of shared and transboundary resources, including watersheds, lakes, coastal margins and regional seas. Much of the context is commonly established with respect to water allocation and management or capture fisheries management, but even in these areas the development and application of workable approaches can be problematic. Interactions with respect to aquaculture are as yet relatively poorly developed and implemented, but can be expected to take a greater role. In the EU, the development and application of the Water Framework Directive in the last decade has provided a context for aquaculture, amongst other uses, and could be a useful precursor for similar approaches elsewhere, but this has required significant investment within a wealthy region with well developed governance systems. A related area, also open to further development is the interaction between aquaculture and other sectors in conditions of steadily increasing resource pressure and wide diversities of resource value, *e.g.* between biodiversity and conservation, residential development, tourism and primary production. In these areas, as with others, further dialogue, negotiation of market and societal value and related tradeoffs will be required. Externalities associated with aquaculture or potentially impacting on it, also need to be further addressed, valued more explicitly, and brought into management frameworks. While resource pricing or market mechanisms may help to drive efficient allocation and maximise societal and ecosystem benefits, they might not be sufficient for a complete accounting for more subtle or complex issues. Approaches such as the Ecosystem Approach for Aquaculture (EAA), developed conceptually from the equivalent for fisheries (EAF), may be useful in developing more holistic valuation, decision-making and management arrangements. However, these need to be developed in practical contexts, recognising the capacities of governance agents.

Social and community issues

A range of social and community issues may be involved in governance approaches, including labour conditions – access and discrimination, minimum wages, health and safety, worker welfare systems, training and skill development and wider social objectives, including credit access for target groups, rights, consultative and co-management approaches, and links with political empowerment and local democratic processes. More generally responsibilities for food safety and consumer protection can also be included. Certification systems for aquaculture practices and products are beginning to include standards for monitoring social responsibility and equity and are increasingly engaging a range of stakeholders including communities, NGOs, public authorities and academia/research institution to define aims and indicators and develop approaches to meet social aims.

However, except for localities and countries where aquaculture has specific economic or resource use importance or where there are social compensation issues surrounding larger scale commercial ventures, it is important to set social development and protection issues into context. Aquaculture can be important in meeting objectives for rural employment, livelihood support, access for vulnerable groups and national food security, but the conditions and limitations for these need to be better understood, together with the wider framework in which these contributions can be made.

Knowledge and capacity building

A further area of sectoral governance which is commonly encountered is that of developing and applying knowledge and building capacity, in public sector agencies and in the civil society and private sector roles. The record on these has been rather variable and while there has been substantial public sector investment in aquaculture, the returns, particularly in developing countries, have been uncertain at best. As a consequence it has been easy to lose confidence in the value of inputs or a sense of where and how future investment could be placed. Apart from the larger private sector entities, analyses suggest that there are notable constraints in innovation and knowledge building, with key issues being:

- The limited capacity of individual producers, particularly in artisanal/small-scale sector and the difficulty of overcoming resistance to collective approaches;
- Public sector research and extension functions and motivations being independent of aquaculture sector concerns and being unrelated to applicable value-building outcomes;
- Limitations in NGO capacity, particularly in linking social development with technical and market knowledge and with local and external innovation and learning processes;
- Difficulties in building effective and goal-oriented strategies, employing partnerships between public, private and third sector agencies and building capacities appropriately.

Table 1.27 outlines some of the issues and possible strategies.

Table 1.27: Constraints to development and uptake of aquaculture

Area of concern	Issues	Possible strategies
Past research and knowledge strategies	Scope too narrow; primarily zoology and basic technology, intensification; neglect of social and environmental context, short-term in response to funding	Post-hoc analysis, lessons learned; focus forwards towards integrated approaches
Present state of research and knowledge building	Wide variation in capacity between regions. Specific needs of different types of development poorly appreciated, inappropriate resource allocation, lack of understanding of farming systems; need for integrated strategies, multi-disciplinary staff resource; lack of long-term funding support, operating funds; low motivation, lack of competition, dynamism, quality of training	Improved procedures for research strategy, selecting priority areas, multidisciplinary approaches, appropriate protocols, co-operation mechanisms and means to integrate plans, skills and outputs; more focus on operating expenditures, improved selection, training, motivation, evaluation, staff conditions, external communication; programme funding continuity
Disparities in distribution of knowledge	Wide regional variation in basic knowledge and techniques available, impeded flow of knowledge, lack of competition, interchange, communication; need for evaluation, need wider participation with developed country activities	Better communication, meeting, exchanges of ideas, network access, external evaluations of work programmes, better regional mechanisms, develop high standard regional scientific journals.
The use of research	Communication gap between public sector institutes, universities, production sector, inappropriate dissemination mechanisms, top-down approaches, unrealistic demonstrations	Better fora for exchange of ideas, participation; validation under real field and economic conditions, etc; mechanisms for joint financing of research, strengthened user/producer groups, systematic procedures to evaluate development
Institutions	Resources spread across too many institutes, emphasis on capital structures, low priority to innovative research; limited term funding for regional institutions, problems of funding in general for operation and for wider networking.	Develop national entities, with clear priorities co-ordinated linked centres, access to international co-operation; formal structures for regional co-operation and specific action programmes for innovative research

Source: Muir (2005)

Conclusions

The onward rise of aquaculture?

The future of aquaculture has to be seen within the overall context of future directions in macro economic conditions and regulatory frameworks. These in turn will be driven by events, social trends and political responses. However, key features can be defined (*e.g.* OECD/FAO, 2009; Ambler-Edwards *et al.*, 2009) as:

- Potential impact of climate change and the need to move to a lower-carbon economy with potentially higher energy costs;

- Food security in the context of rising populations, increased pressures on land and freshwater resources and impact of climate change on agriculture and fisheries productivity;
- The ability of national and international bodies to manage capture fisheries at sustainable levels during a likely period of ecological change;
- Increasing demands by consumers for food that is good value, high quality, safe and with ethically sound provenance (*i.e.* social and environmental sustainability) and
- The need to maintain positive economic activity and growth for social stability.

Globally, aquaculture is expected to meet a growing deficit for aquatic foods associated with stagnating capture fisheries supply and rising demand. However demand will be greatest for lower priced products substituting for similarly priced fishery products. Much of this will be exported in frozen form from Asian countries exploiting their low cost-base. A review of European markets (STAQ, 2002) noted that around 63% of supply had a first sale price below EUR 1/kg and 85% below EUR 2/kg. For capture fisheries supply 73% was priced at below EUR 1/kg and 97% below EUR 2/kg, while for aquaculture 96% was priced at over EUR 2/kg and 85% in the EUR 2-4 category. While such disparities are not so strong in other markets, for example in South and East Asia, where price differentials between aquaculture and fisheries products, particularly in freshwater species, are not so marked (FSRFD, 2004), the supply-price-future investment interaction needs to be explored further. Issues such as future income distribution will be critical in determining the affordability of aquaculture product, and hence the investment and resource competitive potential for growth. While major global markets will retain an important role, particularly with respect to product attributes and the potential for adding value, the greatest growth in demand is also likely to come from emerging economies undergoing demographic transition.

Strategically, analyses of future potential need to be more market based and a greater level of information about markets and industry performance will be needed to facilitate quality analysis. The importance of consolidation for the production of commodity species or raw material needs to be recognized and focus on large scale environmental capacity, production conditions and equity from supply countries needs to be further addressed. However, the importance of small and micro-scale enterprises in vulnerable communities and ecosystems in providing employment and stewardship of resources is also critical. This can be addressed through production of differentiated niche products with a variety of value additions. With respect to overall strategies for aquaculture species and products, the question of species or product diversity aims and the potential for genetic gain in target species is also important. Table 1.28 outlines the implications of these two decision axes. At this stage the global perspective is likely to be that for the lower-right quadrant, with high genetic gains associated with a small number of key species and a strong focus towards product development from these. This does not preclude a wider diversity within total global production, but this will be less advanced with respect to biotechnical efficiency.

Table 1.28: Scenarios for future development

Species diversity; low genetic-linked gain:	***Species diversity; high genetic-linked gain:***
Wide range of species primarily occupying HUV markets, some being forced to operate at very low margins; increasing competition from imports, but moderate opportunity for replacing appreciated capture fishery stocks with 'natural' products. Possible opportunities for small scale producers; low to moderate growth potential, potentially good conservationist image associated with unmodified stocks, though careless strain management could be negative.	Wide range of species, but limited degree of product development; flexible opportunity to occupy HUV markets or compete with lower cost, *e.g.* capture fisheries and other food product markets. Moderate to high growth, but constrained by acceptance of product form. Biotechnology skills/costs may favour larger producers, but licensing may allow small-scale producers to participate. Neutral-poor conservationist image may be improved with biodiversity support programmes.
Product diversity; low genetic-linked gain:	***Product diversity; high genetic-linked gain:***
Limited degree of further development of other species - only to the point of niche markets, and developing high quality specialised profiles for producers; otherwise widening product base for 2-3 main species, with steadily levelling prices. Moderate growth, with dominance by primary species, and steadily increasing penetration of traditional markets, possibly disadvantaging traditional suppliers.	Some degree of development of other species, but substantial development of product forms based on steadily reduced base prices of key species. Potentially very high growth, with major food supply consequences, and primary role of large scale producers and specialist biotechnology suppliers. Very limited opportunity for specialist and small scale producers, reduced pressure on wild fisheries due to low prices may improve conservation impact, reducing fishery employment.

Source: Developed from Muir and Young (1998)

Strategic directions

Resource contexts will become increasingly important for the sector. Output from inland areas will continue to be significant, from greater areas and more intensive use of pond systems and wider development of lake or reservoir based cage culture. There will be a greater need for integration with other functions as water demands increase for agriculture, power generation, water and sanitation and industrial use (see *e.g.* EC, 2008). Coastal areas are likely to become more important for a range of aquaculture production, (Olsen *et al.*, 2008; Whitmarsh and Palmieri, 2008) and where land-based enrichment occurs, increasingly the case in major delta zones, integrated systems are likely to become more common, with plants, molluscs and lower food chain fish species taking up a nutrient removal role as well as contributing to market output. Changes in feed design and formulation will also be important in permitting efficient intensification across a range of species and systems, using a more diversified raw material base.

In terms of competitive conditions, the aquaculture sector is increasingly part of a highly internationally competitive food industry, in which context several major trends are observable:

- Large food supply companies are emerging, developing major relationships with retail and food service outlets, integrating backwards to link with producers and to supply international markets. So far, investment in supply is less attractive, as profitability is higher in the downstream subsector, but is being considered strategically, particularly if resources become more constrained. Long-term supply contracts can also be relevant, effectively also providing investment backing for specialist aquaculture producers.

- Large aquaculture sector producers are also emerging – producing stock or feeds, and integrating forwards to added-value production to link in with food supply sectors. This is primarily based on their main production species for which they have specialised capability.

- Large fishing industry entities are seeking to diversify and expand output, acquiring aquaculture capacity to link in supplies for national and global markets; building on product and market chain knowledge, reducing supply risk and widening market presence.

- Non-sector interests in pioneer fields, *e.g.* energy supply companies, agro-industrial and/or biofuel companies are also expressing interest in aquaculture investment, either as CSR (corporate social responsibility) approaches or with an aim for macro-scale integration. Partnerships with specialist aquaculture enterprises may also be possible. Sovereign wealth funds investing in future food production capacity have so far confined targets to terrestrial production, but might also be extended to aquaculture.

The broader issues of investment and capital policy, fiscal conditions, risk environment and trade policy will all be critical in defining the shape and context of the macro scale sector. Smaller scale producers will be less influenced by policy themes at this level, though this may depend on the extent to which marketing links are established between specialist products and more generic aquaculture output. They will however be much more connected with policies associated with social development, natural resource allocation and management and market access.

The influence of climate change

Climate change will be major driver for aquaculture in most regions, with increasingly important adaptation and risk management requirements. The viability, location and form of future growth will be critically defined by current work being developed to determine the type, scale and location of risks, potential impacts, policy and management strategies and investment responses (FAO, 2009c). These elements will require to be fully integrated into planning processes rather than be considered as optional modifying factors. Aquaculture is also likely to play a valuable mitigation/ecosystem quality enhancement role in salinising coastal zones and in inland water conservation/value development strategies and these functions are likely to become much more important. The potential for creating a market for protecting or enhancing aquatic ecosystem services is yet to be specified, but may come to have a useful role in rural economies.

As with capture fisheries, GHG (greenhouse gas) contributions from aquaculture are small, but there will be similar obligations to reduce impacts. As noted by FAO (2008b), sectoral policies would need to address resource access and use, production options and market related measures such as certification, transparent mitigation standards, comparators with other food sectors and where required, suitable social inclusion and protection. Key areas could include fishery based and other feed inputs, water and energy efficiency. Though genetic modification technologies may have valuable impacts (*e.g.* widening scope for low-impact aquaculture species or making agricultural crop materials or waste products usable for growing carnivorous aquatic species) these would require to be evaluated within wider social and political criteria. Technologies and management approaches should be accessible to small and rural farmers.

There may also be potential for some activities, especially seaweed and mollusk aquaculture and other potentially sequestering systems (Thorn *et al.*, 2008), to be part-funded through carbon emissions trading or offset schemes or to be used to reduce the 'carbon liability' of related production. Though trading schemes have had only limited relevance to the sector so far, food supply systems with lower carbon emission levels or capable of sequestering carbon may have future competitive advantage. Nutrient/emissions trading within global public goods may also open up similar markets in materials such as nitrogen and phosphorous, allowing aquaculture producers to earn valuable credits through their ability to take these up, or find incentives to reduce their outputs.

Data, standards, knowledge and capacity development

National and regional development strategies for aquaculture need to be based on sound market and economic understanding linked with knowledge of the impacts of innovation, technology change, and human/institutional capacity building. To date, many plans and strategies are based primarily on biotechnical issues – ability to rear organisms, land areas, theoretical availability of water or feedstuffs, without considering practical enterprise issues or impacts of output on national or other markets. Practical issues such as resource rights, availability of capital and the time needed to develop supply chain components such as seed, feed and services also need to be considered. The importance of good sectoral data cannot be underestimated, as is the need to link this effectively with other data sources to develop higher order measures and indicators and integrate data acquisition with analysis and feedback. Knowledge exchange, through private sector interests and in wider public sector arenas will become more significant and more necessary. Features will include a wider range of partnerships; greater use of objective-defined approaches; use of ICT for a wider range of interactive purposes.

At a global level, higher income aquatic food consumers and the trade they support have tended to drive product standards and quality attributes, in turn creating technology drivers in supplying countries. There is a strong argument for developing partnerships, commercial ownerships or joint initiatives across the global supply networks. Related to this, commercial information and a clear sense of the competitive advantages achievable through different policy environments, agroecological conditions, technology application, enterprise behaviour and technical skill needs to be developed further so that states can be well positioned for domestic supply, export of products and services, productive investment and sustainably high returns on natural resources.

There is an increasing need for holistic evaluation perspectives for the sector, in which the overall efficiency of performance – judged by key criteria linked to profitability, environmental risk and social acceptability - can be defined and targeted (see *e.g.* Barbier, 2007; Turner *et al.*, 2008). This array of criteria corresponds to the reality of sustainable development for the sector. Simple stand-alone measures such as energy efficiency, food conversion or volumetric productivity will not in themselves be sufficient and policy makers, industry and technology developers will require to share and develop perspectives to ensure better overall technology performance targets. From this in turn could be derived more effective sectoral goals and better criteria for R&D investment. At the same time, these issues will link with other emerging policy areas – in food, environment, industry and social welfare.

Notes

1. According to the UN Food and Agriculture Organisation (FAO), aquaculture implies some form of intervention in the rearing process of aquatic organisms to enhance production, such as regular stocking, feeding, protection from predators etc. It also implies individual or cooperate ownership of the stock being cultivated.

2. FAO statistics continue to distinguish between brackish-water and marine environments for aquaculture. However there are significant practical problems in defining brackish water and in allocating production between the two environments. Very few countries have the means and resources to do this effectively. As all aquaculture in saline waters is carried out within coastal margins/Economic Exclusion Zones (EEZs) it is more useful to group both categories as ‘coastal aquaculture’. If genuine open sea/open ocean aquaculture develops in the future, possibly even in high seas zones, it will be more useful to differentiate this.

References

Ambler-Edwards S., K. Bailey, A. Kiff, T. Lang, R. Lee, T. Marsden, D. Simons, and H. Tibbs (2009), (Food futures), *Rethinking UK Strategy,* Chatham House.

Anderson, J.L. and D. Valderrama (2009), "Trends in the international trade of seafood products", in Einarsson H. and Emerson W. (eds.), *International seafood trade: challenges and opportunities*, FAO/University of Akureyri Symposium, 1-2 February 2007, Akureyi, Iceland. FAO Fisheries and Aquaculture Proceedings, No. 13, Rome, 121 p.

Anrooy, R.V., P.A. Secretan, Y. Lou, R. Roberts, and M. Upare (2006), "Review of the current state of world aquaculture insurance", *FAO Fisheries and Aquaculture Technical Paper*, 493, 107. Rome.

Asche, F., A. Guttormsen, T. Sebulonsen, and E. Sissener, (2005), "Competition between farmed and wild salmon: the Japanese salmon market", *Agricultural Economics*, 2005, Vol. 33, issue 3, pp. 333-340.

Asche, F., K. Roll, and S. Tveteras (2008), "Future trends in aquaculture: Productivity growth and increased production", in Holmer *et al.* (eds.), Aquaculture in the Ecosystem. Springer.

Ayer N.W. and P.H. Tyedmers (2009), "Assessing alternative aquaculture technologies: life cycle assessment of salmonid culture systems in Canada", *Journal of Cleaner Production* 17, pp. 362-373.

Barbier, E.B. (2007), "Valuation of ecosystem services supporting aquatic and other landbased food systems", in D.M. Bartley, C. Brugère, D. Soto, P. Gerber and B. Harvey (eds), *Comparative assessment of the environmental costs of aquaculture and other food production sectors: methods for meaningful comparisons*, FAO/WFT Expert Workshop, 24-28 April 2006, Vancouver, Canada. FAO Fisheries Proceedings, No. 10, Rome, FAO, pp. 71-86.

Bell, G.J. and R. Waagbo, (2008), "Safe and Nutritious Aquaculture Produce: Benefits and Risks of Alternative Sustainable Aquafeeds", in Holmer *et al* (eds.), *Aquaculture in the Ecosystem*, Springer.

Bondad-Reantaso, M., J.R. Arthur, and R.P. Subasinghe (2008), "Understanding and applying risk analysis in aquaculture", *FAO Fisheries and Aquaculture Technical Paper*, 519, p. 324.

Bostock, J.C. (2009), "Use of information technology in aquaculture", Chapter 35, in Burnell, G. and Allan, G. (eds), *New technologies in aquaculture: Improving production efficiency, quality and environmental management*, Woodhead Publishing, Oxford, pp. 1064-1118.

Bunting S.W. (2007), “Regenerating aquaculture: enhancing aquatic resources management, livelihoods and conservation”, in Pretty J., A. Ball, T. Benton, J. Guivant, D. Lee, D. Orr, M. Pfeffer, H. Ward (eds.), *SAGE Handbook on Environment and Society*, SAGE Publications.

Bunting S.W., J. Pretty (2007), “Aquaculture development and global carbon budgets: emissions, sequestration and management options”, Centre for Environment and Society, Occasional Paper 2007-1, University of Essex, UK.

Buschmann A.H., Cabello F., Young K., Carvajal J., Varela DA. and Henrıquez L. (2009), “Salmon aquaculture and coastal ecosystem health in Chile: Analysis of regulations, environmental impacts and bioremediation systems”, Ocean & Coastal Management 52 (2009), pp. 243-249.

Corner, R.A., A. Brooker, T.C. Telfer, and L.G. Ross (2006), “A fully integrated GIS-based model of particulate waste distribution from marine fish-cage sites”, Aquaculture 258, pp. 299-311.

Delgado, C.L., N. Wada, M.W. Rosegrant, S. Meijer, & M. Ahmed, (2003), *Fish to 2020: Supply and demand in changing global markets*, International Food Policy Research Institute (IFPRI) and WorldFish Center, Washington, D.C., Penang, Malaysia.

De Silva, S. and F.B. Davy (eds.) (2009), “Success Stories in Asian Aquaculture 2009 Published by the Network of Aquaculture Centres in Asia-Pacific”, Bangkok, Thailand.

European Commission (2002), “A strategy for the sustainable development of European Aquaculture. Communication from the Commission to the Council and the European Parliament”, COM(2002) 511 Final, Brussels.

European Commission (2008), “Communication from the Commission a “Roadmap for Maritime Spatial Planning: Achieving Common Principles in the EU”, COM(2008) 791 Final, Brussels.

European Commission (2009), “Communication from the Commission on Building a Sustainable Future for European Aquaculture – A New Impetus for the Strategy for the Sustainable Development of European Aquaculture”, COM(2009) 162 Final, Brussels.

FAO (Food and Agriculture Organization of the United Nations) (1995), *Code of Conduct for Responsible Fisheries*, FAO, Rome.

FAO (2008a), *Yearbooks of Fishery Statistics: Summary Tables of Fishery Statistics*, FAO, Rome.

FAO (2008b), Committee on Fisheries, Sub-Committee on Aquaculture, “Opportunities for addressing the challenges in meeting the rising global demand for food fish from aquaculture”, COFI/AQ/IV/2008/6 Fourth Session, Puerto Varas, Chile, 6-10 October 2008.

FAO (2009a), *The state of world fisheries and aquaculture 2008*, FAO, Rome, www.fao.org/fishery/sofia.en.

FAO (2009b), *Yearbook of Fishery Statistics: Summary Tables of Fishery Statistics,* FAO Rome.

FAO (2009c), *Responsible Fish Trade*, FAO Technical Guidelines for Responsible Fisheries 11, FAO, Rome.

FAO (2009d), “Report of the Expert Workshop on Climate Change Implications for Fisheries and Aquaculture”, Rome, Italy, 6-9 April 2008, FAO Fisheries Report No. 870, Rome, 30p.

FAO (2009 in prep.), *A review of fuel and energy requirements in the fishery sector.*

Ferreira J.G., H.C. Andersson, R.A. Corner, X. Desmit, Q. Fang, E.D. De Goede, G.U.H. Groom S.B., B.G. Gustafsson, A.J.S. Hawkins, R. Hutson, H. Jiao, D. Lan, J. Lencart-Silva J., R. Li, X. Liu, Q. Luo, J.K. Musango, A.M. Nobre, J.P. Nunes, P.L. Pascoe, J.G.C. Smits, A. Stigebrandt, T.C. Telfer, M.P. De Wit, X. Yan, X.L. Zhang, Z. Zhang, M.Y. Zhu, C.B. Zhu, S.B. Bricker, Y. Xiao, S. Xu, C.E. Nauen, M. Scalet (2008), SPEAR: *Sustainable options for people, catchment and aquatic resources*, www.spear.cn (accessed Sept. 23 2009).

Framian, B.V. (2009), “Definition of data collection needs for aquaculture: Part 1”, Review of the EU aquaculture sector and results of costs and earnings survey, European Commission. FISH/2006/15-Lot 6, www.ec.europa.eu/fisheries/publications/studies/aquadata_part1_en.pdf.

FSRFD (2004), *The future for fisheries: Fisheries Sector Review and Future Development Study*, in Collaboration with DANIDA, DFID and USAID, Department of Fisheries, Dhaka, Bangladesh, Co-ordinator/editor JF Muir, 2003.

Gatesoupe, E.J. (2009), “Diet and husbandry techniques to improve disease resistance: new technologies and prospects”, Chapter 10, in Burnell, G. and Allan, G. (eds), *New technologies in aquaculture: Improving production efficiency, quality and environmental management*, Woodhead Publishing, Oxford, pp. 267-311.

Globefish (2009), /www.globefish.org/dynamisk.php4?id=4649.

Handisyde, N.T. and L.G. Ross (2009 in prep.), GIS- based overviews of environmental loading in global aquaculture.

Handisyde N.T., L.G. Ross, M.C. Badjeck, E.H. Allison; (2006), “The effects of climate change on world aquaculture: a global perspective”, Final Technical Report, Aquaculture and Fish Genetics Programme, DFID, Institute of Aquaculture, University of Stirling, Stirling.

Hasan, M.R., Hecht T., De Silva S.S. and Tacon A.G.J. (eds) (2007), *Study and analysis of feeds and fertilizers for sustainable aquaculture development,* pp. 3-17. FAO Fisheries Technical Paper No. 497, Rome.

Intrafish (2009), www.intrafish.no/global/news/article252373.ece.

IPCC (2007), *Climate Change 2007: Impacts, Adaptation and Vulnerability*. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Summary for Policy Makers. (online version www.ipcc.ch).

Jackson, A. (2009), “Fish in – fish out ratios explained Aquaculture Europe”, 34 (3), Sept. 2009.

Kautsky N., H. Berg, C. Folke, J. Larsson, M. Troell (1997), “Ecological footprint for assessment of resource use and development limitations in shrimp and tilapia aquaculture”, *Aquaculture Research* 28, pp. 753-766.

Kurien, J. (2005), “Responsible fish trade and food security”, FAO Fisheries Technical Paper 456, Rome, www.globefish.org/files/tp_456_290.pdf

Little, D.C. and P. Edwards (2003), "Integrated Livestock-Fish Farming Systems", Food and Agriculture Organization of the United Nations, Rome.

Lorenzen, K. (2008), "Understanding and managing enhancement fisheries systems", Reviews in Fisheries Science 16,: pp. 10-23.

Molden, D., Oweis, Y. Theib, S. Pasquale, J. Kijne, W. Hanjra, A. Munir, Bindraban, Prem S. Bouman, B. Cook, S. Erenstein, O. Farahani, H. Hachum, A. Hoogeveen, J. Mahoo, H. Nangia, V. Peden, Don Sikka, A. Silva, P. Turral, Hugh Upadhyaya Ashutosh Zwart, Sander (2007), "Pathways for increasing agricultural water productivity", in David Molden (ed.), *Water for food, water for life: A Comprehensive Assessment of Water Management in Agriculture*, London, UK: Earthscan; Colombo, Sri Lanka: IWMI, pp. 279-310.

MRAG (2008), *DFID Policy Brief on Fisheries and International Trade*, Policy Brief No 7, Marine Resources Assessment Group, London.

Muir, J.F. (1995), "Perspectives on Aquaculture. Aquaculture and food security", 224 pages, Mimeo, Study document commissioned for FAO, Rome.

Muir J.F. (2005), "Managing to harvest? Perspectives on the potential of aquaculture", Philosophical Transactions of the Royal Society B 360, pp. 191-218.

Muir J.F. and J.A. Young (1998), "Strategic issues in new species development for aquaculture".

Societa Italiana per il Progresso della Zootechnica. 33rd International Symposium, New Species for Mediterranean Aquaculture; Alghero, Sardinia, 23-24 April, 1998.

Nath, S.S., J.P. Bolte, L.G. Ross, and J. Aguilar-Manjarrez, (2000), "Applications of Geographical Information Systems (GIS) For Spatial Decision Support in Aquaculture", Aquacultural Engineering 23, pp. 233-278.

Naylor RL., R.J. Goldburg, J.H. Primavera, N. Kautsky, MCM Beveridge, J. Clay, C. Folke, J. Lubchenco, H. Mooney, M. Troell (2000), "Effect of aquaculture on world fish supplies", *Nature* 405, pp. 1017-1024.

Neori (2008), "Essential role of seaweed cultivation in integrated multi-trophic aquaculture farms for global expansion of mariculture: an analysis", J. Appl Phycol 20, pp. 567-570.

Ni D.V., R. Safford, E. Maltby (2001), "Environmental change, ecosystem degradation and the value of wetland rehabilitation in the Mekong Delta", in Adger W.N., Kelly P.M., Ninh N.H, (eds.), *Living with environmental change: social resilience, adaptation and vulnerability in Vietnam*, Routledge, London, pp. 122-135.

Olsen, Y., O. Otterstad and C. Duarte (2008), "Status and Future Perspectives of Marine Aquaculture", Holmer *et al* (eds.), *Aquaculture in the Ecosystem*, Springer.

Renault, T. (2009), "Controlling viral diseases in aquaculture: new developments: new technologies and prospects", Chapter 9 in Burnell, G. and G. Allan (eds.), *New technologies in aquaculture: Improving production efficiency, quality and environmental management*, Woodhead Publishing, Oxford, pp. 244-266.

Ross L.G., N. Handisyde, D.C. Nimmo (2009), "Spatial decision support in aquaculture: the role of geographical information systems and remote sensing" in Burnell G. and G. Allan (eds.), *New technologies in aquaculture*, Cambridge: Woodhead Publishing, p. 707-747.

STAQ, (2009), *European Aquaculture Competitiveness: Limitations and Possible Strategies*, Report to the European Parliament, IP/B/PECH/IC/2008_177.

Sturrock, H., R. Newton, S. Paffrath, J. Bostock, J. Muir, J. Young, A. Immink, and M. Dickson (2008), "Prospective Analysis of the Aquaculture Sector in the EU. Part 2: Characterisation of emerging aquaculture systems", European Commission Joint Research Centre, Spain.

Tacon, A. and M. Metian (2008), "Global overview on the use of fish meal and fish oil in industrially compounded aquafeeds: Trends and future prospects Aquaculture" 285, pp. 146-158.

The FishSite (2009), www.thefishsite.com/fishnews/10436/chile-abuses-antibiotic-use-on-salmon-farms.

Thom R.M., S.L. Blanton, D.L. Woodruff, G.D. Williams and A.B. Borde (2001), "Carbon sinks in nearshore marine vegetated ecosystems". Proceedings of the 1st National Conference on Carbon Sequestration, 14-17 May 2001, National Energy Technology Laboratory, Department of Energy, USA.

Tyedmers, P., N. Pelletier and N. Ayer (2007), "Marine Aquaculture and the Sustainability of Seafood Production Systems: A comparative analysis", A report to the United States Marine Aquaculture Task Force, convened by the Woods Hole Oceanographic Institution.

Turner R.K., S. Georgiou and H. Fisher (2008), "Valuing ecosystem services: The case of multi-functional wetlands", *Earthscan*, 235 pages.

Utter, F. and J. Epifanio (2002), "Marine aquaculture: Genetic potentials and pitfalls", Reviews in Fish Biology and Fisheries 12, pp. 59-77.

Valdimarsson G. (2009), "Fish in the global food chain: challenges and opportunities", in Einarsson H. and Emerson W. (eds.) (2009), *International seafood trade: challenges and opportunities*, FAO/University of Akureyri Symposium 1-2 February 2007, Akureyi, Iceland. FAO Fisheries and Aquaculture Proceedings No. 13, Rome 121 pages.

Whitmarsh, D. and M.G. Palmieri (2008), "Aquaculture in the Coastal Zone: Pressures, Interactions and Externalities", in Holmer *et al.* (eds.), *Aquaculture in the Ecosystem*, Springer.

WEF (2008), *The Competitiveness Report 2008-2009*, World Economic Forum, Geneva, Switzerland. Porter Michael E. and Schwab Klaus, www.weforum.org/documents/gcr0809/index.html.

Chapter 2

Climate change, food security and aquaculture

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Abstract

Hunger and malnutrition remain among the most devastating problems facing the world's poor and needy. With the world population expected to grow by 2.6 billion between 2005 and 2050 (roughly equal to the total global population in 1950 of 2.5 billion), there are growing concerns about the long term sustainability of many existing food production systems to meet future demands for food. Aquaculture is widely viewed as an important weapon in the global fight against malnutrition and poverty, particularly within developing countries where over 93% of global production is currently realised; the aquaculture sector providing in most instances an affordable and much needed source of high quality animal protein, lipids, and other essential nutrients.

Aquaculture has been the fastest growing animal food producing sector globally for over half a century, (average compound growth rate of 8.1% per year since 1961), with total global production in 2007 reported as 65.2 million tonnes valued at USD 94.5 billion. Over 91.1% of total global production was produced in Asia with China alone producing 63.2% of total global aquaculture production.

However, the aquaculture sector is not without its problems and critics. Major issues related to the unregulated development of more intensive industrial scale production systems and include potential environmental concerns, potential resource use concerns, potential social concerns, and potential food safety concerns.

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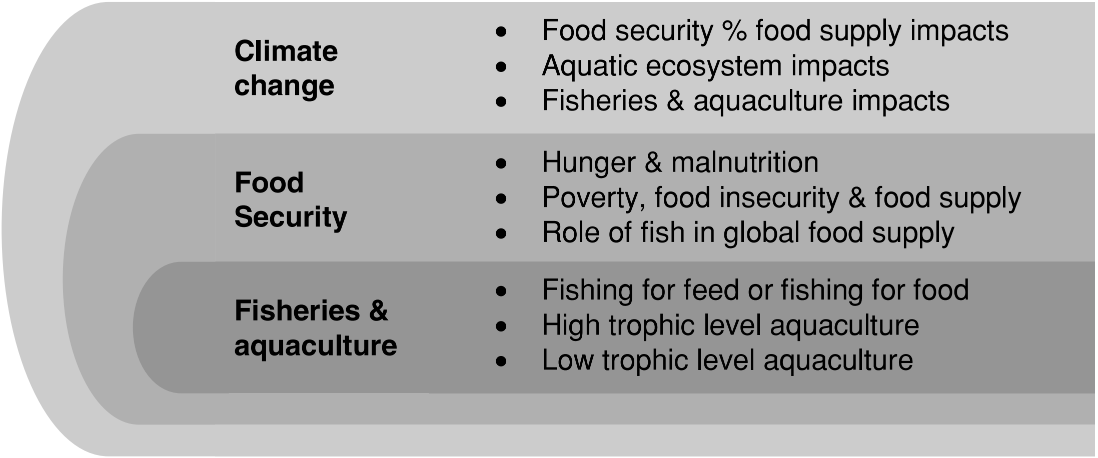
Introduction

The overriding influence of climate changes on global food security, including fisheries and aquaculture production, is beyond doubt. Figure 2.1 shows a diagrammatic representation of the linkages between these sectors, and the main discussion points covered in this paper.

Figure 2.1: Climate change, food security, and aquaculture continuum and major discussion points



Climate change: food security, fisheries and aquaculture impacts

According to the United Nations Framework Convention on Climate Change (UNFCCC; www.unfccc.int) the average temperature of the earth's surface has risen by 0.74 degrees °C since the late 1800s and is expected to increase by another 1.8 °C to 4 °C by the year 2100. The reason for this global warming is believed to be due to the increase of heat-trapping `greenhouse gases’ in the atmosphere and in particular carbon dioxide, methane and nitrous oxide. Whilst greenhouse occur naturally and are critical for life on earth, in augmented and increasing quantities they are believed pushing the global temperature to artificially high levels and altering the climate. The main causes of global warming are believed to be due to industrialization and the burning of fossil fuels (coal, oil and gas) to meet increasing energy demands and the spread of intensive agriculture to meet increasing food demand, which is often accompanied by deforestation. Moreover, the process of global warming shows no signs of abating and is expected to bring about long term changes in weather conditions (FAO, 2008).

For the purposes of the present paper, it is sufficient to summarize here those potential impacts of climate change on food security and global food supply, as follows:

Agriculture and food security (FAO, 2008)

- Agriculture is important for food security in two ways, 1) by producing the food people eat, and 2) by providing the primary source of livelihood for 36% of the world's total workforce. In the heavily populated countries of Asia and the Pacific, this share ranges from 40 to 50% and in sub-Saharan Africa, two-thirds of the working population still make their living from agriculture. It follows therefore, that if agricultural production in the low-income developing countries of Asia and Africa is adversely affected by climate change, the livelihoods of large numbers of the rural poor will be put at risk and consequently their vulnerability to food insecurity increased.

Food, fibre and forest products (http://unfccc.int)

- Crop yield is projected to increase in temperate regions for a local mean temperature rise of 1-3 °C and then decrease beyond that in some regions;
- In tropical areas, crop yield is projected to decrease, even with relatively modest rises of 1-2 °C in local temperature, increasing the risk of hunger;
- Increases in the frequency of droughts and floods are projected to affect local crop production negatively, especially in subsistence sectors at low latitudes.

Aquatic foods and food security (FAO, 2009a, 2009b)

- *Availability* of aquatic foods will vary, positively and negatively, through changes in habitats, stocks and species distribution. These changes will occur at regional and local levels in inland, coastal and marine systems, due to aquatic ecosystem shifts and impacts on aquaculture;
- *Stability* of supply will be impacted by changes in seasonality, increased variance of ecosystem productivity, increased supply risks and reduced supply predictability – issues that may also have large impacts on supply chain costs and retail prices;
- *Access* to aquatic foods will be affected by changes in livelihoods and catching or culture opportunities combined with transferred impacts from other sectors (*i.e.* increased prices of substitute foods), competition for supply and information asymmetries. Impacts may also arise from rigid management measures that control temporal and spatial access to resources;
- *Utilization* of the aquatic products and the nutritional benefits produced will be impacted: changes in range and quality of supply; market chain disruptions; greater food safety issues; and reduced opportunities to consume products. This is particularly critical for countries with high per capita fish consumption;

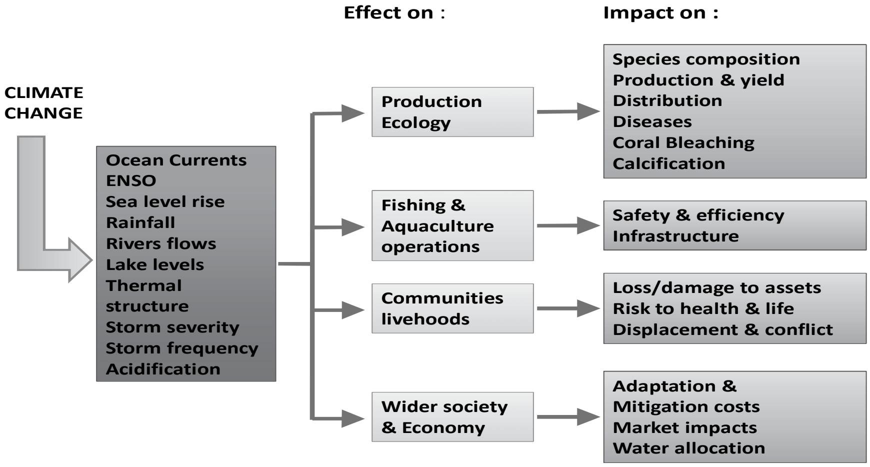
- Food security will also be positively affected by increasing the percentage of fish used for direct human consumption (versus fish used for feed) and reducing post-harvest losses through spoilage and waste. Climate change will add to the complexity of addressing these issues and climate events may have a direct negative impact on the control of spoilage and waste.

Fisheries and aquaculture ecosystem and livelihood impacts (Cochrane et al., 2009; FAO, 2009a, 2009b; Handisyde et al,. 2006)

- Ecosystem impacts, including modification in distribution of marine and freshwater aquatic species; altered ecosystem productivity; alteration of marine and freshwater food webs; increased risk of species invasions and spread of vector-borne diseases; alteration of intensity, frequency and seasonality of climate patterns (*e.g.* . El Niño) and extreme events (*e.g.* floods, droughts storms) affecting the stability of marine and freshwater resources adapted to or affected by these and sea level rise, glacier melting, ocean acidification and changes in precipitation, groundwater and river flows will significantly affect coral reefs, wetlands, rivers, lakes and estuaries, requiring adapting measures to exploit opportunities and minimize impacts on fisheries and aquaculture systems (FAO, 2009a);
- Livelihood impacts, including changes in distribution, species composition and habitats will require changes in fishing practices and aquaculture operations, as well as in the location of landing, farming and processing facilities; extreme events will also impact on infrastructure, ranging from landing and farming sites to post-harvest facilities and transport routes (they will also affect safety at sea and settlements, with communities living in low-lying areas at particular risk); water stress and competition for water resources will affect aquaculture operations and inland fisheries production and are likely to increase conflicts among water dependent activities; livelihood strategies will have to be modified for instance with changes in fishers migration patterns due to changes in timing of fishing activities. Reduced livelihood options inside and outside the fishery sector will force occupational changes and may increase social pressures and may have particular gender dimensions, including competition for resource access (FAO, 2009a).

Figure 2.2 summarizes the potential climate change impacts on fisheries and aquaculture (Allison, 2009).

Figure 2.2: Diagrammatic representation of climate change effects on fisheries and aquaculture



Source: adapted from Allison, 2009

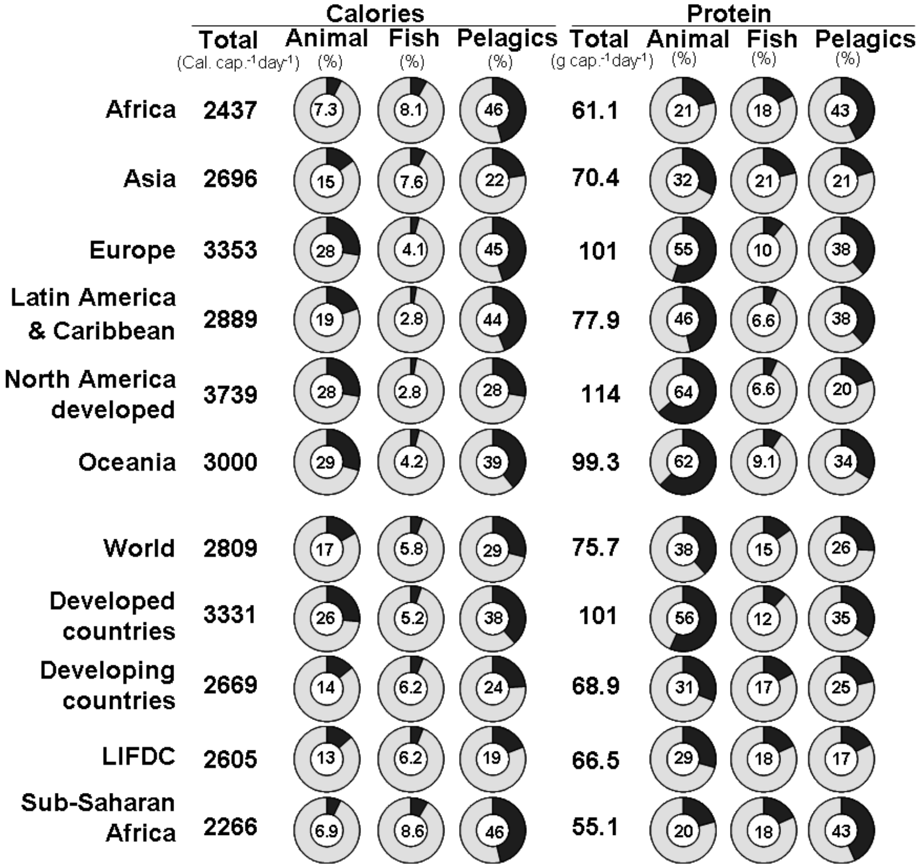
Food security: malnutrition and the role of fish in global food supply

Nutrition and food supply is the keystone that determines the health and well-being of all people, both rich and poor. It allows people to grow, develop, work, play, resist infection and aspire to realization of their fullest potential as individuals and societies. Conversely, malnutrition makes people all more vulnerable to disease and premature death. Without adequate food, people cannot lead healthy, active lives, they are not employable, they cannot care for their children and their children cannot learn to read and write. The right to food cuts across the entire spectrum of human rights – its fulfilment is essential to the fight against poverty and to ensure a world free from hunger. Sadly, hunger and malnutrition remain among the most devastating problems facing the world's poor and needy and continue to dominate the health and well-being of the world's poorest nations; malnutrition still being the number one killer and cause of suffering on earth, causing more deaths than HIV/AIDS, warfare, genocide, terrorism, or any other ailment, particularly within developing countries. Poverty, hunger and malnutrition stalk one another in a vicious circle, compromising health and wreaking havoc on the socioeconomic development of whole countries and entire continents. Nearly 30% of humanity, especially those in developing countries, including infants, children, adolescents, adults, and older persons, bear this triple burden. This remains a continuing travesty of the recognized fundamental human right to adequate food and nutrition, and freedom from hunger and malnutrition, particularly in a world that has both the resources and knowledge to end this catastrophe (WHO, 2000).

According to the United Nations Development Program, the World Health Organization (WHO), and FAO it is estimated that about one-fifth of the world's population is currently living in extreme poverty (defines as living on less than USD 1 per day), with more than 4 billion people earning less than USD 4 per day and the majority living within developing countries. Moreover, with the world population expected to grow by 2.6 million between 2005 and 2050 (a number roughly equal to the total global population in 1950 of 2.5 billion; Campbell *et al.*, 2007), there are growing doubts as to the long term sustainability of many existing agricultural and aquacultural food production systems to meet the increasing global demand for food (Serageldin, 2002).

Food fish, whether captured or cultured, plays an important role in human nutrition and global food supply, particularly within the diet and food security of the poor and needy as a source of much needed essential dietary nutrients (Tacon and Metian, 2009). Figure 2.3 shows the contribution of fish (includes both fish and shellfish) and pelagic fish to total daily per capita calorie and protein intake by major geographical region and country grouping (FAO, 2009c). Moreover, whereas the per capita supply of food fish for direct human consumption from capture fisheries has not been able to keep pace with population growth (per capita food fish supply from capture fisheries decreasing by 10.4% from 10.6 to 9.5 kg/capita from 1995 to 2007), food fish supply from aquaculture continues to grow (increasing by 74.4% from 4.3 to 7.5 kg/capita from 1995 to 2007), and is expected (at its current growth rate) to match food supply from capture fisheries in 2012. Food fish represents a major source of animal protein (contributing more than 25% of the total animal protein supply) for about 1.25 billion people within 39 countries worldwide, including 19 Sub-Saharan countries (FAO, 2009c). Despite the importance of food fish in the diet of peoples within the African continent, the Sub-Saharan region is the only region of the world where per capita consumption of fish has fallen (aquaculture representing only 3.1% [158 000 tonnes] of total capture fisheries landings in the region [5.1 million tonnes] in 2006) (FAO, 2009c).

Figure 2.3: Contribution of fish (includes both fish and shellfish) and pelagic fish to total daily per capita calorie and animal protein intake by major geographical region and country grouping in 2003



Source: Tacon and Metian, 2009

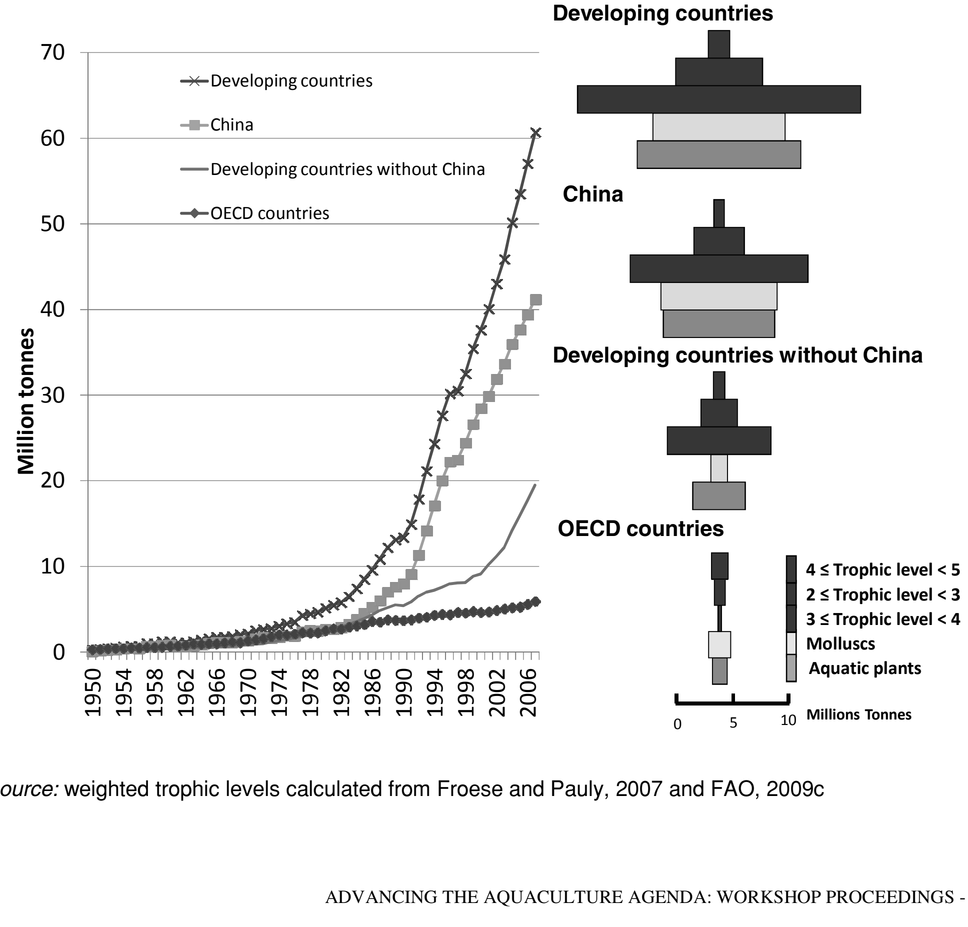
Aquaculture: Role in global food supply and sustainability implications

Of the different agricultural food production systems, aquaculture (the farming of aquatic animals and plants) is widely viewed as an important weapon in the global fight against malnutrition and poverty, particularly within developing countries where over 93% of global production is currently realised; the aquaculture sector providing in most instances an affordable and much needed source of high quality animal protein, lipids, and other essential nutrients. Aquaculture has been the fastest growing animal food producing sector globally for over half a century, with production (excluding aquatic plants) growing at an average compound rate of 8.1% per year since 1961, as compared with 3% for terrestrial farmed meat production, 3.4% for egg production and 1.5% for milk production over the same period. According to FAO over 340 different species of farmed aquatic plants and animals were produced in 2007 (the latest year for which complete statistical information exists), with total global production in 2007 reported as 65.2 million tonnes (major species groups: finfish 48.9%, aquatic plants 22.7%, molluscs 20.1%, crustaceans 7.5%) and valued at USD 94.5 billion. By region over 91.1% of total global production was produced in Asia in 2007, followed by the Americas (3.8%), Europe (3.6%), Africa (1.3%) and Oceania (0.2%); China alone producing over 41.2 million tonnes of farmed aquatic produce in 2007 or 63.2% of total global aquaculture production (FAO, 2009c).

In marked contrast with capture fisheries where the bulk of the fish species harvested are marine carnivorous fish species positioned high in the aquatic food chain, the mainstay of farmed fish production are omnivorous and herbivorous fish species positioned low in the aquatic food, including carps, tilapia and catfishes. Whereas marine capture fisheries have been feeding the world on high trophic level carnivorous fish species since mankind has been fishing the oceans, aquaculture production within developing countries has focused, by and large, on the production of lower trophic level species (Figure 2.4). However, like capture fisheries, aquaculture focus within OECD or economically developed countries has been essentially on the culture of high value-, high trophic level-carnivorous fish species. The long term sustainability of these production systems is questionable unless the industry can reduce its dependence upon capture fisheries for sourcing raw materials for feed formulation and seed inputs (Tacon *et al.* 2010).

However, as with all agricultural terrestrial food production systems, the aquaculture sector has not been without its problems and critics. Major problems and issues raised have been mainly related with the unregulated development of more intensive industrial scale production systems, and in particular with farming systems for the production of high value crustacean and carnivorous finfish species.

Figure 2.4: Global trends in aquaculture production expressed in weighted mean trophic level by economic country grouping, including China



Source: weighted trophic levels calculated from Froese and Pauly, 2007 and FAO, 2009c

Specific issues relate to perceived unsustainable aquaculture practices and/or the potential negative impacts of the sector and have included a variety of potential environmental concerns (regarding habitat loss, pollution, escapes, genetic and disease interactions with wild populations, and possible marine mammals, turtles and bird interactions), potential resource use concerns (regarding feed selection and use, water use, land use, energy use, wild seed collection etc), potential social concerns (regarding displacement of coastal fishing and farming communities, disruption of seafood prices, local food supplies, and food security, possible livelihood impacts, reduced access to community resources, salinization of potable water and ground water, social exclusion, potential conflicts with tourism, recreational fishing, and commercial fishing etc), and potential food safety concerns (regarding the possible contamination with of farmed produce with unwanted heavy metals, pollutants, chemicals, medicants, and pathogens). However, it must also be stated that the majority of the above listed issues and concerns are usually species, farm and country specificand can be mitigated or their impacts greatly minimized by strict adherence to the principles and guidelines within the FAO Code for Responsible Fisheries, and in particular article 9 of the Code dealing with aquaculture development (FAO, 1995, 1997, 2001). The solution is better governance, not just by policymakers to ensure this adherence, but by operators, too.

References

Allison, E.H. (2009)", "Climate change impacts on fisheries: implications for trade and trade policy". Presention made at Asia Regional Dialogue on Trade and Climate Change, 30 April-1st May 2009 (Bangkok, Thailand), International Centre for Trade and Sustainable Development, (www.ictsd.org/downloads/2009/05/edward-hugh-allison.pdf).

Campbell, M., J. Cleland, A. Ezch, and N. Prata (2007), "Return of the population growth factor", *Science* 315, 1501–1502.

Cochrane, K.; C. De Young, D. Soto, T. Bahri (eds.) (2009), *Climate change implications for fisheries and aquaculture: overview of current scientific knowledge,* FAO Fisheries and Aquaculture Technical Paper No. 530, Rome, FAO, 212p.

FAO (1995), *Code of Conduct for Responsible Fisheries,* Rome, FAO, 41p.

FAO (1997), *Aquaculture development. FAO Technical Guidelines for Responsible Fisheries No. 5,* Rome, FAO, 40p.

FAO (2001), *Aquaculture development. 1. Good aquaculture feed manufacturing practice, FAO Technical Guidelines for Responsible Fisheries No.5, Supplement1*, Rome, FAO, 47p.

FAO (2008), "Climate change and food security: a framework document", Inter-Departmental Working Group on Climate Change, FAO, Rome, Document K2595/E, 93p.

FAO (2009a), "Climate change and fisheries and aquaculture', Committee on Fisheries, Twenty-eighth Session, Rome, Italy, 2 – 6 March 2009, CFI/2009/8, 12p.

FAO (2009b), *The State of World Fisheries and Aquaculture 2008,* FAO Fisheries and Aquaculture Department, FAO, Rome, 176 pp.

FAO (2009c), Fishstat Plus: Universal Software for Fishery Statistical Time Series. Aquaculture Production: Quantities 1950–2007, Aquaculture Production: Values 1984–2007; Capture Production: 1950–2007; Commodities Production and Trade: 1950–2007; Total Production: 1970–2007, Vers. 2.30.

FAO Fisheries Department, Fishery Information, Data and Statistics Unit, Rome.

Froese, R., and D. Pauly (eds.) (2007), FishBase.WorldWideWeb electronic publication, www.fishbase.org, version (12/2007).

Handisyde, N.T., L.G. Ross, M-C. Badjeck and E.H. Allison (2006), "The effects of climate change on world aquaculture: a global perspective", Final Technical Report produced by the Institute of Aquaculture, Stirling, U.K. and sponsored by the Department for International Development, DFID, 151p.

Serageldin, I. (2002), "World poverty and hunger—the challenge for science", *Science* 296, 54–58.

Tacon, A.G.J., M. Metian, G.M. Turchini and S.S. De Silva (2010), "Responsible aquaculture and trophic level implications to global fish supply", *Reviews in Fisheries Science*, 18:94-105.

Tacon, A.G.J. and M. Metian (2009), "Fishing for feed or fishing for food: increasing global competition for small pelagic forage fish", *Ambio*, 38(6):294-302.

WHO (2000), "Nutrition for Health and Development: A global agenda for combating malnutrition", Geneva, World Health Organization, 2000 (Document WHO/NHD/00.6).

Chapter 3

Norway: Aquaculture zoning policy and competition for marine space in aquaculture management

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Abstract

Environmental sustainability is a prerequisite for the long-term development and growth of aquaculture production. Well-organized zoning policies contribute to the efficient use of space whilst minimizing the industry's environmental impact. Thus, effective management of marine space is necessary to ensure environmental sustainability. Moreover, it also ensures balanced co-existence between different user-interests in coastal zones.

Norwegian zoning policy with respect to sustainability in aquaculture is presented in the Government's 'Strategy for an environmentally sustainable Norwegian aquaculture' of 2009. The strategy establishes the criteria that define environmental sustainability, identifies, problems, sets key goals and describes measures to be taken. It focuses on five main areas where aquaculture has an impact on the environment:

- *Genetic interaction and escapes*
- *Pollution and discharges*
- *Disease, including parasites*
- *Zoning*
- *Feed and feed resources.*

Zoning in this respect is a horizontal issue which affects all of these issues except feed. Thus, finding well-functioning solutions to these challenges depends in part upon finding and apt zoning strategy. The strategy identifies the following goal for zoning policy: 'The aquaculture industry will have a location structure and zoning which reduces impact on the environment and risk for infection'. The case study presents the Norwegian zoning strategy and the related key challenges faced by authorities in ensuring an environmentally sustainable aquaculture industry.

Introduction

Over the past 40 years, aquaculture has developed into a major industry in Norway, with over 900 000 tonnes of farmed fish produced in 2009, equivalent to nearly USD 3 billion in first-hand turnover. Norway has become one of the world's biggest exporters of seafood, of which farmed fish now represent more than half of total Norwegian seafood exports. More than 4 500 people are directly employed in the industry. There are also a high number of employees in the supply industry and in processing and transport companies. This makes the aquaculture industry important for employment and value creation, especially in rural areas along the Norwegian coast.

The Norwegian aquaculture industry faces a range of environmental challenges. Among the most important is efficient utilisation of coastal space, while ensuring low impact on ecosystems. The Aquaculture Act has an environmental provision which states that aquaculture must be established, run and closed down in an environmentally responsible manner. When evaluating the concept of environmental responsibility, the precautionary principle comes into play, which entails that ignorance may not be used as an excuse for delaying or avoiding the initiation of proportionate and cost-effective measures to counteract serious or irreversible damage to the environment. Any potential impact from aquaculture must therefore be assessed in relation to the total environmental load from other activities.

In April 2009, the Minister of Fisheries and Coastal Affairs launched a *Strategy for an environmentally sustainable Norwegian aquaculture industry*. The strategy focuses on the environmental aspects of sustainable fish farming, based on five main areas in which the industry impacts the environment (the impact model). These are:

- Spatial planning and area management;
- Disease, including parasites;
- Genetic interaction and escapes;
- Pollution and discharges and
- Feed and feed resources.

The strategy document discusses details of challenges, status, measures initiated, future goals and the Government's proposals for new measures for each of these five areas. The first four have important implications for coastal area planning and will be addressed in this paper.

Establishment of aquaculture sites

The current Aquaculture Act came into force 1 January 2006. Due to a need for the authorities to safeguard the needs of the society, *i.e.* rural area development, environmental integrity and market access issues, a licence is required for the establishment and operation of each aquaculture site. Environmental considerations and optimised use of the coastal zone are aspects that are taken into account when establishing, operating and closing down sites. Prior approval of the site environmental and area management issues are therefore of paramount importance.

Application for a new site or for expansion of an existing site is a demanding and lengthy process governed to a large extent by the Aquaculture Act. From 1 January 2010, the responsibility for coordinating the review process for such applications was transferred from the Directorate of Fisheries to the County Council authorities. Several other sector authorities are involved in reviewing applications for compliance with the various guidelines and regulations such as pollution, animal health and welfare, harbour and fairways, biodiversity and spatial planning. For a licence to be granted, all authorities involved must issue their approval or statement as briefly described below. The local municipality announces the application to the general public, clarifies land and sea area use according to the Planning and Building Act. The County Governor decides the application pursuant to the Pollution Control Act and subsequently issues a statement with respect to nature conservation, recreational fishing and expected implications for wild salmonids in the area.

The Norwegian Food Safety Authority and the Directorate of Fisheries govern the different decisions laid forth in a regulation for production expansion of existing aquaculture sites and establishment of new sites. For each application, compliance with required distances to other aquaculture facilities and rivers is evaluated. The evaluation also includes the maximum standing biomass being sought relative to disease risk and control and the applicant’s ability to perform responsible delousing treatments. An adequate contingency plan for handling of high mortality and serious diseases must accompany the application. Further considerations include the general disease situation in the area and whether there are any risk factors that can compromise the welfare of farmed fish. Within a defined endemic zone for pancreas disease, a prioritisation criterion will apply in addition to other criteria. This entails that new licenses for salmon are allocated in accordance with a regional strategy for mitigating the disease risk. Risk for spread of disease to wild fish stocks is also considered. Also, a special regulation forbids new commercial salmonid aquaculture sites within designated national salmon fjords.

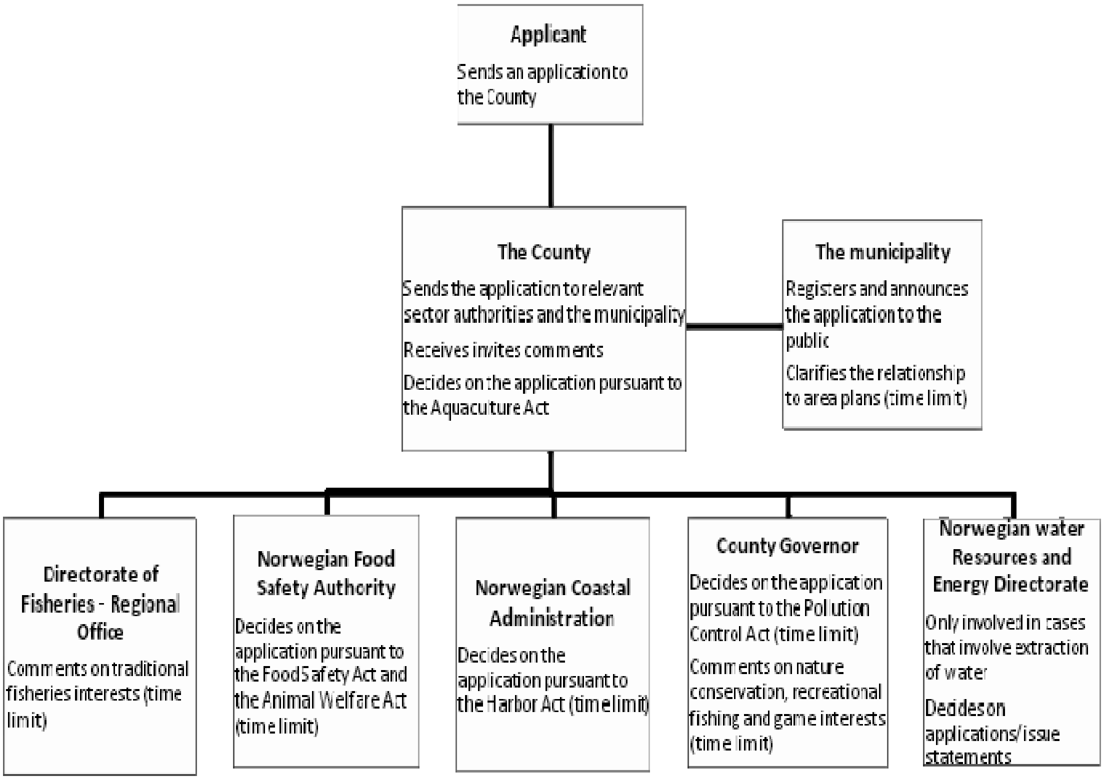
A new Planning and Building Act came into force on 1 July 2009, providing wide powers for municipal authorities to enable planning of areas for farming specific fish species or groups of species. The aim is to stimulate the municipal authorities to draft and update local development plans. In addition, municipal authorities were given powers to levy a property tax on farming facilities in seawater from 2009. This may further motivate them to plan for aquaculture. Municipal authority development plans are important tools for planning the use of coastal space. A good plan will avoid conflicts among aquaculture, fishing and other activities and balance private and community interests. The Act also facilitates planning across local authority boundaries through new provisions on regional planning and inter-authority joint planning.

When establishing a large site, normally above 3 200 metric tonnes of fish, or hatchery with more than 5 million fry, it is decided whether an environmental impact assessment (EIA) should be undertaken. An EIA must include documentation on the facility's impact on the environment, natural resources or the local community.

The Norwegian Costal Administration decides on the application pursuant to the Harbour Act. In addition, the Norwegian Water Resources and Energy Directorate will be involved if extraction of fresh water is planned.

After receiving the written decision from all of the above sector authorities, the County Council authority either issues the license, or declines the application. If any of the above sector authorities decline the application, the applicant has the right to appeal the decision to the relevant sector authority via the country council authority.

Figure 3.1: The application process for establishment of sites for aquaculture purposes



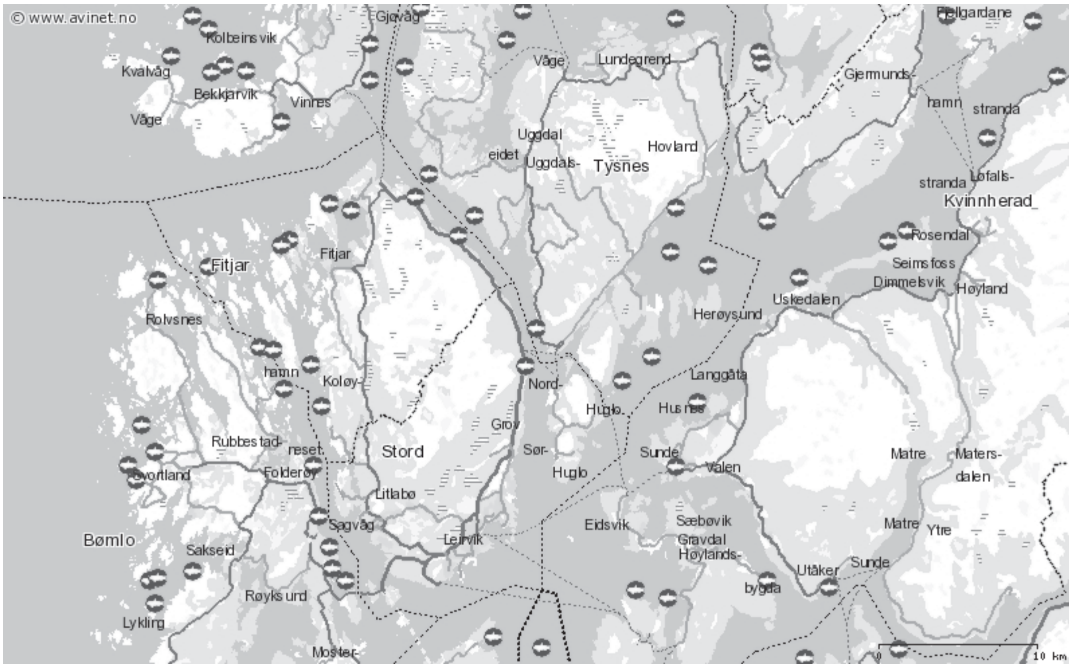
Spatial planning and area management

Overall aim: The aquaculture industry has a siting structure that reduces the impact on the environment and the risk of infection.

Effective utilisation of coastal space facilitates maximum production within a limited geographical area without unacceptable impact on the environment. This is important for minimising the occurrence of infectious diseases, pollution and discharges and for maximising growth, health and welfare of farmed fish. An optimal allocation of aquaculture sites is also important for the preservation of biological diversity and habitats in general, and of particular importance for Norway's wild Atlantic salmon.

The current structure of sites is a result of the rapid growth of the aquaculture industry over the past 30 years. This is particularly true for traditional salmon farming, but also for new species, such as cod and mussels. Due to a lack of regional and national plans, establishments of new sites are not sufficiently coordinated. This development has probably contributed to major fish health problems experienced by the industry in recent years, particularly concerning the impact of pancreas disease and sea lice in Western Norway, where the density of farming facilities is the highest.

Figure 3.2: Picture representing a 2500 km^2 area south of Bergen on the West coast



On the map shown here above, there are approximately 70 sites approved for farming of salmon and trout. This area is in Norwegian terms considered a high density area.

A shortage of new, suitable sites also makes it difficult to relocate a farm to improve the production conditions. Also, salmon and trout farmers are not allowed to relocate licenses between the Directorate of Fisheries' regions[1] and the possibility of derogation is low. The spatial occupation of coastal areas by aquaculture installations has also resulted in conflicts between the aquaculture industry and other users of the marine environment. Fisheries, tourism and recreational activities require access to coastal space. Additionally, industrial facilities, harbours and shipping routes may occupy large areas.

At present, the authorities lack essential tools to oppose the inefficient use of coastal space, as decisions involving changes in production licenses are usually made for single sites. Following an amendment of the Aquaculture Act in 2009, relocation of sites may be enforced by the central authorities, *i.e.* the Directorate of Fisheries, when necessary due to environmental or socio-economic concerns. Furthermore, a licence may be withdrawn in accordance with the Aquaculture Act if production at a particular site is no longer considered to be environmentally appropriate, *e.g.* when investigations show that ecosystems have been adversely affected by farming activities. Withdrawal may also be performed if the disease situation or awareness of disease or fish welfare conditions have changed significantly since the licence was granted. However, these statutes are not suitable as a tool for changing the structure of sites for large areas. This must be performed as part of a national plan for management of coastal space.

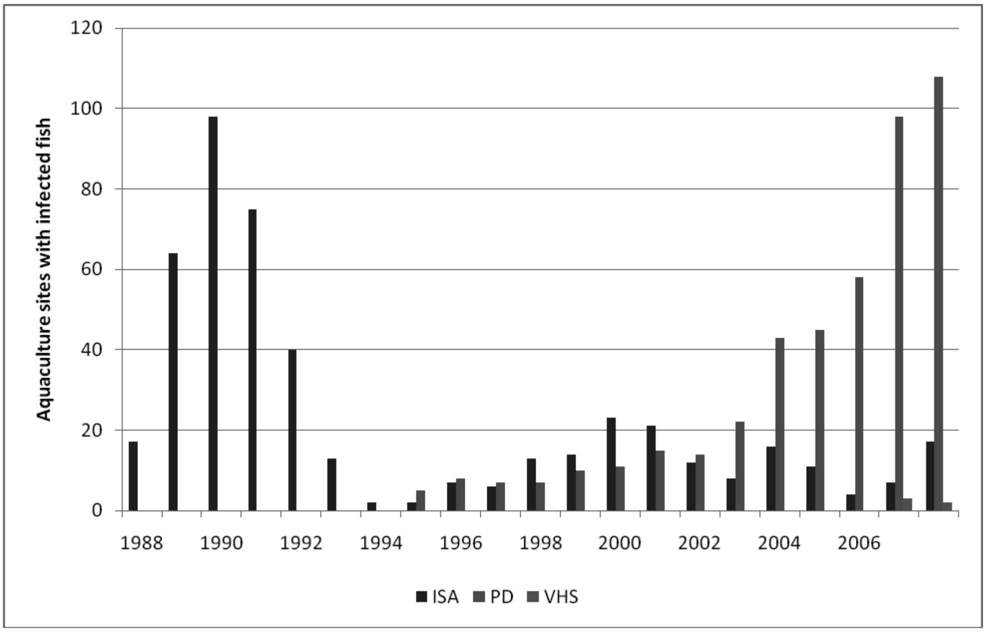
In September 2009, the Ministry of Fisheries and Coastal Affairs therefore established an expert committee for the efficient and sustainable utilisation of coastal space for aquaculture purposes. In their final report which will be presented in February 2011, the committee will outline principles for a new general structure of the aquaculture industry, ensuring sufficient space for aquaculture activities, efficient utilisation of allocated space and environmentally sustainable production. The recommendations will be an important contribution to future national plans for the development of the aquaculture industry.

Disease management

Overall aim: Disease in aquaculture has no regulating effect on wild stocks and as many farmed fish as possible grow to slaughter size with minimal use of veterinary medicines.

Optimal area management is essential for the control of infectious diseases. The health situation in Norwegian salmonid aquaculture has improved greatly over the last 20 years, due to vaccines and the implementation of other measures against the most common bacterial diseases. However, viral diseases, such as pancreas disease (PD), are currently associated with major economic losses. In 2008, the economic losses due to PD were estimated to approximately USD 200 million. Dispersal of pathogens between sites appears to be the most important causal factor for disease outbreaks. This implies that the current minimum distance between sites may not be optimal.

Figure 3.3: Overview of the incidence of some notifiable viral diseases during the past 20 years



On its own initiative, the aquaculture industry has formed a steering group to combat pancreas disease within the established endemic zone (which for all practical purposes is the Norwegian West Coast from Stavanger to Molde). The group has proposed extensive structural changes for the aquaculture industry. The proposal entails organising aquaculture into geographically distinct areas to limit infection, separated by “fire-gates” to prevent or reduce the risk of infection between neighbouring zones, closure of less optimal sites and structural operation of transport of fish in well boats. This will require "viable, synchronised production plans" for all sites situated within the zones. For the plan to be successful, all farmers within the area must support and implement the proposed actions on a voluntary basis. This may be difficult for small operators.

The initiative from the aquaculture industry has been welcomed by the authorities. The industry should further develop a code of best practice, incorporating safe transportation of fish, avoidance of moving growing fish between sites, synchronised production and fallowing and other elements that may improve the disease situation. Along with regulatory changes and an improved overall structure of sites, the aquaculture industry and authorities may in the future be more capable of combating emerging infectious diseases.

Diseases and parasite infestations in farmed fish may also represent a serious threat to wild stocks. This is particularly true for sea lice. While infestation with sea lice occurs naturally in wild stocks, the problem has been intensified by the multitude of hosts present on aquaculture sites. In addition to being passed from fish to fish, it can also be widely dispersed by currents. Due to their inherent biology, sea lice have the largest range of dispersal of all known fish pathogens. The current structure of sites in the aquaculture industry is consequently not well suited to minimize sea lice dispersal between sites and to wild salmonid stocks.

The tolerance limits for sea lice infestation have not yet been determined. The Institute of Marine Research, the Norwegian Institute for Nature Research and others have found high levels of sea lice on wild fish in some areas. For example, catches from the Hardangerfjord area show that wild salmon and sea trout may have 3-5 times more lice than what is considered to be a fatal dose. In a worst case scenario, this may have regulating effects on stocks of migrating salmon and hence be considered not environmental sustainable.

Synchronised winter and spring delousing are now mandatory along most of the Norwegian coastline. The campaigns aim at reducing the number of sea lice in the fjords during the spring migration of wild stocks. The Norwegian Food Safety Authority is also in the process of establishing zones for synchronised fallowing of sites, in order to reduce the impact of sea lice on wild fish. Successful synchronisation of treatment and fallowing for larger areas require an optimal allocation of sites. The size of a zone must be appropriate with regard to the synchronised operation, as well as practical management of the production cycle. The density of sites within a zone must not exceed a level that will compromise fish health, welfare or environmental sustainability of the area. Also, zones must be placed sufficiently far apart to prevent spread of pathogens between them.

Genetic interaction and escapes

Overall aim: Aquaculture do not contribute to permanent changes in the genetic characteristics of wild fish stocks

World stocks of wild Atlantic salmon have been significantly reduced over the past 30 years. Around one third of Atlantic salmon has their spawning grounds in Norway and Norway has committed to take special managerial responsibility for wild Atlantic salmon through international agreements. Salmon have disappeared from 45 watercourses in

Norway. About 100 of the remaining 400 Norwegian populations are vulnerable. However, historic data from Norway show fluctuations and trends vary in different regions over time. There may be several reasons for the decline in wild salmon stocks over the last 30 years, for instance natural fluctuations in food availability and water temperature in the Norwegian Sea, pollution, acid rain, watercourse diversion, infestation with *Gyrodactylus salaris*, overfishing, aquaculture etc.

There is general agreement that substantial and persistent interbreeding with escaped, migrant, farmed salmon is detrimental to wild salmon. Escapes in recent years have mainly been caused by damage to installations, technical inadequacies, human error, predators and lack of control systems or incompetence among salmon farmers. Both the authorities and the aquaculture industry have worked hard to reduce the number of escapes.

Wild stocks inhabiting the various watercourses and fjords along the Norwegian coastline may differ in tolerance levels and robustness, due to both genetic and environmental factors. It is therefore necessary to develop suitable indicators to measure the effects of escapes from aquaculture.

In some areas it is clear that the ecosystems are particularly vulnerable. This was discussed in a Government report to the Parliament *On the conservation of wild salmon and the designation of salmon watercourses and salmon fjords.*[2] As one of the measures to protect wild salmon stocks, 52 national salmon watercourses and 29 national salmon fjords were established in 2007. Within these watercourses and fjords, aquaculture activities are restricted and as a main rule no new sites will be established within the protected areas. A similar protection regime for vulnerable stocks of wild cod will also be considered.

A major concern in cod farming is genetic interaction with wild stocks due to release of ova and fry from sea cages. The consequences of this type of escape from aquaculture sites are unknown. Various approaches to reduce the release of fry and sexual products from farmed cod are being attempted, including changes in cage constructions and breeding. The Government's ambition is to introduce a zero tolerance to unintentional release of egg and fry within 2015. As a precautionary measure, the Directorate of Fisheries has in recent years prohibited the establishment of cod farms on known spawning grounds for wild cod. This was given statutory authority in 2009. Mapping of spawning grounds for wild marine stocks is a lengthy process and the picture is therefore not yet complete.

Pollution and discharges

Overall aim: All aquaculture sites maintain an acceptable environmental state and have not higher emissions of nutrient salts and organic materials than the receiving waters can tolerate.

In general, discharges of nutrient salts and organic materials from aquaculture constitute a minor environmental problem in Norway. The long coastline and extensive use of sites with high levels of water circulation and good water quality are contributory factors. As a result, the carrying capacity and self-purification properties are relatively good for most sites. However, discharge of nutrient salts and organic materials from farming may have negative local effects in some areas. Additionally, regional effects cannot be excluded. The decomposition of organic materials may result in oxygen reduction and changes in benthic biodiversity. Discharges of nutrient salts may also cause increased algal growth and eutrophication.

The establishment of a new site is often performed without full awareness of the environmental consequences, as knowledge of marine ecosystems is incomplete. A programme for a national survey of marine biological diversity including spawning and nursery areas in coastal zones has been initiated.

Methods for monitoring the benthic effects of aquaculture (MOM) are defined in the national standard NS9410, and made mandatory by regulation. The so-called B-investigation monitors effects of aquaculture activities on site-level. The frequency of investigation depends on the level of discharge attributed to the site. It is also compulsory to perform a B-investigation before establishment of a new site. The more comprehensive C-investigation provides an assessment of the environmental impact for a larger geographical area than the B-investigation. C-investigations from several sites are useful for an evaluation of the total discharge levels from the aquaculture industry in a given area. Results from these investigations may be useful for local and regional plans for aquaculture.

The MOM system will be integrated into a cohesive management system for environmental monitoring and spatial planning of sites for aquaculture (MOLO). In addition to implementation of the C-investigation, this will include evaluations of the allocation of sites within an area, the maximum size of each site and how many sites an area may carry. Once implemented, the MOLO system will improve the current practice for establishment of new sites and contribute to an increased environmental sustainability for aquaculture on local and regional levels. It will also be necessary to coordinate regional plans with a future national plan for utilisation of coastal space for the aquaculture industry.

Notes

1. The Norwegian coast is divided into a total of seven relatively large regions.

2 Report to Stortinget no. 32 (2006-2007).

Chapter 4

France: A case study on aquaculture governance

Fisheries Department

French Ministry for Food, Agriculture and Fisheries

Abstract

French aquaculture is dominated by small to medium enterprises producing shellfish; in particular oysters and mussels. In fact, 85% of the total European oysters come from France and the remaining production is absorbed by the domestic market. In addition to shellfish, France also farms marine and freshwater species, including salmon, trout, sea bass and sea bream and increasingly sturgeon for caviar production.

Despite high internal demand, the aquaculture sector in France is stagnating. Main constraints for further development are identified: competition for marine space in coastal areas, market competition and the image of the sector. The French government has taken specific action to support the sector's development, and commissioned a report on its status in 2007. In response to the report, a number of governmental initiatives have been implemented: marketing and product developments; partnerships with the NGOs to improve interaction between the environment and aquaculture; R&D projects to provide technical support for the sector; regional marine-aquaculture development plans and the development of the industry overseas.

Importantly, a Bill for the Modernisation of Agriculture and Fisheries was presented to the French Parliament on 13 January 2010, making it mandatory to draw up regional plans for the development of marine aquaculture. At EU level, France issued a memorandum on the sustainable development of aquaculture in Europe in 2008 which was signed by 17 other Member States.

Introduction

In response to growing demand for aquatic products, for both human and animal consumption, the global aquaculture sector is expanding rapidly, growth being particularly noticeable in specific parts of the world. In Europe, the general trend does not reflect this, as aquaculture is by and large in decline, except in a small number of countries. France is not one of the countries where aquaculture is expanding: French aquaculture production (shellfish and finfish) is not on the rise but stagnating or even in decline in some branches.

The global aquaculture sector[1]

Aquaculture's input to the world supply of fish, crustaceans, molluscs and other aquatic animals has been steadily increasing, from 3.9% of the total weight of output in 1970 to 36% in 2006 (47% of the fish supply). There has accordingly been a considerable rise in the volume of output, from under 1 million tonnes in the early 1950s to a reported 51.7 million tonnes in 2006, worth a total of USD 79.1 billion. Including aquatic plants, global aquaculture production in 2006 stood at 66.7 million tonnes or, in value terms, USD 85.9 billion (see breakdown in Table 4.1).

For a relevant analysis of aquaculture products as a share of the global consumption of aquatic products (see Table 4.1), it is important to bear in mind the predominant role played by China in the aquaculture sector. In 2006, China accounted for 67% of the global supply of farmed aquatic animals and 72% of that of aquatic plants.

Table 4.1: Global aquaculture production

Global aquaculture production in 2006	Volume (million tonnes)	Value (USD billion)	% of total volume	% of total value	Share of aquaculture products compared to total aquatic production	
Freshwater fish	27.8	29.5	54%	37%	76%	47%
Saltwater fish	1.7	6.3	3%	8%	4%	
Amphihaline fish	3.1	11.8	6%	15%	65%	
Molluscs	14.1	11.9	27%	15%		65%
Crustaceans	4.5	18	9%	23%		42%
Other aquatic animals	0.5	1.6	1%	2%		51%
Total aquatic animals	51.7	79.1	100%	100%		36%
Total aquatic plants	15	6.8	100%	100%		93%
Total	**66.7**	**85.9**	**100%**	**100%**		

Source: FAO, 2008

The geographical breakdown of global aquaculture output (excluding aquatic plants) is shown in the two figures below:

Figure 4.1: Aquaculture output by region in 2006, in volume terms (excluding aquatic plants)

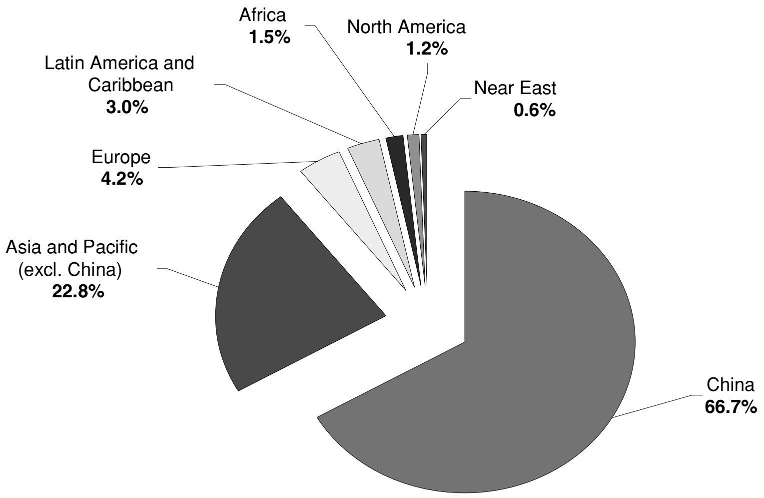
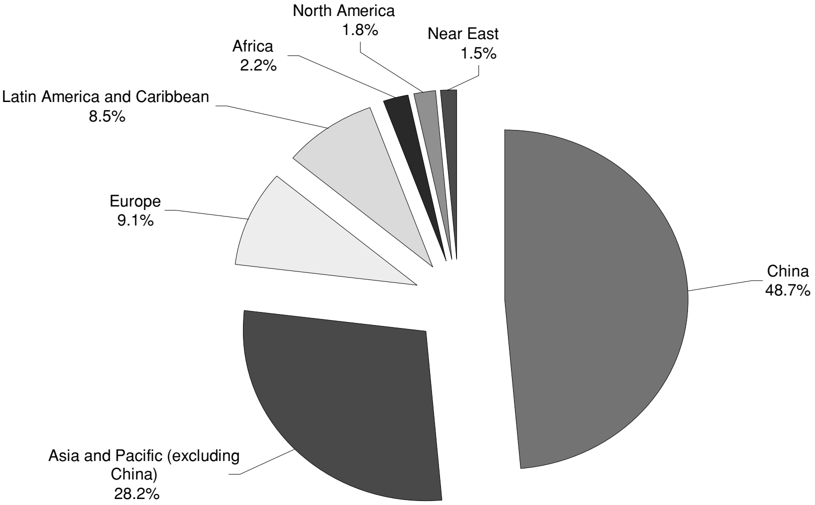


Figure 4.2: Aquaculture output by region in 2006, in value terms (excluding aquatic plants)



While growth in capture fisheries came to a halt towards the mid-1980s, the average annual growth rate for aquaculture has remained at 8.7% worldwide since 1970. This sector is continuing to grow at a faster pace than any other animal-based food production sector. The average annual growth rates from 2000 to 2006 in brackish, fresh and salt water were 11.6% (due largely to prawn), 6.5% and 5.4%, respectively in terms of volume.

A region-by-region analysis of output over the period 1970-2006 shows that growth was not uniform. Latin America and the Caribbean reported the highest average annual growth rate (22%), followed by the Near East (20%) and Africa (12.7%). Over the same period, China's aquaculture production rose by an annual average of 11.2%. Since 2000, however, Chinese growth has dropped to 5.8%, compared with 17.3% in the 1980s and 14.3% in the 1990s. At the same time, growth in European and North American production slowed down sharply and stabilised at 1% per annum since 2000.

The aquaculture sector in the European Union[2]

Leading aquaculture species in the European Union:

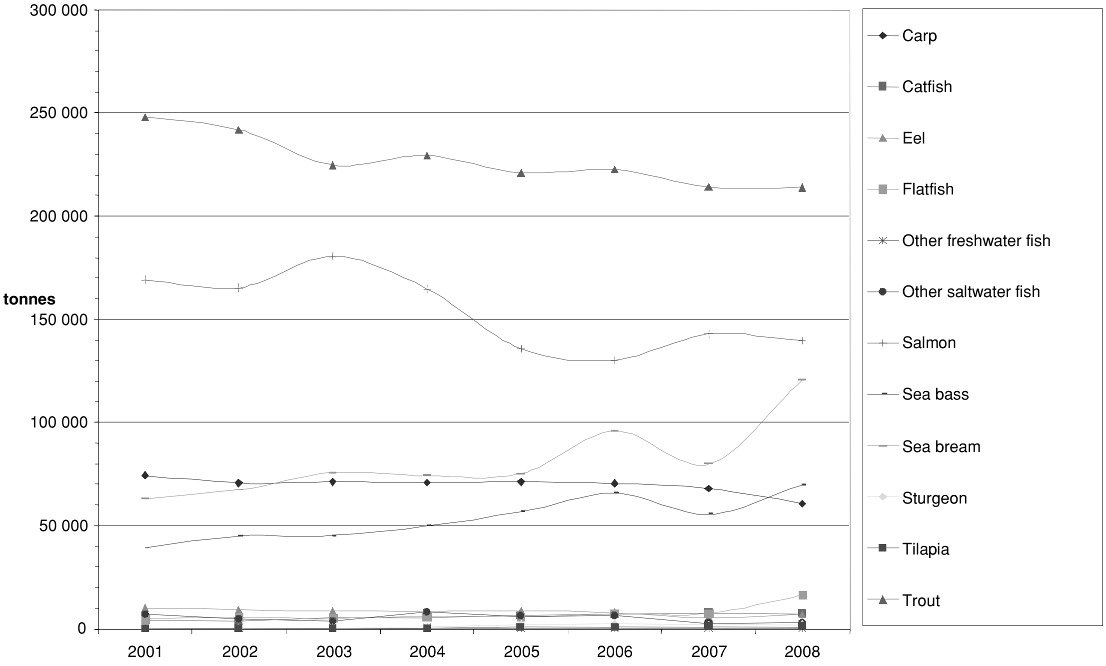
- Oysters: production is largely dominated by France; other Member States, including Ireland, are also producers.
- Mussels: the leading producers are Spain, Italy, the Netherlands and France.
- Clams: production is dominated by Italy, Spain and Portugal.
- Trout: virtually all Member States have trout farms. The leading producers are Italy and France, followed by Denmark, Germany and Spain.
- Atlantic salmon: the main producers are the United Kingdom (Scotland) and Ireland. It is worth noting that the output of Norway alone (not in the EU) is ten times that of the EU.
- Sea bass and sea bream: the main producer is Greece. Spain, France and Italy are also producers.

After a period of growth in the 1990s, fish-farming in the European Union began to stagnate. EU fish output in 2002 stood at 615 000 tonnes and in 2008 at 642 000 tonnes, an annual growth rate of 0.5%.

The figures for 2001-2008 show a downward trend for carp (-2.9% per annum), eel (-5%), salmon (-2.7%) and trout (-2.1%). These species accounted for over 80% of the European aquaculture production in 2001. There was growth in some still minor species such as catfish (+8.7%) and turbot (+19%) over the same period. Among the major species, the largest increases were for sea bass (+8.7%) and sea bream (+9.7%). Consequently most EU Member States, with the exception of Greece [+9.4% per annum (sea bass/sea bream)] and Spain [+4.1% per annum (sea bass/sea bream/turbot)], saw a decline in fish-farming between 2001 and 2008.

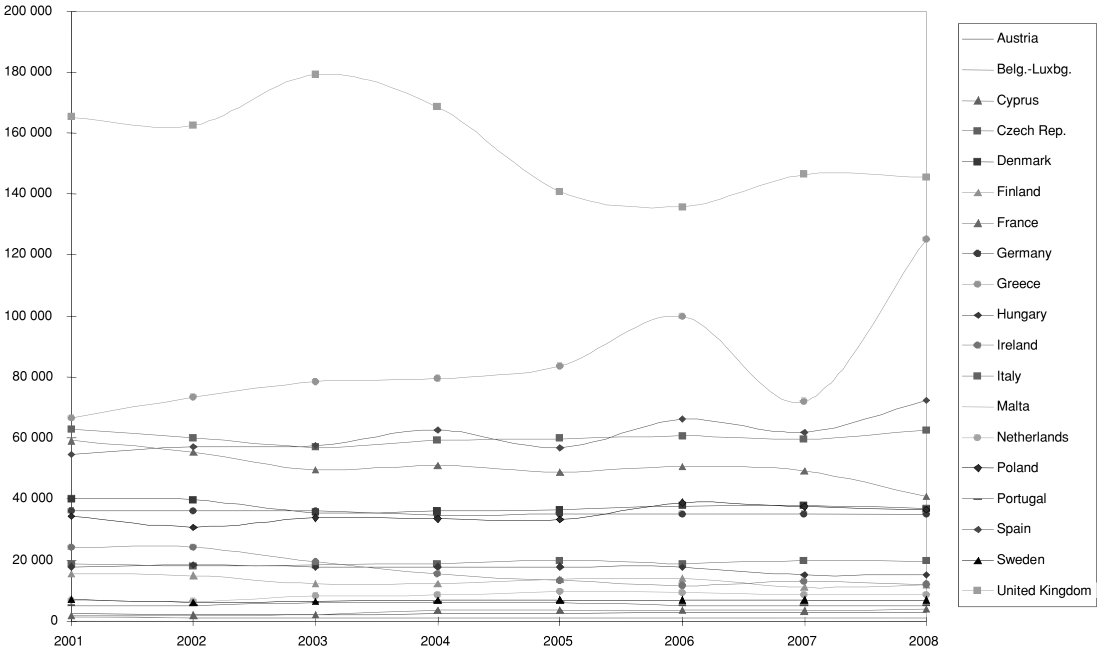
EU shellfish production, however, has generally remained stable.

Figure 4.3: Farmed fish output in the EU, by species



Source: Data from the Federation of European Aquaculture Producers

Figure 4.4: Farmed fish output in the EU, by country



Source: Data from the Federation of European Aquaculture Producers

French aquaculture[3]

French aquaculture comprises shellfish- and finfish-farming, both at sea and on land. Seaweed production is expanding but remains on a very small scale. Shellfish output is stable. Fish-farming, however, is in decline: marine fish-farming is fairly stable but has never reached the output levels hoped for in the 1980s-1990s, while land-based fish-farming, in particular salmon farming, is in noticeable decline. Caviar production, however, is booming.

French shellfish production

Features of the industry

French shellfish production focuses mainly on cupped oysters, flat oysters, mussels and, to a lesser extent, clams and cockles. The majority are produced on maritime public property. In 2007 the sector numbered some 3 120 firms, most of them traditional small businesses as almost 2 180 producers (70%) are self-employed. It employs a total of 18 400 people, 7 200 of them on a full-time basis, representing 9 300 full-time equivalents. The number of firms has been declining since 2001 but shellfish production has remained stable. 2 500 firms focus mainly on oysters and 500 on mussels, packaged for consumer sales. Some 50 firms, including hatcheries, specialise in the production of spat or juveniles, a branch known as *demi-élevage* (pre-growth breeding).

