Workshop report

PREAMBLE

With the global human population expected to reach 9 billion by 2050, demand for food and feed will substantially increase. The manner in which food and feed production is increased to meet the demand of the world's growing population is a major challenge. Increasing production from the sea through expanded aquaculture may be a better alternative to further land development, which could involve clearing more rain forests, draining more aquifers or using more fertilizers and pesticides as agriculture spreads to marginal lands. Current overexploitation in wild fisheries means that fisheries cannot provide a solution. Expansion of land-based aquaculture and coastal aquaculture faces constraints because of an increasing lack of suitable land and water sites, a dependence on reliable supply of good quality water and, particularly in the coastal zone, the potential for conflicts with other users.

For these reasons, it is believed that the expansion of aquaculture into deeper and farther offshore marine waters is a high priority and should be facilitated through research, development and appropriate regulatory management.

Offshore mariculture offers significant potential for increasing world food production in an environmentally sustainable way. Its expansion is important to achieving the goal of world food security, providing alternatives to wild stock fisheries, and fostering economic development, particularly in coastal regions of the world.

There are potentially significant environmental, economic and food security benefits from the sustainable expansion of mariculture of finfish, shellfish and macroalgae in marine sites that are located farther offshore. However, the achievement of this potential will require, among other things, governments and developmental agencies to work together with the offshore aquaculture industry to develop policy and regulatory frameworks that enable mariculture to move farther off the coast in an environmentally sustainable way. The achievement of this goal also requires policies to facilitate appropriate technological developments.

OBJECTIVES AND APPROACH

The main objective of this technical workshop was to assess the current situation and future prospects for offshore mariculture development around the globe through eight expert reviews. The main output of this workshop was the identification of activities and intervention areas (covering technical, environmental, spatial and governance issues) to be included as components of an FAO action programme in support of offshore mariculture development. The workshop was organized in five main sessions covering technical, environmental, spatial, economics/marketing and policy/governance issues related to offshore mariculture development and focusing on the following themes:

- discussion and agreement on a working definition for offshore mariculture;
- presentation and discussion of the reviews commissioned on offshore mariculture development;
- proposal, discussion and drafting of a series of actions by FAO, coastal States/governments and the industry to address the main issues identified in support of offshore mariculture development.

DEFINITION OF OFFSHORE MARICULTURE

The term offshore mariculture is understood differently among nations and stakeholders, although it clearly refers to farming farther off the coast and in more exposed locations be it in archipelagic waters or the high seas. Nevertheless, the great diversity of coastal waters makes it difficult to define “typical” conditions and it may be challenging to distinguish a farming site that is beyond “coastal”.

To facilitate discussions at the workshop, mariculture activity was operationally classified in three categories based on site location (coastal, off the coast and offshore) and then described according to general criteria according to the distance from the coast, water depth, degree of exposure, access to the site and the operational requirements for a farm. However, even these criteria give only a preliminary idea of feasibility, the actual sites, with the prevailing conditions, should always be considered individually.

According to the criteria agreed at the workshop, mariculture is considered “offshore” when it is located > 2 km or out of sight from the coast, in water depths > 50 m, with waves heights of 5 m or more, ocean swells, variable winds and strong ocean currents, in locations that are exposed (open sea, e.g. ≥ 180° open) and where there is a requirement for remote operations, automated feeding, and where remote monitoring of operating system may be required.

WORKSHOP RECOMMENDATIONS

After initial presentations and discussions on a wide variety of topics related to offshore mariculture (see Annex 1), the workshop participants identified eight key issues (not listed in rank order) for the expansion of mariculture offshore. After identifying the issues, the workshop participants were divided into two working groups (WGs), with WG-1 focusing on technical, economic and marketing issues and WG-2 focusing on environmental, policy and governance issues. The two WGs then identified opportunities and challenges and the corresponding actions for FAO to support the development for offshore mariculture for each of the eight issues. The experts’ findings are summarized below.

WORKING GROUP 1: TECHNICAL, ECONOMIC AND MARKETING ISSUES

1. Need for enabling governance to facilitate development of aquaculture technologies

Opportunities and challenges – The global increase in fish consumption tallies with trends in food consumption in general. Per capita food consumption has been rising in the last few decades. A self-sustaining mariculture, driven by feed resources mainly taken from outside the human food chain, may increasingly contribute to food supply. Mariculture can also contribute to a reduced pressure on wild stocks. Different coastal States have widely varying plans for developing aquaculture in their coastal waters, and enabling governance can facilitate technological development, leading in time to a realization of mariculture’s full potential.

However, there is a general lack of understanding on the potential for offshore aquaculture to contribute to fish output, food security and nutrition in the coming decades. Furthermore, there appears to be a misunderstanding regarding offshore mariculture as if it were equivalent only to farming in areas beyond national jurisdiction (ABNJ), while the potential in areas of national jurisdiction has yet to be fully exploited.

Actions – FAO has a very important role to play in the process of enabling governance that may facilitate development and dissemination of technology among its Members. FAO should give a clear recommendation to Members that, because of global food security, food safety concerns and human nutrition benefits, there will probably be a need to expand mariculture to more exposed waters to increase seafood production. FAO should, in this regard, take the initiative to conduct a cost–benefit analysis of current coastal mariculture versus offshore alternatives considering both farming in the areas of national jurisdiction, where most farming will take place in the coming decades, and in ABNJ.

There is also a need to strengthen national policies and develop international principles for offshore mariculture development, and to include all main stakeholders in this process. Governments of Members should be urged to create and enable policies and regulations to support mariculture and provide other incentives for commercial development.

2. Economic and technological issues associated with a transition from coastal to offshore aquaculture

Opportunities and challenges – The current development of mariculture of species such as salmon (*Salmo salar*), seabream and seabass and experimental/pilot farming of other species such as cobia (*Rachycentron canandum*) and amberjacks (*Seriola* spp.) provides excellent and promising technological advances for moving mariculture farther offshore. However, the economic viability of offshore mariculture is a major challenge and better technologies still need to be developed. There are also concerns about the availability of capital for investments in research and development (R&D) and for the development of commercial farms. Moreover, there is no clear candidate species of finfish available that has proved both economic and physiological feasibility for offshore production and, while species of shellfish and aquatic plants are better identified, the economic viability of their production is still questionable. A transition from coastal to off-the-coast and offshore mariculture will demand the development of new or suitably adapted technologies throughout the value chain, with obvious scientific challenges. This is what is needed if global seafood supply is to be increased in a way that minimizes impacts on benthic and pelagic ecosystems as demanded by society.

Actions – Good access to information on the economics of offshore mariculture can help would-be investors and coastal States in developing economically feasible technologies for offshore mariculture, and FAO can help to provide this. FAO can also help Members by funding demonstration and pre-commercial projects including a variety of species. Member government actions are also needed to create conditions for increased investment in mariculture and to allocate funds for R&D. Governments should also encourage international cooperation and technology transfer among stakeholders.

3. Inadequacy of information on coastal States' interest and opportunities in mariculture development

Opportunities and challenges – The increasing pressure on the use of coastal zones from alternative activities such as tourism and urban development provides strong impetus for aquaculture to move off the coast. However, the interest and capacity of coastal States for developing mariculture in general, and offshore mariculture in particular, is not well known. There may indeed be more interest than generally believed, and access to accurate information on technology, markets and economic potentials may help to clarify the situation. This will require innovations in tools and methods to collect the relevant information from Members, and may contribute to global interaction in general.