French production marketed in 2007 was an estimated 193 600 tonnes for a turnover of some EUR 400 million. The breakdown was as follows: 113 200 tonnes of oysters (111 600 tonnes cupped and 1 600 tonnes flat), 76 600 tonnes of mussels and 3 800 tonnes of other shellfish, mainly clams and cockles.

The production of cupped oysters, the leading product, has by and large been stable since the early 1990s and meets demand. Flat-oyster output was hit very hard by diseases in the 1970s-80s but there is still some residual production. Research is under way to select oysters that display resistance to one of the diseases *(bonamiosis).*

Mussel output has risen steadily over the decade, thanks in part to suspension techniques, but does not meet domestic demand. The aim is therefore to increase output in years to come: higher productivity in traditional growing sites and the use of new, preferably offshore sites could significantly push up mussel output over the next few years. Owing to French eating habits, virtually all mussels are marketed live and processed mussels account for a very marginal share of the market.

Trade balance

France is the first oyster producer in Europe (85% of European oyster production). For mussels it ranks second, with 15% of European production, well behind Spain (around 50% of European production).

In 2007, France exported around 9 000 tonnes of oysters and imported 3 700 tonnes, generating a surplus of EUR 28 million. Trade in oysters is marginal compared with production which is absorbed mainly by domestic demand. Conversely mussel imports (58 900 tonnes in 2007), mainly from Ireland, the Netherlands, Spain and Denmark, largely exceed exports (4 400 tonnes), leaving a trade deficit of EUR 78 million. The problems involved in increasing the production of oysters, together with the trade deficit for mussels, mean that there is little prospect of developing exports.

French fish-farming[4]

Features of the sector

Fish-farming in France falls into four quite separate categories: salmon-farming, caviar (sturgeon) production, marine fish-farming and freshwater (pond) fish-farming. Their combined production amounted to 53 000 tonnes in 2007, for a turnover of some EUR 250 million. The sector employs some 2 000 full-time equivalents in 511 businesses.

With regard to *salmon-farming* (37 000 tonnes in 2007), there are 365 private fish-farms, mostly run by the self-employed. These businesses employ 1 235 full-time equivalents. They are found throughout the country, but are mostly concentrated in Brittany and Aquitaine. There are also 91 non-commercial fish-farms (run by government or associations promoting angling and aquatic environment conservation) which focus on restocking rivers or on leisure fisheries. These employ 185 full-time equivalents. The number of salmon farms, like salmon production, has fallen sharply since 2001, under the combined impact of growing environmental constraints and keener market competition

Freshwater (pond) fish-farming (around 9 000 tonnes) is a traditional activity in lake areas, often carried out as a part-time activity. However, there are around 100 professional freshwater (pond) fish-farmers.

The *sturgeon industry* is small (16 businesses employing 108 full-time equivalents) but quite buoyant. In 2007, it produced 21 tonnes of caviar, or 15% of the global output from aquaculture, estimated at 140 tonnes. Caviar accounts for 81% of total turnover in this industry (or EUR 11.4 million of the EUR 14.4 million generated in 2007). In 2007 fish-farmers in this industry marketed 231 000 alevins (under 50 grams) for a turnover of EUR 0.5 million, 136 000 alevins (under 300 grams) for a turnover of EUR 0.2 million and 320 tonnes of adult fish (alive or dead), for a turnover of EUR 2 million.

As for *marine fish-farming* (6 600 tonnes in 2007), France has 39 businesses employing some 500 full-time equivalents for an overall turnover of EUR 64 million in 2007. The sector is small in size, geographically dispersed and produces a diverse range of species (sea bass, sea bream, turbot, meager and salmon). According to the findings of IFREMER, the French sea-fisheries research institute, France has developed some high-tech production industries. However, competition with other coastal activities is hampering the expansion of marine fish-farming in France. In fact, no new growing facilities have been set up since the year 2000. Consequently, the sector has specialized in saltwater fish hatcheries (almost a dozen) producing over 70 million alevins, 72% for the export market. The turnover generated by hatcheries in 2007 came to EUR 17 million.

Trade balance

There is a trade surplus in trout in terms of volume and value. In 2007, exports amounted to 5 230 tonnes (45% to Germany and 33% to Belgium), for a total of EUR 16.84 million, while imports amounted to 2 595 tonnes (46% from Spain) for a total of EUR 8.97 million. The trout market is largely a domestic market. However, it is in difficulty (with consumer sales down 29% in volume terms from 1997 to 2007) owing to competition from imported Norwegian salmon. In 2007 France imported 134 300 tonnes of salmon, or EUR 575 million in value terms. These imports came mainly from Norway (50% of imports) and the United Kingdom (15%). Consequently France has a large trade deficit in salmon.

France imported 10 680 tonnes of sea bass and sea bream in 2007, over half of it from Greece. The sharp rise in output and in marketed fish in several countries, compounded by the impact of the global economic and financial crisis, has dramatically pushed down prices and pushed up imports over the past two years.

In 2007, France's caviar output in volume terms, on the rise since 1993, drew level with imports, thereby reducing France's trade deficit in this product.

Public initiatives to develop French aquaculture

France has a good education system and high-quality research institutions. Aquaculture professionals are well trained and skilled. France also has an environment conducive to aquaculture, both at sea and on land, owing to its many watercourses, thousands of hectares of ponds and 5 500 km of coastline. Yet in spite of these assets and growing consumer demand for aquatic products (average consumption has risen from 25 to 35 kg per person per annum in 15 years), the sector is not expanding.

Apart from keener market competition, there are several factors behind this situation. In terms of marine aquaculture, the main factor hampering development is clearly the problem of access to space in coastal zones. Competing land use along the coastline (a variety of economic activities, including growing urbanisation and tourism, as well as environmental conservation) and the conflict this causes make it hard to obtain permits to develop new production sites.

Difficult access to the coast and a lack of new facilities since 2000 in the marine fish-farming sector also reflect the poor image of the fish-farming sector. Against a backdrop of growing concern for the environment, fish-farming is attracting criticism in particular with regard to:

- Waste (suspended matter, nitrogen and phosphorus emissions), veterinary drug residues, escapes and

- Fish meal/oils from industrial fisheries used to feed farmed fish,

whereas the advantages of fish-farming (*e.g.* quality, regularity, freshness of products, indicator of water quality) are not sufficiently perceived. Several initiatives have accordingly been launched to try to halt this trend and promote the sustainable development of French aquaculture.

As some fishery resources become scarcer and the need is felt for sustainable, responsible fisheries, aquaculture is playing an increasingly important part in feeding the population. France and the European Union cannot reasonably limit their strategy of providing the population with seawater and freshwater supplies to imports. Furthermore, the aquaculture industry generates wealth, creates jobs and provides a certain social structure, in both coastal and rural zones, and more particularly in wetlands. The increase in French, European and global demand for aquatic products is an opportunity to develop the sector.

On this basis, Michel Barnier, then Minister for Agriculture and Fisheries, and Jean-Louis Borloo, Minister for Ecology, Energy, Sustainable Development and Regional Development, decided at the end of 2007 to commission an expert report on the status of aquaculture in metropolitan France and its overseas departments and territories to Mrs. Tanguy, Mayor of Guilvinec, in conjunction with Mr. Ferlin, Engineer-General of the Water and Forestry Engineering Division and Mr. Suche, Administrator-General for Maritime Affairs.

The report was presented to the Ministers in November 2008. It identifies and analyses the strengths and weaknesses of the French aquaculture sector, along with the obstacles to its expansion. It sets out numerous recommendations for developing the sector, at regional, national and European level. The report's recommendations include:

- Raising awareness, with the help of promotional campaigns, about aquaculture and the quality of its products;

- Enhanced initiatives promoting more widespread, sustainable and high-quality aquaculture, to raise the industry's profile and appeal;

- Large-scale investment in research and development and greater technical support for the industry;

- A new vision statement for the development of sustainable aquaculture, one goal being to obtain the support of all the stakeholders and remove the main obstacle to the development of marine aquaculture, namely the competition for coastal space;

- A special focus on the development potential of this industry in France's overseas departments and territories.

Government initiatives already under way or in the pipeline in response to the report's recommendations:

The aquaculture industry has for many years been closely monitored by government departments and French research institutions. However, to meet the trend in demand for aquatic products and enable French aquaculture to benefit from these developments and foster its expansion, government initiatives have been stepped up over the past few years. Examples include the following policies and projects:

Communications and product development

An ambitious communications programme to raise the profile of fish-farming and awareness of the quality of its products was launched in 2009-2010 by the joint trade association *Le Comité Interprofessionnel des Produits d'Aquaculture* (CIPA) and co-financed by the Ministry of Food, Agriculture and Fisheries and the European Fisheries Fund. To enhance product development and consumer perceptions, the trade association will be launching several initiatives aimed at product differentiation (including organic farming and official labelling schemes).

Partnerships with the environmental world, developments in production practices, and research programmes to learn more about and improve the interaction between the environment and aquaculture

To promote sustainable aquaculture and raise awareness, several initiatives have been launched:

- A tripartite charter, signed in 2007, by the central government, *Le Conservatoire du littoral et des rivages lacustres* (a government agency that reports to the Ministry of the Environment and addresses the conservation of coastal zones and lakeshores) and the shellfish industry, and the development of a guide for sustainable salmon farming, now being drawn up in conjunction with the World Conservation Union (IUCN) with funding from the Ministry of Food, Agriculture and Fisheries;
- New aqua-environmental measures, within the framework of the European Fisheries Fund, to support fish-farms which develop particularly environment-friendly farming methods (organic aquaculture, extensive freshwater farms);
- An increase in research and development programmes;
- A reduction in nitrogen waste from fish-farming, for instance through the PROPRE (“clean”) scheme, which stands for responsible and sustainable fish-farming in a clean environment. Launched in spring 2009, the scheme is co-financed by the Ministry of Food, Agriculture and Fisheries and the European Fisheries Fund;
- A reduction in the use of industrial fishery resources to feed farmed fish. Examples include the VEGEAQUA research programme by the AQUIMER cluster, run by IFREMER, INRA (national institute for agricultural research) and SYSAAF (trade association for French poultry and aquaculture breeders) in partnership with four fish-farming enterprises. The purpose of this three-year project, due to start in 2010, is to select genetic strains of sea bass, sea bream and trout adapted to rich feed based on raw plant materials as a partial replacement for fish meal and fish oils;
- With regard to shellfish production, new ecosystem management tools to promote the sustainable development of the shellfish industry in Lower Normandy and the conservation of high-quality ecosystems (the OGIVE project, developed by IFREMER).

R&D projects to provide technical support for the sector, above and beyond environmental issues

In addition to the research programmes above, other research projects have been undertaken as part of the drive to provide the aquaculture industry with more technical support:

- A research programme conducted by IFREMER to gain insight into, and better manage, interannual variability in cupped oyster recruitment in France (VELYGER); other programmes will focus on the comparatively high death rate in cupped oyster spat and juveniles observed over the past two years.

- The AQUA-OFFSHORE-II research programme being drawn up with IFREMER, which calls on the logistical support of four French enterprises to test a new model of submersible offshore cage in the Mediterranean and in France's overseas departments/territories. If successful, this programme could provide more scope for fish-farming businesses in coastal zones, where conflicting land-use is holding back the industry's expansion.

Furthermore, proposals to improve conditions for research, expertise and technical support for the oyster industry have been put forward by a team comprising members of the General Council for Agriculture, Food and Rural Areas, the General Council for the Environment and Sustainable Development, and France's Food Safety Agency (AFSSA).

Regional marine-aquaculture development plans

Owing to the specific problems of coastal zone access, the government decided to present a Bill for the Modernisation of Agriculture and Fisheries to the French Parliament on 13 January 2010, making it mandatory to draw up regional plans for the development of marine aquaculture.

These plans will be drawn up by Regional Prefects, in collaboration with coastal stakeholders, *i.e.* government departments, local authorities, statutory bodies (including marine reserve agencies, the *Conservatoire du littoral* and research institutions), trade associations and other coastal-zone users. One of the objectives is to draw up an inventory of existing aquaculture sites and identify, through dialogue with all the stakeholders, other potential sites that could be set aside to develop aquaculture. The Agriculture and Fisheries Modernisation Act is expected to become law by the end of 2010.

Developing the industry overseas

The Convention on Overseas Departments/Territories, held in 2009, resulted in a number of measures to develop the local economy, one of which was specific to the aquaculture sector. Central government is co-financing the construction of an IFREMER centre for applied research on the island of Mayotte; the findings will be circulated to all overseas departments and communities, in particular via the newly established overseas producers association *Union des Aquaculteurs d'Outre-mer* (UAOM). Furthermore, croaker is the species with the greatest development potential for marine fish-farmers overseas. To ensure the rational management of genetic breeding stock by both overseas departments and communities, two applied-research programmes will begin in 2010, one focusing on drawing up an assisted fertilisation protocol for croaker, the other on the selection of brood stock.

French initiatives at the Community level

As the future of French aquaculture is closely tied to that of European aquaculture and the relevant Community framework, national initiatives have received support from the EU. In spring 2008 France issued a memorandum on the sustainable development of aquaculture in Europe. Signed by 17 other Member States (Bulgaria, Czech Republic, Cyprus, Estonia, Finland, Greece, Hungary, Italy, Latvia, Lithuania, Malta, Poland, Portugal, Romania, Slovakia, Slovenia and Spain), the memorandum was submitted to the Council, the European Parliament and the European Commission in June 2008 and sets out the following broad ideas:

- Introduction of an integrated community policy, in particular to streamline and simplify all legislation relating to aquaculture, with a view to promoting development and competitiveness in the sector;
- Development of a European communication policy to raise the profile of aquaculture and awareness of its products;
- Need for a framework ensuring that aquaculture products are healthy, of high quality and environment-friendly (compatibility between aquaculture and the environment) ;
- Implementation of economic-support tools to ensure a future for the sector. This includes start-up support for young aquaculture producers but also new schemes enabling aquaculture producers to take out insurance cover for the risks they face (climate-related damage, human/animal health crises).

The European Commission, for its part, presented a Communication in April 2009 to the European Parliament and the Council entitled "A new impetus for the Strategy for the Sustainable Development of European Aquaculture" [COM(2009)162]. The Communication seeks to identify the causes of aquaculture's stagnation in Europe. Its aim is to lend new impetus to the Strategy for the Sustainable Development of European Aquaculture. The Strategy involves promoting competitive European aquaculture based on R & D for new technologies (European Aquaculture Technology and Innovation Platform), maritime spatial planning to promote the development of aquaculture in coastal zones, compatibility between aquaculture and the environment, and the integration of animal health and welfare, including fish-feed considerations.

Following this Communication, the Council of Fisheries Ministers of the European Union unanimously adopted, in June 2009, a series of conclusions on a sustainable development strategy for this sector.

The next step is to translate those conclusions into concrete initiatives, in particular through changes to the Community regulatory framework. The reform of the Common Fisheries Policy in 2012 should accordingly be an opportunity to make aquaculture a major pillar of that policy. In its memorandum on reform of the Common Fisheries Policy, issued in December 2009, France, drawing on the Council's conclusions, reiterated the importance of:

- Simplifying and streamlining the entire legislative framework relating to aquaculture;
- Maritime spatial planning to enable development in this industry, hindered as it is by growing competition for maritime and coastal space;
- More economic support for the industry (start-up support for young aquaculture producers, risk cover/management);
- Support for innovation and research;

- Raising the profile of aquaculture and awareness of the quality of its products.

Notes

1. FAO, 2008.
2. A new impetus for the Strategy for the Sustainable Development of European Aquaculture – Impact Assessment, Directorate-General for Internal Policies, European Parliament, 2009.
3. Source: French Ministry of Food, Agriculture and Fisheries– FranceAgriMer.
4. Source: Ministry of Food, Agriculture and Fisheries.

Chapter 5

Greece: Best practices in aquaculture management and development

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Abstract

Greek aquaculture boomed over the last two decades, mainly due to massive production increases in sea bass and sea bream. Technological developments, favourable natural conditions and available national and EU funds for production infrastructure investments drove this intensification in production. The paper provides an extensive overview of the regulatory framework of the aquaculture sector, including legislation for licences, environmental protection, coastal zone development and the regulation of competition over land and water resources. It also specifies the role that public funding played in terms of increasing production volumes and product promotion.

Increases in production however stressed the need to improve the management of environmental impacts of intensive aquaculture production. Among the mechanisms to control these impacts are integrated coastal zone management and the promotion of best practices in controlling diseases. These measures contribute to improve the image of the industry – which is an important precondition to strengthen product acceptance which faces fierce competition from other producing countries. Other important challenges for the sector that need to be tackled are access to production sites and complex licensing procedures.

Introduction

The low productivity of the Eastern Mediterranean, the overfishing of many stocks and the increase in demand for high quality fishery products are the main reasons for the rapid increase of the aquaculture sector in Greece and all over the world. Although Greece has faced a stabilization of capture fisheries at about 120 000 tonnes for decades, fisheries production declined over the past years, mainly due to the implementation of decommissioning schemes. At the same time the increase of the demand for fishery products forced the country to increase the imports to meet domestic demand. One solution to this situation was the development of the aquaculture sector.

Until the 1980s only extensive culture in lagoons and intensive aquaculture of trout (*Oncorhynchus mykiss)* in frewh waters was carried out in Greece. During the last 25 years intensive marine aquaculture developed considerably and the country is now leading producer of the euryaline species of sea bass and seabream among the Mediterranean countries. Reasons for this development are the natural advantages of the geography (long coast line with many sheltered bays for anchor-ageing floating cages), the favorable climatic conditions, the locally available knowledge and access to national and European Union subsidies for investment in production infrastructure. As a result, after overcoming technical difficulties in reproduction and larval rearing, feeds and cage technology, the total annual aquaculture production volume increased rapidly from 3 000 tonnes to 113 000 tonnes during the years 1987-2007, consisting of 30 000 tonnes of mussels, 3 000 tonnes of trout and the balance of euryaline finfish (FAO Fishery Statistics, 2009). In 2008, Greek marine aquaculture production of gilthead sea bream *Sparus aurata* (L.) and European seabass, *Dicentrarchus labrax* (L.) accounted for 41% of the total Mediterranean production [60 000 tonnes gilthead sea bream, 35 000 tonnes of European seabass (FEAP, 2008)]. Tables 5.1 and 5.2 represent the annual aquaculture production from 1986 to 2007 (General Directorate of Fisheries).

Table 5.1: Annual production of marine fish farms from 1986 – 2007

Year	Fish farms with floating cages			Hatcheries		
	Number of farms	Annual production (tonnes)	Value in GRD x 10^9 or EUR x 10^6	Number of hatcheries	Fingerlings x 10^6	Value in GRD x 10^9 or EUR x 10^6
1986	5	90				
1987	12	105		2	3	
1988	25	238	GRD 0.48	2	3	
1989	30	500	GRD 1.15	5	3.1	
1990	107	2 185	GRD 5.68	10	11	GRD 1.63
1991	139	3 450	GRD 9.14	13	23.2	GRD 3.25
1992	133	7 850	GRD 18.84	15	41.1	GRD 5.75
1993	171	11 500	GRD 21.85	19	60.0	GRD 7.02
1994	189	13 500	GRD 24.66	22	70.5	GRD 7.04
1995	193	17 670	GRD 30.80	23	91.1	GRD 8.50
1996	205	21 210	GRD 39.50	23	99.7	GRD 9.6
1997	229	26 720	GRD 52.65	25	99.5	GRD 9.05
1998	247	31 129	GRD 59.60	29	147.7	GRD 13.38
1999	266	42 627	GRD 65.50	33	160.7	GRD 13.73
2000	282	50 295	GRD 76.14	36	193.7	GRD 15.01
2001	290	58 108	GRD 76.34	41	250.95	GRD 18.45
2002	308	62 457	EUR 230.7	39	269.51	EUR 68.95
2003	307	66 376	EUR 293.0	38	238.35	EUR 57.25
2004	309	64 784	EUR 281.8	38	289.67	EUR 63.33
2005	311	76 424	EUR 323.3	39	300.90	EUR 65.99
2006	329	80 753	EUR 354.6	39	349.11	EUR 72.57
2007	332	87 341	EUR 370.4	39	350.32	EUR 72.47

Table 5.2: Annual production of mussels and shrimps farms

Year	Mussels farms			Shrimps farms		
	Number of farms	Annual production (tonnes)	Value in GRD x 10^9 or EUR x 10^6	Number of farms	Annual production (tonnes)	Value in GRD or EUR x 10^6
1986		230				
1987	72	400				
1988	41	1 100	GRD 0.22			
1989	52	1 840	GRD 0.35			
1990	87	3 800	GRD 0.57			
1991	94	5 898	GRD 1.062			
1992	123	8 391	GRD 1.762			
1993	253	16 700	GRD 1.837			
1994	319	19 075	GRD 1.602	1	5	GRD 15.0
1995	330	21 200	GRD 2.078	1	3	GRD 10.0
1996	350	22 000	GRD 2.090	1	0	0
1997	346	25 000	GRD 2.463	1	6	GRD 21.6
1998	395	26 013	GRD 2.783	1	2	GRD 7.2
1999	458	25 365	GRD 3.123	1	0	0
2000	564	32 550	GRD 3.174	1	0	0
2001	566	31 981	GRD 3.198	1	0	0
2002	574	31 823	EUR 11.902	1	4	EUR 0.052
2003	575	31 540	EIR 12.459	1	0	0
2004	577	28 803	EUR 11.889	1	0	0
2005	553	26 066	EUR 11.326	1	7.1	EUR 0.120
2006	602	28 318	EUR 11.975	1	10.3	EUR 0.110
2007	590	22 197	EUR 9.406	1	4	EUR 0.066

National policies and strategies

The Ministry for Rural Development and Food is responsible for aquaculture development. The main aquaculture policy issues are:

- Planning and implementing national and European projects for aquaculture development;
- Controlling the production to respect the needs of the local and Mediterranean markets;
- Supplying markets with high nutritional value and quality products at satisfactory prices;
- Increasing employment and non-removal of population from their homeland;
- Funding studies for research and technology to improve aquaculture production and the adoption of adequate marketing policies at national and European level and
- Protecting the environment as a pre-requisit for sustainable aquaculture development.

Aquaculture projects are strictly regulated by a permit system based on clearances issued by various agencies responsible for spatial planning and environmental protection, navigation, shipping, health protection, protection of antiquities, commercial fisheries, tourism, recreation, nature conservation and wildlife. The licensing authorities that coordinate these agancies are the Ministry for Rural Development and Food and the Ministry for the Environment, Energy and Climate Change.

The licenses both for the installation and the operation of an aquaculture farm are issued by the regional administration of the country through the local Agriculture Development Service of the Ministry for Rural Development and Food, with the collaboration of the relevant services to achieve the development of the sector and the protection of the environment. These services belong to the:

- Ministry of Defense;
- Ministry of Finance, Competitiveness and Navigation;
- Ministry of Environment, Energy and Climate Change ;
- Ministry of Civilization and Tourism;
- Ministry for Rural Development and Food (Fishery-Veterinary Science Sector);
- Ministry of Health and Social Solidarity.

Decision makers must also take into account the political realities, the perception of the local population of the project and the relationship of the proposed project to other projects operating in the area. In general there are regional differences in policy and licenses which are mainly granted on the basis of site-specific (spatial planning and environmental) criteria. The aquaculture sector operates at a central-regional administrative and prefectural authority level, in a direct connection with the local Fishery Services, as the country's administrative system is divided into: (i) the central administration (Ministries); (ii) the regional administration (13 regions); (iii) the prefectural authorities (52 prefectural authorities); and (iv) the local authorities (923 municipalities-communities).

Finally, the licenses for installation and operation indicate the proper operation of the unit (maximum water quantity, method of treatment of outflow, limits of leased area, non-obstruction of fishing, shipping, etc.).

Possible problems arising through the non-application of operational rules and procedures provided by the relevant regulations concerning all activities using common resources set up by the Ministry for Rural Development and Food are solved by informal (ad hoc) committees consisting of aquaculture experts from the public (ministries, institutes, universities) and the private sector.

Basic aquaculture legislation

Present legislation concerning site selection and the requirements which must be met for the establishment and operation of intensive and semi-intensive aquaculture sites (on-growing cage farm units, shellfish farms, land based farms, hatcheries with associated land-based facilities for marine and freshwater species etc.) consists of:

- Law No. 420/1970 “Fisheries Code”. This Law refers to the lease of marine sites via public sale, for trial cultivation;

- Presidential Decree 142/1971 “Licensing of establishment of aquatic organisms’ farming, by the Minister of Agriculture” which has been modified by the Presidential decree No. 332/1983 for the devolution of previously referred duties to the correspondent Prefects;

- Law No. 1845/1989 “Development and utilization of the agriculture research and technology – protection of forests and other terms”, chapter C, article No. 32 which refers to leasing sites without public sale and

- Law No. 3208/2003 “Protection of forest ecosystems, regulation of rights over forest areas and other terms” suggests that all duties concerning leasing marine sites, renewing lease, issuing licenses for project establishment and operation of aquaculture farms is devolved to the General Secretariat of the respective Region (which is the competent regional authority of the Ministry for Rural Development and Food).

The legal framework mentioned above has been supplemented over the years, by various ministerial and other services’ interventions, for example Ministerial Decisions, guidelines, circulars etc., aiming especially at resolving management problems within the sector, but also meeting the needs of the market.

Leasing of shellfish farming sites

The procedures of leasing marine sites for shellfish farming are the same as those described for fish farms, besides that no site can be leased outside designated Shellfish Farming Zones as determined by the Presidential Decree No. 79/2007. According to that Decree (article No. 25 – "Areas-zones of production or relocation of live bivalves"), special zones are determined through the respective Prefect's decision as suitable for production or relocation of bivalves on-growing farms, after having obtained approval of the Prefectural Veterinary Authority and the local Port Authorities.

Coastal zone development policy

The basic legal framework governing the establishment and operation of aquaculture production sites on the seashore and the coastal zone contains the following:

- Law No. 2971/2001 "Seashore, coastal zone and other terms" provides information about seashore and coastal zone ownership and defines the procedure of determining the borders and protecting the seashore and the coastal zone and

- Ministerial Decision 109313/5914/130/2004 "Evaluation of facilities and installations which exist on the seashore and the coastal zone".

There is also specific legislation for land-based facilities for the maintenance and support of aquaculture activities. The legal framework governing the installation of land-based facilities built to maintain and support marine aquaculture farms consists (among others) of:

- Law No. 3325/2005 "Licensing of project establishment and operation concerning industrial installations in the context of sustainable development and other terms". This law applies to both hatcheries and processing facilities and refers to the license issued by the Directorate of Development of the respective Prefecture and

- Presidential Decree No. 79/3-5-2007 embodies the Regulations No. 853/2004 (EC) "on the hygiene of foodstuffs" and 852/2004 "laying down specific hygiene rules for food of animal origin" into the national legislation. According to this Decree, a license for project establishment and operation is needed from the Veterinary Service of the Prefecture specifically for processing facilities. The provision of licensing needed for the establishment and operation of land-based projects requires full commitment to the terms specified in the Decree.

Competition for land and marine and freshwater resources

Special legislation exists concerning water use permits for aquaculture activities. The Presidential Decree No. 51/2-3-2007: "Determination of measures and procedures for the integrated management and protection of water sources, in conformity with Directive No.

2000/60 of 23-10-2003 establishing a framework for Community action in the field of water policy" incorporated all the terms referred to in the pre-mentioned Directive into the national legal framework related to water policy. It also contains a thorough appendix for the classification of water sources and the parameters of water quality control. For the definition of the structure of the Directorate of Aquaculture and Inland Brackish and Fresh Waters, Ministerial Decision No. 47630/16-11-2005 has been issued, while the Ministerial Decision No. 43504/5-12-2005 "Categories of water use permits and the delivery of projects to exploit water, issuing procedure, content and duration" defines all the necessary documentation needed to obtain a water use permit for all aquaculture projects, including land-based projects. The competent authority for the issuing of the water use permit is the regional Directorate of Waters.

Aquaculture and the environment

The exploitation of the biological resources, whether through aquaculture or capture fisheries, is concentrated in the narrow coastal zone, which is subject to natural environment fluctuations brought about by mixing of water from the land with that in the sea. This coastal zone has a delicate environmental balance and is limited in size. It is also affected by human activities (sea traffic, industries, urban development, tourism, swimming, etc.), which impact on water quality (Barnabe, 1990).

Water quality also depends on the capacity to assimilate waste from urban, industrial and agricultural sources in biological and geochemical cycles. When the volume of waste becomes too big to be assimilated in these cycles, the fundamental balance of the ecosystem is disturbed, marine life is threatened and pollution arrives. However, long-term pollution caused by fish farms is less dangerous for the ecosystems than the pollution caused by other human activities, such as agriculture, urban, or industry effluents. These pollution sources are not only a danger for farmed fish, but also affect the quality of the aquaculture product by deleterious factors, such as various toxic substances, which are dissolved in the sea environment.

Investors have to submit a preliminary environmental impact study (EIS) and an environmental impact assessment (EIA) for the approval of the activity and the issuing of the license to protect aquaculture production sites and the marine environment in which floating net cages will be installed and operated. Physical parameters (temperature, density, ionic, colour, turbidity, suspended solids) and chemical parameters (salinity, ionic composition, dissolved gases salts and molecules, dissolved and particulate organic matter) of the seawater are measured before and during the operation of a fish farm.

These studies have to be presented to the local competent services of the Environmental Planning Directorate of the Ministry for the Environment, Energy and Climate Change and to the Aquaculture and Inland Waters Directorate of the Ministry of Rural Development and Food. Subsequently, these studies are forwarded to the local administrations in which the fish farm will be installed and operated. In a public meeting the studies are presented and evaluated by the local authorities.

The environmental regulations governing the aquaculture sector and its supporting facilities consist mainly of:

- Law No. 1650/1986 "for the protection of the environment";
- Ministerial Decision No. 69269/5387/25-10-1990 "Classification of projects into categories, contents of Environmental Impact Assessment

document, determination of the content of Specific Environmental Assessments and other related terms";

- Law No. 3010/2002 "Conformation of Law No. 1650/1986 with the Directives 97/11/EC and 96/61/EC, procedure of delimitation and regulation of subjects for water streams and other terms";

- The articles No. 18 and 19 of the Law No. 1650/1986 determine the types, characteristics and the procedure for the declaration of protected sites; Ministerial Decisions No. 414985/1985 and No. 33318/3028/1998 which were issued to adapt national legislation with the Directives 79/409/EC on the "Conservation of wild birds" and 92/43/EC on the "Conservation of natural habitats and of wild fauna and flora", together with the above law, constitute the basic legal framework for the determination of protected natural sites in Greece. Areas included in the Directive 92/43/EC are suggested as "Sites of Community Importance (SCI)" while areas included in the Directive 79/409/EC are considered "Special Protection Areas (SPA)". By 2005, Greece had identified more than 350 sites that have been declared as "protected sites" and are candidates for the NATURA 2000 network.

- Ministerial Decision No. 15393/2332/5-8-2002 "Classification of public and private works into categories according to article No. 3 of the Law No. 1650/1986 as it was replaced with article No. 1 of Law No. 3010/2002" constitutes the legal procedure of classifying projects according to their environmental impacts and issuing environmental terms for their operation.

- Ministerial Decision No. 11014/700/Φ104/14-3-2003 "Procedure prior to issuing Preliminary Environmental Assessment and Evaluation and Approval of Environmental Terms decisions, according to article No. 4 of the Law No. 1650/1986 as it was replaced by the article No. 2 of the Law No. 3010/2002".

Mechanisms for controlling environmental impacts

It is an unquestionable fact that non-compliance with environmental regulations causes a disorder in the ecosystem. Aiming at maintaining a balance between the productive activities of aquaculture units and the marine environment in which fish farms are installed and operated, the national and community legislation applies. Responsible services of the Ministries for Rural Development and Food, of the Ministry of the Environment, Energy and Climate Change, of the prefectural authorities and research centres constantly monitor and record environmental impacts. Systems which the State has installed for certain cultures (shellfish, cyprinids, salmonids), permanently record the abiotic water parameters, so that the aquaculture farmers can be informed about and absolutely compliant with the limits imposed by the environmental legislation. At the same time, the Ministry of Environment monitors through specialized laboratories the waters of all coastal areas of the country (based on the Directives of the European Union).

In the case of threats to public health, the competent Veterinary Service of the Ministry for Rural Development and Food takes measures, in co-operation with the Ministry of Health and Social Solidarity, which are mandatory for the producers.When the services identify threats for the marine environment, prior to providing penalties, the aquaculture farmer is requested to finance an EIA study, carried out by research centres to evaluate of the degree of pollution. Based on the results of the study, the fish farmer is obliged to either change the initial location of his unit permanently or to carry out regular fallowing to reduce the environmental impact of the aquaculture farm (Klaoudatos, 2001).

Integrated Coastal Zone Management (ICZM). Towards a sustainable protection of the environment

The shared use of public domains and the conservation policies for the Mediterranean Sea reduce the availability of suitable aquaculture production sites. But at the same time, demand for aquaculture products is increasing, in particular due to their capability to offer a constant supply of quality products at relatively stable prices. The competent authority for the environmental licensing of sites protected by special legislation (NATURA 2000, Ramsar, etc.) is the Ministry of the Environment, Energy and Climate Change, or otherwise the regional services of the competent Ministry (Directorate of Physical Planning).

Due to the rapid growth of the aquaculture sector in Greece over the past 20 years, another challenge aroused: the competition for space between the developing industry and traditional uses of the coastal zone. Further sector development therefore needs spatial and environmental integration, as well as for the formulation of a spatial planning framework in the context of Integrated Coastal Zone Management (ICZM).

The legislative framework for spatial planning in Greece is Law 2742/1999 ‘Spatial Planning, sustainable development and other provisions’. With regard to aquaculture, this law requires the establishment of ‘Areas of Organized Development of Aquaculture Activities’, known as ‘POAY’ (acronym of the respective Greek terminology). Taking into account the provisions of the law, the Ministry of the Environment, Energy and Climate Change developed the ‘Strategic Plan for aquaculture’ in 2000, which proposed broader areas for development at a nationwide scale. According to the specifications and requirements of the Ministerial Decree No 17239/2002, studies for the definition of ‘POAY’ were conducted in various regions to identify areas for the development of aquaculture. These studies currently are at the stage of public consultation for their final implementation.

The development of ‘POAY’ has important benefits, both at the socio-economic and the environmental-management level. The spatial integration of aquaculture activities within ‘POAY’, guarantees their integration in the coastal zone and minimizes land-use conflicts. It also enables the vertical integration of productive activities, the reduction and mitigation of environmental impacts by taking appropriate measures (*e.g.* monitoring of the marine environment, R&D, fallowing etc.), the support of innovative entrepreneurship and the promotion of local production. (NAYS ltd record data; Argyrou and Papaioannou, 2008).

Best practices in controlling diseases. Hygiene of aquaculture products

To control the spread of diseases Greek farmers initially used antibiotics. Nowadays they use vaccines to protect farmed fish from diseases. With regard to food hygiene of animal by-products, all facilities must adapt their operation process regarding disposal and processing of animal waste and its placing on the market to the Regulation (EC) No 1774/2002 "for the determination of sanitary rules regarding animal by-products not intended for human consumption". In Greece compliance is verified during the procedure of issuing Environmental Terms of Operation as far as aquaculture farms are concerned.

The Presidential Decree No. 79/30-5-2007 contains the "necessary supplementary measures for the application of Regulations (EC) No. 178/2002, 852/2004, 853/2004 and 882/2004 concerning specific hygiene rules for food of animal origin, official controls performed to ensure the verification of compliance with feed and food law, animal health and animal welfare rules and the adaptation of the national veterinary legislation to the Directive (EC) 2004/41" (the pre-mentioned Directive refers to food hygiene and health conditions for the production and placing on the market of certain products of animal origin intended for human consumption).

Circular No. 289663/23-12- 2003 was issued by the Veterinary and Public Health Service of the Hellenic Ministry for Rural Development and Food for the "Classification and disposal of animal by-products not intended for human consumption, according to the Regulation (EC) No. 1774/2002". Circular No. 251996/9-2-2005 "Remote areas and incineration or landfill of animal by-products" was issued by the same service to determine specific sites in Greece which can be characterized as "remote" and the categories of animal by-products to which the pre-mentioned methods can be applied (in line with article No. 24 of the Regulation (EC) No. 1774/2002). Circular No. 280741/26-8-2004 was issued by the Veterinary and Public Health Service of the Hellenic Ministry of Rural Development and Food to define the difference between the incineration and the combustion of animal waste, as well as the difference between "landfill" and "sanitary landfill", in the context of Regulation No. 1774/2002 - appendix I, the Directive (EC) No. 2000/76 "on the incineration of waste" and the SANCO/445/2004 "Guidance Note on the application of Community legislation regarding animal and public health and waste, to animal by-products" (Ministry of Rural Development and Food, personal communication, 2008; EUROPA site: http://eur-lex.europa.eu/en/index.htm). Presidential Decree No. 28/5-3-2009 harmonized Directives 2006/88/EC of the Council and 2008/53/EC of the European Commission on animal health requirements for aquaculture animals and products thereof, and on the prevention and control of certain diseases in aquatic animals.

In addition to compliance with EU food safety regulation, Greece's commitment to food safety and quality has led to the certification of Greek aquaculture products according to national standards:

- ISO 14000 (environmental management);
- ISO 9001:2000 (quality management systems) and
- ISO 22000/HACCP (Food Safety).

The use of a national quality assurance scheme is very important to ensure the quality standards for aquaculture products and to safeguard the products in a competitive market.

The Agricultural Products Certification and Supervision Organization (AGROCERT) is a private legal entity operating for the public benefit under the supervision of the

Ministry for Rural Development and Food. It is responsible for the implementation of the national policy on quality in agriculture.

The main competences of AGROCERT are the following:

- Certification of agricultural production systems;
- Certification of agricultural products;
- Evaluation, approval and supervision of private control and certification bodies accredited by the National Accreditation System and
- Preparation and publication of voluntary sector standards and development of specifications for quality assurance of agricultural products.

State funding and subsidies

Over time the aquaculture sector of Greece as an EU member state has benefited from funding and subsidies from the EU to promote its development and to ensure a sustainable and viable sector, in competition with other aquaculture products of the world. Several programming periods have marked the EU history of the aquaculture sector, which have provided several funding opportunities to the sector. Under Council Regulation (EEC) No 3760/92, and in particular through the relevant National Operational Programme 'Fisheries 1994-1999', the aquaculture sector benefited from EUR 116.5 million allocated to aquaculture related projects.

At the end of the programming period, under measure 3.1 dedicated to aquaculture production capacity increase, 162 investment projects had been financed in Greece for a total value of EUR 84 million (all species included). The latter funding increased sea bass and sea bream farming capacity by 8 754 tonnes (4 341 tonnes for sea bass and 4 413 tonnes for sea bream) and fry production capacity by 16.3 million fingerlings. Moreover, measure 3.2, which was dedicated to improvements without capacity increase, financed the improvement (hygiene, safety, environmental) of 49 production units in Greece for a total value of EUR 16.9 million.

Under Council Regulation (EC) No 2792/1999 for the programming period 2000-2006, about EUR 120 million were allocated for aquaculture related projects, accounting for almost 40% of the total funding available through the National Operational Programme 'Fisheries 2000-2006'. The programme was closed on 31-12-2009 and has exceeded the absorbance expectations of 100% (absorbance 117.36%) for aquaculture (measure 3.2). For instance, under measure 3.2 dedicated to aquaculture, 229 projects, covering the total of the available budget, have been selected and approved for financing in Greece so far (December 2009 data). 86 of these projects, with a total budget of EUR 41.5 million - of which EUR 18.7 million were public expenditure - are related to production capacity increases. In particular, these projects have increased the annual production by 10 689 tonnes for marine fish (initial increase forecast 8 000 tonnes), by 936 tonnes for freshwater fish (initial increase forecast 800 tonnes), by 3 819.8 tonnes for shellfish (initial increase forecast 3 456 tonnes) and by a total of 60 million fingerlings (initial increase forecast 50 millions). Moreover, 143 farms (marine, fresh water fish and shellfish) have been selected for financing under the action 'modernization of existing units without increasing production capacity' with a total funding of EUR 28.9 million (public expenditure), out of a total cost of EUR 64.2 million.

The Commission had requested that no more funding should be directed for any increases of the production capacity for sea bass and sea bream after the end of 2002 via the Financial Instrument for Fisheries Guidance (FIFG) and through the Operational Programme Fisheries 2000-2006. This was largely due to the fact that Greece was producing sea bass and sea bream at volumes higher than permitted by the farm capacity-licenses and consequently higher than the officially declared volumes. Most of all however, because of the evident market impacts, namely a price collapse for the two species in question. However, a 2004 European Commission study, contracted to the University of Stirling, revealed that actual production was indeed much higher than officially reported but that there was no overproduction of sea bass and sea bream, but merely under-marketing of it. The Commission then revoked its previous decision and allowed the financing of projects concerning production capacity increases. This suggested however that emphasis should be given to the financing of projects that concern the marketing and promotion of the industry and its products.

In addition to measure 3.2 which concerns the direct financing of aquaculture projects, there was an additional measure of the Operational Program Fisheries 2000-2006 (measure 4.3) referring to the promotion of sea bass and sea bream marketing and fisheries certification, labelling etc. The latter measure had a budget of EUR 5.5 million and the final absorption amounted to EUR 3.8 million. Only in 2007 a project for the promotion of sea bass and sea bream was approved and funded in Greece, at a cost of EUR 3 million for a duration of 15 months.

Positive impacts of aquaculture development

Aquaculture, like any other food producing industry, needs: a good image with consumers, mutual understanding to obtain planning permissions and licenses, to be able to attract good quality employees and to market its product. Aquaculture also operates in a world where the media influence the public opinion.

Just as other food production industries, aquaculture has been hit by "food scares" about additives in farmed finfish, trace levels of antibiotics and parasite treatments which contribute to a neutral or negative image of the sector in the public opinion. Consumers are also well informed and increasingly interested in the general sustainability of food production and issues such as pollution from on-growing units, the unsustainable use of fish meal in farmed fish diets, effects on wild fish stocks and in particular, animal welfare.

In Greece public efforts to improve the sectors image include public education, new legislation, better location of farms based on integrated coastal zone management and technology development. All these activities have resulted in a significant improvement in public opinion towards aquaculture. Today, the sector's overall image is mostly positive. Consumers tend to consume farmed products without any apprehension.

Positive aspects associated with the image of the industry are stable supply, affordable price and safety. Perceived aquaculture product attributes are quality, freshness and controlled food safety and hygiene. In countries where it benefits from the positive aspects of seafood in general, it is also perceived as a nutritious and healthy source of protein (Barazi, 2009).

Conclusions

New socioeconomic conditions affecting agriculture in Europe and worldwide include the globalisation of agricultural markets, the expansion of the European Union, the development of a new Common Agricultural Policy within the European Union (Agenda, 2000) and the increasing demand for quality control of agricultural products. In addition, environmental protection measures dictate sustainable management of natural resources and the preservation of biodiversity. The need to include all these factors has resulted in a major change from quantitative to qualitative production. Greek aquaculture today is mainly focused on the production of high quality, certified products produced by innovative procedures compatible with sustainable development principles. Improved quality and the resulting increase in value of Greek aquaculture products will be achieved through technological innovations resulting from focused, well-coordinated aquaculture research. Greece as a member of the EU faced also some challenges which are specific to EU countries as:

- Competition with imports;
- High costs associated with compliance to stringent environmental, health and animal welfare regulations; and
- Lack of a level playing field among member states and mainly with respect to third country imports.

The future of aquaculture growth in the Mediterranean is greatly dependent upon the solution of some common problems for countries within and external to the EU, as the competition for space and the simplification of the licensing procedure and legislation. The future development of the industry is also dependent on measures and responsibilities taken by the State authorities which can substantially improve the business environment.

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References

FAO-Fisheries and Aquaculture Information and Statistics Service (2009), www.fao.org/figis/servlet/SQServlet?ds=Aquaculture&k1=COUNTRY&k1v=1&k1s=84&outtype=html.

FEAP (2008), Production and price reports of member associations of the F.E.A.P, p. 17, www.aquamedia.org/FileLibrary/11/Productionreport2008.pdf.

Barazi-Yeroulanos, L. (2009), "Regional Synthesis of the Mediterranean Aquaculture Sector & Development of a Strategy for Marketing and Promotion of Mediterranean Aquaculture", CAQ/GFCM.

Klaoudatos, S. D. (2001), "Environmental impact assessment of Mediterranean aquaculture farms. Practical experiences in Greece. Cahier Options Méditerranée", Vol 55, pp. 109-127.

OECD Workshop "Advancing the Aquaculture Agenda" 15-16 April 2010, OECD Conference Centre, Paris, France.

Chapter 6

Korea: The current status of and future plans for aquaculture

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Abstract

It is acknowledged that the aquaculture industry has developed rapidly over the last half century in Korea. While aquaculture technologies have considerably improved since then, Korea's aquaculture industry still has to face a number of important challenges.

The paper analyzes the role and the current state of aquaculture in Korea and suggests measures to efficiently overcome domestic and foreign challenges. Aquaculture production needs to be supported through appropriate production site allocation and access to relevant technologies. Aquaculture production also needs to take environmental aspects into consideration to respect natural carrying capacities. The productivity of marine resources can be also enhanced if enabling business environments are created and supported by research and development.

Precondition for consolidating Korea's position as one of the world's leading aquaculture producers are that varieties are improved, new technologies developed and that information on international market trends is collected, analyzed and distributed.

Introduction

It is acknowledged that the aquaculture industry has developed rapidly over the last half century in Korea. During those years, aquaculture technologies have advanced, aquaculture facilities expanded, types of farmed fish species increased and unit productivity improved. Aquaculture activities have been primarily located along the southern coast which is considered to have the best natural conditions for aquaculture production in Korea due to a relatively favourable oceanic environment for warm-water fish farming, such as warm water temperature and protection from strong storms and seasonal typhoons. However, excessive aquaculture activities in a rather limited area also caused difficulties.

In the 1960s and 1970s, when aquaculture technology was developed with a focus on seaweed seedlings, aquaculture was considered a good source for seafood for Korean consumers. Since the mid-1980s, when marine net cage and land-based technologies for finfish were developed, marine aquaculture rapidly advanced. Serious international competition and additional challenges had to be faced by the industry from July 1997 on when fishery products were imported from neighbouring countries in large quantities. In the 2000s, the production volume of some marine products, especially flounder and rockfish, increased in parallel with fishery imports (Table 6.1). Under the WTO regime, Korean aquaculture faces great competition as low-priced live fish flows in from overseas in great amounts. In addition, the industry has to deal with natural disasters like typhoons and red tides in addition to marine pollution.

Table 6.1: Development stages of major achievements in Korean aquaculture

Stages	Year	Production trends	Major species and achievements
First	Before 1945	Initial development	Laver, oyster, clam, Manila clam
Second	1946 - 1960		
Third	1961 - 1975	Expansion of seaweed production and technical advances	Artificial seedling production of laver, sea mustard and sea tangle
Fourth	1976 - 1985	Expansion of shellfish production and technical advances	Shellfishes production enlarged owing to technical advances of seedlings production and on-growing for oyster, abalone, ark shell, etc.
	1986 - 1999	Expansion of finfish production and technical advances	Intensive aquaculture for finfish increased, especially flounder and rockfish
Fifth	After 2000	Production adjustment and regulation	Ecosystem-based and consumer-oriented aquaculture

Current status and trends

Capture production from coastal and deep-sea fisheries rapidly decreased or stagnated from 1986 as stock decreased and coastal countries adopted policies to exploit their resources themselves. An increase in capture fisheries is unlikely to occur due to structural adjustment including the reduction of the fishing fleet, as accessible domestic fishing grounds are reduced as a result of fishery agreements with China and Japan. To compensate, aquaculture is fostered through seedling production in order to guarantee a stable supply of the favourite domestic species.

In 2008, aquaculture production amounted to 1.38 million tonnes (41.1% of the total fisheries production) and played an important role as an animal protein source (Table 6.2). The total licensed area for aquaculture in 2008 was about 136 083 ha, with 58.4% of the area was allocated to seaweeds, followed by shellfish and fish aquaculture (Table 6.3). Cooperative aquaculture accounted for more than 5 000 ha or 4.3% of the total licensed aquaculture areas.

Table 6.2: Annual aquaculture production as percentage of total fisheries production

	1995	2000	2001	2002	2003	2004	2005	2006	2007	2008
Total fisheries	3 347	2 514	2 665	2 476	2 487	2 519	2 714	3 032	3 275	3 363
Aquaculture	996	653	656	782	826	918	1 041	1 259	1 386	1 382
%	30.0	26.0	24.6	31.6	33.2	36.4	38.4	41.5	42.3	41.1

Source: Korean Statistical Information Service - www.kosis.kr

Table 6.3: Annual increase of licensed area by aquaculture group (ha, % in parenthesis)

Group	2000	2001	2002	2003	2004	2005	2006	2007	2008
Total	121 973	122 218	122 243	121 853	123 169	124 668	130 889	132 416	136 083
Fish	2 216 (1.8)	2 256 (1.8)	2 302 (1.9)	2 136 (1.8)	2 002 (1.6)	1 822 (1.5)	1 986 (1.5)	1 962 (1.5)	1 988 (1.5)
Shellfish	44 819 (36.7)	46 171 (37.8)	47 138 (38.6)	47 381 (38.9)	47 087 (38.2)	48 193 (38.2)	49 550 (37.9)	49 261 (37.2)	49 169 (36.1)
Seaweed	71 543 (58.7)	70 201 (57.5)	69 209 (56.6)	68 062 (55.8)	69 348 (56.3)	69 503 (56.3)	74 757 (57.1)	76 183 (57.5)	79 504 (58.4)
Others	3 395 (2.8)	3 590 (2.9)	3 594 (2.9)	4 274 (3.5)	4 732 (3.8)	5 150 (3.8)	4 596 (3.5)	5 010 (3.8)	5 422 (4.0)

Source: Korean Statistical Information Service – www.kosis.kr. Numbers in round brackets indicate component proportion ratios

Problems and difficulties

Korean marine finfish aquaculture was traditionally carried out in relatively small-scaled pens in naturally protected locations along the south coast. Advancements in aquaculture technology over the last decades allowed expanding aquaculture production along the entire coast. However, recently, negative impacts of aquaculture production have been recognized. Failures to maintain production volumes within the natural carrying capacity have hindered further progress. Resentment against the aquaculture industry also emerged, blaming it to be a main culprit of increased pollution and decreased aesthetic value of the coast. To worsen the situation, seasonal typhoons hitting the southern coast of the peninsula caused considerable damages to the industry. The Korean government as well as fish farmers suffered economic losses of over 500 million US dollars when typhoon Memi attacked the southern coasts in 2003.

Many efforts have been made to construct aquaculture clusters and to develop technologies to support the aquaculture industry, but these efforts are not sufficient to secure the international competitiveness of Korean aquaculture products. Korean aquaculture is penalized by high production costs and high mortality rates due to excessive concession of aquaculture licenses and to high stocking densities.

Pollution of aquaculture sites caused by intensive fish farming

In Korea, of the suitable sites of 176 000 ha, 127 000 ha were assigned as production sites for aquaculture. These are mostly situated on the west and south coast (Table 6.4). Production sites for aquaculture have potentially negative impacts on the environment and therefore careful consideration should be given to the development of these sites. This has not always been done in the past when production sites were assigned without appropriate environmental assessments. As a result, some farmed fish species were in oversupply, which led to a sharp decline in commodity prices.

Table 6.4: Estimated area development in aquaculture

Type of aquaculture	Developed area	Appropriate area	Excessive area	Excess rate (%)
Total	**127 518**	**112 646**	**14 872**	**11.6**
Fish	2 966	2 795	171	5.7
Shellfish	50 194	48 199	1 995	3.9
Seaweed	69 229	56 523	12 706	18.3
Others	5 129	5 058	-	-

Source: Korean Maritime Institute (December 2003) - A study on the potential of growing fish

Marine waste and different pollutants destroy the spawning grounds and habitats of aquatic organisms and the overall ecosystem. Severe pollution caused by the accumulation of organic matter like nitrogen and phosphorus also threatens the safety of marine products. Korea has a foreshore of 2 393 km^2 on its south and west coasts, which accounts for 2.4% of the national territory and in which major fish and shellfish like laver, hard clam and Manila clam reproduce. The foreshore is particularly important as it contributes to the purification and improvement of the water quality. Since 1987, a foreshore of 810.5 km^2 has been officially reclaimed along the southern and western coasts widely to develop agriculture, housing and other industries which can benefit from the tidal belts. However, indiscriminative reclamation has reduced the purifying power of natural water and destroyed the habitats of various aquatic organisms.

Illegal expansion of production sites beyond allocated areas

Intensive aquaculture beyond mandatory regulation was intended to increase harvest but caused environmental deterioration of production grounds, conflict with ship navigation and lower productivity of production sites due to the presence of diseases, the aging of the sites and poor management. Illegal behaviour such as excessive production, oligopoly, unlicensed fish farms and changes of species without permission makes it difficult to maintain a sustainable production system. It also deteriorates the quality of products and contributes to imbalances between supply and demand, causing a fall in product prices. Furthermore, there are difficulties in appropriately managing already developed production sites and research or supervisory institutes consider it difficult to provide technological and long-term guidance to aquaculture farmers. Intensive aquaculture will exacerbate damages from typhoon, red tide and/or abnormal temperature. Recovery from those damages is costly, both for the national budget and the aquaculture farmers as well.

Natural disaster and disease outbreaks

Recently, harmful red tides and typhoons tend to increase, placing a great burden on public finances and on the aquaculture farm management. For example, the red tides in 2003 caused damages of KRW 21.5 billion, which is less than the damage of KRW 76.5 billion incurred in 1995, but the affected region and scale were the greatest ever. In addition, in 2003 typhoon Memi caused damages for a value of KRW 453.9 billion in the aquaculture sector. In 2006, due to disease outbreakes the mortality rate reached 8.5% of the total production volume. Poor systematic measures were taken to look into the causes of the diseases and to develop efficient treatments. Vaccines for treating various viral diseases have not yet been developed.

Future plans and strategies

Strengthen regulation against illegal expansion of production sites

By the end of the 1990s the government of the Republic of Korea actively supported aquaculture under the slogan of changing "from catching fish to growing fish". As a result, some regions were saturated with aquaculture farms and face serious environmental problems. Moreover, aquaculture oversupply has caused in some cases sharp declines in prices, leading to bankruptcy of some farms. This situation calls for severe limitations for the development of new production sites and for the restructuration of existing aquaculture sites to ensure competitiveness. New licenses shall not be given for products in oversupply, like laver, brown seaweed, and some fish species, while other species with high commercial value like tuna and mackerel shall be better developed. It is also necessary to restrict the irresponsible development of land-based seawater fish farms, which is currently only to be reported but doesn't require a license. To do so, the government needs to regulate the establishment of farms by changing the current post-reporting system to a prior-permit system. The regulation of illegal aquaculture farms such as unlicensed and excess facilities needs to be intensified.

Aquaculture production sites for each variety shall be relocated according to natural carrying capacities and existing licensed farms need to be prioritized. Enclosing nets, which frequently suffer damages from red tides, typhoons, etc., shall be first moved to open sea production sites so that environmental conditions of coastal areas can recover. Production sites for certain species (*e.g.* ark shell and others) with expiring licences or low productivity should take a temporary rest or be redeveloped for other species. In order to deal with the instability of management caused by poor product quality, oversupply and declining prices, the requirements for aquaculture facilities need to be improved according to the carrying capacity to ensure sustainable production.

Innovate aquaculture species and technologies

In Korea, a total of 85 species have been cultivated, out of which 61 species in marine waters (including 21 kinds of fish such as flounder, rock fish, and red sea bream). As the demand for high value fish products increases, research on new fish species is now focussing on commercial valuable species like tuna.

Presently, aquaculture species are loosing their resistance to diseases and frequently perish in large quantities due poor water quality, intensive stocking densities and recessive varieties. Exotic incurable diseases from other countries are widely spread as farmed species frequently move between regions and countries. This situation calls for the development of an aquaculture disease monitoring and control system. The government has introduced a marine disease management system to quickly treat diseases and minimize damages for farmed species. The first qualification test of this system was conducted in October 2004 when 40 marine disease managers were trained. Since then, 18 - 43 marine disease managers were trained each year, totalling 136 managers now active on site. In order to reduce damages from diseases, the early development of vaccines and treatments is needed in the future as pollution is likely to increase and intensive farming puts high pressure on aquatic organisms. The government already established the marine animal diseases management law to prevent the occurrence and diffusion of major marine diseases.

Apply ecosystem-based environment friendly aquaculture systems

In Korea, most coastal aquaculture farms in gulfs have been developed for specific fish species only and the environmental load of pollutants progresses in one direction only. In other words, in fish farms using artificial feeds, fish feed left overs, faeces and inorganic matter cause the deterioration of the production site environment. Inland farms with intensive production are in fact more severely deteriorated.

This calls for the establishment of poly-culture, where emissions from one species may be used by other cultured species at a different trophic level. That is to say, the environment of a production site can be improved and the productivity enhanced when feed leftovers or solid waste are removed by shellfish and filter feeders, sinking feed dregs used by benthos, and inorganic matters absorbed by seaweed. Research is being conducted to implement ICZM (Integrated Coastal Zone Management) for aquaculture. Once the research is completed, relevant systems and laws for coastal aquaculture will be developed.

Regulate mandatory use of extruded pellets

In fish aquaculture, the cost of feed accounts for 40 - 50% of aquaculture management costs. Feed is also a major factor directly related to the growth of fish. It is necessary to develop environment-friendly extruded pellets to increase the current diffusion rate for extrude pellet of 20% to at least 80% and to diminish the pollution of production sites caused by raw feeds. To do so, good quality extruded pellet, which can be trusted by aquaculture farmers, shall be developed and the government shall introduce an incentive system to encourage aquaculture farms to use extruded pellets. This should contribute to preventing indiscriminate hunting of resources, reducing pollution and establishing environment-friendly aquaculture practices. Since 2004, the government provides fish farmers with subsidized extruded pellets However, the subsidy provision rate shall be increased and mid- and long-term systems be set up to discourage the use of raw feeds.

Restore trust in aquaculture products

In Korea, most fishery products are consumed as sliced raw fish in restaurants. However, it is reported that fermented fresh fish is better than live sliced raw fish in shape and taste. It is also reported that, when live fish is kept in a water tank of a restaurant, captured fish will loose vitality much faster than farmed fish and that, accordingly, the taste of the flesh will quickly deteriorate. Therefore, it is necessary to properly inform consumers who favour captured fish and to adjust their perception of aquaculture products. Besides, if distribution systems are improved to deliver fresh fish to households through a cold chain, new demand will be created. Furthermore, in order to secure consumers' trust in the safety of aquaculture products, a traceability system informing about the supply of feed and drugs from the farm to the fork needs to be introduced and implemented.

In Korea, one of the most vulnerable aspects of aquaculture is distribution. The National Federation of Fisheries Cooperatives is in charge of selling seaweeds and some fish. But the sale of most seafood is in the hands of small- and middle-sized distributors. This implies that the base for the consumption of aquaculture products could be expanded if producer associations directly operate sales centres to ensure an equal distribution of the margins along the value chain. A key requisite for high-grade marine products is freshness and safety. To ensure these, live fish distribution facilities need to be modernized and amplified and value added products should be developed to satisfy the tastes of various consumers.

In the framework of international free trade, Korean marine products cannot and shall not cater only to the domestic market but expand to other markets. This implies the collection of information about aquaculture technologies in neighbouring countries which have similar cultural, geographical and environmental conditions. For the future, Korean aquaculture shall be internationally competitive. Trends in foreign markets need to be understood, the competition structure of related industries analyzed and international comparison be made. Comprehensive analysis shall include all aspects of aquaculture, from the seedling production industry, feeds industry, test research and development, consumption patterns to food cultures.

Aquaculture farms could also be converted to locations where fishery, ecology and leisure can be experienced so that aquaculture farmers may also earn income from other than the farming. Enclosing net farms shall integrate recreational fishing sites. Private insurances for aquaculture product hazards shall be urgently introduced so that compensations for damages from typhoon, red tide, disease and other natural disasters can be covered.

Conclusions

This paper aims to analyze the role and the current state of aquaculture in Korea and suggests comprehensive countermeasures to efficiently overcome domestic and foreign challenges. Three sides of the Korean peninsula are surrounded by 380 000 km^2 of sea and capture fishery and aquaculture is considered an important food industry, along with agriculture. It is not sure if the Korean aquaculture industry will develop into a sustainable environment-friendly industry due to the eutrophicated coasts, high levels of pollution caused by aquaculture farm effluents and international pressure to open the domestic market.

In order for aquaculture to overcome current challenges and to develop into a prosperous and sustainable industry, aquaculture management needs to be stabilized through appropriate production methods and technologies. To achieve this, aquaculture production site development shall take environment issues into consideration. Aquatic organisms, if appropriately managed within the carrying capacity of the environment, will be a sustainable renewable food resource. The productivity of marine resources can be also enhanced if appropriate surroundings are created and maintained through research. Korea will have a comparative advantage over neighbouring countries and other producers around the world when varieties are improved and diffused, new aquaculture technologies developed, information on international trends is collected and analyzed, and the potential is nurtured to meet the world's rapidly changing conditions.

Lastly, aquaculture shall be continuously developed and fostered from a future-oriented and strategic perspective, not simply from a short-sighted economic one, as farmed aquatic products are a dispensable resource in the future.

Chapter 7

Spain: National plans for the promotion and development of marine aquaculture

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Abstract

The aim of a Marine Farming National Plan is to promote and develop marine aquaculture to achieve specific objectives of interest for a significant part of the country. These objectives can be related to research, development, innovation or any other activity and their achievement is considered to be important for Spanish aquaculture.

Since 1988, a total of 107 National Plans have been developed, 17 of which are currently being implemented. These initiatives aimed mainly at the inclusion of new species and at the technical improvement of production conditions. In recent years a greater effort has been made on matters related to environmental and health impacts, analytical methodologies, product quality, technologies, and production management and planning.

The results of these National Plans have contributed to (i) the improvement of competitiveness through the optimisation of production systems and the incorporation of new technologies; (ii) to the stimulus of research activity; (iii) to the integration of results into administrative proceedings and (iv) to the generation of knowledge on environmental impacts of aquaculture.

Introduction

A National Plan is an operation aimed at harmoniously promoting and developing marine aquaculture within the national territory. It is oriented to achieve specific objectives of interest for all aquaculture stakeholders. The focus of a National Plan can be within the scope of research, development, innovation or in any other aquaculture activity whose implementation is considered to be important for the harmonious development of that activity in Spain.

The National Plans were created by the Law 23/1984 on Marine Farming, in which Article 25 states that the Ministry of Agriculture, Fisheries and Food (currently the Ministry of the Environment and Rural and Marine Affairs) draws up the National Plans of Marine Farming by common consent with the Autonomous Communities involved and gives due consideration to the necessary financial resources required for their implementation. The Autonomous Communities implement the said plans within the scope and powers of their statutes. To assess the fulfilment of the National Plans, the Government, via the National Advisory Board for Marine Farming (JACUMAR), gathers all information deemed to be required from the Autonomous Communities.

Description

Operation

The National Plans are identified and approved by JACUMAR. The go-ahead for any Plan is dependent upon the existence of a common interest between several Autonomous Communities. A priority selection criterion is the participation of a minimum of three Autonomous Communities. In assessing projects, advice is taken from the National Agency for Evaluation and Foresight (ANEP).

Once a Plan has been approved, a Working Group is created for its development and teams are assigned to tackle the various tasks. The groups can be involved in research or other activities and are from universities, research bodies or private companies. Each Autonomous Community is responsible for the financial management of the budg*et al.* located to it.

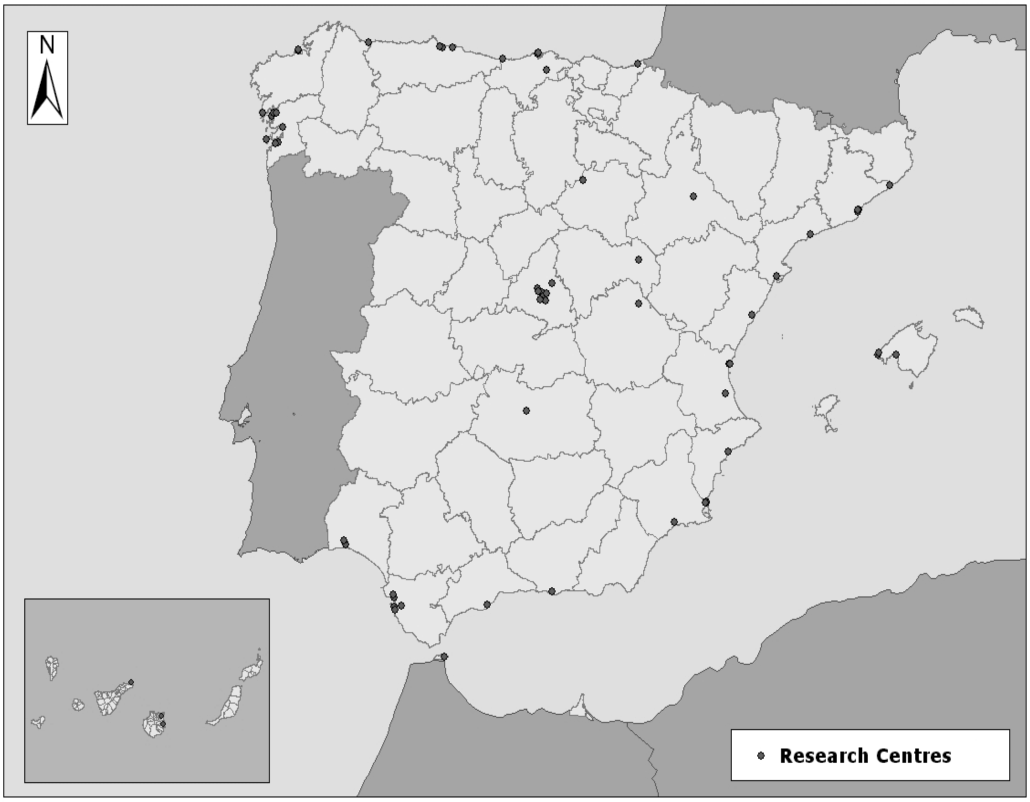
There is a Follow-up Group which assesses a Plan’s results by analysing the Annual Implementation Reports and the Final Reports. This group consists of a representative for each Autonomous Community and of staff from the Secretariat of the National Advisory Board for Marine Farming.

Participants

Since their implementation, ten of the twelve coastal Autonomous Communities have participated in the National Plans. Andalusia, Catalonia and Galicia, through their Research Centres, have participated in the most.

Fifty six Research Centres have participated in the National Plans (see Figure 7.1).

Figure 7.1: Distribution of research centres participating in the National Plans



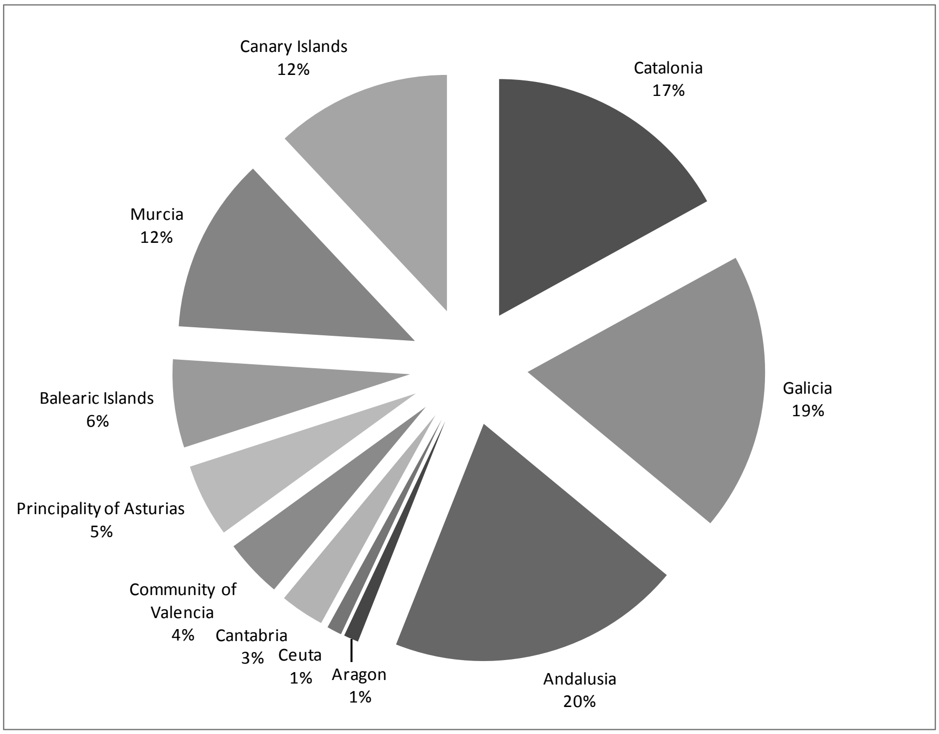
Source: JACUMAR

More than 40 companies have participated in the development of the National Plans. The projects developed by the Autonomous Communities of Andalusia, Valencia and Galicia have had the largest participation by companies.

Budget distribution

Since its creation in 1988, JACUMAR has allocated EUR 32.37 million for the financing of National Plans - an annual average of nearly EUR 1.5 million. The Autonomous Communities of Andalusia, Galicia and Catalonia have received the greatest financial support since 1988, as shown in Figure 7.2.

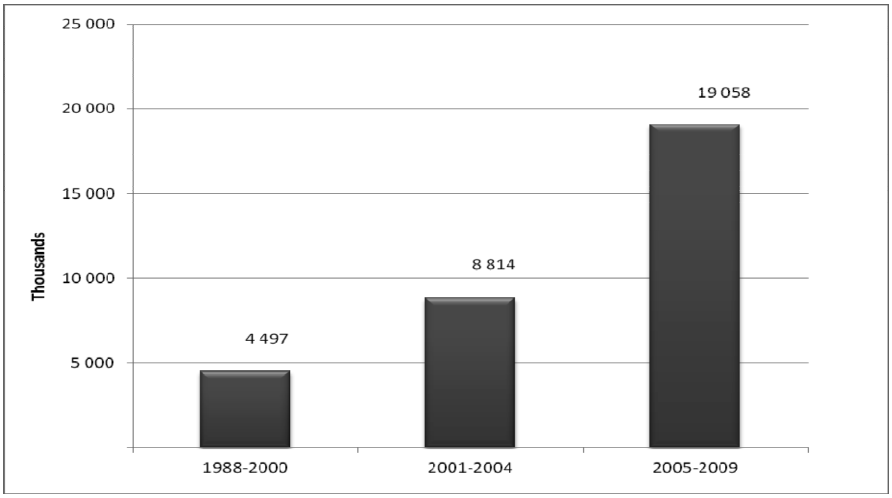
Figure 7.2: Proportion transferred to each Autonomous Community



Source: JACUMAR

The period 2005-2009 had the largest budget (EUR 19.06 million) allocated for the development of National Plans, as indicated in Figure 7.3. This is an increase of 53.75% over the previous period.

Figure 7.3: Economic analysis of 1988-2009 National Plans (total budget per period)



Source: JACUMAR

One of the operations carried out to improve the development of National Plans has been the establishment of some Strategic Lines of Action. Their objective is to enhance the implementation and transfer of the knowledge derived from the Plans to the various players in the sector. These Strategic Lines are:

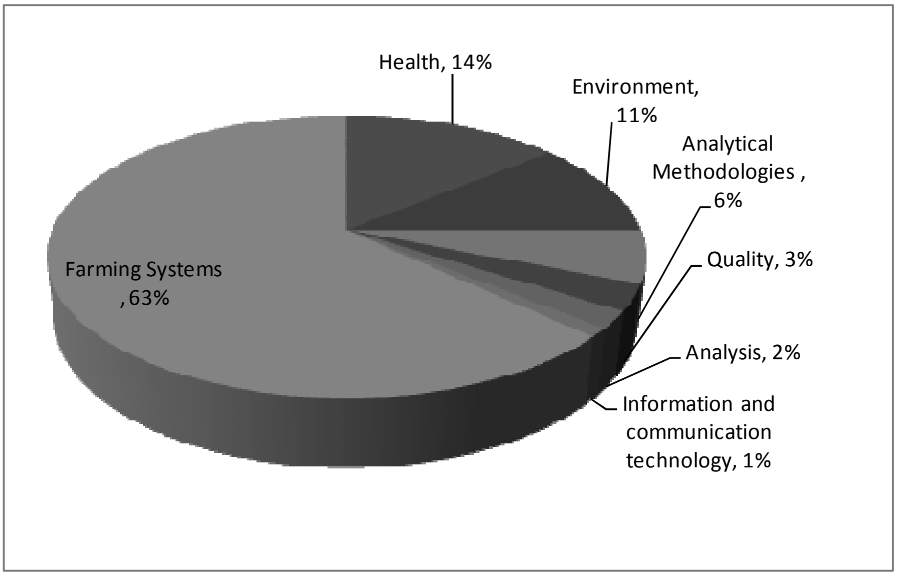
- The incorporation of new species;
- The optimisation of production conditions;
- The environmental management of aquaculture;
- Quality and security of aquaculture products and
- Health aspects of producing aquaculture.

Budget location in relation to the Strategic Line of the National Plans has varied in each period. In 1988-2000 the budget was largely allocated to incorporate new species. However, in 2001-2004 and 2005-2010 the Strategic Line with greatest financial support was for the optimization of production conditions, through the progressive increase of resources allocated to the study of environmental aspects and food quality and security.

Principal subjects and species studied

The principal subject of the National Plans has been: Farming Systems, with a special interest in system optimisation and improvement, the viability of new farming techniques and the introduction of new species. Other subjects have also been covered, such as: aspects of health and environment, analytical methodologies, product quality, the search for suitable areas in which to develop the activity and the use of information technology tools. Figure 7.4 shows the percentage of National Plans developed per subject.

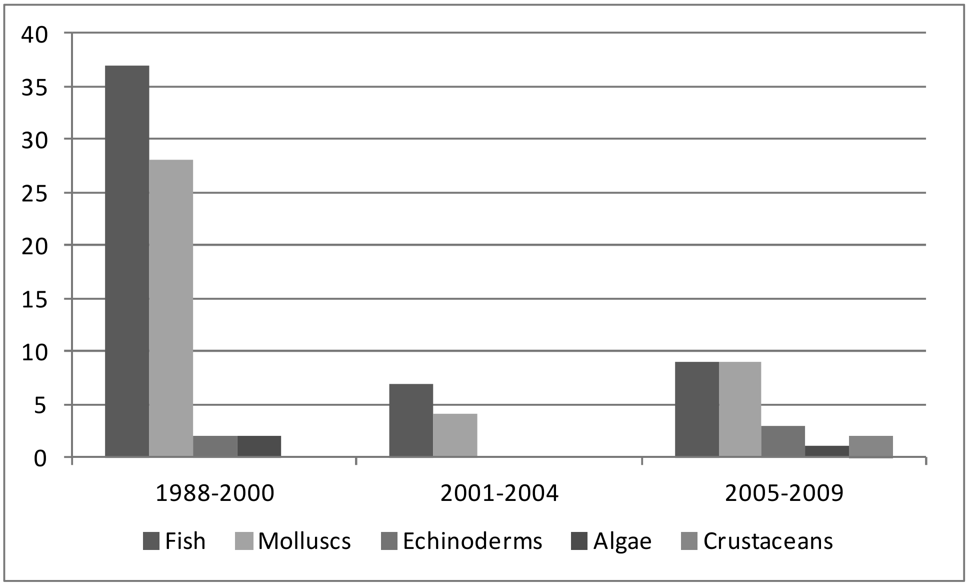
Figure 7.4: Percentage of National Plans developed per subject



Source: JACUMAR

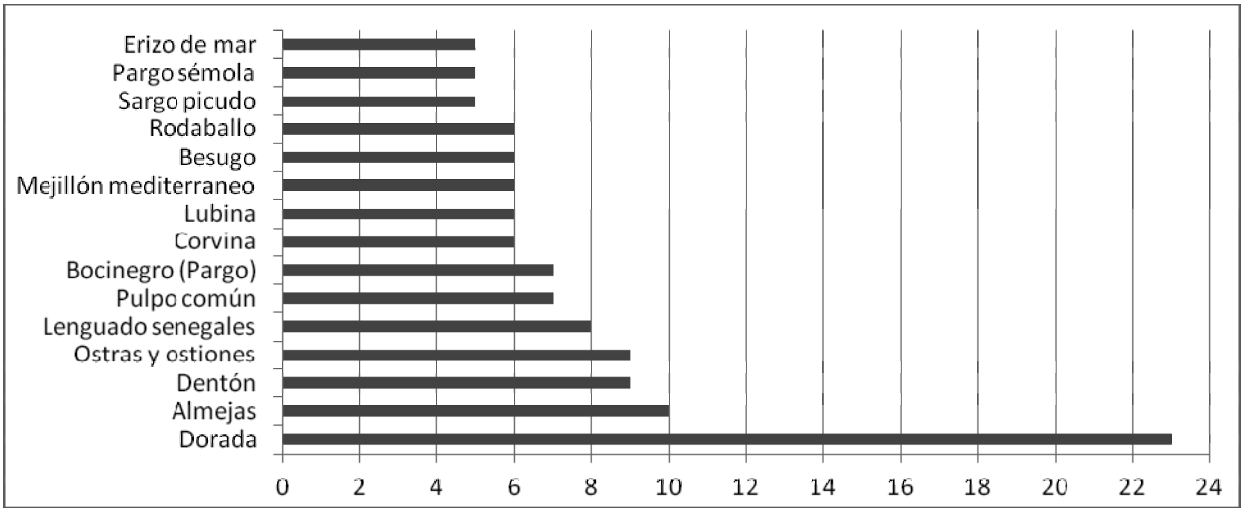
Fish is the most studied group of species, followed by molluscs. Within fish the most studied family is that of *Sparidae,* in particular sea bream (*Sparus aurata*), followed by dentex (*Dentex dentex*). Senegalese sole (*Solea senegalensis*) is another highly studied specie. The most studied molluscs are oyster (*Ostrea edulis*) and clams. Figure 7.5 shows the number of National Plans addressing the study of each species in each period. The number of Plans which include the most studied species is shown in Figure 7.6.

Figure 7.5: Number of plans per species group per period



Source: JACUMAR

Figure 7.6: Number of National Plans which include the most studied species

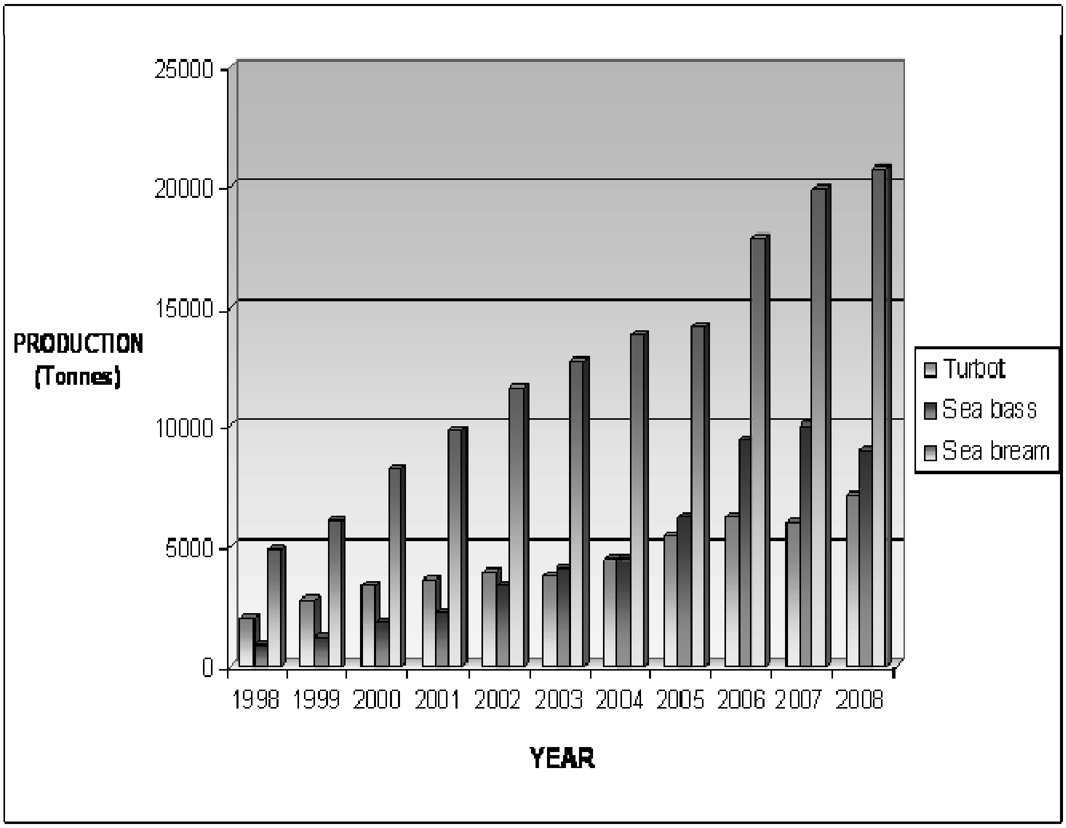


Source: JACUMAR

During the early years National Plans focused on the study of one species only, however, in recent years it has become common to study several species in one National Plan. During the period 1988-2000 the National Plans served to promote the farming of species which are now considered to be well established in Spanish aquaculture: sea bream (*Sparus aurata*), sea bass (*Dicentrarchus labrax*) and turbot (*Psetta maxima*) (Figure 7.7).

The results achieved in the National Plans have contributed to boosting the farming of species which are currently in a consolidation process, such as meagre (*Argyrosomus regius*), Senegalese sole (*Solea senegalensis*), red sea bream (*Pagellus bogaraveo*) or common octopus (*Octopus Vulgaris*).

Figure 7.7: Production evolution of sea bream, sea bass and turbot, 1998-2008



Source: JACUMAR

National Plans under development

Since 1988 a total of 107 Plans have been developed, over four periods and with different implementation systems. To date, there are 17 National Plans under development which, according to the Strategic Line of Action, are the following:

Incorporation of new species

- Breeding of spider crab (*Maja sp.*) - [Start: 2006 – End: 2010]

This project develops an integrated farming process for captive spider crab and evaluates its possible restocking in the Mediterranean.

Optimisation of production conditions

- Farming and management of stony sea urchin *(Paraentrotus lividus) -* [Start: 2005 – End: 2010]

This Plan develops the farming of stony sea urchins to harvest juveniles and analyses the situation of the resource, its management and degree of exploitation in order to develop appropriate management protocols and methods for sustainable production.

- Optimisation of farming and dandling of the stony sea urchin *(Paracentrotus lividus)* - [Start: 2010 – End: 2013]

This project includes bio-energetic studies, the preparation of animal foods extruded for the pre-fattening of juveniles and adults, sensorial analysis, financial studies on the viability of farming, and studies to determine the relevance of marine toxins for food safety and the exploitation of the stony sea urchin.

- Hatchery farming of new species of bivalve molluscs - [Start: 2006 – End: 2010]

This Plan includes the following objectives: the production of bivalve seeds for commercial interests,; a study on the adaptation of adults and larval farming; post-larval farming and on feeding at the various stages of hatchery farming; a study on seed farming systems in both controlled facilities and the natural environment; the treatment of pathological problems for breeding bivalves and of the various farming stages; the development of an appropriate protocol for each species for seed reproduction in hatcheries and its adaptation to the natural environment.

- Farming of mytilids: spreading and sustainability - [Start: 2006 – End: 2010]

This project analyses the possibilities of open-sea mussel platform farming, assesses the economic impact of toxin control methods and determines the technical and economic viability of farming.

- Optimising the fattening of the common octopus *(Octopus vulgaris) -* [Start: 2007 – End: 2010]

The objectives of this Plan are: to obtain animal foods with the required texture for handling and consumption and with an optimum nutrient composition for fattening; to evaluate the efficacy of artificial diets by carrying out fattening tests in different systems; and to carry out restocking experiments.

- Nutrition and feeding of the common octopus *(Octopus vulgaris)* paralarvae and sub-adults - [Start: 2010 – End: 2013]

This Plan seeks to determine the best farming system for the common octopus paralarvae and analyses the nutrition, feeding, histology and enzymology procedures of farmed preys and paralarvae. It also aims to develop animal foods that can be commercially produced with satisfactory productivity yields.

- Integrated aquaculture: pilot experiment for the development of multitrophic farming systems - [Start: 2007 – End: 2011]

This Plan evaluates the implementation of integrated multitrophic farming systems in Spain by means of a technical-scientific follow-up on farmed stocks to evaluate their growth and quality; and an environmental follow-up of the natural environment using indicating parameters will analyse the possible impact.

- Optimisation of intensive farming of clams and identification of genetic markers for the follow-up of restocks (*Ruditapes decussatus, Venerupis pullastra, Ruditapes philippinarum*) - [Start: 2008 – End: 2010]

This Plan optimises the intensive farming of these species by determining the quality criteria of egg-lays, carrying out feeding tests on larvae and identifying the micro-biotic flora associated with mortalities. Restock follow-up is carried out by identifying genetic markers, the genetic characterisation of natural stocks, and comparing the genetic viability of natural stocks and of the seeds from natural progenitors.

- Development of a pilot programme for the genetic improvement of sea bream *(Sparus aurata)* - [Start: 2009 – End: 2011]

The global objective of this project is to devise a protocol for a methodology making the development of selection outlines for this species feasible and enabling the study of genetic character parameters for commercial use, and the evaluation and management of breeding sea bream under the industry’s conditions.

- A basis for reproduction control and knowledge of the natural Defense system of the Senegalese sole *(Solea Senegalensis)* - [Start: 2009 – End: 2011]

The aim of this Plan is to achieve controlled captive reproduction of farmed Senegalese sole specimens and to determine the farming conditions for optimum immune response and resistance to pathogens in juveniles.

Environmental management of aquaculture

- Treatment of wastewaters in marine farming and land based auxiliary facilities - [Start: 2006 – End: 2010]

This National Plan develops different wastewater treatment and use techniques, it promotes the treatment of sewage water by using biological plant and animal filters and the coarsest effluent solids are converted into usable biological material for commercial use. Integrated farming systems and their handling protocols, which provide profitability to the aquaculture activity, are also implemented.

- Selection of indicators, setting of reference values, design of programmes and of method and measurement protocols for environmental studies on marine aquaculture - [Start: 2008 – End: 2010]

The aim of this project is to establish the basis for the design of aquaculture protocols and environmental follow-up plans and to create a protocol for formulating programmes of environmental observance to make it easier for companies to carry out appropriate environmental studies, and to simplify the environmental management of marine aquaculture by the administrations.

- Proposals and improvements for the design and control of plans for restocking and evaluating the impact of escapes - [Start: 2008 – End: 2010]

This Plan defines the quality of specimens to be released; determines the ideal conditions for their release; develops adaptation techniques; evaluates the existing labels and the feasibility and efficacy of genetic markers; follows-up released specimens; determines the possible effects that the farmed species could have on wild species; and establishes action protocols, preventive and correction measures for escapes. Information campaigns are carried out to gain the collaboration of the fisheries sector.

Food quality and safety of aquaculture products

- Quality characterisation of bred fish - [Start: 2008 – End: 2011]

This project enables the establishment of criteria to define the quality of bred fish, to estimate their nutrient value and sensorial attributes against extractive fished species, to describe the evolution of deterioration following its slaughter and during ice storage until its consumption; and to determine the level of pollutants in bred and extractive fish. Possible changes in commercial presentation are studied, including an evaluation of their acceptance and preservation.

Health aspects related to aquaculture

- Health management of aquaculture - [Start: 2007 – End: 2010]

This Plan includes two projects: “Adaptation to new regulations” and “Characterisation and standardisation of animal health conditions in marine aquaculture”. The aim of the first one is to facilitate the collaboration between players and administrations, to gather information on diseases, to propose criteria to elaborate epidemiological data bases, and to promote consensus on follow-up programmes under the new legal framework. The “Characterisation and Standardisation of animal health conditions in marine aquaculture” project elaborates action strategies for the design of an Epidemiological Observance Network for diseases holding special interest for the appropriate authorities, where the farmed and wild specimen (farmed and other sentinel species) are observed.

- Methodology comparison to determine paralysing toxins in bivalves related to PSP and its application in Spanish aquaculture - [Start: 2007 – End: 2010]

This project compares methods to determine paralysing toxins (PSP) and studies their applicability in follow-up programmes taking into account several factors, such as: speed of analysis, costs, sample preparation, and staff training. It proposes appropriate methodologies and management systems for the control programmes and defines the most appropriate methods for the establishment of observance plans.

Lessons learned

The results of these National Plans are essential for the sustainable development of the activity, since several important conclusions have been drawn from them relating to environmental, economic and social aspects. As a result of these studies direct improvements have been made in the development of the activity, in its interaction with the administrations and with other production sectors. Some of the most remarkable results and conclusions follow.

- Optimisation of production systems:
  - Consolidating open-sea farming systems by promoting operations related to the formulation of recommendations to prevent accidents and the problems associated with them.
  - Reproduction of specific captive species, such as Senegalese sole (*S. Senegalensis*)
  - Control of the whole biological cycle of some specific captive species, such as sea bream (*S. aurata*), sea bass *(D. labrax)* and turbot *(P. maxima).*

- Improvement of research activity:
  - Improvement of communication channels and coordination between multidisciplinary research groups of the various Autonomous Communities to optimise operations, resources and create greater objective coherence.
  - Creation and development of standardised databases, which can be updated and consulted within the network, very useful both to draw conclusions at national level as well as to determine dispersions and synergies between Autonomous Communities.
  - Theoretical design of an Epidemiological Observance Network.
- Contributing to the improvement of environmental aspects related to aquaculture:
  - Development of effective techniques for quantifying the spatial extent of waste.
  - Identification and development of measures and operations to minimise waste and to estimate by-products, enabling the sector to reduce production losses, waste and by-products at origin, thereby directly reducing the purchasing costs of raw and auxiliary materials, production costs and waste/by-product management costs.
  - Preparation and publication of a Guide for Minimising Waste in Aquaculture as a means to raise awareness in the sector and as a direct means to contribute to cost-saving measures and environmental improvements.
  - Gathering of appropriate indicators to monitor the environmental impacts of marine farms and to determine areas suitable for the activity.
  - Development of comparative studies on the ecosystems present in the areas where the activity is developed in order to know their preservation state, to decide the minimum critical distance to locate an aquaculture facility, to provide a more realistic view of the classical methods for evaluating its environmental impact, which are specially important for the conservation of ecosystems sensitive to anthropic disturbances, such as the sea-grass meadows *(Posidonia oceanica and Cymodocea nodosa)*.
  - Improve the quality of the environment through the use of bio-filters and recovering bio-deposits used in soil reclamation or fertilization.
  - Implementation of corrective measures to minimise or mitigate the environmental impact produced by marine farms in floating cages and platforms.
  - Definition of specific tools and criteria to enable administrations with authority over marine farming to uniformly define the environmental

studies required from the sector (that is, uniformity both in the environmental studies prior to the development of the activity, as well as in the surveillance programmes that must be carried out during the development of the activity).

- Improvement of the sector's competitiveness:
  - Better knowledge of optimum farming structures, depending on the needs and oceanographic conditions of each area.
  - Optimisation of new farming technologies (cages, hatcheries, etc.).
  - Creating bio-economic models from theoretical and experimental parameters that indicate the economic viability for the industrial production of species, such as sole.
  - Final consumer tests to determine product acceptance and to determine the sensorial profile of some species.
  - Boost to new business activities (new species, new farming systems, new products and presentations).
  - The involvement of companies in the projects has had an awareness-raising effect in relation to the environmental, economic and social problems created.
  - Improved knowledge on the part of fish farmers on their production yield and level of losses, enabling them to act accordingly.
- Information transfer to the sector:
  - Presentation of papers at conferences, forums, and in reports, etc.
  - Periodical meetings with collaborating companies to share results and experiences.
  - Participation on expert panels by the various administrations with authority over aquaculture and the environment and by the different players or sectors involved in the activity.
  - Open sessions at research centres with the administrations involved, business representatives of the sector, private consultancy firms and other research centres participation.
  - Preparation of protocols and manuals to ensure the uniformity of environmental studies and of environmental observance programmes.
  - Development of standardised protocols for sampling and pathogen diagnosis.
  - Preparation of Good Practice Guidelines on health control

Additional information

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Chapter 8

Turkey: Best practices in aquaculture management and sustainable development

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Abstract

Turkey is a peninsula with a coastal line of 8 333 km and 177 714 km of rivers. Marine and inland waters suitable for fisheries and aquaculture cover approximately 26 million hectares. Official figures indicate that total fishery production in 2008 was 646 310 tonnes, with 152 186 tonnes coming from aquaculture. Aquaculture, although being a very young sector, has been increasing very rapidly, accounting now for 24% of the total Turkish fishery production. Turkey has the third fastest growing aquaculture sector in the world and aquaculture is playing an increasingly important role in the Turkish economy, as fishery products are the only products of animal origin that can be exported to the EU.

However the current distribution of sea farms, most of them located in the Aegean region in enclosed bays or coastal waters where they compete with other activities is considered a constraint and the main problem for the future expansion of the sector. Both the government and the private sector learned lessons after facing serious problems in the last years. After a new Environmental Law entered into force the Ministry of Agriculture and Rural Affairs implemented several actions with other related stakeholder. New marine farming zones were determined and inshore sea farms moved to offshore locations. Turkey is also involved in national and international projects for developing the sector in a sustainable way.