Actions – FAO should collect information through surveys to gauge the interest among its Members for developing offshore mariculture. FAO should also assist its Members by identifying logistics and infrastructure that may facilitate developments, provide advice for conducting spatial analyses to estimate potential for offshore mariculture, and also for zoning and selection of sites for development.

4. Ensuring offshore aquaculture sustainability and expansion

Opportunities and challenges – As noted earlier, the growing global human population will require more food, and sustainable and scalable food production in the sea is becoming increasingly important. Aquaculture production, both inland and in coastal zones, is increasingly threatened by pollution and user conflicts, thus opening up an opportunity for offshore mariculture. One of the challenges in doing this is to develop new sources of raw materials for feed that should be, as far as possible, from a lower trophic level than is currently often the case and, preferably, not from sources that serve the existing human food chain. This is necessary if mariculture is to increase its net contribution to the human food supply and not simply to substitute fish for animal products that are now produced on land. A related challenge and benefit in doing this is to ensure that more people can take advantage of the nutritional benefits of seafood production.

Actions – The major recommendations is for FAO to provide advice and guidance to stakeholders and a forum for discussion among them on issues related to global food security, the increasing importance of the sea in future food production and the challenges related to more mariculture activity. Furthermore, FAO should review the sustainability of different food production options, especially offshore mariculture, to set the agenda in terms of research challenges to improve performance of offshore mariculture, but also to guide Members as to relative merits of offshore mariculture in relation to alternative food production options such as forest clearance for agricultural production. This requires participation by both public and private sectors and the creation of conditions that facilitate investments and technology transfer.

WORKING GROUP 2: ENVIRONMENTAL, POLICY AND GOVERNANCE ISSUES

5. The negative image of mariculture (environment and products)

Opportunities and challenges – Aquaculture, in particular mariculture, in some areas of the world has triggered environmental and social concerns, which have influenced the way the public perceives aquaculture. The image of aquaculture is frequently negative across countries and regions, and very often based on the negative impacts of very few commodity species. Moving aquaculture offshore would probably diminish many environmental and food safety risks, if properly conducted. To counteract the negative image of aquaculture, there must be more proactive rather than reactive communication with society. The aquaculture industry and its stakeholders must be more visible and be seen to be socially and environmentally responsible. Removal of negative perceptions takes time, and a paramount premise is transparency and the avoidance of environmental and food safety scandals. The ultimate challenge is to tackle this negative image by clarifying responsibilities with public and political stakeholders, and to make mariculture a prioritized activity in most coastal nations.

Actions – The aquaculture industry and relevant international organizations such as FAO must strive to improve the reputation of the industry among the general public, regulators and policy-makers. The sea will be needed to feed humanity in centuries to come, and it is paramount that this message of global food security and environmental sustainability is clearly communicated to governments by all stakeholders involved. Important aspects in this regard are environmental interactions, use of resources and marine space and food safety. It is also important to communicate that mariculture can help to reduce pressure on commercial fishing and that, by increasing the production of macroalgae as raw material for feed, it may well become a self-sustaining industry.

To improve the image of aquaculture, it is recommended that FAO, through the Committee on Fisheries (COFI) and its Sub-Committee on Aquaculture (SCA), place mariculture on its agenda. Elements of a possible strategy should include the dissemination of widely proven and recognized facts to all involved stakeholders, interaction and discussion with interest groups, be they non-govermental organizations (NGOs), associations or other stakeholder groups, and establishment of frameworks for certification of processes and products. These involve, for example, questions related to feed resources, emission of wastes, species introductions and problems of mariculture escapes.

Governments should promote the sustainable development of mariculture, giving unbiased transparent information to the public and supporting well-managed mariculture actions and actors. It is also vital to establish and fund R&D programmes and to stimulate and support the implementation of education programmes at all levels.

6. Improved understanding of negative and positive interactions between offshore mariculture and the environment

Opportunities and challenges – All food-producing activities and natural resource industries have environmental impacts, and some level of impact must be accepted for mariculture. Furthermore, the fact that aquaculture can have much less impact than other terrestrial sources of protein is a relevant opportunity for the expansion of this sector. It is also important to recognize that mariculture is affected by environmental degradation of coastal and open ocean waters, for example by toxic pollution, which can harm aquatic animals and lead to concerns about food safety. There is generally a poor understanding in society that it is the aquaculture industry itself that becomes the primary victim of environmental degradation. Expansion of mariculture to open waters may reduce this vulnerability because of the greater capacity of such waters to dilute pollutants. For example, the pollution from other sources (including the spreading of disease) becomes less and the impact of aquaculture is more effectively mitigated by natural processes in the benthic and pelagic offshore ecosystems.

There is a general lack of environmental data for potential offshore mariculture locations and of resources for research to provide them, and yet they are essential if offshore mariculture is to be able to validate its promise. This is especially the case in many developing countries, and, therefore, the development and implementation of education and training programmes that can increase the human capacity to undertake environmental assessments is important in all of them.

Actions – FAO must play an active role to inform Members and society in general that mariculture depends on a clean and unpolluted environment, which means, in turn, that a sustainable mariculture industry itself must be environmentally responsible. This calls for action to build awareness of the “two-way” environmental interactions in mariculture.

It is important to develop methods and indicators for estimating carrying capacity of open marine ecosystems, to identify limiting factors and to contribute to establishing guidelines for best environmental practices. Due to the general gap in data from offshore locations, it is important to gather together what data there are and to draw on relevant experience from coastal mariculture. Governments must adopt and implement an ecosystem approach to aquaculture governance and allocate funds to establish the knowledge and build the competence needed to implement it. FAO should strive to promote global sharing of knowledge and experiences gained about the responsible development and management of offshore mariculture among Members.

7. Limited guidance for development of offshore mariculture

Opportunities and challenges – Although there are some useful experiences in culturing finfish, shellfish and macroalgae in exposed off-the-coast and offshore waters in some countries, there is still very little offshore mariculture undertaken anywhere in the world. Therefore, systematic expansion of offshore mariculture around the world still presents many challenges. These include engineering of systems to be able to withstand and be operable in exposed waters, and the identification of suitable areas and species, especially finfish species, that can thrive in offshore conditions and meet consumers' demands for quality and value. These challenges will be particularly large in developing countries.

Actions – Gathering experience and sharing of knowledge is paramount to finding solutions for these challenges, and FAO can play an active part in these processes. Activities may include regional workshops, initiatives in capacity building and provision of guidelines for best practices in offshore mariculture. FAO must also inform and motivate Members to take part in the development of offshore mariculture. A major source of motivation is the importance that mariculture can have for future global food security. Governments need to develop national strategies and work together with FAO on this important issue, and to provide the resources needed to do it. In turn, it is important for the mariculture industry to participate from the very beginning, and to be encouraged to farm shellfish and marine plants by incentives that recognize the environmental benefits of doing so.

8. Enabling policy and regulatory frameworks for offshore mariculture

Opportunities and challenges – Mariculture has relatively limited space for development in most of the world's coastal waters; therefore, there is a growing interest in moving mariculture farther offshore where there is vast potential, fewer competing uses, and space availability is not an issue. Expansion of the mariculture industry can help to meet the growing demands for seafood that cannot be met by fisheries alone. However, at present, there is a general absence of effective governance and regulatory structures to allow for offshore mariculture development, although many countries have suitable locations for offshore mariculture in their national waters. Policy and law-making are sovereign acts, and it may be a challenge in many countries to convince policy-makers of the importance of developing mariculture offshore and to support it, especially in those countries that lack the human and financial capacities for monitoring, control and enforcement.