Introduction

Turkey is a peninsula and given the large availability of lakes, dammed lakes, ponds, reservoirs, rivers and springs it has a major potential for aquaculture. With a coastline of 8 333 km and 177 714 km of rivers, the marine and inland water sources suitable for aquaculture are approximately 26 million ha (Table 8.1, Table 8.2). It is known that there are 247 species in the Black Sea, 200 in the Sea of Marmara, 300 in the Aegean Sea and 500 in the Mediterranean. However, only a few species of commercial interest represent almost the 60% of the total Turkish production (Deniz, 2001).

Table 8.1: Marine resources in Turkey

Marine resources	Coastlines (km)	Surface area (ha)
Mediterranean, Aegean Sea, Marmara Sea, and Black Sea	7 144	23 475 000
Istanbul and Dardanelles	1 189	1 133 200
Total	**8 333**	**24 607 200**

Source: MARA

Table 8.2: Freshwater resources in Turkey

Freshwater resources	Number of resources	Surface area (ha)	Length (km)
Natural Lakes	200	900 118	-
Dam Lakes	159	342 377	-
Ponds	750	15 500	-
Rivers	33	-	177 714
Total	**1 142**	**1 261 995**	**177 714**

Source: MARA

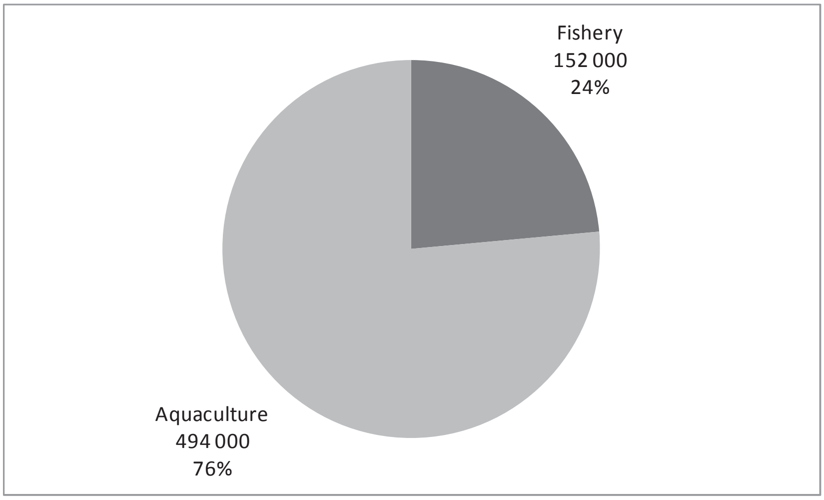
Official figures indicate that total fishery production in 2008 was 646 310 tonnes (Table 8.3), with 436 671 tonnes originating from fisheries and 152 186 tonnes from aquaculture (Deniz and Karasubenli, 2008). The contribution of aquaculture was 24% in terms of volume and 43.7% in terms of value of the total fisheries production in 2008 (Figure 8.1).

Table 8.3: Fishery and aquaculture production in Turkey in the past decade (tonnes)

Year	Inland	Marine	Total aquaculture	Total fisheries production	% of total fisheries production
1999	37 770	25 230	63 000	636 824	9.89
2000	43 385	35 646	79 031	582 376	13.57
2001	37 514	29 730	67 244	594 977	11.30
2002	34 297	26 868	61 165	627 847	9.74
2003	40 217	39 726	79 943	587 715	13.60
2004	44 115	49 895	94 010	644 492	14.59
2005	48 604	69 673	118 277	544 773	21.71
2006	56 694	72.249	128.943	661.991	19.47
2007	59 033	80 840	139 873	772 323	18.11
2008	66 527	85 629	152 186	646 310	24. 00

Source: MARA, 2008

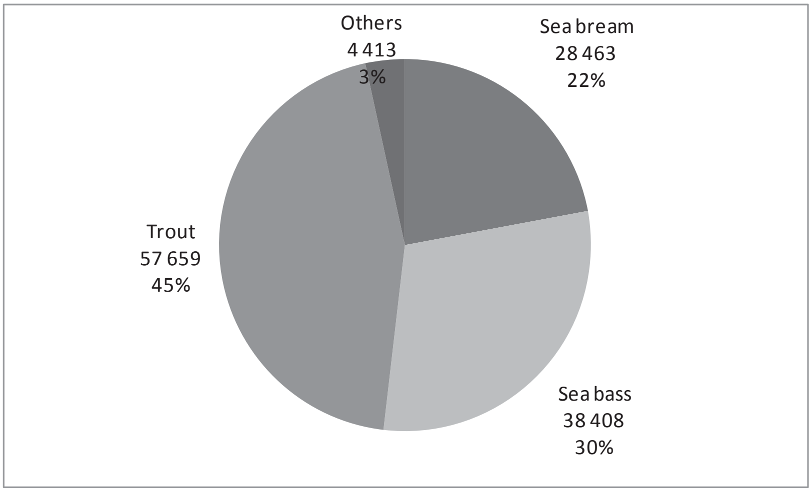
Figure 8.1: Contribution of Turkish fisheries production in 2008 (volume, tonnes)



Source: TURKSTAT

The main developments took place during the 1990s with the rapid increase in sea bass and sea bream production, the development of rainbow trout and sea bass farming in the Black Sea, kuruma shrimp on the Mediterranean coast, mussel in the northern Aegean and Sea of Marmara, and more recently the development of turbot culture in the Black Sea. The sector has developed to such an extent that Turkey is currently the third largest finfish aquaculture producer in the World and the second largest producer of both sea bass and sea bream and of rainbow trout (Figure 8.2).

Figure 8.2: Distribution of aquaculture production by species in 2008 (tonnes)



Aquaculture is an important economic activity in the coastal and rural areas of many countries. It offers opportunities to alleviate poverty, creates employment, helps community development, reduces overexploitation of natural aquatic resources and contributes enhancing food security. For example it is estimated that the aquaculture sector in Turkey provides employment for approximately 25 000 people.

Current average annual per capita fish consumption is very low compared to many European countries, but it is expected that the fast aquaculture development will lead to increases in domestic fish consumption. Annual average per capita fish consumption in the world is about 16 kg while it is only about 8 kg in Turkey. As the average annual per capita fish consumption in the EU is 25 kg, the consumption in Turkey needs to be doubled to reach world average and tripled to reach EU consumption levels (Deniz, 2008).

Aquaculture in Turkey

Aquaculture in Turkey started with carp and trout farming in the 1970s and developed with gilthead sea bream/sea bass farming in the Aegean and Mediterranean seas in the mid 1980s, followed by cage culture of trout in the Black Sea during the 1990s and more recently tuna rearing in the Aegean Sea and the Mediterranean Sea in the early 2000s. The sector has rapidly developed to 1 855 farms with a total capacity of 238 756 tonnes in 2009, thanks to governmental support and technical developments. There are 1 499 inland fish farms with a capacity of 104 629 tonnes and 356 marine farms with a capacity of 134 121 tonnes.

The Euphrates and the Tigris river systems which are within the GAP Region[1] consist of 2 235 km of rivers, 6 481 ha of natural lakes, small lakes and approximately 129 987 ha of dam lake, the construction of which has been completed by the General Directorate of State Hydraulic Works and opened for operation, are suitable for inland aquaculture. There is and increasing need for the development of aquaculture as capture fishery resources become scarcer. Several natural water resources make Turkey an ideal country for aquaculture development (Gozgozoglu, 2002).

The first aquaculture practices in Turkey initiated in inland waters during the 1970s (trout production) and in 1985 for marine fish production. Due to the late start of aquaculture practices compared to other countries and to uninformed practices in the initial stages as well as inadequate follow up of relevant technological development, aquaculture in Turkey has been relatively underdeveloped (Okumus and Deniz, 2007).

The sector has by now developed to such an extent that Turkey is currently the third largest farmed finfish producer in Europe, the largest producer of rainbow trout and the second largest producer of both sea bass and sea bream. The sectors' rapid development has been driven by various factors including relatively high demand for fish, availability of sheltered sites and good water quality, government supports, until recently lose or flexible regulations, high private sector interest in aquaculture investment, rapid development of marine hatchery technology and low labour cost.

Aquaculture is one of the fastest growing industries in Turkey, having grown by over 20% in volume overr the past ten years. During the 1990s production of three major species (rainbow trout, sea bass and bream) increased rapidly until 2000 and then declined during the following two years due to the serious general economic crisis faced by the country in general and has continued to increase again since then.

Table 8.4: Aquaculture of commercially important species: 2004-2008 (tonnes)

Species	2004	2005	2006	2007	2008
Trout	48 082	49 282	57 659	61 173	68 649
Carp	683	571	668	600	629
Sea bream	20 435	27 634	28 463	33 500	31 670
Sea bass	26 297	37 290	38 408	41 900	49 270
Mussel	1513	1 500	1 545	1 100	196
Others	-	2 000	2 200	1 600	1 772
TOTAL	94 010	118 277	128 943	139 873	152 186

Source: MARA

Aquaculture management

Aquaculture Legislation

Article 13 of the Fisheries Law states that those who wish to farm aquatic species for commercial purposes are obliged to apply for a permit at the Ministry of Agriculture and Rural Affairs (MARA), informing the Ministry about the location, characteristics and management of the facilities and the enterprise's project and plans. Permission is issued by MARA if there are no adverse effects in terms of public health, the national economy, navigation or science and technology (Gozgozoglu, 2007).

The provisions of the last paragraph of Article 4 of the Fisheries Law 1380 are also applicable for production units to be established in the sea and inland waters. According to Article 13 of the Fisheries Law, the procedures and principles applying to aquaculture are determined by the Aquaculture Regulation, which was issued in 2004. This regulation was amended in 2007 and 2009 and now includes fish welfare issue.

This regulation covers and sets out rules for the following issues:

- Site selection for inland and marine farms;
- Application and evaluation procedures for fish farming licenses;
- Project approval and license issuing;
- Production capacity improvement, species etc, cancellation, site changes and sales;
- Other aquaculture activities (tuna fattening, organic farming, etc.);
- Import of brood fish, egg and fry;
- Compulsory technical staff employment;
- Fish health management;
- Environmental impacts and protection;
- Monitoring and control of farming activities;
- Fish welfare.

Licensing procedure

The Directorate General of Agricultural Production and Development (DGAPD) of MARA is responsible for aquaculture activities. All aquaculture producers must have an aquaculture license and register with the Aquaculture Department of DGAPD. The details of the application, issuing and cancellation of the aquaculture license are described in the Aquaculture Regulation.

Entrepreneurs or applicants need to submit their applications either to the central office (Aquaculture Department of DGAPD in Ankara) or to Provincial Directorates of MARA with all the relevant supporting documentation - for example a written application with species, capacity and production system clearly mentioned and a map of the area.

Applications for trout, carp, sea bass and sea bream on-growing farms and hatcheries for these species up to two million fry per year capacity can be submitted to the Provincial Directorates, whilst applicants for other on-growing species (namely turbot, sturgeon, eel, algae, molluscs and crustaceans) and trout, carp and sea bass/sea bream hatcheries with an annual capacity of more than two million have to apply directly to the Aquaculture Department in Ankara. A team of experts from the central or provincial office then visits the site and prepares a preliminary survey report. If the report is positive, a preliminary license is issued for eight months and can be extended up to four months. Supporting documentation submitted for the preliminary license must include an application letter, site map, the preliminary survey report and a water quality report.

According to current environmental impact assessment (EIA) legislation those fish farms with annual capacity of less than 30 tonnes do not require an EIA. Fish farms with an annual capacity between 30-1 000 tonnes may require EIA and this is decided upon by EIA commissions in each province. Farms must submit an EIA report if they produce over 1 000 tonnes per year.

The entrepreneur prepares the full project documentation, which includes a farm or hatchery design and feasibility report and an EIA report. Approval is also needed from other related institutions dependent on the nature of the project. If the project is approved the license is issued and issued with a ‘producer certificate’. The licensing process takes about one year. The rental contract period for marine cages sites is for a maximum of 15 years and the contract can be terminated earlier by the government.

Problems encountered by the sector

Compared to agriculture and livestock production, aquaculture is a rather young sector. Its legislations and technical guidelines are changed and updated to adapt to progress and to overcome implementation difficulties.

Problems have been mainly occurred in marine aquaculture on the Aegean and Mediterranean coasts, were sea bass and sea bream farm activities conflict with other sectors, namely tourism, environmental protection, maritime, recreation, etc. Commercial marine aquaculture was started with sea bream and sea bass in closed and sheltered bays by using traditional, small size wooden cages in Mugla City in Turkey in 1985. Marine aquaculture zones were determined by MARA along the coastlines in 1988 and fish farms were relocated to these zones. However, the currently allocated zones are insufficient for the large number of new applications driven by rapid developments of farming techniques; cage technology and fish feed technology. After the new Environmental Law came into force, new aquaculture zones were determined with the consensus of all related institutions according to the Environmental Law and the Notification on Defining Sensitive Enclosed Bays and Gulfs Areas in Coastal Waters where fish farms shall not be set up. After the Environmental Law was put into practice for implementing articles related to fish farms, inshore marine farms were moved to new offshore areas.

With its expansion, the marine aquaculture sector has increasingly to deal with conflicts over space. Insufficient consultation between stakeholder groups hampers the reaching of agreements.

Lessons learned

Up to now, all developments and difficulties encountered by the sector have provided an opportunity to reassess and restructure public policies as well as private action. New regulations entered into force and existing ones were amended to meet EU requirements. For instance, the aquaculture legislation was amended and aligned with EU regulations including fish welfare in 2009. In addition, notifications related to site selection and monitoring for fish farms came into effect in 2007 and 2009 respectively.

The problems encountered by the sector contributed to raise awareness about inadequate sector planning and management aspects. Studies including all stakeholder perspectives have since been commissioned to develop integrated coastal management plans. In this respect, after the introduction of the Environmental Law, new off-shore farming sites were determined by MARA, MEF and other stakeholders and inshore farms were relocated to these sites.

In addition to regulation and planning activities, national and international scientific projects on sustainable aquaculture have been implemented. These projects are:

- FAO Technical Cooperation Project (TCP/TUR 3101) - Developing a Roadmap for Turkish marine aquaculture site selection and zoning using an ecosystem approach to management. This project was implemented in 2009 and has contributed to the preparation of:

  - An agreed strategy (Ecosystem Approach to Aquaculture - EAA) for the development of mariculture;
  - A pilot aquaculture zoning plan;
  - A road map for the implementation of the EAA;
  - Trained farmers;
  - Dissemination of brochures about marine aquaculture and EAA in Turkey.

- National Project on *Determination of environmental impacts of fish farms on the marine ecosystem:* This project has been implemented with MARA, MEF and SUFED since 2007. The aims of the project are:

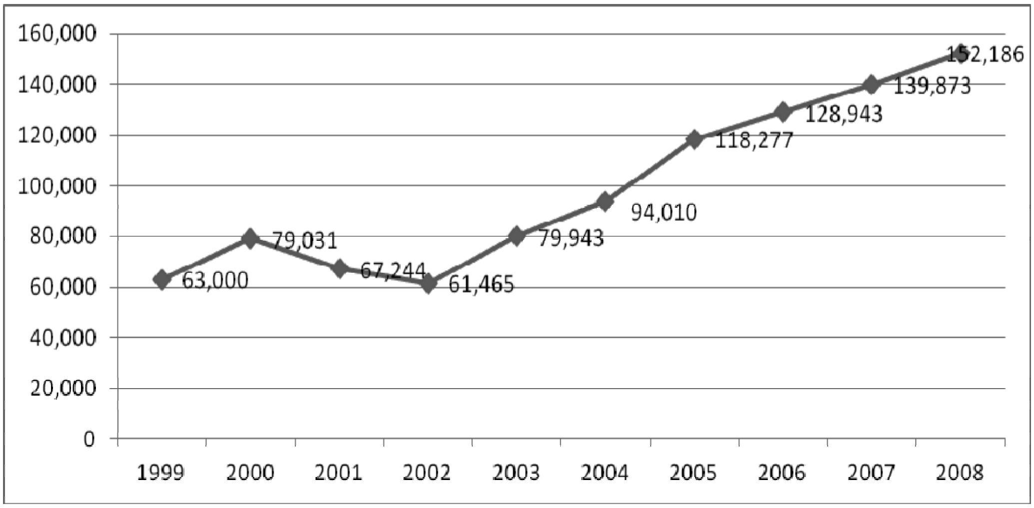
  - To determine the environmental effects of fish farms on marine ecosystems;
  - To develop continuous real time and central control systems;
  - To serve as a pilot study for other similar projects along the coastal regions of Turkey;
  - To demonstrate interactions between sectors.

Conclusions

In 2007 world total fisheries production was 143 billion tonnes, with 36% originating from aquaculture. The proportion of aquaculture in total production has been increasing rapidly. Aquaculture is the fastest growing food production sector in the world in the past decade.

Turkey has great potential for inland and marine aquaculture development. Total fisheries production in 2008 was 646 310 tonnes, with a contribution of 24% from aquaculture in terms of volume and 43.7% in terms of value. In 2009, 1 885 fish farms were producing 238 756 tonnes per year including 1 499 inland fish farms and 356 marine fish farms in Turkey (Figure 8.3):

Figure 8.3: Growing trend of the Turkish aquaculture sector



- Over the last decade, Turkish aquaculture production increased by 237%;
- Turkey now holds a 25% share of the European sea bream and sea bass market;
- Aquaculture accounts for the majority of the Turkish fish production with fish being the only animal product exported into EU countries;
- Turkey is the third fastest growing country in the world in aquaculture;
- Turkey has occupied the first place in trout production among European countries;
- Turkey has occupied the second place in sea bass and sea bream production in the world;
- Approximately 25 000 people are employed in the sector;
- Latest developments in the aquaculture sector place Turkey in an important position, both in the Mediterranean basin and among the EU countries.

Despite these improvements the Turkish aquaculture sector had and has to face serious conflicts over resources with other sectors. Over time, all parties have recognised the importance of integrated coastal plans based on participatory approaches and collective intelligence.

New offshore farming zones have since been established through those plans and critical reallocation of existing farms away from inshore areas took place. Through this, conflict was transformed into opportunities for sustainable aquaculture.

Notes

1 GAP (South Eastern Anatolian Project) is a multi-sectoral and integrated regional development project based on the concept of sustainable development.

References

Deniz, H. (2001), “Environmental impact of aquaculture in Turkey and its relationship to tourism, recreation and sites of special protection”, Proceedings of the seminar of the CIHEAM Network on Technology of Aquaculture in the Mediterranean (TECAM) jointly organized by CIHEAM and FAO, Zaragoza (Spain) 17-21 January 2000, *Cahier Options Méditerranéennes*, Volume 55, pp. 159-173.

Deniz, H. and A.Ç. Karasubenli (2008), *Environmental policies in force and its effect on aquaculture in Turkey*, MED Black Sea ICM 08 (unpublished).

Deniz, H. (2008), “The First Workshop on Developing a Roadmap for Turkish Marine Aquaculture Site Selection and Zoning Using an Ecosystem Approach to Management”, 16-17 July 2008, Izmir, Turkey, 2008.

Gozgozoglu, E. (2003), “The fishery industry in Turkey”, EASTFISH.

Gozgozoglu, E. (2007) *Aquaculture Legislation, Marine Aquaculture* in Candan, A., S. Karatas, H. Kucuktas and I. Okumus, Turkish Marine Research Foundation, Istanbul, Turkey.

Okumus, I. and H. Deniz (2007), “Past, present and future of the marine aquaculture”, Marine aquaculture in Turkey, TUDAV.

Chapter 9

Integrated Multi-Trophic Aquaculture

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Abstract

Fulfilling aquaculture's growth potential requires responsible technologies and practices. Sustainable aquaculture should be ecologically efficient, environmentally benign, product-diversified, profitable and societally beneficial. Integrated multi-trophic aquaculture (IMTA) has the potential to achieve these objectives by cultivating fed species (e.g. finfish fed sustainable commercial diets) with extractive species, which utilize the inorganic (e.g. seaweeds) and organic (e.g. suspension- and deposit-feeders) excess nutrients from aquaculture for their growth. Thus, extractive aquaculture produces valuable biomass, while simultaneously rendering biomitigating services. Through IMTA, some of the food, nutrients and by-products considered "lost" from the fed component are recaptured and converted into harvestable and healthy seafood of commercial value, while biomitigation takes place (partial removal of nutrients and CO2, and supplying of oxygen). In this way, some of the externalities of fed monoculture are internalized, hence increasing the overall sustainability, profitability and resilience of aquaculture farms. A major rethinking is needed regarding the definition of an "aquaculture farm" (reinterpreting the notion of site-lease areas) and regarding how it works within an ecosystem, in the context of a broader framework of Integrated Coastal Zone Management (ICZM). The economic values of the environmental/societal services of extractive species should be recognized and accounted for in the evaluation of the true value of these IMTA components. This would create economic incentives to encourage aquaculturists to further develop and implement IMTA. Seaweeds and invertebrates produced in IMTA systems should be considered as candidates for nutrient/carbon trading credits within the broader context of ecosystem goods and services. Long-term planning/zoning promoting biomitigative solutions, such as IMTA, should become an integral part of coastal regulatory and management frameworks.

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Introduction

The global seafood industry is at a crossroads: as capture fisheries stagnate in volume, they are falling increasingly short of a growing world demand for seafood. It is anticipated that by 2030, there will be a 50-80 million tonne seafood deficit (FAO, 2009). This gap will likely not be filled by capture fisheries but by aquaculture operations, which already supply almost 50% of the seafood consumed worldwide (FAO, 2009). Consequently, it is imperative to design the ecosystem responsible aquaculture practices of tomorrow that maintain the integrity of ecosystems and yet ensure the viability of this sector and its key role in food provision, safety and security.

Without a clear recognition of the industry's large-scale dependency and impact on natural ecosystems and traditional societies, the aquaculture industry is unlikely to either develop to its full potential, continue to supplement ocean fisheries, or obtain societal acceptance. The majority of aquaculture production still originates from relatively sustainable extensive and semi-intensive systems (Tacon *et al.*, 2010); however, the rapid development, throughout the world, of intensive marine fed aquaculture (*e.g.* carnivorous finfish and shrimp), and to a lesser extent some shellfish aquaculture, is associated with concerns about the environmental, economic and social impacts that these, often monospecific, practices can have, especially where activities are highly geographically concentrated or located in suboptimal sites whose assimilative capacity is poorly understood and, consequently, prone to being exceeded.

For many marine aquaculture operations, monoculture is, spatially and managerially, often the norm. Species are cultivated independently in different bays or regions. Consequently, the two different types of aquaculture (fed *versus* extractive) are often geographically separate, rarely balancing each other out at the local or regional scale, and, thus, any potential synergy between the two is lost. In an aquaculture environment with fixed spatial limits (*e.g.* lease boundaries), increased production generally comes at the expense of the natural environment, as the farmer tends to squeeze more and more production into a fixed area. Once the natural system is destabilized, the risk that the entire operation will collapse increases. To avoid pronounced shifts in coastal processes, the solution to nutrification by fed aquaculture is not dilution, but extraction and conversion of the excess nutrients and energy into other commercial crops produced by extractive aquaculture (*e.g.* seaweeds and suspension- and deposit-feeding invertebrates).

To continue to grow, while developing better management practices, the aquaculture sector needs to develop more innovative, responsible, sustainable and profitable technologies and practices, which should be ecologically efficient, environmentally benign, product-diversified and societally beneficial. Maintaining sustainability, not only from an environmental, but also from economic, social and technical perspectives, has become a key issue, increased by the enhanced awareness of more and more demanding consumers regarding quality, traceability and production conditions. Integrated multi-trophic aquaculture (IMTA) has the potential to play a role in reaching these objectives by cultivating fed species (*e.g.* finfish fed sustainable commercial diets) with extractive species, which utilize the inorganic (*e.g.* seaweeds) and organic (*e.g.* suspension- and deposit-feeders) excess nutrients from aquaculture for their growth.

The need for diversification and combining fed and extractive aquaculture into IMTA systems

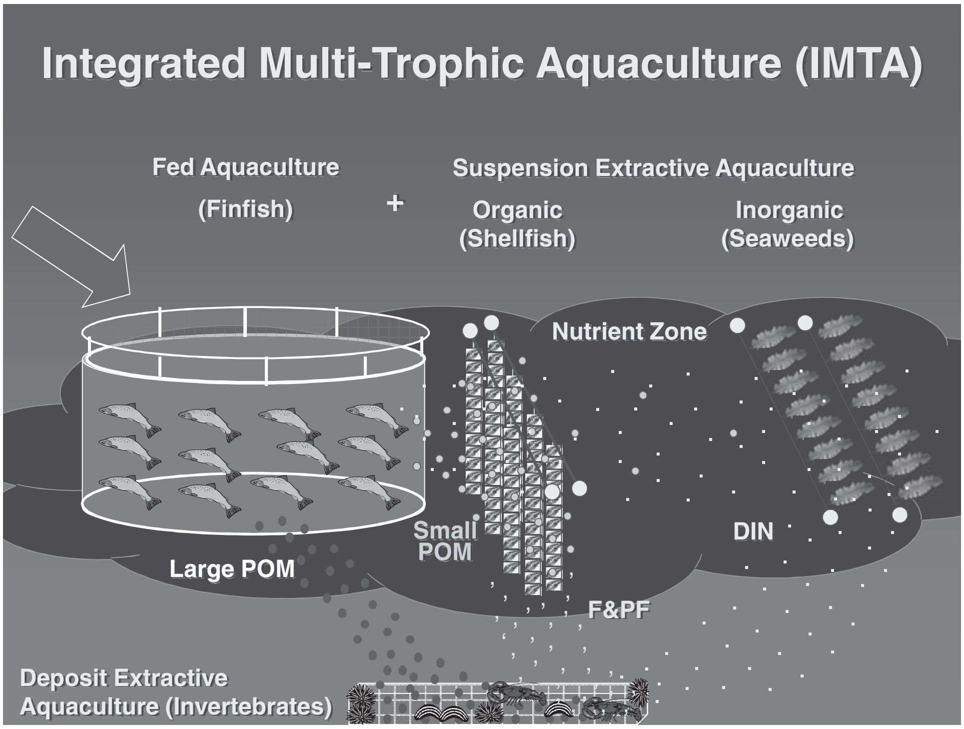
The common old saying "Do not put all your eggs in one basket", which applies to agriculture and many other businesses, should also apply to aquaculture. Having too much production of a single species leaves a business vulnerable to issues of sustainability because of fluctuating prices in what has become commodity markets and potential oversupply, and the possibility of catastrophic destruction of one's only crop (diseases, damaging weather conditions). Consequently, diversification of the aquaculture industry is advisable for reducing the economic risk and maintaining its sustainability and competitiveness.

From an ecological point of view, diversification also means cultivating more than one trophic level, *i.e.* not just cultivating several species of finfish (that would be "polyculture"), but adding into the mix organisms of different and lower trophic levels (*e.g.* seaweeds, shellfish, crustaceans, echinoderms, worms, bacteria, etc.), chosen according to their roles in the ecosystem and their established or potential commercial value, to mimic the functioning of natural ecosystems. Staying at the same ecological trophic level will not address some of the environmental issues because the system will remain unbalanced due to non-diversified resource needs.

It is also important to consider that while some ecosystem goods (*e.g.* fish) generally have a higher market price than other ecosystem goods (potentially making them a more attractive investment), ecosystems are not based on the same principles, but on a balance of biomass between organisms having different complementary functions and a balance of energy flows. Evolving aquaculture practices will require a conceptual shift towards understanding the working of food production systems rather than focusing on technological solutions. In other words, we have to think about how to make the "Blue Revolution" greener and should more appropriately talk of the "Turquoise Revolution"!

One of the innovative solutions promoted for environmental sustainability (biomitigation), economic stability (product diversification and risk reduction) and societal acceptability (improved support for the industry and its differentiated safe products), is IMTA. This practice combines, in appropriate proportions, the cultivation of fed aquaculture species (*e.g.* finfish) with inorganic extractive aquaculture species *(e.g.* seaweeds) and organic extractive aquaculture species (*e.g.* suspension- and deposit-feeding invertebrates) for a balanced ecosystem management approach that takes into consideration site specificity, operational limits, and food safety guidelines and regulations (Figutr 9.1). The aim is to increase long-term sustainability and profitability per cultivation unit (not per species in isolation as is done in monoculture), as the wastes of one crop (fed animals) are converted into fertilizer, food and energy for the other crops (extractive plants and animals), which can, in turn, be marketed. Feed is one of the core operational costs of finfish aquaculture operations, but with IMTA this cost is reduced because some of the food, nutrients and energy considered lost in finfish monoculture are recaptured and converted into crops of commercial value, while biomitigation takes place. In this way all the cultivation components have a commercial value, as well as a key role in recycling processes and rendering services. The harvesting of the different types of crops participates in the capture and export of nutrients outside of the coastal ecosystem. The biomass and functions of the fed and extractive species naturally present in the ecosystem in which aquaculture farms are operating must also be accounted for or this will lead to the development of erroneous carrying capacity models. For example, the 158 811 tonnes (fresh weight) of the intertidal seaweed, *Ascophyllum nodosum* (rockweed), in proximity to salmon aquaculture operations in southwest New Brunswick, Canada, are not neutral in the ecosystem and represent a significant coastal nutrient scrubber which should be taken into consideration to understand the functioning of that part of the Bay of Fundy.

Figure 9.1: Conceptual diagram of an integrated multi-trophic aquaculture (IMTA) operation*



*Including the combination of fed aquaculture (e.g. finfish) with suspension organic extractive aquaculture (e.g. shellfish), taking advantage of the enrichment in small particulate organic matter (POM), inorganic extractive aquaculture (e.g. seaweeds), taking advantage of the enrichment in dissolved inorganic nutrients (DIN), and deposit organic extractive aquaculture (e.g. echinoids, holothuroids and polychaetees), taking advantage of the enrichment in large particulate organic matter (POM) and faeces and pseudo-faeces 9F&PF) from suspension-feeding organisms. The biotrubation on the bottom also regenerates som DIN, which becomes available to the seaweeds.

The IMTA concept is extremely flexible (Chopin, 2006). To use a musicology analogy, IMTA is the central/overarching theme on which many variations can be developed according to the environmental, biological, physical, chemical, societal and economic conditions prevailing in parts of the world where the IMTA systems are operating. It can be applied to open-water or land-based systems, and marine or freshwater systems (sometimes called "aquaponics" or "partitioned aquaculture").

What is important is that the appropriate organisms are chosen at multiple trophic levels based on the complementary functions they have in the ecosystem, as well as for their economic value or potential. In fact, IMTA is doing nothing other than recreating a simplified, cultivated ecosystem in balance with its surroundings instead of introducing a biomass of a single type one thinks can be cultivated in isolation from everything else. Integration should be understood as cultivation in proximity, not considering absolute distances but connectivity in terms of ecosystemic functionalities. It should be made clear that in the minds of those who created the acronym "IMTA", it was never conceived to be viewed with the minimalist perspective of only the cultivation of salmon (*Salmo salar*), kelps (*Saccharina latissima* and *Alaria esculenta*) and blue mussels (*Mytilus edulis*) within a few hundred meters: this is only one of the variations and the IMTA concept can be extended within very large systems like the Yellow Sea (see below).

The paradox is that IMTA is not a new concept. Asian countries, which provide more than two thirds of the world's aquaculture production, have been practicing IMTA (often described as a type of "polyculture") for centuries, through trial and error and experimentation. Why, then, is this common-sense solution not more widely implemented, especially in the western world? The reasons for this generally center around social customs and practices, and market driven economic models not considering externalities, that we are already familiar with, even if common sense tells us that we should modify them. Human society does not change quickly unless there are compelling reasons to do so. The fact that we are currently at a crossroad should motivate us to improve current aquaculture practices, without further delay. Moreover, if Asian cultures are accustomed to the concept of considering wastes from farming practices as resources for other crops rather than pollutants, this attitude still has a long way to progress in the western world where aquaculture is a more recent development.

Western countries are regularly reinventing the wheel. Research on integrated methods for treating wastes from modern mariculture systems was initiated in the 1970s (Ryther *et al.*, 1975, 1978). After that period, the scientific interest in integrated aquaculture/ecological aquaculture stagnated, and it was not until the 1980s and 1990s that a renewed interest emerged, based on the common-sense approach that the solution to nutrification is not dilution but extraction and conversion through diversification within an ecosystem-based management perspective (Indergaard and Jensen, 1983; Costa-Pierce *et al.*, 1988; Neori *et al.*, 1991; Edwards, 1993; Chopin, 1995; Buschmann *et al.*, 1996; Troell *et al.*, 1997; Costa-Pierce, 2002). The term "IMTA" was first coined at a workshop in Saint John, New Brunswick, Canada, in March 2004, when Jack Taylor and Thierry Chopin combined "multi-trophic aquaculture" and "integrated aquaculture" into "integrated multi-trophic aquaculture".

This interest has likely been an indirect result of the increased demand for aquaculture products. This increase has in turn, resulted in intensified cultures, a decrease in available habitat (space available for cage sites/aquaculture leases), and increased environmental impacts on the immediate ecosystem. IMTA is potentially a method whereby production can be intensified, diversified and yet be environmentally responsible, thereby ensuring a sustainable aquaculture industry. Multi-trophic integration appears to be one logical next step in the evolution of aquaculture.

The trend in the global recognition of the need for more advanced ecosystem-based aquaculture systems began to show up in the scientific world through the aquaculture conference circuit. For example, in recognition of this growing interest, the Aquaculture Europe 2003 Conference in Trondheim, Norway, whose theme was "Beyond Monoculture. New Multitrophic Systems – Potential and Constraints", was the first large international meeting (389 participants from 41 countries) with what would become known as IMTA as the main topic. In 2006, at the joint European Aquaculture Society and World Aquaculture Society Conference in Florence, Italy, IMTA was recognized as a serious research priority and option to consider for the future development of aquaculture practices. In 2010, IMTA was the topic of a full day session (17 presenters from 12 countries) during the first day of the World Aquaculture Society meeting in San Diego, California USA. To date, the term "IMTA" has been used in more than 100 scientific publications. The determination to develop IMTA systems will, however, only come about if there are some visionary changes in political, social, and economic reasoning. This will be accomplished by seeking sustainability, long-term profitability and responsible management of coastal waters. It will also necessitate a change in consumers' attitudes towards eating products cultured in the marine environment in the same way that they accept eating products from recycling and organic production systems on land, for which they are willing to pay a higher price for the perceived quality or ethical premiums. The differentiation of IMTA products through eco-labelling will be key for their recognition and command of premium market prices.

IMTA, while not being the panacea to and for everything, is, however, one of the improvement options

IMTA has never been portrayed as the solution to and for everything! For example, IMTA does not address the issues of escapees from open-water fish farms. It is, of course, in the interest of everybody, especially the industry (to not lose money) to reduce the number of escapees. This is, however, a question of engineering of the rearing systems (cages, netting material, etc.) and the suitability of the environment to survival should escapes occur. To solve the escapee issue, it has been suggested that fish farms should be pulled from the open water and placed on land or in closed containment. Moving on land is, however, not a guarantee for zero escapees. There are well-known escapee cases from land-based operations, with serious consequences. For example, the bighead carp (*Hypophthalmichthys nobilis*) and the silver carp (*Hypophthalmichthys molitrix*) were brought from Asia to the southern USA in the 1970s to help control algal proliferation in channel catfish (*Ictalurus punctatus*) farms. There are reports of escapees into the lower Mississippi River system, especially associated with flood episodes in the early 1990s. Self-sustaining populations have been able to move northward to enter the Upper Mississippi River system and the Illinois River system. Presently, there are fears that these fish could enter the Great Lakes system through the Chicago Sanitary and Ship Canal and the Des Plaines River to finally reach Lake Michigan, after an escape of around 2000 km in approximately 20-30 years. Electric fish barriers have been put in place, but their efficiency has been questioned. The use of rotenone, a biodegradable piscicide, was authorized but seemed to have killed more common carps (*Cyprinus carpio*; itself an introduced species from Europe in the 1830s) than bighead and silver carps. On April 26, 2010, the US Supreme Court decided not to get involved in a dispute over how to prevent these carps from making their way into the Great Lakes; it turned down a new request by the State of Michigan to consider ordering permanent closing of the Chicago-area shipping locks. What the impacts on the ecosystems could be, should these fish get into the Great Lakes systems, is unknown, but they are well-known for their ability to consume large amounts of algae and zooplankton, eating as much as 40% of their body weight per day, and they are fierce competitors when it comes to securing their food needs. The silver carp is also a danger to recreational fishers, water-skiers and boaters because of its habit to jump out of the water when startled by boat motors or other noises, creating life-threatening aerial hazards with high speed impacts.

The number of escapees from land-based facilities is not as well documented as with cage-based aquaculture. Perhaps because land-based fish escapes are more likely to occur as a continuous "trickle" instead of a single major event such as a net tear that would lead to "large scale" escapes. However, reports do surface from time to time in the media, particularly if there is some novelty in the story. A recent example is the report of the cultured salmonid brown trout, *Salmo trutta*, escaping from a pond farm in the United Kingdom. A wildlife photographer caught them in action, making large leaps out of the water straight into a metal feed pipe a meter above and connected to a tributary of a river[1]. Ideally, land-based recirculation systems would reduce the potential for escapes. However, most recirculation systems have at least partial water exchange (Timmons *et al.*, 2002) and where there is water exchange and discharge, there is a potential for escapees. These systems are still not widely used and to the authors knowledge there has not been any initiative taken to document escapees, or lack thereof, within these systems. It may, therefore, be premature to classify such systems as "escape proof". It is unlikely that any land-based aquaculture operations could ever be 100% "escapee-proof" and, consequently, they will also need to develop anti-escapee strategies (avoiding flood plains, electric fences, grids of the appropriate mesh, catchment basins, etc.).

Moving to land-based or closed containment operations is one approach that may help address some sustainability issues but is not without its problems. Large amounts of energy, often diesel or electric power, are required to pump and aerate water. Nutrients are either pumped back into the water or settled somewhere and "trucked" off site. All of these processes leave a 'carbon footprint', and only partly solve the issue of excess nutrients. IMTA, or its variations called "aquaponics" or "hydroponics", will have to be added to closed-containment or land-based systems to treat the effluents. One 'impact' may simply be traded for another. Ayer and Tyedmers (2009), in their life cycle assessment of alternative aquaculture technologies, warned that we could be in a case of environmental problem shifting, not solving, where, while reducing local ecological impacts, the increase in material and energy demands may result in significant increased contributions to several environmental impacts of global concern, including global warming, non-renewable resource depletion, and acidification.

Land-based or closed containment operations have also been advocated as a way of controlling diseases and their transmission. However, the proponents very often equate diseases to the sole problem of sea lice, leaving the issues related to viral or bacterial pathogens unaddressed. Some concerns have been expressed that multiple species on the site might increase the risk for disease transmission. It must, however, be realized that sites in the ocean and on land will always have additional unintended species associated with the operation, ranging from micro-organisms to marine mammals, depending on the situation. The question is not whether to have only one species on the site, but at what density do negative interactions occur with the unintended ones and are there any positive interactions associated with more diversified systems? In fact, two studies (Skår and Mortensen, 2007; Robinson, personal communication) have demonstrated in laboratory experiments that the blue mussel, *Mytilus edulis*, is capable of inactivating the infectious salmon anaemia virus (ISAV), as well as the infectious pancreatic necrosis virus (IPNV). Mussels are, consequently, not a likely reservoir host or vector for ISAV and IPNV. Put in an IMTA perspective, this could mean that mussel rafts could be strategically placed to serve as a kind of sanitary/biosecurity cordon around salmon cages to combat certain diseases. Pang *et al.* (2006) also reported reduced total bacteria and *Vibrio* counts in a seaweed-abalone IMTA system.

In regard to parasites, anecdotal information indicates that mussels can consume some of the early larval stages (*nauplius*) in the life cycle of sea lice and several studies, in both Europe and New Zealand, have highlighted the fact that mussels can consume small zooplankton. Since the *nauplius* stage is probably the most dispersive stage due to its size, having a biofilter such as mussels at IMTA sites may decrease the frequency of exposure from outside sources. One of the 14 projects of the recently created Canadian Integrated Multi-Trophic Aquaculture Network (CIMTAN) will investigate the role of bivalves in potentially reducing sea lice populations. Another CIMTAN project is looking into the possibility that mussels could reduce the horizontal transmission of *Loma salmonae*, responsible for microsporidial gill disease of salmon (MGDS), a serious endemic gill disorder in marine netpen reared, and wild, Chinook (and other Pacific) salmon. Trials will examine the proof of principle that blue mussels remove microsporidial spores from water and to what extent these spores retain short-term infectious potential as determined by branchial xenoma expression in test fish.

IMTA is not entering directly the debate regarding the inclusion of fish meal and fish oil in commercial feeds (nor are land-based or closed containment operations). IMTA could, however, provide a partial solution. Modern commercial salmon diets in Canada contain much less fish meal (about 15-25%) and fish oil (about 15-20%) than they did less than ten years ago (40 to 60%). In Atlantic Canada, by-products (trimmings) of wild catch fisheries are used to supply a major portion of the fishmeal ingredients. The feed company Skretting has now produced a salmon feed which includes no marine ingredients. Some eNGOs arguing for fish meal/fish oil replacement have also voiced concerns that, after all, marine fish should eat marine ingredients… Obviously, one cannot have it both ways! Finding replacements for marine ingredients is a priority and there are several large research projects worldwide addressing this issue. Using land plant proteins is not without its impacts. Extra farmland area (more deforestation) would be needed, which, moreover, would need to be irrigated on a planet already suffering from water availability problems. The price of some staple food crops used in traditional agriculture (corn, soya, etc.) would rise considerably due to announced competition for their uses, as recently seen when they were potentially sought out as energy crops for the production of biofuels. Partial substitution with organisms already living in water, such as seaweeds, could, in fact, be a very interesting option. If cultivated in the water column in IMTA systems, there would, moreover, be no issue of raking seaweeds attached to the bottom of the ocean.

It has taken decades to reach current salmon production levels and learn new species husbandry. We are now realizing that we have to rethink the definition of what an "aquaculture site" is, within the broader framework of Integrated Coastal Zone Management (ICZM). Amending regulations to allow such culture will not occur overnight. This should, however, not discourage the finfish industry from practicing IMTA, as even small amounts of co-cultured species production are useful. When the project started on the east coast of Canada, in 2001, there were obviously no IMTA sites in the Bay of Fundy. Nine years later, five out of 96 sites in SW New Brunswick have the combination salmon (or cod)/mussels/kelps and 11 other sites have been amended to develop IMTA. This is a respectable conversion of almost 16% in nine years. Moreover, it would not be reasonable to anticipate an instant conversion, as the industry needs to develop markets to absorb the co-cultured biomass: this also takes time and can only be progressive.

IMTA is slowly gaining recognition and developing in more regions of the globe

Presently, the most advanced IMTA systems in open marine waters and in land-based operations have three components (fish, suspension feeders or grazers such as shellfish, and seaweeds in cages, rafts or floating lines), but they are admittedly simplified systems. More advanced systems will have several other components (*e.g.* crustaceans in mid-water reefs; deposit feeders such as sea cucumbers, sea urchins and polychaetes in bottom cages or suspended trays; and bottom-dwelling fish in bottom cages) to perform either different or similar functions, but for various size ranges of particles, or selected for their presence at different times of the year (different species of seaweeds, for example).

The most advanced IMTA systems, near commercial scale or at commercial scale, can be found in Canada, Chile, South Africa, Israel and China (Chopin *et al.*, 2008; Barrington *et al.*, 2009). On-going research projects related to the development of IMTA are taking place in the United Kingdom (mostly Scotland), Ireland, Spain, Portugal, France, Turkey, Norway, Japan, Korea, Thailand, the USA and Mexico.

What will it take to increase the acceptance and adoption of IMTA as a responsible aquaculture practice of the future?

In order to ensure further development of IMTA systems worldwide, from the experimental concept to the full commercial scale, defining and implementing the appropriate regulatory and policy frameworks and creating the proper financial incentive tools will be required.

Proving the concept at the economic level: establishing the economic value of IMTA systems and their co-products

It is important to ensure that additional co-cultured species increase profit potential. Several IMTA projects throughout the world have now accumulated enough data to support the proof of concept at the biological level. The next step is the scaling up of these experimental systems to reproduce the biological outcomes at a commercial scale, in conjunction with appropriate measures of economic and social potential otherwise required to promote the benefits of IMTA over mono-specific aquaculture.

Initially, open-water IMTA farms require planning and design as a complete system, considering the "integrated" in IMTA rather than clusters of different crops. Optimal design will not only facilitate nutrient recovery, but should also promote augmented growth beyond what would be expected were these species cultured in isolation. In addition to the obvious economic return from increased growth rates from additional species, some less tangible benefits should also be factored in, such as the biomitigating services rendered by the extractive species. Economic analyses need to be inserted in the overall modelling of IMTA systems, especially as they move to commercial scale in coastal communities. It will, then, be possible to compare profitability and economics between IMTA and monocultures. Such models could also explore the savings due to multi-trophic conversion of feed and energy which would otherwise be lost, the pricing and marketing potential of organic and other eco-labels, the reduction of risks through crop diversification and the increase in social acceptability of aquaculture (including food safety, food security and consumer attitudes towards buying sustainable seafood products).

Economic diversification should also mean looking at seafood from a different angle. Research and development on alternative species should no longer be considered R&D on alternative finfish species for food consumption, but rather on alternative marine products. Aquaculture products on the market today are very similar to those from traditional fishery resources, and are thus, often in direct competition. The opportunity exists to diversify from traditional seafood products to a potentially large untapped array of bioactive compounds of marine origin (*e.g.* pharmaceuticals, nutraceuticals, functional foods, cosmeceuticals, botanicals, pigments, agrichemicals and biostimulants, and industry-relevant molecules). The culture of species that might otherwise be inappropriate for food markets fits well within the sustainability and management concept of IMTA. Applications with seaweeds, or seaweed-derived products, remain a field to explore, especially in the western world. It may also be interesting to observe how new seaweed cultivation initiatives in different parts of the world for biofuel production could be an additional driver to adopt IMTA practices.

Putting in place enabling legislation for the commercialization of IMTA products

For IMTA to develop to a commercial scale, appropriate regulatory and policy frameworks need to be put in place. Present aquaculture regulations and policies are often inherited from previous fishery frameworks and reasoning, which have shown their limitations. To develop the aquaculture of tomorrow, the present aquaculture regulations and policies need to be revisited. Adaptive regulations need to be developed by regulators with flexible and innovative minds, who are not afraid to put in place mechanisms that allow the testing of innovative practices at the R&D level, and, if deemed promising, mechanisms that will take these practices all the way to C (commercialization). As the IMTA concept continues to evolve, it is important that all sectors of the industry are aware of the implications of the changes involved, so that they can adapt in a timely and organized manner.

To move research from the "pilot" scale to the "scale up" stage, some current regulations and policies may need to be changed or they will be seen as impediments by industrial partners who will see no incentive in developing IMTA. For example, an earlier version of the Canadian Shellfish Sanitation Program (CSSP) prevented the development of IMTA because of a clause that specified that shellfish could not be grown closer than 125 m of finfish netpens. This paragraph was clearly not written with IMTA in mind, but it seriously impinged its development. After four years (2004-2008), it was amended so that IMTA practices could develop to commercial scale legally, based on recent, reliable and relevant data and information provided by three government departments and the IMTA project on the East coast of Canada. While four years may seem long, it is a relatively short delay considering that regulations and legislations require thorough review with due governmental process involving several federal and provincial departments. This suggests that new aquaculture practices should be accompanied by timely regulatory review to avoid market delays for new products. As governments move to revise current regulatory regimes, it will be necessary to press the importance of accommodating and indeed encouraging new sustainable solutions such as IMTA. IMTA also requires approaching aquaculture development and management with a holistic approach and not one species, or group of species, at a time. We know that this approach has led to many failures in the management of the fisheries; we should be particularly vigilant that the same flaw is not repeated in the management of aquaculture.

Developing commercial and economic models for IMTA systems

It is important to ensure that newly emerging sustainable aquaculture approaches generate net economic benefits for society if they are to be advocated. Assuming that this is true (and preliminary evidence suggests that this is true for IMTA, but research is continuing), the development and promotion of IMTA will be multi-faceted from an economic perspective. Does the IMTA system generate enough additional commercial profits under existing tax and related incentives to be adopted voluntarily by commercial aquaculture operators? What if not? Presumably some adjustments would be needed to bring these tax and related incentives in line with the social desirability of promoting IMTA over conventional aquaculture practices. What sorts of new incentives would be needed and what are the dynamics governing the adoption of new technologies in a concentrated industry such as finfish aquaculture (versus terrestrial small farming agriculture)? These are the sorts of questions that need to be addressed in assessing the economics aspects of IMTA. Research into these questions is just in its infancy. In this section we examine the commercial case for promoting IMTA as distinct from any need for regulatory measures to support its adoption.

A commercial model of integrated salmon-mussel farms was developed by Whitmarsh *et al.* (2006) using baseline data from farms on the west coast of Scotland. The net present value (NPV) of a salmon-mussel IMTA system was greater than the combined NPV of salmon and mussel monocultures, assuming a 20% greater production rate of mussels due to their proximity to fish cages and a discount rate of 8%. Enhanced mussel productivity translated into a measurable financial benefit, recognized as a genuine "economy of integration". Integration was economically profitable if the price of salmon remained constant or dropped by 1% per year; however, a drop of 2% per year would result in a negative NPV for this IMTA system, making it a financially unattractive investment. It should be noted, however, that the aquaculture operation would be non-viable due to the salmon prices rather than the value of the associated species, in this case mussels.

The IMTA project in the Bay of Fundy, Canada, is presently developing an economic model (Ridler *et al.*, 2007). Economic estimates (with risk scenarios) have been undertaken to compare the profitability of a kelp/mussel/salmon IMTA system with salmon monoculture. Profitability (NPV) was estimated by projections over 10 years (5 salmon harvests) using discount rates of 5% and 10%. To take risk into consideration, three scenarios were run, and each scenario was given a probability of occurrence. The optimistic scenario, Scenario 1, has 5 successful salmon harvests with the usual mortality rate of 11% and a probability of occurrence of 20%. Scenario 2 (intermediate, 40% probability of occurrence) has 4 successful salmon harvests and one harvest with a mortality rate of 70%. Pessimistic Scenario 3 (40% probability of occurrence) has 4 successful harvests and there is no fifth harvest as all fish are assumed destroyed. Scenarios 2 and 3 are plausible because of infectious salmon anaemia, other diseases, or winter chill. The NPVs for these scenarios are shown in Table 9.1.

Table 9.1: Scenarios of salmon monoculture versus kelp/mussel/salmon IMTA in the Bay of Fundy, Canada.

Operation	Discount rate	Scenario 1 (optimistic)	Scenario 2 (intermediate)	Scenario 3 (pessimistic)
Salmon monoculture	NPV at 5%	8 146 477	2 664 112	50 848
IMTA	NPV at 5%	8 906 435	3 296 037	674 850
Salmon monoculture	NPV at 10%	6 885 181	2 391 135	-228 345
IMTA	NPV at 10%	7 508 913	3 014 866	403 579

Note: Ten year run net present value (NPV) discounted at 5% and 10% (in USD).

Source: Ridler *et al.*, 2007.

Additional revenues from mussels and seaweeds more than compensate for additional costs, providing higher NPVs for IMTA than for salmon monoculture in all scenarios. Mussels and seaweeds provide alternative uncorrelated sources of income, thereby softening the damaging effect of salmon losses. Even under the pessimistic scenario (3), IMTA provided a positive NPV at both discount rates. Just one bad harvest can have a negative impact on the entire ten year run of a monoculture salmon farm, whereas IMTA effectively reduces the risk. The natural factors that affect salmon mortality may not necessarily affect mussels and kelps. For instance, salmon experience winter chill at -0.8 ˚C, while mussels and kelps can survive much colder temperatures (*e.g.* mussels live in the intertidal zone that can experience drops to -40 ˚C); similarly, kelps are temperate cold water organisms and, in fact, grow mostly between winter and late spring). Therefore, the addition of these co-products can reduce risk (it is unlikely that all three species will be affected simultaneously) and increase the overall sustainability, profitability and resilience of aquaculture farms.

Nobre and collaborators are presently comparing abalone (*Haliotis midae*) monoculture to abalone/seaweed IMTA at a South African farm with an abalone annual production of about 240 tonnes. In the IMTA setting, seawater is recycled and up to 30% of the wild kelp, *Ecklonia maxima*, consumed by abalone is replaced by *Ulva lactuca* grown on site in the recirculation system. The overall commercial gain from using an IMTA approach was estimated at between USD 1.1 and 3.0 million per year, including a significant increase in farm profits (USD 200 000 to 700 000). The environmental benefits included the reduction of nitrogen discharges into adjacent coastal waters by 3.7 to 5.0 tonnes per year, the reduction in harvesting of wild kelp beds by 2.2 to 6.6 hectares per year, and the reduction of CO_2 emissions (reduced pumping needs) by 290 to 350 tonnes per year. The values of the environmental and societal (jobs) benefits by adopting an IMTA design were larger than the gains in farm profitability.

Further development of these economic models and others is proceeding and will help to shed light on the current economic (society) and commercial (industry) attractiveness of IMTA.

Recognising and valuing the biomitigating services rendered by the extractive components of IMTA

The above economic analyses indicate that the outlook for IMTA is promising. It is, however, important to note that these analyses were based solely on the commercial values from the sale of biomass - being of fish, shellfish or seaweeds - and using conservative price estimates for the co-cultivated organisms based on known applications.

One aspect not considered and not factored into the commercial/economic analyses described above, is the fact that the extractive component of an IMTA system not only produces a valuable multi-purpose biomass, but also simultaneously renders waste reduction services to society. Through IMTA, some of the food, nutrients and by-products considered “lost” from the fed component are recaptured and converted into harvestable and healthy seafood of commercial value, while biomitigation takes place (partial removal of nutrients and CO_2, and supplying of oxygen). In this way, some of the externalities of fed monoculture are internalized by extractive co-cultures, thus increasing the overall sustainability, profitability and resilience of aquaculture farms. The economic values of the environmental/societal services of extractive species should, therefore, be recognized and accounted for in the evaluation of the true value of the IMTA components. It is particularly important to recognize that once nutrients have entered coastal ecosystems, there are not many removal options available: the use of extractive species being one of the few realistic and cost-effective options.

Ecosystem services have been ignored until recently (Costanza *et al.*, 1997). To improve the sustainability of anthropogenic nutrient loading practices such as aquaculture, incentives such as Nutrient Trading Credits (NTC) should be established as a means to promote nutrient load reduction or nutrient recovery. During the last few years, there has been much talk and excitement about carbon credits. However, within coastal settings the concerns have largely been with nitrogen, due to the fact that its typical role as the limiting nutrient is not any longer the case in some regions. Potential effects of carbon loading in the marine environment should also be considered. Organic carbon loading below fish farms may promote localized benthic anoxia and, consequently, hydrogen sulfide release. Hydrogen sulfide concentrations (or its proxy, the redox potential) form the basis of environmental regulations of cage-based aquaculture in several jurisdictions. Ocean acidification due to increased dissolved CO_2 levels has also prompted serious new concerns (Feeley *et al.*, 2004). With an appropriate composition of co-cultured species, IMTA has the potential to remove dissolved (inorganic) and solid (organic) forms of nitrogen, carbon, phosphorus (more an issue in freshwater environments), etc., making extractive aquaculture a good candidate for a NTC or other suitable approaches.

Currently, there are few countries with laws or regulations that require aquaculture operations to responsibly internalize their environmental costs, such as nutrient discharges. There are some precedents, such as where land-based trout farmers in Denmark are allowed to increase their feed quota with documented evidence of reduced effluent discharge (Thomsen, 2006), but such incentives are not widely spread. In most jurisdictions, adjacent ecosystems are left to accommodate the nutrient load, and performance based standards are used to determine if farms have exceeded their assimilative capacity.

The implementation of regulations resulting in internalization of environment costs by fish farms, without a direct economic compensatory response such as the Danish feed quota increase, could result in a significant reduction in profitability. In land-based systems, it is relatively easy to quantify nutrient load and concentration via comparison between farm inflows and outflows, thereby creating a benchmark for "economic compensation". Such values are practically impossible to empirically measure in an open-water system, "leaky" by definition, and, consequently, so is the practical implementation of such incentives. However, Troell *et al.* (1997) and Chopin *et al.* (2001) demonstrated that by integrating the seaweed, *Gracilaria*, in the dual role of nutrient scrubber and commercial crop (for agar production), with salmon farms in Chile, the environmental costs of waste discharges would be significantly reduced and profitability significantly increased.

Interestingly, the removal of nitrogen could be much more lucrative, by approximately a factor 100, than that of carbon (see example below). The cost of removing nitrogen is not clearly defined, but there are six interesting studies that may help define a range of possible prices for economic evaluation of the NTC concept. Chopin *et al.* (2001) indicated that at some sewage treatment facilities the cost of removing 1 kg of nitrogen varies between USD 3 and USD 38, depending on the technology used and the varying labour costs in different countries. An interesting case to consider is the municipality of Lysekil, in Sweden, which is paying approximately USD 10 per kg removed by the filter-feeding mussel, *Mytilus edulis*, to the farm Nordic Shell Produktion AB (Lindhal *et al.*, 2005, 2009). Ferreira *et al.* (2007, 2009), with the development of the Farm Aquaculture Resource Management (FARM) model, determined a net value of EUR 18-26 billion per year of nutrient eutrophication reduction services provided by shellfish aquaculture in the coastal waters of the European Union. Gren *et al.* (2009) calculated that the cleaning costs of nutrients by mussel farming can be considerably lower than other abatement measures and estimated that mussel farming should be credited between EUR 0.1 and 1.1 billion per year in the Baltic Sea.

Using the information above, and only for illustration purposes, without presuming what the final design of IMTA sites will be in the future, we can make some preliminary calculations for the IMTA project on the East coast of Canada to get an idea of the monetary magnitude of these services. There are presently 96 finfish sites in South West New Brunswick. Because of the Bay Management Area Plan, put in place to create a fallowing period and contain diseases, only 2/3 of the sites (*i.e.* 64 sites) are active in any given year. If each site was designed to have eight seaweed rafts (38 ropes of kelps, 35 m long and supporting a biomass of 15 kg/m), there would be 512 rafts producing 10 214.40 tonnes fresh weight (FW) of seaweeds. With an average of 0.35% nitrogen content in FW kelp tissues, the harvesting of kelps would equate to the removal of 35.75 tonnes of nitrogen from the ecosystem per year. If the nitrogen removal was fixed at USD 10 per kg, this would represent a NTC of USD 357 504; if it was fixed at USD 30 per kg, this would represent a NTC of USD 1 072 512. The same could be applied to another key nutrient, phosphorus. With an average of 0.04% phosphorus content in FW kelp tissues, 4.09 tonnes of phopshorus would be removed per year. With a value of USD 4 per kg removed (Chopin *et al.*, 2001), this would represent another contribution to the NTC of USD 16 343.04, a much smaller amount but it could also be an important way of extracting phosphorus, at a time when some are predicting it to be the next element human society will be short of (in its natural or mined forms).

Carbon Trading Credits (CTC) could also be calculated. There may be some arguments about what is meant by trapping and sequestering carbon. Some may argue that it should be reserved to long/geological term storage (sink) and not to transient storage (Lackner, 2003). This is, in fact, a question of how long one allows the recycling clock to run. There is no permanent storage of carbon; it happened to have been sequestered over geological time to suddenly be reused at an accelerated rate over the last few centuries. But the first law of thermodynamics, as enunciated by Antoine Laurent de Lavoisier more than two centuries ago, still applies: “Rien ne se perd, rien ne se crée, tout se transforme”, *i.e.* “Nothing is lost, nothing is created, everything is transformed”. If even temporary removal of carbon from the ocean until further transformation can be credited for potentially increasing seawater pH and absorbing CO_2 from the atmosphere and/or the cultivated animals, then we can do the following calculations. With an average of 3% carbon content in FW kelp tissues, 306.43 tonnes of carbon would be removed per year. With the value for carbon removal often cited to be around USD 30 per tonne (Lackner, 2003), this would represent a CTC of USD 9 192.96: a large amount of carbon, but for a much smaller financial amount, underlining the difficulty in removing dissolved nutrients from aquatic systems and the acute issue of their presence in coastal systems.

Similar calculations could be applied to the organic extractive component of IMTA. In the case of shellfish, accumulation of nitrogen, phosphorus and carbon should be considered both in meat and shells, especially rich in calcium carbonates.

Moving to a much larger scale, the occurrence of large and recurrent “green tides” should also be brought into focus. Large proliferations of opportunistic green algae, especially of the genus *Ulva*, as a response to large anthropogenic nutrient loading, have been in the news over the last few years in places around the world such as Northern Brittany in France, the southern regions of the United Kingdom, and Venice in Italy. The green tide event that got a lot of attention was the one in

Qingdao, China: as it occurred just before the sailing competitions of the 2008 Olympic Games held there, it was reported on by a lot of foreign journalists. We need to ask ourselves: are these green tides a negative media photo opportunity, or are they reminders of the significant role seaweeds play in coastal processes and the services they render? Within three weeks, 1 million tonnes of *Ulva prolifera* were removed from the vicinity of Qingdao to allow the sailing boats and windsurfs to compete (but it is estimated that approximately 2 million tonnes of *U. prolifera* sank to the bottom of the Bay, another environmental problem shifting, but not a solution). With an average nitrogen content between 0.3% and 0.5% in the tissues and a nitrogen removal cost between USD 10 and USD 30, the harvesting of 1 million tonnes equated to between 3 000 and 5 000 tonnes of nitrogen removal for a NTC value between USD 30 and 150 million! Additional NTCs of USD 1.6 million for the removal of 400 tonnes of phosphorus, and CTC of USD 900 000 for the removal of 30 000 tonnes of carbon should also be factored in. In 2009, there was another green tide event covering at least 17 400 km^2 of the Yellow Sea. We are now beginning to understand this phenomenon (Liu *et al.*, 2009; Pang *et al.*, 2010). As a massive cultivation of the juvenile river crab, *Eriocheir sinensis*, is taking place in Animal Aquaculture Ponds (AAPs) in the province of Jiangsu, south of the province of Shandong where Qingdao is located, large organic fertilizer applications are made periodically in ponds of the green alga *Chlorella*, which is used to feed rotifers, which are then used to feed the river crabs. The AAPs, with very high levels of ammonium and phosphates, are the reservoirs of germlings of *U. prolifera*, which are then discharged along the coast, where they find favorable conditions to bloom and be transported north by the prevailing currents and winds. A smaller green tide occurred in 2007, in 2008 it hit the coast around Qingdao and in 2009 it stayed offshore, but out of sight should not mean out of mind. If urgent measures are not taken, this will be a recurrent event for years to come.

Is there a solution? Green tides are not the cause, but the unintentional consequence of coastal eutrophication. With the presence of sufficient nutrients and solar energy, these opportunistic species, with a well-adapted anatomy, morphology and physiology, will proliferate. Obviously, it would be beneficial to reduce nutrient loading at the source; but this may not be possible in the present context of economic development along the coastal zone of China. The problem is that *U. prolifera* is presently an unwanted and uncontrolled growing nuisance species of limited commercial value. The solution may be to create a competition for nutrients by intentionally cultivating species, which not only carry on the biomitigation, but also have a commercial value, where *U. prolifera* starts to enter the coastal environment in order to control its proliferation. This time, the IMTA concept has to be interpreted as an integrated land pond/coastal aquaculture system in a supra Integrated Coastal Zone Management (ICZM) effort, beyond provincial borders, to address issues at the Yellow Sea scale. We understand that this "out of the box" approach to ICZM will, initially, raise eyebrows as the idea of growing more seaweeds (but of commercial value) to contain the proliferation of other seaweeds, presently considered nuisances, is not the most intuitive approach for a lot of people or decision makers! The question is simple: what are the best nutrient scrubbers once nutrients are in a dissolved state and have reached coastal waters? The answer is seaweeds, but can we, preferably, grow the ones we have applications for?

The development and adoption of technology often depends in part on the level of legislative pressure from a nation's government, itself reacting to pressures from consumers, ENGOs and the public at large. If environmental legislation remains a low priority with government, then little progress toward the use of biofilters (as a means of effluent mitigation) will occur. The only motivator will be profits obtained from additional product growth and regulatory incentives. Therefore, if governments put legislative pressure on the proper management of wastewater effluent, openly support the use of biomitigation for effluent management, and put in place the appropriate corresponding financial tools (funding for IMTA R&D, outreach and technology transfer, and NTC and CTC incentives), then the development of IMTA will be encouraged.

It is also important to note that present aquaculture business models do not consider or recognize the economic value of the biomitigating services provided by biofilters, as there is no cost associated with aquaculture discharges/effluents in land-based or open-water systems. Regulatory and financial incentives may therefore be required to clearly recognize the benefits of the extractive components of IMTA systems (seaweeds and invertebrates). A better estimate of the overall cost/benefits to nature and society of aquaculture waste and its mitigation would create powerful financial and regulatory incentives to governments and the industry to jointly invest in the IMTA approach, as the economic demonstration of its validity would be even more obvious. Moreover, by implementing better management practices, the aquaculture industry should increase its societal acceptability, a variable to which it is very difficult to give a monetary value, but an imperative condition for the development of its full potential. Reducing environmental and economic risk in the long term should also make financing easier to obtain from banking institutions (Brezeski and Newkirk, 1997).

Conclusions

Several IMTA projects, in different parts of the world, have now accumulated enough data to support the proof of concept at the biological level. The next step is the scaling up of more experimental systems to make the demonstration at a commercial scale, and to document the economic and social advantages of the concept, which will be key to offering IMTA to practitioners of monospecific aquaculture as a viable option to their current practices. Underlying this demonstration will be the development of a better understanding of the major ecological interactions involved with IMTA systems. Working on appropriate food safety regulatory and policy frameworks in the respective countries will be essential for enabling the development of commercial scale IMTA operations in a more universal fashion.

We need to rethink how an aquaculture farm works within the broader framework of Integrated Coastal Zone Management (ICZM), where integration can range from the small scale (a leased site with its spatial limits) to the larger scale of a region connected by the functionalities of the ecosystem. Selecting the right combination of species with complementary ecological functions will be critical. They will have to be appropriate for the habitat, the available culture technologies, and the environmental and oceanographic conditions. They will have to be complementary in their ecosystem functions, growing to a significant biomass for efficient biomitigation, commanding an interesting price as raw material or presenting an interesting added-value for their derived products, and their commercialization should not generate insurmountable regulatory hurdles.

Economic analyses need to be undertaken as part of the overall modelling of IMTA systems as they get closer to commercial scale and their economic benefits and costs, as well as impacts on coastal communities, are better understood. It will then be possible to add profitability, resilience, social/economic desirability and economic impacts to the comparison between IMTA and monoculture settings. These models will need to be sufficiently flexible with respect to the most volatile parameters and explicit assumptions so as to allow modelling of IMTA systems that is tailored to the environmental, economic and social conditions of the different regions where they will be installed. They could be modified to estimate the impact of organic and other eco-labellings, the value of biomitigating services for enhanced ecosystem resilience, the savings due to multi-trophic conversion of feed and energy which would otherwise be lost, and the reduction of risks through crop diversification and increased societal acceptability.

Nutrient extractive aquaculture is a viable ecological engineering option for managing the externalities generated by aquaculture operations. Effective government legislation/regulations and incentives to facilitate the development of IMTA practices and the commercialization of IMTA products will be necessary. True recognition of the environmental/economic/societal services of extractive crops would create strong incentives to develop sustainable marine agronomy practices, such as IMTA, in which seaweeds and invertebrates should also be considered as candidates for a variety of regulatory measures that internalize these benefits. For example, nutrient and carbon trading credits could be used to promote nutrient removal, CO_2 sequestration, oxygen provision and coastal eutrophication reduction. Including NTC and CTC in the financial spreadsheets of aquaculture operations would create economic incentives to encourage aquaculturists to further develop and implement IMTA systems and increase the societal acceptability of aquaculture by the general public. Only when these services are properly recognised and valued, will we be able to establish the true value of the extractive components of IMTA so that biomitigative solutions become an integral part of coastal regulatory and management frameworks.

At the present time, we seem to be at the stage of recognition, awareness and communication of the concepts of ecosystem services and biomitigating services rendered by extractive aquaculture (the differences between the two not always being clearly identified and explained in some publications). Next will come the time to transform the concepts into biomitigative solutions and then their inclusion in regulatory and management frameworks. Establishing and implementing a structure for the payment schemes (credits or incentives) of these services will be a delicate matter. Will it be one agency, but with funds coming from where? Should it be a regional, national or international agency(ies), trading at which scale(s)? Will an extractive aquaculture operation in existence for many years receive credits, or will only the new ones? Would a fed aquaculture operation also practicing extractive aquaculture be eligible for credits, or will it be the case for the extractive only aquaculture operations? What about the situation in which people run both types of farms. Moreover, due to complex hydrographic and current patterns, it is obvious that extractive species at a site are not limited to absorbing/sequestering the nutrients generated exclusively at that site. Consequently, is it possible to establish a clear spatial nutrient removal budget which would be associated with the corresponding credits/incentives? Will the sequestration have to be “permanent”, or will a temporary removal/storage be acceptable and more realistic? A lot of regulatory details will have to be worked out before this complex scheme becomes reality.

There is still a large amount of education required to bring society into the mindset of incorporating IMTA into their suite of social values. Some of the attitudinal surveys conducted in Canada (Ridler *et al.*., 2007; Barrington *et al.*., 2010) and the USA (Shuve *et al.*, 2009) indicate that the general public is in favour of practices based on the "recycling concept". Perceptions will have to change. Why is recycling and the concept of “what is waste for some is gold for others” well accepted in agricultural practices, but is not yet acquired when transposed to aquaculture practices? Will a greater appreciation of the sustainable ecological value of the concept, a willingness to support it tangibly with shopping money, and an increased pressure on elected representatives emerge? This will be the ultimate test. The degree to which researchers and extension people become creatively involved with this educational component will be vital to the success of IMTA practices.

For some, the ecological, engineering, economic and social challenges remaining to be solved may be daunting. However, the goal is to develop modern IMTA systems, which are bound to play a major role worldwide in sustainable expansions of the aquaculture operations of tomorrow, within their balanced ecosystem, to respond to a worldwide increasing seafood demand with a new paradigm in the design of the most efficient food production systems. As was the case on land where the acquisition of food by hunter/gatherer societies had to evolve towards agricultural practices, we will have to accept an evolution in our seafood procurement. The agricultural revolution has been associated with significant changes in landscape and land use; we can expect that the “turquoise” (a greener blue!) revolution will also trigger significant “seascape” and “sea use” modifications, all the way to our deepest human social structures and governance. Let us also not forget that we are still in the infancy of modern, intensive aquaculture and that some agricultural practices have taken centuries to develop into better, not necessarily yet best, management practices.

Beyond the biological, environmental, economic, technological, engineering and regulatory issues of aquaculture developments, it will all come down to the basic question of societal acceptance. Are we ready to evolve in our use of the “last frontier” of this planet and consider not only the challenges of the physical forces at sea (wave exposure, winds, currents, depth, etc.) but also those of shipping routes, fishing zones, offshore gas and mineral extraction areas, migration routes for marine mammals, recreational uses, and then finally deal with the concept of zoning some portions of the oceans for large aquaculture parks, as sustainable food production systems for an ever seafood hungrier human population? The same question of readiness for marine spatial planning could also be applied to emerging projects of wind farms and biofuel farms at sea. In fact, combining IMTA open-ocean farms with wind, underwater turbine and/or biofuel farms could be a means for reducing their cumulative footprint. However, if the “Not In My Back Yard” (NIMBY) and the “Build Absolutely Nothing Anywhere Near Anything” (BANANA) attitudes continue to prevail, especially in the western world, then we will not be able to secure our seafood or our energy in an ecosystem responsible manner despite all the rhetoric we can hear today regarding alternative technologies and solutions.

Basically, are we ready to "walk the talk"? Thankfully, as Jules Verne wrote more than 130 years ago, "tout ce qui est impossible reste à accomplir" (*i.e.* "all that is impossible remains to be accomplished")...!

Additional information

- Web site of Thierry Chopin: www.unbsj.ca/sase/biology/chopinlab/
- Web site on IMTA on Wikipedia: www.en.wikipedia.org/wiki/Integrated_Multi-trophic_Aquaculture

Notes

[1] www.telegraph.co.uk/earth/earthnews/3318094/Photographer-captures-trouts-great-escape.html

References

Ayer, N.W. and Tyedmers, P.H. (2009), "Assessing alternative aquaculture technologies: life cycle assessment of salmon culture systems in Canada", *Journal of Cleaner Production* 17: 362-373.

Barrington, K., Chopin, T. and Robinson, S. (2009), "Integrated multi-trophic aquaculture IMTA) in marine temperate waters", in Integrated mariculture: a global review, pp 7-46.

D. Soto (Ed.), *Integrated Mariculture. A global review*, FAO Fisheries and Aquaculture Technical Paper No. 529, FAO, Rome, 183 p.

Barrington, K., Ridler, N., Chopin, T., Robinson, S. and Robinson, B. (2010), "Social aspects of the sustainability of integrated multi-trophic aquaculture', *Aquaculture International* 18: 201-211.

Brzeski, V. and Newkirk, G. (1997), "Integrated coastal food production systems – a review of current literature", *Ocean and Coastal Management* 34: 55-71.

Buschmann, A.H., Troell, M., Kautsky, N. and Kautsky, L. (1996), "Integrated tank cultivation of salmonids and Gracilaria chilensis (Gracilariales, Rhodophyta)", *Hydrobiologia* 326/327: 75-82.

Chopin, T. (1995), "Mixed, integrated, poly-, or multi-level aquaculture - whatever you call it, it is time to put seaweeds around your cages!", In: Proc. Conference on Cold Water Aquaculture to the Year 2000, St. Andrews, Canada, 6-8 September 1995, Aquaculture Association of Canada, Special Publication No. 2 (1997): 110; 117 p.

Chopin, T. (2006), "Integrated Multi-Trophic Aquaculture. What it is and why you should care and don't confuse it with polyculture", *Northern Aquaculture* 12 (4): 4.

Chopin, T., Buschmann, A.H., Halling, C., Troell, M., Kautsky, N., Neori, A., Kraemer, G.P., Zertuche-Gonzalez, J.A., Yarish, C. and Neefus, C. (2001), "Integrating seaweeds into marine aquaculture systems: a key towards sustainability", *Journal of Phycology* 37: 975-986.

Chopin, T., Robinson, S.M.C., Troell, M., Neori, A., Buschmann, A.H. and Fang, J. (2008), "Multitrophic integration for sustainable marine aquaculture: 2463-2475", In: The Encyclopedia of Ecology, Ecological Engineering (Vol.3), S.E. Jørgensen and B.D. Fath (eds.), Elsevier, Oxford.

Costanza, R., d'Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R.V., Paruelo, J., Raskin, R.G., Sutton, P. and van den Belt, M. (1997), "The value of the world's ecosystem services and natural capital", *Nature* 387: 253-260.

Costa-Pierce, B.A., Zainal, S. and Effendi, P. (1988), "ICLARM and south-south technology transfer: Philippine aquaculture technology and Indonesia. Part 1. Naga", *The ICLARM Quarterly* 11: 10-11.

Costa-Pierce, B.A. (2002), *Ecological Aquaculture: The Evolution of the Blue Revolution* Blackwell Science, Oxford, 382 p.

Edwards, P. (1993), "Environmental issues in integrated agriculture-aquaculture and wastewater-fed fish culture systems", In: Environment and Aquaculture in Developing Countries, pp 139-170, R.S.V.

Pullin, H. Rosenthal and J.L. Maclean (eds.), ICLARM Conference Proceedings 31.

FAO (2009), *The State of World Fisheries and Aquaculture 2008*. FAO of the United Nations, Rome, xvi + 176 p.

Feely, R.A., Sabine, C.L., Lee, K., Berelson, W., Kleypas, J., Fabry, V.J. and Miller, F.J. (2004), "Impact of anthropogenic CO2 on the CaCO3 system in the oceans", *Science* 305 (5682): 362-366.

Ferreira, J.G., Hawkins, A.J.S. and Bricker, S.B. (2007), "Management of productivity, environmental effects and profitability of shellfish aquaculture – the Farm Aquaculture Resource Management (FARM) model", *Aquaculture* 264: 160-174.

Ferreira, J.G., Sequeira, A., Hawkins, A.J.S., Newton, A., Nickell, T.D., Pastres, R., Forte, J., Bodoy, A. and Bricker, S.B. (2009), "Analysis of coastal and offshore aquaculture: application of the FARM model to multiple systems and shellfish species", *Aquaculture* 289: 32-41.

Gren, I.M., Lindhal, O. and Lindqvist, M. (2009), "Values of mussel farming for combating eutrophication: an application to the Baltic Sea", *Ecological Engineering* 35: 935-945.

Indergaard, M. and Jensen, A. (1983), "Seaweed biomass production and fish farming", In: Energy from Biomass. Proc. 2nd EC Conference on Biomass, Berlin, September 1982. A. Strub, P. Chartier, and G. Schleser (eds.). Applied Science Publishers, London.

Lackner, K.S. (2003), "A guide to CO2 sequestration", *Science* 300: 1677-1678.

Lindhal, O. and Kolberg, S. (2009), "Can the EU agri-environmental aid program be extended into the coastal zone to combat eutrophication?", *Hydrobiologia* 629: 59-64.

Lindahl, O., Hart, R., Hernroth, B., Kollberg, S., Loo, L.-O., Olrog, L., Rehnstam-Holm, A.-S., Svensson, J., Svensson, S. and Syversen, U. (2005), "Improving marine water quality by mussel farming: a profitable solution for Swedish society", *Ambio* 34: 131-138.

Liu, F., Pang, S.J., Chopin, T., Xu, N., Shan, T.F., Gao, S.Q. and Sun, S. (2009), "The dominant Ulva strain of the 2008 green algal bloom in the Yellow Sea was not detected in the coastal waters of Qingdao in the following winter", J. *Appl. Phycol.* DOI 10.1007/s10811-009-9489-7.

Neori, A., Cohen, I. and Gordin, H. (1991), “Ulva lactuca biofilters for marine fishpond effluents. II. Growth rate, yield and C:N ratio”, *Botanica Marina* 34: 483-489.

Pang, S.J., Xiao, T. and Bao, Y. (2006), “Dynamic changes of total bacteria and Vibrio in an integrated seaweed-abalone culture system”, *Aquaculture* 252: 289-297.

Pang, S.J., Liu, F., Shan, T.F., Xu, N., Zhang, Z.H., Gao, S.Q., Chopin, T. and Sun, S. (2010), “Tracking the algal origin of the Ulva bloom in the Yellow Sea by a combination of molecular, morphological and physiological analyses”, *Marine Environmental Research* 69: 207-215.

Ridler, N., Wowchuk, M., Robinson, B., Barrington, K., Chopin, T., Robinson, S., Page, F., Reid, G., Szemerda, M., Sewuster, J. and Boyne-Travis, S. (2007), “Integrated multi-trophic aquaculture (IMTA): a potential strategic choice for farmers’, *Aquaculture Economics and Management* 11: 99-110.

Ryther, J.H., Goldman, J.C., Gifford, C.E., Huguenin, J.E., Wing, S.A., Clarner, J.P., Williams, L.D. and Lapointe, B. (1975), “Physical models of integrated waste recycling-marine polyculture systems’, *Aquaculture* 5: 163-77.

Ryther, J.H., DeBoer, J.A. and Lapointe, B.E. (1978), “Cultivation of seaweeds for hydrocolloids, waste treatment and biomass for energy conversion’, Proceeding of the Ninth International Seaweed Symposium 9: 1-16.

Shuve, H., Caines, E., Ridler, N., Chopin, T., Reid, G.K., Sawhney, M., Lamontagne, J., Szemerda, M., Marvin, R., Powell, F., Robinson, S. and Boyne-Travis, S. (2009), “Survey finds consumers support Integrated Multi-Trophic Aquaculture. Effective marketing concept key”, Global Aquaculture Advocate 12 (2): 22-23.

Tacon, A.G.J., Metian, M., Turchini, G.M. and De Silva, S.S. (2010), “Responsible aquaculture and trophic level implications to global fish supply”, *Reviews in Fisheries Science* 18 (1): 94-105.

Thomsen, B. (2006), “Freshwater aquaculture in Denmark: a new platform for sustainable growth’, Proceeding of the Canadian Freshwater Aquaculture Symposium, Aquaculture Canada 2004, Aquaculture Association of Canada Special Publication 11: 26-30.

Timmons, M.B., Ebeling, J.M., Wheaton, F.W., Summerfelt, S.T. and Vinci, B.J. (2002), *Recirculating aquaculture systems* (2nd edition), NRAC Publication No. 01-002, Cayuga Aqua Ventures, Ithaca, 769 p.

Troell, M., Halling, C., Nilsson, A., Buschmann, A.H., Kautsky, N. and Kautsky, L. (1997), “Integrated marine cultivation of Gracilaria chilensis (Gracilariales, Rhodophyta) and salmon cages for reduced environmental impact and increased economic output’, *Aquaculture* 156: 45-61.

Whitmarsh, D.J., Cook, E.J. and Black, K.D. (2006), “Searching for sustainability in aquaculture: an investigation into the economic prospects for an integrated salmon-mussel production system’, *Marine Policy* 30: 293-298.

Chapter 10

Norway: Escapes of fish from aquaculture

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Abstract

The environmental effects of escapes are acknowledged as a key environmental problem related to on-growing of fish in sea cages. Several recent literature reviews on the effect of salmon escapees have concluded that strong evidence of genetic and phenotypic differences between farmed and wild salmon exists and that genetic change has occurred in some wild populations that escapees have mixed with. Salmon that escaped from Norwegian fish farms between 2006 – 2009 represent 0.1 – 0.3% of the total amount of fish in the fish farms. Compared to the number of wild salmon migrating to the Norwegian coastline however, escaped farmed salmon represent 20-100% annually.

Escapes are caused by a variety of incidents related to farming equipment and their operation. Escapes of salmon can be categorized broadly into structural failure (40%), operational related-failure (16%), biological (10%) and external and other causes (34%). 18% of the escape events were large (more than 5 000 individuals) and led to 94% of the number of escapees. On the contrary, 44% of the events were small (less than 200 individuals), contributing with only 0.3% of the number of escapees. This information is important and valuable in deciding the best strategy to reduce escapes from marine fish farms and to develop appropriate technical standards for equipment and management.

Introduction

Definition of escapes from aquaculture

Escapes of juvenile and larger fish from sea-cages have been reported for almost all species presently cultured around the world, including Atlantic salmon, Atlantic cod, rainbow trout, Arctic charr, halibut, sea bream, sea bass and meagre. Recently, a second form of escape has come into focus, involving the escapement of viable eggs spawned by farmed individuals from sea-cage facilities, or so called 'escape through spawning' (Jørstad *et al.*, 2008). This phenomenon has forced a redefinition of the term 'escapes from aquaculture' to include the escapement of fertilized eggs into the environment.

Report scope

Here, we document the current status of knowledge on the causes and extent of escapes, their environmental and economic consequences, and measures to mitigate and prevent escapes. We address both escapes of juvenile/larger fish and escape through spawning. As most of the research and development on the escapes issue over the past two decades has been related to the Norwegian fish farming industry, we use Norway as a case study to describe the development of measures to deal with escapes. Finally, we provide a series of recommendations for policy-makers to implement measures to prevent escapes as marine aquaculture develops in other countries.

Background to the issue: the Norwegian fish farming industry

The Norwegian marine aquaculture industry, which commenced in 1969-70, is widely considered a commercial success story. Today, Norway is a world-leader in the culture of salmon in sea-cages; 582 farms operated in coastal waters in 2008 and produced 797 000 tonnes of Atlantic salmon and 92 000 tonnes of rainbow trout (Kjønhaug, 2009). Approximately 325 million individual Atlantic salmon and rainbow trout were held in sea-cages in Norway at any given time (Norwegian Fisheries Directorate, 2009). The Atlantic cod aquaculture industry is comparatively small, and produced approx. 10 000 tonnes across 40 farms in 2008, corresponding to 25 million fish held in the sea. Significant advances in containment technologies have been made since the industry commenced, with modern production and fish transportation systems now typically large and highly mechanized.

Farm sites

In the early phase of sea-cage salmonid aquaculture, farm sites were located next to the shore and in very sheltered areas with little water exchange or flushing. Expansion of the industry in terms of both farm number and size demanded sites which experienced greater water exchange. Modern sites are located further from the shore, but are still sited in bays, sounds, fjords or scattered amongst islands within archipelagos. Currents at any site are driven by complex combinations of several driving forces, such as large-scale current systems (*e.g.* the Norwegian coastal current), tide, wind, pressure field, internal waves, estuarine circulation and freshwater runoff.

Sea-cage technology

Sea-cages in the 1970s were mainly small and square (*e.g.* 12 m x 12 m wide, 5-7 m deep, volume ~ 800 m^3), hexagonal or circular (*e.g.* circumference of 50 m, 5 m deep, volume ~ 1 000 m^3). As production subsequently increased, wider and deeper cages were developed. Presently, salmon are typically held in either square or rectangular sea-cages of 20-40 m sides, 20 to 35 m deep or circles of 90-157 m in circumference and up to 48 m deep. Cage volumes range from 20 000-80 000 m^3. Square cages are typically clustered together in a steel platform with between 4-28 cages per site with little distance (2-4 m) between adjacent cages. Circular cages are arranged in mooring grids in single or double rows but with typically greater space between them (>20 m) than square cages. Initially, cage arrangements within sites were chosen based on logistical considerations such as moorings, shelter, and accessibility and to minimise the surface area of coastal space the cages occupied. Present day cage arrangements have moved towards positioning grid systems perpendicular to the dominant current direction to maximise water flow, oxygen supply and the removal of wastes from individual cages.

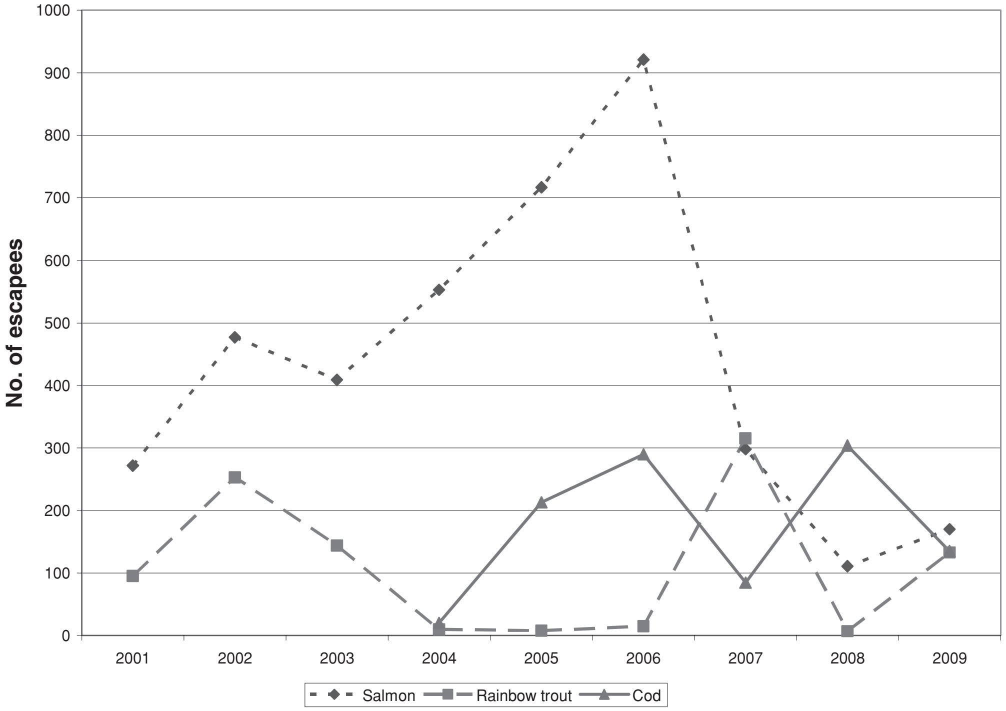
Biomasses and stocking densities

Based on the maximum allowable stocking density of 25 kg/m^3 in Norway (Norwegian Ministry of Fisheries and Coastal Affairs, 2008) and normal harvest weights of 4-5 kg, individual cages in the 1970s held ~ 10 000 fish. Modern day cages may now contain 200 000-400 000 individuals. In practice, the largest Norwegian sites produce more than 10 000 tonnes of salmon biomass, involving more than 2 million individual salmon.

Causes and extent of escapes

Knowledge of the extent and causes of escape incidents from sea-cage fish farms varies greatly from country to country. Several European countries, such as Norway and Scotland, have legislated reporting requirements whereby farmers are obligated to report escape incidents, their size and cause when they occur. In contrast, Mediterranean countries have no such requirements, thus no statistics are available on the number of escapes or the underlying causes of escapes (Dempster *et al.*, 2007). Norway has the most comprehensive record of escapes, with available official numbers back to 2001 for salmonids and to 2004 for Atlantic cod (Figure 10.1). The real number of escapes has been speculated to be considerably higher (Torrissen, 2007), because not all escape incidents are detected or some go unreported. Significant escape events of salmon have also occurred in other major salmonid producing countries. Over one million salmon were reported to have escaped from Scottish farms during the period from 2002-2006 (Thorstad *et al.*, 2008). The proportion relative to production volume of Atlantic cod that escapes is high in comparison to salmon (Moe *et al.*, 2007a). In each of the following years, 2005, 2006, and 2008, over 200 000 cod escaped from Norway’s farms.

Figure 10.1: Number of escapes for salmon, rainbow trout and cod

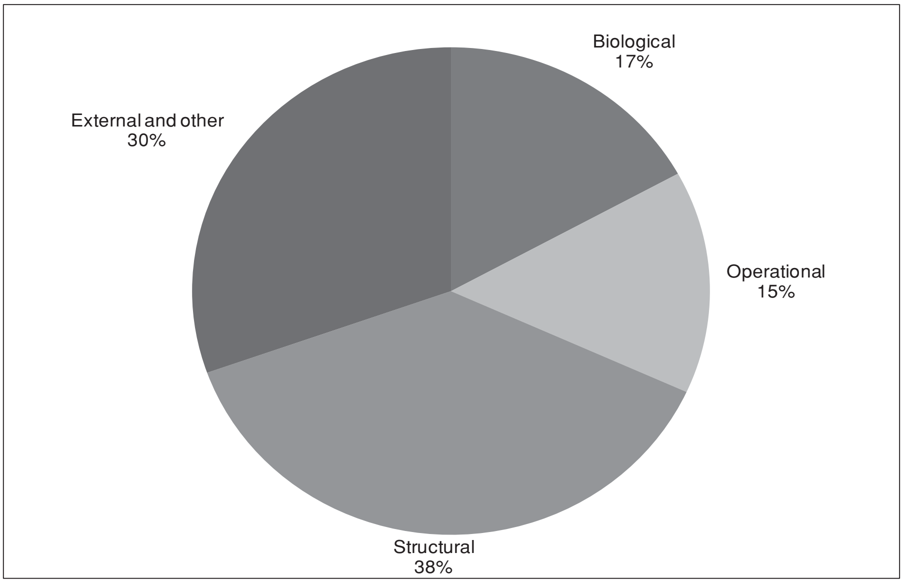


Source: Norwegian Fisheries Directorate, 2009.

No official statistics on the extent of escapees exist for Mediterranean countries; however, data available from companies that insure fish farm businesses indicate that escapes are a significant component of economic losses claimed by farmers (EU FP-6 ECASA project, 2007). From 2001-2005, 76 claims accounting for 36% of the total value of all insurance claims made by fish farmers in Greece were due to stock losses from storms, while damage to farm equipment due to storms accounted for 19%. Further, 39 registered ‘predator attacks’ resulted in claims of 10.4% of the total value of all insurance claims, although the proportion of this which relates to stock loss or cage damage is unknown. What evidence exists suggests that escapes are a relatively frequent occurrence from sea-cage aquaculture on a pan-European scale.

Escapes are caused by a variety of incidents related to farming equipment and their operation. Reports by fish farming companies to the Norwegian Fisheries Directorate following escape events during the period from 2006 – 2009 indicate that escapes of salmon (by total number of fish escaped) can be categorized broadly into structural failure (38%), operational related-failure (15%), biological (17%) and external and other causes (30%) (Jensen *et al.*, forthcoming; (Figure 10.2). Structural failures may be generated by severe environmental forcing in strong winds, waves and currents, which may occur in combination with component fatigue or human error in the way farm installations have been installed or operated (Jensen *et al.,* 2006). Operational related-failures leading to escapes include collisions with boats, incorrect handling of nets or damage to nets by boat propellers. 18% of the escape events were large (more than 5 000 individuals) and led to 94% of the number of escapees. On the contrary, 44% of the events were small (less than 200 individuals), contributing with only 0.3% of the number of escapees (Jensen *et al.*, forthcoming). For cod, there is gathering evidence that additional reasons for escape are present. This stems from behavioral differences in the way cod interact with cages, through biting of the netting, which may increase wear and tear and contribute to the creation of holes (Moe *et al.*, 2007a), and a far greater level of exploratory behavior near the net wall which may increase the chances of cod swimming through a hole (Bjørn *et al.*, 2007).

Figure 10.2: Causes of escape based on reports by fish farming companies to the Norwegian Fisheries Directorate 2006 – 2009



Source: Jensen *et al*, forthcoming.

Structural failures, while relatively infrequent, lead to the greatest number of fish escaping (tens to hundreds of thousands of fish per incident), therefore, they have, and will continue to be, the area of greatest focus in preventing escapes. Operational errors that cause escapes are more frequent, but typically lead to spills as small as a few individuals to thousands of fish, so they are of secondary importance in mitigating the escapes problem. Below, we document in detail the status of knowledge on three of the main causes of structural failures leading to escapes and provide examples.

Progressive mooring failure

Flexible circular tubes made of poly-ethylene (PE) are the most commonly used floating collars in Norwegian aquaculture. The major part of the flexible floating collars is moored using either a grid or a ladder mooring system. The floaters are connected to the mooring using bridles (Fredheim and Langan, 2009). Traditionally the grid mooring system was oriented to minimize the total drag force on the fish farm, *i.e.* with the direction of the main current running through the length of the fish farm. Orienting the farm in this manner reduces the total drag as only the front nets are fully exposed to the current (the subsequent ones are in the shadow of those in front and will experience a reduced current velocity). However, when the farm is oriented in this manner the number of mooring lines in the same direction as the main current is limited. During a storm, the current velocity increases, especially in the upper water layers, introducing large forces on the nets. These forces are transferred to the mooring lines through the bridles. If one mooring line breaks or one anchor drags, the loads on the remaining mooring lines might be exceeded and they will rupture one by one, resulting in a complete failure of the fish farm. This was the cause of the complete breakdown of a fish farm in which close to 500 000 salmon escaped from a fish farm in central Norway in August 2005.

Breakdown and sinking of (steel) fish farm

Hinged steel fish farms are popular work stations as, due to their buoyancy, they allow the use of heavy auxiliary equipment and fork lifts on the farm. Due to their construction the farm in general has no or limited flexibility in the horizontal plane (Fredheim and Langan, 2009). This gives rise to structural problems when exposed to short-crested irregular waves, as the waves induce forced vertical displacement of the bridges and introduce large stresses and strains in the structure. Fatigue and crack propagation in or close to the hinges is often the result and this can rapidly lead to separation of the bridges and tearing of the net. In January 2006, close to 150 000 cod escaped from a fish farm in northern Norway during a storm. The fish escaped after the farm collapsed under the combined loading from wind, waves and ice (Jensen, 2006). Due to forced displacement induced by the waves and ice, the farm was torn apart and the fish escaped.

Abrasion and tearing of net

Net failure, and the subsequent formation of a hole, is by far the dominant means of escape for fish from Norwegian aquaculture. Approximately two thirds of escape incidents and number of fish escape due to a hole in the net. Multiple reasons exist for the formation of holes. Biting by predators or caged fish, abrasion, “collisions” with boats, flotsam and cage handling procedures (*e.g.* lifting) are among the most common causes of holes in the net. The trend in Norway is that fish farms are moving into areas with stronger and steadier currents in order to improve the water quality. As a result, forces on the net increase and with increased forces, net deformation increases accordingly (Lader *et al.*, 2008). Several large scale escapes have occurred over the past two-three years due to contact (and thus abrasion) between the net and the sinker tube chain (Moe, 2008, 2009).

Economic consequences of escapees

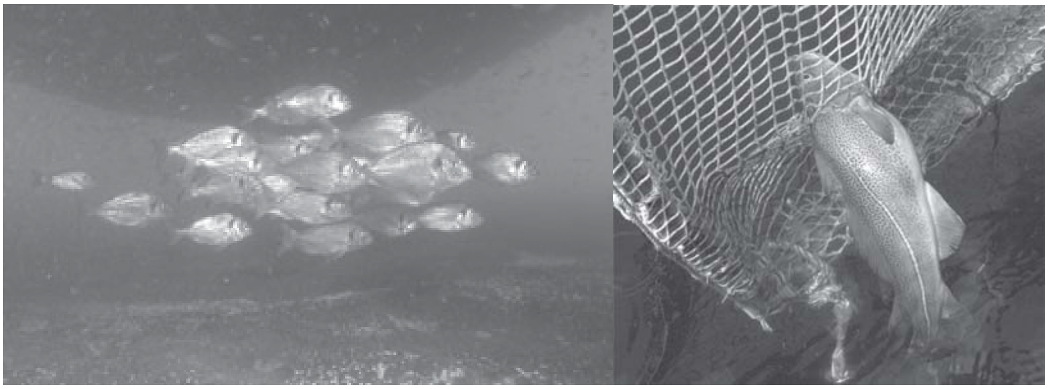
Relatively little information exists on the direct costs of escapes, although the European Union’s 7th Research Framework project Prevent Escape (www.sintef.no/preventescape) is currently assessing the cost of escape to the fish farming industry across Europe and the true cost of escapes is thus likely to be known by 2011. In Norway, as escapes on average cause losses of less than 0.2% of the fish held in sea-cages each year, the direct economic cost to the industry is relatively small, even when the cost of re-placing damaged equipment or paying for recapture efforts is accounted for. This may mean that little direct economic incentive exists for the industry to invest further time and resources to prevent escape events. However, the greatest cost of escape to the industry is indirect as escapes damage the industry’s reputation. The popular press invariably paint the aquaculture industry’s environmental credentials in a negative light when escape events occur and escapes fuel criticism from environmental groups (*e.g.* WWF, 2005). The extent to which this restricts the industry from expanding the number of sites it uses and the amount of fish it produces is immeasurable, but is likely to be significant, as the threat of escapes to wild populations are commonly discussed in relation to industry expansion (Naylor *et al.*, 2005; Hindar *et al.*, 2006). Therefore, it is a stated goal of both the Norwegian authorities and the Norwegian Fish Farmers Association to reduce escapes of fish to a level where they do not threaten wild populations (Norwegian Fisheries Directorate, 2009; Norwegian Seafood federation (FHL)).

Environmental consequences of escapees

The present level of escapes is regarded by many as a problem for the future sustainability of sea-cage aquaculture (Naylor *et al.*, 2005; WWF, 2005) as escapees (Figure 10.) can have detrimental genetic and ecological effects on populations of wild conspecifics. A single fish farm may hold hundreds of thousands to millions of cultured fish. In the Mediterranean Sea, approximately 500 million sea bass and 450 million sea bream are held in sea cages, with wild stock numbers believed to be considerably lower (ICES, 2006). Similarly, over 325 million Atlantic salmon are held in sea-cages in Norway at any given time (Norwegian Fisheries Directorate, 2009), which far outnumber the approximately 1 million salmon that return to Norwegian rivers from the ocean each year to spawn. Due to the large numerical imbalances of caged compared to wild populations, escapement raises important concerns about ecological and genetic impacts. Evidence of ecological effects on wild populations is largely limited to Atlantic salmon, as these interactions have been intensively studied, with more limited information for Atlantic cod and virtually no information for other species, including the major species farmed throughout the Mediterranean Sea (sea bream and sea bass).

In a comprehensive review of the effects of escaped Atlantic salmon on wild populations, Thorstad *et al.* (2008) concluded that while outcomes of escapee-wild fish interactions vary with environmental and genetic factors, they are frequently negative for wild salmon. As fish farms areas are typically located close to wild fish habitats, escaped fish may mix with their wild con-specifics. Consequently, the potential exists for escapees to interact negatively with wild populations, through competition, transfer of diseases and pathogens, and interbreeding. In some instances, positive short-term effects on local fisheries may be possible (Soto *et al.*, 2001).

Figure 10.3: Escaped sea bream (Sparus aurata) beneath a sea-cage (left) and an escape attempt by a cod (Gadus morhua) from a sea-cage in Norway (right)



Sources: Photograph on left © Arturo Boyra, www.oceanafrica.com and
photograph on right © Heidi Moe, SINTEF Fisheries and Aquaculture.

Transfer of diseases and pathogens

Escape incidents may heighten the potential for the transfer of diseases and parasites, which are considered to be amplified in aquaculture settings (*e.g.* Heuch and Moe, 2001; Bjørn and Finstad, 2002; Skilbrei and Wennevik, 2006; Krkošek *et al.*, 2007). Concerns that escapees may act as vectors of pathogens to wild fish heightened with the escape of 60 000 salmon infected with infectious salmon anaemia (ISA) from a fish farm in northern Norway and 115 000 salmon from a farm infected with pancreas disease (PD) in southern Norway in 2007. In addition, escapees from salmon aquaculture in Norway have been identified as reservoirs of sea lice in coastal waters (Heuch and Mo, 2001).The ability for escaped fish to transfer disease to wild fish depends on the extent of mixing between the two groups, which in turns varies with the timing and location of the escape. Several studies have mapped the dispersal of adult farmed salmon after escape and shown that they disperse over large geographical areas, migrating in significant numbers up rivers during autumn where they spawn together with wild salmon (*e.g.* Furevik *et al.*, 1990; Whoriskey *et al.*, 2006; Hansen, 2006). However, while escaped and wild fish mix, little direct evidence for disease transfer has been found to date.

Competition for food

Escaped salmon could also potentially compete for food with wild stocks, although this appears unlikely to be the case for oceanic waters. Escaped salmon from the Faeroe Islands survived after escape and migrated to offshore feeding grounds where they consumed much the same diet as wild salmon (Jacobsen and Hansen, 2001). Similarly, salmon escaped from Scottish farms also feed on natural prey in the ocean (Hislop and Webb, 1992). However, food in the ocean does not appear to be limiting for wild salmon populations (Jonsson and Jonsson, 2004), thus competitive interactions are unlikely to be substantial, although limited information exists to assess if this is also the case for coastal waters (Jonsson and Jonsson, 2006).

Interbreeding

Interbreeding may be particularly problematic for wild salmonid populations, when farmed fish are genetically divergent from wild stocks (Triantafyllidis, 2007). Successful spawning of escaped farmed salmon in rivers both within and outside their native range has been widely documented (see review by Weir and Grant 2006). The ability of escaped salmon to interbreed with wild salmon depends on their ability to ascend rivers, access spawning grounds and spawn successfully with wild partners. While the spawning success of farmed female salmon may be just 20-40% that of wild salmon and even lower for males (1-24%; Fleming *et al.,* 1996, 2000), large escape events in regions where spawning rivers and streams host small wild populations can lead to swamping of spawning areas with escapees. Once at spawning grounds, escaped females have greater success in spawning with wild males than escaped males have in spawning with wild females, thus successful breeding most often results from escaped females with wild males. Escaped farmed females are often larger than their wild counterparts; this may lead to escaped salmon outcompeting wild salmon of smaller size for optimal spawning positions. In addition, escaped female salmon may also interfere with wild salmon breeding through destroying the spawning redds of wild fish if they spawn later than wild salmon (Lura and Sægrov, 1991, 1993). Combined, these effects of spawning can lead to a high proportion of farm x wild hybrids in particular streams.

As smolts, farm salmon escapees and farmed-wild hybrids may directly interact and compete with wild smolts for food, habitat and territories. Farm juveniles and hybrids are generally more aggressive and consume similar resources in freshwater habitats as wild fish. In addition, they grow faster than wild fish, which may give them a competitive advantage during certain life stages. Ultimately, invasions of escaped farmed salmon have the potential to impact the productivity of wild salmon populations negatively through juvenile resource competition and competitive displacement. Fleming *et al.* (2000) determined that invasion of a small river in Norway by escapees resulted in an overall reduction in smolt production by 28% due to resource competition and competitive displacement. Local fisheries could therefore suffer reduced catches as wild fish stocks decline (Svåsand *et al.*, 2007).

Environmental consequences of escapees other than salmon

At present, little direct evidence exists for negative interactions of escaped and wild fish exists other than for salmon. Radio-telemetry studies of simulated cod escapes have indicated that escapees mix with wild populations in fjord environments and move to spawning grounds in the spawning season (Uglem *et al.*, 2008). Behavioral studies have further indicated that escaped farmed cod are likely to hybridise with wild cod (Meager *et al.*, 2009). However, farmed male cod have limited reproductive success in sperm competition with wild male cod, which lowers the risk of genetic introgression from escapees (Skjæraasen *et al.*, 2009).

Escapees may also establish populations in habitats beyond their natural range. In the Canary Islands, sea bass are non-indigenous, yet populations have established and are increasing in coastal areas, although abundances depend strongly on distance from fish farms (Toledo Guedes *et al.*, 2009). This distribution could mean that escaped individuals show site fidelity or mortality rates are high because of sport and professional fisheries and, therefore, the population size might be highly dependent on a continual supply of escapees.

Contribution of escapees to local fisheries

Escaped salmon due not appear to greatly benefit local fisheries in Europe other than through short-term captures after escape incidents, however escapees of other species may support local fisheries to an extent (Soto *et al.*, 2001; Sánchez-Lamadrid, 2004). Deliberately released sea bream in the Mediterranean Sea were able to adjust to a natural diet and subsequently grew well, indicating they adapted to life in the wild and likely added to local population numbers (Sánchez-Lamadrid, 2004). In addition, while small-scale escape events are relatively frequent, very few escaped sea bream or sea bass occur near the sea-cages they escaped from (Dempster *et al.*, 2002; Fernandez-Jover *et al.*, 2008), which suggests that escapees move away from farms to other more favorable habitats or they are fished by sport and professional fisheries. Similarly, recaptures of Atlantic cod escapees in local commercial and recreational fisheries in Norway are high (approximately 40%; Uglem *et al.*, 2008), indicating that local fisheries receive temporary increases after escape events.

Impacts of 'escape through spawning'

Fish farming in sea-cages is increasing worldwide; both the volumes produced and the numbers of fish species cultured are increasing. During the last decade, the culture of species that may reproduce within sea-cages has become more common. Examples of such species within European aquaculture are Atlantic cod (Jørstad *et al.*, 2008), sea bream (Dimitriou *et al.*, 2007) and possibly sea bass and meagre. Knowledge of the extent and ecological effects of reproduction of farmed fish within sea-cages is, however, sparse.

Spawning of Atlantic cod in sea-cages and egg escape

In the culture of Atlantic cod, some fish mature during the first year of culture, while a majority of farmed cod are believed to mature during the second culture year. This means that almost the entire culture stock in any particular farm has the potential to spawn in the sea-cages before they are slaughtered. Efforts to preventing maturation, mainly through manipulation of the light regime in sea-cages, have so far been unsuccessful. Although maturation can be delayed, it is difficult to inhibit maturation completely (*e.g.* Taranger *et al.*, 2006; Karlsen *et al.*, 2006). The use of hybridization, sterilization and polyploidy to counter this problem are possibilities, but problems such as initially higher mortality, greater fingerling costs, poorer growth and consumer acceptance need to be solved before they are taken up by industry (Triantafyllidis *et al.*, 2007).

Spawning of Atlantic cod within a small experimental sea-cage and dispersal of the spawned eggs in a fjord system has been demonstrated (Jørstad *et al.*, 2008). Larvae from genetically marked farmed cod that spawned in a single sea-cage were found in plankton net samples up to 8 km away from an experimental farm during the natural spawning season of cod (Jørstad *et al.*, 2008). Furthermore, in the proximity of this farm, 25% of the cod larvae in plankton samples were determined by genetic analyses to have originated from the 1000 farmed cod. This indicates that if spawning occurs within commercial cod farms where numbers of animals are far greater, the contribution of 'escaped' larvae to cod recruitment within fjords may be substantial. Moreover, the escape of eggs will likely be a persistent phenomenon in cod culture. The escape of large quantities of eggs from caged cod may be problematic as; 1) coastal cod populations in Norway are presently 'red-listed' as vulnerable (IUCN), principally due to overfishing; 2) coastal cod have a high fidelity to specific spawning grounds (*e.g.* Wright *et al.*, 2006); and 3) sea-cage cod farms are often located within short distances of known wild cod spawning grounds (Uglem *et al.*, 2008). Recent research also suggests that cod eggs may be entrained in the vicinity of the spawning grounds long after spawning (Knutsen *et al.*, 2007). Therefore, there is considerable potential for larvae from escaped cod eggs to experience favourable conditions for survival and recruitment to coastal cod stocks. This may cause significant ecological and genetic effects in wild populations in the future.

Spawning of sea bream in sea-cages and egg escape

In the Mediterranean region, information about spawning by fish kept in sea-cages is sparse. In Greece, the largest EU producer of sea bream, a spectacular increase in both the number of fish farms and their production capacity took place over the past decade, accompanied by a substantial decrease in the price of sea bream. This industrial development led to structural and functional changes in the rearing process. To increase product diversify and reach different markets, some farms started to produce larger fish. At these farms, farming durations increased from just 12 to 18 months before 1995 (Petridis and Rogdakis, 1996) to durations of up to 40 months after 1999 (Dimitriou *et al.*, 2007). Gilthead sea bream is a protandrous hermaphrodite species and the increased farming duration has resulted in the production of fish of a size compatible with that necessary for fish to reach the stage of sex inversion and female sexual maturation, normally observed at the age of two years in the wild (Zahra *et al.*, 1978). The aforementioned changes in rearing processes have resulted in the presence of large gilthead sea bream individuals (larger than 500 g) in cages during the normal reproductive period of their wild counterparts (November-March: Bauchot and Hureau, 1986). There is evidence that sex inversion and the production of both male and female gametes occur within cages under the present industrial rearing pattern (Dimitriou *et al.*, 2007). A doubling of the population of wild sea bream within the Messolonghi lagoon in Greece, based on standardised commercial fishing trap catch returns, correlates with the advent of farming sea-bream to large sizes in the region. Spawning within sea-cages is suspected to have led to greater recruitment to wild sea bream stocks (Dimitriou *et al.*, 2007). Ecological and economic consequences of this population shift have ensued as while more wild sea-bream are now available to the fishery, they are of much smaller mean size, resulting in an overall lower economic return to local fishers. The wider ecological consequences of greater recruitment of fish spawned in sea-cages into natural populations, if any, remain undocumented.

Mitigating and preventing escapes: The Norwegian experience

Over the past decade, Norway has established a range of processes and tools to deal with the problem of escapes. These include:

1. Mandatory reporting of all escape incidents;

2. Establishment of the Norwegian Escapes Commission to learn from past escape events and disseminate knowledge to both fish farmers and aquaculture equipment suppliers;

3. Introducing enforceable technical regulations for the design, dimensioning, installation and operation of sea-cage farms;

4. Ongoing investment in research and development projects to improve the design and material properties of sea-cage equipment; and

5. Training of fish farm operators in the different aspects of why and how to prevent escapes. Here, we detail these efforts, describe their effect on dealing with the escapement issue, and discuss improvements that can be made.

Mandatory reporting of escapes

Mandatory reporting of escape incidents was introduced by Norway in the 1980s, while a national statistic was established in 2001. This has enabled:

1. Assessment of the overall status of the escapes problem at an industry-wide scale from year to year (Figure 10.1);

2. Assessment of the causes of escapes;

3. And efforts to recapture escapees to be made. Without this basic process in place, coordinated action to deal with escapes is unlikely. While mandatory reporting does provide basic and general information, understanding the detailed causes of escapes requires different processes.

The Norwegian Aquaculture Escapes Commission (AEC)

Official statistics collated from mandatory reporting and other sources of information which apportion causality to escape events typically provide little explicit detail to support technological development to improve farming equipment and modify operations to avoid mistakes that cause escapes. Categorization of causes may also be inaccurate, as causes are rarely investigated in detail (Valland, 2005). Such detail only comes through thorough investigation of the causes of escape incidents on a case-by-case basis (*e.g.* Rist *et al.*, 2004). Jensen (2006) visited eight fish farms in northern Norway after two severe storms in January 2006 caused damage to numerous farms in the region. While ‘storm’ was listed as the official cause of these escapes, the specific circumstances behind each event varied widely. Storms may damage surface floaters, tear nets through net deformation or rubbing of the nets on net weights in the strong currents they generate, and overload the mooring structures that hold the farm in place. At a smaller scale, an understanding of how individual components perform in the mooring system (such as anchors, shackles, ropes, bolts and mooring coupling plates), the cage system (net material, cage ropes and cage weights), and the steel platform or polyethylene floaters is crucial to ensure each element is engineered to match the particular characteristics of each farm type and location.

To meet the challenge of more accurately determining causes of escapes, the Norwegian government established The Aquaculture Escapes Commission (AEC) in September 2006. Since its establishment, the AEC has compiled data on all reported escape occurrences in Norway and has a mandate to conduct more thorough investigations of individual escape events when required. The AEC disseminates information to manufacturers of fish farming equipment when improvements have been identified, and may issue warnings to fish farmers regarding the use of specific sea-cage technologies (More here on role of AEC, successes, and how it can be improved).

Norwegian technical standard (NS9415) for sea-cage farms

The Norwegian technical standard NS9415 (Marine fish farms: Requirements for design, dimensioning, production, installation and operation regulations) was implemented through Norwegian legislation on 1 April, 2004 and introduced requirements for the technical standard of marine fish farms in Norwegian waters. From this date the main components (floater, net cage, feed barge and mooring system) of new farms must be independently certified against the standard. In addition, farming sites needed to be classified (wind, waves and current conditions) with 10- and 50-year return periods. For existing farms and equipment in use before April 1 2004, there is a transition system lasting until 2012. This system is such that specially accredited companies asses the fish farms, carry out mooring and other technical analysis and based on this evaluate the capability of the fish farm to meet the requirements in NS9415 and to withstand the environmental forces on the specific fish farm site. If the fish farm equipment is proven capable for the site, the fish farm will receive a certificate stating proof of capability. This proof of capability has a time period of two years and can be reissued up to 2012. From 2010, all the main components of a fish farm have to be certified. A significant revision resulting in strengthening of the standard occurred in 2009. NS9415 specifies requirements for design of feed barges, floaters, net cages and mooring systems necessary to cope with environmental forces (*e.g.* wind, waves and currents) at fish farm sites and the handling and use of equipment.

As an immediate result of introduction of NS9415 in 2004, several farms replaced their existing equipment and all new equipment post 2004 had to be independently certified as per the standard. This appears to have precipitated a dramatic reduction in the number of major escape incidents in Norway, although with a time lag of several years after the standard was introduced, as old equipment was gradually replaced with new. Since the last major escape event in 2005 of 500 000 salmon from a single farm, the number of escaped salmon has been significantly reduced both in the total number of escapees and the proportion of stocked number of salmon in sea-cages. This reduction is principally due to a sharp decline in large-scale escapes resulting from the full breakdown of fish farms when mooring system and/or floaters fail. Such failures are becoming increasingly uncommon as the NS9415 standard is modified and strengthened over time.

Research and development to make sea-cage equipment more robust

Development of the NS9415 standard has been informed by a significant amount of industrial research to improve the materials, structures and designs of sea-cage farms (*e.g.* Fredheim, 2005; Fredheim and Langan, 2009; Jensen, 2005, 2006; Jensen and Lien 2005a, 2005b; Lader *et al.*, 2007a, 2007b, 2008; Lien and Jensen, 2005; Moe *et al.*. 2005, 2007a, 2007b, 2009a, 2009b). This research has come through significant investments by the Norwegian Research Council and The Fishery and Aquaculture Industry Research Fund (*e.g.* SIKTEK, IntelliStruct, SECURE, CodNet, CodNet2 and WaveNet projects) and recently the European Union’s 7th Research Framework (*e.g.* Prevent Escape project; www.sintef.no/preventescape).

Training

As a relatively large portion of the escape incidents are either due to operational errors or to operations damaging equipment and thus leading to escapes, an increased focus on how operations are performed is appropriate. Some farming companies have good and well documented systems for training and education of employees, but in general more focus is required. Fish farming is a complicated multi-disciplinary activity in which expertise on several different topics are required. So far, education has focused mainly on the biological aspects of farming, with comparatively less attention on the more technical aspects.

To address this gap, several times a year the Norwegian Seafood Federation (FHL) arranges voluntary anti-escape workshops. The workshops are often led by industrial engineers from SINTEF Fisheries and Aquaculture and are attended by fish farmers, technology producers, the Norwegian Fisheries Directorate and accredited aquaculture equipment certification companies. Typical topics for the workshops lectures are information about regulations, escape causes, and practical measures to prevent escapes.

Mitigating the escape of Atlantic cod eggs from sea-cages

At present, the culture of Atlantic cod in sea-cages in Norway is a relatively new activity of limited size compared to the large Atlantic salmon industry. Further, the possibility that escaped fertilized eggs may have genetic and ecological effects on wild populations has only recently been recognized (Jørstad *et al.*, 2008) and much remains to be documented before the likely importance of this effect is known.

Measures to prevent the escape of fertilized eggs from sea-cages are in the research and development phase. Halting sexual maturation through manipulation of the light regime in sea-cages has been trialled with some success, but it is difficult to inhibit maturation completely (*e.g.* Taranger *et al.*, 2006; Karlsen *et al.*, 2006). Hybridization, sterilization and polyploidy are possible alternate strategies, but higher initial mortality, greater fingerling costs, poorer growth and consumer acceptance mean that these techniques are not preferred by the industry (Triantafyllidis *et al.*, 2007). Investigating techniques to stop cod from spawning in sea-cages remains a research and development priority for Norwegian aquaculture.

Conclusions

Based on the Norwegian experience of dealing with the escapes problem, we recommend a range of measures for other countries to introduce effective anti-escape measures. Essentially, many of the components of the strategy to tackle escapes already in place in Norway can be directly transferred to industries in other countries. We outline these principles below in five steps, and discuss how some of these measures may be improved in Norway:

1. Mandatory reporting of all escape events, including: i) the number of fish that escaped and their size; ii) a description of the sea-cages technology involved; iii) categorisation of the operational circumstances or environmental conditions at the time of escape; and iv) an estimated cause of escape.

2. A defined mechanism to collect, analyze and learn from the mandatory reporting. This information must then be effectively disseminated to equipment

suppliers and fish farmers so improvements can be made. Within Norway the Aquaculture Escapes Commission (AEC) has this role, although the formation of a full commission to achieve this may not be necessary in other countries.

3. As causes of escapes estimated by farmers are often inaccurate, we recommend mandatory, technical assessments to determine the causes of ‘large-scale, escape incidents. Based on escape statistics in Norway, ‘large-scale’ escape events due to technical or structural failures can be considered to be those that cause the loss of more than 10 000 fish. The technical assessment must occur rapidly (within 48 hours) after the escape event. At present, no mechanism for this is in place in Norway. When technical assessments are made, they are often done weeks to months after the incident. This can lead to a loss of evidence, often making the root cause difficult to ascertain. Learning from each large-scale escape event would assist recommendations for the design and properties of sea-cage systems and help improve technical standards.

4. Introduction of a technical standard for sea-cage aquaculture equipment coupled with an independent mechanism to enforce the standard. Within Norway, the highly detailed NS9415 technical standard has perhaps been the most useful tool at an industry-wide scale to prevent escapes. Voluntary standards are unlikely to be effective; therefore we recommend enforcement through legislations. Within the next few years, NS9415 is likely to be developed into an international standard (ISO), which will facilitate implementation in sea-cage industries through the world.

5. Certain operations within fish farming (*e.g.* correct anchoring and mooring, connecting net-cages to floaters and correct weighting of net-cages in currents) are likely to pose a higher risk of an escape event occurring if they are done incorrectly. Therefore, these key processes should be identified, and mandatory training of staff who undertake these processes would likely reduce human errors that lead to escapes. Many other industries have similar mandatory training requirements for operators to perform particular tasks, thus legislative precedents would likely exist in most countries that could be drawn upon.

Additional information

The SINTEF Centre for Research-based Innovation in Aquaculture Technology (CREATE) (www.sintef.no/create) is focussing research on operations and design of fish farms with the aim of reducing the probability and extent of any escape incidents.

The European Union's 7th Research Framework project Prevent Escape (www.sintef.no/prevent) will assess technical and operational causes of escape incidents, assess the extent of escapes of reproductive gametes and fish, determine the inherent behaviours that pre-dispose certain species of fish towards a higher probability of escaping, and document the dispersal of escapees to develop and test recapture strategies. Information from the project will feed into research aimed at improving operations and equipment production, and advancing national and international standards for the design, construction and use of aquaculture equipment. The project's main goal is to determine practical, implementable measures to prevent escapes and mitigate the effects of escapees.

References

Bauchot, M. L. and J.C. Hureau (1986), "Sparidae" in P.J. Whitehead, M.L. Bauchot, J.C. Hureau, J. Nielsen and E. Tortonneese (eds.), *Fishes of the North-Eastern Atlantic and Mediterranean*, Vol. 2, pp. 883-907, UNESCO, UK.

Bjørn, P.A. and B. Finstad (2002), "Salmon lice, *Lepeophtheirus salmonis* (Krøyer), infestation in sympatric populations of Arctic char, *Salvelinus alpinus* (L.), and sea trout, *Salmo trutta* (L.), in areas near and distant from salmon farms", *ICES Journal of Marine Science*, 59: 131-139.

Dempster T., P. Sanchez-Jerez, J-T. Bayle-Sempere, F. Giménez-Casalduero and C. Valle (2002), *Attraction of wild fish to sea-cage fish farms in the south-western Mediterranean Sea: spatial and short-term temporal variability*, Marine Ecology Progress Series 242: 237-252.

Dempster, T., H. Moe, A. Fredheim and P. Sanchez-Jerez (2007), "Escapes of marine fish from sea-cage aquaculture in the Mediterranean Sea: status and prevention", CIESM Workshop Monograph 32: 55-60.

Dimitriou, E., G. Katselis, D.K. Moutopoulos, C. Akovitiotis and C. Koutsikopolous (2007), "Possible influence of reared gilthead sea bream (*Sparus aurata, L.*) on wild stocks in the area of the Messolonghi lagoon (Ionian Sea, Greece)", *Aquaculture Research* 38: 398-408.

Fernandez Jover, D., P. Sanchez-Jerez, J. Bayle-Sempere, C. Valle and T. Dempster (2008), "Seasonal patterns and diets of wild fish assemblages associated with Mediterranean coastal fish farms", *ICES Journal of Marine Science* 65: 1153-1160.

Fleming I.A., B. Jonsson, M.R. Gross and A. Lamberg (1996), "An experimental study of the reproductive behaviour and success of farmed and wild salmon (*Salmo salar*)", *Journal of Applied Ecology* 33: 893-905.

Fleming I.A., K. Hindar, I.B. Mjølnerød, B. Jonsson, T. Balstad and A. Lamberg (2000), *Lifetime success and interactions of farm salmon invading a native population*, Proceedings of the Royal Society of London series *B* 267: 1517-1523.

Fredheim A. (2005), "Current Forces on Net Structures", Doctoral thesis, Norwegian University of Science and Technology (NTNU), Trondheim, Norway.

Fredheim A. and R. Langan (2009), "Advances in technology for offshore and open ocean aquaculture", in G. Burnell and G. Allen (eds.), *New technologies in aquaculture: Improving production efficiency, quality and environmental management*, Woodhead Publications 2009, Cambridge, UK.

Furevik D., H. Rabben, K.O. Mikkelsen and J.E. Fosseidengen (1990), "Migratory patterns of escaped farmed Atlantic salmon", *ICES C.M.* 1990/F:55, 19 pp.

Hansen L.P. (2006), "Migration and survival of farmed Atlantic salmon (*Salmo salar L.*) released from two Norwegian fish farms", *ICES Journal of Marine Science* 63: 1211-1217.

Heuch P.A. and T.A. Mo (2001), "A model of salmon louse production in Norway: effects of increasing salmon production and public management measures", *Dis. Aquat. Org.* 45: 145-152.

Hindar K, I.A. Fleming, P. McGinnityand O. Diserud (2006), "The genetic and ecological effects of salmon farming on wild salmon: modelling from experimental results", *ICES Journal of Marine Science* 63: 1234-1247

Hislop J.R.G and J.H. Webb (1992), "Escaped farmed Atlantic salmon (*Salmo salar*) feeding in Scottish coastal waters", *Aquaculture and Fisheries Management* 23: 721-723.

ICES (2006), “Report of the Working Group on Environmental Interactions of Mariculture (WGEIM)”, 24-28 April 2006, Narragansett, Rhode Island, USA. ICES CM 2006/MCC:03, 195 pp.

Jacobsen J.A. and L.P. Hansen (2001), "Feeding habits of wild and escaped farmed Atlantic salmon, Salmo salar L., in the Northeast Atlantic", *ICES Journal of Marine Science* 58: 916–933.

Jonsson B. and N. Jonsson (2004), "Factors affecting marine production of Atlantic salmon (Salmo salar)", *Canadian Journal of Fisheries and Aquatic Sciences* 61: 2369-2383.

Jonsson B. and N. Jonsson (2006), "Cultured Atlantic salmon in nature: a review of their ecology and interaction with wild fish", *ICES Journal of Marine Science* 63: 1162-1181.

Jørstad K.E., T. van der Meeren, O.I. Paulsen, T. Thomsen, A. Thorsen and T. Svåsand (2008), "Escapes" of eggs from farmed cod spawning in net pens: recruitment to wild stocks", *Reviews in Fisheries Science* 16: 1-11

Jensen Ø (2005), "Islaster – isvekst og forslag til tiltak" (Ice loads – ice growth and suggestions for measures), SINTEF report no. SFH80 A064062.

Jensen Ø, E. Lien (2005a), "Risiko – designlaster og sikkerhet" (Risk- design loads and safety), SINTEF report no. SFH80 A064059.

Jensen Ø, E. Lien (2005b), "Miljøkriterier på lokalitet" (Environmental loads at sites), SINTEF report no. SFH80 A064058.

Jensen Ø. (2006), "Gjennomgang av tekniske krav til oppdrettsanlegg - basert på rømmingstilfeller i januar 2006" (Assesment of technical requirements for flatinf fish farms – based on escape incidents January 2006), SINTEF report no. SFH80 A066056.

Jensen Ø, T. Dempster T, M.A. Heide, E. Høy and A. Fredheim (forthcoming), "Escapes of fish from Norwegian aquaculture: causes and recommendations to prevent escape events"

Karlsen Ø, B. Norberg, O.S. Kjesbu and G.L. Taranger (2006), "Effects of photoperiod and exercise on growth, liver size, and age at puberty in farmed Atlantic cod (Gadus morhua L.)", *ICES Journal of Marine Science* 63, 355-364.

Kjønhaug A.F. (2009), "Produksjon av laks og regnbueørret 2008" (Production figures for salmon and rainbow trout 2008), in A-L. Agnalt, I.E. Bakketeig, T. Haug, J.A. Knutsen and I. Opstad (eds.), *Kyst og Havbruk 2009*, *Fisken og Havet, special issue* 2-2009, 128-130

Knutsen H, O.E. Moland, L. Ciannelli, E.S. Heiberg, J.A. Knutsen, J.H. Simonsen, S. Skreslet and N.C. Stenseth (2007), *Egg distribution, bottom topography and small scale cod population structure in a coastal marine system*, Marine Ecology Progress Series 333: 249-255.

Krkošek M, J.S. Ford, A. Mortonne, S. Lele, R.A. Myers and M.A.Lewis MA (2007), "Declining wild salmon populations in relation to parasites from farm salmon", *Science* 318: 1772-1775.

Lader P.F., A. Olsen, A. Jensen, J.K. Sveen, A. Fredheim and B. Enerhaug (2007a), "Experimental investigation of the interaction between waves and net structures - Damping mechanism", *Aquaculture Engineering* 37(2): 100-114.

Lader P.F. and A. Fredheim (2007b), "Dynamic properties of a flexible net sheet in waves and current - A numerical approach", *Aquaculture Engineering* 35(3): 228-238.

Lader P., T. Dempster, A. Fredheim and Ø. Jensen (2008), "Current induced net deformations in full-scale sea-cages for Atlantic salmon (Salmo salar)", *Aquaculture Engineering* 38(1): 52-65.

Lien E. and Ø. Jensen (2005), "Interaksjon – totalsystem" (Interaction –total systems), SINTEF report no. SFH80 A064060.

Lura H. and H. Sægrov (1991), "Documentation of successful spawning of escaped farmed female Atlantic salmon, Salmo salar, in Norwegian rivers", *Aquaculture* 98: 151-159.

Lura H. and H. Sægrov (1993), "Timing of spawning in cultured and wild Atlantic salmon (Salmo salar) and brown trout (Salmo trutta) in the River Vosso, Norway", *Ecology of Freshwater Fish* 2: 167-172.

Meager J.J. and J.E. Skjæraasen, A. Fernö, Ø. Karlse, S. Løkkeborg, K. Michalsen and S.O. Utskot (2009), "Vertical dynamics and reproductive behaviour of farmed and wild Atlantic cod Gadus morhua", *Marine Ecology Progress Series* 389:233-243.

Moe H., R. Gaarder, L.M. Sunde, J. Borthen and K. Olafsen (2005), "Rømmingsfrie nøter for torsk" (Escape-free net cages for cod), SINTEF Report no. SFH A 054041, Trondheim, Norway.

Moe H., T. Dempster, L.M. Sunde, U. Winther and A. Fredheim (2007a), "Technological solutions and operational measures to prevent escapes of Atlantic Cod (Gadus morhua) from sea-cages", *Aquaculture Research* 38: 90-99.

Moe H., A. Olsen, O.S. Hopperstad, Ø. Jensen and A. Fredheim (2007b), "Tensile properties for netting materials used in aquaculture net cages", *Aquaculture Engineering* 37(3): 252-265.

Moe H. (2008a), "Inspeksjon av not - vurdering av tilstand og mulige årsaker til skader" (Inspection of net cage – assessment of condition and possible causes of damage), The Norwegian Aquaculture Escapes Commission, www.rommingskommisjonen.no/index.php?sideID=56&listeID=20&ledd1=20

Moe H. (2008b), "Inspeksjon av not på Austevoll -vurdering av tilstand og mulige årsaker til skader" (Inspection of net cage at Austevoll – assessment of condition and possible causes of damage), The Norwegian Aquaculture Escapes Commission, www.rommingskommisjonen.no/index.php?sideID=56&listeID=20&ledd1=20

Moe H., R.H. Gaarder, A. Olsen and O.S. Hopperstad (2009a), "Resistance of aquaculture net cage materials to biting by Atlantic Cod (Gadus morhua)", *Aquacultural Engineering* 40: 126-134.

Moe H., O.S. Hopperstad, A. Olsen, Ø. Jensen and A. Fredheim (2009b), "Temporary-creep and post-creep properties of aquaculture netting materials", *Ocean Engineering* 36: 992-1002.

Moe H. (2009c), "Inspeksjon av not for RKA, kartlegging av skader og vurdering av årsak" (Inspection of net cage for the Aquaculture Escape Commission – assessment of condition and possible causes of damage), The Norwegian Aquaculture Escapes Commission, www.rommingskommisjonen.no/index.php?sideID=56&listeID=20&ledd1=20

Naylor R., K. Hindar, I.A. Fleming, R. Goldburg, S. Williams, J. Volpe, F. Whoriskey, J. Eagle, D. Kelso and M. Mangel M (2005), "Fugitive salmon: assessing the risks of escaped fish from net-pen aquaculture", *BioScience* 55(5), 427-437.

Norwegian Fisheries Directorate (2009), *Statistics for Aquaculture 2009,* www.fiskeridir.no/fiskeridir/kystsone_og_havbruk/statistikk

Petridis D. and Y. Rogdakis (1996), "The development of growth and feeding equations for sea bream, Sparus aurata L., culture", *Aquaculture Research* 27: 413-419.

Sánchez-Lamadrid A. (2004) "Effectiveness of releasing gilthead sea bream (Sparus aurata, L.) for stock enhancement in the bay of Cádiz", *Aquaculture* 231: 135-148.

Skilbrei O. and V. Wennevik (2006), "Survival and growth of sea-ranched Atlantic salmon, Salmo salar L., treated against sea lice before release", *ICES Journal of Marine Science* 63: 1317-1325.

Skjæraasen J.E., I. Mayer, J.J. Meager, G. Rudolfsen, Ø. Karlsen, T. Haugland, O. Kleven (2009), "Sperm characteristics and competitive ability in farmed and wild cod", *Marine Ecology Progress Series* 375:219-228.

Soto D., F. Jara and C. Moreno (2001), "Escaped salmon in the inner seas, southern Chile: Facing ecological and social conflicts", *Ecological Applications* 11: 1750-1762.

Svåsand T., D. Crosetti, E. García-Vázquez and E. Verspoor (eds.) (2007), "Genimpact-Evaluation of genetic impact of aquaculture activities on native populations", *GENIMPACT,* http://genimpact.imr.no/__data/page/7649/genetic_impact_of_aquaculture.pdf

Taranger, G.L., L. Aardal, T. Hansen, and O.S. Kjesbu (2006), "Continuous light delays sexual maturation and increases growth of Atlantic cod (Gadus morhua L.) in sea cages", *ICES Journal of Marine Science* 63:365-275.

Thorstad E.B., I.A. Fleming, P. McGinnity, D. Soto, V. Wennevik, F. Whoriskey (2008), "Incidence and impacts of escaped farmed Atlantic salmon Salmo salar in nature", *Report from the Technical Working Group on Escapes of the Salmon Aquaculture Dialogue*, 108 pp.

Torrisson O.J. (2007), "Status rapport for norsk havbruk" (Status report for Norwegian aquaculture 2007), in E. Dahl, P.K. Hansen, T. Haug and Ø. Karlsen (eds.), *Kyst og havbruk, Fisken og havet*, No. 2–2007, p 10-12.

Triantafyllidis A. (2007), "Aquaculture escapes: new DNA based monitoring analysis and application on sea bass and sea bream", *CIESM Workshop Monograph* 32: 67-71.

Toledo Guedes K., P. Sanchez-Jerez, G. Gonzalez-Lorenzo and A. Brito Hernandez (2009), "Detecting the degree of establishment of a non-indigenous species in coastal ecosystems: sea bass Dicentrarchus labrax escapes from sea cages in Canary Islands (Northeastern Central Atlantic)", *Hidrobiología* 623:203-212.

Uglem I., P.A. Bjørn, T. Dale, S. Kerwath, F. Økland, R. Nilsen, K. Aas, I. Fleming, and R.S. McKinley (2008), "Movements and spatiotemporal distribution of escaped farmed and local wild Atlantic cod (Gadus morhua L.)", *Aquaculture Research* 39: 158-170.

Weir L.K. and J.W.A. Grant (2005), "Effects of aquaculture on wild fish populations: a synthesis of data", *Environmental Research* 13: 145-168.

Whoriskey F.G., P. Brooking, G. Doucette, S. Tinker and Carr (2006), "Movements and survival of sonically tagged farmed Atlantic salmon released in Cobscook bay, Maine, USA", *ICES Journal of Marine Science* 63: 1218-1223.

Wright P.J., E. Galley, I.M. Gibb and F.C. Neat (2006), "Fidelity of adult cod to spawning grounds in Scottish waters", *Fisheries Research* 77: 148-158.

WWF (2005), "On the run – escaped farmed salmon in Norwegian waters", WWF Norway Report 2/2005. 44p. http://assets.panda.org/downloads/wwfsalmonontherun.pdf

Chapter 11

Chile: Experiences in controlling sea lice

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Abstract

Caligus rogercresseyi, a marine copepod found in Chilean waters, is a native parasite which has been transmitted to farmed species such as salmonids. In Chile, this parasite remained under control until the end of 2006, when the threshold of infestation was about the five adult Caligus/fish. This ration grew exponentially in the following year, reaching 34 adult Caligus/fish per site. Following this, for general diagnosis and monitoring purposes, SERNAPESCA implemented the sea lice surveillance program that includes an Annual General Diagnosis by Cage of Caligidosis (DGJA) and biweekly monitoring.

The results of the initial diagnosis were unsatisfactory, obtaining a general level of high prevalence (0.76) and average abundance levels of over 11 Caligus/fish, with areas where the abundance even exceeded 30 Caligus/fish. In response to this, SERNAPESCA developed a specific monitoring program, which includes new products (Deltamentrina 1% and Diflubenzuron 80%) a coordinated application of the treatments. Following this, fortnightly monitoring detected a progressive decline in the abundance and prevalence of this parasite.

Introduction

In Chile, sea lice are a disease caused by copepod *Caligus rogercresseyi.* This is an endemic ectoparasite present in various native species such as Patagonian blennie, *Eleginops maclovinus,* and Chilean silverside, *Odonthestes regia,* from which it has adapted to survive in farmed salmonids (mainly Atlantic salmon and rainbow trout). The parasite is considered a disease among salmonids since the early 1980s (Reyes, 1983).

Caligus rogercresseyi is one of the eight species of the *Caligus genus* existing in Chile. There are other ten species of the *Lepeophterius genus*, which are related to massive parasite problems in salmonids of the northern hemisphere. *Caligus* is better known as sea lice. It appears on the skin, eyes, fins and gills of the fish, causing wounds, blindness, stress, loss of appetite and higher susceptibility to bacterial or viral infection.

The problem was initially treated with different organ phosphorus products and Ivermectin. However, when the use of emamectine benzoate in fish was approved and registered in 1999, it became the only authorized product to control *Caligus*. The parasitism remained at acceptable levels in Chile until 2005. Since then, the common 5 adult-lice/fish infestation level started to increase significantly. By the end of 2006 and early 2007, the sanitary situation of some farms was highly affected by the presence of the parasite, which in many cases led to a need to empty the farms and to implement the first prolonged coordinated fallowings in various farming areas. It is important to note that at that time the private industry –through its Technical Institute Intesal– carried out a periodic monitoring of the parasitic load in farms. However, this monitoring only obtained information a certain amount of farms and was not constant which impeded a coordinated health management or disease control measures.

In 2007, as a result of various interdisciplinary workshops and round tables, SERNAPESCA of the Ministry of the Economy, which led those events, proposed to include *Caligidosis* in List 2 of High-Risk Disease in Chile, that is, a relevant disease present in the country that can be subject to public sanitary surveillance and control programs. This was established in Resolution 1669/07 issued by the Undersecretariat for Fisheries (Subpesca).

To obtain a general diagnosis of the situation, by farm, zone and species, SERNAPESCA issued the *Specific Sanitary Program for Surveillance of Caligidosis* (PSEVC) established in Resolution 1789/07, which included the first *Annual General Diagnosis per Cage (DGJA).* This implies the monitoring of a major number of cages per farm, followed-up throughout the year by bimonthly monitoring. The results from that first diagnosis showed a high prevalence (0.76) and average abundance levels over 11 caligus/fish, including areas with average abundance higher than 30 lice/fish. Based on this information, SERNAPESCA created the first *Specific Sanitary Program for Controlling Caligidosis* (PSECC) through Resolution 1883/07.

In September 2007, the use of Alphamax® (Deltametrine) baths under a controlled application regime was authorized.

Based on the results obtained from the implementation of the aforementioned programs, critical points and other aspects were identified, which allowed strengthening surveillance and control by merging them in the *Specific Sanitary Program for*

Surveillance and Control of Caligidosis (PSEVCC) established through Resolution 2117/09.

Description

Evolution of the regulation

The regulation implemented to deal with this sanitary problem evolved from an assessment strategy of the national situation regarding parasitism of *Caligus rogercresseyi* to a more integrated strategy for permanent monitoring and therapeutic and sanitary management procedures that integrate spatial and temporal aspects.

The following table 11.1 summarizes the evolution of the different instruments included in the regulatory strategy implemented in the *Program for Surveillance and Control of Caligidosis*.

Table 11.1: Summary of the evolution of the different instruments in the *Program for Surveillance and Control of Caligidosis*

Document and objectives	Surveillance instruments	Control instruments
Resolution 1789/07: PSEVC Determining the prevalence and abundance levels of *Caligus* before and after PSECC. Obtaining information that enables the design and revision of a system for monitoring *Caligus*. Establishing a standardized system for collecting data, and effectively analyzing the information.	DGJA: process in which all cages of all marine and estuarine salmon farms are sampled in July, to count the number of lice. Monitoring: bimonthly sampling carried out in all marine centers to estimate the *Caligus rogercresseyi* infestation level. Report (DGJA and bimonthly): Report issued by the farming company to the Aquaculture Unit of SERNAPECS. Trained Staff: companies should train the staff that counts *Caligus*.	None
Resolution 1883/07: PSECC *Stage I* Lowering winter abundance of *C. rogercresseyi* through coordinated treatment per zone. Preventing outbreaks of *Caligidosis* during the following summer season. Contributing to containing the outbreak of ISA by controlling this vector. Upgrading the general sanitary status and welfare of the affected salmonids.	None	Coordinated treatment: establishing the obligation to administer a simultaneous treatment –orally or via bath with pyrethroids– within an area, when the results from DGJA exceed 20-adult-lice/fish. For lower values, voluntary (not necessarily coordinated) treatments were established. Monitoring of results from treatments: obligation to report the results from treatments administered and repeating treatment according to resulting loads.
Resolution 448/08: PSECC (maintains objectives of Res. 1883/08) Lowering abundance of *C. rogercresseyi* through a coordinated treatment per zone. Contributing to containing outbreak of ISA by controlling this vector. Upgrading the general sanitary status and welfare of the affected salmonids.	None	Coordinated treatments: obligation to apply a simultaneous treatment –orally or via bath with pyrethroids– within a zone, when the results of monitoring exceed ten-adult-lice/lunch. For lower values, voluntary (not necessarily coordinated) treatments were established Monitoring of treatments results: obligation to report the results from treatments applied and repeating treatment according to results obtained.

Table 11.1 (cont.):

Resolution 2117/09: PSEVCC Monitoring the prevalence and abundance of *C. rogercresseyi* in all and sea and brackish water salmon farming centers. Establishing a standardized data monitoring and recording system in order to effectively analyze them, for the implementation or modification of the control strategy.	DGJA: parasitic account of 10 fish per cage, in all cages of the farming centers, in sea or brackish water. It should be carried out, at least, once a year, by the second half of July. Stocking in different dates shall require DGJA. A summer season account shall be required. Bimonthly Monitoring: account of parasitic loads required to the sea or brackish water farming centers, to estimate the infestation level by caligida.	Bay Management Areas (AMS in Spanish): the concept of zoning was incorporated, defining geographic and hydrographic zones, according to the presence or absence of the High-Risk Disease y/o its causing agent in each BMA; established in Resolution 450/09 issued by SERNAPESCA. Treatment Request: a particular application form is established to request the use of drugs (those with special use authorization).
Lowering the abundance of *C. rogercresseyi* through coordinated treatment per zone, thus improving the general sanitary status and welfare of the affected salmonids.	NEI (High Infestation level): parasitic abundance considered to be a sanitary risk for the center. Currently established in 6 lice/fish for all Bay Management Areas (AMS), except those considered of a higher risk, in which a three lice/fish level is established. Qualified sampler: a person able to recognize and account the different stages of *Caligus*, through a compulsory standardized training program.	Coordinated Treatment: establishes the obligation to administer simultaneous treatment –orally or via bath with pyrethroids–within a zone, when results of the monitoring exceed 6 lice/fish, differentiating the type of treatment to be administered, according to abundance per stage (juvenile and/or adult). It establishes minimum values of three adults and one juvenile to authorize treatments. For abundances between three and six, a voluntary and always coordinated treatment is established per BMA. Supervision of treatment administration: treatment by bath requires supervision by qualified personnel. Monitoring treatment results: given the accumulation of information, the obligation to repeat treatments is eliminated. Coordinated Treatment Intervals: intervals set by the Service, based on the duration of the parasite cycle, in which the centers within a BMA can coordinately administer treatments. Such intervals can be moved according to the loads, environmental harshness and other demonstrable relevant situations. Environmental Monitoring: farming centers should monitor possible environmental impacts, according to established protocols.

Therapeutic strategy

Until 2007, emamectine benzoate was the only authorized drug to fight this parasitism. Its continuous and uncoordinated use by the industry seemed to be affecting its efficiency, as shown by the continuous increase of the parasitic load and the frequency of the treatments administered with this drug.

The key causes for the increase in parasites were:

- The lack of complementary active principles to alternate disease control therapies;
- The sustained increase of production volumes of susceptible species in geographic zones that favor the parasite development;
- High stocking densities of farmed species; and
- The lack of a joint coordinated control strategy for the operational management of geographic farming zones.

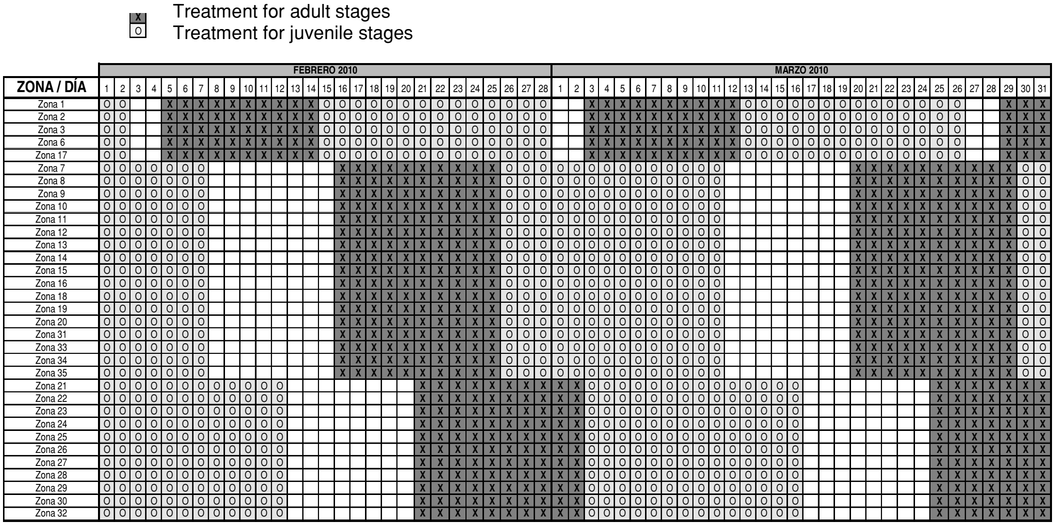
Since 2007, within the framework of the integrated management of the disease, the industry, along with SERNAPESCA sought to accelerate the authorization of alternative therapeutic products to enable drug-alternation strategies. Currently, there are two other products for controlling *caligidosis*: Deltametrine 1% and Diflubenzuron 80% and approval for Teflubenzuron is expected soon. A summary of effectiveness per stage, as well as the use regime are shown in the following table.

Table 11.2 Summary of use of therapeutic and drug products

Drug	Effectiveness juveniles	Effectiveness adults	Use regime
Emamectine B.	Yes	Yes	Registered since 1999.
Deltametrine 1% (Alphamax®)	No	Yes	With special use authorization since 2007.
Diflubenzuron 80%	Yes	No	With special use authorization since 2008. Registered since 2010.
Teflubenzuron	Yes	No	Under evaluation since 2009.

Additionally, a coordinated therapeutic management strategy has been gradually incorporated per Bay Management Area (BMA) and in specific time periods or treatment intervals, according to the development stage of the parasite.

Figure 11.1: Coordinated treatment intervals per BMA for February and March 2010

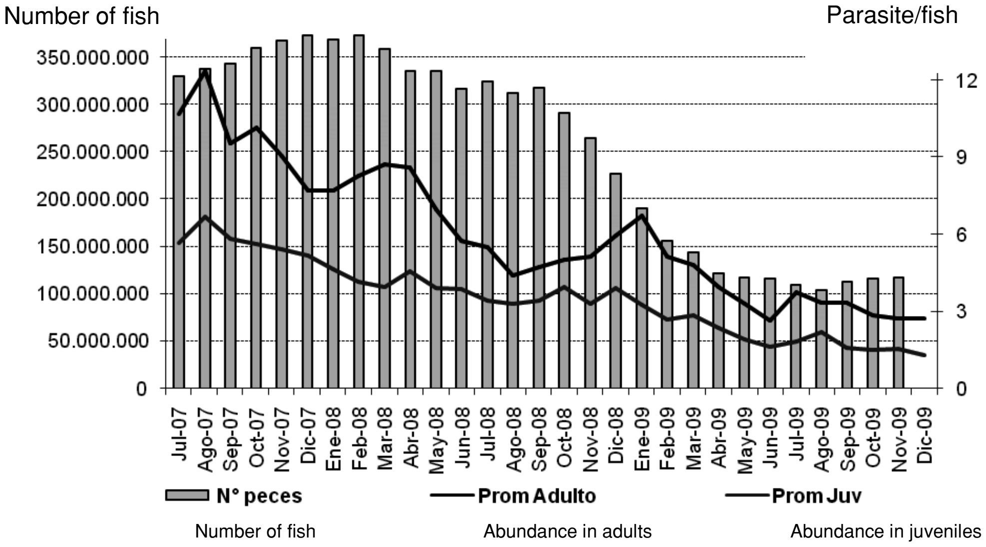


X Treatment for adult stages
O Treatment for juvenile stages

	FEBRERO 2010																												MARZO 2010																														
ZONA / DÍA	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Zona 1	O	O			X	X	X	X	X	X	X	X	X	X	O	O	O	O	O	O	O	O	O	O	O	O	O	O			X	X	X	X	X	X	X	X	X	X	O	O	O	O	O	O	O	O	O	O	O	O	O	O			X	X	X
Zona 2	O	O			X	X	X	X	X	X	X	X	X	X	O	O	O	O	O	O	O	O	O	O	O	O	O	O			X	X	X	X	X	X	X	X	X	X	O	O	O	O	O	O	O	O	O	O	O	O	O	O			X	X	X
Zona 3	O	O			X	X	X	X	X	X	X	X	X	X	O	O	O	O	O	O	O	O	O	O	O	O	O	O			X	X	X	X	X	X	X	X	X	X	O	O	O	O	O	O	O	O	O	O	O	O	O	O			X	X	X
Zona 6	O	O			X	X	X	X	X	X	X	X	X	X	O	O	O	O	O	O	O	O	O	O	O	O	O	O			X	X	X	X	X	X	X	X	X	X	O	O	O	O	O	O	O	O	O	O	O	O	O	O			X	X	X
Zona 17	O	O			X	X	X	X	X	X	X	X	X	X	O	O	O	O	O	O	O	O	O	O	O	O	O	O			X	X	X	X	X	X	X	X	X	X	O	O	O	O	O	O	O	O	O	O	O	O	O	O			X	X	X
Zona 7	O	O	O	O	O	O	O									X	X	X	X	X	X	X	X	X	X	O	O	O	O	O	O	O	O	O	O	O	O	O	O									X	X	X	X	X	X	X	X	X	X	O	O
Zona 8	O	O	O	O	O	O	O									X	X	X	X	X	X	X	X	X	X	O	O	O	O	O	O	O	O	O	O	O	O	O	O									X	X	X	X	X	X	X	X	X	X	O	O
Zona 9	O	O	O	O	O	O	O									X	X	X	X	X	X	X	X	X	X	O	O	O	O	O	O	O	O	O	O	O	O	O	O									X	X	X	X	X	X	X	X	X	X	O	O
Zona 10	O	O	O	O	O	O	O									X	X	X	X	X	X	X	X	X	X	O	O	O	O	O	O	O	O	O	O	O	O	O	O									X	X	X	X	X	X	X	X	X	X	O	O
Zona 11	O	O	O	O	O	O	O									X	X	X	X	X	X	X	X	X	X	O	O	O	O	O	O	O	O	O	O	O	O	O	O									X	X	X	X	X	X	X	X	X	X	O	O
Zona 12	O	O	O	O	O	O	O									X	X	X	X	X	X	X	X	X	X	O	O	O	O	O	O	O	O	O	O	O	O	O	O									X	X	X	X	X	X	X	X	X	X	O	O
Zona 13	O	O	O	O	O	O	O									X	X	X	X	X	X	X	X	X	X	O	O	O	O	O	O	O	O	O	O	O	O	O	O									X	X	X	X	X	X	X	X	X	X	O	O
Zona 14	O	O	O	O	O	O	O									X	X	X	X	X	X	X	X	X	X	O	O	O	O	O	O	O	O	O	O	O	O	O	O									X	X	X	X	X	X	X	X	X	X	O	O
Zona 15	O	O	O	O	O	O	O									X	X	X	X	X	X	X	X	X	X	O	O	O	O	O	O	O	O	O	O	O	O	O	O									X	X	X	X	X	X	X	X	X	X	O	O
Zona 16	O	O	O	O	O	O	O									X	X	X	X	X	X	X	X	X	X	O	O	O	O	O	O	O	O	O	O	O	O	O	O									X	X	X	X	X	X	X	X	X	X	O	O
Zona 18	O	O	O	O	O	O	O									X	X	X	X	X	X	X	X	X	X	O	O	O	O	O	O	O	O	O	O	O	O	O	O									X	X	X	X	X	X	X	X	X	X	O	O
Zona 19	O	O	O	O	O	O	O									X	X	X	X	X	X	X	X	X	X	O	O	O	O	O	O	O	O	O	O	O	O	O	O									X	X	X	X	X	X	X	X	X	X	O	O
Zona 20	O	O	O	O	O	O	O									X	X	X	X	X	X	X	X	X	X	O	O	O	O	O	O	O	O	O	O	O	O	O	O									X	X	X	X	X	X	X	X	X	X	O	O
Zona 31	O	O	O	O	O	O	O									X	X	X	X	X	X	X	X	X	X	O	O	O	O	O	O	O	O	O	O	O	O	O	O									X	X	X	X	X	X	X	X	X	X	O	O
Zona 33	O	O	O	O	O	O	O									X	X	X	X	X	X	X	X	X	X	O	O	O	O	O	O	O	O	O	O	O	O	O	O									X	X	X	X	X	X	X	X	X	X	O	O
Zona 34	O	O	O	O	O	O	O									X	X	X	X	X	X	X	X	X	X	O	O	O	O	O	O	O	O	O	O	O	O	O	O									X	X	X	X	X	X	X	X	X	X	O	O
Zona 35	O	O	O	O	O	O	O									X	X	X	X	X	X	X	X	X	X	O	O	O	O	O	O	O	O	O	O	O	O	O	O									X	X	X	X	X	X	X	X	X	X	O	O
Zona 21	O	O	O	O	O	O	O	O	O	O	O	O									X	X	X	X	X	X	X	X	X	X	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O								X	X	X	X	X	X	X
Zona 22	O	O	O	O	O	O	O	O	O	O	O	O									X	X	X	X	X	X	X	X	X	X	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O								X	X	X	X	X	X	X
Zona 23	O	O	O	O	O	O	O	O	O	O	O	O									X	X	X	X	X	X	X	X	X	X	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O								X	X	X	X	X	X	X
Zona 24	O	O	O	O	O	O	O	O	O	O	O	O									X	X	X	X	X	X	X	X	X	X	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O								X	X	X	X	X	X	X
Zona 25	O	O	O	O	O	O	O	O	O	O	O	O									X	X	X	X	X	X	X	X	X	X	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O								X	X	X	X	X	X	X
Zona 26	O	O	O	O	O	O	O	O	O	O	O	O									X	X	X	X	X	X	X	X	X	X	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O								X	X	X	X	X	X	X
Zona 27	O	O	O	O	O	O	O	O	O	O	O	O									X	X	X	X	X	X	X	X	X	X	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O								X	X	X	X	X	X	X
Zona 28	O	O	O	O	O	O	O	O	O	O	O	O									X	X	X	X	X	X	X	X	X	X	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O								X	X	X	X	X	X	X
Zona 29	O	O	O	O	O	O	O	O	O	O	O	O									X	X	X	X	X	X	X	X	X	X	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O								X	X	X	X	X	X	X
Zona 30	O	O	O	O	O	O	O	O	O	O	O	O									X	X	X	X	X	X	X	X	X	X	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O								X	X	X	X	X	X	X
Zona 32	O	O	O	O	O	O	O	O	O	O	O	O									X	X	X	X	X	X	X	X	X	X	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O								X	X	X	X	X	X	X

Previous to the implementation of the *Caligidosis Control Program* in early 2007, some farms registered more than 50 *caligus* per fish. This started to change with the growing awareness about the parasite being a stress factor and immunosuppressant which enables the development of other diseases and hence significantly affects productive results. Previous to 2007, emamectine b. was the only product used. This drug gradually lost effectiveness due to different causes, including its uncoordinated administration. Later, Deltametrine 1%, a very effective drug used for adult stages, was added to the control strategy. Since then, and since coordinated treatment per BMA started to be implemented, the parasitic load showed an important decrease. Figure 11.2 shows the evolution of parasitic abundance since 2007 to 2009.

Figure 11.2: Evolution of monthly abundance (2007-2009) per stage



Lessons learned

The following summarizes key lessons learned from the disease outbreak in Chile:

- It is important not to underestimate parasitic agents as immune-suppressants and, therefore, as agents that facilitate the development of bacterial or viral pathologies.

- There is need for a surveillance and control system applicable to the whole industry.

- Surveillance through periodic monitoring of abundance allows a real-time idea of the situation and behavior of the parasite and the conditions that affect its abundance, thus helping to adopt and/or maintain appropriate control sanitary measures.

- The control strategy for this parasitoids should not be addressed from the perspective of one farm, but assessed in the context of the epidemiologic situation of a whole area.

- In the aforementioned context, areas are defined as a set of farms that share geographic, hydrographic and environmental characteristics that can determine the sanitary status of this set of farms; its management should include prevalent pathologies.

- Government policies should reach consensus among the different players of the system and be flexible enough to cover eventualities.

- Reported information should be consistent, timely and reliable. The State should have the power and possibility to verify such qualities as well as recording tools that allow effective and efficient analysis.

- It is necessary to maintain permanent standardized programs for technical training for the public and private sector in surveillance (monitoring of abundance), as well as control matters (administration of treatments). The creation or maintenance of parallel information monitoring and recording systems in the public and the private sector undermines the base of these programs.

- The private sector should assimilate the importance of public programs for the sustainability of the sector and allocate the necessary human and logistic resources for their correct and timely fulfillment.

- In order to ensure the commitment of the private sector, the State has to feed back the system with information about the programs' achievements as well as their sanitary and economic impacts.

- The development of these programs should involve the participation of aquaculture producers, the academia, governmental and non-governmental organisations, as well as stakeholders with direct or indirect implications for the success of such programs.

- It is important to combine and, if possible, alternate therapeutic products to reduce the risk of losing effectiveness.
- The periodic evaluation of surveillance and control strategies should be complemented with applied local research to allow timely adjustment, especially regarding the loss of sensitivity towards the different therapeutic agents.
- Studies and monitoring of environmental impacts should be considered an essential element for authorizing the use of therapeutic product.

Additional information

Caligus Program website
www.sernapesca.cl/index.php?option=com_content&task=view&id=531&Itemid=632

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Chapter 12

Chinese Taipei: A control strategy for viral diseases in grouper seed production

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Abstract

Groupers fish in Chinese Taipei which are consumed in particular during festival seasons or special occasions as a status symbol and are expensive. Grouper stocks suffer from overfishing and aquaculture production which has developed considerably since the 1970s to overcome the supply constraints posed by wild stocks. Due to their rapid growth and commercial profitability, groupers soon became the most important marine fish culture in Chinese Taipei. The government actively supported this development, e.g. by removing trade barriers for fry. Production reached 17 000 tonnes in 2008. The success in larviculture is attributed to a series of factors: mass production of fertilised eggs; aggregated hatchery businesses, experienced operators and specialized subsystems; and high efficiency in the production of live food.

Problems persist in the grouper seed culture industry; in particular, through a large mortality that is disease-related. These problems at the nursery stage include swim bladder inflation syndrome, white spot, whirling disease (viral nervous necrosis or VNN) and iridovirus-like infestation. To increase the success rate of larviculture, a sanitization tool and indoor green water recirculation culture system is suggested. To increase the survival rate of fingerling culture, an indoor clear water recirculation culture system has been designed.

Introduction

Human consumption demand for live groupers has grown markedly in the last few decades in Southeast Asia. Most of this demand was met by capture fisheries, however there are some issues related to grouper fisheries that need to be addressed if trade is to remain viable in the future. Groupers are very vulnerable to overfishing and their population size is relatively small. In many areas groupers have been overexploited. The use of destructive fishing methods have destroyed the habitats on which reef-associated species depend for shelter and food. An urgent need to develop an alternative source of supply for grouper was needed to reduce the fishing pressure on wild stocks. The solution was to establish a full-cycle aquaculture system (the use of hatchery-reared fingerlings) and expand the mariculture of groupers.

Fish has played an important role in the culture and cuisine of China for centuries. The consumption of high standard fish has been important in their cultural and social habits particularly in business dinners and banquets. Groupers, one of the most highly priced fish in Chinese Taipei, are consumed during festival seasons or special occasions as a status symbol. They are kept alive until cooking to ensure freshness -a practice that has developed over the centuries and continues today.

In Chinese Taipei, the grouper culture began in 1972 by practicing grow-out of wild-caught fry. Seed supply from the wild soon became insufficient and therefore research was carried out to produce seeds in hatcheries which succeeded in the mid 1980s. Since then, Chinese Taipei has developed a technologically advanced grouper mariculture industry. Due to their rapid growth and commercial profitability, groupers soon became the most important marine fish culture in Chinese Taipei. There are more than 600 hatcheries and grow-out farms with a production area of more than 700 ha. Strong government support allowed grouper hatcheries and the industry to develop and flourish. Barriers to grouper fry exports and imports were removed to promote the industry. Chinese Taipei is currently able to produce grouper seeds on a commercially viable basis and to supply fertilied grouper eggs and seeds for the export markets. The main hatchery-reared species are *E. coioides, E. malabaricus, E. lanceolatus and E. fuscoguttatus*. Currently, fifteen species of groupers are being cultured in Chinese Taipei. The production of market-sized groupers in Chinese Taipei increased from about 1 000 tonnes in the early 1990s to about 17 000 tonnes by 2008. About 38 million grouper fries are produced annually.

The major constraint to the development of grouper culture appears to be the consistent production of fingerlings. Larviculture of grouper has always been unreliable, with highly variable but generally low survival rates. Chinese Taipei grouper farmers have however overcome the problem of high mortality.

Reasons for the success of Chinese Taipei’s grouper larviculture industry

Mass production of fertilised eggs

Generally, the fish breed naturally in ponds. At the peak of the breeding season up to 20 kg of eggs (30 million eggs) are produced per day by 300 breeders in a single 0.2 ha pond. Brood stock farmers can produce 20 billion fertilized grouper eggs to provide more than 1 000 grouper hatcheries for their annual demand. Hormonal injection is usually carried out to induce the fish to breed earlier in the season. Fingerlings produced early in the season attract higher prices than those produced later in the season, so there is an economic rationale for inducing brood stock to spawn early.

Aggregated hatchery business, experienced operators and specialized subsystems

The grouper culture system involves a series of farms specialized in one of the particular area of the production system. Brood stock farms produce fertilised eggs. Brood stock is kept in outdoor ponds and induced to spawn artificially or allowed to spawn naturally. Fertilized eggs then go to a hatchery farms where the eggs are raised to 3 cm total length (TL). Larviculture uses both indoor and outdoor methods and is undertaken using either green water or clear water techniques. Fingerling farms raise fingerlings until they reach 7-9 cm TL, at which stage they are transferred to outdoor ponds. At the grow-out farms, fish are grown to market size (600-700 g). In southern Chinese Taipei, culture is carried out in ponds over extensive areas of the coast. It takes 10–14 months to reach market size for *E coioides*.

High efficiency in the production of live food

Provision of live food for the early larvae of grouper is one of the difficulties which restrict the development of grouper culture. High attrition occurs as fish larvae fail to encounter suitable food. Copepods and rotifers are recognized as food by many fish larvae. They elicit a feeding response and may provide excellent nutritional benefits. Unfortunately, it is difficult to keep copepods and rotifers supply in a sustainable way at a hatchery farm. In Chinese Taipei, live food farmers exist who have specialised in developing an intensive cultivation system for the production of copepods and rotifers. The availability of a steady supply of live food makes commercial-scale culture of difficult marine fish species possible.

In order to promote Chinese Taipei as the fish seed supply center in the Asia-Pacific region and to export high quality seeds to the region, the Fish Breeding Association of the Republic of China was founded in May 1996. An integrated system of fishery organizations, information network and marketing chain components will enable the establishment of a quality verification system and a regular supply of aquatic seeds. Supported by government funding, researchers from the Chinese Taipei Fisheries Research Institute and several universities are actively involved in the development of grouper culture techniques. Through research and application of bio-technology and advanced breeding technology, grouper culturists may be able to upgrade their operations and remain competitive.

Problems and solutions

Problems persist in the grouper seed culture industry, in particular, disease-related mortality. The disease problems in the nursery stage include swim bladder inflation syndrome, white spot, whirling disease (viral nervous necrosis or VNN) and iridovirus-like infestation. The integration of the above mentioned seed production subsystems contribute to the success of grouper seed production. Unfortunately, it also provides a great chance for disease cross infection, especially, viral diseases. The reasons are:

- Fertilised eggs supplied by brood stock farmers may be vertically infected by virus;
- Live food supplied by live food farmers may be contaminated by virus;
- Viral contamination of water, fertilised eggs and live food may cause low success rate in hatchery farms; and
- Larvae carrying virus may also cause high mortality in fingerling culture farms.

Research by governmental institutions and experiments by private industry to solve disease problems is ongoing. Viral diseases can be best managed by a combination of quarantine and vaccination programs. However, the grouper seed culture involves four different subsystems which are operated in different locations and Chinese Taipei may face great difficulty to perform a complete quarantine program. On the other hand, research on vaccine also encountered a technical gap between laboratory operation methods and real industrial operation protocols. Therefore, the strategy to perform the quarantine and vaccination program needs to be carefully considered.

Quarantine in brood stock farms is almost an impossible operation. Considering the temporal requirement to obtain mature grouper, it takes at least three years for mature female and another one to three years for the process of sex reversal to reach a sufficient sex ratio. Contamination of water by virus may happen easily during such a long period of time and water treatment to achieve a virus-free condition is almost economically unfeasible for a normally operated brood stock farm. Further, raw food is usually supplied to compensate the nutritional requirement which may not be completely supplied by artificial feed for the brood stock. There is no doubt that a virus may be carried by the raw food into the brood stock culture system. Therefore, vaccination seems to be a reasonable choice for the brood stock to prevent virus infection. However, vaccination needs to be conducted regularly due to the primitive nature of the immune system in fish. Immune memory may not last a long period of time and brood stock may still not immunize to the virus one year after the vaccination. The vaccination needs to be operated nationwide. Based on the consideration of availability and quality of fertilised eggs, single hatchery farms may obtain fertilised eggs from several different brood stock farms. If vaccination is not performed nationwide, a viral disease may still spread throughout hatchery farms.

Live food for grouper larviculcure includes copepods and rotifers and they are usually delivered by different suppliers. Copepods are collected from outdoor ponds which contain a certain amount of cultured fish. Feed supplied for the fish may indirectly create an environment which provide the living condition for copepod. This copepod culture technique may cause copepod contaminated by virus as long as the fish species in the pond is also a viral carrier. Rotifer contamination may happen in a somewhat different manner. In order to achieve a steady and productive yield of rotifer, rotifer farmer need to fertilise the rotifer pond with organic fertilizer such as fermented fish meal or fermented raw fish. Organic fertiliser is the major source of viral contamination for rotifer and hence grouper larvae. There is no room to improve this situation from an economic point of view. Rotifer farmer cannnot survive in the market if the rotifer culture system is upgraded to a virus-free system. Besides this, hatchery farmer may obtain rotifer from several different rotifer farms depending on the availability of rotifer. A similar linkage between hatchery farms and copepod farms also exists. Therefore, the web-like linkage of live food supply creates a similar linkage of viral contamination. This situation may wipe out any effort to avoid virus contamination in the brood stock farms. Even if fertilised eggs are virus-free, grouper larvae can still be infected by virus from food supply. Hatchery farms tried to raise their own virus-free rotifer but were not successful. They were unable to sustain a steady rotifer supply mainly due to the lack of a web-like linkage.

The two different techniques in the hatchery farms include both indoor and outdoor methods and are undertaken using either with green water or clear water techniques. Green water technique needs solar energy and is carried out in outdoor ponds. The area of outdoor ponds needs to be large enough to sustain a stable micro algae flora during the process of larviculture. This technique is superior to maintain water quality; however, it is almost impossible to maintain quarantine. Contamination of virus from water or air may happen all the time. Moreover, weather conditions may affect the larvae survival rate dramatically. Clear water technique is an indoor culture technique. It applies organic fertiliser to cultivate bacteria and hence water treatment can be achieved by bio-processing of microorganisms. Although the effects of weather changes are limited, it is still difficult to achieve a satisfactory water quality for larviculture. Even if quarantine is feasible for the clear water technique, water quality is still a limitation to ensure the success rate. An epidemic of viral disease usually happens in the late stage of larviculture. To avoid this situation, some researchers try to vaccinate the larvae with viral protein through rotifer carrier. However, the application of this technique may be limited by the stability of rotifer supply. The production of carrier rotifer still needs to be web-linked to ensure the sustainable supply. Besides, a virus may attack grouper larvae well before larvae have developed a functional immune system and at this stage, a vaccination is not feasible.

Fingerling farms may face a major risk if larvae from hatchery farms are a virus carrier. Virus-carrying larvae may be completely wiped out several days after transfer into the fingerling farm. If they can survive thereafter, they still face the risk of virus infection from untreated sea water and feed for fingerling culture. Fingerling farmer may obtain larvae from several different hatchery farms depending on the availability of larvae. This linkage makes quarantine more difficult unless larviculture subsystem and fingerling subsystem merge into a single one.

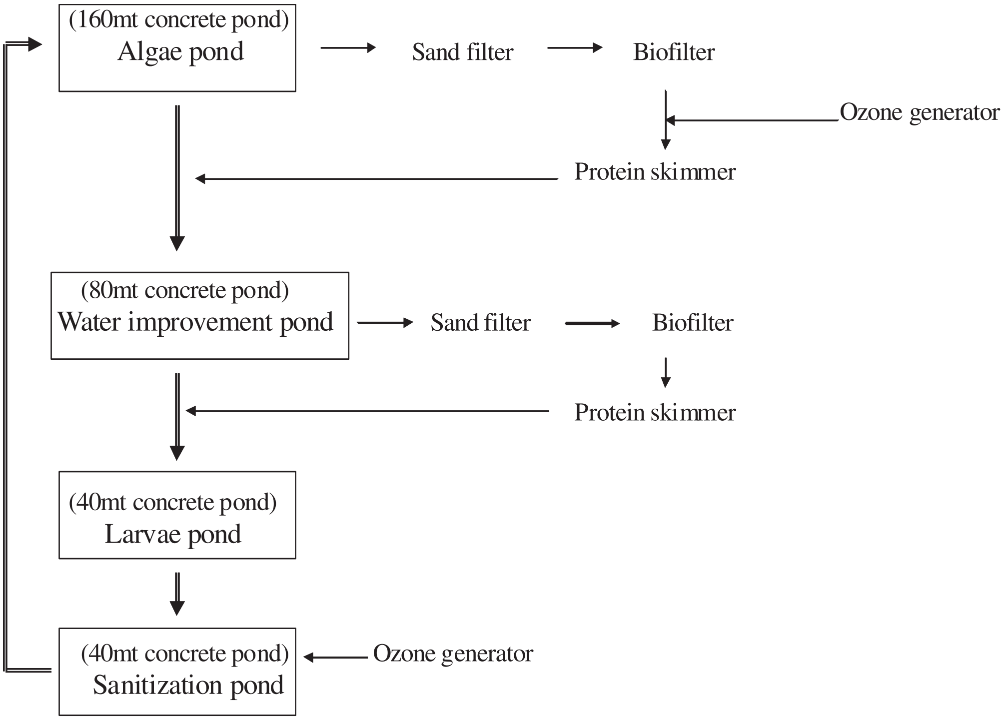
Since feed switching from live food to artificial feed is relatively difficult for grouper larvae, fingerling farmers usually apply use fish or shrimp for fingerling culture. To ensure water quality, fresh sea water flow through with a high exchange rate. At this stage larvae have completed metamorphosis and well developed immune systems. It is a preferred stage for vaccination. However, fingerlings with 3 cm TL are difficult to handle for invasive treatment of vaccine, especially for large quantity of fingerlings. Oral administration of vaccine is a much more feasible operation technique if fingerlings culture can be switched to artificial feed.

It can be concluded that possible sources of viral contaminations in seed production are from fertilised egg, live food, raw feed and sea water. The most feasible way for quarantine operation is a merged system which combines both larviculture and fingerling culture subsystems. It is necessary to consider this basic information to design a control strategy for viral disease in grouper seed production.

Solution for larviculture

To increase the success rate of larviculture, a sanitization tool and indoor green water recirculation culture system (Figure 12.1) is suggested. Ozone treatment is recommended for fertilised eggs and live food sanitization. Due to the high oxidative potential and short half-life of ozone in sea water, it can effectively reduce the titer of virus and yield limited damage to fertilised eggs and live food. Basically, all the material going into this system must be sanitized by ozone, including sea water, fertilized eggs, rotifer and copepod. In addition, indoor culture system can effectively prevent possible viral contaminations from open water and air. The whole culture system is set up inside a greenhouse which provides sufficient sunlight for microalgae growth. Water temperature can be maintained at a rather constant level. Water quality is maintained by bio-processing of microalgae and bacteria. Bacteria and algae flora can be sustained at relative stability for a long period of time due to the high species diversity and thus the concentration of N-NH_3 can be effectively controlled.

Figure 12.1: Green water recirculation system for larviculture



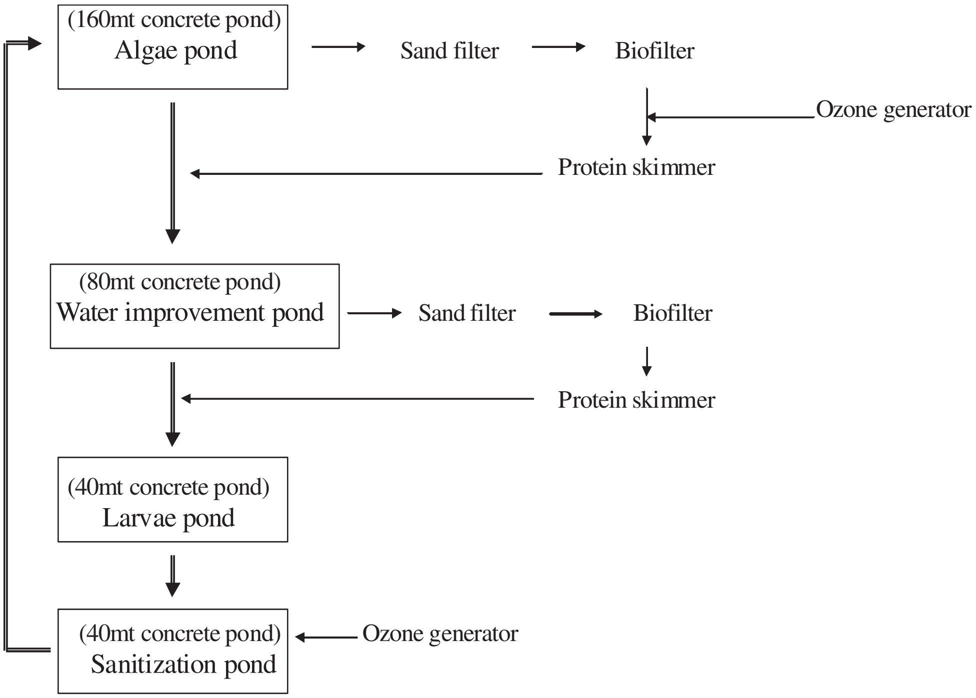
Solution for fingerling culture

To prevent the possibility of cross contamination of virus, this culture system can only accept larvae supplied by quarantined culture system. To increase the survival rate of fingerling culture, an indoor clear water recirculation culture system was designed (Figure 12.2). The entire culture system is set up inside a concrete building. Fingerlings are cultured in 300-liter tanks with high water exchange rates.

The benefits of small tank culture are:

- High density fingerling culture is feasible due to high water exchange rates. It is possible to reach a density of 10 000 fingerlings/tank;
- Feed switching from live food to artificial feed is much easier due to high density of fingerlings creating a "feeding frenzy" phenomenon; and
- Fingerlings sieving is easier to handle to avoid cannibalism.

Figure 12.2: Clear water recirculation system for fingerling culture



Conclusions

The shortage of land is a major constraint for aquaculture development in Chinese Taipei. The grouper culture industry possesses bright prospect in the future. However, faced with limited land resource, the grouper culture industry needs to adjust to reduce the dependence on land. The design of recirculation culture systems allows high density culture as it reduces the dependence on land significantly. Further, the design of green houses reduces the dependency of fossil energy and water treatment techniques reduce the amount of waste water effluents.

In Chinese Taipei, grouper farmers are specialized in different aspects of the culture from hatching to grow-out. Farmers always experiment with different species for culture and hatchery to enhance their ability to compete in the market. Recirculation systems provide a reliable experimental tool which may help them to achieve the goal. Currently, several new species are being maricultured and captive-bred on experimental basis, including *E. tukula, E. bruneus, E. multinotatus, E. flavocaeruleus, E. cyanopodus,* *Plectropomus leopardus, Plectropomus laevis, Cromileptes altivelis* and *Cephalopholis sonnerati*. Several of these species are in demand for the live reef food-fish markets. Captive-breeding or intensive mariculture will in fact provide a consistent alternative supply of grouper without harvesting from sensitive reef environments. Sustainable mariculture can be achieved with the responsible application of well-defined mariculture protocols and the use of indigenous species.

The World Resources Institute reported that nearly 70% of the world's marine fish stocks are overfished or fished to their biological limit. Decline in fish population in coral reefs have reached an alarming stage due to habitat loss, which is mainly due to destructive fishing practices. Traditionally, aquaculture has helped to keep the supply of fish steady through selective breeding Producing more farmed fish is a logical approach to reduce the fishing pressure on coral reefs. Under these circumstances, a full-cycle culture of grouper in Chinese Taipei will be one of the alternative solutions to coral reef conservation and reduce the dependency on wild-caught grouper for market supply.

Chapter 13

The Netherlands: Best practices in managing ecosystem impacts in aquaculture through RAS technologies

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Abstract

The Dutch finfish aquaculture sector is unique in Europe and worldwide. This innovative sector is based solely on recirculation aquaculture systems (RAS). RAS are land based fish production systems in which water from the rearing tanks is re-used after mechanical and biological purification to reduce water and energy consumption and to reduce nutrient emission to the environment. The water consumption in RAS is entirely based on water exchange to compensate for evaporation, incidental losses and to control water quality. Because of its controllability, water temperatures in a RAS are kept constant at the optimal rearing temperature for the target species.

Typically a RAS consists of a fish rearing unit and a water purification unit. The latter is composed of the following components: solids removal (sedimentation or mechanical screening), ammonia conversion to nitrate (biological oxidation beds), carbon dioxide removal and/or degassing, re-oxygenation of the water. The case study looks at the sustainability implications of RAS and draws lessons learned from the Dutch experience.

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Introduction

The Dutch finfish aquaculture sector is unique in Europe and worldwide. This innovative sector is based solely on recirculation aquaculture systems (RAS, (Verreth and Eding 1993; Martins, Eding *et al.,* 2005; Schneider, Blancheton *et al.,* 2006)). RAS are land based fish production systems in which water from the rearing tanks is re-used after mechanical and biological purification to reduce water and energy consumption and to reduce nutrient emission to the environment. The water consumption in RAS is entirely based on water exchange to compensate for evaporation, incidental losses and to control water quality. Because of its controllability, water temperatures in a RAS are kept constant at the optimal rearing temperature for the species under concern. Typically a RAS consists of a fish rearing unit and a water purification unit. The latter is composed of the following components: solids removal (sedimentation or mechanical screening), ammonia conversion to nitrate (biological oxidation beds), carbon dioxide removal and/or degassing, re-oxygenation of the water.

Extra components that might be integrated in some RAS are the removal of fine suspended solids, COD removal through degradation, disinfection units, denitrification and/or dephosphatation/flocculation units, protein skimmer and so on (Losordo and Timmons 1997; Eding and van Weerd 1999; Kamstra, Rand *et al.,* 2000; Martins, Eding *et al.,* 2005; Schneider and Verreth 2008). The Dutch aquaculture sector developed with the application of RASs in the seventies and eighties (Verreth and Eding 1993; Kamstra, Heul van der *et al.,* 1998; Kamstra, Eding *et al.,* 2001; LNV 2004). The sector is the only one consequently and nearly exclusively applying RAS technology in indoor farming systems for several species, such as African catfish, eel, tilapia, sturgeon, pikeperch, barramundi, turbot, sole, yellowtail kingfish and other species (Schneider and Verreth, 2008). The sector has experienced several ups and downs during the last thirty years and is currently facing one of its biggest challenges (Table 13.1), which is evident from a decreasing production and a reduction in farm numbers.

Table 13.1: Production of the most important species of the Dutch aquaculture RAS industry

	2007-2008		September 2009		Expected for the end of 2009	
	No. of farms	*Production*	*No. of farms*	*Production*	*No. of farms*	*Production*
Eel	43	4 250	20	3 000	19	<3 000
African Catfish	18	3 100	~10	1 500	5-6	1 000
Nile tilapia	4	840	0[1]	0	0	0
Turbot	4	210	2	100	2	210[2]
Barramundi	2	135	0	0	0	0
Pikeperch	2	130	3	130	3	130
Dover Sole	1	10	1	20	1	20
Claresse®	1	100	3	2 500 [3]	2	3 000

Notes: Production in metric tons per year. [1] small production scale, [2] 2010, [3] capacity,

Source: Bron: 2007-2008 IMARES, 2009 and sector interviews.

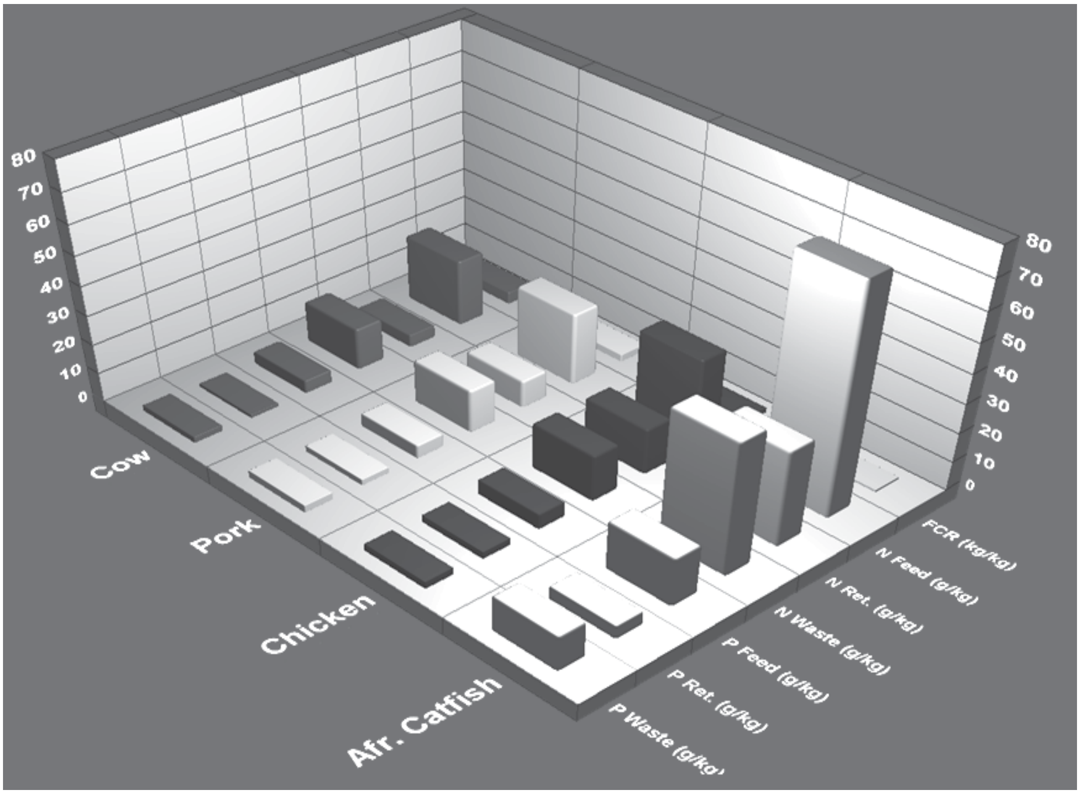
Compared to cages, flow-through systems or ponds RASs present several advantages. These are: water and energy savings, water quality control, low environmental impacts, high biosecurity and an easier control of waste production (Losordo, 1998; Losordo, 1998; Martins, Eding *et al.*, 2005; Schneider and Verreth, 2008; Schneider and Verreth, 2008). The main disadvantages are high capital costs, high operational costs, intensive management and skill requirements, and the difficulty to treat a disease within an operational system (Schneider, Blancheton *et al.*, 2006). The European Commission (European Commssion, 2009) and other experts label RASs as an underexploited but high potential production method meeting several ecological, economical and social sustainability criteria (Muir 1982; Eding and van Weerd, 1999; Martins, Eding *et al.*, 2005; Schneider and Verreth, 2008; Schneider, Fuentes *et al.*, 2009). The Dutch sector has applied RAS based on its advantages and implemented it into an operational framework of several regulations and codes of conduct. This national case study discusses RAS management practices with particular focus on its ecological sustainability and related governance aspects. This discussion is structured along the lines of input and output using the RAS itself as system boundary.

Description

Environment and ecological sustainability

From an environmental point of view the input into RAS is mainly fish, nutrients (*i.e.* feed), water and energy (Timmons, Ebeling *et al.*, 2001). The nutrient retention by fish inside a RAS is more efficient compared to other husbandry organisms in other animal production systems. This is caused not only by the high retentions of fish per se due to its biology, but as well as FCR in RAS as system are lower than in other (aquaculture) systems (Losordo 1998; Losordo 1998). In absolute numbers fish emit more nitrogen and phosphorus than other organisms per kg feed, but more important, their nutrient retention is higher per kg product (Figure 13.1) due to the better FCR. This data varies by fish species, age, genetic background, temperature and of course applied diets.