Actions – FAO should encourage governments to prioritize mariculture as an important food production sector and to create the policies and laws needed to make it happen. Coastal States must take responsibility for leasing space for and monitoring and enforcement of mariculture activities as well as providing incentives for education, research and technology transfer. In addition, there should be incentives to industry for investment in offshore mariculture, including financing, insurance and creation of secure property rights. The industry should be involved in the creation of policy and laws to encourage private development. FAO should also facilitate the establishment of governance instruments needed to enable offshore mariculture development, and ensure that governance becomes ecosystem-based while complying with laws of the sea.

STEPS FOR BROADER ACTIONS

It is clear that production of more food from the sea is needed to feed humanity in the future, so it is of paramount importance to inform governments and all stakeholders about the potential value of off-the-coast and offshore mariculture to address this need. In the same vein, it is also important that they recognize that the expansion of mariculture worldwide will be challenging and, if it is to supplement food from agriculture in a significant way, production must increasingly come from the lowest trophic levels, i.e. filter feeders, aquatic plants and plankton, or through their utilization as feed components for fed aquaculture species. Furthermore, feed sources for fed mariculture must be sustainable and preferably come from the lowest marine trophic level. Specific actions recommended by the workshop participants are as follows:

FAO actions

1. The FAO Committee on Fisheries (COFI) and the COFI Sub-Committee on Aquaculture (SCA) must place mariculture on their agendas.
2. There is a need to expand mariculture offshore to increase seafood production, and FAO must inform and encourage Members to take part in its development. A major motivating factor is the vital role that mariculture will have in addressing global food security in the future. This situation is little understood and recognized in society today, especially in developed countries.
3. FAO should provide a forum through which the potential importance of the sea in future food production can be communicated to the public and specific groups of stakeholders.
4. FAO must guide and support Membes and industry in the development needed to expand mariculture to offshore locations, including the provision of the following services:
    - spatial analyses studies to estimate the potential for sustainable offshore mariculture development, including zoning and site selection;
    - development of funding mechanisms for pre-commercial projects and demonstrations farms;
    - cost–benefit analysis of current coastal mariculture versus the open ocean alternatives;
    - gathering of relevant experience and sharing of knowledge to support the engineering and environmental innovations needed;
    - production of technical publications and other information to support commercial development;
    - provision of technical guidelines for best practices of offshore mariculture;
    - organization of regional offshore mariculture workshops, initiatives for capacity building, and creation of databases to share data and information.
5. Expanding mariculture to offshore locations has major technical and biological challenges. FAO must encourage Members to undertake and guide the research and development that is needed. Available knowledge and expertise from current exposed mariculture activities can be of immense value, especially for those countries that are starting offshore mariculture.
6. FAO must advise governments to consider, whenever technically possible, establishing environmental incentives for integrated multitrophic aquaculture (IMTA) to combine the cultivation of fed aquaculture species (e.g. finfish) with organic extractive aquaculture species (e.g. shellfish / herbivorous fish) and inorganic extractive aquaculture species (e.g. seaweed) to create balanced systems for environmental sustainability (biomitigation), economic stability (product diversification and risk reduction) and social acceptability (better management practices).

7. The real and perceived environmental impacts of mariculture are a major concern to society. FAO must communicate that mariculture depends on a healthy and unpolluted environment and should lead a process to improve the negative image of mariculture in society. Appropriate means for communicating this message are:
   - dissemination of facts to FAO Members, society, and to active groups of involved stakeholders;
   - interaction and discussion with active interest groups;
   - communication of challenges related to the provision of sustainable feed resources, waste emissions, species introductions and problems of escapes;
   - communication of the benefits of mariculture, including the comparative trophic efficiency of aquatic animals and the environmental services that extractive aquaculture can provide.
8. FAO should involve all main stakeholders in developing methods and indicators for estimation of the carrying capacity of different bodies of water and establish guidelines for best environmental practices in open ocean ecosystems that include protocols for food safety and biosecuirity.
9. Governance of mariculture must become ecosystem-based while complying with national and international laws of the sea. FAO should initiate a process to establish international principles and governance instruments needed for undertaking offshore aquaculture in international waters when and if this may take place, although it is recognized that many countries have suitable locations for offshore mariculture in their national waters.

Actions of coastal States/governments

1. Before any progress can be made, governments must be convinced to prioritize mariculture as an important food sector and develop national strategies together with FAO if the organization can be of help. Prioritizing mariculture has to be justified by assessments showing favourable potential. This is needed before moving into more comprehensive policy- and law-making to create and enable policies and regulation regimes to support mariculture.
2. The environment for investment in mariculture, including financing, insurance and creation of property rights in marine waters, must be met by appropriate incentives. Government must create conditions for increased investment in mariculture, and stimulate international cooperation and technology transfer among the stakeholders, i.e.:
   - provide incentives to enable and stimulate domestic and foreign investments in offshore mariculture;
   - direct support to well-managed offshore mariculture activities, including the culturing of shellfish and plants offshore;
   - contribute together with FAO to give unbiased transparent information to society;
   - facilitate technology transfer among producers and supporting industries.
3. Expanding mariculture to offshore locations will require major national and international research, development and innovation efforts, and governments must plan and implement research programmes covering the main challenges in engineering, natural science and social science, i.e.:
   - promote the entire mariculture industry as a cluster for active research;
   - private commercial actors should be encouraged to contribute to the funding;
   - stimulate and support the implementation of education programmes at all levels;
   - support technology transfer.

Actions of the industry

1. The industry must drive the process of expanding mariculture from the very beginning, and should be involved in all aspects of policy-and law-making as far as possible to facilitate the development of sustainable offshore mariculture.
2. The industry must build awareness of both the beneficial and adverse environmental interactions of mariculture while more actively disseminating their activities to society.

Annex 1 – Expanding mariculture farther offshore

A synthesis of the technical, environmental, spatial and governance issues and opportunities

This document provides a synthesis of the main information used as background for the workshop, including the technical papers and case studies presented during the event, as well as relevant points of discussion and technical recommendations from the workshop. This paper was prepared with inputs from the experts that attended the workshop.[1]

1. PROSPECTS FOR MARICULTURE

Aquaculture has been the fastest-growing animal food producing sector in the world for many years. Mariculture, in 2010, made up 30 percent of the global aquaculture production excluding aquatic plants, with 18.1 million tonnes and a value of USD34.4 billion. Mariculture production compares with 77.4 million tonnes harvested by the world's capture fisheries in the same year. The rate of increase in global mariculture production exhibited a pronounced increase as the harvest from fisheries levelled off in the early 1990s. The combined global food harvest from mariculture and fisheries was estimated at 128.3 million tonnes in 2010 (FAO, 2012a), of which, however, 20.2 million tonnes of capture products were destined to non-food uses including fishmeal and fish oil production. This represented an apparent per capita consumption of about 5 g of protein per day, accounting for about 16.6 percent of animal protein and 6.5 percent of total protein consumption in 2009 (FAO, 2012b). In addition, mariculture produced 19 million tonnes of aquatic plants with an estimated value of USD 5.7 billion, accounting for 96 percent of global production including capture fisheries. The majority of aquaculture activities currently take place in developing countries, where aquaculture traditionally has been undertaken in freshwater. However, mariculture is currently increasing, and there is a strong interest in expanding further in several of these countries and in other countries where aquaculture is a relatively new food production sector.