Figure 13.1: Absolute nutrient retention of cattle, pig, chicken in African catfish in absolute numbers per kg feed



Source: Schneider, 2006.

RAS systems are similarly more efficient in terms of water use (Verdegem, Bosma *et al.*, 2006). Here the water used for the primary production (such as drinking water for land animals, water needed for production and processing of feed, or water in the tanks) is integrated into the calculation (Table 13.2).

The most important outputs of the operation are fish as end product and the emitted nutrients as a waste product. The latter needs to be managed to avoid negative environmental impacts. This is illustrated by the productivity of Dutch RASs in general and of several species in particular ((Kamstra, Rand *et al.*, 2000; Verdegem and Eding, 2001; Schneider and Verreth, 2008), Table 13.2 and Table 13.4.

Table 13.2: Total water use in several animal protein production sectors

	m^3/kg fresh weight	%feed related
	Animal Production	
Pigs: (farrow-finish)	4.7	99
Eggs:	2.7	96
Milk (per liter)	0.8	99
	Aquaculture	
Pellet-fed pond	11.5	20
Recirc – Clarias	0.5	80
Recirc – Eel	0.7	86
Recirc – Turbot	1.4	37

Source : Verdegem, Bosma *et al.,* 2006

Table 13.2: Water use, waste discharge and productivity in several aquaculture systems

System Type	Water use	Waste Discharge	Productivity
	(l/kg fish)	(g/COD / kg fish)	(MT/ha/Year)
Pond	2 000	286	10-15
Flow-Through System	14 500-210 000	780	Variable
RAS	100-900	150	300-2 500

Source: Verdegem and Eding, 2001.

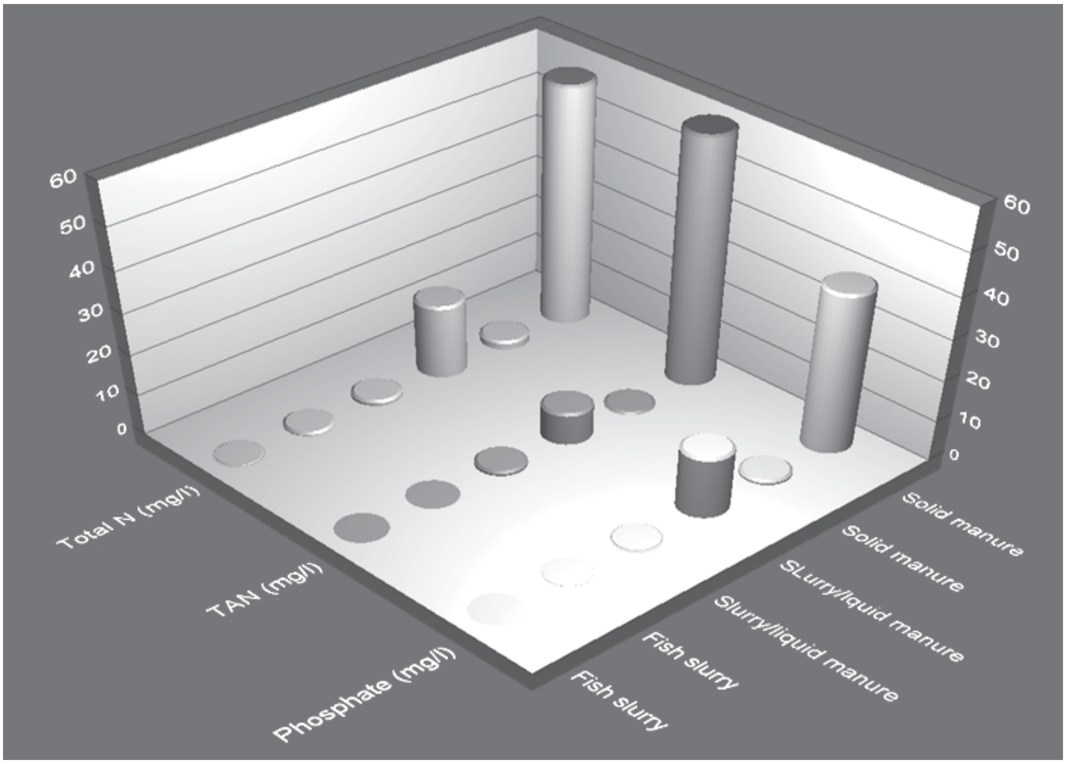
Table 13.3: Density and productivity of several species cultured in Dutch RAS

	Catfish	Eel	Tilapia	Turbot
Density (kg/m^2/jr)	250-500	125	80	55
Productivity (kg/m^3/jr)	>1 000	300	270	55

Source: Kamstra, Rand *et al.,* 2000.

Fish emit lower levels of nutrients due to the higher retention and more efficient resource use compared to other animal productions. For example: African Catfish produces per kg product 28g of nitrogen and 4g of phosphorus waste and retains most fed nutrients. Other animals, cattle, chicken, pig, are much less efficient and release between 28 to 77gN and 5-8gP per kg product (Schneider, Verreth *et al.*, 2002; Schneider, 2006). It is important to note that this waste emitted by the primary production process still needs to be managed. Compared to ponds or flow-through systems RAS emit this waste from the system in higher concentrations and at clearly defined emission points (Verdegem and Eding, 2001). This allows for an easier waste management, meaning either the destruction or recuperation of the nutrients and thereby limiting negative environmental impacts (Losordo, 1998; Losordo, 1998; Timmons, Ebeling *et al.*, 2001; Bergheim and Brinker, 2003). However compared to other agricultural protein production the waste originating from RASs is rather thin and diluted (De Boer, Van Der Togt *et al.*, 2000; Burton and Turner, 2003; Tamminga, 2003; Tchobanoglous, Burton *et al.*, 2003). Generation of bio-gas or incineration of fish slurry alone seems therefore not feasible based on energy content and amount generated by average sized farm (Lanari and Franci, 1998; Burton and Turner, 2003; Gebauer, 2004). The combination with manure from cattle or pigs might be possible. It is however not practiced on a scale that allows for a clear evaluation of the added value of fish sludge to the process (Figure 13.2).

Figure 13.2: Concentrations of nutrients in different forms of manure, based on different sources



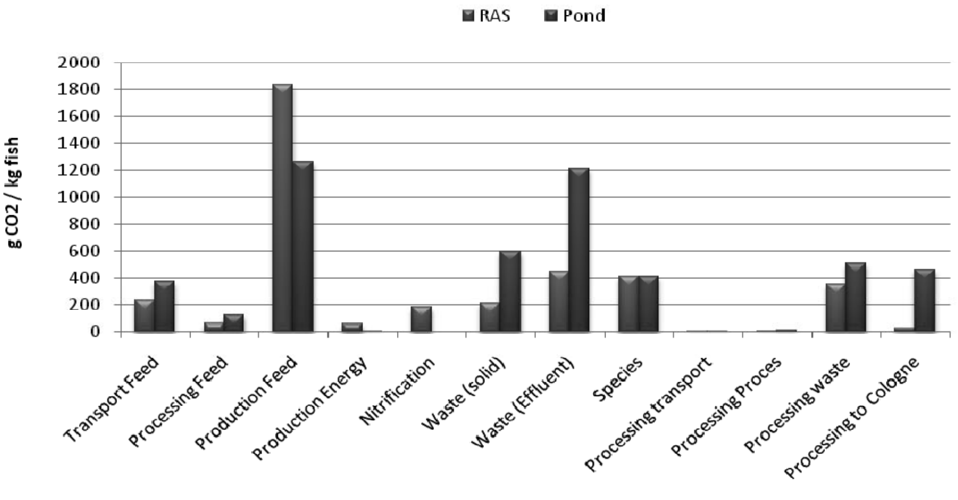
The environmental impact of RAS is rather limited as normally end-of-pipe treatments should be included in the system set-up. Therefore pure waste treatment by mechanical and biological filtration inside the system can be differentiated from “end-of-pipe” waste management (Chen, Ning *et al.***,** 1996; Chen, Stechey *et al.*, 1997; Bergheim and Cripps, 1998; Bergheim, Cripps *et al.*, 1998; Schneider, Sereti *et al.*, 2007). Such end-of-pipe treatment is most often destructive (Chen, Ning *et al.*, 1996; Chen, Stechey *et al.*, 1997). Possible measures practiced in Dutch RASs are denitrification, the conversion of nitrate into gaseous nitrogen, mineralization of the sludge in septic tanks or geotubes and the subsequent re-use as fertilizer (Schneider, Sereti *et al.,* 2004; Schram, Sereti *et al.,* 2006; van Rijn, Tal *et al.,* 2006). A process in which more nutrient are recuperated is the use of wetlands, or polish ponds where the nutrients are converted into biomass (Summerfelt, Adler *et al.,* 1999; Rosati 2000; RAMSAR 2002; d'Orbcastel, Blancheton *et al.,* 2009). This is practiced by some farms in The Netherlands. The residual water is often discharged into the sewage system and post-treated in municipal wastewater treatment plant (Schram, Sereti *et al.,* 2006).

New technologies are focussing on either the integration of low trophic species converting the fish sludge into valuable secondary products, *e.g.* other fish species, sea cucumber, worms, algae or alternative intermediate products, such as activated sludge processes (Shpigel and Neori, 1996; Blancheton, 2000; Neori, Shpigel *et al.*, 2000; Schneider, Verreth *et al.*., 2001; Neori, Chopin *et al.*, 2004; Schneider, Sereti *et al.*, 2004). The generated sludge, bioflocs, are re-used then as fish feed (McIntosh, 2001; Hari, Kurup, *et al.*, 2004; Schneider, Cong *et al.*, 2006). Some Dutch farmers work on the integration of fish with saline vegetables and algae, while other farmers are recuperating CO_2 and nutrients in integrated systems culturing tomatoes or peppers in greenhouses (*e.g.* projects like: Zeeuwse Tong, Ecofutura, and Vigour Fishion).

One farm emission that should be avoided at all costs is drug residue, such as antibiotics. In general compared to other systems, drug use is minimal in RASs. This is the result of culture in a confined environment without outside pathogen pressure, such as a closed and insulated building, good quarantine measures and other health management procedures (Bebak 1998; Timmons, Ebeling *et al.,* 2001). Dutch farmers are furthermore obligated to document all drug use and to be able to refer to valid prescriptions for curative applications (www.aquacultuur.nl then look for: gedragcodesvoorviskweek.pdf).

If the system input and outputs are integrated into one framework then the ecological sustainability of RAS can be evaluated and compared to other systems. This can be done either using operational sustainability indicators or through more general tools such as life cycle analysis (LCA) or CO_2 foot prints (Aubin, Papatryphon *et al.,* 2009; Aubin and Van der Werf 2009; d'Orbcastel, Blancheton *et al.,* 2009; Pelletier, Tyedmers *et al.,* 2009). A recent study compared African catfish culture in RAS in The Netherlands with Pangasius pond culture in Vietnam using the same retail outlet in Cologne, Germany (Figure 13.3). CO_2 emissions from Dutch production were lower during the production and processing process, including feed production (data in submission). Such approaches, comparing productions for sustainability indicators, can then be used in governance frameworks leading to overall better management practices.

Figure 13.3: CO_2 emission from catfish RAS and pangasius culture in Vietnam (data in submission)



Governance

In governance frameworks there are also measures interacting as RAS input or output comparable to the input and output structure chosen to describe environmental management. Important in terms of aquaculture governance on the input side is which species is acceptable for culture. Besides the market potential, production sustainability and animal health and welfare during the culture process are important aspects. In Dutch regulations, the admission of new species for aquaculture is regulated by a two step process (www.aquacultuur.nl, LNV). First the fish farmer (RAS operator) has to file a request to culture the new species, demonstrating that the species is suited for culture in RAS based on literature and experience. Besides the welfare needs of the species there is also a requirement for the operator to be sufficiently experienced to culture fish and the facilities to be appropriate. Based on the request an exemption is granted to culture the species for a maximum period of 2 years on an experimental basis. Within these two years the farmer has to generate a report covering wide aspects of the species performance during the experimental period. Finally, based on an independent evaluation, the species may be placed on the list of species for farming purposes in the Netherlands (www.aquacultuur.nl). This is a rather rigid policy. However it leads to an assessment of the culture conditions for the benefit of the animal and consequently improves quantity and quality of sustainable production. Furthermore, it ensures an easier societal acceptance of the species, because its health and welfare was assessed during the culture process and judged to be appropriate.

At present this national policy is being integrated with the European regulation concerning the use of alien species in aquaculture (EC. Nr. 708/2007). Within this act, alien species that are not yet cultured in the European Union, are only allowed to be cultured provided a risk assessment procedure has been completed and a licence has been granted by the authority. These procedures must prevent any escapees not only of the fish species but also of associated organisms, such as bacteria, viruses or parasites. This is comparatively easy to manage in a RAS. RASs normally have a quarantine unit where newly arrived fish are scanned for diseases (common sector practice). Furthermore, RASs should only have a direct connection with the outside environment through an end-of-pipe treatment. This is normally a septic tank or something comparable. The environmental conditions inside those septic tanks make it most unlikely that any organism survives let alone escapes (Tchobanoglous, Burton *et al.,* 2003; Schram, Sereti *et al.,* 2006). Other governance measures try to stimulate sustainable aquaculture, as for example the use of feeds containing less fish meal, methods that decrease energy needs and welfare friendly slaughtering methods (maatlat duurzame aquacultuur (measuring rod), SMK).

Another important aspect is the management of soft inputs (*i.e.* knowledge). In The Netherlands “knowledge exchange meetings” have recently been established to facilitate the knowledge exchange within the aquaculture sector (www.visserijinnovatieplatform.nl). Other dissemination measures next to direct dissemination trough workshops and specified publications are the work of the Dutch aquaculture society (more than 400 members) and of the Dutch aquaculture producer organisation (NeVeVi).

Besides to knowledge the government uses European Fisheries Funds to facilitate the sustainable growth. For example there are subsidies allowing farmers to update their installations, to diversify their production with new species, and to bring new species to the market. Other subsidies are supporting innovations in private-public partnerships.

Another instrument with focuses on the system output are regulations impacting nutrient emissions. In the Netherlands the Polluter Pays Principle (PPPrinciple) has been put successfully into practice. This regulation can as well been found back in the EC regulation (Water Directive 2000/60/EC). On European level this principle suggests fining nutrient emitting users. In the Dutch environment these fees are paid on base of inhabitant equivalents. These fees affect cost price shares in Dutch RAS farms and are about EUR 15 000 per 100MT fish depending on feed, fish, waste management practices and nutrient emissions and depending on the location of the farm, as fees vary among the Dutch provinces (Eding, Sereti *et al.,* 2004).

Instruments as the PPPrinpicle stimulate more sustainable aquaculture practices as waste is not emitted but concentrated by means of recirculation and waste treatment to about 150 times higher concentration than in flow through systems. In addition, techniques such as denitrification and other methods reducing water consumption are further stimulated.

Other instruments with a focus on environmental sustainability integrate system inputs and outputs. The hallmark from the Dutch foundation for environmental certification (SMK) is a good example (www.smk.nl). Here good sustainability practices, covering ecological aspects are awarded with a certificate. Other certification schemes under development are the GlobalGAP standards for fish cultured in RAS. At a European level this is supported by a significant Dutch commitment. GlobalGAP is a business to business label, ensuring basic sustainability criteria for all kinds of food products (www.globalgap.org). Another example already under development is the Aquaculture Stewardship Council (ASC) funded by the WWF and the Dutch institute for sustainable trade (IDH), an NGO label. This certificate will act between business and customer directly. It promotes product and process sustainability comparable to the MSc. These overall governance aspects can also be found in the policy of the Ministry of Agriculture, Nature and Food Quality (LNV) which is committed to sustainable aquaculture development, and is in line with the recent European policy on sustainable development of the aquaculture industry.

In conclusion the Dutch aquaculture sector is characterised by innovation, application of sustainable techniques for fish production, ensuring fish welfare in a governance framework. Within the framework all stakeholders work together towards a sustainable and viable sector.

Lessons learned

Based on the argumentation mentioned above, one might conclude that Dutch aquaculture is prosperous and a problem free production environment. Especially recently the Dutch sector had to fight on several fronts and as a consequence it has lost significant ground. The result is a decline of the number of farms and their production volume (Table 13.1).

At the moment there are two major developments in the primary production segment. The first development is that the number of catfish farms has decreased but the farming capacity increased. This is a typical sign of consolidation in a mature market. Here especially less efficient farmers are facing bankruptcies. The reasons for this development are multi-factorial, ranging from failures in marketing, lack of cooperation, competition and others.

The second development is that in the eel culture segment both the number of farms and the production decreased. This is occurring as a direct result of the discussions regarding the environmental sustainability of eel production through capture based aquaculture. Until today young eel are caught in European estuaries and subsequently transferred to farms for grow out. However, eel is an endangered species (CITES) and the continuing pressure on a population which is already characterised by depressed recruitment has lead to a discussion involving social sustainability aspects, such as culture and heritage of eel fishing as well as consumption. As result, several Dutch and German supermarkets have removed eel from their shelves, restricting the retail market.

The culture of other fish species, such as turbot, sole and tilapia have to deal with production costs that are too high for mass market competition. As a result they have to focus on niche markets, which limit their potential. Several initiatives such as the Happy Shrimp farm (indoor RAS for white leg shrimps) were not even able to establish themselves in such niche markets and subsequently vanished.

Another lesson that has been learned the hard way is the need for an absolutely pristine product quality. Even though it cannot be measured in an objective way, aquaculture products and especially those from RAS are often suspected to be of inferior quality, in terms of texture, fat content and taste compared to fishery products. A real negative aspect is off-flavour, the muddy taste of fish that has stored geosmin or 2-methyl-iso-borneol in its fat tissue. These two substances are released by blue algae or fungus inside the RAS (Gautier, Boyd *et al.,* 2002; Turchini, Moretti *et al.,* 2007; Percival, Drabsch *et al.,* 2008; Hurlburt, Brashear *et al.,* 2009). The only counter measure for the moment is fish depuration. For depuration fish is housed in clean water (flow through) without feeding them for several days and in case of sturgeon even weeks (Schneider and Eding 2001). If depuration is not successful and fish with off-flavour are brought to the market then a whole farming operation or even the whole market for a species can suffer severely. This happened a couple of years ago with the sale of off-flavour Barramundi on a Dutch fish auction. As a result of this and other failures, several bankruptcies led to significant amounts of money and trust being lost by investors.

Based on these experiences several projects and initiatives have combined efforts in the Netherlands trying so solve the issues either directly or indirectly. At the moment studies are conducted along the aquaculture value chain, assessing markets and market potentials, new species are constantly screened for their chances when introduced to those markets, techniques inside and outside RAS are improved constantly to lower cost prices and to increase sustainability. Tools to assess sustainability are developed and implemented in certification schemes.

Conclusions

Overall the Dutch aquaculture sector is innovative and nested in a well structured governance framework. Stakeholders dialogues are facilitated and several umbrella organisations and instruments are in place allowing the sector to develop within the boundaries set by environmental sustainability. Such boundaries are animal welfare, nutrient emissions, introduction of new species, drug use and others. However, due to several reasons the sector is at this time in heavy weather. Several famers have been forced to temporarily stop their operation while waiting for the storm to blow over, while some less fortunate ones have gone bankrupt. This calls for a re-focussing of aquaculture governance to bring the sector back on its fins.

Additional information

- Ministry of Agriculture, Nature and Food Quality: www.minlnv.nl
- IMARES: www.imares.nl, LEI: www.lei.wur.nl, NGvA: www.ngva.nl
- Aquacultuur: www.aquacultuur.nl, Nevevi: www.pvis.nl.

References

Aubin, J., E. Papatryphon, H.M.G. van der Werf and S. Chatzifotis (2009), "Assessment of the environmental impact of carnivorous finfish production systems using life cycle assessment", *Journal of Cleaner Production* 17(3): 354-361.

Aubin, J. and H.M.G. Van der Werf (2009), "Fish farming and the environment: A life cycle assessment approach", *Cahiers Agricultures* 18(2): 220-226.

Bebak, J. (1998). *The Importance of Biosecurity in Intensive Culture. Recirculating Aquaculture*, Roanoke, Virginia, Virginia-Tech.

Bergheim, A. and A. Brinker (2003). "Effluent treatment for flow through systems and European Environmental Regulations." *Aquacultural Engineering* 27: 61-77.

Bergheim, A. and S.J. Cripps (1998), *Effluent Management: Overview of the European Experience*, Recirculating Aquaculture, Roanoke, Virginia, Virginia-Tech.

Bergheim, A., S.J. Cripps and H. Liltved (1998), "A system for the treatment of sludge from land-based fish-farms", *Aquatic Living Resources* 11(4): 279-287.

Blancheton, J.P. (2000), "Developments in recirculation systems for Mediterranean fish species", *Aquacultural Engineering* 22(1-2): 17-31.

Burton, C.H. and C. Turner (2003, *Manure Management: Treatment Strategies for Sustainable Agriculture,* Bedford, UK, Silsoe Research Institute.

Chen, S., Z. Ning and R.F. Malone (1996). "Aquaculture Sludge Treatment Using an Anaerobic and Facultative Lagoon System", International conference on recirculation technology, Roanoke, Virginia, Virginia-Tech.

Chen, S., D. Stechey and R.F. Malone (1997), "Suspended solids control in recirculating aquaculture systems" in M.B. Timmons and T.M. Losordo, *Aquaculture Water Reuse Systems: Engineering Design and Management,*. Amsterdam, The Netherlands, Elsevier. 27: 61-100.

D'Orbcastel, E.R., J.P. Blancheton and J. Aubin (2009), "Towards environmentally sustainable aquaculture: Comparison between two trout farming systems using Life Cycle Assessment", *Aquacultural Engineering* 40(3): 113-119.

De Boer, I.J.M., P.L. Van Der Togt, M. Grossman and R.P. Kwakkel (2000), "Nutrient flows for poultry production in The Netherlands", *Poultry Science* 79(2): 172-179.

Eding, E.H., V. Sereti, O. Schneider, A. Kamstra, M. C.J. Verdegem and J.A.J. Verreth (2004), "The development of low ("zero") discharge freshwater systems in a polluter pays principle environment", World Aquaculture 2004, Hawaii, USA, World Aquaculture Society.

Eding, E.H. and J.H. van Weerd (1999), "Grundlagen, Aufbau und Management von Kreislaufanlagen"in M. Bohl, *Zucht und Produktion von Süßwasserfischen,* Frankfurt, Germany, DLG-Verlagsgesellschaft-GmbH: 436-491.

European Commssion (2009), "A new impetus for the Strategy for the Sustainable Development of European Aquaculture", European Commission: 13.

Gautier, D., C.E. Boyd and R.T. Lovell (2002), "Sampling channel catfish ponds for pre-harvest off-flavor detection", *Aquacultural Engineering* 26(3): 205-213.

Gebauer, R. (2004), "Mesophilic anaerobic treatment of sludge from saline fish farm effluents with biogas production", *Bioresource Technology* 93(2): 155-167.

Hari, B., B. M. Kurup, J. T. Varghese, J. W. Schrama and M. C. J. Verdegem (2004). "Effects of carbohydrate addition on production in extensive shrimp culture systems." *Aquaculture* 241(1-4): 179-194.

Hurlburt, B.K., S.S. Brashear, S.W. Lloyd, C.C. Grimm, J.L. Thomson and P.V. Zimba (2009), "Impact of weather on off-flavour episodes at a Louisiana commercial catfish farm", *Aquaculture Research* 40(5): 566-574.

Kamstra, A., E.H. Eding and O. Schneider (2001), "Top Eel Farm Upgrades Effluent Treatment in Netherlands", *Global Aquaculture Advocate* 4(3): 37-38.

Kamstra, A., J.W. Heul van der and M. Nijhof (1998), "Performance and Optimisation of Trickling Filters on Eel Farms", *Aquacultural Engineering* 17: 175-192.

Kamstra, A., P. Rand, A. Aarninck and K. Kloet (2000), "Recirculation Systems for Farming Eel in Western Europe: Towards a Certified Environmental Performance", Recirculating Aquaculture, Roanoke, USA, COTA, Virginia Tech.

Lanari, D. and C. Franci (1998), "Biogas production from solid wastes removed from fish farm effluents", *Aquatic Living Resources* 11(4): 289-295.

LNV, M. v. (2004), Viskweek in Nederland, een aanzet voor een nationale agenda ten behoeve van de verdure duurzame ontwikkeling van de viskweek, Den Haag.

Losordo, T.M. (1998), "Recirculating Aquaculture Production Systems: The Status and Future." *Aquaculture Magazine* 24(Jan./Febr.): 38-53.

Losordo, T.M. and M.B. Timmons (1997), "Aquaculture Water Reuse Systems: Engineering Design and Management" in M.B. Timmons and T.M. Losordo, *An introduction to Water Reuse Systems,* Amsterdam, The Netherlands, Elsevier. 27: 1-8.

Martins, C., E.H. Eding, O. Schneider and J.A.J. Verreth (2005), "Recirculation Aquaculture Systems in Europe", Oostende, Belgium, Consensus working Group, European Aquaculture Society: 31.

McIntosh, R.P. (2001), "High rate bacterial systems for culturing shrimp", Aquacultural Engineering Society's 2001 Issues Forum, Shepherdstown, USA, Aquacultural Egineering Society.

Muir, J.F. (1982), "Recirculated Water Systems in Aquaculture" in J.F. Muir and R.J. Roberts, *Aquaculture,* London & Canberra, Westview Press, 1: 357-447.

Neori, A., T. Chopin, M. Troell, A.H. Buschmann, G.P. Kraemer, C. Halling, M. Shpigel and C. Yarish (2004), "Integrated aquaculture: rationale, evolution and state of the art emphasizing seaweed biofiltration in modern mariculture", *Aquaculture* 231(1-4): 361-391.

Neori, A., M. Shpigel and D. Ben-Ezra (2000), "A sustainable integrated system for culture of fish, seaweed and abalone", *Aquaculture* 186(3-4): 279-291.

Pelletier, N., P. Tyedmers, U. Sonesson, A. Scholz, F. Ziegler, A. Flysjo, S. Kruse, B. Cancino and H. Silverman (2009), "Not All Salmon Are Created Equal: Life Cycle Assessment (LCA) of Global Salmon Farming Systems", *Environmental Science & Technology* 43(23): 8730-8736.

Percival, S., P. Drabsch and B. Glencross (2008), "Determining factors affecting muddy-flavour taint in farmed barramundi, Lates calcarifer", *Aquaculture* 284(1-4): 136-143.

RAMSAR (2002), "Information Sheet on Ramsar Wetlands." from www.wetlands.org/reports/ris/3NL032en.pdf.

Rosati, R. (2000), "Treatment of Shrimp Pond Effluent Using Constructed Wetlands", *The Global Aquaculture Advocat* 3(3): 94-95.

Schneider, O. (2006), *Fish waste management by heterotrophic bacteria conversion,* Wageningen, The Netherlands, Wageningen University.

Schneider, O., J.P. Blancheton, L. Varadi, E.H. Eding and J.A.J. Verreth (2006), "Cost Price and production strategies in European Recirculation Systems.Linking Tradition & Technology Highest Quality for the Consumer", Firenze, Italy, WAS.

Schneider, O., T.L. Cong, V. Sereti, J.W. Schrama, E.H. Eding and J.A.J. Verreth (2006), "Bacteria or commercial diet: The preferences of Litopenaeus vannamei" *Aquaculture Research* 37: 204-207.

Schneider, O. and E.H. Eding (2001), *Paling- en meevalteelt in recirculatiesystemen*. Gent, Meetjesland.

Schneider, O., B.J. Fuentes, R. Bosma and E.H. Eding (2009), "SustainAQ Deliverable 2", IMARES Reports, Ijmuiden, Yerseke, IMARES: 100.

Schneider, O., V. Sereti, E.H. Eding and J.A.J. Verreth (2004), "Analysis of nutrient flows in integrated intensive aquaculture systems"m *Aquacultural Engineering* 32(3/4): 379-401.

Schneider, O., V. Sereti, E.H. Eding, J.A.J. Verreth and A. Klapwijk (2007), "Kinetics, design and biomass production of a bacteria reactor treating RAS effluent streams", *Aquacultural Engineering* 36: 24-35.

Schneider, O., J. Verreth and E.H. Eding (2002), "Framework introduction of zero nutrient discharge aquaculture by farming in integrated recirculating systems in Asia: ZAFIRA", World Aquaculture 2002, Beijing, World Aquaculture Society, USA.

Schneider, O. and J.A.J. Verreth (2008), *Europäische Aquakultur in Kreislaufanlagen,* Eurotier, Hannover, DLG.

Schneider, O. and J.A.J. Verreth (2008), "Fischfang und Fischerzeugung - Perspektiven für Forschung und Wirtschaft" in *Haltungssysteme für die*

Fischerzeugung und deren ökonomische Betrachtung, Hannover, Dachverband Agraforschung.

Schneider, O., J.A. J. Verreth and E.H. Eding (2001), *ZAFIRA, Introduction of a framework of Zero Nutrient Discharge Aquaculture by Farming in Integrated Recirculating Systems in Asia*, Aquacultural Engineering Society's 2001 Issues Forum, Shepherdstown, USA, Aquacultural Egineering Society.

Schram, E., V. Sereti, F.E. d. Buisonje, H.H. Ellen and H.W. v.d. Mheen (2006), "De productie van reststromen door de Nederlandse visteelt", *IMARES Reports,* H.W. v.d. Mheen,Ijmuiden, Wageningen IMARES.

Shpigel, M. and A. Neori (1996), "The integrated culture of seaweed, abalone, fish and clams in modular intensive land-based systems. Proportions of size and projected revenues" *Aquacultural Engineering* 15(5): 313-326.

Summerfelt, S.T., P.R. Adler, D.M. Glenn and R.N. Kretschmann (1999), "Aquaculture sludge removal and stabilization within created wetlands", *Aquacultural Engineering* 19: 81-92.

Tamminga, S. (2003), "Pollution due to nutrient losses and its control in European animal production", *Livestock Production Science* 84(2): 101-111.

Tchobanoglous, G., F.L. Burton and H.D. Stensel (2003), *Wastewater Engineering Treatment and Reuse,* Boston, McGraw-Hill.

Timmons, M.B., J.M. Ebeling, F.W. Wheaton, S.T. Summerfelt and B.J. Vinci (2001), *Recirculating Aquaculture Systems,* Ithaca, NY, USA, Cayuga Aqua Ventures.

Turchini, G.M., V.M. Moretti, T. Mentasti, E. Orban and F. Valfre (2007), "Effects of dietary lipid source on fillet chemical composition, flavour volatile compounds and sensory characteristics in the freshwater fish tench (*Tinca tinca L.*)", *Food Chemistry* 102(4): 1144-1155.

van Rijn, J., Y. Tal and H. J. Schreier (2006), "Denitrification in recirculating systems: Theory and applications", *Aquacultural Engineering* 34(3): 364-376.

Verdegem, M., R. Bosma and J. Verreth (2006), "Reducing Water Use for Animal Production through Aquaculture", *Water Resources Development* 22(1): 101-113.

Verdegem, M. and E.H. Eding (2001), "Biological control of water purification and nutrition in aquatic recirculation systems. Proposal for "Adaptation for the Future", Wageningen.

Verreth, J.A.J. and E.H. Eding (1993), "European Farming Industry of African Catfish (*Clarias gariepinus*) Facts and Figures", *Journal of the World Aquaculture Society* 24(2): 6-13.

Chapter 14

Agriculture's impact on aquaculture: Hypoxia and eutrophication in marine waters

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Abstract

Over the last 20-30 years aquaculture has become a major source of food and livelihood. As aquaculture production expands there are emerging threats from land-based activities, primarily from agriculture but also from an expanding human population. Environmental externalities of nutrient enrichment and resulting eutrophication and hypoxia have recently become key stressors at global scales.

Globally, it was not obvious that dissolved oxygen would become critical in brackish and shallow coastal systems until the 1970s and 1980s when large areas of low dissolved oxygen started to appear with associated mass mortalities of invertebrate and fishes. Bottom fisheries are displaced from these areas and it is the reason they are called dead zones. From the middle of the 20th century to today, there have been drastic changes in dissolved oxygen concentrations and dynamics in many marine areas.

No other environmental variable of such ecological importance to balanced ecosystem function as dissolved oxygen has changed so drastically, in such a short period of time. Currently there are over 500 hypoxic systems covering over 240 000 km^2 around the globe related to human activities. The great future challenge will be to integrate agriculture and other land based activates with aquaculture in a manner that addresses the multiple needs of humans but also protects ecosystem services and function that humans depend on. If nutrient and organic loading can be controlled and reduced, systems will recover from hypoxia.

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Introduction

Over the last 20-30 years aquaculture has become a major source of food and livelihood. Globally, as production from capture fisheries remains constant or declines, aquaculture production continues to show strong growth. As aquaculture production expands there are emerging threats from land-based activities, primarily agriculture but also from expanding populations in the coastal zone. This report summarizes and assesses the environmental externalities of nutrient enrichment, eutrophication, and hypoxia associated with the expanding agriculture on the aquaculture sector.

Globally, it was not obvious that dissolved oxygen would become critical in brackish and shallow coastal systems until the 1970s and 1980s when large areas of low dissolved oxygen started to appear with associated mass mortalities of invertebrate and fishes. From the middle of the 20th century to today, there have been drastic changes in dissolved oxygen concentrations and dynamics in many marine coastal areas. No other environmental variable of such ecological importance to balanced ecosystem function as dissolved oxygen has changed so drastically, in such a short period of time. Currently there are over 500 hypoxic systems covering over 240 000 km^2 around the globe related to human activities.

The great challenge for the future will be to integrate agriculture and other land based activates, and aquaculture management in a manner that addresses the multiple needs of humans but also protects ecosystem services and function that humans depend on. Institutions capable of integrating these different sectors with shared goals to feed people will have to be developed. If nutrient and organic loading can be controlled and reduced, systems will recover from hypoxia.

A central premise for management of externalities from agriculture into the future must include an ecosystem approach that centers on the sustainability to address the multiple needs of humans with adequate protection of ecosystem services and function that humans also depend on. Intensification and technological improvements may sustain the profitability of agriculture, but it does so at a cost to water quality, which directly impacts on aquaculture and other ecosystem services. Strides have been made recently in mitigating nutrient and organic loadings, but as agricultural production expands even lower nutrient loading levels will become a problem. Recent studies have shown that after years of eutrophication, it may not be as simple as reducing nutrients to reverse water quality problems, especially associated with hypoxia.

Background, scope objectives

While aquaculture has ancient roots in Asia, it was in the 1970s that aquaculture started to increase the ecosystem service[1] of food provisioning worldwide. This growth has led aquaculture to become a significant source of food and income to much of the world population. By 2050, the world will need 70 to 100% more food (Godfray *et al.*, 2010) and aquaculture in coastal waters will be an important component of this expansion. Total global capture production averaged about 90.5 million tonnes per year from 1997 to 2007 and many stocks are currently over exploited. In contrast, aquaculture production has continued to show strong growth, increasing from about 37 million tonnes in 2002 to 50 million tonnes in 2007. Aquaculture systems now account for roughly 35% of total fish production (FAO, 2009). Finfishes account for about half of aquaculture production followed by mollusks and plants each 20% to 23%.

As aquaculture production expands there are emerging threats from land-based activities, primarily agriculture but also from industrial activities and expanding populations in the coastal zone. Human population expansion has lead to an exponential modification of landscapes and seascapes at the expense of ecosystem function and services including pervasive effects from fueling coastal primary production with excess nutrients to fishing down the food web (Foley *et al.*, 2005, Lotze *et al.*, 2006, MA 2005, Vitousek *et al.*, 1997, Pauly *et al.*, 1998, Jackson *et al.*, 2001). Crop and rangelands now cover over 25% of the Earth's land area, and are currently expanding (Swinton *et al.*, 2007). Long-term records of nutrient discharges provide compelling evidence of a rapid increase in the fertility of many temperate coastal ecosystems starting about 50 years ago (Galloway *et al.*, 2004). On a global basis, by 2050, coastal marine systems are expected to experience, from today's levels, a 2.4-fold increase in nitrogen and 2.7-fold increase in phosphorus loading from this population expansion (Tilman *et al.*, 2001), with serious consequences to ecosystem structure and function.

To ignore environmental degradation of water quality will jeopardize future production of both aquaculture and capture fisheries. Land-based activities are recognized as a major problem to the sustainability of coastal ecosystems. Also, as aquaculture expands, care must be taken to keep aquaculture from degrading the water quality it depends on (Dasgupta, 2010). This report summarizes and assesses the environmental externalities associated with the expanding agriculture pollution on aquaculture and marine ecosystems.

Key environmental issues

Along with the large increase in food provisioning service that agriculture provides come a series of negative environmental issues. The primary externalities and issues discussed in this report will be those that affect regulating services of water quality and trophic structure, and the supporting services of nutrient cycling, biodiversity, and habitat. The Millennium Ecosystem Assessment (MA, 2005) provides a framework for describing the key environmental issues in terms of ecosystem services (Table 14.1). One of the most difficult areas in the ecosystem service chain relates to trade-offs among services. Often, optimizing delivery of a given service may reduce or impair another (Mooney, 2010). Agriculture provides a primary example. The enhanced provisioning of food can result in loss of clean water and stress to biodiversity that supports other services (MA, 2005).

Table 14.1: Global status of provisioning, regulating, and cultural ecosystem services

Service	Sub-category	Status	Notes
Provisioning Services			
Food	Crops	+	Substantial production increase
	Livestock	+	Substantial production increase
	Capture fisheries	-	Declining production due to overharvest
	Aquaculture	+	Substantial production increase
	Wild foods	-	Declining production
Fiber	Timber	+/-	Forest loss in some regions, growth in others
	Cotton, hemp, silk	+/-	Declining production of some fibers, growth in others
	Wood fuel	-	Declining production
Genetic resources		-	Lost through extinction and crop genetic resource loss
Biochemicals, natural medicines		-	lost through extinction, overharvest
Freshwater		-	Unsustainable use fro drinking, industry and irrigation
Regulating services			
Air quality regulation		-	Decline in ability of atmosphere to cleanse itself
Climate regulation	Global	-	Net source of carbon sequestration since mid-century
	Regional and local	-	Preponderance of negative impacts
Water regulation		+/-	Varies depending on ecosystem change and location
Erosion regulation		-	Incresed soil degradation
Water purification and waste treatment		-	Declining water quality
Disease regulation		+/-	Varies depending on ecosystem change
Pest regulation		-	Natural control degraded through pesticide use
Biological control, trophic strucutre		+/-	Trophic dynamic regulations of populations
Pollination		-	Apparent global decline in abundance of pollinators
Natural hazard regulation		-	Loss of natural buffers (wetlands, mangroves)
Supporting services			
Soil formation		+	Weathering of rock and erosion
Photosynthesis		+	
Primary production		+	Net primary production has increased
Biodiversity		-	Loss of species
Nutrient cycling	Nitrogen	-	Large-scale changes from general eutrophicaiton
	Phosphorus	-	
Water cycling		-	Major changes from structural change in rivers, water
Habitat, refugia		-	Withdrawal and climate change
Cultural services			
Spiritual and religious values		-	Rapid decline in sacred groves and species
Aesthetic values		+/-	Decline in quantity and quality of natural land
Recreation and ecotourism			More areas accessible but many degraded

Status indicates whether the condition of the service globally has been enhanced (+) or degraded (-) in the recent past. Ecosystem services directly linked to aquaculture are in bold.

Source : Costanza *et al*, 1997; MA 2005.

Globally, human activities have lead to large-scale modification of landscapes and seascapes at the expense of ecosystem function and services (Foley *et al.*, 2005, Lotze *et al.*, 2006; Halpern *et al.*, 2008). Alterations to nutrient cycles, primarily nitrogen and phosphorus used in agricultural industries, have fueled primary production and caused widespread eutrophication of inland and coastal waters. This eutrophication has driven changes in trophic structure and formation of low dissolved oxygen or hypoxia in bottom waters at global scales (Díaz and Rosenberg, 2008). But these are only part of a complex of multiple stressors that interact to shape and direct ecosystem level processes (Cloern, 2001; Breitburg and Riedel, 2005).

What is eutrophication?

Eutrophication is the leading cause of water quality impairment around the world. It is the over-enrichment of water with nutrients such as nitrogen and phosphorus as a result of human activity. Eutrophication can be defined simply as the increase in the rate of production and accumulation of organic carbon in excess of what an ecosystem is normally adapted to processing (Nixon 1995; Rabalais 2004). Eutrophication can be harmful to both freshwater and marine ecosystems, and leads to a progression of symptoms that include (Selman *et al.*, 2008):

- Excessive phytoplankton and macroalgal growth that is the source of organic carbon for accumulation. This can also reduce light penetration and lead to a loss of submerged aquatic vegetation (SAV).

- An imbalance of nutrient ratios that can lead to a shift in phytoplankton species composition and creating conditions that are favorable to nuisance and toxic algal blooms. Harmful algal blooms (HABS) can cause fish kills and shellfish poisoning in humans.

- Changes in species composition and biomass of the benthic (bottom-dwelling) community; eventually leading to reduced species diversity and increased dominance of gelatinous organisms such as jellyfish.

- Low dissolved oxygen and formation of hypoxic or dead zones (oxygen-depleted waters). These oxygen-starved areas stress aquatic ecosystems, often leading to fish kills, altered ecosystem energy flows, and in severe cases ecosystem collapse.

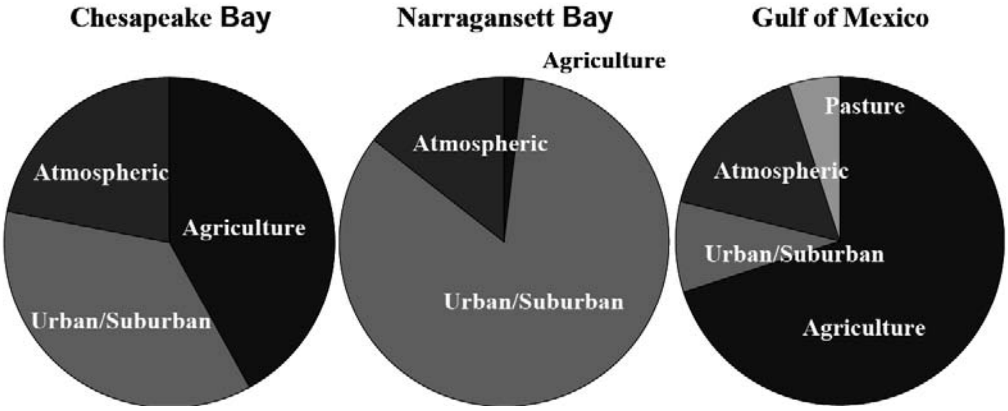
Sources of nutrients to coastal waters are diverse and vary from system to system. Nutrients enter coastal ecosystems through atmospheric deposition, surface water runoff, and groundwater (Table 14.2). Within the United States, municipal wastewater is the primary driver of eutrophication in Narragansett Bay, in the northern Gulf of Mexico it is agriculture, and in Chesapeake Bay atmospheric, urban/suburban, and agricultural sources are all co-equal (Figure 14.1). Broad scale regional differences also exist in the relative importance of nutrient sources. For example, in the US and the EU, agricultural sources are generally the primary contributors to eutrophication, while in Asia and Africa nutrient pollution is primarily attributed to municipal wastewater.

Table 14.2: Sources and pathways of nutrients entering coastal systems

	Pathways		
Sources	**Air**	**Surface Water**	**Groundwater**
Fossil Fuel Combustion	X		
Septic Systems			X
Urban Stormwater Runoff		X	
Industry		X	
Urban Wastewater/Sewage		X	
Agricultural Fertilizers	X	X	X
Livestock Operations	X	X	X
Aquaculture		X	

Source: Seman *et al.,* 2008

Figure 14.1: Comparison on the relative distribution of majour souces of nitrogen pollution in three coastal eco-systems experiencesing hypoxia



Urban/suburban includes both point (industrial and sewage effluent) and nonpoint sources

Source: Jewett *et al.*, 2009

What is hypoxia?

Oxygen is necessary to sustain the life of fishes and virtually all higher invertebrates. When the supply of oxygen is cut off or consumption exceeds resupply, oxygen concentrations can decline below levels that will sustain animal life. This condition of low oxygen is known as hypoxia. Water devoid of oxygen is referred to as anoxic. Ecologists have borrowed the term hypoxia from the medical community but the meaning and processes for the environment are the same. The medical condition is a deficiency in the amount of oxygen reaching tissues. Similarly, a water body can be deprived of adequate oxygen for proper ecosystem functioning. Hypoxic and anoxic waters differ qualitatively as well as in the quantity of oxygen they contain; anoxic waters typically contain concentrations of hydrogen sulfides (H_2S) that are lethal to most macrofauna.

Hypoxia in bottom waters of estuaries, coastal seas and other similar systems is typically caused when algae die, sink to the bottom, and are decomposed by bacteria, which use up the available dissolved oxygen. When this process is coupled with stratification of the water column, which limits mixing of more oxygen rich waters from the surface to the bottom, oxygen depletion can occur (Rabalais and Turner, 2001; Rabalais and Gilbert, 2008). Hypoxia is typically seasonal, forming in the spring and summer months in North America and in summer and autumn months in Europe. Some systems, such as the Baltic and Caspian Seas, experience year-round hypoxia due to the severity of eutrophication (Dumont, 1998; Karlson *et al.*, 2004).

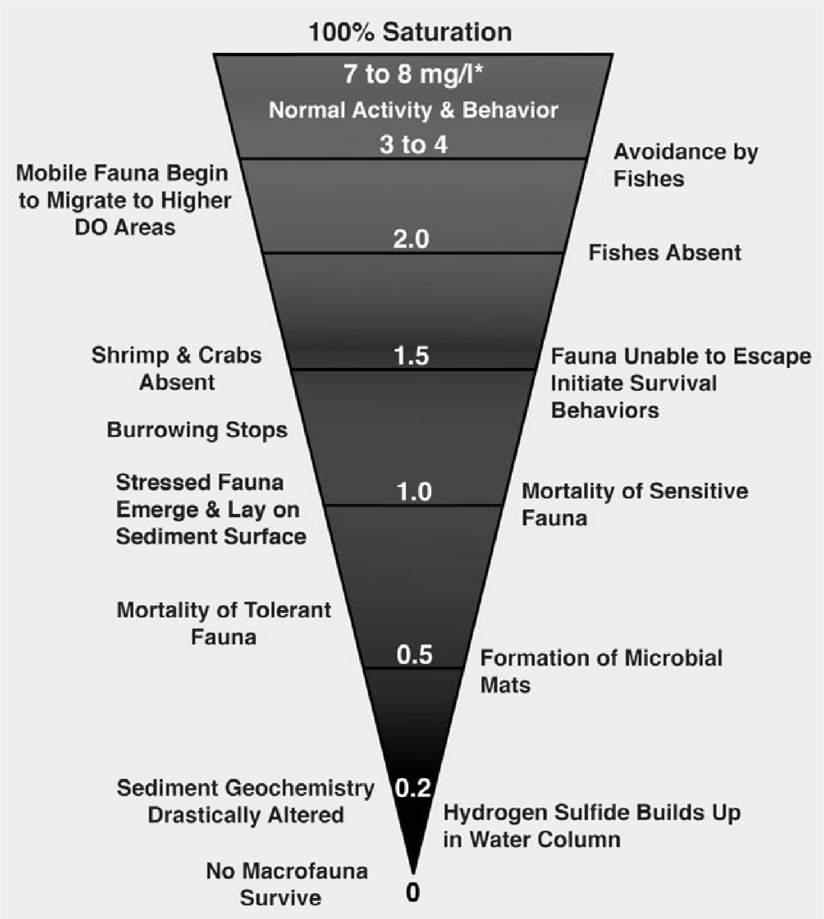
Hypoxic areas are sometimes referred to as dead zones. The term was first applied to the northern Gulf of Mexico hypoxic area (Rabalais *et al.*, 2002, 2010) refers to the fact that fish and shrimp avoid and migrate out of hypoxic areas. When fishermen trawl in bottom waters of these zones little to nothing is caught. The link between hypoxia and dead zones is best applied to inshore and coastal waters where oxygen depletion occurs in otherwise normoxic (well oxygenated) waters, with evident migration or mortality of fishes and large invertebrates. In the absence of larger fauna, smaller organisms (*i.e.* foraminiferans, nematodes) and microbes persist, such that the regions are not truly dead. And the fully oxygenated upper water column supports diverse communities, including productive fisheries.

Two other forms of hypoxia are important to consider and can affect aquaculture. The first is diel-cycling hypoxia, which, like the hypoxic bottom waters described above, is often caused or exacerbated by anthropogenic nutrient enrichment. In shallow waters with diel (or day-night) cycling hypoxia mid-day oxygen concentrations can be very high due to oxygen generated by photosynthesizing algae and macrophytes. When light levels drop too low for photosynthesis, however, algae and macrophytes (along with other organisms present) continue to respire and consume oxygen, but do not generate oxygen. As a result, oxygen concentrations can drop substantially during night and early morning hours (Tyler *et al.*, 2009). Like the bottom layer hypoxia described above, diel cycling hypoxia is most prevalent during warm months when both biomass and respiration rates are high. The second intermittent form of hypoxia is upwelling of deep oxygen minimum zone waters into nearshore areas. Although increasing oceanic temperatures and land-based nutrients can have some affect on the depth and characteristics of oxygen minimum zones, upwelling into nearshore habitats is largely a natural process cause by winds that advect surface waters offshore (Levin *et al.*, 2009).

Because of its low solubility in water small changes in the absolute amount of oxygen dissolved in water lead to large differences in percent air saturation. Depending on temperature and salinity, water contains 20–40 times less oxygen by volume and diffuses about ten thousand times more slowly through water than air (Graham, 1990). Thus what appear to be small changes in oxygen can have major consequences to animals living in an oxygen-limited milieu.

While many authors and water quality regulations focus on concentrations of dissolved oxygen below 2–3 mg O_2/L as a threshold value for hypoxia in marine and brackish water environments, such arbitrary limits may be unsuitable when examining potential impacts of hypoxia on any one given species (Vaquer-Sonyer and Duarte, 2008). Hypoxia becomes detrimental when behavioral and physiological responses result in altered behavior or negative impacts, such as reduced growth, loss of reproductive capacity, mortality, reduced biodiversity, and loss of secondary production, including fisheries (Figure 14.2). For example, Atlantic cod (*Gadus morhua*) growth in the St. Laurence is reduced below about 7 mg O_2/L or 70% air saturation (Chabot and Dutil, 1999). Shrimp and fish avoid dissolved oxygen below 2 mg O_2/L (approximately 30% air saturation) in the northern Gulf of Mexico hypoxic zone, while sharks and rays emigrate from the area at a oxygen concentrations below 3 mg O_2/L (Rabalais *et al.*, 2001a).

Figure 14.2: Cone of faunal response to declining oxygen concentration

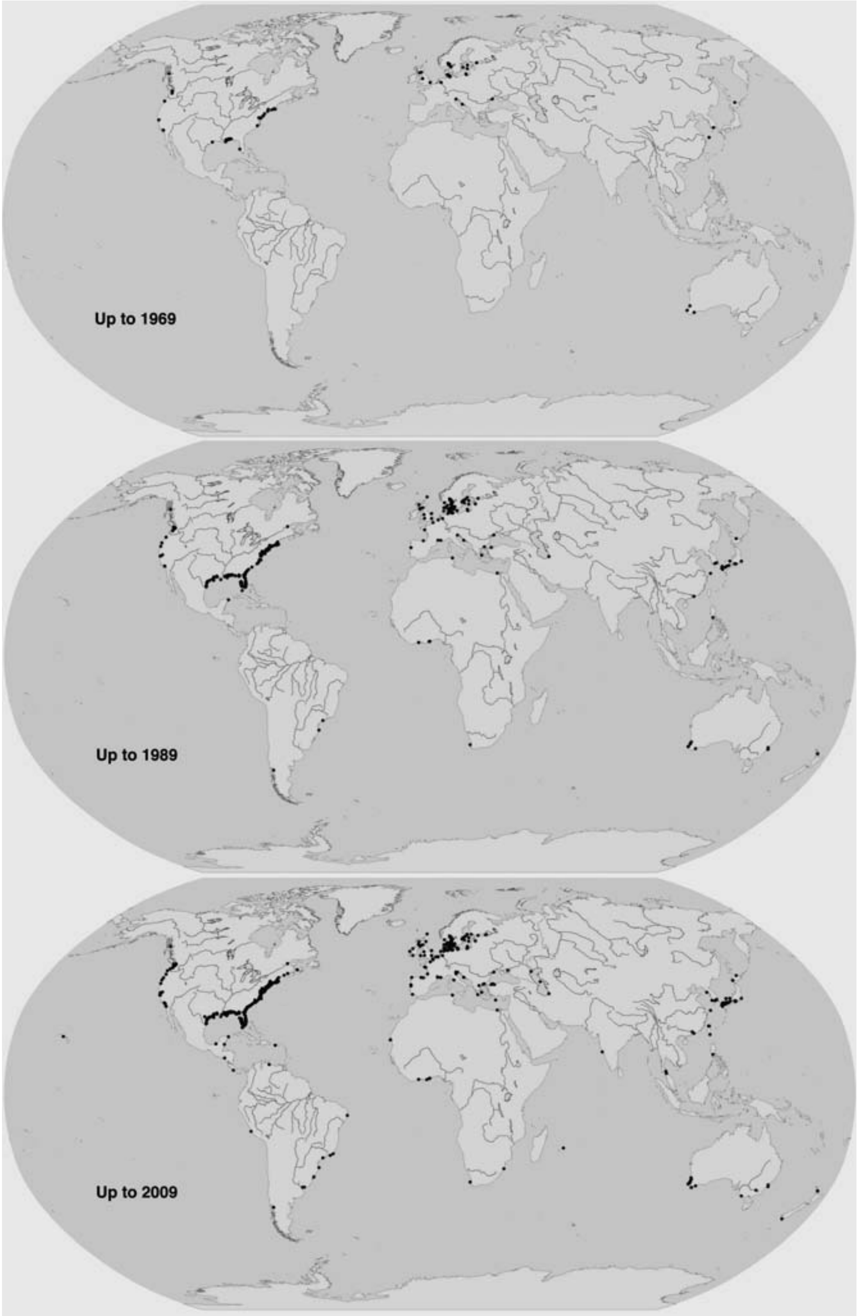


Source: based on data from Diaz and Rosenberg, 1995 and Rabalais *et al.,* 2001a

Increase in eutrophication and hypoxia

Hypoxia is the most severe symptom of eutrophication and is becoming more prevalent (Figure 14.3). The number of hypoxic zones in coastal waters has increased dramatically over the past 50 years, rising from about ten documented cases in 1960 to nearly 500 in 2010 (Rabalais *et al.*, 2010). Eutrophication and associated hypoxia in freshwater systems was also widespread in the 20th century and related to industrial and municipal discharges high in both nutrients and organic matter. In tidal portions of rivers and other water bodies near dense population centers, these types of discharge have caused severe hypoxia and anoxia. Effective nutrient management has reversed this trend where it has been rigorously implemented (Jeppesen *et al.*, 2005; Smith *et al.*, 1987). In some systems, for example, the Mersey (Jones, 2006) and Delaware (Weisberg *et al.*, 1996) River estuaries, areas devoid of fishes were reported as early as the 1800s. These conditions persisted until improvements in sewage treatment were implemented and water quality improved. But by the 1980s it became clear that nutrients in runoff from agricultural lands had increased, replacing nutrients removed by sewage treatment and that water quality declined in many coastal areas (Smith *et al.*, 1987; OSPAR 2000; Díaz and Rosenberg, 2008).

Figure 14.3: Global distribution of documented cases of hypoxia related to human activies, each represented by a dot



The number of hypoxic areas is cumulative for the successive time periods

Source: Rabalais *et al.,* 2010

Many coastal systems that are currently hypoxic were not so when first studied. For systems with historical data from the first half of the 20th century, declines in oxygen concentrations started in the 1950s and 1960s for the northern Adriatic Sea (Justić *et al.*, 1987), between the 1940s and 1960s for the northwest continental shelf of the Black Sea (see case studies), and in the 1970s for the Kattegat (Baden *et al.*, 1990). Declining dissolved oxygen levels were noted in the Baltic Sea as early as the 1930s (Fonselius, 1969), but it was in the 1950s that hypoxia became widespread (Karlson *et al.*, 2002). Other systems have experienced hypoxia since the beginning of oxygen data collection, for example, in the 1900s for Kamak Bay, Korea (Lim *et al.*, 2006), 1910s for Oslofjord, Norway (Mirza and Gray, 1981), 1920s for Thames Estuary, England (Andrews and Rickard, 1980), 1930s for Chesapeake Bay (Newcombe and Horne, 1938), and 1970s for the northern Gulf of Mexico (Turner and Rabalais, 2008).

Annual hypoxia does not appear to be a natural condition for most coastal waters, except some fjords and some upwelling areas. Even in Chesapeake Bay, which had hypoxia when DO measurements were first made in the 1910s in the Potomac River (Sale and Skinner, 1917) and 1930s in the mainstream channel (Officer *et al.*, 1984), the geological record suggests that hypoxia was not an annual, seasonally persistent feature of the system prior to European colonization (Zimmerman and Canuel, 2000). Similarly, geochronologies from the hypoxic area on the continental shelf of the northern Gulf of Mexico also indicate that the current seasonal hypoxia, which can cover over 20 000 km^2, did not form annually prior to the 1950s (Sen Gupta *et al.*, 1996). Hypoxia was recorded with the first oxygen measurement made in the area in the summer of 1973 on the central Louisiana continental shelf (Rabalais *et al.*, 2002) and has been an annual event ever since.

Importance of integrating impacts from multiple drivers

The effects of nitrogen enrichment and hypoxia on food webs and fisheries are strongly influenced by the extent to which these two factors co-occur. The perceived effects of nutrient enrichment and hypoxia also depend on the spatial scales of interest, which range from local, sometimes severely affected water masses to entire fisheries ecosystems (Breitburg *et al.*, 2009). To a degree, increased nutrients will increase biological production, whereas hypoxia reduces biomass and habitat quality and quantity (Caddy, 1993; Rabalais and Turner, 2001; Nixon and Buckley, 2002).

Aquaculture in coastal waters illustrates the problems of considering one stressor at a time. Culture of fish and shellfish requires good water quality, which is a function of many physical, chemical, and biological processes. In general, nutrient enrichment should lead to improved culture situations, particularly for plants and filter-feeding mollusks, if other environmental drivers are not degraded. Degradation in oxygen is one of the most serious threats to aquaculture. This usually unseen decrease in oxygen in bottom and shallow waters can lead to reduced growth and mortality. The emphasis on dissolved oxygen is warranted given the importance of oxygen for sustaining life for all fishes and invertebrates. Metaphorically speaking, the American Lung Association motto could be adopted for this situation. "When you can't breathe, nothing else matters."

Use of an ecosystem-based management approach that addresses cumulative effects to ensure the protection and maintenance of all ecosystem components, while promoting multiple sustainable uses is needed. For example, environmental management dictates that effects from nitrogen and phosphorus loading need to be considered in setting limits for total nutrient loading. To gain better understanding of how the stressors discussed above will interact in the context of both aquaculture and coastal eutrophication will require new research directions on responses to these multiple stressors. How the effects of nutrient enrichment resulting from agriculture interacts with other ecosystem stressors, such as toxic contaminants, capture fisheries, habitat loss, and climate change, will determine the future direction for aquaculture in any given area. In addition, systems vary tremendously in the amount of nutrient loading that will cause hypoxia because of variation in physical characteristics of systems (Breitburg *et al.*, 2009).

Trends in aquaculture to mitigate effects of agricultural pollution

Multiculture

A major development in the sustainability of aquaculture has been the culture of combinations of offsetting species. Offsetting species are those that can reduce negative impacts of eutrophication drivers from both agriculture and other aquaculture species. For example, filter-feeding bivalves can be used to take up organic matter resulting from nutrient discharges from land-based nutrient activities or intensive fish culture. In particular, oysters (*Crassostrea gigas*) have been found to grow up to three times faster and have better condition factors when grown near Chinook salmon cages compared to control sites. This is a consequence of the greater availability of particulate organic matter (Jones and Iwama, 1991). Not all filter feeding bivalves can benefit from co-location with finfish aquaculture, however. Mussels, *Mytilus edulis*, grow well on a diet of phytoplankton organic matter but their growth does not increase in response to organic matter from fish farms (Taylor *et al.*., 1992). This difference in response between bivalve species is related to fine details in life-histories, primarily diet preferences and feeding mechanisms (Dame, 1996).

As the characteristics of each species are different, there are some combinations of species that will work better than others at optimizing production and reducing environmental stress from agricultural related eutrophication. For example, macroalgae can be very efficient at directly taking up nutrients, and bivalves are most efficient at converting consumed organic matter into biomass. An added benefit to these species groups is that plants and filter feeders do not require additional input of feed to grow well, and therefore do not contribute to water quality problems. In contrast, most fishes and crustaceans are higher up the food chain and require higher protein content food to sustain higher growth rates, which can add to agricultural eutrophication stresses. Costa-Pierce (2008) in a review of ecosystem approaches to aquaculture in marine water found that combinations of species could lessen environmental impacts and at the same time maximize economic and social profit.

It has even been proposed that in systems that have lost historic populations of filter-feeding bivalves, restoration of these populations would reduce hypoxia by sequestering nutrients and organic matter in bivalve biomass (Newell *et al.*, 2005). For example, in Chesapeake Bay intense mortality associated with fisheries and disease caused a dramatic decline in eastern oyster stocks and associated Bay water filtration, which may have exacerbated the effects of eutrophication driven by excess nutrient loading (Kemp *et al.*, 2005).

Movement into offshore waters

Multiple uses of estuarine and marine habitats have increased in recent years from many different economic sectors (such as aquaculture, capture fisheries, recreation, marine transportation, mineral mining, oil and gas development, and recently, renewable energy; Halpern *et al.*, 2008; Godfray *et al.*, 2010). The growing awareness of the cumulative negative environmental impacts in inshore water from multiple sources makes the expansion of aquaculture into offshore or open coastal waters an important option. Movement to the offshore provides needed area and also eliminates or greatly lessens concerns over impacts from land-based eutrophication. The move of aquaculture into offshore waters may be especially important for fishes that require feeding and have high oxygen demands. Open coastal areas tend to have sufficient physical drivers (wind, current, and tides) to disperse wastes and excess food, and maintain good water quality, particularly for oxygen. While there is a general long-term trend of declining oxygen in coastal waters, the decline is greatest within 30 km of the coastline (Gilbert *et al.*, 2009). For filter feeders and plants, the move to offshore waters could reduce growth as nutrients and primary production decline with distance offshore.

To accommodate competing uses in both inshore and offshore waters, spatial planning needs to be undertaken to manage estuarine and marine habitats in a manner that reduces conflict, and enhances compatibility among uses, and sustains ecosystem functions and services (Turnipseed *et al.*, 2010). Aquaculture should be a big part of any coastal and marine spatial planning.

Principle externalities

The principle externalities effecting aquaculture can be divided into market or economic drivers and environmental or ecosystem health drivers. Controlling and accounting for environmental quality externalities will be a major concern for expansion and sustainability of aquaculture. There is a very tight coupling of aquaculture to ecosystem health. Both capture fisheries and aquaculture are vulnerable to external factors that shock ecosystems and reduce water or habitat quality (Smith *et al.*, 2010). Here we consider environmental drivers.

Damage to aquaculture and coastal ocean fisheries

Damage to both aquaculture and capture fisheries is likely to occur through intensification of eutrophication and hypoxia in both the inshore and offshore waters. Effects on mobile wild finfish and crustaceans, however, will be fundamentally different from sessile or captive aquaculture stocks. Wild stocks of many mobile species at least have some ability to behaviorally avoid habitats negatively impacted by eutrophication (Breitburg *et al.*, 2009). In contrast, mobility is constrained by aquaculture making organisms particularly susceptible to mortality resulting from negative effects of eutrophication as behavioral avoidance will be limited. Both hypoxia and HABS are of particular concern. For example, mass mortality of cultured fish (yellowtail *Seriola quinqueradiata* and red sea bream *Pagrus major*) in the eastern Seto Island Sea due to HABs is a frequent occurrence (Truslé 1995). In the eutrophic Prevost Lagoon hypoxia and H_2S can result in reduced bivalve production (Guyoneaud *et al.*, 1998).

Hypoxia fundamentally affects the use of space and movement through the system by altering migration pathways and transport. For example, a hypoxic event in 1976 that affected an area of about 1 000 km^2 along the coast of New York and New Jersey displaced demersal fishes and also blocked the migration of pelagic bluefish (*Pomatomus saltatrix*). Northward migrating bluefish that encountered the hypoxic zone did not pass through or around it, but stayed to the south waiting for it to dissipate and then continued their migration north (Azarovitz *et al.*, 1979). Hypoxia also alters spatial patterns of human use by influencing the spatial distribution of fisheries resources (Selberg *et al.*, 2001, Craig and Crowder 2005). Most negative effects tend to occur locally, within the region of the water body in which oxygen concentrations are reduced, but much wider ranging consequences can be mediated through the indirect effects of altered distributions and abundances (Breitburg *et al.*, 2009).

Fish kills are the most dramatic manifestation of both HABs and hypoxia and result from a combination of severe physical conditions and the failure of mobile animals to avoid or escape lethal conditions. The frequency and magnitude of fish kills have increased as nutrient-related hypoxia has worsened. Hypoxia-related kills that involve thousands to millions of finfish and crustaceans have been reported from systems as diverse as Mariager Fjord in Norway, Neuse River Estuary in North Carolina, along the Texas coast, and subtropical Richmond River Estuary in New South Wales (Fallesen *et al.*, 2000; NCDWQ 2006; Walsh *et al.*, 2004; Thronson and Quigg, 2008). In US waters, menhaden (*Brevoortia tyrannus* and *B. patronus*) kills feature prominently in records (Thronson and Quigg, 2008). These fish possess swim bladders, float where they are readily seen, and travel in large schools, so kills are often highly visible and affect large numbers of individuals.

It is important to consider that habitats avoided are functionally lost to species (Breitburg 2002; Rabalais and Turner, 2001). As a result, habitat loss due to hypoxia is far greater than would be estimated by calculations based on species recruitment or survival tolerances. Because species vary in their oxygen requirements, sensitive predators can lose access to prey. Crowding in more highly oxygenated refuges can result in density-dependent growth reductions (Eby and Crowder, 2002) or increased cannibalism (Aumann *et al.*, 2006). Because hypoxia can make deeper, cooler waters unavailable in the summer, or overlaps with nursery habitat, the combined effects of temperature and oxygen can result in habitat compression or squeeze that affects both pelagic and demersal species (Coutant 1985; Niklitschek and Secor 2005; Pearce and Balcom, 2005).

Some of the clearest examples of hypoxia-related population and fisheries declines involve systems in which discharges of raw sewage have caused severe oxygen depletion in tidal river portions of rivers and estuaries. The location and seasonal persistence of hypoxia appears to be particularly damaging to anadromous and catadromous species that require use of, and transit through, both saline and freshwater portions of systems to complete life cycles (Breitburg *et al.*, 2009). Large stretches of river estuaries such as the Mersey, Thames, Elbe, and Delaware have been described as devoid of fish prior to implementation of primary sewage treatment (Thiel *et al.*, 1995; Weisberg *et al.*, 1996; Tinsley, 1998; Jones, 2006). These hypoxic zones have blocked upriver spawning migrations or downriver outmigrations of species such as American shad (*Alosa sapidissima*) in the Delaware (Weisberg *et al.*, 1996); sea trout (*Salmo trutta*) in the Mersey (Jones, 2006); and sturgeon (*Acipenser sturio*), Atlantic salmon (*Salmo salar*), allis shad (*Alsoa alosa*), twait shad (*Alosa *fallaxx fallax*) sea lamprey (*Petromyzon marinus*), and European eel (*Anguilla anguilla*) in the Scheldt (Maes *et al.*, 2007), resulting in population declines or local extirpations.

There is also persuasive evidence of system-wide declines in fisheries landings and abundances of sensitive species in systems with very high percentages of bottom hypoxia (Breitburg *et al.*, 2009). For example, abundances of demersal fish and crustaceans, including mantis shrimp (*Oratosquilla oratoria*), have declined in Tokyo Bay, where up to two-thirds of the bottom becomes hypoxic during summer (Kodama *et al.*, 2002, 2006). Hypoxia also appears to contribute to system-wide fisheries declines in combination with pathogens (*e.g.* American lobster, *Homarus americanus*, in Long Island Sound; Pearce and Balcom, 2005) and other effects of eutrophication (*e.g.* reduced plaice recruitment in the Kattegat; Pihl *et al.*, 2005), particularly where the co-occurring or interacting stressors affect organisms in highly oxygenated areas that would otherwise serve as refuges from hypoxia.

Degradation of particularly critical or essential habitat can affect recruitment or fisheries landings. One of the better-known examples is the interannual variation in egg mortality and fisheries landings of Baltic cod in the Baltic. Spawning success of cod in the central Baltic is hindered by hypoxic and anoxic water below the halocline (70–80 m) where salinity is high enough to provide buoyancy for cod eggs (Nissling and Vallin, 1996; Cardinale and Modin, 1999; Köster *et al.*, 2005). In the Western Atlantic, hypoxia appears to contribute to low per capita productivity and slow recovery of cod stocks in the Gulf of St. Lawrence (Dutil *et al.*, 2007). Along the Texas and Louisiana shelf of the Gulf of Mexico, interannual variation in landings of brown shrimp (*Farfantepenaeus aztecus*) is negatively correlated with size of the hypoxic zone (O'Connor and Whitall, 2007). However, Texas fisheries regulations may contribute to the apparent strength of this correlation as fishing is prohibited on the inner shelf that serves as a refuge from hypoxia during much of the summer when northern Gulf of Mexico hypoxia is most extensive.

The continued expansion and development of hypoxia related to eutrophication may be the biggest externality that will damage both aquaculture. Hypoxia already forces movement of wild stock from large areas both inshore and offshore and at times can cause extensive mortality. It is also a major reason for the practice of fallowing of aquaculture facilities (O'Connor *et al.*, 1989). As aquaculture moves into offshore and deeper waters, oxygen will be a limiting factor in many areas around the globe that seasonally develop severe bottom water hypoxia. Offshore areas that may be risky places for aquaculture include the northern Gulf of Mexico off the coasts of Mississippi, Louisiana, and Texas, much of the Danish straits, the northern Adriatic Sea, the northwest Black Sea, the East China Sea off the Changjiang River (Rabalais *et al.*, 2010). If upwelling and OMZ move into shallower coastal water, as predicted with global climate change (Keeling *et al.*, 2010) and has occurred off the coast of Washington and Oregon (Chan *et al.*, 2008), then these areas will also be risky for aquaculture.

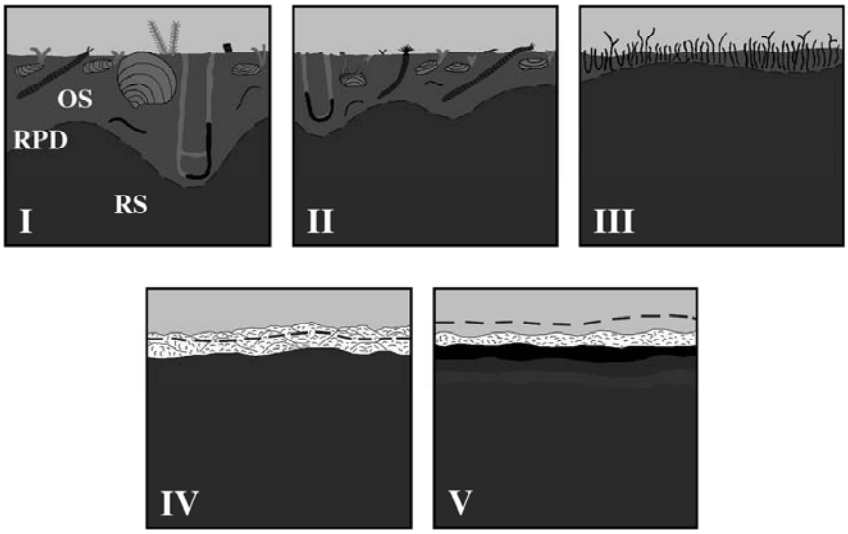
Water and sediment quality

Sedimentary processes are very important in development of hypoxia because this is where excess organic material in the form of senescent phytoplankton, fecal pellets, marine aggregates, and excess waste from finfish aquaculture is deposited. It then is either decomposed by aerobic and anaerobic processes or buried. As aerobic bacteria decompose the organic matter, the oxygen concentration overlying the sediments is consumed, and hypoxic/anoxic conditions can develop. In this transition from oxic to anoxic conditions, numerous biological and geochemical shifts occur. Bioturbation by benthic organisms declines, mortality increases, and bacteria thrive, which impacts elemental cycling (Middleburg and Levin, 2009).

In the Baltic Sea interannual changes in dissolved inorganic phosphate (DIP) pools below the pycnocline were positively correlated to changes in sediment area covered by hypoxic water (Conley *et al.*, 2002a). The changes in DIP were attributed to the release of phosphorus during hypoxic conditions with it returning to the sediments during non-hypoxic periods. Similarly, the flux of nitrogen in the form of ammonium from microbial respiration increases. The nitrification/denitrification cycle within sediments, which returns N_2 to the atmosphere, is the main mechanism for removal of reactive nitrogen. This cycle is disrupted by the limited availability of oxygen in sediments during hypoxia and the greenhouse gas N_2O is produced (Paulmier and Ruiz-Pino, 2009).

With continued accumulation of organic carbon at the seabed, microbial decomposition and oxygen consumption increase, but not in simple linear relationships (Meyer-Reil and Köster, 2000). The redox potential discontinuity layer migrates upward to the sediment-water interface, sulfate respiration replaces oxygen respiration, H_2S is generated from the sediments and oxygen penetrates less deeply into the sediments as the bioturbation potential of the infauna decreases during their demise due to sulfide toxicity or lack of sufficient oxygen (Figure 14.4) (Rumohr *et al.*, 1996; Gutiérrez *et al.*, 2000). Some shifts in the benthic microbial community are visible at the sediment-water interface in the form of bacterial mats (Jørgensen, 1980; Rosenberg and Díaz, 1993). These bacterial mats are indicators of near anoxic conditions and are commonly observed in both eutrophication driven hypoxia and where naturally occurring oxygen minimum zones intersect the seabed (Graco *et al.*, 2001; Levin *et al.*, 2009). When oxygen is severely depleted, or anoxic, H_2S builds up in the bottom waters as anaerobic bacteria metabolism reduces sulfate to H_2S (Jørgensen, 1980), the sediment becomes almost uniformly black, and there are no signs of aerobic life. Hydrogen sulfide is toxic to most metazoans and contributes to the overall mortality of benthic organisms.

Figure 14.4: Model stages of Baltic Sea benthos along a south/north transect (Danish straits to Bothnian Sea)



Notes : I:Climax community dominated by deep-burrowing species and a deep RPD layer. II: First signs of low oxygen stress, strong fluctuations, decreasing species reichness, increased biomass/production and shallowe RPD layer. III: Periods of hypoxia, dominated by small worms and RPD layter close to the sediment/water interface. IV: Long periods of hypoxia and formation of bacterial mats (*Beggiatoa* spp.) at the sediment surface, no macrofauna. V: Complete break-down of benthic communities

Water quality can be either degraded or improved by aquaculture depending on the species and environmental conditions. Certain groups of species, primarily mollusks and plants, can reduce organic and nutrient loading to the water column (Table 14.3). But physical drivers play a large role in determining the degree of impact to the water column. Suspension-feeders serve to couple pelagic and benthic processes because they filter suspended particles from the water column and the undigested remains, ejected as mucus-bound feces and pseudofeces, sink to the sediment surface. This biodeposition can be extremely important in regulating water column processes (Newell, 2004). Nitrogen excreted by the bivalves and regenerated from their biodeposits is recycled back to the water column to support further phytoplankton production. Where biodeposits are incorporated into surficial aerobic sediments that overlay deeper anaerobic sediments, microbially mediated, coupled nitrification-denitrification can permanently remove nitrogen from the system as N_2 gas. Consequently, aquaculture of bivalves may provide a supplement to water quality management and offset negative effects of agricultural nutrient loading. For example, modeled effect of mussel culture on nitrogen cycling at the mouth of the Gullmar Fjord, Swedish west coast, was to reduce the net transport of nitrogen by 20% (Lindahl *et al.*, 2005).

Table 14.3: Examples of multiculture or polyculture that have improved production and environmental quality

Species Combinations	Aquaculture/ecosystem response	Reference (in Costa-Pierce 2008)
Shrimp and Bay Scallop	Scallops grew quickly in shrimp pond water at intermediate densities.	Walker *et al.*, 1991
Shrimp, Mullet, and Oysters	4 ha modular shrimp system produced 40 t shrimp, 7 t mullet, 500 000 oysters per year	Sandifer and Hopkins 1996
Shrimp and Mangroves	Devoting 30-50% of shrimp pond to mangroves gave highest annual economic return.	Binh *et al.*, 1997
Salmon and Macroalgae	Improved water quality and increased economic return.	Buschmann *et al.*, 1996
Seabream, Bivalves, and Macroalgae	Improvements in whole system productivity and economics, but higher capital and marketing costs.	Shpigel and Neori 1996
Seabream and Mullet	Mullet under seabream reduced organic matter accumulations and improved sediment quality	Angle *et al.*, 1992
Salmon and Mussels	Mussels grew well on organic matter waste from salmon, good economic potential	Troell *et al.*, 1999
Salmon and Bivalves	Higher economic potentials with integration of scallops, oysters, and salmon	Cross 2004
Salmon and Seaweed	Improved water quality and economics, but increased management and marketing needed	Chopin *et al.*, 1999

Source: Summarised from Costa-Pierce (2008)

Currents may be the most significant driver of water quality around aquaculture facilities. Development of hypoxia and anoxia under aquaculture facilities, for example, is directly correlated to currents. Aquaculture sites well flushed by tidal currents, as in the Rias Baixas, northwest Spain, do not allow accumulation of organic matter (Tenore *et al.*, 1982). High flow rate bring a continuous supply of oxygen to the sediment water interface, which permits the survival of modified benthic communities even when sedimentary processes become anaerobic (Godbold and Solan, 2009). Low rates of water renewal can lead to deoxygenation in the overlying water column as sedimentary BOD increases (Pearson and Black, 2001). For example, fish culture in enclosed brackish waters of the Finnish archipelago, in the northern Baltic Sea, increased the level of eutrophication and enhanced algal mat growth, which at times has lead to anoxia and reductions in local fish and benthic populations (Bonsdorff *et al.*, 1997). When currents can keep surface sediments from becoming anaerobic impacts tend to be localized and not extend far from the culture facility.

Habitat

The process of eutrophication has occurred over long time periods during which basic characteristics of the ecosystem have changed, such as composition of the phytoplankton community, sequential demise of components of the benthic community, shifts in sedimentary structure and composition, and biogeochemical processes. Eutrophication from excess nutrients from land runoff and the subsequent development of hypoxia do not occur in a vacuum. Other stressors such as overfishing, habitat destruction, invasive species, and global climate change also contribute to degradation of habitat (Galloway *et al.*, 2008; Oguz, 2005; Cloern, 2001; Rabalais *et al.*, 2008).

The effect of hypoxia on sustainable yields of capture fisheries and aquaculture will depend on both the severity of eutrophication and whether critical or essential habitat is negatively affected. In the majority of highly nutrient-enriched systems, eutrophication creates a spatial and temporal mosaic of habitats that vary in physiological suitability. Eutrophication can simultaneously stimulate prey production and create areas of less favorable or completely unsuitable habitat by causing hypoxia, increasing macroalgal growth, and leading to the decline or disappearance of SAV. A result of this mosaic of prey-enhanced and degraded habitats, eutrophication, in general, and hypoxia, in particular, fundamentally alter the way mobile organisms utilize space and move through systems (Breitburg *et al.*, 2009).

Opportunistic and adaptive behaviors of mobile stocks can reduce the potential negative effects of eutrophication-degraded habitat patches (Pihl *et al.*, 1992; Brandt and Mason, 1994). However, this is not an option for captive aquaculture stocks. Avoidance of low dissolved oxygen concentrations and crowding of organisms into favorable habitat patches comes at a cost to predator or prey or both. In the northern Gulf of Mexico large-scale hypoxia (up to 22 000 km^2) on the Louisiana shelf occurs in regions that typically support high-density brown shrimp and results in substantial habitat loss (up to ~25% of the Louisiana shelf from May to September), with shifts in distribution and associated high densities both inshore and offshore of the hypoxic region. These shifts in spatial distribution during hypoxia have implications for organism energy budgets, trophic interactions, and fishery pressure (Craig and Crowder, 2005; Craig *et al.*, 2005).

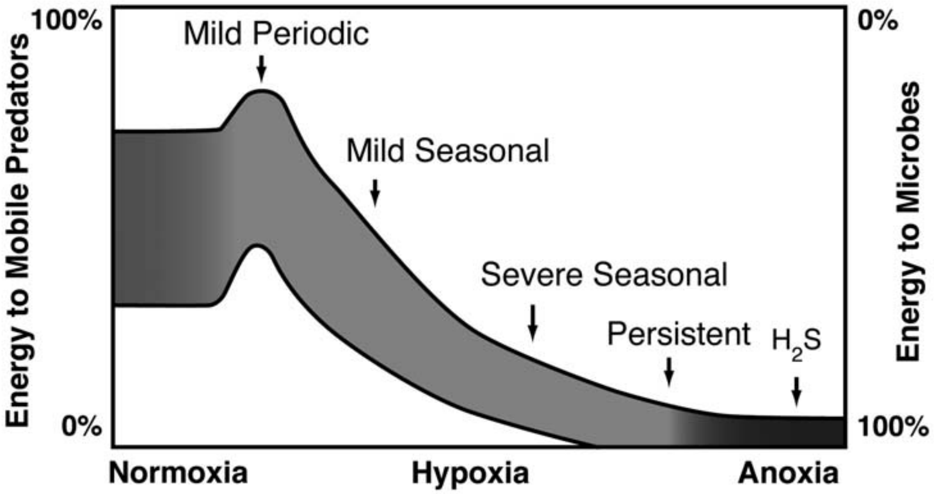
Effects of fisheries on eutrophication, and of eutrophication on fish yields, may be strongest in systems with extensive aquaculture production. Excess feed and feces associated with intensive cage culture of fish can cause localized hypoxia and HABs, resulting in losses of both cultured and wild fish production (Rosenthal, 1985; Naylor *et al.*, 2000). Bivalve aquaculture, in contrast, removes phytoplankton and can sometimes reduce negative effects of nutrient enrichment. Removal of farmed suspension-feeder biomass may have a greater potential than fisheries exploitation of wild populations to reduce eutrophication because of high rates of aquaculture removals. Aquaculture may, however, be particularly susceptible to mortality resulting from negative effects of eutrophication.

Function

In marine ecosystems, oxygen depletion has become a major structuring force for communities and energy flows. The elimination of fauna and compression of habitat by hypoxia not only alters population dynamics but also have profound effects of ecosystem energetics and functions. If oxygen concentrations decline below tolerance levels, organisms die and are decomposed by microbes. Ecosystem models for the Neuse River estuary (Baird *et al.*, 2004), Chesapeake Bay (Baird and Ulanowicz, 1989), and Kattegat (Pearson and Rosenberg, 1992) all show a hypoxia-enhanced diversion of energy flows into microbial pathways to the detriment of higher trophic levels.

Specific ecological effects will depend on the duration and severity of hypoxia. Short-lived and mild hypoxia may not have severe costs to energy flows as communities have been pre-conditioned to other eutrophication stresses and have developed resilience to hypoxia. Within a narrow range of conditions hypoxia facilitates upward trophic transfer as physiologically stressed fauna being forced to the sediment surface during hypoxia may be exploited by epibenthic predators (Pihl *et al.*, 1992). Under mild hypoxia, prey may also experience a relief from predation, as hypoxia is typically more stressful to the predators than the prey. In the Kattegat, for example, seasonal hypoxia led to an estimated 23% reduction in predation by crabs (Pearson and Rosenberg, 1992). Upward energy transfer is not enabled in areas where hypoxia is severe as either the benthos is killed directly and/or predators would be too stressed to enter the area. In all cases, the increase in the proportion of production transferred to predators is temporary and as mortality occurs, microbial pathways quickly dominate energy flows (Figure 14.5).

Figure 14.5: Conceptual view of how hypoxia alters ecosystem energy flow



Notes: For normoxia, area indicates the range of energy transferred from the benthos to higher-level predators, typically 25 to 75% of macrobenthic production. As a system experiences mild or periodic hypoxia, there can be a pulse of benthic energy to predators. This "windfall" is typically short-lived and does not always occur. With declining oxygen, higher-level predation is suspended, benthic predation may continue, and the proportion of benthic energy transferred to microbes rapidly increases. Under persistent hypoxia, some energy is still processed by tolerant benthos. Microbes process all benthic energy as H_2S, and anoxia develops.

Source: Diaz and Rosenberg, 2008

This energy diversion tends to occur in ecologically important places (nursery and recruitment areas) and at the most inopportune time (summer) for predator energy demands, and causes an overall reduction in an ecosystem's functional ability to transfer energy to higher trophic levels and renders the ecosystem potentially less resilient to other stressors. Reduction of the primary prey base for demersal predators from dead zones has consequences for ecosystem functioning and services other than biomass production for food webs. Key geochemical cycles are controlled by a complex interaction of oxygen, bioturbation, and sediment properties, for example, the balance between nitrification and denitrification.

Systems exposed to extensive periods of hypoxia and anoxia have low annual benthic secondary production with the amount of productivity a function of how quickly benthos can recruit and grow during periods of normoxia. Marine benthic systems suffering from hypoxia and anoxia at present once had benthic life. In some systems it is possible to make crude estimates of the biomass from prehypoxic times, *e.g.* estimate the "missing biomass" of today. For areas of the Baltic that are now persistently hypoxic and anoxic (70 000 km^2, Karlson *et al.*, 2002) missing biomass amounts to about 1.7 million metric tonnes wet weight, which represents about 30% of total Baltic secondary production (Elmgren, 1989). Similarly, estimates for Chesapeake Bay indicate that about 67 000 million tonnes wet weight is lost because of hypoxia each year, about 5% of total Bay secondary production (Díaz and Schaffner, 1990). If we assume about 40% of the benthic biomass is passed up the food chain in the Baltic (Möller *et al.*, 1985) and 60% in Chesapeake Bay (Díaz and Schaffner, 1990), then a total of 700 000 million tonnes wet weight of potential fish food energy is lost in the Baltic and 27 000 million tonnes wet weight in Chesapeake Bay. In the northern Gulf of Mexico that experience severe seasonal hypoxia, benthic biomass is reduced by as much as 9.3 million tonnes wet weight/km^2 (Rabalais *et al.*, 2001b), which is approximately a 113 000 million tonnes wet weight lost from the fisheries forage base when the size of the dead zone is 20 000 km^2, assuming a 60% transfer efficiency.

These losses in biomass from hypoxia deprive higher trophic levels of significant amounts of forage base. Because of the physiological dependence of productivity on temperature, hypoxia develops at times when production and benthic recruitment generally peak for non-opportunistic species; thus the longer hypoxia lasts the less time a system has to regain the lost biomass through production. The duration of seasonal hypoxia then becomes the primary factor affecting ecosystem energy flows. Within most systems that have strong seasonal cycles, increases in populations are related to recruitment events timed to take advantage of the input of new organic matter and populations decline from a combination of resource depletion and predation. The shorter the time between arrival of the new organic matter and the onset of hypoxia the greater the effect on energy flows up the food chain as during hypoxia energy is shunted to microbial pathways (Díaz and Rosenberg, 2008).

Economic consequences for fisheries and ecosystem services

Some aspects of agriculture can contribute to enhanced ecosystem services in terrestrial ecosystems (Swinton *et al.*, 2007), but in marine ecosystems agriculture impacts are usually negative and rarely positive (Tilman *et al.*, 2001, Galloway *et al.*, 2008). This is due to the transformative nature of excess nutrients in fueling eutrophication, altering productivity pathways and species composition. For example, the primary negative drivers on biodiversity appear to be displacement of long-lived sensitive species by short-lived opportunistic spices adapted to rapidly respond to the influx of organic matter and alteration or loss of habitat quality.

The growing demand for the ecosystem service of food provisioning has resulted in stress and change to regulating and supporting ecosystem services (Table 14.1). This expanding need for food provisioning has lead to over half of all ecosystem services being degraded or used unsustainably (MA, 2005). The increasing production of food services, such as crops, livestock, and aquaculture, has led to a consumption of an increasing fraction of other service (for example, diverting more water for irrigation or capturing more fish from the sea) and has put downward pressure on others (for example, habitat quality and biodiversity). Much of this downward pressure can be traced to agricultural waste products (nutrient, toxic chemical, organic runoff). There are many examples of mortality and stress on fisheries species from eutrophication driven hypoxia (Table 14.4).

Table 14.4: Examples of fisheries mortality or losses related to eutrophication driven hypoxia

System	Country	Fisheries	Comment	References (in Díaz and Rosenberg 2008)
Beauford Inlet	Australia	Massive fish kills reported as early as 1936	Eutrophic inlet with high nutrients and at times HABs	Brearley 2005
Scheldt Estuary	Belgium	Flatfish stressed by low oxygen, Low oxygen tolerant eels declined with improved oxygen and diadromous fish returned.	Improved from nutrient management from 1970s to 1980s	Maes *et al.*., 2004, Buysse *et al.*., 2008
Ebrie lagoon	Cote d'Ivoire	Fish kills, loss of biodiversity, altered trophic structure	Domestic waste and industrial waste from coastal population	Ukwe *et al.*., 2006
Limfjord/Løgstør Bredn.	Denmark	Demersal fisheries gone.	Heavily polluted with anoxic conditions.	Jorgensen 1980, Hylleberg 1993
Humber estuary	England	Adverse effects on fish migrations.	Related to industrial discharge. Lowest oxygen in turbidity maximum from bacterial respiration.	Uncles *et al.*., 1998, 2000
Mersey Estuary	England	With recovery fish returned, Salmon runs from 1990's	Improved from nutrient management.	Jones 2006
Prevost Lagoon	France	Reduced aquaculture production	1976 bacterial blooms with H_2S production and Purple Sulfur bacteria present, Increased macroalgae	Guyoneaud *et al.*., 1998, Reijs *et al.*., 1999
Sommone Bay	France	Collapse of cockle fishery	Eutrophication first became apparent in 1982-85	Desprez *et al.*., 1992
Thau Lagoon	France	Mortality/Reduced shellfish production	Runoff and coastal population contribute to eutrophication.	Mazouni *et al.*., 1996, Chapelle *et al.*., 2000
Rhine River	Germany	River described as almost lifeless in 1960s	Heavily polluted with anoxic conditions, improved from management.	Anonymous 2006
Ise Bay	Japan	Shellfish and fisheries in shallow areas and tidal flats reduced	low oxygen water upwells into shallower areas and causes damage.	Nakata *et al.*., 1997

Table 14.4: Examples of fisheries mortality or losses related to eutrophication driven hypoxia (cont.)

System	Country	Fisheries	Comment	References (in Díaz and Rosenberg 2008)
Tokyo Bay	Japan	Avoidance and reduced abundance, failure of spring cohort of whipfin Dragon, reduced stomatopod fishery	High fisheries production in early 1930s from moderate eutrophication, by mid 1930s industrial development lead to decline of fisheries and high eutrophication, 1940s Bay quickly recovered and fisheries restored, peak yield in 1960. By 1970s Bay bad again and fisheries declined. Hypoxia and anoxia in inner Bay June to October.	Kodama *et al.*, 2002, 2006
Chinhae Bay	Korea	Reduced		Lim *et al.*, 2006
Chonsu Bay	Korea	Reduced		Lim *et al.*., 2006
Jinhae Bay	Korea	Oyster mortality related to oxygen and red tide	Related to summer algal blooms, annual from 1980s	Lee and Kim 2008
Kamak Bay	Korea	Reduced		Lim *et al.*, 2006
Youngsan Estuary	Korea	Reduced		Lim *et al.*, 2006
Clyde Estuary	Scotland	Salmon runs returned in 1983 with improved oxygen, had been absent for >120 years.	Inner part anoxic in 1970s, now hypoxic, outer part not hypoxic since 1980s.	SEPA 2008
Gotland Basin	Sweden	Low oxygen hampers the development of cod eggs; cod prey has also been reduced: large isopod and snake blenny have disappeared from deep waters	Due to long-term eutrophication of Baltic, areas are reconlonized after renewal of bottom water	Nissling and Vallin 1996
Kattegat (SE)	Sweden, Denmark	Reduced demersal fish abundance, Norway Lobster fishery effected	Related to general eutrophication, oxygen lowest in Sept-Oct	Baden *et al.*, 1990, Josefson and Jensen 1992
Black Sea NW Shelf	Ukraine, Romania, Bulgaria	Reduced demersal fisheries, now recovering	First reported in the 1960's, Improved from nutrient reductions in the 1990's, by 1993 hypoxic was eliminated. Hypoxic even in 2001 caused mass fish kill.	Mee 2006

Table 14.4: Examples of fisheries mortality or losses related to eutrophication driven hypoxia (cont.)