Numerous publications have questioned the ability of humans to feed the world's growing population with nutritious food in the centuries to come, and some have pointed to the opportunity for more effective use of the oceans for producing food through mariculture (Marra, 2005; FAO, 2006; Duarte *et al.,* 2009). The oceans cover some 70 percent of the Earth's surface, and their primary production, mainly undertaken by microscopic phytoplankton, is comparable with that of the terrestrial ecosystem (Field *et al.,* 1998). However, remarkably little food is derived from the oceans, and it could thus be questioned if these immense marine areas can effectively be exploited to help feed humanity in the future (Duarte *et al.,* 2009). Other documents have underscored the technological, environmental and legal challenges and constraints for mariculture development (Diana, 2009). With the uncertain perspectives of global agriculture developments in mind (Miller, 2008) – increasingly driven by environmental concerns – the further exploration of the world oceans to provide food is a discussion item on many international development agendas. The need for such dialogue is further

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[1] This document was prepared with the technical assistance and inputs of Yngvar Olsen (Norwegian University of Science and Technology, Norway).

reinforced in view of the uneven availability and potentially limiting freshwater supply for plant and animal production (CAWMA, 2007). This is further exacerbated by the envisaged effects of climate changes and population growth. Most likely, the further growth in freshwater aquaculture may largely depend on the intensification of pond production, among others, and through the adequate reuse of water. In view of the limitations in freshwater supplies in many regions of the world, Duarte *et al.* (2009) suggest that a self-sustaining mariculture industry could possibly provide a significant proportion of the needed animal protein in the future.

The majority of global mariculture production is undertaken in coastal locations, generally sheltered and characterized by relatively low hydrodynamic energy, shallow waters and proximity to coastal supporting infrastructure. The expansion of mariculture to more exposed waters off the coast is more challenging from a technological, environmental and spatial viewpoint, as well as from a legal aspect. In general, the greater the distance offshore that a mariculture activity is located, in deeper waters and in areas with an increased degree to weather exposure, the higher the degree of technology complexity that will be required, along with greater capital investments. Furthermore, operating costs may also increase.

The increasing pressure on the use of coastal zones from alternative activities such as tourism and urban development provides strong impetus to move mariculture activities of finfish, molluscs and macroalgae into offshore waters. In many countries with well-developed mariculture industries, there is often a growing concern about the capacity of the environment to assimilate wastes in coastal waters, as well as on issues such as disease outbreak and transfer and farmed fish escapees, which may negatively interact with wild fauna and coastal ecosystems as a whole (Tacon and Halwart, 2007). There is also an increasing level of interaction between mariculture operations and other users of coastal waters, at times leading to severe conflicts among key stakeholders. Furthermore, well-organized non-governmental organizations (NGO) have also been successful in influencing public opinion against the proliferation of mariculture activities in coastal waters in many parts of the world, calling for the moving of production farther off the coast.

2. OFF-THE-COAST AND OFFSHORE MARICULTURE: OPERATIONAL DEFINITIONS AND SOME GOVERNANCE IMPLICATIONS

2.1 Criteria for the definition of "off the coast"

The physical diversity of coastal waters, including their topography, hydrodynamic energy exposure and water depths, makes it difficult to define the conditions typical of offshore aquaculture and attempts to do this must be seen as an operational approach rather than an absolute. To facilitate the discussion and move forwards in addressing relevant offshore mariculture issues, the workshop experts proposed a general "operational criteria" for defining mariculture activities. These are grouped in three broad categories, based on the distance from the coast and water depths, thus underlining the degree of exposure, but also according to fish-farm operational requirements and accessibility (Table 1).

According to these criteria, off-the-coast mariculture differs from coastal mariculture primarily by the distance to the coast and the degree of exposure. Coastal mariculture is undertaken in shallow (<10 m) and usually sheltered waters typically <0.5 km from the coast. Off-the-coast mariculture takes place 0.5–3 km from the coast in water depths between 10 and 50 m. The sites can be partly sheltered, but currents are stronger, and wind and wave affect installations more severely than at coastal mariculture sites. Offshore mariculture production is located in areas >2 km, or out of sight, from the coast in water depths >50 m and under the influence of powerful hydrodynamic energy, i.e. waves, ocean swells, ocean currents and strong winds. The term "open ocean" mariculture can include both off-the-coast and offshore mariculture.

TABLE 1

General criteria for defining coastal, off-the-coast and offshore mariculture

Parameters	Coastal mariculture	Off the coast mariculture	Offshore mariculture
Location/ hydrography	· <500 m from the coast · <10 m depth at low tide · within sight · usually sheltered	· 500 m to 3 km from the coast · 10–50 m depth at low tide · often within sight · somewhat sheltered	· >2 km generally within continental shelf zones, possibly open ocean · >50 m depth
Environment	· Hs[1] usually <1 m · short-period winds · localized coastal currents · possibly strong tidal streams	· Hs <3–4 m · localized coastal currents · some tidal streams	· Hs 5 m or more, regularly 2–3 m · oceanic swells · variable wind periods · possibly less localized current effect
Access	· 100 % accessible · landing possible at all times	· >90 % accessible on at least once daily basis · landing usually possible	· usually >80 % accessible · landing may be possible, periodic, e.g. every 3–10 days
Operation	· manual involvement, feeding, monitoring and more	· some automated operations, e.g. feeding, monitoring and more	· remote operations, automated feeding, distance monitoring, system function
Exposure	· sheltered	· partly exposed (e.g. >90° exposed)	· exposed (e.g. >180°)

[1] Hs = significant wave height, a standard oceanographic term, approximately equal to the average of the highest one-third of the waves.

Source: Modified from Muir (2004).

There is a general belief that off the coast and particularly offshore mariculture facilities will require a higher degree of automation and remote control in their operations. Accessibility will depend on weather and waves, but will also depend on the scale and technological level of the farms. Large and advanced offshore mariculture farms in the future may be accessible at all time regardless of weather conditions. It may also happen that staff will live aboard in the control unit of the farms most of the time, as on offshore oil platforms.

The "distance from the coast" criteria can be problematic, however, as it can be understood differently in different circumstances. If "coast" is defined in legal terms as the baseline of the coast, which can be a line connecting fringing islands of the outer archipelago, it follows that coastal mariculture taking place in internal waters (legally defined as inside the baseline; see Figure 1) can be quite exposed (significant wave height [Hs] of up to 3–4 m). Depending on the contour of the baseline, aquaculture activities that take place in internal waters may even be considered as off the coast activities according to the criteria set out in Table 1, if the baseline is set farther away from the coast owing to the presence of distant islands within the sovereign State. This situation is quite typical for the majority of the production locations of Atlantic salmon in northern Europe and in the Chilean fjords. On the other hand, in some other locations, for example along the Mediterranean coast of Spain and Turkey, fish farms can be more than 180° exposed while the distance to the land and water depth can be less than 2 km and 50 m, respectively. In these sites, mariculture has been undertaken for more than 15 years using regular high density polyethylene (HDPE) fish cages. This is certainly a special case as the Mediterranean Sea, a so-called marginal sea, is less influenced by extreme winds. There are other similar situations where mariculture is practised in open bays such as in Sungo Bay (Yellow Sea) off the coast of eastern China, where waters may remain relatively calm even as far out as 5 km or more from the shore owing to the prevailing winds and the orientation of the bay itself with respect to the open sea.

The use of the criteria in Table 1 calls for a careful approach because the term "offshore" can be understood differently and because offshore mariculture locations, according to the above criteria, can be found in internal waters in some countries with extensive archipelagos, as well as on the border of international waters in other countries, and it definitively includes areas beyond national jurisdiction (ABNJ). These criteria can only provide a preliminary idea of the farming conditions and location.

Each farming site, with its prevailing physical and environmental conditions, should always be considered independently.

The basic production principles and technologies for off-the-coast and offshore mariculture remain, however, similar to those of modern coastal mariculture in terms of gear used (e.g. cages), use of dry feeds and selection of the farmed species. The choice of offshore farming sites may, on the other hand, be motivated by different economic drivers. Also, it may be anticipated that there will be a need for more automation and use of more sophisticated and remote-controlled feeding and monitoring systems, as well as the choice of species well suited for offshore mariculture conditions. The farming scale will probably be larger for offshore operations than that in coastal sites, possibly dictated by economic and operational reasons. It may also be speculated that the annual production for an offshore finfish farm could probably be higher than the largest off-the-coast salmon farms of today (e.g. 10 000 tonnes or 2.5 million 4 kg fish per year).

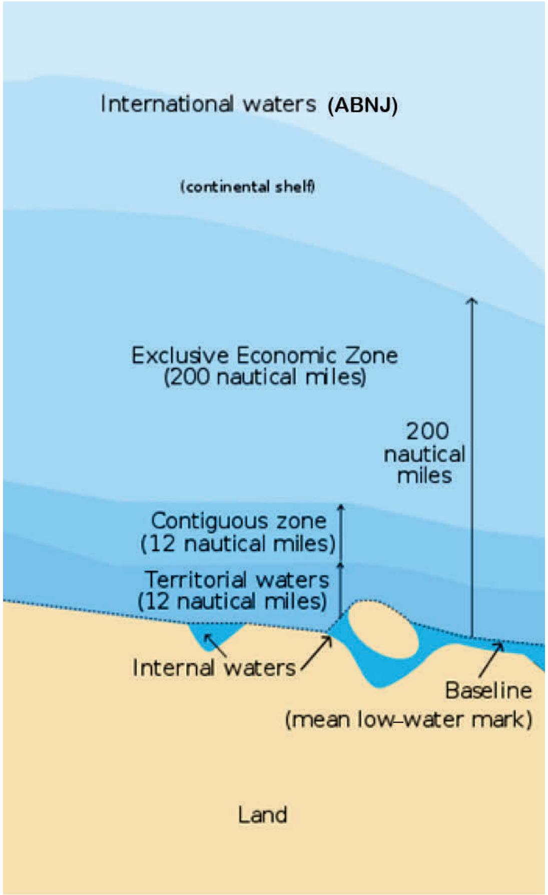
2.2 Some governance implications

Because of the variable coastal topographies, wind exposure and hydrodynamics of coastal countries, there is no unique relationship between the legal grouping of national and international waters of the proposed criteria defined in Table 1. The coastal States have, with few exceptions, the full sovereignty to regulate mariculture activities in internal and territorial waters, extending 12 nautical miles (22 km) from the baseline of the coast. Furthermore, coastal States are also admitted other privileges and responsibilities for utilizing and governing resources within the exclusive economic zone (EEZ) extending to 200 nautical miles (370 km), but there is a legal vacuum regulating mariculture operations in the high seas or ABNJ, leading to a series of potential issues that could arise from such activity. On the other hand, coastal States are obliged to enforce national regulations over any offshore mariculture project at any location in ABNJ conducted by one of their citizens, but not against non-nationals. At the same time, according to the United Nations Convention on the Law of the Sea (UNCLOS), a State is in no position to grant any type of tenure to any portion of the high seas (or ABNJ), provide for the exclusive possession of a farm site, or even grant an effective authority for the use of a particular site.

In contrast to fisheries, there is no specialized body of international law dealing with mariculture. Mariculture is only incidentally affected by aspects of international law that were designed to deal with other issues. Mariculture can be affected by a number of provisions of general international law, such as the developing regime for the protection of the marine environment (Long, 2007) and by treaties. Many treaties create general obligations that can have an impact on state management over mariculture operations, e.g. the 1982 UNCLOS, which requires States to prevent, reduce or control pollution of the marine environment from a number of specified land-based sources (Percy, Hishamunda and Kuemlangan, 2013). Furthermore, many treaties, particularly those that deal with fisheries or the marine environment, can have repercussions on the development of mariculture activities. For example, the Convention for the Protection of the Marine Environment in the North-East Atlantic (OSPAR Convention) has a number of initiatives designed to minimize the impact of mariculture on the marine environment (Long, 2007). Also the 1992 Convention on Biological Diversity (CBD) has potential implications for mariculture (Wilson, 2004) together with codes of practice, whether voluntary or not, such as the FAO Code of Conduct for Responsible Fisheries (the Code) (FAO, 1995).

International law deals with marine activities by placing geographical areas of the sea into a number of categories ranging from internal waters to the territorial sea to the EEZ and, ultimately, to the high seas or ABNJ (Figure 1). Territorial waters and the contiguous zone are included in the EEZ. The coastal State can exercise essentially

FIGURE 1
Generalized sea areas and jurisdiction in international rights



The **baseline** is the low-water line along the coast officially recognized by the coastal State. Straight baselines can alternatively be defined connecting fringing islands along a coast, across the mouths of rivers, or with certain restrictions across the mouths of bays.

Intemal waters are defined as waters landward of the baseline, over which the State has complete jurisdiction; not even innocent passage is allowed. Lakes, rivers and archipelagic waters within the outermost islands are considered internal waters.

A State's **territorial sea** extends up to 12 nautical miles (22 km) from its baseline. The State has sovereignty over its territorial sea, but ships from all nations have the right of friendly passage.

The **contiguous zone** is a band of water extending from the outer edge of the territorial sea to up to 24 nautical miles (44 km) from the baseline, within which a State can exert limited control as in the territorial sea.

An **exclusive economic zone** (EEZ) extends from the outer limit of the territorial sea to a maximum of 200 nautical miles (370.4 km) from the territorial sea baseline, thus it includes the contiguous zone. A coastal State has control of all economic ressources within its EEZ.

The **international waters (or high seas; ABNJ)** are oceans, seas and waters outside of national jurisdiction.

Source: Modified from UNCLOS (1982).

the same rights of sovereignty over its internal waters as it does over land, and this includes mariculture activity. The same appears to apply also for the territorial sea, but some international obligations are involved, including the right to passage by ships. Restrictions on mariculture activities in territorial waters are imposed when these threaten commercial navigation. The coastal State is entitled to legislate in order to protect facilities and installations, including mariculture installations, within the territorial sea, but it must give due publicity to its laws and regulations (1982 UNCLOS, Art.21[4]). International law does not impose other general restrictions on how the coastal State manages mariculture within the territorial sea.

The sovereign rights to manage natural resources undoubtedly allow coastal States to establish, protect, regulate and manage mariculture operations in the EEZ. The international interest in the EEZ has, however, placed additional obligations on those rights where the conduct of the State might affect the EEZ of neighbouring States or international waters/ABNJ. Those obligations take two principal forms that deal with pollution control and the management of straddling and highly migratory fish stocks. The sovereign rights of the coastal State within the EEZ are accordingly limited where they have an impact on highly migratory fish stocks (Articles 63 and 64 of the UNCLOS). These articles gave rise to an agreement commonly known as the Fish Stocks Agreement (1995) (U.N. Doc. A/CONF.164/37). It has commanded a high degree of support and places several obligations on the parties that can have an impact on the conduct of mariculture activities within the EEZ. It addresses a number of issues that are often controversial in the management of mariculture, including minimizing waste discards, impacts on fish stocks, and protection of biodiversity in the marine environment.