System	Country	Fisheries	Comment	References (in Díaz and Rosenberg 2008)
Mobile Bay	US-Alabama	Occasional shoreward migration of hypoxia stressed fish and crustaceans (Jubilees), Mortality of oyster	May have been hypoxic in 1800s. Has winter hypoxia. Some improvement in oxygen between 1900s and 2000s.	Loesch 1960, May, 1973
Connecticut River	US-Connecticut	Fish kill of Alosa up river related to low oxygen in 1966-1971	Episodic events in tidal freshwater zone	Moss *et al*., 1976
Bald Eagle Creek	US-Delaware	Fish kills	Eutrophication and limited tidal exchange with adjacent body of water	Luther *et al*., 2004
Delaware River	US-Delaware	Recovering American shad and striped bass fishery	low oxygen first recorded in 1915, Improved from nutrient management	Patrick 1988, Weisberg *et al*., 1996
Pepper Creek	US-Delaware	Fish migrate in and out of creek depending on oxygen	Daily cycle of oxygen from supersaturated to hypoxic	Tyler *et al*., 2009, Tyler and Targett 2007
Inner Continental Shelf	US-Florida	Mortality of fishes from combined effects of HAB and low oxygen.	low oxygen from HAB (toxic dinoflagellate *Karenia brevis*) bloom in August 2005. Multiple stressors involved in mortalities.	FWRI 2005
Pensacola Bay	US-Florida	Loss of fisheries species, Fish kills	Primarily related to industrial discharges. Some improvement in oxygen between 1980s and 2000s.	Hagy *et al*., 2006, Hagy and Murrell 2007
Inner & Mid Continental Shelf	US-Louisiana	Avoidance, Area coincides with historic white and brown shrimp fishing grounds	Annual hypoxia developed in 1970s, is now the largest hypoxic area in US. Related to discharge and nutrient loads from Mississippi/Atchafalaya River Plumes.	Rabalais and Turner 2001, Craig and Crowder 2005

Table 14.4: Examples of fisheries mortality or losses related to eutrophication driven hypoxia (cont.)

System	Country	Fisheries	Comment	References (in Díaz and Rosenberg 2008)
Chesapeake Bay Mainstem	US-Maryland	Crabs killed in pots	Seasonal anoxia detected in sediment record as far back as 1934-1948. Low oxygen area has increased from 1980 to 2000, anoxia has also increased.	Officer *et al.*, 1984, Kemp *et al.*., 2005
Patuxent River	US-Maryland	Avoidance, low egg hatching/larval mortality, bay anchovy eggs killed by hypoxia	Duration and spatial extent of low oxygen increased from 1930-79. Hypoxia may have occurred in 1700s from watershed modifications and wet periods. Rise in anoxia in 1970s linked to nutrient runoff and wet weather.	Keister *et al.*., 2000, Breitburg *et al.*, 1992
Long Island Sound	US-New York	Avoidance, some mortality.	Hypoxic June to September; duration, frequency, spatial extend all increased since 1987. Oxygen declined from 1990s to 2000s	Howell and Simpson 1994, Schimmel *et al.*, 1999
New York Bight	US-New York	Surf clam/finfish mortality, Avoidance, northward migration of bluefish blocked	Clam weather lead to stratification and bloom of *Ceratium tripos*, one time event. May have involved upwelling on nutrient rich water	Boesch and Rabalais 1991
Albemarle Sound	US-North Carolina	Mortality	Hurricane increased freshwater and nutrient input. Hypoxia has worsened in 2000s	Paerl *et al.*, 2000
Neuse River Estuary	US-North Carolina	Fish kills, mortality of oyster. Reduced prey abundance and habitat quality for fish.	Improvement in oxygen from 1990s to 2000s.	Lenihan and Perterson 1998, Baird *et al.*, 2004
Inner Continental Shelf	US-Oregon	Mass Mortality	Hypoxia developed on inner shelf in 2000s. Related to upwelling and phytoplankton bloom associated with California Current System. Shifting wind patterns lead to extensive shallow shelf hypoxia, may be related to global climate change.	Grantham *et al.*, 2004, Chan *et al.*, 2008

Source: based on Diaz and Rosenberg, 2008

Unless stress on nonprovisioning ecosystem services can be lessened, for example through ecosystem based management, there will likely be declines in food provisioning services from aquaculture with negative economic consequences. The effects of eutrophication vary from system to system, and there are accounts of loss of aquaculture production, and presumably loss of economic value, related to failure of supporting ecosystem services. For example, general eutrophication of coastal lagoons on the French Mediterranean coast has deteriorated water quality and at times led to the develop hypoxia. This in turn has reduced the lagoon systems supporting ecosystem services and lowered the production potential for aquaculture, in, for example, Thau Lagoon (Mazouni *et al.*, 1996). Combinations of stressors from agriculture, and municipal and industrial wastewater put greater pressure on ecosystem services but provisioning by aquaculture may not be negatively affected, as in Lake Saroma, Japan and Saldanha Bay, South Africa, where there are accounts of ecosystem degeneration but aquaculture production does not appear affected (Table 14.4). Even at sub-optimal levels of dissolved oxygen that are not near hypoxic, there can be reductions in growth of cultured salmon (Page *et al.*, 2005). From the beginning of fish aquaculture dissolved oxygen was recognized as a limiting factor and many cultured species were selected because of their tolerance to low dissolved oxygen. For example, carp (*Carassius* spp.) can survive months of hypoxia and is possibly the most anoxia-tolerant vertebrate (Nilson and Renshaw, 2004).

Cost of lost ecosystem services

The Millennium Ecosystem Assessment (MA, 2005) documented the importance of ecosystem services to humans and how losses and degradation of these services was occurring, primarily through unsustainable human activity. The valuation of these services is difficult in terms of either monetary costs or nonmarket ecological costs. Costanza *et al.*, (1997) estimated ecosystems to provide at least USD 33 trillion (in 1994 US dollars) worth of provisioning and supporting services annually. The majority of this value is outside the market system, in services such as gas regulation (USD 1.3 trillion/year), disturbance regulation (USD 1.8 trillion/year), waste treatment (USD 2.3 trillion/year) and nutrient cycling (USD 17 trillion/year). About 63% of the estimated value is contributed by marine systems (USD 20.9 trillion/year). Most of this comes from coastal systems (USD 10.6 trillion/year). About 38% of the estimated value comes from terrestrial systems, mainly from forests (USD 4.7 trillion/year) and wetlands (USD 4.9 trillion/year) (Costanza *et al.*, 1997). Sustainability of food provisioning services require that supporting services be maintained as a sort of natural capital. In this sense ecosystem services are complementary rather than substitutable (Costanza and Daly, 1992).

Aquaculture production will be particularly sensitive to loss of ecosystem services from eutrophication. The primary ecosystem services needed by aquaculture are:

Regulating Services:
- Water purification and waste treatment
- Biological control, trophic structure

Supporting Services:
- Nutrient cycling
- Habitat

These are also the ecosystem services most affected by eutrophication and the development of hypoxia. Significant reductions in any of these four services will reduce or eliminate aquaculture productivity, and other ecosystem services and functions. To investigate the cost of lost ecosystem services to aquaculture productivity will require data on the number, size, and area of aquaculture facilities. The area of ecosystems affected by other stressors that reduce services will also need to be accounted for. The values assigned to ecosystem services by Costanza *et al.*, (1997) are a first approximation of their relative magnitude (Table 5). As such, the valuation should be interpreted with caution, but these estimates do show that there are significant externalities associated with environmental stressors.

Table 14.5: Valuation of ecosystem services lost to hypoxia

Value in USD/Km^2/yr					**Total Area**	
Habitat	**Nutrient cycling**	**Biodiversity**	**Biological Control**	**Habitat**	**(Km^2)**	**% Total Area**
Ocean	15500 500	500	0	332000000	91.5	
Shelf	143100 4000	3900	0	26600000	7.3	
Estuaries	2110000	21000	7800	13100	1800000	0.5
Seagrass/Algal Beds		1900200	0	0	0	2000000
Coral	5800 1000	500	700	620000	0.2	

Total value in millions USD (Value in USD/Km^2/yr x Total Area)

	Nutrient cycling	**Biodiversity**	**Biological Control**	**Habitat**
Ocean	5146000	166000	166000	0
Shelf	3806550	106400	103700	0
Estuaries	3798000	37800	14000	23600
Seagrass	3800400	0	0	0
Coral	3600 600	300	400	

Value lost to hypoxia in millions USD (Value in USD/Km^2/yr x Hypoxic Area)

Lost	**Nutrient cycling**	**Biodiversity**	**Biological Control**	**Habitat**	**Hypoxic Area**	**% Hypoxic**
Shelf Natural	164600	4600	4500	0	1150000	4.3
Shelf Human	24300	700	700	0	170000	0.6
Estuaries	147700 1500	600	900	70000	3.9	

Notes: Assumptions are that hypoxia completely eliminates the ecosystem service for the entire year, which may not be the case for seasonal hypoxia, and that value lost is a relative

Source: Value of services based on Costanza *et al.* (1997). Estimates of hypoxic area based on Díaz and Rosenberg (2008)

Current estimates are that hypoxia related to eutrophication annually affects at least 240 000 km^2 globally (Díaz and Rosenberg, 2008). About 70 000 km^2 are inshore (estuarine/brackish waters and embayments), and about 170 000 km^2 are coastal offshore waters. There is also another 1.1 million km^2 of outer continental shelf bottom area affected by natural oxygen minimum zones (Helly and Levin, 2004). In total, about 4% of estuarine/brackish water and about 5% of shelf area are affected globally by hypoxia of some type. This translates to losses in ecosystem services in the billions of USD (Table 14.5).

The value lost highlights the importance of developing sustainability in agriculture through an ecosystem-based management approach that considers land-sea interactions. Integration of aquaculture into management plans, especially multiculture of species that can lessen impacts of land based activities offers the possibility of offsetting declines or even increasing the value of nutrient cycling services by removal of nutrients and organic matter as cultured species biomass.

Future issues and projected trends for agriculture and aquaculture

As both agriculture and aquaculture expand to provide more food for a growing human population, the greatest challenge faced is sustainability (Godfray *et al.*, 2010). The 1992 Rio Declaration on Environment and Development (UNCED 1992) laid the groundwork for future sustainable development around the world. This early attempt at integrated coastal management can still be used as a means of bringing agriculture and aquaculture to environmental and social sustainability. Goals towards sustainable forms of aquaculture or other coastal development should be stated as (Olsen, 2003):

- Specific improvements in ecosystem services (for example, aerial extent of mangroves or improved water quality).

- Specific improvements in the quality of life of the human population in the area of concern (for example, greater equity in how coastal resources are allocated, improved livelihoods, reduced conflicts among user groups).

Olsen (2003) proposed four orders of outcomes that group sequences of institutional, behavioral and social/environmental changes that can lead to more sustainable forms of coastal development.

One problem with making adjustments to optimize sustainability is that generally, the institutions that should be involved in discussions are often separate entities that compete rather than cooperate, such as ministries of agriculture versus the environment. This is a central impediment to rational decision-making in the ecosystem service context that must be overcome (Mooney, 2010). A much tighter coupling of science, policy, and management will be required to control and reverse the negative effects of agriculture on ecosystem services.

Lack of management of nonpoint nutrient loadings is the main factor fueling the expanding number of dead zones. The challenge will be to reduce nutrient loads reaching our coastal systems by increasing the efficiency of agriculture and restoring landscapes. As with climate change and increasing atmospheric CO_2, the time to act to reduce excess nitrogen and phosphorus is now. More people require more provisioning services of food, fuel, and fiber. So problems with oxygen in our coastal seas will not solve themselves. There is growing evidence that delays in reducing nutrient loads to marine systems will be increasingly costly to both humans and ecosystems. Over the years, the accumulation of organic matter and nutrients within ecosystems has set the stage for shifts that led to more hypoxia for a given input of additional nutrients. Once past this tipping point, greater reductions in nutrients will be required to control dead zone formation and reduce their size (Turner *et al.*, 2008). In addition, systems may not recover along the same trajectory as they degrade and may take many years to recover altered ecosystem services and functions (Duarte and Conley 2009; Kemp *et al.*, 2010).

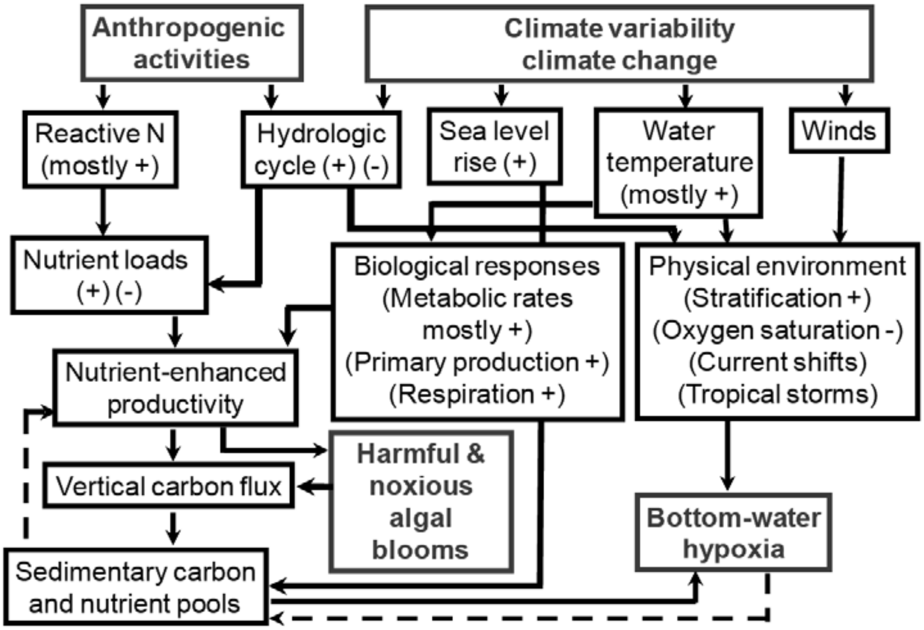
Projected impact of climate change

Superimposed on the immediate environmental issues related to eutrophication from export of agricultural nutrients to coastal waters is global climate change. The world's climate has changed and human activities will continue to contribute to the acceleration of greenhouse gases and temperature rise. The regional outcomes of the various global climate change scenarios (IPCC, 2007) will be manifested in many different and synergistic effects on various components of ecosystems. Policy decisions, such as incentives to use food crops for production of biofuels, will contribute to the expansion of agriculture and eutrophication of marine waters (Costello *et al.*, 2009; UNEP, 2009). Climate change effects will be difficult to detect in the near-term because they currently exist within the 'background' variability inherent in estuarine and marine systems as a result of both natural and anthropogenic forces (Díaz and Breitburg, 2009; Rabalais *et al.*, 2009, 2010).

Generally perceived as having mostly negative impacts, climate change provides an additional reason for agriculture and aquaculture to move towards sustainability. The positive side of climate change appears to be limited to expanding suitable habitat area for tropical and temperate species as temperatures increase, and possibly higher metabolism and growth. But for cold-water boreal species, higher temperatures will lead to habitat squeeze and contraction of range to higher and higher latitudes.

The primary negative impacts for aquaculture will be from the combined effects of climate change and expanding agriculture (Figure 14.6) because increased temperatures increase both hypoxia and oxygen requirements of many organisms. Increased water temperatures decrease oxygen solubility and increase microbial respiration that consumes dissolved oxygen. Oxygen concentrations in the Danish straits declined 0.238 (±0.084) mg O_2/l/^oC from 1965 to 2003 as temperatures rose (about 2 ^oC rise over the period) (Conley *et al.*., 2007). This decline in oxygen was very close to the predicted effect of temperature on the solubility of oxygen (approximately -0.26 mg O_2/l/^oC). By the end of this century a 4 ^oC rise in temperature would reduce oxygen by another 0.952 mg O_2/l (Conley *et al.*, 2009) and would severely impact aquaculture and capture fisheries in the Danish straits. In addition to lower concentrations of oxygen, hypoxia would expand in area and duration (Díaz and Rosenberg, 2008; Rabalais *et al.*, 2009, 2010). For the Danish straits the area of hypoxia would approximately double with a 4 ^oC rise in temperature and in the most severe years would cover most of the region (Conley *et al.*, 2009).

Figure 14.6: Potential physical and hydrological changes resulting from climate change and their interaction with current and future human activities



Dashed lines represent negative feedback to the system.

Source: Rabalais *et al.*, 2009

Conclusions

Management of aquaculture cannot be successful without coordinated management of other stressors, principally nutrient runoff from agriculture, in a broader management strategy. Recent scientific and ocean policy assessments within the US determined that a fundamental change in our current management system is required to assure long-term health of coastal and ocean areas in order to sustain the ecosystem services and benefits they provide to society (IOP, 2009). The IOP task force concluded that present management strategies for these areas cannot properly account for cumulative effects, sustain multiple ecosystem services, and holistically and explicitly evaluate the tradeoffs associated with proposed alternative human uses. The task force proposed development of a new planning approach called coastal and marine spatial planning (CMSP) to facilitate maintenance of essential ecosystem services, encourage compatible uses, minimize conflicts, evaluate tradeoffs in an open and transparent manner, and include significant and meaningful stakeholder involvement.

Ideally, any management strategy would also be adaptive and offer a way to address the pressing need to take steps to manage for factors affecting hypoxia. The National Research Council (2004) identified six elements of adaptive management that are directly relevant to goal setting and research needs:

- Resources of concern are clearly defined.
- Conceptual models are developed during planning and assessment.

- Management questions are formulated as testable hypotheses.
- Management actions are treated like experiments that test hypotheses to answer questions and provide future management guidance.
- Ongoing monitoring and evaluation is necessary to improve accuracy and completeness of knowledge.
- Management actions are revised with new cycles of learning.

Adaptive management is designed to support action in the face of the limitations of scientific knowledge and the complexities of large ecosystems (Holling, 1978).

Management efforts to reduce the size of seasonal hypoxia in the northern Gulf of Mexico provide a good case study. This hypoxic zone is the largest in US coastal waters and is driven by freshwater and nutrients derived from the Mississippi and Atchafalaya River Basins (MARB) that cover 41% percent of the contiguous United States. Additional details on development and causes can be found in Rabalais *et al.*, (2007) and Turner *et al.*, (2007).

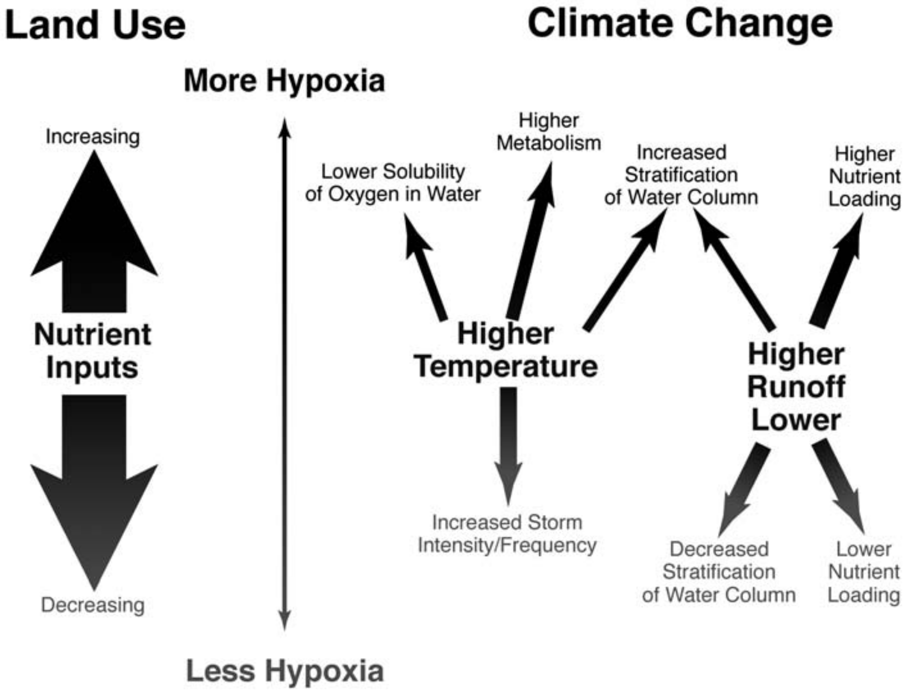
In 1998, the US EPA established the Mississippi River/Gulf of Mexico Watershed Nutrient Task Force (MTF) to bring together stakeholders and consider options for reducing, mitigating, and controlling hypoxia. An integrated science assessment, requested by the MTF, was published in 1999 and 2000 (CENR, 2000, www.oceanservice.noaa.gov/products/pubs_hypox.html). Using this science assessment, the Task Force developed its first Action Plan (MTF 2001), which was endorsed by Federal agencies, states, and tribal governments. The goal was to reduce the five-year running average size of the hypoxic zone to 5 000 km^2 by 2015. It estimated that an overall reduction in nitrogen load of 30–45% would be required. In 2007, EPA Science Advisory Board updated the science assessment (US EPA 2007) that was used by the Task Force to update the Action Plan (MTF 2008). The Action Plan retained the goal of reducing the hypoxic zone to less than 5 000 km^2 by 2015 but this time acknowledged the difficulty of meeting this goal. The 2008 plan also identified the requirement that phosphorus as well as nitrogen loads be reduced and increased the required nitrogen reduction to at least 45%. Implementation of the Action Plan was based on a series of voluntary and incentive-based activities that address both reducing nutrient inputs and increasing assimilation in aquatic ecosystems, including proper timing and amount of fertilizer applications, best management practices on agricultural lands, restoration and creation of wetlands, river hydrology restoration, riparian buffer strips, nutrient removal from storm- and wastewater, and coastal diversions.

Although overall total annual nutrient loads to the northern Gulf from 2001–2005 for nitrogen declined relative to the previous 24-year average, reductions in nitrate during the critical spring period have not occurred (MTF 2008). Further, the five-year running average (2004–2008) of the hypoxic area at 17 100 km^2 is more than three times the Action Plan goal of 5 000 km^2. The adaptive management approach put forth commits to a reliance on sound science and continual feedback between the interpretation of new information and improved management actions as the key to targeting actions within watersheds where they will be most effective.

Great strides have been made in mitigating nutrient and organic loadings from point source discharges. Similar effort will need to be applied to non-point agricultural runoff.

As agricultural production expands even lower nutrient loading levels will become a problem. Recent studies have shown that after years of eutrophication, it may not be as simple as reducing nutrients to reverse water quality problems, especially associated with hypoxia (Turner *et al.*, 2008; Rabalais *et al.*, 2010; Kemp *et al.*, 2010). If in the next 50 years humans continue to modify and degrade coastal systems as in previous years (Halpern *et al.*, 2008), human population pressure will likely continue to be the main driving factor in the persistence and spreading of coastal dead zones (Figure 14.7). Expanding agriculture for production of crops to be used for food and biofuels will result in increased nutrient loading and expand eutrophication effects. Climate change, however, may make systems more susceptible to development of hypoxia through direct effects on stratification, solubility of oxygen, metabolism, and mineralization rates. This will likely occur primarily though warming, which will lead to increased water temperatures, decreased oxygen solubility, increased organism metabolism and remineralization rates, and enhanced stratification.

Figure 14.7: Relative contribution of global climate change and land use to future hypoxia



Thickness of arrows indicated relative magnitude of effect

Source: Diaz and Breitburg, 2009

Notes

1 Ecosystem services are simply defined as ‘‘the benefits people obtain from ecosystems’’ (MA 2005) and are summarised in Table 14.1.

References

Andrews, M.J. and D.G. Rickard (1980), “Rehabilitation of the inner Thames estuary”, *Marine Pollution Bulletin* 11, pp. 327-332.

Aumann, C.A., L.A. Eby and W.F. Fagan (2006), “How transient patches affect population dynamics: the case of hypoxia and blue crabs”, *Ecological Monographs* 76: 415-38.

Azarovitz, T.R., C.J. Byrne, M.J. Silverman, B.L. Freeman, W.G. Smith, S.C. Turner, B.A. Halgren and P.J. Festa (1979), “Effects on finfish and lobster” in R.L. Swanson and C.J. Sindermann (eds.) *Oxygen depletion and associated benthic moralities in New York Bight*, NOAA Professional Paper 11, pp. 295-314.

Baird, D. and R. E. Ulanowicz (1989), “The seasonal dynamics of the Chesapeake Bay ecosystem”, *Ecological Monographs* 59, pp. 329-364.

Baird, D., R.R. Christian, C.H. Peterson and G.A. Johnson (2004), “Consequences of hypoxia on estuarine ecosystem function: Energy diversion from consumers to microbes”, *Ecological Applications* 14, pp. 805-822.

Bonsdorff, E., E.M. Blomqvist, J. Mattila and A. Norkko (1997), “Coastal eutrophication: causes, consequences and perspectives in the archipelago areas of the northern Baltic Sea”, *Estuarine*, *Coastal and Shelf Science* 44, pp. 63-72.

Brandt, S.B. and D.M. Mason (1994), “Landscape approaches for assessing spatial patterns in fish foraging and growth’, in Stouder, D. J., K. L. Fresh and R. J. Feller (eds.), *Theory and Application of Fish Feeding Ecology,* University of South Carolina Press, Columbia, SC., pp. 211-240.

Breitburg, D.L. (2002), “Effects of hypoxia, and the balance between hypoxia and enrichment, on coastal fishes and fisheries”, *Estuaries* 25, pp. 767-781.

Breitburg, D.L. and G.F. Riedel (2005), “Multiple stressors in marine systems” in Norse, E.A. and L.B. Crowder (eds.), *Marine Conservation Biology: The Science of Maintaining the Sea’s Biodiversity*. Island Press, Washington, DC., pp. 167-182.

Breitburg, D. L., D.W. Hondorp, L.W. Davias, and R.J. Díaz (2009), “Hypoxia, nitrogen and fisheries Integrating effects across local and global landscapes”, *Annual Review Marine Science* 1, pp. 329-350.

Buslé, J. (1995), “The impact of harmful algal blooms on finfish. Mortality, pathology and toxicology”, 6th Conférence Internationale Sur Le Phytoplancton Marin, Nantes, 18-22 Octobre 1993, IFREMER, Plouzane, *The impact of harmful algal blooms on finfish: occurrence of fish kills, pathology, toxicological mechanisms, ecological and economic impacts, A review*, 75 pages.

Caddy, J. F. (1993), "Towards a comparative evaluation of human impacts on fishery ecosystems of enclosed and semi-enclosed seas', *Review of Fisheries Science* 1, pp. 57-95.

Cardinale M. and J. Modin (1999), "Changes in size-at-maturity of Baltic cod (*Gadus morhua*) during a period of large variations in stock size and environmental conditions", *Fisheries Research* 41, pp. 285-95.

CENR (Committee on Environment and Natural Resources) (2000), "Integrated Assessment of Hypoxia in the Northern Gulf of Mexico", National Science and Technology Council Committee on Environment and Natural Resources, Washington, D.C.

Chabot, D. and J.-D. Dutil (1999), "Reduced growth of Atlantic cod in non-lethal hypoxic conditions", *Journal Fish Biology* 55, pp. 472-491.

Cloern, J.E. (2001), *Our evolving conceptual model of the coastal eutrophication problem,* Marine Ecology-Progress Series 210, pp. 223-253.

Conley, D. J., C. Humborg, L. Rahm, O.P. Savchuk and F. Wulff, F. (2002), "Hypoxia in the Baltic Sea and basin-scale changes in phosphorus biogeochemistry', *Environmental Science and Technology* 36, pp. 5315-5320.

Conley, D.J., J. Carstensen, G. Ærtebjerg, P.B. Christensen, T. Dalsgaard, J.L.S. Hansen, and A.B. Josefson (2007), "Long-term changes and impacts of hypoxia in Danish coastal waters", *Ecological Applications* 17: S165-S184.

Conley, D.J., J. Carstensen, R. Vaquer-Sunyer and C.M. Duarte (2009), "Ecosystem thresholds with hypoxia", *Hydrobiologia* 629, pp. 21-29.

Costa-Pierce, B. (2008), "An ecosystem approach to marine aquaculture: A global review" in D. Soto, J. Aquilar-Manjarrez and N. Hishamunda (eds.), *Building an ecosystem approach to aquaculture,* FAO, Universitat de les Illes Balears Experts Workshop, 7-11 May 2007, Palma de Mallorca, Spain, FAO Fisheries and Aquaculture Proceedings. No. 14, Rome, pp. 81-115.

Costanza, R. and H. Daly (1992), "Natural capital and sustainable development", *Conservation Biology* 6, pp. 37-46.

Costanza, R., R. d'Arge, R. de Groot, S. Farber, M., Grasso, B. Hannon, S. Naeem, K. Limburg, J. Paruelo, R.V. O'Neill, R. Raskin, P. Sutton and M. van den Belt (1997), "The value of the world's ecosystem services and natural capital", *Nature* 387, pp. 253-260.

Costello, C., W.M. Griffin, A.E. Landis and H.S. Matthews (2009), "Impact of biofuel crop production on the formation of hypoxia in the Gulf of Mexico", *Environmental Science and Technology* 43, pp. 7985-7991.

Coutant, C.C. (1985), "Striped bass, temperature, and dissolved oxygen: a speculative hypothesis for environmental risk", *Transactions of the American Fisheries Society* 114, pp. 31-61.

Craig, J.K. and L.B. Crowder (2005), "Hypoxia-induced habitat shifts and energetic consequences in Atlantic croaker and brown shrimp on the Gulf of Mexico shelf", *Marine Ecology Progress Series* 294, pp. 79-94.

Craig, J.K., L.B. Crowder and T.A. Henwood (2005),"Spatial distribution of brown shrimp (*Farfantepanaeus aztecus*) on the northwestern Gulf of Mexico shelf: effects of abundance and hypoxia", *Canadian Journal of Fisheries and Aquatic Science* 62, pp. 1295-1308.

Crawford, C.M., C.K. Macleod and I.M. Mitchell (2003), "Effects of shellfish farming on the benthic environment', *Aquaculture* 224, pp. 117-140.

Dame, R.F. (1996), *Ecology of marine bivalves: an ecosystem approach.* CRC Press, Boca Raton, Florida, 254 pages.

Dasgupta, P. (2010), "Nature's role in sustaining economic development', *Philosophical Transactions of the Royal Society B* 365, pp. 5-11.

Díaz, R. J. and D.L. Breitburg (2009), "The hypoxic environment", in Richards, J.G., A.P. Farrel and C.J. Brauner (eds) *Fish Physiology* Vol. 27, Academic Press, Burlington, pp. 1-23.

Díaz, R.J. and R. Rosenberg (1995), "Marine benthic hypoxia: A review of its ecological effects and the behavioural responses of benthic macrofauna", *Oceanography and Marine Biology*, *an Annual Review* 33, pp. 245-303.

Díaz, R.J. and R. Rosenberg (2008), "Spreading dead zones and consequences for marine ecosystems', *Science* 321, pp. 926-928.

Díaz, R.J. and L.C. Schaffner (1990), "The functional role of estuarine benthos", pp. p. 25-5, in M. Haire and E.C. Krome (eds.), Perspectives on the Chesapeake Bay, 1990. Advances in estuarine sciences, Rpt. No. CBP/TRS41/90, Chesapeake Research Consortium, Gloucester Pt., Virginia.

Duarte, C.M. and D.J. Conley (2009), "Return to neverland: shifting baselines affect eutrophication restoration targets", *Estuaries and Coasts* 32, pp. 29-36.

Dutil, J.-D., E.-L. Sylvestre, L. Gamache, R. Larocque and H. Guderley (2007), "Burst and coast use, swimming performance and metabolism of Atlantic cod *Gadus morhua* in sublethal hypoxic conditions", *Journal of Fish Biology* 71, pp. 363-75.

Eby, L.A. and L.B. Crowder (2004), "Effects of hypoxic disturbances on an estuarine nekton assemblage across multiple scales", *Estuaries* 27, pp. 342-351.

Elmgren, R. (1989), "Man's impact on the ecosystem of the Baltic Sea: Energy flows today and at the turn of the century', *Ambio* 18, pp. 326-332.

Fallesen, G., F. Andersen and B. Larsen (2000), "Life, death and revival of the hypertrophic Mariager Fjord, Denmark", *Journal of Marine Systems* 25, pp. 313-321.

FAO (2009), *The state of world fisheries and aquaculture 2008*. ISSN 1020-5489, Rome, Italy, 196 pages.

Foley, J.A., R. DeFries, G.P. Asner, C. Barford, G. Bonan, S.R. Carpenter, F.S. Chapin, M.T. Coe, G.C. Daily, H.K. Gibbs, J.H. HelkowskiT. Holloway, E.A Howard, C.J. Kucharik, C. Monfreda, J.A. Patz, I.C. Prentice, N. Ramankutty and P.K. Snyder (2005), "Global consequences of land use", *Science* 309, pp. 570-574.

Graham, J.B. (1990), "Ecological, evolutionary, and physical factors influencing aquatic animal respiration", *American Zoologist* 30, pp. 137-146.

Galloway, J.N., F.J. Dentener, D.G. Capone, E.W. Boyer, R.W. Howarth, S.P. Seitzinger, G.P. Asner, C.C. Cleveland, P.A. Green, E.A. Holland, D.M. Karl, A.F. Michaels, J.H.

Porter, A.R. Townsend, and C.J. Vörösmarty (2004), "Nitrogen cycles: past, present, and future", *Biogeochemistry* 70, pp. 153-226.

Galloway, J. N., A.R. Townsend, J.W. Erisman, M. Bekunda, Z. Cai, J.R. Freney, L.A. Martinelli, S.P. Seitzingerand M.A. Sutton (2008), "Transformation of the nitrogen cycle Recent trends, questions, and potential solutions", *Science* 320, pp. 889-892.

Gilbert, D., N.N. Rabalais, R.J. Díaz and J. Zhang (2009), "Evidence for greater oxygen decline rates in the coastal ocean than in the open ocean", *Biogeosciences Discussion* 6, pp. 9127-9160.

Godbold, J.A. and M. Solan (2009), "Relative importance of biodiversity and the abiotic environment in mediating an ecosystem process", *Marine Ecology Progress Series* 396, pp. 281-290.

H.C.J. Godfray, J.R. Beddington, I.R. Crute, L. Haddad, D. Lawrence, J.F. Muir, J. Pretty, S. Robinson, S.M. Thomas, and C. Toulmin (2010), "Food Security: The Challenge of Feeding 9 billion People", *Science* 327, pp. 812-818.

Graco, M., L. Farías, V. Molina, D. Gutiérrez and L.P. Nielsen (2001), "Massive developments of microbial mats following phytoplankton blooms in a eutrophic bay II Implications for nitrogen cycling", *Limnol. Oceanogr.*, 46, pp. 821-832.

Gutiérrez, D., V.A. Gallardo, S. Mayor, C. Neira, C. Vasquez, J. Sellanes, M. Rivas, A. Soto, F. Carrasco and M. Baltazar (2000), "Effects of dissolved oxygen and fresh organic matter on the bioturbation potential of macrofauna in sublittoral sediments off Central Chile during the 1997/1998 El Niño", *Marine Ecological Prog. Ser.*, 202, pp. 81-99.

Guyoneaud, R., R. De Wit, R. Matheron and P. Caumette (1998), "Impact of macroalgal dredging on dystrophic crises and phototrophic bacterial blooms (red waters) in a brackish coastal lagoon", *Oceanologica Acta* 21, pp. 551-561.

Halpern, B.S., S. Walbridge, K.A. Selkoe, C.V. Kappel, F. Micheli, C. D'Agrosa, J.F. Bruno, K.S. Casey, C. Ebert, H.E. Fox, R. Fujita, D. Heinemann, H.S. Lenihan, E.M.P. Madin, M.T. Perry, E.R. Selig, M. Spalding, R. Steneck and R. Watson (2008), "A global map of human impact on marine ecosystems", *Science* 319, pp. 948-952.

Holling, C.S. (ed.) (1978), *Adaptive Environmental Assessment and Management,* John Wiley and Sons: New York, 1978.

Helly, J.J. and L.A. Levin (2004), "Global distribution of naturally occurring marine hypoxia on continental margins" in *Deep-Sea Research (Part I)* 51, pp. 1159-1168.

IOP (Interagency Ocean Policy Task Force) (2009), "Interim framework for effective coastal and marine spatial planning", The White House Council on Environmental Quality, Washington, D.C., 32 pages.

IPCC (Intergovernmental Panel on Climate Change Climate Change) (2007), "Impacts, adaptation and vulnerability", Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. M.I. Parry, O.F. Canziani, J.P. Patulikof, P.J. van der Linden and C.E. Hanson (eds.), Cambridge University Press, Cambridge, UK., 976 pages.

Jackson J.B.C., M.X. Kirby, W.H. Berger, K.A. Bjorndal, L.W. Botsford, B.J. Bourque, R.H. Bradbury, R. Cooke, J. Erlandson, J.A. Estes, T.P. Hughes, S.K. Lange, C.B. Lenihan, J.M. Pandol, C.H. Peterson, R.S. Steneck, M.J. Tegner and R.R. Warner

(2001), "Historical Overfishing and the Recent Collapse of Coastal Ecosystems", *Science* 293, pp. 629-638.

Jeppesen, E., M. Søndergaard, J.P. Jensen, K.E. Havens, O. Anneville, L. Carvalho, M.F. Coveney, R. Deneke, M.T. Dokulil, B. Foy, D. Gerdeaux, S.E. Hampton *et al.* (2005), "Lake responses to reduced nutrient loading: an analysis of contemporary long-term data from 35 case studies", *Freshwater Biology* 50, pp. 1747-1771.

Jewett, E.B., C.B. Lopez, D.M. Kidwell, S.B. Bricker, M.K. Burke, M.R. Walbridge,P.M. Eldridge, R.M. Greene, J.D. Hagy, H.T. Buxton and R.J. Díaz (2009), "Scientific assessment of hypoxia in U.S. coastal waters", Interagency Working Group on Harmful Algal Blooms, Hypoxia, and Human Health of the Joint Subcommittee on Ocean Science and Technology. Washington, DC., 160 pages.

Jones P.D. (2006), "Water quality and fisheries in the Mersey estuary, England: A historical perspective", *Marine Pollution Bulletin* 53, pp. 144-154.

Jones, T.O. and G.K. Iwama (1991), "Polyculture of the Pacific oyster, *Crassostrea gigas* (Thunberg), with Chinook salmon, *Oncorhynchus tshawytscha", Aquaculture* 92, pp. 313-322.

Jørgensen, B.B. (1980), "Seasonal oxygen depletion in the bottom waters of a Danish fjord and its effect on the benthic community", *Oikos* 34, pp. 68-76.

Justic′, D., T. Legovic′ and L. Rottini-Sandrini (1987), *Trends in oxygen content 1911-1984 and occurrence of benthic mortality in the northern Adriatic Sea,* Estuarine Coastal Shelf Science 25, pp. 435-445.

Karlson, K., R. Rosenberg and E. Bonsdorff (2002), "Temporal and spatial large-scale effects of eutrophication and oxygen deficiency on benthic fauna in Scandinavian and Baltic waters – a review", *Oceanography and Marine Biology: an Annual Review* 40, pp. 427-489.

Katsuki, K., K. Seto, R. Nomura, K. Maekawa and B.-K. Khim (2008), "Effect of human activity on Lake Saroma (Japan) during the past 150 years: Evidence by variation of diatom assemblages", E*stuarine Coastal and Shelf Science* 81, pp. 215-224.

Kemp, W.M., J.M. Testa, D.J. Conley, D. Gilbert and J.D. Hagy (2010), "Temporal responses of coastal hypoxia to nutrient loading and physical controls", *Biogeosciences* 6, pp. 2985-3008.

Kemp, W.M., W.R. Boynton, J.E. Adolf, D.F. Boesch, W.C. Boicourt, G. Brush, J.C. Cornwell, T.R. Fisher, P.M. Glibert, J.D. Hagy, L.W. Harding, E.D. Houde, D.G. Kimmel, W.D. Miller, R.I.E. Newell, M.R. Roman, E.M. Smith and J.C. Stevenson (2005), "Eutrophication of Chesapeake Bay historical trends and ecological interactions", *Marine Ecology Progress Series* 303, pp. 1-29.

Kodama K., I. Aoki and M. Shimizu (2002), "Long-term changes in the assemblage of demersal fishes and invertebrates in relation to environmental variations in Tokyo Bay, Japan", *Fisheries Management and Ecology* 9, pp. 303-313.

Kodama K., T. Horiguchi, G. Kume, S. Nagayama, T. Shimizu, H. Shiraishi, M. Morita and M. Shimizu (2006), "Effects of hypoxia on early life history of the stomatopod *Oratosquilla oratoria* in a coastal sea", *Marine Ecology Progress Series* 324, pp. 197-206.

Levin, L.A., W. Ekau, A.J. Gooday, F. Jorissen, J.J. Middelburg, S.W.A. Naqvi, C. Neira, N.N. Rabalais and J. Zhang (2009), "Effects of natural and human-induced hypoxia on coastal benthos", *Biogeosciences* 6, pp. 2063-2098.

Lim H.S., R.J. Díaz, J.S. Hong and L.C. Schaffner, L.C. (2006), "Hypoxia and benthic community recovery in Korean coastal waters", *Marine Pollution Bulletin* 52, pp. 1517-1526.

Lindahl, 0., R. Hart, B. Hernroth, S. Kollberg, L.-O. Loo, L. Olrog, , A.-H. Rehnstam-Holm, J. Svensson, S. Svensson and U. Syversen, U. (2005), "Improving marine water quality by mussel farming: a profitable solution for Swedish society", *Ambio* 34, pp. 131-137.

Lotze, H.K., H.S. Lenihan, B.J. Bourque,R.H. Bradbury, R.G. Cooke, M.C. Kay, S.M. Kidwell, M.X. Kirby, C.H. Peterson and J.B.C. Jackson (2006), "Depletion, Degradation, and Recovery Potential of Estuaries and Coastal Seas", *Science* 312, pp. 1806-1809.

MA (Millennium Ecosystem Assessment) (2005), *Ecosystems and Human Well-being: Synthesis*. Island Press, Washington, DC., 155 pages.

Maes J., Stevens M. and J. Breine (2007), "Modelling the migration opportunities of diadromous fish species along a gradient of dissolved oxygen concentration in a European tidal watershed", *Estuarine Coastal and Shelf Science* 75, pp. 151-62.

Mazouni, N., J.-C. Gaertner, J.M. Deslous-Paoli, S.Landrein and M. Geringer d'Oedenberg (1996), "Nutrient and oxygen exchanges at the water–sediment interface in a shellfish farming lagoon (Thau, France)', *Journal of Experimental Marine Biology and Ecology* 205, pp. 91-113.

Meyer-Reil, L.-A. and M. Koster (2000), "Eutrophication of marine waters effects on benthic microbial communities", *Marine Pollution Bulletin* 41, pp. 255-263.

Middelburg, J. and L.A. Levin (2009), "Coastal hypoxia and sediment biogeochemistry", *Biogeosciences* 6, pp. 1273-1293.

Mirza, F.B. and J.S. Gray (1981), "The fauna of benthic sediments from the organically enriched Oslofjord, Norway", *Journal of Experimental Marine Biology and Ecology* 54, pp. 181-207.

Möller, P., L. Pihl and R. Rosenberg (1985), "Benthic faunal energy flow and biological interaction in some shallow marine soft bottom habitats", *Marine Ecology Progress Series* 27, pp. 109-121.

Mooney, H.A. (2010), "The ecosystem-service chain and the biological diversity crisis", *Philosophical Transactions of the Royal Society B* 365, pp. 31-39.

MTF (Mississippi River/Gulf of Mexico Watershed Nutrient Task Force) (2001), "Action Plan for Reducing, Mitigating, and Controlling Hypoxia in the Northern Gulf of Mexico", Washington, D.C.: Offices of Wetlands, Oceans, and Watersheds, U.S. Environmental Protection Agency.

Mississippi River/Gulf of Mexico Watershed Nutrient Task Force. (2004), "A Science strategy to support management decisions related to hypoxia in the Northern Gulf of Mexico and excess nutrients in the Mississippi River Basin", prepared by the Monitoring Modeling and Research Workgroup of the Mississippi River/Gulf of

Mexico Watershed Nutrient Task Force, U.S. Geological Survey Circular 1270, 58 pages.

Mississippi River/Gulf of Mexico Watershed Nutrient Task Force (2008), "Gulf Hypoxia Action Plan 2008 for Reducing, Mitigating, and Controlling Hypoxia in the Northern Gulf of Mexico and Improving Water Quality in the Mississippi River Basin", Washington, DC.

NCDWQ (North Carolina Division of Water Quality) (2006), "Annual Report of Fish Kill Events", Div. Water Qual. Environ. Science Section, Raleigh, NC.

Naylor, R.L., R.J. Goldburd, J.H. Primavera, N. Kautsky, M.C.M. Beveridge, J.Clay, C. Folke, J. Lubchenco, H. Mooney and M. Troell (2000), "Effect of aquaculture on world fish supplies", *Nature* 405, pp. 1017-1024.

Newcombe, C.L. and W.A. Horne. (1938), "Oxygen-poor waters of the Chesapeake Bay", *Science* 88, pp. 80-81.

Newell, R.I.E. (2004), "Ecosystem influences of natural and cultivated populations of suspension-feeding bivalve mollusks: A review", *Shellfish Research* 23, pp. 51-61.

Newell, R.I.E., T.R. Fisher, R.R., Holyoke and J.C. Cornwell (2005), "Influence of eastern oysters on N and P regeneration in Chesapeake Bay, USA" in Dame, R. and S. Olenin (eds.), *The comparative roles of suspension feeders in ecosystems*. Springer, Berlin, pp. 93-12.

Niklitschek, E.J. and D.H. Secor (2005), "Modeling spatial and temporal variation of suitable nursery habitats for Atlantic sturgeon in the Chesapeake Bay", *Estuarine Coastal and Shelf Science* 64, pp. 135-48.

Nilsson, G.E. and G.M. Renshaw (2004), "Hypoxia survival strategies in two fishes: extreme anoxia tolerance in the North European crucian carp and natural hypoxic preconditioning in a coral-reef shark", *Journal of Experimental Biology* 207, pp. 3131-3139.

Nilsson H. and R. Rosenberg (2000), "Succession in marine benthic habitats and fauna in response to oxygen deficiency: analyzed by sediment profile-imaging and by grab samples", *Marine Ecology Progress Series* 197, pp. 139-149.

Nissling, A. and L. Vallin (1996), "The ability of Baltic cod eggs to maintain neutral buoyancy and the opportunity for survival in fluctuating conditions in the Baltic Sea", *Journal of Fish Biology* 48, pp. 217-227.

Nixon, S.W. (1995), "Coastal marine eutrophication: A definition, social causes, and future concerns", *Ophelia* 41, pp. 199-219.

Nixon, S. W. and B.A. Buckley (2002), "A strikingly rich zone. Nutrient enrichment and secondary production in coastal marine ecosystems", *Estuaries* 25, pp. 782-796.

O'Connor, B.D.S., J. Costelloe, B.F. Keegan and D.C. Rhoads (1989), "The use of REMOTS technology in monitoring coastal enrichment resulting from mariculture", *Marine Pollution Bulletin* 20, pp. 384-390.

O'Connor, T. and D. Whitall (2007), "Linking hypoxia to shrimp catch in the northern Gulf of Mexico", *Marine Pollution Bulletin* 54, pp. 460-63.

Officer, C.B., R.B.Biggs, J.L. Taft, L.E. Cronin, M.A. Tyler and W.R. Boynton (1984), "Chesapeake Bay anoxia: origin, development, and significance", *Science* 223, pp. 22-27.

Oguz, T. (2005), "Long-term impacts of anthropogenic forcing on the Black Sea ecosystem", *Oceanography* 18, pp. 104-113.

Olsen, S.B. (2003), "Frameworks and indicators for assessing progress in integrated coastal management initiatives", *Ocean and Coastal Management* 46, pp. 347-361.

OSPAR Commission. (2003), "OSPAR integrated report 2003 on the eutrophication status of the OSPAR maritime area based upon the first application of the comprehensive procedure", London, U.K., 59 pages.

Page, F.H., R. Losier, P. McCurdy, D. Greenberg, J. Chaffey and B. Chang (2005), "Dissolved oxygen and salmon cage culture in the southwestern New Brunswick portion of the Bay of Fundy" in Hargraves, B.T. (ed.), *Environmental effects of marine finfish aquaculture,* Springer, Berlin, Germany, pp. 1-28.

Paulmier, A. and D. Ruiz-Pino (2009), " Oxygen minimum zones (OMZs) in the modern ocean", *Progress in Oceanography* 80, pp. 113-128.

Pauly, D. and V. Christensen (1995), "Primary production required to sustain global fisheries", *Nature* 374, pp. 255-257.

Pearce, J. and N. Balcom (2005), "The 1999 Long Island Sound lobster mortality event: findings of the comprehensive research initiative", *Journal of Shellfish Research* 24, pp. 691-697.

Pearson, T.H. and K.D. Black (2001) "The environmental impacts of marine fish cage culture" in Black, K.D. (ed.), *Environmental impacts of aquaculture*. Sheffield Academic Press, Sheffield, UK, pp. 1-31.

Pearson, T.H. and R. Rosenberg (1992), "Energy flow through the SE Kattegat: A comparative examination of the eutrophication of a coastal marine ecosystem", N*etherlands Journal of Sea Research* 28, pp. 317-334.

Pihl, L., S.P. Baden, R.J. Díaz and L.C. Schaffner (1992), "Hypoxia induces structural changes in the diet of bottom-feeding fish and crustacean", *Marine Biology* 112, pp. 349-361.

Pihl, L., J. Modin and H. Wennhage (2005), "Relating plaice (*Pleuronectes platessa*) recruitment to deteriorating habitat quality: effects of macroalgal blooms in coastal nursery grounds", *Canadian Journal of Fisheries and Aquatic Science* 62, pp. 1184-93.

Rabalais, N.N. (2004), "Eutrophication" in Robinson, A.R., J. McCarthy and B.J. Rothschild (eds.), *The Global Coastal Ocean Multiscale Interdisciplinary Processes*, The Sea, Vol. 13, Harvard University Press, pp. 819-865.

Rabalais, N.N. and D. Gilbert (2008), "Distribution and consequences of hypoxia" in E.R. Urban, B. Sundby, P. Malanotte-Rizzoli and J. Milello (eds.), *Watersheds, Bay, and Bounded Seas: The Science and Management of Semi-Enclosed Marine Systems,* Island Press, Washington, D.C., pp. 209-225.

Rabalais, N. N. and R.E. Turner (eds.) (2001), "Coastal Hypoxia Consequences for Living Resources and Ecosystems", *Coastal and Estuarine Studies* 58, American Geophysical Union, Washington D.C., 454 pp.

Rabalais N.N., D.E. Harper and R.E. Turner (2001a), "Responses of nekton and demersal and benthic fauna to decreasing oxygen concentrations" in Rabalais N.N. and R.E. Turner (eds.), *Coastal Hypoxia Consequences for Living Resources and Ecosystems*, American Geophysical Union, Washington, D.C., pp. 115-128.

Rabalais, N. N., L.E. Smith, D.E. Harper, and D. Justić,(2001b), "Effects of seasonal hypoxia on continental shelf benthos" in: Rabalais, N. N. and R.E. Turner (eds.), *Coastal Hypoxia Consequences for Living Resources and Ecosystems*, Coastal and Estuarine Studies 58, American Geophysical Union, Washington, D. C., pp. 211-240.

Rabalais, N.N., R.E. Turner and W.J. Wiseman (2002), "Gulf of Mexico hypoxia, aka the dead zone", *Annual Review of Ecology and Systematics* 33, pp. 235-263.

Rabalais, N.N., R.E. Turner, D. Justic´and R.J. Díaz (2009), "Global change and eutrophication of coastal waters", *ICES Journal of Marine Science* 66, pp. 1528–1537.

Rabalais, N.N., R.E. Turner and D. Scavia (2002), "Beyond science into policy: Gulf of Mexico hypoxia and the Mississippi River", *BioScience* 52, pp. 129–42.

Rabalais, N.N., R.J. Díaz, L.A. Levin, R.E. Turner, D. Gilbert and J. Zhang (2010), "Dynamics and distribution of natural and human-caused hypoxia", *Biogeosciences* 6.

Rumohr, H., E. Bonsdorff and T.H. Pearson (1996), "Zoobenthic succession in Baltic sedimentary habitats", *Archives of Fisheries and Marine Research* 44, pp. 179-214.

Rosenberg, R. and R.J. Díaz (1993), "Sulphur bacteria (*Beggiatoa* spp.) mats indicate hypoxic conditions in the Inner Stockholm Archipelago", *Ambio* 22, pp. 32-36.

Rosenthal, H. (1985), "Constraints and perspectives in aquaculture development", *GeoJournal* 10, pp. 305-324.

Selberg, C.D., L.A. Eby and L.B. Crowder (2001), "Hypoxia in the Neuse River Estuary: responses of blue crabs and crabbers", *North American Journal of Fisheries Management* 21, pp. 358-366

Selman, M., S. Greenhalgh, R. Díaz and Z. Sugg (2008), *Eutrophication and hypoxia in coastal areas: A global assessment of the state of knowledge,* World Resources Institute Policy Note, No, 1. Washington D.C., 6 pages.

Smith, M.D., C.A. Roheim, L.B. Crowder, B.S. Halpern, M. Turnipseed, J.L. Anderson, F. Asche, L. Bourillón, A.G. Guttormsen, A. Khan, L.A. Liguori, A. McNevin, M.I. O'Connor, D. Squires, P. Tyedmers, C. Brownstein, K. Carden, D.H. Klinger, R. Sagarin, and K.A. Selkoe (2010), "Sustainability and Global Seafood", *Science* 327, pp. 784-786.

Smith, R.A., R.B. Alexander and M.G. Wolman (1987), "Water-Quality Trends in the Nation's Rivers", *Science* 235, pp. 1607-1615.

Sale, J.W. and W.W. Skinner (1917), "The vertical distribution of dissolved oxygen and the precipitation of salt water in certain tidal areas", *Franklin Institute Journal* 184, pp. 837-848.

Sen Gupta, B.K., R.E. Turner and N.N. Rabalais (1996), “Seasonal oxygen depletion in the continental shelf waters of Louisiana: Historical record of benthic foraminifers”, *Geology* 24, pp. 227-230.

Stenton-Dozey, J., T. Probyn and A. Busby (2001), “Impact of mussel (*Mytilus galloprovincialis*) raftculture on benthic macrofauna, in situ oxygen uptake, and nutrient fluxes in Saldanha Bay, South Africa”, *Canadian Journal of Fisheries and Aquatic Science* 58, pp. 1021-1031.

Swinton, S. M., F. Lupi, G.P. Robertson and S.K. Hamilton (2007), “Ecosystem services and agriculture: cultivating agricultural ecosystems for diverse benefits”, *Ecological Economics* 64, pp. 245-252.

Taylor, B.E., G. Jamieson, and T.H. Carefoot (1992), “Mussel culture in British Columbia: the influence of salmon farms on growth of *Mytillus edulis”, Aquaculture* 108, pp. 51-66.

Tenore, K., L. Boyer, R. Cal, J. Corral, F. Garcia, M. Gonzalez, E. Gonzalez, R. Hanson, J. Iglesias and M. Krom (1982), “Coastal upwelling in the Rias Bajas, NW Spain: Contrasting the benthic regimes of the Rias de Arosa and Muros”, *Journal of Marine Research* 40, pp. 701-772.

Thiel, R., A. Sepulveda, R. Kafemann and W. Nellen (1995), “Environmental factors structuring the fish community of the Elbe estuary”, *Journal of Fisheries Biology* 46, pp. 47-69.

Thronson, A. and A. Quigg (2008), “Fifty-five years of fish kills in coastal Texas”, *Estuaries and Coasts* 31, pp. 802-813.

Tilman, D., J. Fargione, B. Wolff, C. D'Antonio, A. Dobson, R.Howarth, D. Schindler, W.H. Schlesinger, D. Simberloff and D. Swackhamer (2001), “Forecasting Agriculturally Driven Global Environmental Change”, *Science* 292, pp. 281-284.

Tinsley D. (1998), “The Thames estuary: a history of the impact of humans on the environment and a description of the current approach to environmental management” in M.J. Attrill (ed.) *A Rehabilitated Estuarine Ecosystem: The Environment and Ecology of the Thames Estuary,* London: Kluwer Academic Publishers.

Turner, R.E. and N.N. Rabalais,(1994), “Coastal eutrophication near the Mississippi river delta”, *Nature* 368, pp. 619-621.

Turner, R.E., N.N. Rabalais, and D. Justic´ (2008), “Gulf of Mexico hypoxia: alternate states and a legacy”, *Environmental Science and Technology* 42, pp. 2323-2327.

Turnipseed, M., L.B. Crowder, R.D. Sagarin and S.E. Roady (2010), “Legal bedrock for rebuilding America's ocean ecosystems”, *Science* 324, pp. 183-184.

Tyler, R.M., D.C. Brady and T.E. Targett (2009), “Temporal and spatial dynamics of diel-cycling hypoxia in estuarine tributaries”, *Estuaries and Coasts* 32, pp. 123-145.

UNCED (United Nations Conference on Environment and Development) (1992), “Rio declaration on environment and development. Annex I”, Rio de Janeiro, Brazil.

UNEP (United Nations Environmental Program) (2009), *Towards sustainable production and use of resources: assessing biofuels,* ISBN: 978-92-807-3052-4, Paris, France, 120 pages.

USEPA (US Environmental Protection Agency) (2007), “ Hypoxia in the Northern Gulf of Mexico: An update by the EPA Science Advisory Board: EPA-SAB-08-004”, December 2007, Washington, D.C., 275 pages.

Vaquer-Sunyer, R. and C.M. Duarte (2008), Thresholds of hypoxia for marine biodiversity. *Proceedings of the National Academy of Sciences of the United States of America*, 105, pp. 15452-15457.

Vitousek, P.M., H.A. Mooney, J. Lubchenco and J.M. Melillo (1997), “Human domination of earth's ecosystems”, *Science* 277, pp. 494-499.

Walsh, S., C. Copeland, and M. Westlake (2004), “Major Fish Kills in the Northern Rivers of NSW in 2001: Causes, Impacts and Responses”, New South Wales Dept. Primary Ind., Ballina Fisheries Center, Australia.

Weisberg, S.B., H.T. Wilson, P. Himchak, T. Baum and R. Allen (1996), “Temporal trends in abundance of fish in the tidal Delaware River”, *Estuaries* 19, pp. 723-729.

Zimmerman, A.R. and E.A. Canuel (2000), “A geochemical record of eutrophication and anoxia in Chesapeake Bay sediments: anthropogenic influence on organic matter composition”, *Marine Chemistry* 69, pp. 117-137.

Chapter 15

Canada:
The National Aquaculture Strategic Action Plan Initiative

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Abstract

Aquatic resource development, including aquaculture, is integral to the economic and cultural fabric of Canada. Nevertheless, aquaculture presents a formidable policy challenge. Jurisdiction over aquaculture is determined by the division of constitutional authority between the federal and provincial / territorial governments set out in the Constitution Act, 1867. Between 1987 and 1995, governments set aside constitutional matters and established bilateral memoranda of understanding (MOUs) to delineate responsibility, avoid duplication and improve support for industry. Despite the MOUs, the regulatory framework governing aquaculture remains complex and costly to navigate. To help fulfil Canada's inherent potential in aquaculture for the benefit of all Canadians, it was apparent that a more strategic approach to sector development was required.

Under the leadership of the Canadian Council of Fisheries and Aquaculture Ministers (CCFAM), the National Aquaculture Strategic Action Planning Initiative (NASAPI) was launched as a national, collaborative exercise to enhance and advance economically, environmentally and socially sustainable aquaculture development. Following extensive consultations, the NASAPI has been launched with an implementation structure designed to improve aquaculture management, policy and regulatory decision-making. It is envisaged that this initiative will enhance the sector's social license and stimulate investor confidence. This paper outlines the process by which Canada was able to address and resolve policy coherence across policy domains.

Introduction

Aquatic resources have long played an important role in Canada's development and growth as a nation. They are integral to the historical, economic and cultural fabric of Canada's coastal communities, providing a strong and reliable resource base around which Canada's national economy and sense of nationhood grew. More recently, aquaculture has emerged as a principal force within the Canadian fish and seafood sector. Today, commercial aquaculture operations exist in every province as well as in the Yukon Territory, and the sector accounts for one third of the total value of Canada's fisheries production. Additionally, more than a dozen First Nations communities are involved in aquaculture for food, social, ceremonial and/or commercial purposes. Nevertheless, Canada's output is a small fraction of global production. In 2006, Canada ranked 23rd among world aquaculture producers and contributed less than 0.3% of total output.

Salmon is the main species produced on Canadian farms, accounting for 69% of total production (145 000 tonnes in 2008), followed by mussels (14%), oysters (8%) and trout (3%). British Columbia contributes the most farm-raised fish and seafood, followed by New Brunswick, Prince Edward Island, Nova Scotia, and Newfoundland and Labrador. In the inland provinces, trout is the main product, accounting for more than 92% of total production. Ontario is the largest producer, followed by Quebec and Saskatchewan.

Regulation and management of aquaculture in Canada

Aquaculture development in Canada presents a formidable policy challenge. The sector straddles the line between fishing and farming, cuts across significant regional differences, and is placed in a complex jurisdictional context involving the participation of municipal, provincial/territorial and federal governments and First Nations. Moreover, 'aquaculture' is not defined in Canadian law which adds further confusion to policy development and regulation in the sector.

Within the Canadian federation, jurisdiction and authority over aquaculture operations and production is determined by the division of constitutional authority between the federal parliament and provincial/territorial legislatures as set out in sections 91 and 92 of the *Constitution Act, 1867*. Clearly, the Act was in place long before aquaculture activities were ever envisaged. Under Section 91 of the Act, the federal government is given exclusive jurisdiction and authority over SeaCoast and Inland Fisheries, including those situated entirely within one province. Section 92 assigns the provinces and territories exclusive jurisdiction over matters dealing with Property and Civil Rights and the Management of Public Lands and general Matters of a Merely Local or Private Nature within the province. Essentially, the federal government has jurisdiction over the waters, including the harvesting and protection of fish within those waters, while the provinces and territories have authority over the seabed within their territory (*i.e.* in the intertidal zone and within the jaws of the land). In Canada, the majority of aquaculture production occurs within federal waters in systems situated on provincial lands.

Further complexity was added to the federal-provincial legal framework in February 2009 when the British Columbia Supreme Court (BCSC) ruled that the activity of *aquaculture is a fishery* which falls under exclusive federal jurisdiction pursuant to sub-section 91(12) of the *Constitution Act, 1867* and struck down the provincial regulatory regime governing aquaculture in the province. In light of the BCSC decision, it is clear that only the federal government has the authority to establish the comprehensive regulatory regime needed to ensure that the industry in British Columbia is appropriately regulated and managed. Notably, the Province of British Columbia retains the authority to grant leases to the seafloor within provincial jurisdiction for purposes of aquaculture, to set labour safety requirements as well as certain measures respecting business practices. In response to the BCSC decision, the Minister of Fisheries and Oceans has confirmed the commitment of the Government of Canada to establish a federal regulatory regime governing aquaculture pursuant to the *Fisheries Act* in the geographic area of British Columbia and along the Pacific coast. Undoubtedly, this will have a significant effect on future management of aquaculture in British Columbia and, potentially, throughout the rest of Canada; however, the scope of this effect remains uncertain since the process to establish a new federal aquaculture regulation is still a work in progress.

The federal Department of Fisheries and Oceans (DFO) is the lead federal agency for aquaculture development. Part of DFO's mandate is to create the conditions necessary for a vibrant and innovative aquaculture industry that is environmentally and socially responsible, economically viable, and internationally competitive for the benefit of all Canadians. These responsibilities include the following:

- Lead agency role to foster innovation and competitiveness through investments in science, R&D and industry development programs;
- Administering, monitoring and enforcing compliance with its important regulations, including: fish habitat, fish communities/ecosystem management, enforcement supporting Canadian Shellfish Sanitation Program and laboratory services and research in support of National Aquatic Animal Health Program;
- Carrying out its ocean management responsibilities relating to conservation and protection, environmental and habitat protection and fish health;
- Small Craft Harbours (wharf infrastructure);
- Coordinating and bringing increased coherence to federal aquaculture program and policy development;
- Facilitating harmonization of federal and provincial aquaculture regulatory frameworks and coordination of intergovernmental aquaculture program and policy development; and
- Facilitating increased dialogue between aquaculture stakeholders on issues of mutual interest.

In addition, several other federal departments and agencies are implicated in the development and management of aquaculture in Canada. Most notably, these include:

- Agriculture Agri-Food Canada
  - International Food Marketing Program
  - Rural Secretariat
  - Farm Credit Canada (aquaculture loans)

- Canadian Environmental Assessment Agency
  - Oversees federal environmental assessment practice and policy under its *Canadian Environmental Assessment Act*

- Canadian Food Inspection Agency
  - Lead for National Aquatic Animal Health Program under *Health of Animals Act*
  - Fish inspection program (processing facilities and operations)
  - Certification of on-farm food safety
  - Biotoxin aspects of Canadian Shellfish Sanitation Program (fisheries and aquaculture)
  - Regulations of fee under the federal *Feeds Act*
  - Regulation of vaccines

- Environment Canada
  - Water quality aspects of Canadian Shellfish Sanitation Program (fisheries and aquaculture)
  - Regulatory responsibilities related to water quality aspects of the *Fisheries Act*
  - Approval of aquaculture biotechnology products

- Health Canada
  - Standard setting under the *Food and Drug Act* (tolerance limits)
  - Approval of veterinary drugs under the *Food and Drug Act*
  - Approval of pesticides under the *Pest Control Products Act*

- Industry Canada (including the National Research Council)
  - Industrial Research Assistance Program
  - Natural Sciences and Engineering Research Council (NSERC) grants
  - Business Development Bank (export programming)

- Regional Development Agencies (Atlantic Canada Opportunities Agency, Canada Economic Development for Quebec Regions, FedNor, Western Economic Diversification)
  - Financial support for business development and R&D
  - Atlantic Innovation Fund

- Statistics Canada
  - Compiles and analyses annual aquaculture production and value-added statistics

- Transport Canada
    - Approval of aquaculture sites for navigational safety under *Navigable Waters Protection Act* (NWPA)
    - Responsible authority for Canadian Environmental Assessment Reviews related to issuance of NWPA permits

Given the cross-disciplinary nature of the aquaculture sector, there is a significant need for coordination across federal departments, agencies and Crown corporations. Therefore, policy coherence amongst these and other federal departments and agencies is maintained through the Interdepartmental Sustainable Aquaculture Program Coordination Committee (SAPCC). The Committee consists of Directors General from each agency with decision-making authority to yield positive results to ensure multilateral support of a growing, vibrant and sustainable aquaculture sector that contributes to the economic prosperity of rural, coastal and First Nations communities, in addition to the overall Canadian economy.

To further distinguish federal and provincial / territorial roles with regard to aquaculture, the Government of Canada signed bilateral Memoranda of Understanding (MOUs) with six coastal provinces (BC, NB, NS, PEI, NL, QC) and one territory (YT) between 1987 and 1995. The MOUs are designed to delineate responsibility, avoid duplication, and improve support for industry. Under the MOUs, responsibility for leasing public lands/waters was transferred to the provinces/territories, which were also given greater control over promotion, development and regulation of the sector. In broad terms, the MOUs allocate federal and provincial / territorial responsibilities regarding aquaculture as follows:

Table 15.1: MOU federal and provincial/territorial aquaculture responsibilities

Federal	Provincial/Territorial	Joint
Science (basic research)	Innovation	Compliance & Inspection
Innovation	Leasing	Review of Lease Applications
Drug & Vaccine Registration	Issue Aquaculture Licences	Development Programming
Conservation & Protection	Education & Training	Coastal Resource Zoning Fish Disease Management

Despite the MOUs, the regulatory framework governing aquaculture in Canada remains complex and costly to navigate. In 2000, a comprehensive study commissioned by the Canadian Aquaculture Industry Alliance concluded that no other Canadian industry is subject to the degree of government intervention as is aquaculture and, comparatively, among five leading aquaculture nations none appear to have the same diffusion in regulatory responsibility on the scale of that in Canada. Justifiably, environmental sustainability is at the core of the federal and provincial regulatory frameworks; however, regulatory duplication and overlap subjects Canadian aquaculture producers to added operating expenses and delays.

To foster a significant improvement in intergovernmental relations with respect to the development and management of ecologically sustainable and economically viable fisheries and aquaculture industries, in June of 1999 the federal government and the governments of the provinces and territories endorsed the Agreement on Interjurisdictional Cooperation with Respect to Fisheries and Aquaculture. In the spirit of cooperation, governments agreed to pursue opportunities where increased efficiency, effectiveness and streamlining would foster mutually beneficial improvements for both orders of government, with particular emphasis on pursuit of a harmonized approach to the development of fisheries and aquaculture policies and objectives. Through the Canadian Council of Fisheries and Aquaculture Ministers (CCFAM) and its public service Strategic Management Committee (CCFAM-SMC), the Ministers are intent upon:

- Identifying and establishing common goals;
- Coordinating public policy objectives;
- Improving consultations and information sharing on inter-jurisdictional matters;
- Improving resource management and services to industry and the public.

Policy coherence amongst federal - provincial/territorial governments is achieved through the CCFAM-SMC. The Committee provides leadership and strategic advice at a decision-making level to facilitate the development and implementation of coordinated federal - provincial/territorial policies, regulations and programs in support of the Canadian aquaculture sector. The Committee also identifies priority areas requiring federal - provincial/territorial coordination and establishes *ad hoc* working groups to address specific issues. Membership is comprised provincial and territorial Assistant Deputy Ministers (ADMs) with responsibilities for aquaculture, as well as the federal Director General (DG) of the Aquaculture Management Directorate (AMD) within Fisheries and Oceans Canada.

The National Aquaculture Strategic Action Plan Initiative (NASAPI)

Considering Canada’s aquatic resource base and other strategic advantages, the current level of output is not commensurate with the opportunity and potential that exists for aquaculture development. The Canadian aquaculture sector is well-positioned to benefit from the following competitive advantages:

- Plentiful resource base (*i.e.* water supplies, low cost energy, labour, etc.);
- Industry experience, expertise and desire to support sustainable development;
- Substantial export potential with proximity to the U.S. market which is increasingly dependent on imported seafood and increasing global demand for fish and seafood due to population growth, increased affluence and the recognized health benefits of the products;
- A considerable potential and need for coastal and rural economic development, including opportunities to diversify traditional agriculture operations and to offer meaningful economic development within First Nations communities.

To help fulfil Canada's inherent potential in aquaculture, it was apparent that a more strategic approach to sector development was required. Under the leadership of the

Canadian Council of Fisheries and Aquaculture Ministers (CCFAM), the National Aquaculture Strategic Action Planning Initiative (NASAPI) was launched as a national, collaborative exercise to enhance and advance economically, environmentally and socially sustainable aquaculture development throughout Canada.

As a first step, it was essential to develop a collective understanding of the challenges and opportunities within the sector. Therefore, for more than nine months, DFO led an extensive and inclusive consultation process to solicit input from interested and affected stakeholders. The latter consisted of more than thirty 1 to 2-day meetings across the country, including specific meetings with Aboriginal peoples. More than 500 representatives from federal and provincial governments, industry, fish feed suppliers, First Nations/Aboriginal groups, NGOs, academia and other parties participated in these sessions. In advance of the sessions, a background document was circulated to stimulate ideas, and strategic questions were posed within the document to guide the discussions.

These consultative sessions generated considerable input regarding the scope and nature of the many challenges and opportunities related to aquaculture development. They also provided numerous suggestions to help formulate solutions to specific issues and helped to establish a more co-operative position from which to address and resolve challenges pertaining to industry, governments and other interested parties. The data and information compiled from these consultations was analyzed using the 'SWOT-Plus' technique, which is an effective tool for revealing the underlying causal factors that must be addressed to generate the intended results. The technique facilitates development of a comprehensive understanding of the core issues leading to the development of options for potential go-forward strategies that are aligned with insights gained through the analysis, thereby identifying specifically ‘what needs to be addressed’ to bring about meaningful implementation and measurable results.

Once the initial drafts of the action plans were prepared, they were reviewed and edited by all-stakeholder steering committees. The members of these committees represented producers and processors, industry associations, federal and provincial/territorial governments, First Nations, other aboriginal groups, non-governmental organizations and academia.

The NASAPI has generated targeted action plans that will facilitate responsible growth in three sub-sectors of the Canadian aquaculture industry - east coast marine finfish, east coast shellfish and freshwater. Action Plans will also be developed for the Pacific finfish and shellfish sectors following development of a federal Regulation for Aquaculture in British Columbia in late spring, 2010. By targeting precise and realistic objectives to be achieved within a five-year time frame, resources (people, time and money) are being directed toward those initiatives that can deliver meaningful and progressive advancement within the industry. The action plans also present an opportunity to renew federal–provincial/territorial coordination and implementation mechanisms to better service industry needs and government objectives for the benefit of all Canadians. Additionally, it is important to recognize that the NASAPI is a dynamic, living process. Therefore, the action plans will be revised and updated regularly to keep them current, on-track and progressive, leading toward solutions to emerging challenges and opportunities in the sector.

Successful implementation of the NASAPI will foster sustainable growth in Canadian aquaculture, generating improved public, investor and consumer confidence in the sector. Attaining this objective, however, will be dependent upon a collaborative effort amongst all pertinent and implicated parties to establish a framework for advancement of aquaculture based on the three principles of sustainable development, which inherently build upon each other.

Environmental Protection	*i.e.*	mandating that maintenance of healthy and productive ecosystems is prerequisite for all aquaculture ventures
will lead to improved		
Social Well-Being	*i.e.*	earning and upholding a social licence[12] to operate
that will enable		
Economic Prosperity	*i.e.*	responsible sectoral growth and development

Within each of the action plans, four principle areas for action are presented:

1. Governance (Regulatory and Management Regimes for Sustainable Development);
2. Productivity & Competitiveness;
3. Social License & Reporting; and
4. Strategic Aboriginal Engagement in Aquaculture. Governments and industry, therefore, are aligning resources to implement specific strategic initiatives and actions as outlined below:

- Governance
    - Environmental Management
    - Introductions & Transfers of Aquatic Organisms
    - Navigable Waters Protection Act
    - On-Site Inspection and Enforcement
    - Access to Wild Aquatic Resources for Aquaculture Purposes
    - Canadian Shellfish Sanitation Program
    - Other Regulatory & Governance Issues
- Productivity & Competitiveness
    - Fish and Shellfish Health
    - Aquatic Invasive Species
    - Emerging Technologies
    - Alternative Species Development
    - Risk Management & Access to Financing
    - Infrastructure
    - Market Access & Certification
    - Labour & Skills Development
- Social Licence & Reporting
    - Aquaculture Sustainability Reporting
    - Coastal Zone Management

- Strategic Aboriginal Engagement in Aquaculture
    - Capacity Building (training, skills development, etc.)
    - Aboriginal aquaculture ventures
    - Governance Partnerships

Within the Atlantic Canadian marine finfish and shellfish sectors, and in the national freshwater sector, 64 strategic objectives have been identified with 174 associated specific action items. Amongst the strategic objectives, 45 are common to all three sectors, reflecting the scope of broader issues that affect all sectors of the Canadian aquaculture industry. For each of the specific action items, lead responsibility for implementation has been assigned to the appropriate industry, federal, provincial / territorial, First Nation, aboriginal or other stakeholder (*e.g.* ENGOs, community groups, etc.) organizations.

Assuming that these measures will be implemented effectively, industry's social licence should improve – but only if First Nations, Aboriginal groups, community interests and the general public are aware of the progress within the sector. Therefore, timely and transparent communications as well as active community engagement are necessary to disseminate information about the economic, social and environmental sustainability of Canadian aquaculture. Therefore, a fundamental component of the NASAPI is the annual compilation of a document entitled *Aquaculture Sustainability Reporting* in which the economic, environmental and social sustainability of Canadian aquaculture will be objectively presented to the Canadian public. DFO will lead this exercise in collaboration with Statistics Canada and the Provinces and Territories.

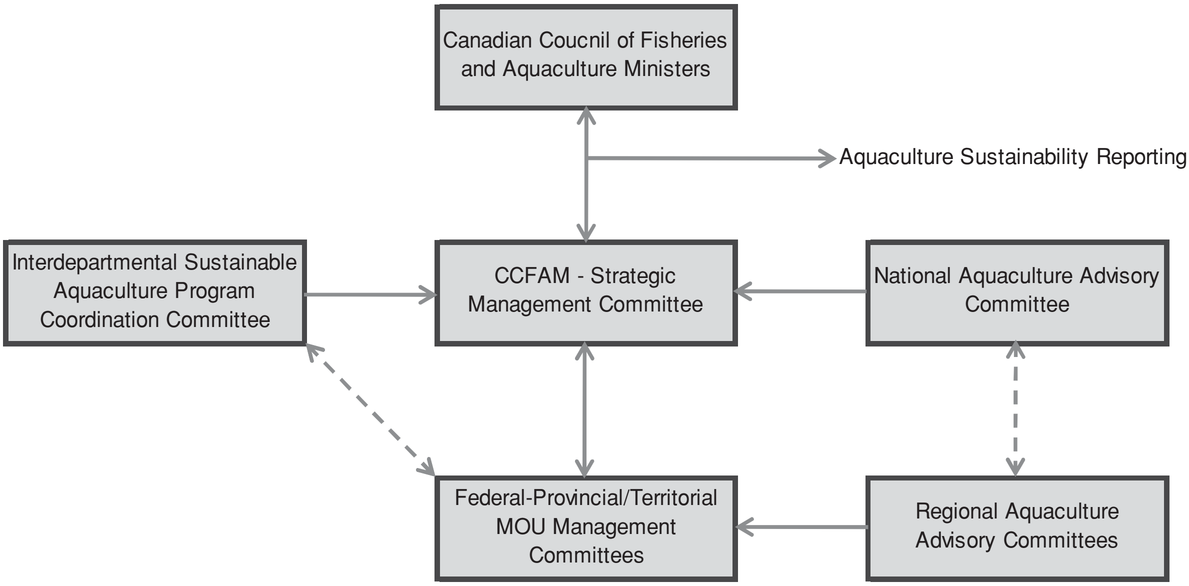
Implementation

In developing an implementation structure for the NASAPI, the intent was to avoid duplication of existing structures and mechanisms for aquaculture governance and management. The federal-provincial/territorial framework provided by the aquaculture MOUs, with increased industry participation, is perceived to be the best means to achieving the objectives of the NASAPI.

Successful implementation of any action plan generally rests within the hands of a guiding coalition that is empowered to oversee the implementation process. For the NASAPI, this guiding coalition is the CCFAM - Strategic Management Committee (CCFAM-SMC) comprised of senior federal government personnel and provincial / territorial Assistant Deputy Ministers responsible for fisheries and aquaculture. The CCFAM-SMC is supported in its efforts by several other bodies, as illustrated in the diagram below.

Regional (provincial / territorial) implementation through the MOU Management Committees is envisaged as the principal interface between industry and governments. Working together, industry and governments will establish an annual work plan specific to their province / territory. The MOU Management Committees will prepare an annual progress report for presentation to the CCFAM-SMC to coincide with each fiscal period. By providing input into the *'Aquaculture Sustainability Reporting'* initiative, the CCFAM-SMC will be the principal interface between the aquaculture sector and the public. As noted above, the Interdepartmental Sustainable Aquaculture Program Coordinating Committee is responsible for policy coordination amongst federal departments and agencies, and federal-provincial/territorial policy coordination is achieved through the CCFAM-SMC.

Renegotiation of the existing MOUs, and development of new MOUs with provinces where they do not yet exist, is among the first actions to be performed during implementation of the National Aquaculture Strategic Action Plans.



Notes

[1] ‘Social licence’ is an emerging concept intended to reduce user-group conflict and generate public acceptance in natural resource sectors. It is based on the notion that the development of natural resources for commercial interests requires consent from communities affected by the proposed development through mutual understandings and agreements. Through meaningful engagement of local stakeholders to recognize their values and beliefs, and to identify appropriate mitigation measures, community support for a project is more readily secured. (Salim, E. (2004) “Striking a Better Balance: The World Bank Group and Extractive Industries: The Final Report of the Extractive Industries Review”, 44 p.; Shepard, R.B. (2008). “Gaining a Social License to Mine”, www.MINING.com April 2008, p. 20-23)

Chapter 16

Connections between farmed and wild fish: Fishmeal and fish oil as feed ingredients in sustainable aquaculture

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Abstract

All farmed fish and crustaceans have a requirement for animal protein and omega-3 fatty acids, if only at the initial fry stage. This has been traditionally met by incorporating marine lipids in feeds, hence somehow copying what takes place in the wild. Key demand drivers by feed manufacturers include scope for cost optimisation while adequately meeting specific nutritional requirements under conditions of rapidly changing ingredient costs for marine ingredients and their commercially available non-marine alternatives.

Innovation increases dietary options to control costs, maintains and improves performance, and addresses supply security. Partial substitution by vegetable proteins and oils has enabled rapid growth in global aquaculture without over-exploitation of marine ingredients. To the extent that the use of marine oil for aquaculture and human consumption could become limiting (due to the unique advantages of its omega-3 content), the development of genetically modified plants incorporating the key nutrients has obvious relevance for long term supply.

To demonstrate that marine ingredients are sourced sustainably, it is important to ensure that the fisheries in question are not overfished and are being managed in compliance with the FAO Code of Conduct for Responsible Fishing. Certification and eco-labels play a role to provide reassurance but pose potential problems for fisheries in developing countries.

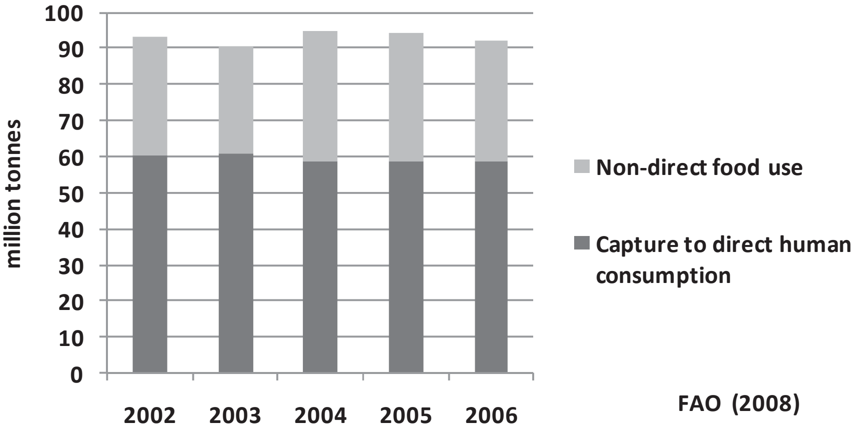
Improved nutrition, better raw material processing and responsibly sourced marine ingredients should ensure that aquaculture has the means to remain sustainable in the future.

Introduction

According to the latest FAO estimates (FAO, 2008), the annual global fish catch (excluding aquaculture) of around 90 million metric tonnes includes approx 30 million metric tonnes representing fish which go for non-direct food use (Figure 16.1). Of this 30 million metric tonnes around 16.5 million metric tonnes goes for fishmeal and fish oil production, the remainder going for a range of uses, including direct feeding as wet fish to animals (particularly fish and crustaceans in Asia), as well as pet foods and fur-producing animals.

The main use of the fishmeal and fish oil derived from that 16.5 million metric tonnes of whole fish is as feed ingredients for the farming of aquatic animals by means of aquaculture, although other uses include pig and poultry feed as well as fish oil supplements for human health. In addition to this fishmeal and fish oil produced from whole fish, an increasing proportion of fishmeal and fish oil is derived from trimmings as a by-product of fish processing (approx. 5 million metric tonnes in 2008). The purpose of this study is to survey the changing usage pattern of fishmeal and fish oil as components of aquaculture feed and to comment on the implications for sustainable aquaculture.

Figure 16.1: Total capture fisheries



The use of fishmeal and fish oil as feed ingredients

Fishmeal was originally a by-product from fish oil production when fish oil was a low cost oil for margarine production. Fishmeal is now increasingly used as a specialist feed ingredient in aquaculture, young pigs and poultry. The main nutritional benefits of fishmeal are that it is high in protein with an excellent amino-acid profile as well as being highly digestible with no anti-nutritional factors. Figure 16.2 shows the changing use of fishmeal from 1960 when it was roughly split 50/50 between pigs and chicken and 2008 when 59% was used by aquaculture, 31% by pigs and only 9% by poultry. In 2008 just over 3 million metric tonnes of fishmeal were used in aquaculture and Figure 16.3 explains that salmonids represented 29% of aquaculture use, crustaceans were 28% and marine fish were 21%, followed by a variety of other freshwater fish.

Figure 16.2: Changing uses of fishmeal

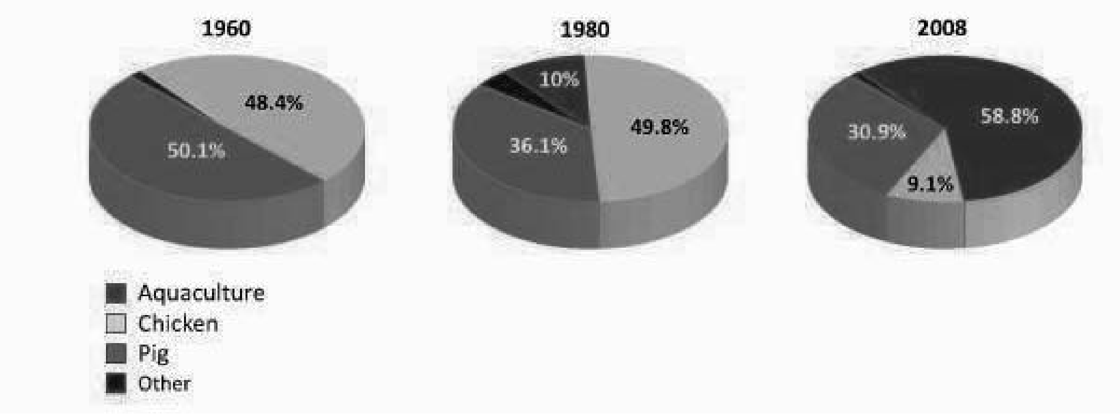
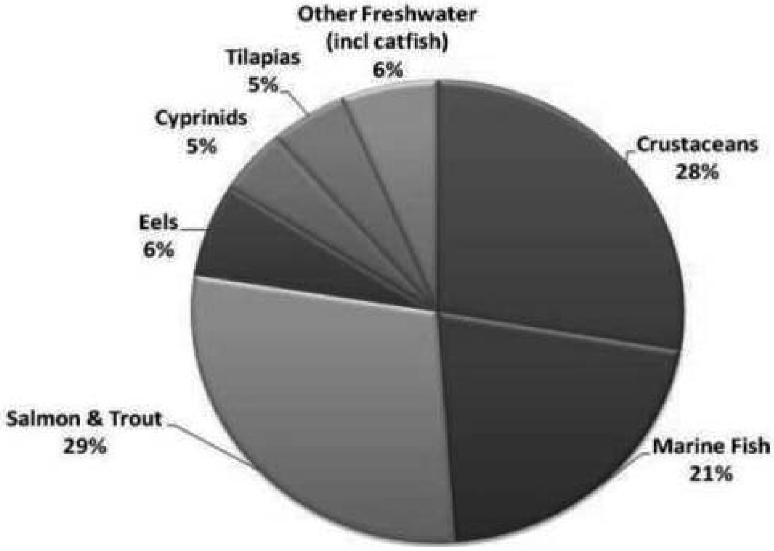


Figure 16.3: Fishmeal usage in aquaculture, 2008



Fish oil was used in the 1960s and 1970s as a low cost source of oil for margarine following hydrogenation, but with the wish to move to unsaturated vegetable margarine, fish oil fell out of favour with margarine manufacturers. However, fish oil is very appropriate for fish feed use being natural, liquid at low temperature and rich in very long chain omega-3 fatty acids, especially EPA and DHA. This last characteristic has fuelled a growth in the market for fish oil as human nutritional supplements for health use mainly via capsules. Fig 16.4 shows the changing use of fish oil from 1970 when it was split 80% between hardened edible oil and 20% industrial usage to the situation in 2010 when it is estimated that 80% will be used for aquaculture, 12% as refined oil for human use and 7% industrial usage. Thus the predominant use of fish oil is in aquaculture and Figure 16.5 shows that this is dominated by salmonids at 76% of total aquaculture use.

Figure 16.4: Changing uses of fish oil

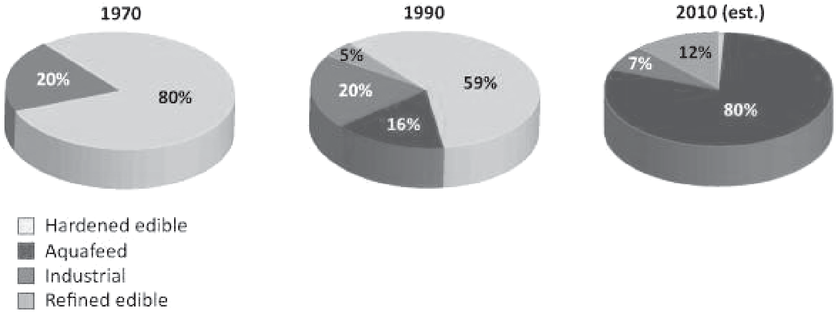
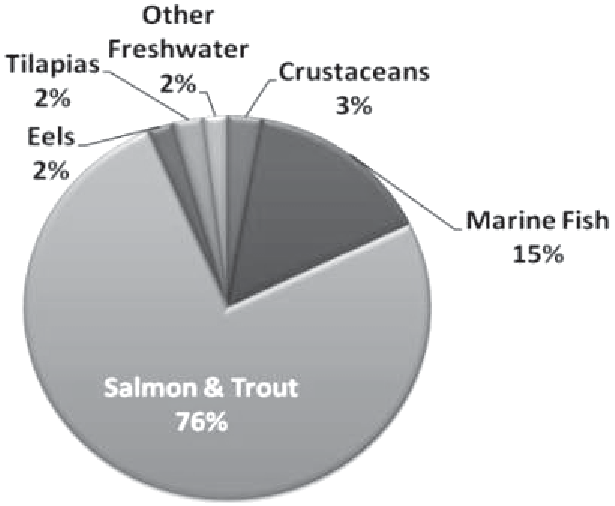


Figure 16.5: Use of fish oil in aquaculture, 2008



Global overview of fishmeal and fish oil production and consumption

Figure 16.6 shows that the use of fishmeal for aquaculture rose during the period 2000 to 2004 and then reached a plateau at about 3.1 million metric tonnes. This compares with total fishmeal supply in 2008 of approx 4.9 million metric tonnes (the balance being taken up mainly by pigs and poultry). It can be seen that the annual use of fish oil for aquaculture over the period 2000 to 2008 remained fairly constant at between 700 000 and 800 000 metric tonnes compared with a total annual supply of around 1.0 million metric tonnes.

Figure 16.6: Global fishmeal and fish oil usage in aquaculture, 200-2008

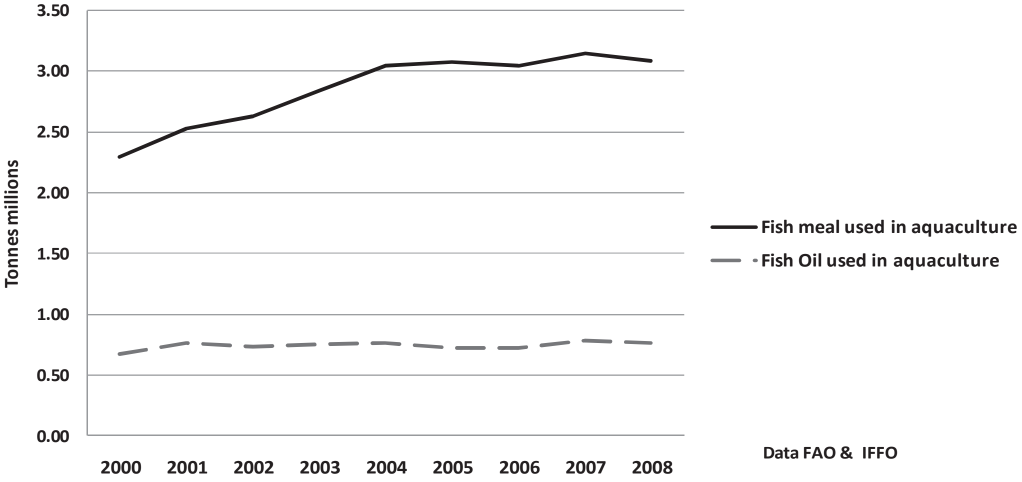


Figure 16.7 and tables 16.1, 16.2 and 16.3 are mass balance calculations derived from data by FAO (2009), IFFO (unpublished), and Tacon and Metian (2008). The model shows that in 2008 16.473 million metric tonnes of wild fish were harvested and processed for fishmeal and fish oil, together with 5.491 million metric tonnes of process trimmings from human consumption fisheries. These inputs yielded 4.942 million metric tonnes of fishmeal, 1.032 million metric tonnes of fish oil and 15.990 million metric tonnes of water (the water obviously remained at the site of production released as water or steam).

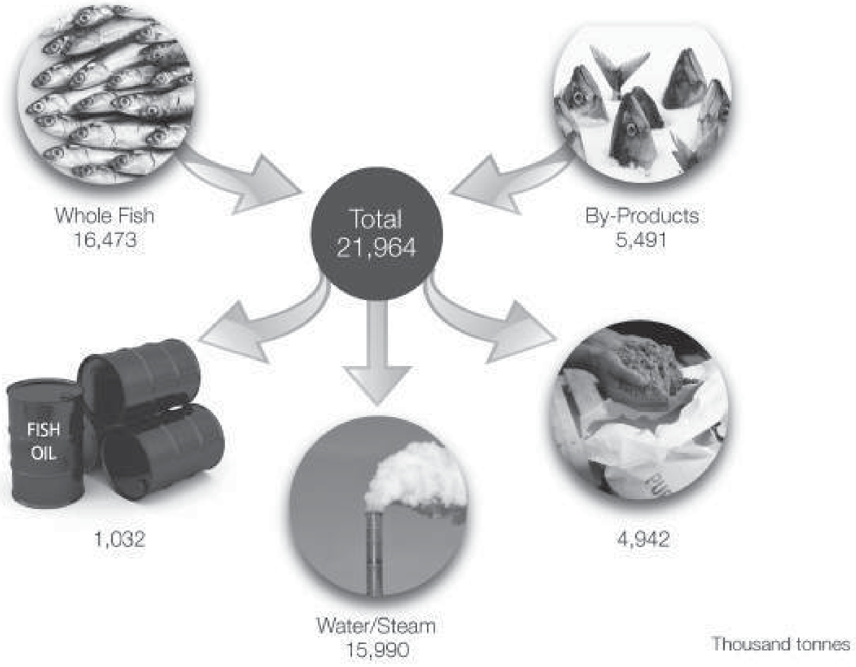
Table 16.1 and table 16.2 are the result of analysing where the outputs of fishmeal and fish oil are used and the amount of raw material and whole fish that can be attributed to each activity on the basis of each marine product separately. The resulting whole fish attribution is then used to calculate a Fish-In:Fish-Out ratio (FIFO) for each fed aquaculture activity (using the definition of fed aquaculture used by Tacon, 2005). These tables show clearly why looking at fishmeal and fish oil attribution separately gives a distorted view. For example, it can be seen that according to Table 16.2, to produce the 120 000 metric tonnes of fish oil going for direct human use, such as capsules, required over 2 million metric tonnes of fish. Whilst being correct, this implies that the fish were only caught for their oil. This is of course not the case since almost as much as five times the amount of meal is extracted as oil.

Given that both fishmeal and fish oil currently yield about the same revenue per tonne (USD 1000-1500/tonne), the fishmeal and fish oil are therefore equally valued and equally important in determining the profitability of the enterprise. It therefore seems logical to combine the fishmeal and fish oil production and conduct a full mass balance analysis of the global system for their production. Table 16.3 is the result of such a mass balance analysis which accounts for all raw materials entering the system and the resulting outputs (meal, oil and water) and their attribution to each destination activity.

Taking fed aquaculture alone it can be seen that, if the inputs and outputs are compared by species, 27.495 million metric tonnes of ‘fed’ aquaculture were produced in 2008 using feed derived from 10.684 million metric tonnes of whole wild ‘feed’ fish representing a Fish-In:Fish-Out ratio of 0.39:1. This is further broken down to show the corresponding ratios for species groupings, ranging from 2.26:1 for farmed eels down to

0.03:1 for carp, with salmonids at a ratio of 1.77:1. It should be noted that this mass balance approach gives FIFO ratios that are lower than those calculated by Tacon and Metian (2008) using the single ingredient approach, but is consistent with those calculated by Jackson (2010).

Figure 16.7: Mass Balance in the global production of fishmeal and fish oil, 2008 (IFFO data)



Source: IFFO

Table 16.1: Fishmeal used in farmed production and the resultant whole fish FIFO ratio, 2008 ('000 tonnes)

	Fishmeal	Raw material	Whole fish	Farmed production	FIFO
Farm animals					
Chicken	440	1 957	1 468	n/a	n/a
Pig	1 263	5 613	4 210	n/a	n/a
Other land animals	160	711	533	n/a	n/a
Aquatic species					
Crustaceans	786	3 494	2 621	4 673	0.56
Marine fish	738	3 281	2 461	2 337	1.05
Salmon and trout	916	4 069	3 052	2 365	1.29
Eels	186	825	619	244	2.53
Cyrprinids	130	577	433	13 037	0.03
Tilapias	143	636	477	2 737	0.17
Other freshwater	180	800	600	2 102	0.29
Aquaculture sub-total	3 079	13 683	10 262	27 495	0.37
Total	**4 942**	**21 964**	**16 473**		

Source: IFFO

Table 16.2: Fish oil used in farmed production and the resultant whole fish FIFO ratio, 2008 ('000 tonnes)

	Fish oil	Raw material	Whole fish	Farmed production	FIFO
Human consumption	126	2 689	2 017	n/a	n/a
Other uses	110	2 340	1 755	n/a	n/a
Crustaceans	28	589	442	4 673	0.09
Marine fish	115	2 455	1 841	2 337	0.79
Salmon and trout	604	12 857	9 642	2 365	4.08
Eels	15	320	240	244	0.98
Cyrprinids	1	24	18	13 037	0.00
Tilapias	18	376	282	2 737	0.10
Other freshwater	15	313	235	2 102	0.11
Aquaculture sub-total	795	16 934	12 700	27 495	0.46
Total	**1 032**	**21 964**	**16 472**		

Source: IFFO.

Table 16.3: Mass balance for fish oil and fishmeal combined including overall whole fish FIFO ratio, 2008 ('000 tonnes)

	Fish oil	Fishmeal	Water	Total	Whole fish	Farmed production	FIFO
			Non-marine uses				
Chicken	0	440	1 178	1 619	1 214	n/a	n/a
Pig	0	1 263	3 380	4 643	3 482	n/a	n/a
Other land animals	0	160	428	588	441	n/a	n/a
Other oil uses	110	0	294	404	303	n/a	n/a
Human consumption	126	0	337	463	347	n/a	n/a
			Aquatic species				
Crustaceans	28	786	2 178	2 992	2 244	4 673	0.48
Marine fish	115	738	2 285	3 138	2 354	2 337	1.01
Salmon and trout	604	916	4 069	5 588	4 191	2 365	1.77
Eels	15	186	537	738	554	244	2.26
Cyrprinids	1	130	350	481	361	13 037	0.03
Tilapias	18	143	430	591	443	2 737	0.16
Other freshwater	15	180	521	716	537	2 102	0.26
Aquaculture sub-total	796	3 079	10 371	14 246	10 684	27 495	0.39
Total	**1 032**	**4 942**	**15 990**	**21 964**	**16 473**		

Source: IFFO.

The impact of innovation on feed formulation for aquaculture

Worldwide a whole range of different species is being cultured, from herbivorous species of carp through omnivorous fish, such as tilapia and pangasius, to carnivorous species, such as salmon, seabass and eels. However, all species of fish, even herbivorous species of carp, have a very high protein requirement when in the early fry or juvenile stage. In the wild these young fish will feed on small microscopic animals or zooplankton and in some extensive farming systems an environment rich in zooplankton can be created by fertilising the pond. However, the commercial rearing of fish under most intensive conditions now requires the production of protein-rich fry feeds which yields the maximum number of healthy, fast growing fry for on-growing. This means that it is very difficult to meet the high protein requirement of young fish and crustacean of different species without the inclusion of fishmeal under farming conditions.

In some farmed species which were formerly fed diets containing a high proportion of fishmeal (*e.g.* salmon and shrimp), a growing knowledge of their nutritional requirements is allowing the partial substitution of the marine ingredients with complementary ingredients, particularly those that are plant-derived. The ability to achieve this substitution is most marked at the latter part of the growth cycle when using on-growing diets and it is being aided by two important developments. Plant breeding has produced new varieties of plants like soya and rapeseed which contain fewer harmful anti-nutritional factors and higher protein levels. This has been combined with new techniques for processing the products post-harvest, which makes the nutrients more bio-available; such techniques include both heat and enzyme treatment.

As regards the security of long-term supply, the limited volumes of fish oil produced globally have led some to speculate that aquaculture production will be limited in the future more by availability of fish oil than of fishmeal. This is likely to be avoided in the short to medium term as fish feed companies have learnt how to make existing volumes of fish oil go further by developing techniques of including a blend of different vegetable oils (*e.g.* rapeseed oil) in diets with the dietary fish oil. These diets combined with special feeding regimes, can give excellent growth performance, when done carefully within appropriate limits and will produce finished aquaculture products, which although lower in total EPA and DHA, have sufficient for fish welfare and to provide some health benefit to the final consumer.

In the longer-term a number of plant breeding companies are working on producing genetically modified varieties of oil seeds which will contain long-chain omega-3 fatty acids. This has now been achieved and the resulting products are currently going through the lengthy licensing process.

The practical result of such innovation is demonstrated by the falling inclusion levels of marine ingredients in salmon and trout diets worldwide over the period 2000 – 2008 (Figure 16.8), which is continuing. The technology of substitution in salmonids is now sufficiently well-developed that, if the price ratio of soyabean meal to fishmeal gets much higher than the long-run average of 3:1 (Figure 16.9), there is reduced demand for fishmeal due to increased substitution of fishmeal by soyabean meal. In a similar way there is a close relationship between the prices of fish oil and rapeseed oil with increased substitution of fish oil if the price climbs above that of rapeseed oil (Figure 16.10), despite the advantage of fish oil's omega-3 content. The challenge for the fish feed formulator is optimising feed costs while meeting nutrient needs of the farmed fish against a background of changing raw material costs.

Figure 16.11 clearly shows that increasing global aquaculture production during 2000 – 2008 has taken place against a simultaneous pattern of stable (or even slightly declining) usage of fishmeal and fish oil for aquaculture. The consequence is that the use of fishmeal and fish oil for aquaculture has not risen since 2004 and 2001 respectively despite 10% annual growth in global aquaculture. This is due mainly to innovations enabling improved efficiency of use and substitution by complementary ingredients. Also given that some cross-substitution of demand exists between fishmeal and fish oil with vegetable proteins and oils, the market has played a role in balancing supply and demand for feed ingredients. At the same time it's clear that demand for marine ingredients by aquaculture has been stronger than for their use in feed for poultry and (grower) pigs at the prices prevailing over the last decade in particular. Whereas it is possible to replace increasing proportions of fishmeal and fish oil with proteins and lipids from non-marine sources, fishmeal and fish oil continue to be vital strategic ingredients for farmed fish and crustaceans, especially at the critical growth stages.

Figure 16.8: Inclusion levels of marine ingredients in Salmonid diets

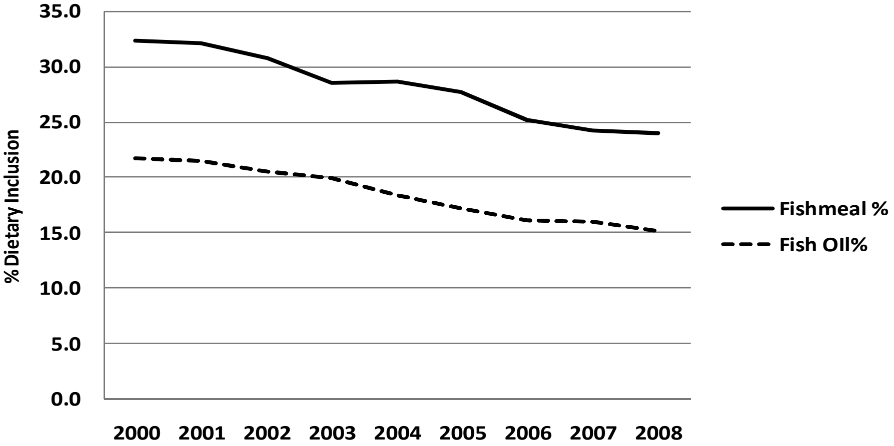


Figure 16.9: Fishmeal to soymeal ration 1998-2009

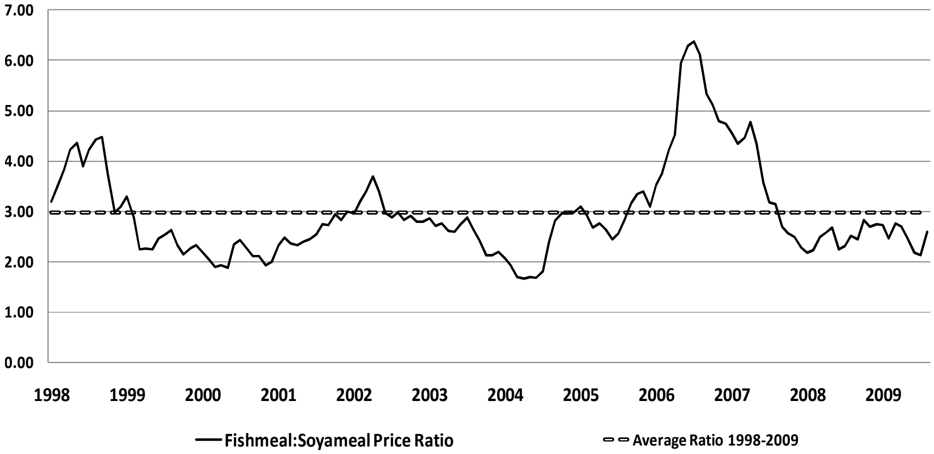


Figure 16.10: Monthly prices of fish oil and rape oil, 1999-2009

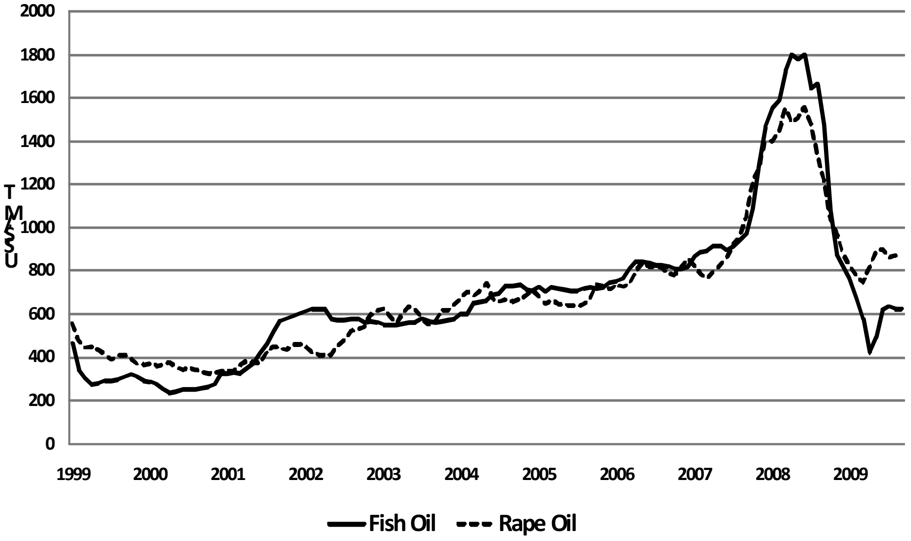
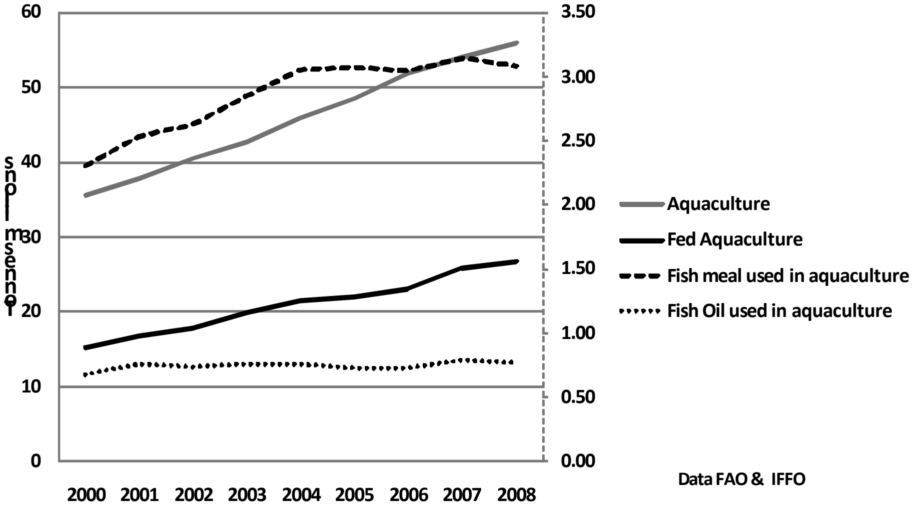


Figure 16.11: Global aquaculture production with fishmeal and fish oil usage, 2000-2008



Data FAO & IFFO

Compliance with the FAO code of Responsible Fishing

Almost all feed fishing takes place within national waters and, as with all fishing, there is the potential risk that short-term benefit will drive over-exploitation. By far the largest feed fishery in the world (and the largest fishery with 6.14 million metric tonnes in 2009) is that for the Peruvian anchovy and it is noteworthy that Peru has in place the following controls to avoid overfishing:

Biomass controls

- Statutory seasons when the fisheries are open and closed
- Annual and seasonal total catch limits

- Only artisanal boats are permitted to fish within five miles of the coast
- Rapid closure when limits are reached or more than 10% juveniles in catch
- Maximum catch limits per vessel (MCLV), a form of catch share

By-catch controls

- By-catch limit 5% (actual 2007 3.6%)
- Minimum mesh size of 1/2 inch (13mm)

Unloading

- Formal declaration of hold capacity
- Closed entry to new fishing boats
- Licences required to fish within the 200 mile limit and to land catch
- Security sealed satellite tracking of all boats operating outside the 5 mile limit
- 24 hour independent recording of landings at 134 unloading points
- Fines and revoking of licences for breaches of rules

The 1995 United Nations FAO Code of Responsible Fishing is the only internationally recognised reference for responsible fisheries management at an intergovernmental level. How closely a country implements the Code is a good measure of the quality of their fisheries management. Compliance with the code is therefore an important objective in focusing efforts to ensure long-term sustainability of fisheries, whether for feed use or human consumption.

The aquaculture supply chain is increasingly demanding assurance that products are produced sustainably; in the case of marine ingredients this is often over and above indications from the government statistics for the fishery in question. The Marine Stewardship Council's (MSC) eco-label is the most widely recognised evidence for sustainable fishing for human consumption and cross-refers to the FAO Code. However, as of today (Feb. 2010) there is virtually no fishmeal and fish oil that comes from MSC approved fisheries and their scheme is focused on the fishery and fish processing plants, whereas fishmeal and fish oil have a different supply chain.

IFFO has recently established a Global Standard for the Responsible Supply of fishmeal and fish oil as a Business-to-Business accreditation scheme with two elements: Responsible Sourcing (*i.e.* demonstrating fishery stocks are responsibly managed in compliance with the FAO code, including avoidance of illegal, unreported, or unregulated (IUU) fish); and Responsible Production (*i.e.* demonstrably well managed factories with control systems to prevent contamination).

Such schemes are a valuable tool to differentiate and reward good practice and to drive up standards and lie at the heart of progress towards sustainable fisheries. At the same it should be noted that the FAO code avoids reference to sustainability and refers instead to responsible practice. However, a problem can arise where ecolabels or accreditation schemes can become a barrier to trade, particularly from poorer regions, if they act in practice to prevent the export of farmed fish or other products to customers demanding accreditation. One way of managing this situation, without in any way diluting the standard, is to construct some form of improvement scheme which offers an incentive for upgrading resources over a transitional period until the improver is able to apply for the standard in question. In the short term a mutually-agreed improvement plan might be followed in order to give some confidence to buyers who might not otherwise wish to source such product; but the main practical difficulty is likely to be a lack of capital to allow the necessary upgrading.

Conclusions

Feed is the highest cost input to most forms of aquaculture and also one of the areas under most scrutiny with regard to sustainability. It is therefore important that aquaculture pays particular attention to the efficient use of feeds and the inclusion of responsibly sourced ingredients. The use of direct ‘trash fish’ feeding for aquaculture, mainly in South East Asia, is an area of concern leading to increased risk of health and hygiene problems and also water pollution, when compared with the use of compounded dry diets. The dominance of feed cost encourages farmers to focus on achieving the best conversion from feed to fish and since fish are excellent converters of feed, many farming systems operate with a feed conversion rate (FCR) of approximately 1:1, although there are always trade-offs between achieving maximum growth, minimum FCR and optimum earnings. However, the optimum solution from a short-term commercial farming standpoint may well differ from that based on optimising resource allocation from a longer term perspective.

With regard to the sustainability of ingredients, this logically applies to *all* ingredients, whether of marine origin or not. As already discussed, marine ingredients should come from fisheries managed under the key principles of the FAO Code of Responsible Fishing. As regards the sourcing of other ingredients, we would suggest that at the minimum they conform to the Brundtland Commission definition of sustainability as production that "meets the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland, 1987). Wherever possible some form of independent verification should be adopted to demonstrate sustainable sourcing and production; in the case of marine ingredients this could include MSC or IFFO (which offer a more rational approach than utilising Fish-in:Fish-out ratios as has been suggested). More work is needed to construct a comprehensive, practical model as a basis for evaluating the overall sustainability of different aquaculture feeds.

References

Brundtland, G.H. (1987), *The Report of the Brundtland Commission: Our Common Future,* Oxford University Press.

FAO (1995), *Code of Conduct for Responsible Fishing,* FAO, Rome.

FAO (2008), *The State of World Fisheries and Aquaculture*, FAO, Rome.

FAO (2009), FAO FISHSTAT, FAO, Rome.

Jackson, A.J. (2010) “Fishmeal and Fish Oil: Prime feed ingredients not limiting factors for responsible aquaculture”, *Global Aquaculture Advocate* January/February, 14-17.

Tacon, A.G.J. (2005), “Salmon aquaculture dialogue: status of information on salmon aquaculture feed and the environment”, *International Aquafeed* 8, 22–37.

Tacon, A.G.J. and Metian, M. (2008), “Global overview on the use of fish meal and fish oil in industrially compounded aquafeeds: trends and future prospects”, *Aquaculture* 285, 146–158.

Chapter 17

Barriers to aquaculture development as a pathway to poverty alleviation and food security

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WorldFish Center

Abstract

The importance of aquaculture production in developing countries is reviewed briefly. Two sets of barriers to realizing the potential of aquaculture to alleviate poverty and improve food security and nutrition are identified: those directly attributable to aquaculture development policies and those arising from a lack of policy coherence for development (PCD). The latter applies to a wide range of sectors, the most important from an aquaculture perspective being energy, environment, agriculture and food production, and trade and sanitary standards. Lack of PCD is apparent at many levels: within development cooperation policies, between aid and non-aid policies within a single donor and between donors, and donor-partner coherence to achieve shared development objectives.

We conclude that development agencies can play a greater role in fostering the emergence of aquaculture as a means of alleviating poverty and improving food security and nutrition. This requires broadening the focus beyond poor producers to include small and medium aquaculture enterprises, adopting a value chain perspective on aquaculture development that fosters a "whole industry" approach that delivers key human development goals, and pursuing greater internal coherence within and between development policies. We also propose that development agencies promote mechanisms and interventions that redress policy imbalances by raising awareness among policy makers and through more integrated approaches to development assistance.

Introduction

Aquaculture addresses poverty and food insecurity through a variety of routes and at various scales. It offers a means for smallholder farmers to diversify production, thereby providing nutritious food for their own families, and sometimes those of their neighbours, while also generating surpluses for sale. Aquaculture enterprises from micro to large scale, providing fish exclusively for sale, create farm income and employment opportunities throughout the value chain and provide affordable, highly nutritious food in response to market demand.

While the development benefits from aquaculture are increasingly understood in development circles, the key question remains: where and in what circumstances is aquaculture the most appropriate option to improve livelihoods, foster economic development and improve food security and nutrition? Equally there is uncertainty as to how aquaculture can minimize impact on the environment, and where other policy investments are needed to foster aquaculture output and optimize its development benefits.

The present paper considers these issues and explains the importance of the aquaculture sector in developing countries. We consider how aquaculture contributes to poverty alleviation and food security and nutrition and review the sector's consumption of, and contribution to, ecosystem services. We analyze how aquaculture affects vulnerability and consider how development policies that focus on smallholder producers limit the potential of the sector to alleviate poverty and improve food security. We examine the coherence of OECD policies on energy, environment, trade and sanitary and phytosanitary standards with those on development, and examine how they can compound external shocks to increase vulnerability of the global poor and the ecological services upon which they depend.

Aquaculture in the developing world

Introduction

Fish provides an important source of protein (>20% animal protein) for 2.6 billion people worldwide and is the dominant source of animal protein in many small island developing states, Bangladesh, Cambodia, Equatorial Guinea, French Guiana, the Gambia, Ghana, Indonesia and Sierra Leone (FAO, 2009). More importantly, it is a rich and highly bioavailable source of much-needed micronutrients and vitamins. Provisional FAO statistics for 2008 show that aquaculture now supplies almost half of all fish consumed. While capture fisheries production has stabilized at around 95 million tonnes for the past 20 years, aquaculture production has grown at an average rate of 7% per annum, ahead of world population growth. Preliminary data for 2008 from the FAO indicate that 53.3 million tonnes was produced, a 6% increase on production in 2007. Farm gate value is estimated at USD 81 billion, but two-three times this figure from a value chain perspective.

The developing world accounts for the vast majority of global aquaculture production and increasingly is a producer of fish for the developed world. Ninety percent of global aquaculture production is from Asia, 67% from China alone. An increasing proportion of

Asian aquaculture production is traded both regionally and internationally, especially with Europe and North America. Three commodities in particular are worthy of note: tropical penaeid shrimp (predominantly *Penaeus monodon* and *P. stylirostris*), Mekong catfish (*Pangasius* spp.) and tilapia (*Oreochromis* spp.). Annual shrimp sales alone are worth an estimated USD 18 billion at farm gate. The Vietnamese striped catfish (*Pangasionodon hypophthalmus*) industry is the fastest growing single species farmed commodity ever recorded and today produces close to 700 000 tonnes, generating an estimated USD 645 million at farm gate values (Phan *et al.*, 2010). Ninety percent of the fish is processed and, trading under a plethora of names, striped catfish has rapidly penetrated markets throughout the developed world, especially in Europe, as an affordable and acceptable substitute for the depleted stocks of marine white fish formally supplied by domestic fisheries.

In contrast, there is little aquaculture production in Africa (775 500 t), the bulk of which (635 000 t) comes from Egypt where the indigenous Nile tilapia is the most important species. Aquaculture production in Africa is, however, now growing rapidly, albeit from a very low baseline. Five of the ten countries with the most rapid rates of production increase are African: Uganda, Mozambique, Malawi, Togo and Nigeria (FAO, 2009). Domestic markets are strong, and negligible amounts of African aquaculture production are traded outside the region (Gordon 2009; Bené *et al.*, 2010). Nonetheless, per capita fish consumption in sub-Saharan Africa remains the World's lowest through a combination of population growth, stagnating capture fisheries supplies and slow regional growth in aquaculture production, compounded by increasing world fish prices that constrain imports.

The bulk of developing world aquaculture is of herbivores and omnivores, in contrast to the intensive production of carnivorous marine finfish that dominates developed world aquaculture (Tacon *et al*., 2010). There is also an enormous diversity of producer types in developing country aquaculture. Smallholder 'subsistence' type fish farmers raise crops of fish in ponds on their farms. Production volumes tend to be low, a result of both small pond size and low productivity, the latter arising through dependence on on-farm (farm wastes), sometimes augmented with off-farm (inorganic fertilizers, manures from intensive agriculture and feeds) resources. The term small and medium aquaculture enterprises (aquaculture SMEs) is applied to a wide range of producer types that produce fish and other aquatic products for sale. The smallest enterprises may generate income from aquaculture as one component of a household livelihood strategy, but many small and medium enterprises are characterized by livelihoods largely dependent on aquaculture. SME production is typically semi-intensive, reliant on fertilizer and/or feed, with production levels between 1 and 100 tonnes per farm per annum. Larger, commercial aquaculture operations, which may produce as much as several thousand tonnes per annum, remain relatively uncommon in developing countries, other than in the Mekong delta of Vietnam. They are generally multinational operations, often targeting multiples in regional and international markets.

The FAO estimates that there are some nine million fish farmers (FAO, 2009), a figure widely acknowledged as a considerable underestimate. The aquaculture value chain comprises producers, those who supply inputs (*e.g* seed, fertilizers and feed) to producers and those engaged in downstream processing, distribution, marketing and trade of aquaculture produce. Although data are scant the numbers employed throughout the aquaculture value chain often exceed those directly involved in production by a factor of two or three. Employment opportunities are provided for a wide variety of actors including many women, the landless and the socially and culturally marginalized.

Aquaculture, ecosystem services and poverty

Aquaculture and ecosystem services

Aquatic foods - plants, shellfish and fish - obtained via hunting (collecting, trapping, fishing) and farming (aquaculture) are one of the most important provisioning ecosystem services derived from aquatic ecosystems - coastal areas, estuaries, lakes, rivers and wetlands (Béné *et al.*, 2010b). While some forms of aquaculture, especially of seaweed and molluscs, provide both food and supporting ecosystem services through the removal of anthropogenically generated nutrients (Soto *et al.*, 2009), the farming of fish and shrimp is dependent upon use of a wide range of provisioning and regulating ecosystem services - land, water, seed, feed and the dispersion and assimilation of wastes, including escaped farmed organisms (Beveridge *et al.*, 1997; Soto, 2009; Béné *et al.*, 2010a). At the farm level, consumption of ecosystem services is largely determined by species, system and intensity of production methods. While land and water use per unit production decreases with intensity of production methods, demand for seed, feed, energy and the use of ecosystem services to disperse and assimilate wastes tends to increase. Attempts to address these issues include policies to promote 'integrated multi-trophic aquaculture', where seaweed, molluscs and occasionally echinoderms are farmed alongside finfish.

While aquaculture can thus make significant contributions to reducing poverty and improving food security and nutrition, it does so at the cost of the ecosystem services consumed. Certain types of aquaculture are particularly heavy users of ecosystem services and therefore need particular care in their planning, design and operation. For example, conversion of mangroves and sea grass beds for aquaculture use should be avoided as they provide a wide range of ecological services, including the sequestration of carbon (Beveridge *et al.*, 2010). Cage aquaculture depends on the use of common property resources – lakes and coastal areas - and, per quantity of fish production, makes greatest use of certain types of ecosystem services (food; waste dispersion and assimilation) (Beveridge, 2004). Good governance, appropriate legal frameworks, strong institutions with good institutional capacity and the adoption of adaptive management are all essential to the sustainable use of such services and the equitable share of benefits from this type of aquaculture. Intensification of production methods is essential to achieving more productive use of land and water (*e.g.* Verreth *et al.*, 2008) but will also increase consumption of other ecosystem services, both provisioning (notably aquaculture feeds) and supportive (the dispersion and assimilation of nutrients and other wastes). Analyses of various types of aquaculture show that energy consumption, and thus global warming potential, is most strongly associated with feed use, especially when feeds are from outside the production area, and with up-stream post-harvest processing and distribution (Tyedmers, 2009; Henrikksen, 2009). Nonetheless, the linkages between different types of aquaculture production systems, value chains, and ecosystem services remain poorly defined and understood, contributing to the lack of policy coherence.

Poverty, vulnerability and aquaculture

One of the most important dimensions of poverty is the ability of individuals and communities to respond effectively to external shocks such as climate change and globalisation of markets. Resilience in the face of external shocks is dependent on both the degree of exposure to such shocks and the adaptive capacity of individuals and communities. A vulnerability framework is useful in examining both potential and realized vulnerability at a range of scales. Individuals whose livelihoods are most exposed to climate change, for example who live in low-lying coastal areas and work as aquaculture labourers, and who are particularly sensitive to impacts through their dependence on aquaculture, are potentially most vulnerable. However, if those who are potentially most impacted through exposure and sensitivity are also young, have had a reasonable education, belong to well-organized producer organizations and are supported by strong institutions with sound policies, then they are more likely to be able to adapt to the impacts of external shocks than those who lack such adaptive capacity (Beveridge *et al.*, 2010). Development investments – including in aquaculture - that reduce exposure to shocks, reduce sensitivity and build adaptive capacity are increasingly seen as key components in effective approaches to reducing poverty. This requires an approach to aquaculture that goes beyond investment in production to investments in better policies, institutional support and services necessary to build adaptive capacity, particularly when exposing producers to the increased risks associated with international markets.

Aquaculture and development

Introduction

For a decade the Millennium Development Goals (MDGs) have provided an agreed international focus for national governments, development agencies, NGOs and private philanthropic organizations in their efforts to reduce global poverty and hunger. There has been no consensus on how to achieve this, however, and some sectors have received less attention. The share of agriculture in overseas development assistance declined from a high of 18% in 1979 to 3.5% in 2004. It also declined in absolute terms, from a high of approximately $8 billion (2004 USD) to $3.4 billion in 2004 (World Bank 2007). Only relatively recently, spurred in particular by the World Development Report (World Bank 2007) and rapidly escalating fuel and food commodity prices during 2007-2009, has greater focus been placed on agriculture and food production.

Within this evolving development arena and only recent resurgence in attention to agriculture, aquaculture has had a particular history. This has differed between Africa and Asia. As reflected by the current levels of production, 53.3 million tonnes in Asia and 775 500 tonnes in Africa, aquaculture has been spectacularly successful in Asia, but not so in Africa. The poor performance of aquaculture in Africa has resulted in little investment in the sector in recent years. This is beginning to change, however, in response to the growing gap between fish demand and supply and emerging signs that many of the historical constraints to aquaculture development can be overcome. The following section examines the case for aquaculture development investment. We do so by first examining experiences from Africa, the continent that has so far faced the hardest challenges, but where potential is seen as being greatest. In doing so we compare the development case for investment in small-holder aquaculture with its direct impact on poor producers, and investment in SME where many fewer people are engaged in production but where the impact on food security and nutrition at national and regional levels are likely to be greater.

Aquaculture in Africa

Since the late 1980s there have been a variety of donor investments in smallholder aquaculture in sub-Saharan Africa. Notable among these are the investments made by GTZ/BMZ (Germany), USAID, CIRAD (France), DFID (UK), SIDA (Sweden) and NORAD (Norway). The WorldFish Center, among others, has used such investments to work with farmers and NGOs through farmer-scientist research partnerships to pursue the development of smallholder-based aquaculture in Cameroon, Ghana and Malawi as a primary focus of efforts to foster the emergence of African aquaculture as an approach to reducing poverty and hunger.

A central conclusion from these investments is that adoption of fish farming by smallholders has produced many benefits. The farm pond assumes a central importance in integrated smallholder systems generating not only crops of fish but also offering additional flexibility to farmers to use the water for alternative crops or for irrigation and household needs if rains are late or smaller than expected (Miller, 2009). *Ex-post* analysis of the development and dissemination of small-scale integrated aquaculture in Malawi (Brummett and Williams, 2000; Dey *et al.*, 2007, 2010; Poumogne and Pemsl, 2008; Russell *et al.*, 2008), for example has shown that:

- total farm productivity improved by 10%;
- per hectare farm income increased by 134%;
- total farm income increased by 61%;
- technical efficiency improved by 40%;
- per capita household consumption of fresh (208%) and dried fish (21%) increased.

There are also positive impacts on the environment: reduced nitrogen loss and improved nitrogen use efficiency (Dey *et al.*, 2007, 2010).

In sum, where input and output markets are weak, but environmental conditions and on-farm resources for aquaculture are adequate, the development of farm ponds as means of diversifying and improving farm productivity has proved successful. The numbers of smallholders practicing aquaculture in southern Malawi, for example, has risen from 300 to 7 000 over the past 25 years (Russell *et al.*, 2008). Because individual farm production is low, this type of subsistence oriented smallholder aquaculture has had little discernible impact on national food fish supplies, but it has had a substantial impact on food security and nutrition of participating smallholders and has helped build the resilience of farmers in times of drought.

There are thus substantial benefits for agriculture households to be gained from integrating fish ponds into agriculture farming systems. To contribute substantially to food supplies and nutrition, this form of aquaculture needs to be widely replicated among the farming population, or intensification is required. Intensification needs to be supported by the development and dissemination of improved pond production technologies, improved seed and feed and provision of effective extension. Smallholder farmers in Africa do not, however, have the resources to pay for these inputs and their sustained provision requires long-term subsidies, especially in terms of technical support (Brummett *et al.*, 2008, 2010). We believe, however, that this can be an appropriate development investment in support of small farm producers, complementing social protection policies such as food for education that helps improve nutrition, protect people against risks and vulnerability, and mitigates against the impact of shocks and supports people with few alternative means of livelihood diversification.

Analysis of performance success in Egypt, Cameroon, Ghana, Nigeria and Uganda shows that fish production begins to significantly impact on food security where conditions support the emergence of small and medium-scale aquaculture enterprises with a more commercial market-led orientation (Brummett *et al.*, 2008, 2010). Where market demand is strong and accessible, such as near centres of high population density, and where the required technologies and expertise have been available entrepreneurial farmers have seized opportunities to specialize in fish production. For example, in the areas where WorldFish has been working in southern Cameroon the number of commercial farms has increased in peri-urban areas. Many of these are new adopters seeking to replicate the success of the minority of project participants who succeeded to commercialize their farms through integrated agriculture-aquaculture.

This experience has shown that the SME sector is more likely to have the assets (educational and health; cash or access to credit to invest in larger ponds and use of off-farm resources, especially seed, fertilizers and feed) to develop and adopt the more productive and profitable technologies. Greater quantities of fish are produced and production is primarily market oriented. Opportunities are thus created for employment not only in production but also in supplying input markets (especially seed), trading and transport in addition to the benefits to poor consumers secured through stabilization of fish prices. As Brummett *et al.* (2008, 2010) have shown in Cameroon, providing public investment to SME aquaculture producers generates more income and food per development dollar invested, and when projects end they are better able to continue to grow, proliferate and generate jobs and food throughout the value chain, ultimately stabilizing fish prices for the benefit of lower income consumers.

Aquaculture in Asia

There is a long tradition of farming herbivorous and omnivorous carps in Asia, especially in wetland areas (Beveridge and Little, 2002). Despite this, aquaculture production was largely only of local importance until the 1970s. Since then growth in production has been substantial, often exceeding 10% annually, and the region now contributes 90% of global production.

As with the green revolution in Asia in the 1960s that was led by smallholders, so has much of the increase in aquaculture production. Growth was spurred by a number of factors: strong and growing demand from rapidly urbanizing populations, stagnating fish and shellfish supplies from fisheries, highly productive farms, availability of fast growing strains of fish such as genetically improved farm tilapia (GIFT) (Asian Development Bank, 2005), investment in education and research, a dynamic private sector, and high levels of public investment in agriculture and in roads needed to get farm produce to market. The past 15 years has also seen the emergence of a vibrant SME aquaculture sector in many Asian countries, especially in China, Vietnam, Thailand, Indonesia and the Philippines. This SME sector targets not only local, national and regional markets but, increasingly, international markets.

In Bangladesh, agriculture is dominated by small and marginal farms. Nonetheless, aquaculture production has risen almost five-fold in 20 years, from 337 818 tonnes in 1988 to 1 612 969 tonnes in 2007 (FAO, 2009). Aquaculture now accounts for two-thirds of fish production, all of which comes from freshwater farms, most of which are operated by smallholders. Fishponds largely originated as borrow pits, excavated to raise homesteads above flood levels. Growth in production has come from an increase in number of aquaculture farmers and improvements in individual farm productivity. This has been achieved through the involvement of public and private sectors and civil society which have driven increases in stocking densities, increased fertilizer and feed use and better management. The impacts of extension are illustrated by the study of Jahan *et al.* (2008). As the result of a five-year USAID funded aquaculture development project, productivity of farms receiving NGO-led provision of technical advice increased by 25% per annum compared to less than 4% per annum for non-project farmers.

Aquaculture and policy coherence for development

Introduction

Fish is one of the most widely traded commodities, and trade from the developing world to the developed is increasing in both volume and in value. OECD member states import 60% of their fish from developing countries (OECD, 2008). South-North trade not only responds to consumer demand but also to the growing requirement for fish oil and fishmeal for intensive fish farming, especially for farmed Atlantic salmon (*Salmo salar*) and rainbow trout (*Oncorhynchus mykiss*) in Western Europe and North America, and sea bass (*Dicentrarchus labrax*) and sea bream (*Pagrus major*) in the Mediterranean. While globalisation underlies much of the policy discussion on fisheries and aquaculture, there remain significant challenges in understanding, gauging and developing appropriate policy responses (OECD/FAO, 2007). Foremost are how best to address concerns about food security, food safety and public health, and potential conflicts with domestic economic policy in developed countries. Increasingly, too, concerns over impacts of trade on internationally agreed targets on limiting greenhouse gas emissions, can be expected to influence policy.

Policy Cohesion for Development, defined by the OECD as ‘the pursuit of development objectives through the systematic promotion of mutually reinforcing policy actions on the part of both [developed] and developing countries’, is one of the MDGs. Development cannot occur through aid alone: globalisation and liberalization increase the gains from interdependence and integration, while lack of PCD has an economic cost both for the global poor and for taxpayers in the developed world. The importance of fisheries in PCD is explicitly recognized in OECD documents (OECD, 2006, www.oecd.org/dataoecd/41/0/41412053.pdf). However, the pursuit of domestic policies, both with regard to aquaculture and to cross-sectoral issues such as environment, energy and consumer protection, can result in a lack of coherence towards development. Key policy sectors and questions to be considered are summarized in Table 17.1.

Table 17.1: Key cross-sectoral policy areas and issues pertaining to aquaculture

Policy area	Issues
Domestic economies and trade	What are the risks associated with an increasing reliance on aquaculture and can the sector absorb growing demand? How much of domestic demand should policy makers accept being met from developing countries and what proportion of the value added throughout the value chains should policies facilitate in domestic as opposed to developing economies?
Sanitary and phytosanitary standards	What are the public health risks associated with aquaculture and with developing country aquaculture in particular? What policies must be implemented and by whom and where to ensure sanitary standards for import of farmed fish and shellfish are met?
Environment	What ecosystem services are consumed by the different types of aquaculture production systems and value chains? What policies both minimize use of ecosystem services and foster equitable use?
Energy	How energy efficient are the different fisheries and aquaculture sub-sectors? What is the effect on global warming potential - and more specifically on national targets - of international trade of fish from different parts of the world and what policies are needed to minimize these whilst maintaining essential commodity supplies?

Sanitary and phytosanitary standards

Trade in aquaculture products is subject to stringent sanitary and pohytosanitary standards with regard to food hygiene, packing traceability and labeling (OECD, 2008). The food safety issues associated with aquaculture products and trade have been reviewed by the WHO and others (WHO, 1999; Jahnke *et al.*, 2002). International standards are developed through CODEX but there are an increasing number of other mandatory and voluntary (public and private) standards being developed. While there are legitimate concerns, these can be unnecessarily protectionist. Private standards are often driven by consumer demands but also to sustain retailers own brands, which may have higher margins (OECD, 2008). Developing countries are concerned about access to information on standards, predictability, transparency and lack of involvement in standards setting, and insufficient funds and knowledge to comply with standards and implement traceability processes. Private production standards for many important aquaculture sub-sectors, such as tilapia, catfish and shrimp, are being developed, but there are fears that the plethora of emerging standards will confuse consumers. There are also concerns about the clarity and stability of standards, and the costs and capacity of developing countries to conform with, in particular, a concern that small, poor producers are particularly disadvantaged by such standards.

Domestic economies and trade

Developed country fisheries catches have stagnated or declined at the same time as demand has been growing due to increasing wealth and changing consumer preferences (FAO 2007; Ernst & Young 2008). The strategy launched in 2002 to help meet demand and engender economic growth and employment by implementing policies to foster growth of domestic production in Europe by 4% per annum (European Commission, 2002), however, has failed (Eurostat, 2007) due to increased competition, the success of substitution products (*e.g.* striped catfish for marine white fish), reduced profit margins, higher investment risks, sector fragmentation, lack of sites for expansion, poor image and increasingly stringent environmental and health regulations. As a result fish imports, which until recently have largely excluded value added products, increased three-fold between 2002 and 2007 (Ernst and Young, 2008).

In 2009, the EC launched a new strategy for the development of a sustainable aquaculture industry: to promote its competitiveness, to establish conditions for sustainable growth and to improve the sectors organization and governance (European Commission, 2009). If successful, and there are those that question how the strategy can be implemented in the face of ever stricter environmental policies, notably the Water Framework Directive, the policy will also likely have adverse impacts on fish imports from developing country aquaculture. What might be better for both exporting and importing counties would be to encourage stronger partnerships across value chains for aquaculture products, and communication and cooperation that explores and brings mutual benefits to producers and consumers, such as is promoted by the Asia-Europe Meeting (ASEM) aquaculture platform: http://www.asemaquaculture.org/content/view/2/5/

Energy

There have been several recent analyses of impact of aquaculture on climate change (*e.g.* Tyedmers, 2009). Henriksson (2009) examined the global warming potential (kg CO_2 tonne production^{-1}) of Asian aquaculture. Confining his analyses to up-stream and on-farm processes, the GWP of shrimp and fish culture was found to be greater than that of oyster farming, while the GWP of extensive fish farming was less than that associated with more intensive aquaculture practices. For shrimp and fish culture the greatest GWP was generally linked with feed use; the exception was for intensive *Pangasius* catfish farming systems in the lower Mekong, where pumping accounted for the greatest proportion of GWP. Extending the boundaries of such analyses is likely to also highlight the importance of not releasing carbon already locked in storage materials such as mangroves when seeking areas for sectoral expansion. Large quantities of carbon are also sequestered in fishpond muds (Bunting *et al.*, 2007). Releases to the atmosphere can probably be greatly reduced through the development of polyculture or use of sediments in crop and vegetable production.

There is also increasing interest in the high transport mileage, and thus high energy use and global warming potential, when importing aquaculture produce from developing countries. However, research is needed on the energy and ecosystem services costs of aquaculture in different parts of the world and policies must strive to balance concerns about climate change with the need for countries to be able to trade their way out of poverty.

Conclusions

Aquaculture has grown dramatically in recent decades to become a major provider of fish and other aquatic foods. The greatest increases in production have been in the developing world, which now supplies not only much of its own demand but also that of the developed world. However sectoral growth has been very uneven, with Asia (including China) producing some 45 million tonnes per annum, and Africa producing less than 0.2% of this amount. The relatively poor performance of African aquaculture has been caused by a number of factors, among them the different market conditions in Africa, but also the externally driven focus on smallholder aquaculture. While this has proved successful in building resilience of poor smallholder farmers to external shocks through improving household nutrition, building social capital (through exchange of fish within communities) and reducing sensitivity to periodic drought, it has not led to significant growth in production at national or continental levels. Rather, current evidence indicates that significant increases in farmed fish production in Africa are most likely to be achieved through careful investment in well targeted value-chain approaches to the development of the SME aquaculture sector in places where this can respond to strong markets and harness the potential of an emerging private sector. In this sectoral context smallholder aquaculture still has an important place, but should be pursued where it provides a viable crop alternative for improving livelihoods of poor smallholders and improving on-farm resource use efficiency. It is unlikely to be a viable approach for increased fish production at national levels.

The importance of aquaculture, and the need for a more holistic approach to its development, is now acknowledged by a number of African countries, as seen in the development of national strategies and in the plans of regional and sub-regional research and development organizations. Although fisheries and aquaculture were something of an afterthought in the CAADP (Comprehensive Africa Agriculture Development Programme), their potential role in achieving the 6% growth annual growth target is recognized through the new Partnership for African Fisheries (PAF) (www.caadp.net/news/?p=133) and elsewhere. The development community has a major opportunity to build on this through the promotion of aquaculture in those countries where market conditions now favour development of the SME sector.

The sustainable growth of aquaculture for poverty reduction and improved food security and nutrition in developing countries needs coherent, mutually supportive policies across a wide range of economic, social and environmental issues. Both national and donor communities have roles to play. To create a favourable investment climate, developing countries must continue to improve governance, promote transparency, accountability, effective user rights and tackle corruption (OECD 2008). Aquaculture will not flourish everywhere but where prospects seem good and where the benefits appear attractive, countries should facilitate dialogue among policy makers, stakeholders, civil society and consumers to assess the prospects for the sector to contribute to meeting MDGs and to resolve trade-offs with other economic sectors and with environmental requirements. National strategies and sectoral plans help establish clear sectoral goals but must be developed within a broad economic, social and environmental policy context. Strategies and plans should focus on addressing key challenges to sectoral growth but are of no value if the resources or political will for implementation are lacking.

For their part, development agencies need to continue to strive for PCD. They must understand the likely development benefits from different types of aquaculture, the economic, social and institutional realities of the countries with which they engage, and the effectiveness and cost-effectiveness of different types of intervention. In any such analysis, the present focus on producers must enlarge to consider the entire value chain, the impacts on ecosystem services and the policy and institutional environment needed for sustainable development of the sector. Investment in training and capacity building is needed with a view to developing technologies to meet local needs, and institutions strengthened so as to develop and implement supportive policies. World Trade Organization and OECD policies make it tough for developing country aquaculture produce, especially from small producers, to enter international markets (Umesh *et al*., 2009). Producers need stability in standards, which must also be clearly communicated. Support is often needed to help meet standards. Some sub-sectors, such as the Vietnamese striped catfish industry, have secured access through investments from government and international development agencies as well as the private sector. A lack of investment hampers others, however. Bangladesh, for example, currently faces constraints on export of farmed freshwater prawns and shrimp to the EU due to concerns related to chemical contamination of products, which it finds difficult to resolve without technical expertise.

There remain concerns that unconstrained expansion of aquaculture, combined with intensification of production methods and demands on ecosystem services, may have undesirable impacts on poverty. While existing approaches such as Life Cycle Analysis help identify and quantify some of the environmental impacts, a wider suite of tools, such as vulnerability frameworks and those being developed in support of the emergent Ecosystem Approach to Aquaculture, are needed to determine and manage both social and ecological impacts, essential for sustainable growth of the sector (Soto *et al.*, 2009). These novel approaches need to be applied more widely and lessons drawn from their strengths and weaknesses. Only by doing so will aquaculture realise its full potential to increase fish production in ways that strengthen livelihoods and national economies in ways that are sustainable.

References

Asian Development Bank (2005), "An Impact Evaluation on the Development of Genetically Improved Farmed Tilapia and their Dissemination in Selected Countries". ADB, Manila, pp. 166.

Béné, C, R. Lawton and E.H. Allison (2010a), "Trade matters in the fight against poverty: narratives, perceptions and (lack of) evidence in the case of fish trade in Africa", *World Development* (in press).

Béné C., M. Phillips, and E.H. Allison (2010b), "The forgotten service: food as an ecosystem service from estuarine and coastal zones" in: van den Belt M. and Costanza R. (eds.) *Ecological Economics of Estuaries and Coasts*, Vol.12, Treatise on Estuarine and Coastal Science, Elsevier (in press).

Beveridge, M.C.M. (2004), *Cage Aquaculture*, 3rd edn., Blackwell, Oxford.

Beveridge, M.C.M and D.C. Little (2002), "The history of aquaculture in traditional societies" in B.A. Costa-Pierce (ed.) *Ecological Aquaculture. The Evolution of the Blue Revolution,* Blackwell, Oxford, pp. 3–29.

Beveridge, M.C.M, M.J. Phillips and D.C. Macintosh (1997), "Aquaculture and the environment: the supply and demand for environmental goods and services by Asian aquaculture and the implications for sustainability", *Aquaculture Research* 28, pp. 101–111.

Beveridge, M.C.M, M.J. Phillips, and A.R. El-Gamal (2010), "Aquaculture and climate change"in L. Curtis, M.C.M. Beveridge, P. Mannini and A.R. El-Gamal (eds.) *Adapting to Climate Change: The Ecosystem Approach to Fisheries and Aquaculture in the Near East and North Africa Region,* FAO (in press).

Brummett, R.E., J. Lazard and J. Moehl (2008), "African aquaculture; realizing the potential", *Food Policy* 33, pp. 371-385.

Brummett, R E, J. Gockowski, V. Poumogne and J.F. Muir (2010), "Targeting agricultural research and extension for food security and poverty alleviation: a case study of fish farming in central Cameroon", (in review).

Dey, M.M., P. Kambewa, M. Prein, D. Jamu, F.J. Paraguas, D.E. Pemsl and R.M. Briones (2007), "Impact of the Development and Dissemination of Integrated Aquaculture Technologies in Malawi" in: *International Research on Natural Resource Management,* FAO, Rome, and CAB International, Cambridge (eds. H. Waibel and D. Zilberman), pp. 118-140.

Dey, M. M., F.J. Paraguas, P. Kambewa and D.E. Pemsl (2010), "The impact of integrated aquaculture-agriculture on small-scale farms in Southern Malawi", *Agriculture Economics* 41, pp. 67-79.

Ernst and Young (2008), “Étude des Performances Économiques et de la Compétitivité de l’Aquaculture de l’Union Européenne”, DG Mare, Rapport Final.

European Commission (2002), “A Strategy for the Sustainable Development of European Aquaculture”, Communication from the European Commission to the European Council and the European Parliament, COM (02) 511.

European Commission (2009), “A New Impetus for the Strategy for the Sustainable Development of European Aquaculture”, Communication from the European Commission to the European Council and the European Parliament, COM (09) 162/3.

Eurostat (2007), *Fishery Statistics: Data 1990-2006*, Luxembourg, Office for Official Publications of the European Commission.

FAO (2007), *Future steps for fish and fishery products: 4. Fish consumption in the European Union in 2015 and 203*0, FAO Fisheries Circular 972/4, Part 1: European Overview, Rome, FAO.

FAO (2009), *The State of World Fisheries and Aquaculture 2008*. FAO, Rome.

FAO/NACA/WHO (1999), *Food Safety Issues Associated with Products from Aquaculture,* WHO Technical Report 883, Geneva, WHO, pp. 55.

Gordon, A. (2009), “Fish trade in Africa – its characteristics, role and importance”, in: M Culberg (ed.) *Fish, Trade and Development*, Royal Swedish Academy of Agriculture and Forestry, Stockholm, pp. 435-442.

Henriksson, P. (2009), “Energy Intensity in Tropical Aquaculture”, unpublished Masters Thesis, University of Stockholm, 40 pages.

Jahan, K.M, M.C.M. Beveridge and A.C. Brooks (2008), “Impact of long-term training support on small-scale carp polyculture farms of Bangladesh”, *Journal of the World Aquaculture Society*, 39, pp. 441-453.

Jahncke, M, S. Garrett, R. Martin, A. Reilly A and E. Cole (eds.) (2002), *Public, Animal and Environmental Aquaculture Health Issues,* Wiley, London, pp. 204.

Kam, S.P., H. Harth, D.E Pemsl, S.K. Kriesemer, S.J. Teoh and M.L.Bose (2008), *Recommendation Domains for Pond Aquaculture*, Studies and Reviews 1848, Penang, WorldFish Center, pp. 40.

Lovshin, L.L., N.B. Schwartz and U. Hatch (2000), *Impacts of integrated fish culture on resource limited farms in Guatemala and Panamá*, Research and Development Series 46, International Center of Aquaculture and Aquatic Environments, Auburn, Alabama, USA.

Miller, J. W. (2009), *Farm Ponds for Water, Fish and Livelihoods,* Diversification Booklet 13, Rome, FAO, pp. 62.

OECD (2006), *Fishing for Coherence: Fisheries and Development Policies, the Development Dimension*, OECD, Paris, pp. 134.

OECD (2008), *Fisheries: Improving Policy Coherence for Development*, Policy Brief, www.oecd.org/dataoecd/41/0/41412053.pdf

OECD/FAO (2007), *Globalisation and Fisheries. Proceedings of an OECD/FAO Workshop,* www.oecd.org/dataoecd/24/51/3997562.pdf (accessed on 17 January 2010).

Phan, L.T., T.M. Bui, T.T.T. Nguyen, J.G. Gooley, B.A.Ingram, H.V. Nguyen, P.T. Nguyen, and S.S. De Silva (2010), "Current status of farming practices of striped catfish Pangasianodon hypophthalmus in the Mekong Delta, Vietnam", *Aquaculture* (in press).

Pouomogne, V. and D. Pemsl (2008), *Country Case Study: Development and Status of Freshwater Aquaculture in Cameroon*, WorldFish Center, Penang, Malaysia.

Russell, A.J.M., P.A. Grötz, S.K. Kriesemer and D.E. Pemsl (2008), *Recommendation Domains for Pond Aquaculture. Country Case Study: Development and Status of Freshwater Aquaculture in Malawi,* WorldFish Center Studies and Reviews No. 1869, The WorldFish Center, Penang, Malaysia, pp. 52.

Soto, D. (ed.) (2009), *Integrated Mariculture: A Global Review*. FAO Technical Paper, 529. Rome, FAO, pp. 183.

Tacon, A.G.J., M. Metian, G.M. Turchini and S.S. De Silva (2010), "Responsible aquaculture and trophic level implications to global food supply", *Reviews in Fisheries Science* 18, pp. 94-105.

Umesh, N.R., A.B. Chandra Mohan, G. Ravibabu, P.A. Padiyar, M.J. Phillips, C.V. Mohan and B. Vishnu Bhat (2009), "Shrimp farmers in India: empowering small-scale farmers through a cluster-based approach" in S.S. De Silva and F.B.Davy (eds.), *Success Stories in Asian Aquaculture*, Netherlands, Springer, pp. 41-66.

Verreth J.A. J., R.H. Bosma, M.C.M. Beveridge, Le Quang Tri, M.E.F. van Mensvoort and A.J. van der Zijpp (2007), "Strategies to enhance the role of fishponds in farming systems" in: A.J. van der Zijpp, J.A.J Verreth, Le Quang Tri, M.E.F van Mensvoort, R.H. Bosma and M.C.M Beveridge (eds.) *Fishponds in Farming Systems,* Wageningen Publishers, Netherlands, pp. 295-304.

World Bank (2007), *World Development Report 2008: Agriculture for Development. Washington*, World Bank.

Chapter 18

Conditions for establishing aquaculture production sites in OECD countries: Survey result discussion and summary

OECD Fisheries Policies Division,
based on information supplied by OECD Committee for Fisheries member economies and observers and released under the responsibility of the Secretary-General

Abstract

In 2009 the OECD conducted a survey on 'Conditions for establishing aquaculture production sites in OECD countries'. The questionnaire aimed to capture main fieatures of the regulatory architecture for aquaculture and to identify areas for improvement. The findings from the survey, integrated with relevant literature, are distilled in key messages to policy makers. These messages focus on (i) the need to simplified regulation and procedures in terms of access to and operation of production sites, (ii) the added value of stakeholder consultation in developing regulation and (ii) the importance of economic incentives.

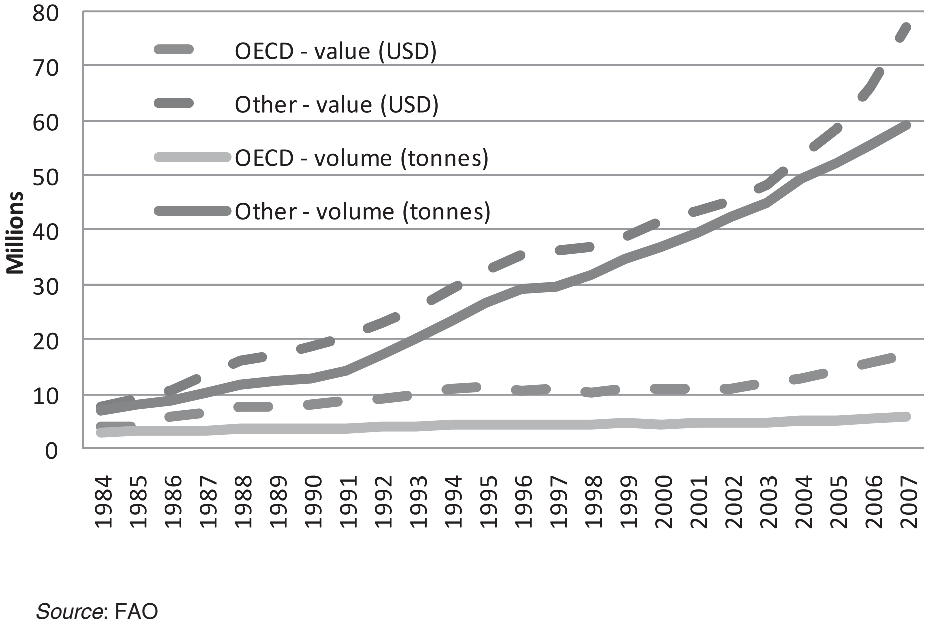
“States should consider aquaculture, including culture-based fisheries, as a means to promote diversification of income and diet. In doing so, States should ensure that resources are used responsibly and adverse impacts on the environment and on local communities are minimized.”
Article 6.19 - General Principles - Code of Conduct for Responsible Fisheries

Introduction

An increasing world population and shifting consumption patterns due to higher income and health motivations ensure a growing demand for seafood. Concurrently, many fish stocks in capture fisheries are overfished. Aquaculture plays therefore an increasingly important role in aquatic protein supply. The contribution of aquaculture to the global food fish supply for human consumption reached 47% in 2006 (FAO, 2009), an impressive figure, especially in view of the G8 leaders’ consideration of food security after the 2008 food crisis.

OECD economies accounted for 35% of the value and 30% of the volume of the total aquaculture production in 1984. These figures decreased to 18% and 9% respectively in 2007, underscoring the increasing importance of developing countries are aquaculture production (Figure 18.1).

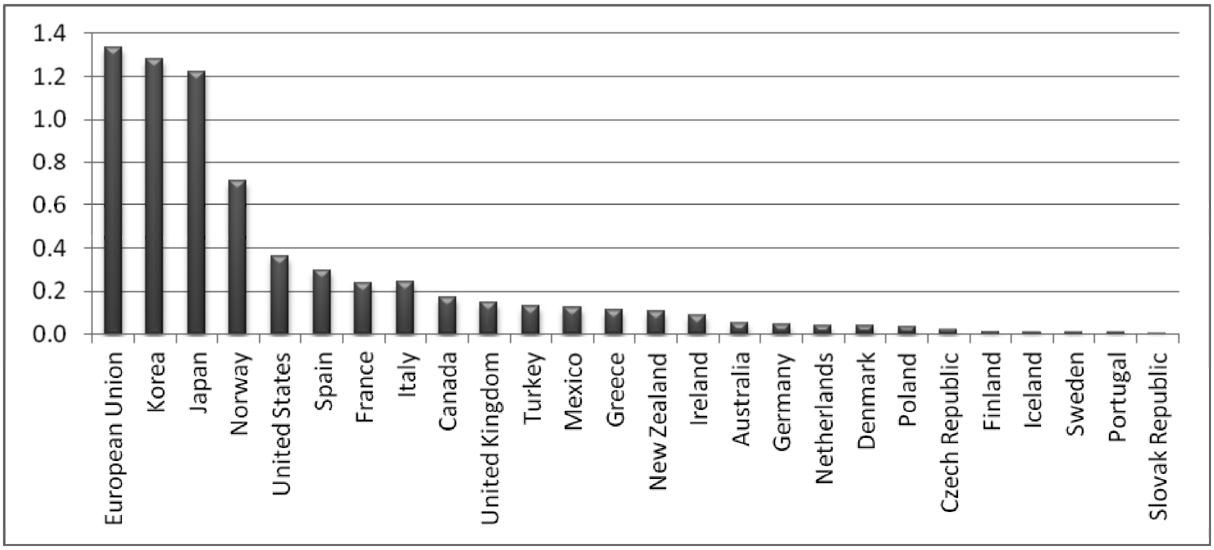
Figure 18.1: Total Aquaculture Production - Volume and value



Source: FAO

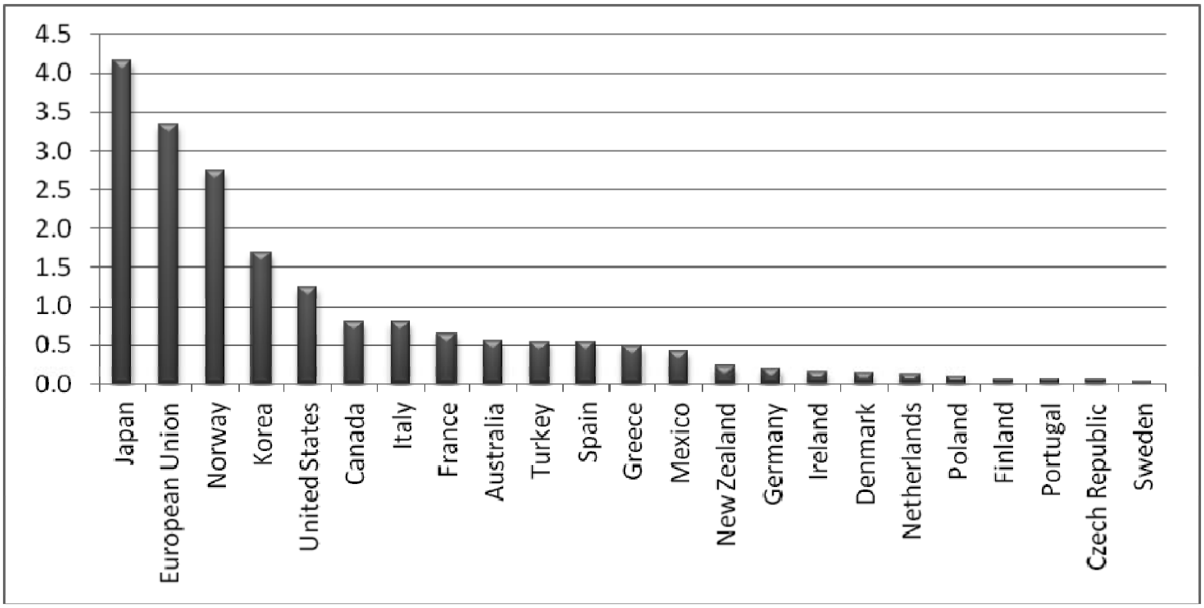
Among OECD economies, Korea, Japan, Norway, USA, Spain and France alone represented around 75% of the aquaculture production in terms of volume in 2006. In terms of value, Japan, Norway, Korea, USA and Canada produce 73% of the total in the same year (Figures 18.2 and 18.3).

Figure 18.2: OECD Aquaculture production in 2006 - Volume (million tonnes)



Source: OECD

Figure 18.3: OECD Aquaculture production in 2006 - Value (USD billion)



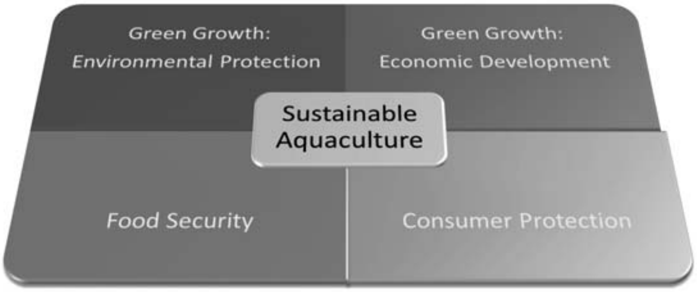
Source: OECD

The performance of the aquaculture sector is a function of four key components and their interplay:

- Resources, including:
    - Biological (species, genetic material, etc.);
    - Physical (land, water, feed, labour)
    - Financial (capital).
- Governance, which encompasses:
    - Access to productive assets (land, water, etc.);
    - Management of externalities (environmental, health, etc.);
    - Enabling policy and institutions environment for biosecurity (safeguard animal health, promote environmental sustainability, and enhance food safety).
- Technology, e.g.:
    - Rearing techniques;
    - Facilities;
    - Biotechnology/engineering;
    - Feed.
- Markets:
    - Demand and supply (function of for example sector reputation, prices, availability);
    - Substitutes;
    - Trade regulations (e.g. food safety regulations, WTO competition issues).

From a policy perspective, the aquaculture sector has several dimensions (Figure 18.4). In the first place, potential negative externalities generated by aquaculture production require measures to ensure environmental protection. Secondly, in terms of economic activity, aquaculture can be an important pillar and employment provider, in particular in rural coastal areas. In this context, access to the publicly managed productive assets land and water is crucial. Thirdly, high aquaculture production volumes contribute to the policy objective 'food security'. There is however an ongoing discussion about the 'fishmeal trap', which questions the ethical acceptability of using fish from capture fisheries for the production of high-value fish. Finally, aquaculture product safety and hygiene is important to ensure consumer protection.

Figure 18.4: Policy dimensions of the aquaculture sector



The concept of ‘sustainability’ contributes to align the different policy measures and objectives associated with the four dimensions. The public sector has a long-term interest in a healthy ecosystem which provides key inputs for current and future economically efficient and safe aquaculture production. By developing policies and a regulatory framework that favour sustainable aquaculture production methods the public sector influences the sectors’ development towards sustainability.

The economic motivation behind government intervention in the aquaculture sector stems mainly from two types of externalities that generate market failures: negative environmental impacts of aquaculture production and externalities deriving from competition for access to scarce land and water resources. As identified in Bartely *et al.* (2007), one function of the public sector is the mitigation of market failures, for example by providing stable structures for human interactions that minimize uncertainty and hence the cost of conducting business.

The OECD Committee for Fisheries has recognized the growing importance of the aquaculture sector at the global level. It has therefore decided to engage in a project dedicated to ‘Advancing the aquaculture agenda’. The overall project objective is to examine the policy challenges for a competitive and sustainable aquaculture sector in OECD countries. It consists of two components:

(i) a Workshop[1] on ‘Advancing the aquaculture agenda: policies to ensure a sustainable aquaculture sector’ and

(ii) an inventory of conditions for establishing aquaculture production sites in OECD countries.

The project is set against the background of two megatrends[2] which are high on international policy agendas: sustainability and food security. In addition, the project fully embraces the vision of the recent OECD Declaration on Green Growth (OECD, 2009) which states that ‘*the OECD can, through policy analysis and identification of best practices, assist countries in their efforts to respond to the growing policy demands to foster green growth and work with countries to develop further measures to build sustainable economies’*.

Method

The Committee for Fisheries (see Programme of Work - Suggested Implementation Plan 2009-2011 [TAD/FI(2008)2/ANN]) agreed that the project Advancing the aquaculture agenda should address the question '*What should the future role of public authorities in regulating aquaculture be*'. The present paper is a summary of the survey conducted to develop the inventory of conditions for establishing aquaculture production sites in OECD countries. It takes stock of key aspects of the existing regulatory framework for aquaculture and for establishing aquaculture production sites in OECD countries. It contributes to the identification of institutional strengths and weaknesses in aquaculture policy frameworks, in particular with regard to access to production sites, and hence to identify key challenges for an economically, environmentally and socially sustainable aquaculture sector in OECD countries. More specifically, the analysis aims to contribute to addressing the following questions:

- *What planning lessons can be learned from examining individual country regulatory frameworks for aquaculture production site access and operation?*

- *How could the planning and regulation process for access to aquaculture production sites be improved?*

The results from the survey are discussed and integrated with evidence from the literature in the following 'Discussion of lessons learned and potential areas for improvement'. The paper concludes with a short section that distils key messages for policy makers.

In Annex I the paper presents a summary of the results of the OECD survey on conditions for establishing aquaculture production sites in OECD countries. 19 OECD member countries[3] out of 30 as well as one observer and one accession country returned the OECD questionnaire. The objective of the survey was to investigate the current governance architecture for the aquaculture sector, in particular with regard to access to and operation of aquaculture production sites. It reflects legal, institutional and management aspects of the aquaculture sector. The questionnaire is structured into three levels (the full questionnaire is available in Annex II):

1. Legal and institutional framework applying to land and water;
2. Relevant regulations for aquaculture production sites;
3. Authorisation system to access and operate aquaculture production sites.

This paper is mainly addressed to policy makers involved in aquaculture regulation and spatial planning at national and sub-national level in OECD countries.

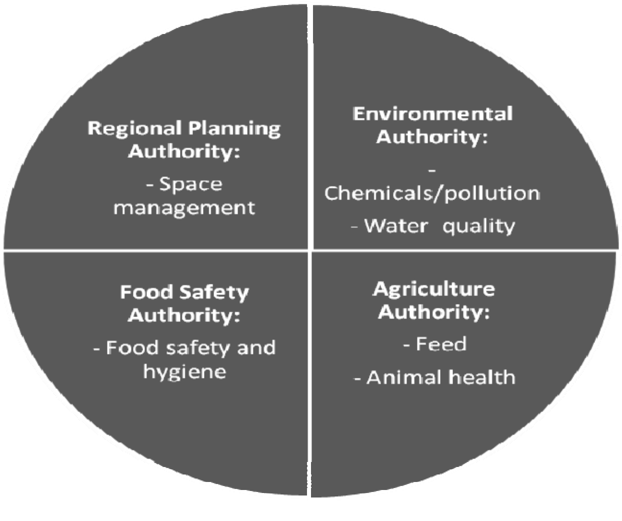
Discussion of lessons learned from the survey and potential areas for improvement

Complexity of regulatory frameworks

The relationship between the regulator and the aquaculture sector are shaped through the sector's governance structure. Governance is intended as the exercise of political, economic and administrative authority to manage the sector. Governments choose their level of engagement with the aquaculture sector primarily based on its economic and strategic importance. The theoretical continuum of regulatory policy options stretches from a 'total control' to a 'laissez-faire' attitude where the industry operates on the basis of self-regulation.

As an economic activity in the International Standard Industrial Classification (ISIC of the United Nations Statistics Division), "aquaculture" was part of "fishing" until the ISIC Rev.3.1 was released in 2002. This is rather illustrative of the legal and institutional situation of aquaculture, as already outlined in the FAO Technical Guidelines (1997): '*Frequently, aquaculture is still under a general fisheries basic legislation, and is often not being recognized as the aquatic equivalent to agriculture.*' Aquaculture regulations overlap often with existing regulations for spatial planning, water quality, animal welfare, pharmaceutical use and food safety due to the need to pursue broader societal goals and consistency with other policy objectives. This explains the fragmentation of responsibility among different national or regional authorities (Figure 18.5). The fragmentation of responsibilities among different administrative entities is a root cause of delays in permit processing.

Figure 18.5: Authorities involved in aquaculture regulation



The survey reveals that the current OECD aquaculture governance system at the legal and institutional level is characterized by a polycentric organisation of authorities and multi-layered institutional arrangements dealing with different aspects of the aquaculture sector. The perception of regulatory complexity is also a recurrent theme in the literature: '*…usually the framework is complex, with permits and regulations associated with a range of government departments and agencies*' (FAO, 2009[a], p. 6).

In many OECD member countries, aquaculture started as a small-medium enterprise (SME) activity. In the EU in particular, aquaculture production units are mostly family businesses or SME with less than ten employees, operating traditional freshwater farms (*e.g.* trout, carp) and marine shellfish farming systems (*e.g.* mussels). These small-sized businesses are particularly vulnerable to complex and slow administrative processes for production licences.

It is interesting to see that despite the existence of a 'Strategy for the Sustainable Development of European Aquaculture', a recent Communication from the Commission to the European Parliament and the Council (2009) affirms that 'the aquaculture industry is still relatively unknown to public authorities and investors'.

Reducing the regulatory burden

OECD countries are increasingly aware of regulatory weaknesses with regard to aquaculture operations. A number of OECD countries has developed or updated dedicated sector policies, strategies and/or plans. This is for obvious reasons happening primarily in countries in which aquaculture has considerably intensified in recent years (*e.g.* Chile, Norway, Mexico, Greece, Sweden). The European Commission during its consultation on the opportunities for the development of aquaculture called for 'clear and simplified procedures, with established time lines for decisions, for obtaining aquaculture operating licences' (European Commission, 2007). Subsequently, in its 2009 Communication the European Commission specifically included 'reducing the administrative burden' among the measures to improve the sector's image and governance (European Commission, 2009).

Box 18.1 provides examples for OECD member country approaches to reduce regulatory complexity in aquaculture at different levels.

Box 18.1: Reducing complexity and increasing coherence in regulation: Examples from Norway, New Zealand and the US

Towards the One-Stop-Shop for aquaculture licenses in Norway

With the new system introduced by the 2006 Aquaculture Act, the industry player directly sends an application to the central fishery authority. The fishery authority sends the application to other relevant authorities as part of their own processing of the application. The fishery authority ensures that statements and decisions are obtained from the local municipality, as well as from other sector authorities, such as the County Governor (environmental authorities), the Norwegian Food Safety Authority and the Norwegian National Coastal Administration. Licenses for land-based aquaculture that entail an encroachment on watercourses, such as hatchery production, must also be evaluated and allocated a license by the Norwegian Water Resources and Energy Directorate (NVE). Again, it is the central fishery authority that arranges for the license on behalf of the applicant.

The purpose of this scheme is to enable applicants to deal with one public agency, which will coordinate the necessary licenses and statements from other sector authorities. Trials have been conducted since 2001 to test alternative models to improve the coordination and efficiency of the application processing between the various sector authorities. Evaluation of the project is not complete, but the aquaculture industry is very satisfied, and the results so far show that the administrative processing time for routine matters has been reduced from over a year to less than six months.

The fishery authority is allocated additional responsibility and competence to undertake an efficient and comprehensive execution of the allocation process, including regulation competence to prescribe time limits for the processing of aquaculture applications. All the processing by the sector authorities can thus be coordinated so that they are finished at the same time or in an appropriate sequence. Norway has recently approved a regulation concerning coordination and time limits in the processing of aquaculture licences. The regulations states that the total executive work shall, as a a main rule, not exceed 22 weeks in cases where a complete application is delivered and where the coastal communities have opened up for aquaculture through their coastal plan.

Source : Norway, Aquaculture Act 2006

New Zealand's aquaculture reform status

New Zealand started a reform of its aquaculture regulation in 2004 to decentralize the sectors' management to regional councils. The first step of the reform amended five existing acts and introduced two new acts, including the Aquaculture Reform Act 2004. Licence applicants are required to obtain a resource consent [*authorization given to certain activities or uses of natural and physical resources required under the New Zealand Resource Management Act*] for marine farming activities from their regional council once a so-called Aquaculture Management Area (AMA) is approved, but they no longer must apply for the subsequent fisheries permit under the Fisheries Act as well.

The Aquaculture Legislation Amendment Bill passed in 2008 and was followed by the second Aquaculture Amendment Bill in 2010, which is at the stage of the second reading in Parliament. This bill is an omnibus bill that amends the Resource Management Act 1991, the Fisheries Act 1996, the Maori Commercial Aquaculture Claims Settlement Act 2004, and the Aquaculture Reform (Repeals and Transitional Provisions) Act 2004 to correct problems with current law and further improve its operation.

Source: www.parliament.nz/en-NZ/PB/Legislation/Bills/9/0/9/00DBHOH_BILL8663_1-Aquaculture-Legislation-Amendment-Bill-No-2.htm

USA: An online 'one-stop-shop'

'Michigan Business One Stop' is hosted on the official website of the US State of Michigan. This online facility has one section dedicated to 'Aquaculture Facility Registration and Permit'. It provides the necessary applications forms through links to the responsible Michigan Department of Agriculture. It also provides a link to the Michigan Aquaculture Development Act, 1996.

The site describes the permit/approval process in its single steps and provides links to all the necessary background documents (e.g. list of approved aquatic species, legislation) and forms:

1. Applicability
2. Pre-application requirements
3. Application submission requirements
4. Procedures and time-frame for obtaining permit
5. Operational requirements
6. Fees
7. Appeal process
8. Public input opportunities

Source : www.onestophelp.state.mi.us/wiki/Aquaculture_Facility_Registration_and_Permit

The regulatory framework ideally should foster the transition to decoupling aquaculture development from negative environmental externalities. Paraphrasing the UNDP *et al., the remedy to global environment and development problems lies not in reducing growth, but in breaking the connection between expanded prosperity and depleted or degraded resources* (UNDP *et al.,* 2000). This concept is also central to the 2009 OECD Declaration on Green Growth.

In 2008 the FAO has proposed an outline for Technical Guidelines on Improving Planning and Policy Formulation and Implementation for Aquaculture Development which may provide useful guidance to regulators in the future (FAO, 2008[a]) and Brugère and Ridler (2004) propose an aquaculture policy planning process that consists of three phases:

1. the development of a policy framework that establishes broad aims for the sectors' development;
2. the development of a sector strategy that outlines the specific objectives associated with each aim of the policy framework; and
3. the development of a plan that specifies and quantifies targets as well as the related activities to achieve the objectives outlines in the policy framework.

A precondition for any regulatory improvement is an appropriate knowledge base about the sector for decision making and management. Transparency and accountability which are important for the sectors reputation also demand the availability of reliable data and information. In this respect FAO has developed a 'Strategy and Outline Plan for Improving Information on Status and Trends in Aquaculture' (FAO, 2008) to develop indicators for the sector's governance and monitoring.

As underlined in Brugère and Hsihamunda (2007), regulatory planning in aquaculture reduces risks, informs decision-making, establishes trust and conveys information. Regulatory uncertainty on the other hand increases operating costs. Hence there is a need for stable, transparent and clear regulations with regard to establishing and maintaining aquaculture production sites. Monitoring systems with timely feedback mechanisms on the other hand are crucial to ensure that the management framework can quickly adapt to emerging threats and needs (*e.g.* disease outbreaks).

The *OECD Regulatory Impact Analysis (RIA)* is a tool for regulatory planning that can be useful for future improvements in aquaculture sector regulation. RIA is an institutionalised model for analysis that provides a systemic approach to critically assessing the positive and negative effects of proposed and existing regulations and non-regulatory alternatives (Box 18.2).

Box 18.2: Steps of a Regulatory Impact Analysis (RIA)

1. Definition of the policy context and objectives, in particular the systematic identification of the problem that provides the basis for action by government.

2. Identification and definition of all possible regulatory and non-regulatory options that will achieve the policy objective.

3. Identification and quantification of the impacts of the options considered, including costs, benefits and distributional effects.

4. The development of enforcement and compliance strategies for each option, including an evaluation of their effectiveness and efficiency.

5. The development of monitoring mechanisms to evaluate the success of the policy proposal and to feed that information into the development of future regulatory responses.

6. Public consultation incorporated systematically to provide the opportunity for all stakeholders to participate in the regulatory process. This provides important information on the costs and benefits of alternatives, including their effectiveness.

Source: OECD (2008)

Raising awareness of the need for stakeholder participation and policy coherence

It clearly emerges from the survey that public awareness (consolidated through international agreements or guidelines, including for example Agenda 21 or the FAO Code of Conduct for Responsible Fisheries) of environmental impacts of aquaculture and the intensification of production has generated additional environmental regulation for the sector, in particular with regard to pollution and discharges, diseases, feed resources, and genetic interaction and escapes. Table 18.1 provides an example of finfish and shellfish farming impacts on coastal processes.

Table 18.1: Aquaculture and impacts on costal processes

Level		Types	Typical species	Characterisitcs	Impact on coastal processes
Finfish	Intensive	Land-based tanks and raceways	Salmon, sea bass (FR) and sea bream (FR), turbot, sole, eel	Often very high intensity production with controlled flow rates and recirculation. Small environmental footprint, often covered and possible to control effluents	Negligible
		Sea cages	Salmon, sea bass, sea bream, halibut, cod	Relies on good initial siting as depended upon site environmental conditions. Permit less control than pump-ashore systems byt sites are less costly and movable.	Minor alterations to nearshore currents
	Semi-intensive	Pond culture	Mullet, sea bass, sea bream, shrimp	Larger environmental food-print than the above, either situated above the high tide in low-lying coastal plains (e.g. salt marshes in Portugal), Usually used for lower density culture of shrimp or finfish e.g. mullets, sea bass and sea bream. May require extensive effluent settlement areas.	Potential small impact on beach sediment drift
	Extensive	Lagoon culture	Mullet, sea bass, sea bream, shrimp	Traditional methods (e.g. Italian *vallicultura*) using natural fry and no or limited supplementary feeds. May require natural compartmentalization of natural lagoon areas.	Impact on lagoodnal hydrodynamics, not open sea hydrodynamics
		Ranching	Salmon, lobster, cod	Restocking of species which are either migratory, returning close to the point of release (e.g. salmon), or non-migratory, remaining for at least a substantial portion of the life-cycle in restricted areas, where they enter the local fishery (e.g. lobster).	Negligible
Shellfish		Suspended rope culture	Mussels, oysters (Mediterranean)	Ropes, covered with spat kept in place by nylon nets, are suspended either from rafts, wooden frames or from long lines of floating plastic buoys.	Negligible
		Bottom culture	Mussels, oysters, scallops	Seed mussels are relayed in suitable grow-out sites.	Negligible – possible localised sediment impacts
		Rack culture	Oysters	Oysters are laid out on wooden trestles or racks laid out in the intertidal zone.	Negligible
		'Bouchot' culture	Mussels (France)	Uses a series of wooden poles as supports, onto which the mussles are transplanted for on-growing.	Negligible
		Ponds	Oysters, shrimp	In France, a special treatment ('*affinage*') may be applied for the supply of top quality oysters – prior to selling these are placed in former salt marshes which have been converted into ponds ('*claires*')	Negligible on open sea hydrodynamics
		Lagoon	Clams	Juveniles are released into controlled marine areas (lagoons, salt pans, large ponds or 'parks' in the open sea)	Possible localised alteration to tidal currents

Source: Poseidon Aquatic Resource Management Ltd. (2006, p. 74)

However, the public concern for environmental sustainability is not necessarily in conflict with the private sector orientation. On the contrary, the industry is developing its own codes of conducts or best aquaculture practices (BAP) to cater to the needs of an increasingly demanding and competitive market with high sensitivity for sustainability. These codes of conducts and BAPs are often a common effort of the industry to improve its reputation. Although with a delay compared to capture fisheries, eco-labelling is thus an issue for aquaculture products and FAO is developing guidelines for aquaculture certification. They are expected to be approved in 2010 and to represent a benchmark for standard developers, like the ongoing WWF Aquaculture Dialogues or the Global Aquaculture Alliance's Best Aquaculture Practices (BAP). In addition, the Aquaculture Stewardship Council is to be established and operative by 2011, following the patterns of the Marine Stewardship Council for sustainable capture fisheries certification.

There seems to be a trend towards promoting this sector self-regulation with regard to environmental sustainability. For example, the Irish Sea Fisheries Board (BIM) introduced ECOPACT, an initiative to facilitate the adoption of environmental management systems (EMS) in the industry. In Australia, a National Aquaculture EMS initiative provides a voluntary cost effective solution to comply with regulations. In the US, the Massachusetts Department of Agriculture Resources and the USDA Risk Management Agency have collaborated with the Massachusetts Shellfish Growers to develop Best Management Practices for Shellfish Farming.

Given the environmental implications of aquaculture, good communication between the regulator and the aquaculture sector and with other competing users of land and water resources is important to reduce constraints for the sector, but also for policy coherence. It is recognised that a number of countries already consult widely among aquaculture and other relevant inter-sectoral stakeholders, *e.g.* through permanent advisory committees or working groups, but in some cases dialogue is still perceived as insufficient. Denmark for example has pointed out the need for a strong and coherent communication platform with wide stakeholder participation, which can address criticism and misconceptions about the industry. Box 18.3 introduces a new environmental performance assessment tool that should improve future environmental impact assessments for aquaculture operations.

Box 18.3: The Global Aquaculture Performance Index (GAPI)

GAPI empowers the seafood industry leaders and policymakers to make informed decisions about the environmental costs and benefits of farmed seafood. GAPI uses a well-established statistical methodology to provide rigorous and objective evaluation of the environmental performance of marine aquaculture. Adapted from Yale and Columbia University's 2008 Environmental Performance Index (EPI) (www.epi.yale.edu/Home), on a 100-point scale, GAPI measures how close marine aquaculture is coming to meeting a suite of environmental targets, or goalposts. GAPI currently assesses performance on a country-species level (e.g. Norwegian Atlantic cod, Scottish Atlantic salmon).

In summer 2010, the GAPI project will launch a web-based, interactive tool that will not only allow users to query the aquaculture database but also to enter real or hypothetical data for analysis and comparison. The development of a Farm- Level Aquaculture Performance Index and a benchmarking study of the environmental performance of marine aquaculture standards will commence in summer 2010. In this phase, developers will also explore the incorporation of social and economic indicators into the GAPI methodology. GAPI is constantly adapting as new science and data become available and novel production technologies are brought on-line.

GAPI condenses vast quantities of complex, environmental data into simple, numerical scores that are easily applied in the policy setting and markets context. From a policy perspective, it allows to assess how well one country's aquaculture sector is performing relative to another. Additionally, it offers direct insight into where the greatest levelof environmental improvement can be most efficiently achieved. The inherent flexibility of the GAPI tool meansthat it can be used to help inform a number of pressing questions, such as:

How close are producers to achieving strong environmental performance in marine finfish aquaculture as a whole? In salmon farming? In cod farming?

How well is one country or region performing compared to another? Is one country performing significantly better than the rest, and why?

How well is one species performing compared to another? For instance, does farmed Arctic char perform better than farmed salmon at this scale?

Are there common modes of production, geographic characteristics, etc. that enable a species or country to perform better than others?

How well is Country X performing on a specific impact area compared to country Y, such as escapes, disease or pollution?

Further, GAPI will quantitatively benchmark existing and proposed aquaculture standards to determine how well they are performing compared to this set of ecological targets and also relative to each other.

Source : Extracts from www.gapi.ca

Comprehensive spatial planning

As outlined in Bartley *et al.* (2007, p. 5), in the case of common property, boundaries and access rights are less well defined and impacts more difficult to contain. But predictable and long-term access to production areas (inland, coastal and marine areas) is crucial for the sectors prosperity. In addition to the protection of public interests, comprehensive territorial planning should also include resource efficiency considerations. For example, while water requirements for aquaculture can appear high compared to other food production systems (*e.g.* crops, meat) it needs to be kept in mind that in contrast with the other systems, aquaculture water use is mainly non-consumptive (Table 18.2).

Table 18.2: Water requirements for different food production systems

Food production system	Water requirements m^3/mt)
Wheat	900
Corn	1 400
Rice	1 912
Soybeans	2 000
Broiler chicken	3 500
Beef	100 000
Clarias: intensive, static ponds	50 - 200
Tilapia: extensive, static ponds	3 000 – 5 000
Tilapia: sewage, minimal exchange ponds	1 500 – 2 000
Tilapia: intensive, aerated ponds	21 000
Carp/tilapia polyculture: conventional ponds	12 000
Carp/tilapia polyculture: semi-intensive ponds	5 000
Carp/tilapia polyculture : intensive ponds	2 250
Channel catfish : intensive ponds	3 000 – 6 000

Source: extracts from IWMI (2007)

Management frameworks for aquaculture production sites should be integrated with other management frameworks, from national water body management to local zoning plans, including integrated coastal zone management (ICZM). Zoning systems can be ‘positive’ (allocated specific areas to aquaculture production) or ‘negative’ (specifically exclude any aquaculture production in a designated area) (FAO, 2009[a]). Marine spatial planning is likely to become more important in the future as marine/off-shore farming and coastal shellfish farming become more important.

Box 18.4 illustrates an Irish model for integrated local management of aquaculture.

Box 18.4: C.L.A.M.S

In Ireland, the unique Co-ordinated Local Aquaculture Management Systems (CLAMS) process is a nationwide initiative to manage the development of aquaculture in bays and inshore waters throughout Ireland at a local level. In each case, the plan fully integrates aquaculture interests with relevant national policies, as well as:

Single Bay Management (S.B.M.) practices, which were initially introduced by salmon farmers to co-operatively tackle a range of issues, and have now been extended to all aquaculture species

The interests of other groups using the bays and inshore waters

Integrated Coastal Zone Management (I.C.Z.M.) plans, and

County Development plans.

The process has been widely adopted in bays and inshore waters where aquaculture is practiced around the Irish coast, as a further proactive step by fish and shellfish farmers, to encourage public consultation on their current operations and their future plans.

CLAMS allows for the successful integration of aquaculture into the coastal zone, taking cognisance of the need to improve environmental compliance, product quality and consumer confidence. As part of its commitment to the sustainable development of the aquaculture industry, the CLAMS process facilitates the gathering and analysis of data in relation to fish farming. This data is then made available to the local community.

Source : BIM - www.bim.ie/templates/text_content.asp?node_id=244

Geographic Information Systems (GIS) can contribute to spatial planning at different levels. The information stored in such systems allows studying spatial relationships and contributes to informed decision-making. As identified before, integrating and managing multiple stakeholder interests is one important contribution towards comprehensive spatial planning (Brugère, C. and N. Hishamunda, 2007).

The importance of economic viability

Aquaculture sector operators are first and foremost economic agents. Profitability expectations determine the amount of capital that is invested in the sector. One recurrent comment in the consultation process on Community Aquaculture in the EC was that the economic and environmental protection dimension of aquaculture should be 'treated on an equal footing' (EC, 2007). The Finnish National Aquaculture Development Program 2015 sets out to develop the industry in a 'more environment-friendly, but in an economic and socially sustainable way'[4].

Access to capital is important for the economic viability of the sector. Paragraph 1 of the Norwegian 2006 Aquaculture Act outlines the overall objective of the government policy as '*to promote the profitability and competitiveness of the aquaculture industry within the framework of a sustainable development and contribute to the creation of value on the coast*'. One of the novelties of the Act is to establish a statutory right to transfer and mortgage aquaculture licences with the ultimate intention to deregulate ownership requirements, shifting the focus from who owns the activity to its management (Norwegian Ministry of Fisheries and Coastal Affairs, 2006). By deregulating the ownership the aquaculture industry becomes 'normalised' in relation to other industries. The asset value of an aquaculture production license increases with its transferability.

This is supposed to increase the creditworthiness of the industry and to allow for long-term loans. The duration of a license is equally important in terms of investment planning and access to credit. Another important feature of licenses is the maximum number of production licenses any given company is allowed to hold. The orientation of the Act confirms the increased public recognition of the main drivers for a healthy aquaculture sector, economic profitability and environmental sustainability.