Article 56 [1][b][iii] of the 1982 UNCLOS treaty states that, within the EEZ, coastal States have jurisdiction with regard to the protection and preservation of the marine environment. Even for principles that are not legally binding, such as the principle on sustainable development and the precautionary approach as dictated in the Rio Declaration, they place a constraint on coastal States when exercising their sovereign rights under Article 56. States can permit mariculture activities, but in a manner that ensures sustainability (Percy, Hishamunda and Kuemlangan, 2013).

The potential for offshore mariculture activities to do significant harm to the ABNJ environment remains a key question and an important issue of discussion. At present, there is very little scientific documentation and evidence on adverse environmental impacts on pelagic communities and/or benthic ecosystems from offshore mariculture activities. However, as an increasing number of farming activities move farther offshore, in deeper and more exposed waters, more information is being gathered on the impacts, allowing a better understanding of the interaction of farming structures and operations and the environment as a whole (Holmer, 2013; Angel and Edelist, 2013).

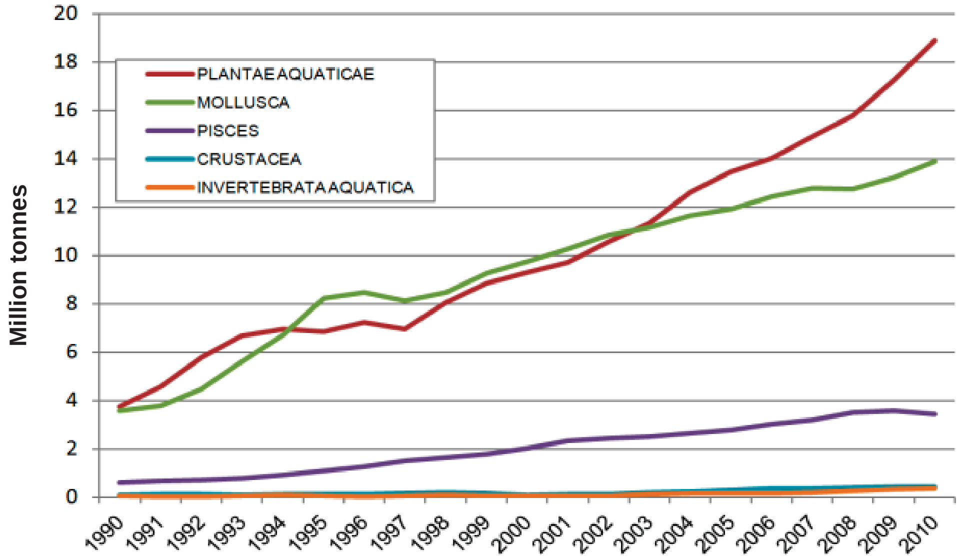
Nevertheless there is a large, unrealized potential for offshore mariculture within EEZs (Kapetsky, Aguilar-Manjarrez and Jenness, 2013), and, most probably, in the coming decades, aquaculture will grow mainly in such areas.

3. STATUS OF GLOBAL MARICULTURE PRODUCTION

3.1 Production and value

Global marine aquaculture production trends for the main species groups show a rapid and steady increase for marine plants (macroalgae) and molluscs in recent decades, whereas finfish and crustaceans exhibit a somewhat slower, although steady, rate of increase (Figure 2). Macroalgae, in particular, are the fastest growing product category over the past decade. Except for crustaceans, which are produced in coastal and inland ponds, the majority of production is undertaken at sea, and the species farmed are candidates for offshore mariculture.

FIGURE 2
Trends in marine aquaculture production, 1990–2010



Source: Global dataset of aquaculture production (quantity and value) 1950–2010. Fisheries and Aquaculture Statistics and Information Service, FAO (extracted August 2012).

TABLE 2
Production and value of the main marine aquaculture products in 2010

Species groups	Total production (tonnes)	Production (%)	Value ('000 US$)	Value (%)	US$/kg
Macroalgae	18 904 903	46	5 602 095	14	0.30
Molluscs	13 881 384	38	13 948 008	35	1.00
Crustaceans	442 467	1	1 969 966	5	4.45
Finfish	3 427 418	9	17 427 942	44	5.08
Others	385 005	1	1 010 535	2	2.62
Total	**37 041 176**	**100**	**54 803 761**	**100**	**1.08**

Source: Global dataset of aquaculture production (quantity and value) 1950–2010. Fisheries and Aquaculture Statistics and Information Service, FAO (extracted August 2012).

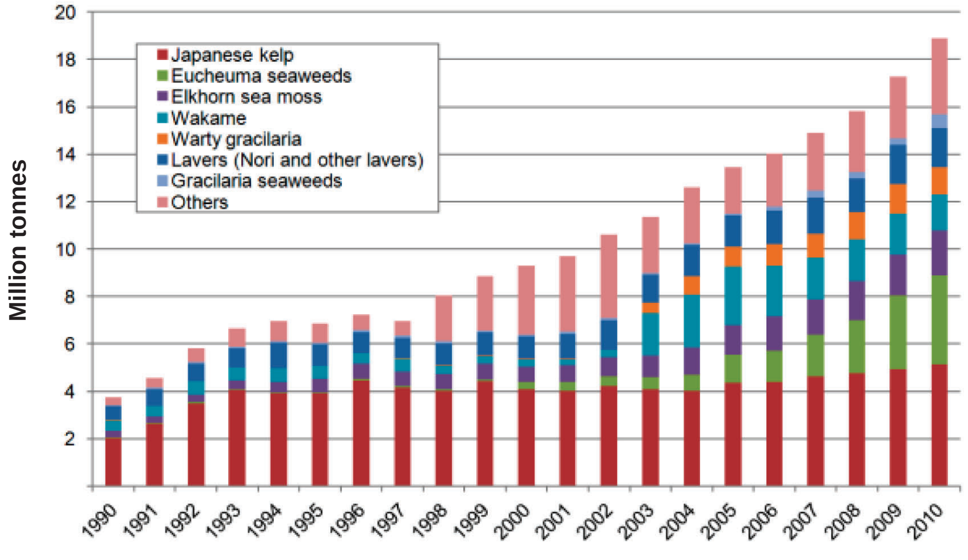
Table 2 summarizes global marine culture production for 2010 by main species groups. It shows that most production by weight (84 percent) consisted of macroalgae and molluscs, and that finfish and crustaceans had the highest unit values (79 percent).

3.2 Production of dominant marine aquaculture species

The main species groups are dominated by a few species. Japanese kelp (*Saccharina japonica*) is dominant among the macroalgae and made up 27 percent of the plants that were farmed in 2010 (Figure 3). The total production of macroalgae has increased from 2003 to 2010, and a number of subdominant species are now also being produced in quantities of more than 1 million tonnes, as reported in 2010.

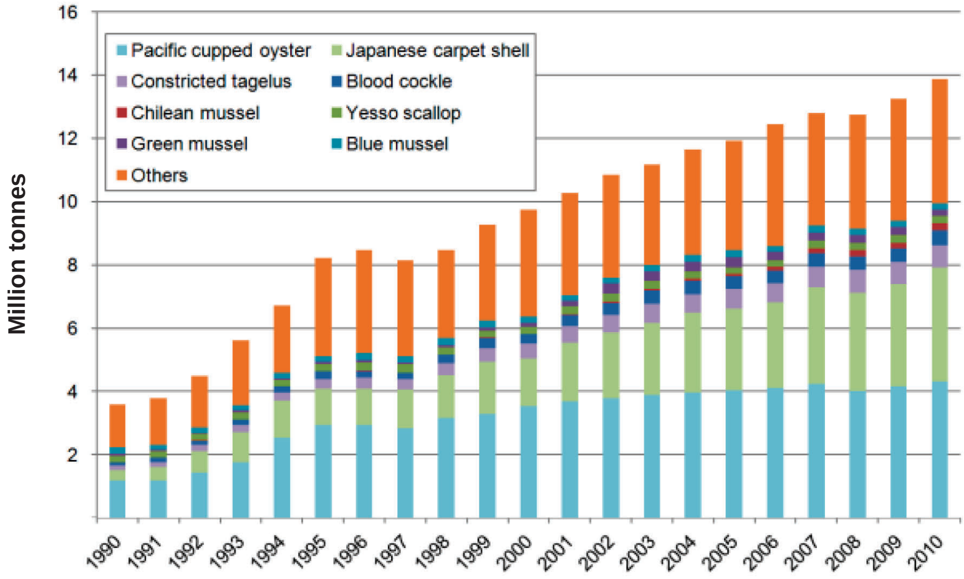
The Pacific cupped oyster (*Crassostrea gigas*) and the Japanese carpet shell (*Ruditapes philippinarum*) were the two main mollusc species produced by marine aquaculture in 2010, accounting for 31 and 26 percent of farmed molluscs, respectively (Figure 4). Several other mollusc species were produced in quantities of more than 100 000 tonnes in 2010 and have exhibited a steady increase in production in the past two decades. In particular, the production of constricted tagelus (*Sinonovacula constricta*) has expanded rapidly since 1990. As regards farmed crustaceans, white leg shrimp (*Litopenaeus vannamei*) was the dominant cultured shrimp species in marine aquaculture, accounting for 78 percent of farmed crustaceans in 2010 (Figure 5). Swimming crabs (*Portunidae*) accounted about 21 percent of farmed crustaceans. Production of other crustacean

FIGURE 3
Top farmed marine plants in marine aquaculture



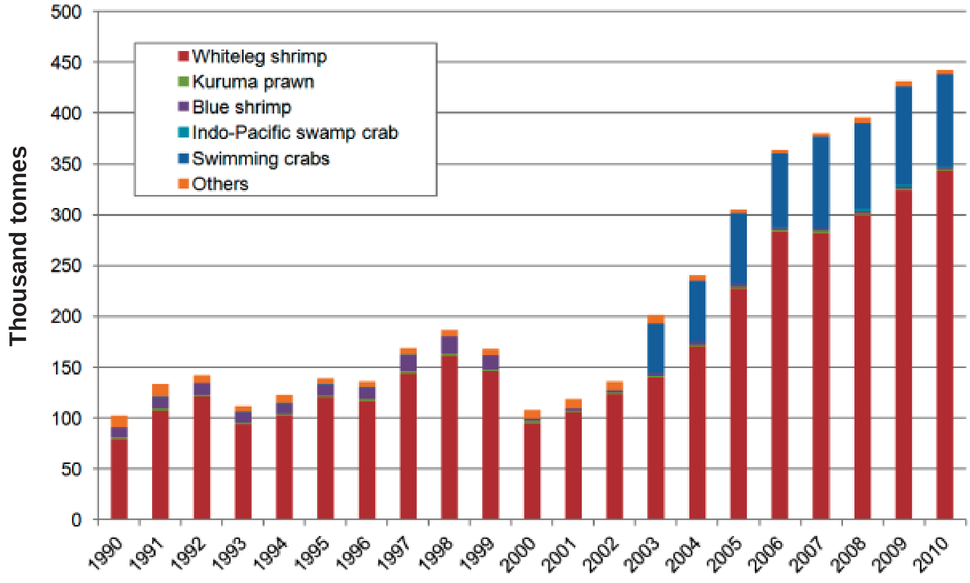
Source: Global dataset of aquaculture production (quantity and value) 1950–2010. Fisheries and Aquaculture Statistics and Information Service, FAO (extracted August 2012).

FIGURE 4
Top farmed molluscs in marine aquaculture



Source: Global dataset of aquaculture production (quantity and value) 1950–2010. Fisheries and Aquaculture Statistics and Information Service, FAO (extracted August 2012).

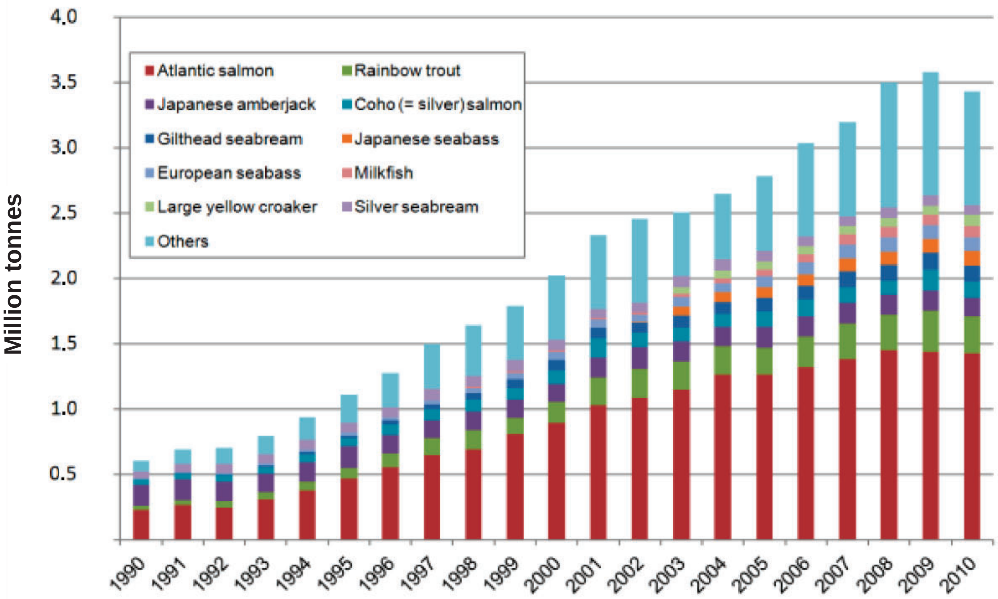
FIGURE 5
Top farmed crustaceans in marine aquaculture



Source: Global dataset of aquaculture production (quantity and value) 1950–2010. Fisheries and Aquaculture Statistics and Information Service, FAO (extracted August 2012).

species, mostly prawns and spiny lobsters, was quite limited in quantity. Atlantic salmon (*Salmo salar*) made up 41 percent of the finfish farmed in marine aquaculture in 2010 (Figures 6) followed by rainbow trout (*Oncorhynchus mykiss*), accounting for 8 percent. While the production in quantities was limited, some finfish species, including several groupers, reached a high unit value.

FIGURE 6
Top farmed finfish in marine aquaculture



Source: Global dataset of aquaculture production (quantity and value) 1950–2010. Fisheries and Aquaculture Statistics and Information Service, FAO (extracted August 2012).