In Denmark, regulations for marine fish farming are readjusted from a fixed feed quota system towards the documentation of environmental effects to avoid unnecessary production restriction. Mexico has identified that 'action is required to develop a coherent, transparent, risk-based set of environmental parameters for aquaculture operations in order to reduce the costs and uncertainty associated with environmental compliance' (OECD 2006, p. 293).

But is needs to stress that growth in the aquaculture industry cannot be determined solely by market demand; it must occur within the limits that the environment can tolerate (Strategy for an environmentally sustainable Norwegian aquaculture industry, 2008). This entails that a ceiling has to be set for how large the industry can become, and ensuring that production remains within what the environment can cope with is a determinative factor in making this assessment. Eco-friendly sustainable production is therefore a precondition for long-term development and growth.

Optimising economic outcomes of aquaculture regulation

Ideally, aquaculture policies, strategies and plans should provide private economic incentives while safeguarding public interest and sustainability. The signatories of the 2009 OECD Declaration of Green Growth committed to *'…work towards establishing appropriate regulations and policies to ensure clear and long-term price signals encouraging efficient environmental outcomes'* and to '*encourage green investment and sustainable management of natural resources.*'

One option to reduce the regulatory burden in aquaculture can be to regulate outcomes rather than inputs (pers. comm. G. Knapp) which is the avenue taken recently by a number of governments (*e.g.* Norway, Denmark). A management framework for aquaculture production sites with clear environmental objectives, associated indicators, standards and reference points provides the private sector with the incentive to identify the most cost-efficient solution in aquaculture production.

Technology developments, economies of scale and access to new markets have fuelled the development and concentration of the industry; in this process, SMEs have often been replaced by bigger players. In this context, the design of the authorization system plays an important role in shaping the sectors' profile. Increased transferability of licenses is likely to contribute to economic efficiency through consolidation and crowding out of smaller activities. As reported in Halweil (2008, p. 14) '*In the salmon industry and other fish-farming sectors, successive waves of consolidation have led farms and aquaculture companies to cannibalize their smaller brethren, often to be cannibalized at a later date by someone even larger. Ownership in industrial aquaculture has become highly concentrated*'. These industrial companies are often international and vertically integrated, from hatcheries and feed producers to the distribution level. In this regard, clear and long-term property right regulations for licences provide one key aspect for aquaculture development.

Box 18.5 illustrates how Malaysia uses economic incentives to attract investment in aquaculture development.

Box 18.5: What the others do: Malaysia's Aquaculture Industrial Zones

According to the Government's 2007 National Aquaculture Development Plan, the Malaysian aquaculture industry will generate revenues up to 5.74 billion USD. In order to overcome the land issue, an Aquaculture Industrial Zone (AIZ) was set up as part of the permanent food production zones by the state governments. Objectives for creating AIZ include among others:

- Create permanent areas for Aquaculture Industry Zones,
- Ensure the production of fish and fish products that are of high quality and safe for consumption,
- Increase private sector participation through the provision of AIZ areas, infrastructure and extension services,
- Create a chain of efficient aquaculture fish production areas.

The regulation of aquaculture activities is done through licensing. The two policies of aquaculture industry zones and licensing are meant to give a degree of certainty to potential investors and fish farmers.

Investment incentives

The government offers tax reduction and incentives for investments in selected food production activities. Incentives are given in the form of exemptions in duty and sales tax. Promoted product and activities for the fisheries sector are spawning, breeding and culturing of aquatic products, off-shore fishing, cultivation and processing of aquatic products, processing of aquaculture feed, and production of breeder stock. Below a list of sample incentives: Investment tax allowance, incentives for research and development, reinvestment allowance, infrastructure allowance double deduction on expenses for promotion of export, special deduction for capital expenditure on approved projects, incentives for cold chain facilities.

Incentives are granted with the following conditions:

I. The investing company should own 100% of the company that undertakes food production.

II. The eligible food products are as approved by the Minister of Finance.

III. The food production project should commence within a period of one year from the date the incentive is approved.

Total equity of local investor/foreign investor in any project involving request for incentives is unlimited, except for aquaculture and deep-sea fishing which are:

a) Aquaculture – at least 30% equity belongs to local investors.

b) Deep-sea fishing – 100% owned by local investor.

Funding is available through the Fund For Food (3F), introduced by the government to provide funding facilities for local companies involved in the food production and processing sector. Under this financial facility, a company can apply for loan of a minimum of RM30000 and a maximum of RM3 millions with 4% interest rate for a maximum period of 8 years.

Source: Department of Fisheries, Indonesia – www.dof. Gov.my/55 and www.fishdept.sabah.gov.my

Key messages for policy makers

In a distilled form, the following key challenges for policy makers in relation to aquaculture production site regulation emerged from the OECD survey and the literature:

- *The need for simplified regulation and procedures in terms of access to and operation of production sites*

There is undeniably a need for regulation to ensure aquaculture sustainability and consistency with other social and policy objectives. This need has to be balanced to avoid that aquaculture producers struggle to comply with fragmented regulation administered by a large number of public authorities. Delays in processing licence applications increase business risks and costs. In a globalising world, complex access procedures restrict development potential and may divert investment capital to aquaculture activities abroad. 'One-stop- shops' can reduce the administrative burden.

- *The added value of stakeholder consultation in developing regulation*

A form of institutionalized dialogue among stakeholders (including relevant inter-sectoral players) can contribute to understand the respective needs and to develop efficient, policy coherent solutions. Regular interaction between all stakeholders can facilitate early recognition of emerging issues.

- *The importance of economic incentives*

As any other private business, aquaculture production is driven by profitability expectations. A regulatory framework that stimulates innovation through output regulation rather than through input restrictions can foster solutions that serve private and public interests alike. Strong and clear property rights/licenses are another crucial ingredient for long-term commitment to sustainable aquaculture production.

In conclusion, the FAO Technical Guidelines already outline the way forward: 'Government authorities will increasingly have a key role to play in enhancing effective collaboration with and among many players, in order to promote sustainable development of aquaculture. Responsibilities for sustainable aquaculture development will need to be shared among government authorities, aquafarmers, manufacturers and suppliers of aquaculture inputs, processors and traders of aquaculture products, financing institutions, researchers, special interest groups, professional associations, nongovernmental organizations, and others.'

The importance and necessity of regulations as assets to achieve the long-term sustainability of the aquaculture sector is acknowledged. The task ahead for policy makers is to overcome current weaknesses in implementing the principles laid out in the FAO Code of Conduct for Responsible Fisheries (CCRF) - Article 9 Aquaculture Development and the FAO Technical Guidelines for Responsible Fisheries No. 5 – Aquaculture Development the related supplements.

Notes

1. The Workshop took place in Paris on 15-16 April and the presentations are available at the OECD website - www.oecd.org/document/3/0,3343,en_2649_33901_44041283_1_1_1_37401,00.html#Presentations

[2]. A megatrend can be understood as '…a pattern of change that will profoundly impress the future of mankind in its relationship with others and with the full gamut of the ecological domain including markets and institutions' (Heilbroner and Milberg 1996 in Choudhury 1999).

3. Belgium, Chinese Taipei, Czech Republic, Denmark, Estonia, EU, Finland, France, Germany, Greece, Iceland, Korea, Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Spain, Sweden, Turkey

4 . Game and Fisheries Research Institute - www.rktl.fi/en/julkaisut/j/478.html

References

Bartley, D.M, C. Brugère, D. Soto, P. Gerber and B. Harvey (eds.) (2007), "Comparative assessment of the environmental costs of aquaculture and other food production sectors: methods for meaningful comparisons", FAO/WFT Expert Workshop, 24-28 April 2006, Vancouver, Canada.

Brugère, C. and N. Hishamunda (2007), "Planning and policy development in aquaculture", *FAO Aquaculture Newsletter* No. 38, FAO, Rome.

Brugère, C. and N. Ridler (2004), "Global aquaculture outlook in the next decades: an analysis of national aquaculture production forecasts to 2030", *FAO Fisheries Circular*. N. 1001, FAO, Rome.

European Commission (2009), "Building a sustainable future for aquaculture. A new impetus for the Strategy for the Sustainable Development of European Aquaculture", Communication from the Commission to the European Parliament and the Council, COM(2009) 162 final.

European Commission (2007), "Overview of the contributions received in answer to the consultation on the opportunities for the development of Community aquaculture", Working document of Directorate-General for Fisheries and Maritime Affairs.

FAO (2009), *The State of Fisheries and Aquaculture 2008*. FAO, Rome.

FAO (2009a), "Environmental impact assessment and monitoring in aquaculture", *FAO Fisheries and Aquaculture Technical Paper,* No. 527, FAO, Rome.

FAO (2008) *Strategy and outline plan for improving information on status and trends of aquaculture.*

FAO (2008a), "Report of the Expert Consultation on improving planning and policy development in aquaculture", *FAO Fisheries Report* No. 858, FIEP/R858(En), FAO, Rome.

FAO (2006), *State of World Aquaculture.* Aquaculture Management and Conservation Service, Fisheries and Aquaculture Management Division, FAO, Rome.

FAO (1997), *Technical Guidelines for Responsible Fisheries No.5 – Aquaculture Development,* FAO, Rome.

Halweil, B. (2008), *Farming fish for the future,* Worldwatch Report 176, Worldwatch Institute, Washington, DC.

Heilbroner and Milberg (1996), in M.A. Choudhury "Global Megatrends and the Community", *World Futures*, Volume 53, Issue 3 1999 , pages 229 – 252, www.informaworld.com/smpp/content~db=all~content=a922784475 .

IWMI/Earthscan (2007), *Water for Food, Water for Life: Comprehensive Assessment of Water Management in Agriculture,* London: Earthscan, Colombo: International Water Management Institute (IWMI).

North, Douglass C. (1993), “Economic performance through time”, Nobel Prize lecture, www.nobelprize.org/nobel_prizes/economics/laureates/1993/north-lecture.html.

Norwegian Ministry of Fisheries and Coastal Affairs (2006), *The Aquaculture Act.*

Ministère de l’Agriculture et de la Pêche (2008), *Pêche et aquaculture. Les enjeux pour demain. Agriculture, Alimentation et Espaces Ruraux,* Cahiers du Conseil général de l’agriculture, de l’alimentation et des espaces ruraux.

OECD (2008), “Building an Institutional Framework for Regulatory Impact Analysis (RIA): Guidance for Policy Makers”, Version 1.1., Regulatory Policy Division, Directorate for Public Governance and Territorial Development.

OECD (2006), *Agricultural and Fisheries Policies in Mexico. Recent achievements, continuing the reform agenda.*

OECD (1995), *The 1995 Recommendation of the Council of the OECD on Improving the Quality of Government Regulation.*

Poseidon Aquatic Resource Management (2006), “Some Aspects of the Environmental impact of aquaculture in sensitive areas*”,* Final Report.

United Nations Development Programme, United Nations Environment Programme, World Bank, World Resources Institute (2000), “World Resources 2000-2001: People and ecosystems: The fraying web of life”.

Annex 18.AI - Survey result summary

The following presentation of the survey results follows the structure of the questionnaire and cites selected articles from the FAO Code of Conduct for Responsible Fisheries.

Legal and institutional framework applying to land, water and aquaculture

Land and water administration

> *"States should establish, maintain and develop an appropriate legal and administrative framework which facilitates the development of responsible aquaculture." (CCRF Article 9.1.1)"*

Land and water are key production factors for the aquaculture sector. One main motivation for the regulation of aquaculture lies in the legal nature of these two main inputs, common property water bodies (inland and marine) and - often in the case of coastal areas - common property land. The OECD survey confirms that both land and water use are commonly administered at the national level and in some countries supplemented by sub-national legislation. The EU has clearly identified access to land and water as crucial for the development of a sustainable and competitive aquaculture sector (European Commission, 2009, p.5).

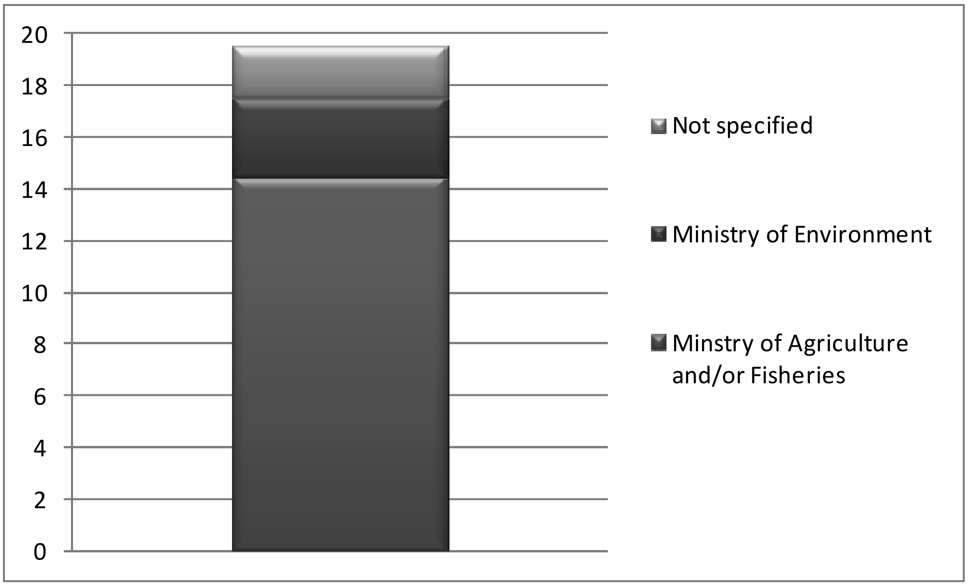
Overall aquaculture regulatory framework

> *"States should produce and regularly update aquaculture development strategies and plans, as required, to ensure that aquaculture development is ecologically sustainable and to allow the rational use of resources shared by aquaculture and other activities." (CCRF Article 9.1.3)*

Only four of the returned questionnaires (Finland, Iceland, New Zealand and Norway) confirmed the existence of a specific stand-alone national aquaculture regulation or policy framework. Aquaculture is otherwise included in the fisheries legislation, in environmental legislation or not specifically included in any other legislation. In Germany for example, the term aquaculture is not mentioned in any of the 16 'Länder' fisheries laws.

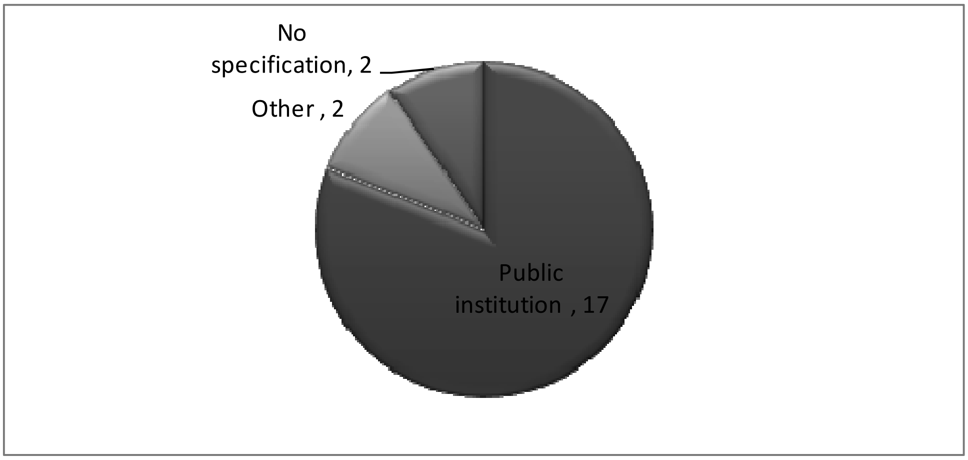
The responsibility for aquaculture regulation and/or policy development is shared among different national authorities in most countries that participated in the survey. The main responsibility lies in 75% of the surveyed cases within the Ministry responsible (exclusively) for agriculture and to a lesser extent within the Ministry of the Environment (Figure 18.A1.1).

Figure 18.A1.1: Which authority is responsible for aquaculture regulation and/or policy making[1]? (Number of respondents)



Compliance control with aquaculture regulations is well anchored in the public domain (Figure 18.A1.2). Finland, for example, ensures compliance with environmental regulations through an environmental permit system while Greece carries out inspections through regional and prefectural authorities. In some cases, the private sector complements public compliance control. In the Netherlands for example the Fish Product Board is an industry organisation which actively monitors the compliance with agreements made. It operates in the area where industry and policy meet.

Figure 18.A1.2: Who is responsible for compliance control with aquaculture regulations? (Number of respondents)

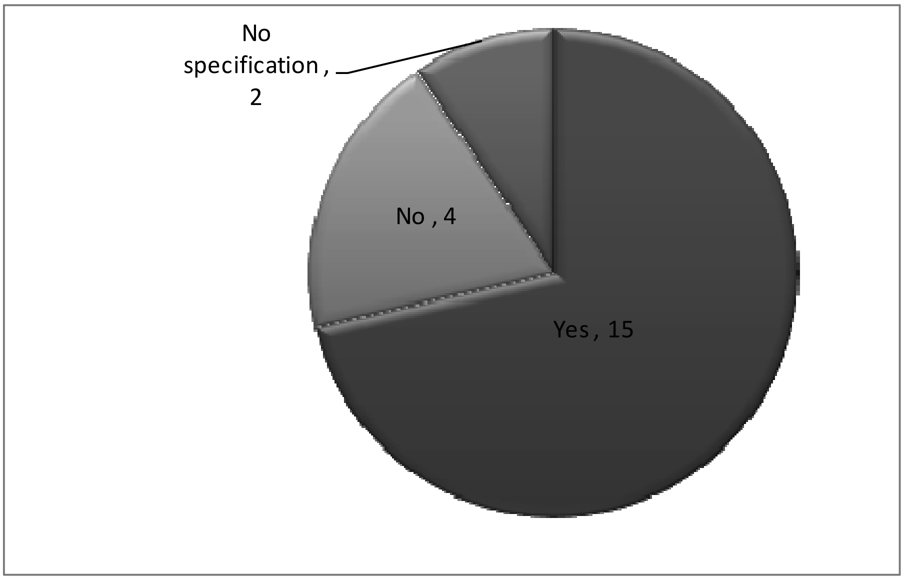


Cross-sectoral management

> *"States should ensure that the livelihoods of local communities, and their access to fishing grounds, are not negatively affected by aquaculture developments." (CCRF Article 9.1.4)*

The survey confirms that in most cases countries integrate aquaculture in some way in regional, coastal/river basin or community management/development plans (Figure 18.A1.3). To ensure policy coherence across different sectors, however, the OECD member countries adopt different strategies. In the case of the Czech Republic for instance, the Act on the Protection of Nature and Landscape prevails over the Act on Fisheries and the Act on Waters. The French Environmental Code regulates coastal zone management and attributes priority to aquaculture in the use of coastal zones outside industrial or port areas.

Figure 18.A1.3: Existance of provisions for cross-sectoral management including aquaculture(number of respondents)



At the EU level, the Integrated Maritime Policy development process launched in 2007 specifically includes aquaculture considerations. Member states are invited to develop marine spatial planning systems, which fully recognize the strategic importance of aquaculture and terrestrial land planning systems, which fully integrates the needs and values of freshwater aquaculture.

In many countries, representatives of the aquaculture industry participate in inter-sectoral commissions, or similar structures, to ensure policy coherence between the sectors. In New Zealand, for example, representative of the Ministries of Fisheries, Conservation, Economic Development, Environment, Local Government and Māori Affairs meet regularly to address aquaculture issues, including the establishment of dedicated Aquaculture Management Areas (AMA). A team of staff from these agencies coordinates and implements aquaculture initiatives in partnership with industry, Māori and local government. This Aquaculture Implementation Team meets regularly and is coordinated by the Ministry of Fisheries2. In Finland, the National Aquaculture Programme 2015 provides that 'employment and economic development centres', the industry, regional councils and environment centres identify suitable aquaculture areas and develop spatial plans to ensure policy coherence between economic and environmental needs.

Specific regulations for aquaculture production sites

"States should promote responsible development and management of aquaculture, including an advance evaluation of the effects of aquaculture development on genetic diversity and ecosystem integrity, based on the best available scientific information." (CCRF Article 9.1.2)

"States should establish effective procedures specific to aquaculture to undertake appropriate environmental assessment and monitoring with the aim of minimizing adverse ecological changes and related economic and social consequences resulting from water extraction, land use, discharge of effluents, use of drugs and chemicals, and other aquaculture activities." (CCRF Article 9.1.5)

Main features of regulations for aquaculture production sites

"States should conserve genetic diversity and maintain integrity of aquatic communities and ecosystems by appropriate management. In particular, efforts should be undertaken to minimize the harmful effects of introducing non-native species or genetically altered stocks used for aquaculture including culture-based fisheries into waters, especially where there is a significant potential for the spread of such non-native species or genetically altered stocks into waters under the jurisdiction of other States as well as waters under the jurisdiction of the State of origin. States should, whenever possible, promote steps to minimize adverse genetic, disease and other effects of escaped farmed fish on wild stocks." (CCRF Article 9.3.1)

"States should, in order to minimize risks of disease transfer and other adverse effects on wild and cultured stocks, encourage adoption of appropriate practices in the genetic improvement of brood stocks, the introduction of non-native species, and in the production, sale and transport of eggs, larvae or fry, brood stock or other live materials. States should facilitate the preparation and implementation of appropriate national codes of practice and procedures to this effect." (CCRF Article 9.3.3)

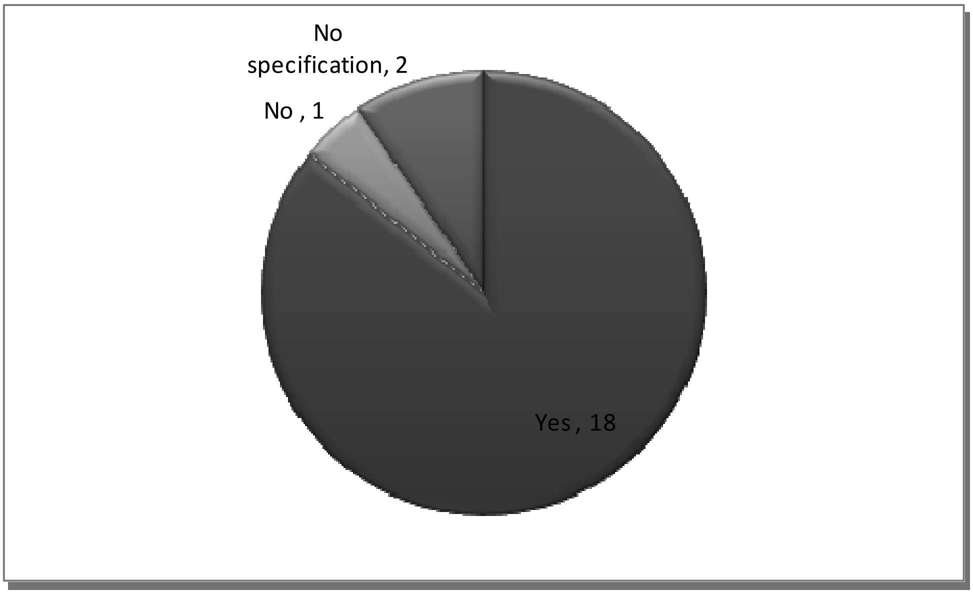
"States should promote efforts which improve selection and use of appropriate feeds, feed additives and fertilizers, including manures." (CCRF Article 9.4.3)

"States should promote effective farm and fish health management practices favouring hygienic measures and vaccines. Safe, effective and minimal use of therapeutants, hormones and drugs, antibiotics and other disease control chemicals should be ensured." (CCRF Article 9.4.4)

"States should regulate the use of chemical inputs in aquaculture which are hazardous to human health and the environment." (CCRF Article 9.4.5)

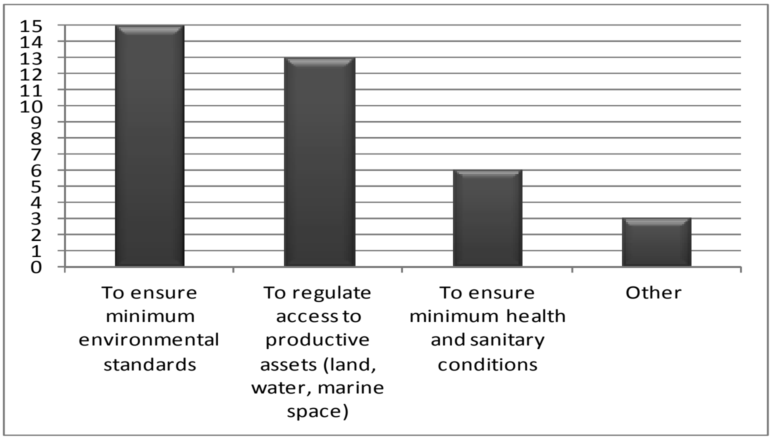
More than 80% of countries confirm the existence of some form of specific regulations for aquaculture production sites (Figure 18.A1.4). In a few cases (countries) the regulation is stand alone while in others it is integrated into spatial planning acts etc. In some cases, rather than using a top-down regulatory approach, the aquaculture strategy or program hands over responsibility for spatial planning to public-private partnerships (*e.g.* in Finland: Employment and Economic Centers, the industry, scientists, Regional Councils and Environmental Centre).

Figure 18.A1.4: Existence of specific regulations for aquaculture production sites among respondents



The main purposes of regulations for aquaculture production sites are to ensure minimum environmental standards and to regulate access to productive assets (Figure 18.A4.5).

Figure 18.A1.5: Main purpose of aquaculture production site regulation (number or respondents)



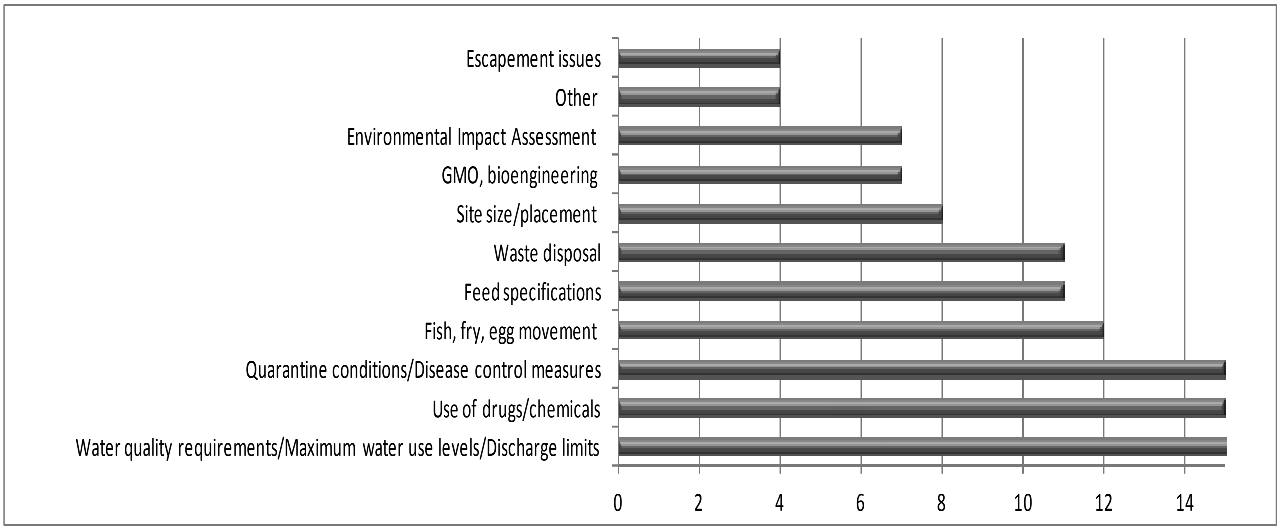
In some cases species or aquaculture system (freshwater; marine fin fish/shellfish; off-shore) specific regulations apply. The survey shows that shellfish farming installation receive more attention in terms of specific regulations or guidelines, in particular with regard to water quality requirements.

Some countries, like New Zealand, the Netherlands, Denmark and Greece use spatial classification systems. The Netherlands divide space into different types of production areas and negative changes in environmental quality attributes can result in the (temporary) reclassification or in the worst case in the closure of a production area. ‘Sampling plans’ describe how boundaries and the classification of production areas and compartments are assessed and designated. Criteria for site selection include for example pollution sources and pollution impact in terms of volume and distribution over time in relation to rainfall and tidal cycles.

The New Zealand system refers to designated Aquaculture Management Areas (AMA). These zones are identified in regional coastal plans. These plans define zones within which aquaculture is permissible; outside these zones aquaculture is prohibited. To create an incentive for aquaculture operators to actively participate in the regional planning process: the regional council can invite members of the aquaculture sector to promote change for an existing regional coastal plan or to provide for a new Aquaculture Management Area (AMA). In case the AMA is successfully designated, the proponents have preferential access to permits within that AMA. In Denmark, the counties have to develop 12-year regional plans including the establishment of aquaculture zones. These plans include shore water quality goals (general, reduced or high level quality goals). In addition, an integrated marine water mapping was conducted to identify restrictions and potential for marine aquaculture. In Greece, the central administration plans to move towards Areas of Organised Aquaculture Development.

The specific aquaculture production site regulations address a broad range of issues (Figure 18.A1.6). Not surprisingly the survey reveals that environmental concerns are dominating this type of regulation, followed by aquatic animal health issues.

Figure 18.A1.6: Aquaculture production related issues covered by regulations (number of respondents)



Regulations for the operation of aquaculture production sites are mostly providing input limits (*e.g.* feed ratios and compositions, drugs, hormones) or output limits (*e.g.* nutrients in effluents, maximum level of waste water). Environmental regulations in some countries use market based mechanisms, more specifically the ‘polluter pays principle’. The Netherlands, for example, use the *inhabitant equivalent principle* which is based on the amount of oxygen-binding substances; the oxygen consumption during biodegradation equals the amount of waste water produced by one inhabitant. In

Denmark, the emission of phosphorus, nitrogen and organic substances was limited at the national level. The calculations for the effluent limits were based on the establishment of fixed feed quotas for each farm. Feed quotas were not transferable between farms. This triggered innovation in terms of feed composition and feeding techniques to allow production to grow despite the fixed feed quotas.

Regulations not specific to aquaculture, but of potential relevance to the establishment and maintenance of aquaculture production sites, can be grouped into the following categories: veterinarian/animal health regulations (*e.g.* legislation on animal feed, drug), food safety regulations (*e.g*. HACCAP/food sanitation laws), environmental and spatial planning regulations.

Regulations referring to animal health and food safety often provide strict requirements for installation features (*e.g.* location of slaughter houses and processing premises) and disease control (e.g. obligation to notify authorities in case of disease suspect and keeping of registers for fish movement, mortality rates, disease outbreaks etc.).

For the EU, all EU "horizontal" legislation is applicable to the aquaculture industry and its products as appropriate. Examples of relevant legislation include:

- *Animal health*: There is a specific package for the control of aquatic animal disease applicable to reared fish, molluscs and crustaceans and wild aquatic animals intended for farming[3]. The Council Directive 2006/88/EC lays down:
    - minimum control measures in the event of a suspicion or outbreak of certain diseases in aquatic animals;
    - minimum preventive measures aimed at increasing the awareness of the competent authorities, aquaculture production businesses operators and others related to this industry, concerning diseases of aquaculture animals;
    - the animal health requirements to be applied for the placing on the market and the imports of aquaculture animals and products thereof.

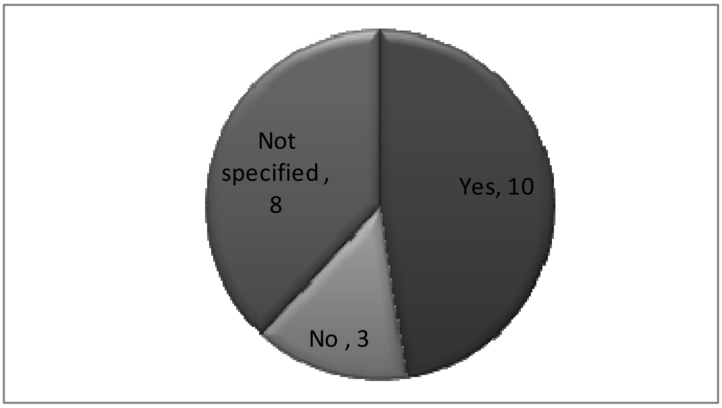
- *Food safety*: Regulation laying down the general principles and requirements of food law, establishing the European Food Safety Authority and laying down procedures in matters of food safety [4]. The Regulation contains also general provisions for traceability which cover all food and feed, all food and feed business operators, without prejudice to existing legislation on specific sectors such as beef, fish, GMOs etc.
    - Regulation (EC) No 178/2002 of the European Parliament and of the Council of 3 October 2002 lays down health rules concerning animal by-products not intended for human consumption.
    - Regulation (EC) No 183/2005 of the European Parliament and of the Council lays down requirements for feed hygiene: feed safety is considered at all stages that may have an impact on feed and food safety, including primary production.
    - Regulation (EC) No 1831/2003 of the European Parliament and of the Council of 22 September 2003 deals with additives for use in animal nutrition.

- *Environment law:* The Water Framework Directive[5] establishes a framework for Community action in the field of water policy.
- Directive 2006/113/EC of the European Parliament and of the Council of 12 December 2006 lays out the quality required of shellfish waters.
- The chemical package [Directive 98/8/EC of the European Parliament and of the Council] regulates the market access and use of biocide products.

The conditions concerning use of alien and locally absent species in aquaculture are established in the Council Regulation (EC) No 708/2007 of 11 June 2007 concerning use of alien and locally absent species in aquaculture and in the Commission Regulation (EC) No 506/2008 of 6 June 2008 amending Annex IV to Council Regulation (EC) No 708/2007 as well as in the Commission Regulation (EC) No 535/2008 of 13 June 2008 laying down detailed rules for the implementation of Council Regulation (EC) No 708/2007.

Thirteen of the 21 respondents answered the question if the regulatory framework for aquaculture installations on private and public space is the same. Only three stated a different treatment (Figure 18.A1.7). In France, an authorization system for fresh water use applies in the case of private property and a concession system regulates the public marine resources.

Figure 18.A1.7: Existence of different regulatory frameworks for aquaculture installations on private and on public space (number of respondents)



Code of conducts

The survey also investigated the existence of codes of conduct for aquaculture developed by the regulator, NGOs or industry associations (Figure 18.13). Codes of Conducts or Best Management Practices focus primarily on environmental impacts of aquaculture and can provide a useful complement to regulation. Eight countries confirm the existence of codes of conducts.

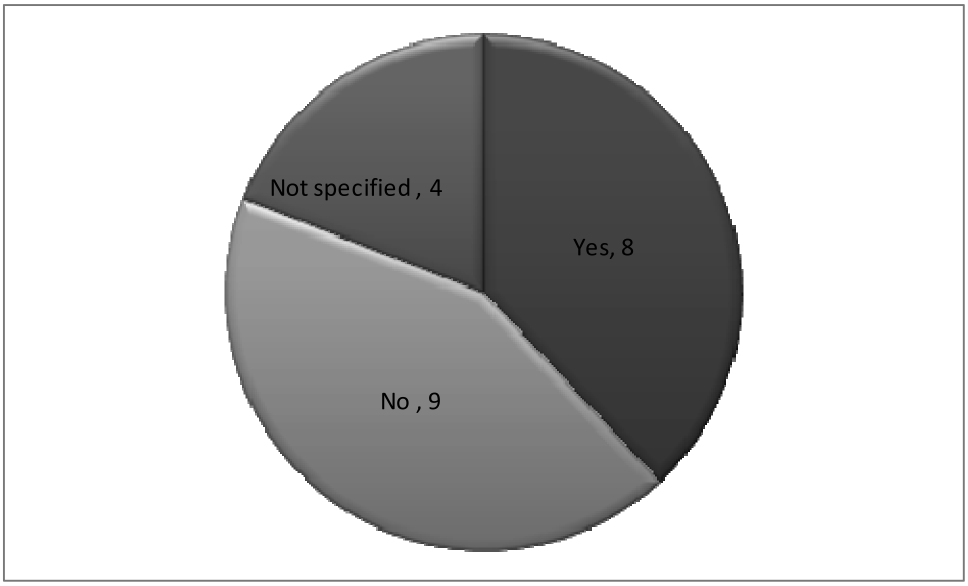
In the EU, the Federation of European Aquaculture Producers (FEAP) gathers national producer associations. FEAP has developed a Code of Conduct for European Aquaculture, which is widely applied by its member organizations.

A number of codes of practice at national level have emerged in OECD countries, applicable either for the entire sector or for specific sub-segments or specie. Examples include:

- Environmental Code of Practice for Irish Aquaculture Companies and Traders (BIM, Irish Shellfish Association, Irish Salmon Growers);
- ISGA Code – "*Good farmers – good neighbours*" (Irish Salmon Growers);
- Shetland Salmon Farmers Association Code of Best Practice;
- Code of Good Practice for Scottish Finfish Aquaculture;
- British Trout Association Code of Practice;
- French Charter for Trout Producers (Inter-professional Committee);
- Manual de Buenas Practicas Medioambientales en la Familia Profesional: Pesca y Acuicultura (Spanish Ministry of the Environment) and
- Marine Fish Farm Manual of the Scottish Environment Protection Agency.

In some OECD member countries producer associations or organic associations have developed specific guidelines or standards for organic aquaculture production.

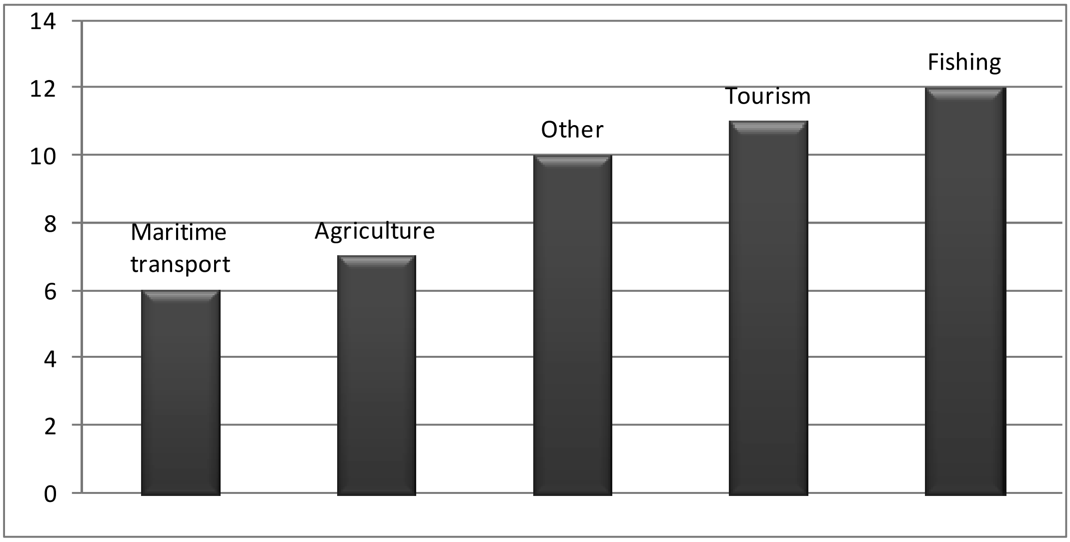
Figure 18.A1.8: Availability of code of conducts for aquaculture (number of respondents)



Conflicting sectors

Among the sectors conflicting with aquaculture production sites competing for the same resources, the fishing sector is the most prominent one, followed closely by tourism. Agriculture and maritime transport seem to be less critical in this respect (Figure 18.A1.9). Other conflicting sectors identified by the survey are the environment/nature conservation, urban development and industry.

Figure 18.A1.9: Conflicting sectors (number of respondents)



Authorisation system to access and operate aquaculture production sites

> *"States should require that the disposal of wastes such as offal, sludge, dead or diseased fish, excess veterinary drugs and other hazardous chemical inputs does not constitute a hazard to human health and the environment." (CCRF Article 9.4.6)*
>
> *"States should ensure the food safety of aquaculture products and promote efforts which maintain product quality and improve their value through particular care before and during harvesting and on-site processing and in storage and transport of the products." (CCRF Article 9.4.7)*

The majority of the countries operate some licensing system for aquaculture operations. The system consists of two main parts: the license itself as an expression of an administrative decision to allow production and a set of additional related laws and regulations which define rights and obligations.

One respondent stated that the '*…system of permits, defined by various laws and controlled by different ministries, is elaborate and complex*[6]' while another one explained that '*despite recent revisions and efforts to simplify the licensing procedures it is still quite complex and time consuming to grant a license for aquaculture production*[7]'.

The maximum amount of licenses in terms of numbers or in terms of production volume can be fixed. In Denmark on the other hand the licences for freshwater and saltwater farms using feed are based on fixed feed quotas. In the case of a restriction, the allocation process can vary: first come first served, auction, drawing of lots among qualified applicants etc. Box 18.A1.1 illustrates the Norwegian option for allocating salmon and trout licences.

Box 18.A1.1: Allocation system for trout and salmon licences in Norway

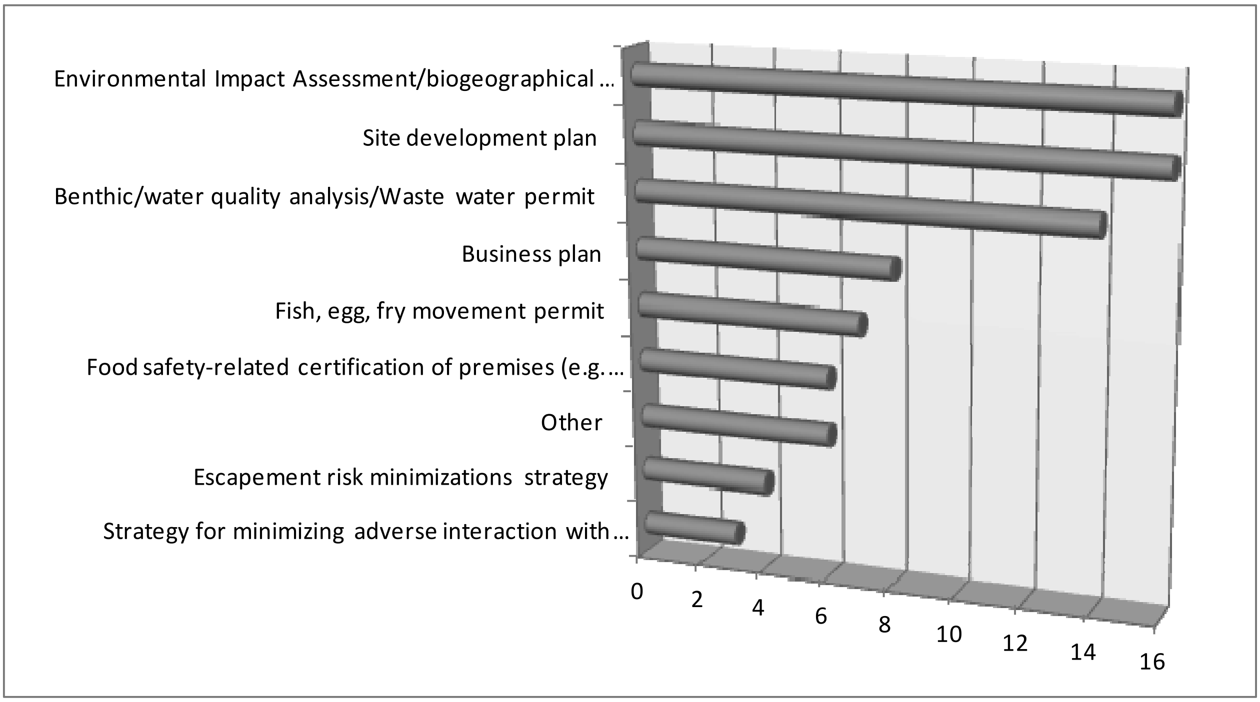
In the case of farming of salmon and trout in Norway there is a limited entry with regards to how many licences to allocate. Since the interest in salmon and trout licences has been greater than the number of licenses advertised, the applicants have had to compete for the licences - normally in so-called allocation rounds.

In accordance to the Aquaculture Act the Ministry of Fisheries and Coastal Affairs may prescribe regulations relating to the number of licences to be allocated, geographic distribution of licenses and prioritization criteria. This implies that licenses are allocated to applicants that meet the licence requirements. The Ministry can also prescribe regulations relating to payment for the allocation of licences. In the 2002, 2003 and 2009 rounds, the payment was a fixed, predefined amount.

Source : Norwegian Ministry of Fisheries and Coastal Affairs

With regard to the required documentation when applying for authorisation for a production site, Environmental Impact Assessment (EIA) documentation is a prominent feature in all countries covered by the survey (Figure 18.A1.10). In some cases it is conducted as a separate administrative procedure while in others it is an integrated part of the licensing procedure itself. In many countries EIA requirements depend on the production volume: only above a certain threshold EIA becomes mandatory (*e.g*. Finland, Portugal, Turkey).

Figure 18.A1.10: Documentation needed to establish aquaculture production sites in OECD countries (number of respondents)



As in the case of EIA also water discharge permits are often administered by regional authorities, both in terms of developing the regulations as well as in terms of cost recovery through fees (*e.g.* New Zealand).

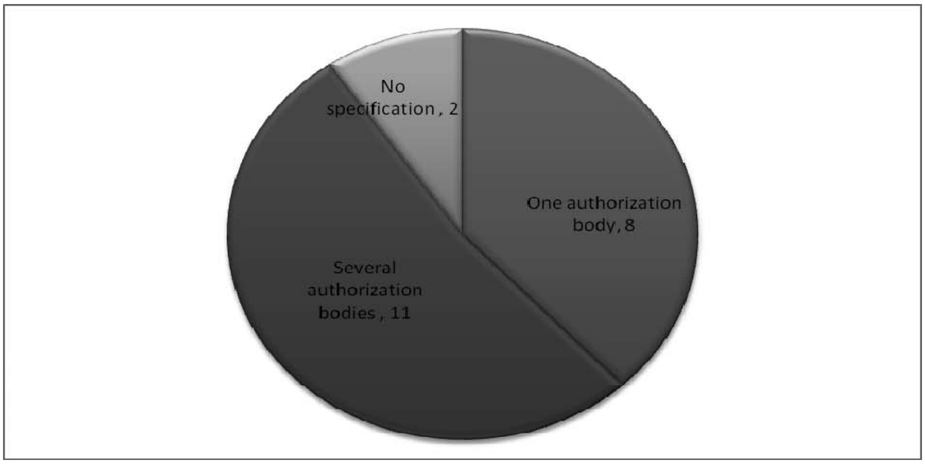
Who grants authorisation?

The ‘One-stop- shop’ solution for aquaculture production site authorisation is rather rare. In most cases, applicants have to deal with different authorities to obtain the necessary approvals (Figure 18.A1.11). There is evidence that regional or local spatial planning authorities play a major role in the approval of site authorizations. For example, In Finland, the regional environmental permission office issues production licences. In the Flemish Region in Belgium applicants have to deal with the Department of Spatial Planning, Housing Policy and Heritage of the Flemish Government and the related municipalities with regard to the site development plan approval. The Flemish Department of Environment, Nature and Energy is responsible for the approval of the EIA while the food safety-related certification of premises is dealt with at the national level (Federal Agency for the Safety of the Food Chain). Similar administrative set-up occurs in other countries, including Chinese Taipei and Finland. In the UK, the responsibility for marine fish farms has been transferred in 2007 from the Crown Estate to local authorities.

Food safety related authorizations on the other hand are usually granted through authorities at the national level. In some cases, the authorization procedure requires a public hearing that can involve institutions like tax authorities, consumers’ services and relevant professional organizations (*e.g.* France, Germany).

OECD countries adopt different systems to communicate the granting of an aquaculture license. In France, the decision is notified to the applicant while in Germany the authorization is considered to be approved if no notice is given within one month after filing the application. In New Zealand the concession of an authority for an aquaculture management area requires a series of certificates of compliance stating the absence of a ‘resource consent’, that is an authorization given to certain activities or uses of natural and physical resources required under the New Zealand Resource Management Act. In Scotland, administrations have a time limit for the processing of planning applications (two months for non-EIA local development applications, four months for major applications). In case the decision is not made within the time frame the applicant has the right to appeal to Scottish Ministers within six month of the non-determination.

Figure 18.A1.11: Responsible authorities involved in the aquaculture production site process (number of respondents)



How is authorisation for a production site granted?

Many countries report a distinction between the authorization system for coastal marine aquaculture and for freshwater inland fisheries, the main reason being the different legal status of the water source involved. Coastal marine aquaculture is generally taking place in a common pool resource (*i.e.* the marine water bodies) while inland freshwater fisheries can take place on a common property (*e.g.* lakes, rivers) or as private land-based aquaculture installations. Requirements for marine fish farming tend to be more restrictive then for inland fish farming. For marine farming, the authority to issue a licence can also depend on the location of the planned activity. In Denmark for example, inshore and coastal farms fall under the responsibility of the county councils while off shore activities are administered thought he Ministry of Transport (Coastal Directorate).

In some countries, some form of production permit is only requested above a certain volume threshold. The threshold is set in terms of production volume (*e.g.* France, Iceland) or in terms of feed volume (*e.g.* in Denmark, Finland). France applies the 'classified installation system', which is used for any industrial or agricultural operation that (potentially) generates risks, pollution or nuisance. Depending on the probability and the level of externalities, an aquaculture activity can be subject to an authorization or a declaration. The threshold for an authorization is currently set at production size of more than 20 tonnes.

Table 18.A1.1 illustrates the French classified installations system procedure which is managed by the Prefect. It should be noted that under this system an Environmental Impact Assessment is only required when an authorization is needed.

Table 18.A1.1: Classified installation system procedure in France

Types of fish farm	Annual production volume	Classified installation system	Law N. 2006-17 on Water and Aquatic Environment
Fresh water farms[1]	< 20 t	na	Declaration
	> 20 t	Authorisation	Declaration
Marine water farms	5-20 t	Declaration	n/a
	> 20 t	Authorisation	n/a

1. Except extensive production –

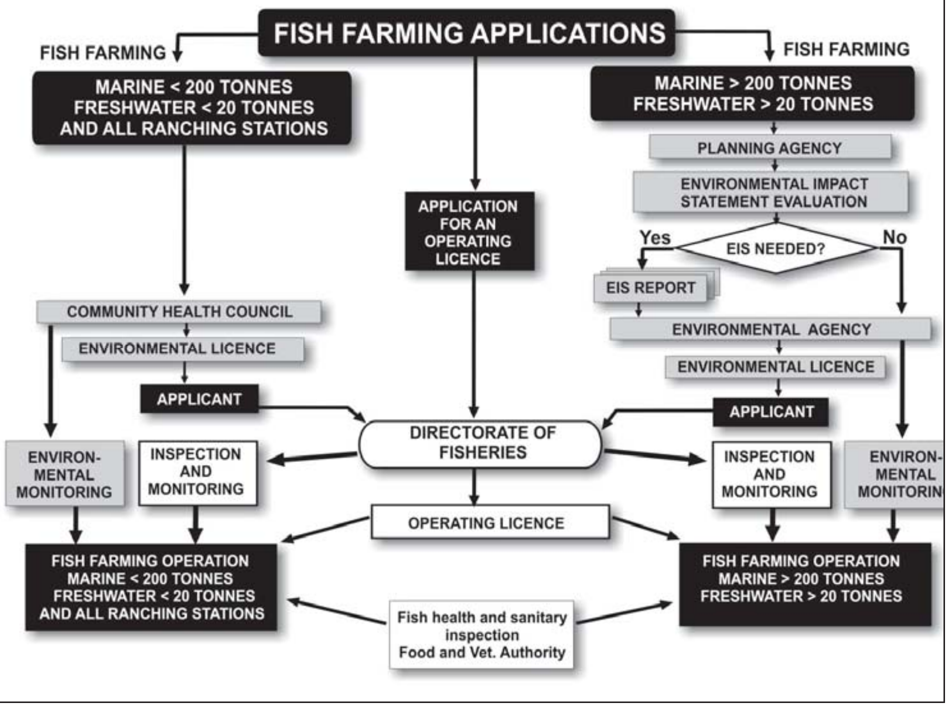
Source : adapted from country survey response.

Transferability of licenses seems to be generally possible but tied to some form of ownership of the production site. A transferred licence however has to be used within the agreed parameters (*e.g.* species, volume, location). Licenses are hence linked to a certain production unit and not necessarily to an individual producer.

With regard to the duration of licences, a period of 5-10 years with the possibility to renew is most common. In a few cases a maximum duration (30-60 years) for a license is established. The establishment of a minimum lease period is uncommon but exists; in the case of Germany for a period of 12 years. It is important to note that some countries specifically indicated the possibility to withdraw a licence to establish or operate a farm (*e.g.* Denmark for ocean farms).

Box 18.A1.2 illustrates the Icelandic licensing and monitoring system which requires different procedures depending on the planned production volume.

Box 18.A1.2: Icelandic Fish Farming and Ranching Licensing and Monitoring System



The survey revealed that 14 countries maintain a public register of aquaculture production sites exists.

Does the use of production sites imply payments?

Licenses can be granted against the payment of a fee or for free. If a fee applies it can be a fixed amount or variable according to different criteria (*e.g.* site size). The survey did not provide much insight in the cost structure of the national licensing systems. It emerged that if applied, administrative fees are often payable to regional authorities (*e.g.* in Finland, Greece).

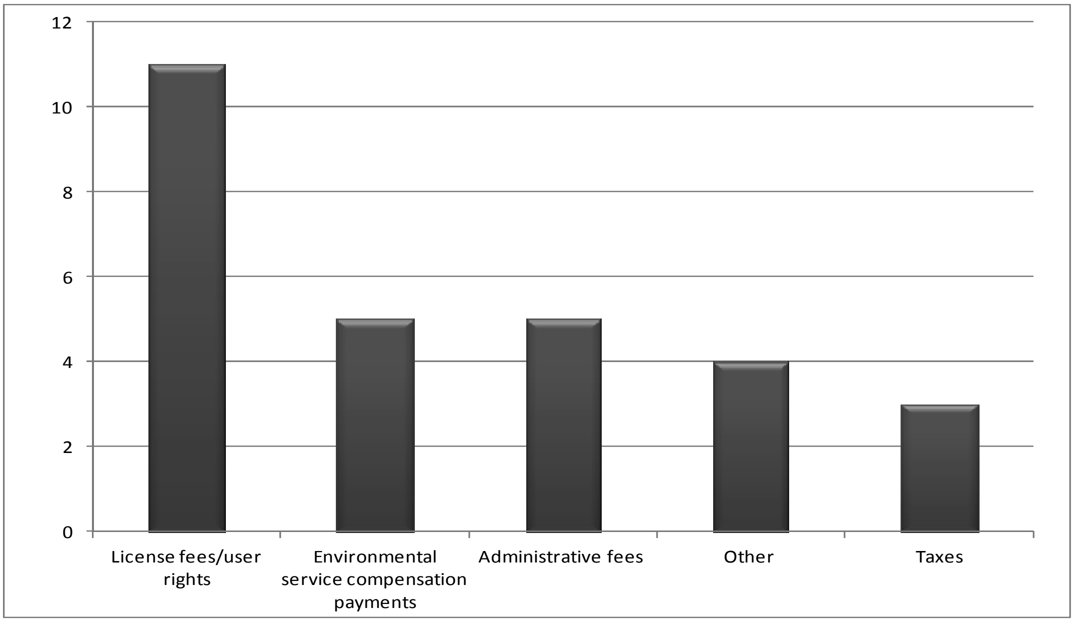
According to the Norwegian Aquaculture Act, '*An open or closed bidding round will be suitable for taking into account the consequences of fluctuations in the market situation for salmon on the ability/willingness to pay for new licences. What is of key importance here is the fact that the payment for licences will be determined based on the industry players' own assessment of the licence's value, and the price will thus correspond to the market value. It will thus be up to the industry players to assess how efficiently the licences can be operated.*' Norway doesn't charges a general fee for the use of sea areas for the purpose of aquaculture. However, each municipality has the opportunity to introduce proper taxation which may also compromise aquaculture facilities. Even though there is no general payment for the use of production sites, payment is collected for aquaculture licences for salmon and trout.

In the United Kingdom, an annual rent is charged for the lease based on production volumes.

Finland establishes fees for environmental compensation payments on a case by case basis while the French water agency charges annual pollution fees for freshwater sites. In the Netherlands, surface waters are administered by provincial authorities who usually delegate the right to grant discharge permits and to charge levies to their water boards.

Other production site related cost items identified by the survey include rent (private cost) and Environmental Impact Assessment and monitoring costs (Figure 18.A1.12).

Figure 18.A1.12: Aquaculture site related cost items (number of respondents)



Annex I8.A2 - Questionnaire on conditions for establishing aquaculture production sites in OECD countries

Introduction and scope

As agreed at the 102st Session of the Committee for Fisheries, an important basis for the work on aquaculture is to establish an inventory of conditions for establishing aquaculture production sites in OECD countries. At the 102st Session it was also agreed that the Secretariat would issue a questionnaire to start such an inventory. The following serves this purpose.

The OECD Workshop on Aquaculture scheduled for April 2010 seeks to examine policy challenges that OECD governments face in aquaculture development by identifying constraints and best practices to create an enabling environment for a competitive and sustainable sector. To this end, this questionnaire gathers information on a range of aquaculture production site issues, including public regulations, major constraints and potential areas for conflict. The questionnaire replies, once received, will be the basis of compiling an inventory of practices of OECD (and observer) countries with respect to conditions for aquaculture installations.

Explanatory notes for completing the template

Countries for which an Aquaculture Profile based on the FAO National Aquaculture Legislation Overview is available are kindly requested to validate or modify the available information as they deem appropriate.

If feasible and appropriate, one questionnaire should be filled for each sub-national administrative unit (e.g. state, territory, county) which manages its own aquaculture regulations.

The questionnaire is divided into three sections. Part 1 on the basic legal and institutional framework seeks identify the main legislative requirements and authorities within which aquaculture production is placed. Part 2 focuses specifically on relevant regulations for aquaculture production site development. Part 3 investigates the authorization system to access and operate production sites (land and marine sites).

If there are different legislation or regulations applying to aquaculture (in particular production site regulations) the answers should always clarify which law, regulation or responsible authority they refer to.

Where specifications are requested, they should be as exhaustive as possible.

Questions 3, 6 and 13 should provide as much information about the allocation of responsibilities and decision making processes within and/or between institutions as possible.

Question 6 refers specifically to spatial management aspects which may affect aquaculture while Question10, Question 12 and Question 18 allow for the recording of other laws and regulations with potential relevance for aquaculture production sites.

Question 8 should provide detailed information about additional laws, regulations or policies resulting from or in addition to the main piece of legislation listed under 6.

With reference to Questions 10, 12 and 18, the Secretariat would greatly appreciate any efforts that can be made to document relevant public regulation, policies and private best practice/code/guideline relating to aquaculture production sites.

Part 1: Basic legal and institutional framework

1. Which administrative entity has primary responsibility for land and water management?

☐ National/federal government (if several administrative entities - please specify)

☐ Sub-level (e.g. territories, departments, regions - please specify)

2. Is there a specific national aquaculture regulation or political framework?

☐ Yes (please specify)
  ☐ Within the fisheries regulation/policy framework:
  ☐ Stand alone

☐ No

3. Which national authority/ies is/are responsible for aquaculture regulation and/or policy development?

☐ At the national level (please specify)

☐ At other levels (please specify)

4. How is compliance with aquaculture regulations and/or policies ensured?

☐ Public institution (please specify)

☐ Other (please specify – e.g. industry self-regulation, compliance and auditing)

5. Cross-sectoral resource management: is aquaculture mentioned in any regional, coastal/river basin or community management/development plans and if so, how is policy coherence across the institutions achieved?

☐ Yes (please specify)

☐ No

Part 2: Relevant regulations for aquaculture production sites

6. Are there any specific regulations for aquaculture production sites?

☐ Yes (please specify)
☐ No

IF YES:

7. Main purpose of the regulation (tick as many as apply)

☐ To regulate access to productive assets (e.g. land, water, marine space, fish stocks)
☐ To ensure minimum environmental standards
☐ Other (please specify)

8. Does the regulation under 6. (directly or indirectly) or any other law/and regulation specify any of the following (tick as many as apply and specify)?

☐ Water quality requirements/discharge limits
☐ Waste disposal
☐ Fish, fry, egg movement
☐ Use of drugs/chemicals
☐ Feed specifications
☐ Stock register
☐ Quarantine conditions/Disease control measures
☐ GMO, bioengineering
☐ Escapement issues.
☐ Environmental Impact Assessment:
☐ Site size/ Site placement (e.g. in terms of minimum distances from spawning area, touristic locations)
☐ Other (please specify)

9. Is the regulatory framework the same for aquaculture installations on private and on public space?

☐ Yes
☐ No (please specify)

10. Are there any codes of conduct for aquaculture production etc. developed by NGOs or industry associations?

☐ Yes (please specify)
☐ No

11. Which sectors are conflicting with aquaculture production site establishment or compete for the same resources (tick as many as apply)?

☐ Agriculture
☐ Tourism/recreation
☐ Maritime transport
☐ Fishing
☐ Other (please specify)

12. Which regulations not specifically dedicated to aquaculture are of relevance to establish and maintain an aquaculture production site (*e.g.* environmental regulations, animal health regulations, food safety regulations)? Please indicate also the respective responsible Ministry/authority.

Part 3: Authorization system to access and operate production sites (land and marine sites)

13. Which documentation must producers provide when applying for authorization for a production site (tick as many as apply and specify responsible authority if applicable)?

☐ Site development plan
☐ Environmental Impact Assessment/biogeographical report
☐ Water licence
☐ Escapement risk minimizations strategy
☐ Strategy for minimizing adverse interaction with seabirds, other marine/terrestrial species
☐ Fish, egg, fry movement permit
☐ Business plan
☐ Food safety-related certification of premises (e.g. HACCP)
☐ Other (please specify)

14. Who grants authorization?

☐ One authorization body (please specify)
☐ Several authorization bodies (please specify body and area of responsibility)

15. How is authorization for a production site granted?

☐ Production license (please specify duration and transferability)
☐ Production site lease (please specify duration and transferability)
☐ Other (please specify)

16. Is there a public register of aquaculture production sites?

☐ Yes
☐ No

17. Does the use of production sites imply any payments?

☐ License fees/user rights
  ☐ To whom (please specify)
  ☐ How often (please specify)
☐ Environmental service compensation payments

  - ☐ To whom (please specify)
  - ☐ How often (please specify)
- ☐ Administrative fees
  - ☐ To whom (please specify)
  - ☐ How often (please specify)
- ☐ Taxes
  - ☐ To whom (please specify)
  - ☐ How often (please specify)
- ☐ Other (please specify)
  - ☐ To whom (please specify)
  - ☐ How often (please specify)

18. Further relevant information, including government agencies, websites, publications, regulations, etc.

Notes

1. If two ministries are indicated they are accounted for as 0.5 in each category
2. For more details: www.aquaculture.govt.nz/governments_role.php).
3. Council Directive 2006/88/EC on Animal Health Requirements for Aquaculture Animals and the related amendment through the Commission Directive 2008/53/EC
4. Regulation (EC) No 178/2002 of the European Parliament and of the Council of 28 January 2002
5. 2000/60/EC of the European Parliament and of the Council of 23 October 2000
6. The Netherlands.
7. Turkey.

Biographies

Malcolm BEVERIDGE,
Director, Aquaculture and Genetic Improvement, WorldFish Centre, Cairo, Egypt

Malcolm Beveridge presented a paper on *Barriers to aquaculture development as a pathway to poverty alleviation and food security: policy coherence and the roles and responsibilities of development agencies*. He has a PhD in ecology from the University of Glasgow and has applied his professional training to the field of aquaculture and fisheries for 30 years. Following a one-year FAO post-doctoral fellowship at the University of the Philippines, he joined the Institute of Aquaculture, University of Stirling, Scotland, where he was appointed Reader in 2000. The following year he joined Fisheries Research Services (Scotland), as Director of the Freshwater Laboratory. In 2006 he was appointed Director of Aquaculture and Genetic Improvement at the WorldFish Center. He has recently held a Visiting Research Fellowship at Imperial College, University of London (2007-2008) and was appointed Buckland Professor in 2008, as a result of which he delivered a number of public lectures on the theme of aquaculture, development and the environment in the UK. He is based in Cairo, Egypt.

Cécile BIGOT
Deputy Director, Aquaculture and Fisheries Economic Survey Department, DG Fisheries and Aquaculture, Ministry of Food, Agriculture and Fisheries, Paris, France

Cécile Bigot participated in the *Panel on national policies, strategies and plans for sustainable aquaculture* and participated in the *Panel on best practices in aquaculture management and development*. She graduated from the National Agronomic Institute of Paris in 1988 and from the National School of Rural, Water and Forestry Engineering in 1989. Since then she held different positions in the Ministry for Food, Agriculture and Fisheries, including as Head of the Viticulture and of the Sea Products Unit. Between 2005 and 2007, Cécile Bigot was advisor for agriculture and fisheries at the French embassy in Spain. In 2007 she was appointed Deputy Director in the Fisheries and Aquaculture Direction of the Ministry for Food, Agriculture and Fisheries, where she currently is responsible for the economic analysis of the fisheries sector and for aquaculture industry policy development.

Torger BØRRESEN
Research Director, Department of Seafood Research, DTU Food, National Food Institute, Technical University of Denmark, Denmark

Torger Børresen chaired the two-day workshop. He received a PhD in biotechnology from the Norwegian Institute of Technology in 1976. He has held various research positions in the Unites States, Norway and Denmark concerning food biochemistry and seafood technology. He has a long-standing experience as manager of research at all levels, including project leadership, management of project groups and a marine biotechnology research centre, department management and top administrative management at institute level. Presently he is the Research Director of the Department of Seafood Research at the National Food Institute, Technical University of Denmark. Torger Børresen has been serving at more than 50 advisory groups for research and development within the food technology area nationally and internationally. He has published more than 100 papers, abstracts, posters, reports and other written material, and given numerous presentations at scientific conferences, many of which have been keynote presentations. He has served on the editorial board of several international journals and is presently co-editor of the Journal of Aquatic Food Product Technology. He has a long experience in collaborating with the industry and industry associations. He coordinated the EU supported research project SEAFOODplus 2004-08, with a total budget of 26 million Euro and 68 participating institutes and industries in 16 countries. He was a member of the Steering Group of the EU supported Cooperative Project CONSENSUS and is presently a member of the European Aquaculture Technology and Innovation Platform (EATIP), where he is serving at one of the Thematic Areas under the Strategic Research Agenda.

Thierry CHOPIN

Professor, Biology Department, University of New Brunswick, Saint John, Canada

Dr. Thierry Chopin presented a paper on *Integrated multi-trophic aquaculture – a responsible practice providing diversified seafood products while rendering services to the ecosystem* and participated in the *Panel on best practices in aquaculture management and development*. He was born and educated in France. He obtained his Doctorate from the University of Western Brittany, Brest, France. He moved to Canada in 1989 and is presently Professor in the Biology Department at the University of New Brunswick in Saint John. Dr. Chopin's research focuses on the ecophysiology and biochemistry of seaweeds of commercial value and the development of integrated multi-trophic aquaculture (IMTA) systems for environmental sustainability (biomitigation), economic stability (product diversification and risk reduction) and societal acceptability (better management practices). Dr. Chopin has published 76 refereed papers, 16 book chapters, 21 non-refereed publications, 263 abstracts (in 29 countries on 6 continents), 1 English/French DVD, and had 412 contacts with the media (magazine articles, newspapers/radio/TV interviews and documentaries). Dr. Chopin is the Scientific Director of the Natural Sciences and Engineering Research Council of Canada (NSERC) Canadian Integrated Multi-Trophic Aquaculture Network (CIMTAN). He is Past President of the Aquaculture Association of Canada, the Phycological Society of America and the International Seaweed Association. He is an advisor to the International Foundation for Science, in Stockholm, and a member of the Editorial Board of the journal Aquaculture International. Dr. Chopin is the recipient of the NSERC Synergy Award for Innovation, the Aquaculture Association of Canada Research Award of Excellence, the New Brunswick BioSciences Achievement Award and was an honouree at the R3 (Research, Results, Recognition) Gala of the New Brunswick Innovation Foundation. Dr. Chopin is also Honorary Vice-Consul of France and Chevalier in the Ordre des Palmes Académiques of France.

Hayri DENIZ

Director of Marine Aquaculture, Aquaculture Department, DG of Agricultural Production and Development, Ministry of Agriculture and Rural Affairs, Ankara, Turkey

Hayri Deniz participated in the *Panel on national policies, strategies and plans for sustainable aquaculture*. He works for the Aquaculture Department of the Ministry of Agriculture and Rural Affairs as Director of Marine Aquaculture since 1988. In addition, he implemented several international and national aquaculture projects funded through international organizations such as FAO-GFCM, EUROFISH and MEDCOAST. He graduated from the Fisheries Faculty of the Mediterranean University in 1887. He holds a PhD in sea bass and sea bream production. His expertise is in marine aquaculture management, interactions between aquaculture and other coastal sectors and integrated coastal zone management.

Sena S. DE SILVA

Director General, Network of Aquaculture Centres in Asia-Pacific, Bangkok, Thailand

Sena S. de Silva gave a presentation on *Knowledge sharing in aquaculture: towards sustainability through effective communication* and participated in the *Panel on enhancing economic conditions for aquaculture*. He graduated from the University of Ceylon with B.Sc (Hons), obtained his PhD from the University of Stirling, UK, and in 1989 was awarded a DSc. by the University of Stirling, United Kingdom, for his contributions to aquaculture and fisheries biology. Currently Sena is the Director General of the Network of Aquaculture Centres in Asia-Pacific, and Honorary Professor of Aquaculture and Fisheries Biology, School for Life and Environmental Sciences, Deakin University, Victoria. Sena has been active in the academia for over 30 years, in Sri Lanka, UK, Singapore and Australia, and associated with major research and development in the Asian region and elsewhere. Sena is recognised as a leading researcher in the fields of fish nutrition, inland fisheries management and aquaculture with a publication record of over 220 original articles in peer reviewed, international journals, 10 edited works and the senior author of three advanced texts related to aquaculture. Sena has received many awards for his contributions including Honorary Life Membership of the World Aquaculture Society in 2006.

Robert DIAZ

Professor, Virginia Institute of Marine Science, College of William and Mary, Virginia, United States

Robert Diaz presented a paper on *Managing agriculture run offs in coastal areas* and participated in the *Panel on best practices in aquaculture management and development*. He is a Professor of Marine Science at the College of William and Mary, Virginia Institute of Marine Science. He received a PhD from the University of Virginia in 1977 and a Doctor Honoris Causa from Gothenburg University, Sweden, in 1996 for his contributions to marine and estuarine ecology. Dr. Diaz has over 35 years of experience working on environmental issues in a variety of marine and freshwater habitats from the intertidal to the deep-sea. He specializes in documenting disturbance, both natural and human, to systems and has developed several methods for evaluating benthic habitats and identifying benthic resource value. His main expertise is in assessment of impacts from low dissolved oxygen (hypoxia, dead zones) on ecosystem processes.

Philippe FERLIN

General Inspector, Conseil Général de l'Alimentation, de l'Agriculture et des Espaces Ruraux (CGAAER), Ministry of Food, Agriculture and Fisheries, France.

Philippe Ferlin graduated from the National Agronomic Institute (INA) of Paris and from the National Institute for Rural, Water and Forestry Engineering (ENGREF) in the mid 60s. He then held different positions in several French research institutes: CEMAGREF (a scientific and technical public research institute under the Ministries of Agriculture and Research), IFREMER (French Research Institute for the Exploitation of the Sea) and INRA (National Institute for Agriculture Research. He became Director of International Relations and Cooperation for IFREMER in the early 1990s and later Director of International Relations for INRA (1998-2005). Philippe Ferlin has then been appointed General Inspector at the Ministry of Food, Agriculture and Fisheries and is chairman of the Expert Group on Sea Affairs. He is also involved in international organisations as FAO expert for fisheries and aquaculture, vice president of the OECD Fisheries Committee and member of the advisory committee of the Institute of Aquaculture of Stirling (UK).

Marion FISCHER

Fisheries and Aquaculture Researcher, FranceAgriMer, Montreuil-sous-Bois, France

Marion Fischer presented the *Findings from a recent study on consumer perceptions of aquaculture products in France*. An agricultural engineer by training, Marion Fischer conducted research in the fish-farming industries of metropolitan and overseas France and Asia for three years, with a focus on the development and marketing of aquaculture products. She is currently a research assistant in the field of fisheries and aquaculture in the Directorate for Markets, Studies and Outlook of FranceAgriMer, and is studying the consumption of aquatic products, in particular through the analysis of consumer panel data. She is also studying changes in consumption patterns, which she is linking to the changing perception of fishery and aquaculture products by consumers, using external studies and surveys carried out for FranceAgriMer.

Arne FREDHEIM

Research Manager and Director, Centre for Aquaculture Technology (CREATE), SINTEF, Trondheim, Norway

Dr. Arne Fredheim presented a paper on *Dealing with escapement issues* and participated in the *Panel on best practices in aquaculture management and development*. He is presently employed with SINTEF Fisheries and Aquaculture, Trondheim, Norway, as a research manager and director for the c Centre for Aquaculture Technology (CREATE). He holds a PhD in marine hydrodynamics from the Norwegian University of Science and Technology (NTNU). CREATE is a multi-disciplinary research centre established among nine partners, research and industry, with the aim to develop technology, products and solutions for the marine fish farming of tomorrow. In addition to heading CREATE, his main current work involves research on topics related to technology for marine aquaculture. Previous research has been on current forces on and flow through net structures, structural and hydrodynamic analysis and assessment of floating fish farms and design criteria to prevent escape of fish from floating aquaculture installations. Dr. Fredheim is a member of the Norwegian Aquaculture Escapes Commission and convener for the workgroup to develop standards for aquaculture technology under the ISO/TC 234 fishery and aquaculture.

Éric GILBERT

Director, Innovation and Sector Strategies, Aquaculture Management Directorate, Department of Fisheries and Oceans (DFO), Ottawa, Canada

Eric Gilbert gave a presented a country case study on *How policy coherence is addressed across policy domains*. He has worked in the aquaculture industry for more than 22 years. He holds an undergraduate degree in biology and a master's degree in Maritime Resources Management with a specialty in aquaculture economics. Mr. Gilbert worked for Quebec's Ministry of Agriculture, Fisheries, and Foods for 12 years before joining Fisheries and Oceans Canada. He is currently responsible for aquaculture innovation as well as for the preparation of strategic action plans for the entire Canadian aquaculture sector. He has extensive experience in the conception and management of programs and policies designed to ensure sustainable aquaculture development in Canada.

Maurice HÉRAL

Director, Prospective and Scientific Strategy, Institut Français de Recherche pour l'Exploitation de la Mer (IFREMER), Issy-les-Moulineaux, France

Maurice Héral gave a presentation on *The role of science and research* and participated in the *Panel discussion on enhancing economic conditions for aquaculture*. He is Director of the Prospective ad Scientific Strategy at IFREMER. His background is in coastal ecology. He has developed carrying capacity models for shellfish, coupling eco-physiological models with food availability. Director of different IFREMER and CNRS laboratories, he was Scientific Director of IFREMER since 2001. He published more than 270 papers in scientific journals and public reports and supervised the realisation of 15 PhD theses. He is member of several review panels and expert in different commissions. He is outgoing chair of the European Fisheries and Aquaculture Research Organisation (EFARO) that he has established and is outgoing ICES vice president. He has coordinated 7 EU contracts and is actually involved in three marine ERA-NETs (EU schemes to support the cooperation and coordination of research activities carried out at national or regional level). Since May 2009, Maurice Héral is also head of the Ecosystems and Sustainable Development Department at the French National Research Agency (ANR), a funding agency for research projects whose aim is to provide funding for the entire scientific community based on calls for proposals and peer review selection processes.

Courtney HOUGH

General Secretary, European Aquaculture Technology and Information Platform

Courtney Hough presented the *Industry perspective on enhancing economic conditions* and chaired the *Panel discussion on enhancing economic conditions for aquaculture*. After starting in scientific research and development, mainly on food product development, Courtney Hough worked on the international development of aquaculture, specialising in project development, market research and economic evaluation. Since 1993, he has been General Secretary of the Federation of European

Aquaculture Producers (FEAP), assuring representation of the FEAP in the European Commission's Advisory Committee on Fisheries and Aquaculture (ACFA) and other European bodies. Courtney Hough has worked as coordinator or participant on a large number of Research and Technological Development (RTD) projects in Europe, as well as training and educational issues. He has worked with the FAO and the IUCN - primarily on networking and preparing reviews on European and global aquaculture. He has participated in many aquaculture-related workshops and conferences, as co-organiser, session chairman and speaker. In 2008, he was appointed General Secretary of the European Aquaculture Technology and Innovation Platform (EATIP), an international non-profit association, which provides pan-European support to the development of the European aquaculture value-chain. Courtney holds a BSc degree in Zoology with Chemistry (1972, Exeter University) and an MSc in Biochemistry (1973, Imperial College, London).

Alistair LANE

Executive Director, European Aquaculture Society (EAS), Oostende, Belgium

Alistair Lane presented *CONSENSUS – a multi-stakeholder platform for sustainable aquaculture in Europe* and chaired the *Panel on best practices in aquaculture management and development*. EAS is an international non-profit association that brings together 500 members from 45 countries for the development of sustainable aquaculture. Alistair Lane has been the Executive Director of EAS since 2000. After graduating with an MSc in Marine Biology, he worked in the aquaculture feeds business for ten years in the United Kingdom, France and Spain, with responsibilities in distribution, marketing and general management. He has a special interest in aquaculture networks and has been involved in several European initiatives related to sustainable aquaculture development, notably the CONSENSUS initiative that has defined indicators and provided balanced information to European consumer organisations. He has participated as an expert in several European Parliament Hearings on aquaculture and is a project evaluator for the European Commission and the Research Council of Norway.

Jung-Uie LEE

General Director, Aquaculture Industry Department, National Fisheries Research and Development Institute (NFRDI), Busan, Korea

Jung-Uie Lee participated in the *Panel on national policies, strategies and plans for sustainable aquaculture.* He started his career in NFRDI in 1983 after graduating in Aquaculture Science at the Cheju National University. His academic qualifications furthermore include an MSc and a PhD in Aquaculture and Fish Biology from the Pukyong National University. In NFRDI he held the following positions: Senior Scientist of the West Sea Fisheries Research Institute, Director of Namjeju Marine Hatchery, Director of Jeju Fisheries Research Institute and Director of the Aquaculture Division. He became Director of the Aquaculture Industry Department in 2009. His current projects include offshore aquaculture development and tuna farming.

Donal MAGUIRE

Director, Aquaculture Development, Irish Sea Fisheries Board (BIM), Co Dublin, Ireland

Donal Maguire presented an Irish case study on *How policy coherence is addressed across policy domains.* A graduate in marine sciences, he is the director of aquaculture development for the Irish Sea Fisheries Board, the state body charged with the development of the seafood sector in Ireland. He has held the post since 1997 and in that capacity has overseen the implementation of the national development programmes applied to aquaculture. Prior to this Mr. Maguire worked as a senior executive in the salmon farming sector in Scotland, particularly on the Western Isles where he ran a number of companies over a period of 14 years.

Marie Christine MONFORT

Seafood Marketing Consultant, Paris, France

Marie Christine Monfort gave a presentation on *Aquaculture products; consumer perceptions* and participated in the *Panel on enhancing economic conditions for aquaculture*. Since 1990 Marie Christine Monfort operates as a consultant 100% dedicated to seafood marketing and deals specifically with issues related to the European market. She assists private companies in their attempts to meet European market requirements and to reach professional buyers, through market studies and tailor-made advice. She guides private investors prior to investing in the seafood business. She also cooperates with public institutions (Ministries of Fisheries, universities), international organisations (EU Commission, FAO, etc.), research institutes and NGOs (WWF, Greenpeace, Seafood Choice Alliance). In the past years, she has extensively worked in the field of sustainability and eco-labelling of aquatic products. Marie Christine Monfort holds a degree in Economics from the Sorbonne University, Paris (Msc in Economics), in Marketing from Nantes University (Msc Marketing) and from the Norwegian Fishery Economics Institute (NHH), Bergen, Norway.

James F. MUIR

Emeritus Professor, University of Stirling and independent adviser, Edinburgh, United Kingdom

James Muir prepared a paper on *Growing the wealth of aquaculture: perspectives and potential*. James Muir is an Emeritus Professor at the University of Stirling and independent adviser in aquatic resources and development, currently co-ordinating the aquatic components of the UK Government Foresight Programme review of the 'Future of Food'. Formerly he was Assistant Director of the Institute of Aquaculture and until its successful completion in 2006 Manager of the UK Department for International Development (DFID) Aquaculture and Fish Genetics Research Programme. A former FAO staff member, he has also served as Senior Fisheries and Aquatic Resources Adviser for DFID, Senior Adviser to WorldFish and as programme developer, consultant and evaluator to a range of agencies. The founder of Stirling Aquaculture and Stirling's well known international MSc in Aquaculture, he has also worked commercially in the salmon, seabass/bream and other sectors. Prof. Muir's background is in engineering, economics and environmental management. He has wide experience in the academic, commercial and public sectors, in development, planning, policy and programme design; education and training; project assessment, management, design and engineering; social and environmental impact assessment. His primary interests are in sustainability strategies, international food and resource policy, development research and knowledge management, and interactions between technical change, economic growth and human development.

Oriol RIBÓ

Senior Scientific Officer, Team Leader Animal Welfare, Animal Health and Animal Welfare (AHAW), European Food Safety Authority (EFSA), Parma, Italy

Oriol Ribó presented on the issue of *Animal welfare and food safety*. He holds a Veterinarian Science degree (1992) and a PhD and Master in Animal Production (1996) from the Veterinarian Faculty of the Autonomous University of Barcelona. From 1996 to 2002 he was researcher in the Institute for the Protection and Security of the Citizen (IPSC) of the Joint Research Centre (JRC- Ispra, Italy) of the European Commission, working on the traceability of animals and food products from animal origin, linked with the BSE and FMD crisis after 1996. After that he worked as consultant in the field of the traceability of animals and food products of animal origin in Italy, Switzerland and Spain (2002-2005). In November 2005, he joined the Animal Health and Welfare (AHAW) Unit of the European Food Safety Authority (EFSA) as Senior Scientific Officer, leading the Animal Welfare Team since May 2007.

Thomas RUTTER

Managing Director, Aquaculture Division, Sunderland Marine Mutual Insurance Limited, United Kingdom

Thomas Rutter gave a presentation on *Managing risk and uncertainty: insurance issues*. He has been employed for 30 years with the Sunderland Marine Mutual Insurance Company Limited; a specialist marine mutual insurer established in 1882. The Company’s Head Office is based in Durham City, England with branches in Australia, New Zealand, Canada, Holland, USA and South Africa. Thomas Rutter has been Managing Director of the Aquaculture Division since 2000, responsible for global underwriting and reinsurance. He was initially employed as a Marine Claims Executive and as an Underwriter since 1991. He has been an Executive Director of the Company since 1995. Within his ambit is the Company’s wholly owned subsidiary, Aquaculture Risk Management Limited (ARM), comprising of a survey team tasked with introducing risk management ‘Best Practice’ techniques to the company’s aquaculture members. Particular interests are in risk management, both financial but with a greater emphasis on physical risk management of losses. Specialist knowledge of aquaculture underwriting, markets and business critical risks has been developed during the 25 years in which Sunderland Marine have acted as insurers to the industry.

Oliver SCHNEIDER

Senior Scientist, Institute for Marine Resources and Ecosystem Studies (IMARES), University of Wageningen, Yerseke, The Netherlands

Dr. Oliver Schneider presented a paper on *Best practices in managing ecosystem impacts of aquaculture: managing finfish aquaculture using RAS technology*. He is senior scientist at the Institute for Marine Resources and Ecosystem Studies (IMARES), Department of Aquaculture of the University of Wageningen. He focuses his research around sustainable aquaculture production within various systems: from extensive ponds to intensive recirculation aquaculture systems (RAS). After his studies at the Institute of

Marine Research, Kiel University (Germany), he became scientific staff at Wageningen University (Netherlands) where he completed a second master in Aquaculture and his PhD. During that period he worked on RAS and its waste management. In 2006, he moved to IMARES where he is responsible for research programs and for project development and coordination. He published several papers and communications and is consultant to different governments and funding bodies. He is involved in several European projects as coordinator or steering committee member (Pro-eel, AquaMed, SustainAQ, GRRAS, Benefish, ZAFIRA). He is furthermore member of the board of directors of the Aquacultural Engineering Society (AES), the Dutch Aquaculture Society and moderator of the thematic workgroup on RAS of the European Aquaculture Society (EAS).

Christina B.G. SCHROEDER
Former WTO Senior Counsellor, Geneva, Switzerland

Christina Schroeder gave a presentation on *Do we need to differentiate farmed and captured species in trade?* She holds a PhD in International Law, International Economics and International Relations from the Graduate Institute of International Studies in Geneva as well as a Masters of Law degree from the University of Stockholm. She worked on the WTO GATT from 1972 to 2005, including as Legal Advisor and/or Secretary of numerous panels and dispute settlement procedures (*e.g.* skimmed milk powder panel; Korea beef panels; sugar and banana panels). She was the Secretary of the Meat Council from 1979-1989 and Secretary for Fisheries and Forestry Issues in Negotiating Group 3 (Natural Resource Based Products) in the Uruguay Round from 1989-1991. Furthermore, she acted as co-ordinator for dispute settlement in the Agriculture Division and as manager for fisheries, forestry and commodities. After retiring from the WTO in 2005, Christina Schroeder has taken up consultancies on fisheries issues with FAO and ACP countries.

Jonathan SHEPERD
Director General, International Fishmeal and Fish Oil Organisation (IFFO), Hertfordshire, United Kingdom

Jonathan Shepherd presented a paper on *Linkages between farmed and wild fish (complementarities and competition).* He is Director General of the International Fishmeal and Fish Oil Organisation (IFFO), which is the trade association representing producers of fishmeal and fish oil and their value chain partners worldwide. Jonathan qualified as a veterinarian and has a PhD in aquaculture economics. After an initial academic career, he started his own aquaculture consultancy firm. Thereafter he held a series of senior posts in Unilever, Peter Hand and Norsk HyGRDo connected with fish farming, pharmaceuticals and feed manufacture. Prior to joining IFFO as Director General in 2004, Jonathan was Group Managing Director of the Danish-based fish feed company, BioMar. He is married and lives in Richmond near London, UK.

Wally STEVENS
Executive Director, Global Aquaculture Alliance, St. Louis, United States

Wally Stevens gave a presentation on *Trade issues in aquaculture: the role of standards and certification* and participated in the *Panel on enhancing economic* *conditions for aquaculture*. A 40-year veteran of the seafood industry, Wally Stevens is considered one of that industry's most influential and respected leaders. An articulate and persuasive spokesperson, Mr. Stevens is frequently asked to speak on key issues affecting the global seafood industry—from seafood safety to free trade to the importance of standards for farming and processing. After his retirement from the Boston-based seafood distribution company, Slade Gorton & Company, Inc., where he was President and Chief Operating Officer, Mr. Stevens was named Executive Director of the Global Aquaculture Alliance (GAA), the leading global advocate and standards-setter for aquaculture seafood. In his role at GAA, Mr. Stevens has helped expand the global reach of GAA's Best Aquaculture Practices (BAP). One of the pioneers of US aquaculture, Mr. Stevens served as President of Ocean Products, a small salmon aquaculture company in the state of Maine. Prior to joining Ocean Products, Mr. Stevens held several management positions at the Chicago-based Booth Fisheries. Mr. Stevens has served as Chairman of the Board of the National Fisheries Institute (NFI), where he helped establish NFI's highly successful "Future Leaders" program. He also served as one of the industry's leading proponents of free trade in seafood, serving as President of the American Seafood Distributors Association (ASDA). Mr. Stevens graduated in 1962 from Plymouth State University where he currently serves as Chair of its President's Council.

Klaoudatos SPYROS

Professor, Department of Ichthyology and Aquatic Environment, School of Agriculture, University of Thessaly, Greece

Professor S. Klaoudatos prepared a country case study on *Best practices in aquaculture management and development*. He is working at the School of Agriculture of the University of Thessaly, Department of Ichthyology and Aquatic Environment. He is involved in the field of Aquaculture since 1972, as assistant researcher in the Hellenic Centre of Marine Research (HCMR). From 1988 to 1994 he was the Director of the Aquaculture Center of Acheloos (Western Greece) and from 1994 to 2002 Head of the Aquaculture Department of the Hellenic Center of Marine Research. He has performed as contributor and co-ordinator in many research projects. He has more than 100 publications in International Scientific Journals and conferences and numerous technical reports for projects held at national and international level. Since 2006 he is Chair of the Committee of Aquaculture of the General Fisheries Commission for the Mediterranean. He is an active member of scientific and steering committees, a consultant in many national and international bodies concerning the aquaculture industry and a national representative in international at hoc and regular meetings for the promotion of aquaculture and marine environmental protection.

Albert TACON

Affiliate Research Faculty, Hawaiian Institute of Marine Biology (University of Hawaii at Manoa) and Affiliate Professor of Aquaculture, University of Hawaii at Hilo, Hawaii, United States

Albert G.J. Tacon presented a paper on *Food security, climate change and aquaculture*. He earned his PhD in 1978 in aquaculture nutrition (University College, Cardiff, Wales) and his BSc in 1973 in Botany and Zoology (Westfield College, University of London, England). Dr. Tacon has over 30 years of experience in aquaculture nutrition and development activities, including 14 years with the FAO within national, regional and inter-regional aquaculture development projects. Dr. Tacon has over 42 in-country work experiences with FAO and other agencies in aquaculture development related activities, and has over 200 aquaculture development related publications. Dr. Tacon is an Affiliate Research Faculty at the Hawaiian Institute of Marine Biology (University of Hawaii at Manoa) and Affiliate Professor of Aquaculture at the University of Hawaii at Hilo. He also serves as Scientific Advisor on Aquatic Resources to the International Foundation for Science, Stockholm, Sweden (since 1998). Dr. Tacon is Editor in Chief of Reviews in Aquaculture, and also serves on the editorial board of Aquaculture Research and Aquaculture Nutrition.

Paloma Carballo TEJERO

Senior Technical Officer, Aquaculture Area Manager, General Direction of Fisheries Management, General Secretariat of the Sea, Madrid, Spain

Paloma Carballo Tejero participated in the *Panel on national policies, strategies and plans for sustainable aquaculture*. She holds a degree in Biology from the Universidad Autónoma de Madrid. She started her career as technical officer at the Spanish Institute of Oceanography before moving on to the General Secretariat of the Sea for the past 22 years. She has extensive experience in the coordination and organization of the Spanish aquaculture sector. She regularly participates in international conferences, meetings of national aquaculture organisations as well as of international fisheries governance bodies like FAO, IUCN, NASCO, EIFAC and relevant EU bodies. She also advised new member countries that have recently joined the EU on aquaculture related issues.

Yngve TORGERSEN

Deputy Director General, Ministry of Fisheries and Coastal Affairs, Oslo, Norway

Yngve Torgersen presented a paper on *Norwegian aquaculture zoning policy and the competition for marine space in aquaculture management* and participated in the final session on *Lessons for policy makers: what future for aquaculture?* He graduated from the University of Oslo with a degree in microbiology in 1989. He worked for six years at the National Veterinary Institute, Oslo, as a research scientist in the field of aquatic animal diseases and general hygiene. From 1995 to 2002 he held different positions in the Royal Norwegian Ministry of Agriculture, Department of Veterinary Services, including Head of the Ministry’s Animal Health Unit. Between 2002 and 2006 Mr. Torgersen worked in the Animal Health Unit of the European Commission in Brussels (DG SANCO). There he was “Chef de file” for aquatic animal health, and responsible for developing the new EU legislation on aquatic animal health. In 2006 he was appointed Deputy Director General in the Royal Norwegian Ministry of Fisheries and Coastal Affairs, where he currently is responsible for the Norwegian Government’s portfolio on environmental sustainability of the Norwegian aquaculture industry. Mr. Torgersen has published more than 40 scientific papers and reports, and has been giving lectures and presentations in the field of general hygiene, aquatic animal health and regulatory issues in aquaculture.

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	Mr. Éric GILBERT Director, Innovation and Sector Strategies
	Mr. Trevor SWERDFAGER Director General
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Advancing the Aquaculture Agenda

WORKSHOP PROCEEDINGS

Aquaculture now provides more than 50% of the global supply of fisheries products for direct human consumption. Given stagnating capture fisheries and a growing demand for seafood, driven by demographics and changing consumption patterns, the importance of aquaculture for food security is likely to increase.

Aquaculture production at the current level of intensity is a relatively new phenomenon. It poses economic, environmental and social challenges, which may be poorly understood or inadequately addressed within current policy frameworks, and hence the sustainability of operations may be compromised. Issues that may constrain the sector's development and performance include the management of externalities and the lack of an enabling business environment.

The OECD Committee for Fisheries acknowledges the important role of aquaculture, both in terms of economic activity and in terms of food security. In April 2010, it organised a workshop with support from the French Ministry of Food, Agriculture and Fisheries to address key policy challenges of the aquaculture sector. Policy makers, academics, industry representatives, NGOs and international organisations gathered to discuss the critical economic, environmental and social aspects of aquaculture. This publication presents a selection of key issues covered by the workshop and includes a large number of country case studies, which provide specific examples of national approaches to aquaculture management.

Related reading

Review of Fisheries in OECD Countries: Policies and Summary Statistics (2010)

Globalisation in Fisheries and Aquaculture: Opportunities and Challenges (2010)

Globalisation and Fisheries: Proceedings of an OECD-FAO Workshop (2007)

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