3.3 Candidate species for offshore mariculture

The primary drivers of species success in aquaculture are biological and behavioural adaptability to farm conditions, and the market attributes of the final product, including:

- they have many human health benefits and/or they have value as a food ingredient, and for the extraction of desired substances;
- they are demanded in the market and adequately priced compared with their production costs;
- they have high tolerance for farming conditions, including handling and crowding, ready acceptance of artificial feeds (for fed species) and perhaps also have natural resistance to parasites and disease;
- they have readily available seed stock, either from hatcheries or natural settlements;
- they exhibit fast or relatively fast growth;
- they have the adaptability to be farmed outside, as well as within their native range;
- they have been, in some cases, genetically improved by selective breeding, extending their advantages even further over new candidate species;
- they have edible meat yields that allow the production of economically attractive value-added products.

Evidence so far shows that only a few of the species that are presently farmed have the characteristics required to become a major farmed species. If, for example, "major" is defined as exceeding 1 million tonnes per year of production, only one farmed finfish species meets this definition, namely, Atlantic salmon, which completely dominates the finfish product category (Table 3). There are four major seaweed species, with Japanese kelp dominant, one major mollusc species, Japanese carpet shell and one major crustacean species, white leg shrimp.

TABLE 3

Production and value of the major species in marine aquaculture reported in 2010

Common name	Scientific name	Production (tonnes)	Production[1] (%)	Value[1] (US$)	Value (%)
Marine plants					
Japanese kelp	*Saccharina japonica*	5 146 883	27	300 868	5
Wakame	*Undaria pinnatifida*	1 537 339	8	666 865	12
Warty *Gracilaria*	*Gracilaria verrucosa*	1 152 108	6	342 092	6
Laver (Nori)	*Porphyra tenera*	564 234	3	1 095 015	20
Molluscs					
Japanese carpet shell	*Ruditapes philippinarum*	3 604 247	26	3 353 640	24
Pacific oyster	*Crassostrea gigas*	4 305 342	31	3 411 877	31
Shrimp					
White leg shrimp	*Penaeus vannamei*	343 206	78	1 499 100	76
Finfish					
Atlantic salmon	*Salmo salar*	1 422 715	42	7 792 644	45
Rainbow trout	*Oncorhynchus mykiss*	287 319	8	1 835 892	11
Japanese amberjack	*Seriola quinqueradiata*	139 077	4	1 187 923	7

[1] Production (%) and Value (%) indicate the proportion of each species representing in the total production of individual taxonomic group in 2010.

Source: Global dataset of aquaculture production (quantity and value) 1950–2010. Fisheries and Aquaculture Statistics and Information Service, FAO (extracted August 2012).

Most species that are suited for coastal mariculture will probably be suitable also for off-the-coast mariculture, whereas it is likely that a smaller group of species will be best suited for offshore mariculture. Crustaceans, or shrimps (which dominate that group), are mostly grown in coastal ponds in the tropics and are not commonly reared in sea-based aquaculture, be it in coastal mariculture, off the coast or offshore mariculture.

The economic interest of offshore mariculture is today primarily related to finfish, but only one species among the “million tonne/year” is a finfish species (see Table 3). Atlantic salmon technology for cage farming is highly developed and economically feasible, but the commercially strong and well-developed salmon companies have so far not led the process of moving production to offshore mariculture locations. There is some doubt about the biological suitability of on-growing salmon in very dynamic offshore waters, and the availability of protected and semi-protected locations has been sufficient to meet production needs up until now. Off-the-coast locations have, however, for a long time been used for on-growing of salmon, and there is recently an emerging trend of moving salmon farms to more exposed production locations, at least in some regions owing increasing environmental pressure on salmon farming, as well as to reduce the occurrence of diseases and parasites (e.g. sea-lice).

There are perhaps no other obvious candidates for offshore mariculture among the other finfish species produced in quantities <200 000 tonnes/year. Table 4 reviews some finfish species that are generally believed to be suited for production in highly dynamic waters and their current state of production. Most of these candidates are currently grown in temperate waters. The required knowledge on the biology and husbandry techniques, along with commercial experience, is currently adequate for some seabream and amberjack species, but still moderate or insufficient for others such as cobia and a number of snapper species. This means that any farming initiatives taken must engage a strong R&D element. Furthermore, the current economic and organizational abilities of the mariculture industry to take unproven species to commercial production in offshore mariculture waters are rather limited, indicating that such offshore developments are likely to take some time.

Mussels, scallops and macroalgae are extractive organisms, and this fact facilitates cultivation in harsh environments. Off-the-coast and offshore mariculture of blue mussels and other mussel species have been tested in the Mediterranean, Atlantic Canada, New Zealand and northeastern United States of America. Many species of

TABLE 4

Brief review of finfish species (excl. Atlantic salmon) potentially suitable for offshore mariculture and their current mariculture production status

Common name (Scientific name)	2007[2]		2011[2]	
	Production (tonnes)	Value (USD)	Production (tonnes)	Value (USD)
Cobia (*Rachycentron canadum*) (De Silva and Phillips, 2007; Benetti, Clark and Feeley, 1999; Liao, 2003; O'Hanlon *et al.,* 2003; Benetti *et al*., 2003)	29 869	56 929	40 863	66 258
Snappers[1] (red snapper, *Lutjanus campechanus*, and mutton snapper, *Lutjanus analis*) (Benetti *et al*., 2006; Benetti, Clark and Feeley,1999; Benetti *et al*., 2002; O'Hanlon *et al*., 2003; Rotman *et al*., 2003; Bridger, 2004; Bridger *et al*., 2003)	16	65	520	3 043
Red drum (*Sciaenops ocellatus*) (Bridger, 2004; Bridger *et al*., 2003)	51 819	65 669	67 339	91 877
Amberjack species (*Seriola* spp.) (e.g. greater amberjack, *Seriola dumerili*, and Japanese amberjack, *Seriola quinqueradiata*) (Benetti, Clark and Feeley, 1999; Corbin, 2006; Rotman *et al*., 2003)	172 548	983 233	160 477	1 398 378
Gilthead seabream (*Sparus aurata*)	124 637	710 838	154 820	928 934

[1] All cultured snapper species are included; mangrove red snapper (*Lutjanus argentimaculatus*) is dominant.

[2] Global dataset of aquaculture production (quantity and value) 1950–2012. Fisheries and Aquaculture Statistics and Information Service, FAO (extracted August 2013).

macroalgae that naturally grow in exposed coastal areas are probably well suited for offshore mariculture as long as there are enough nutrients and organic matter as natural feed. For example, Japanese kelp, a "million tonnes/year" species is cultured in large amounts in open waters in Sungo Bay in China.

Species selection is a major issue of concern as mariculture moves to more exposed locations. Some general questions about mariculture species selection for the future are:

- Is the current pattern of only a few successful species (see Table 3) accidental or is it because, as in agriculture, only a few species have special attributes that make them self-selecting?
- Are there mariculture species with the right characteristics that are waiting to be "discovered" for offshore mariculture?
- If very good species for offshore mariculture are limited in number, will it be necessary to transfer those that are good farther afar from their natural range? If so, what precautions are needed?

Some of the main factors slowing down development for offshore mariculture of finfish in tropical regions have been: (i) no well-established commercial mariculture activity of finfish species that would also be suitable for offshore mariculture; (ii) no developed mariculture onshore infrastructure that could support further developments into offshore mariculture; and (iii) high production costs. Consequently, the development of offshore mariculture farming technology has had to contend with developing culture methods for largely unknown aquaculture species simultaneously with developing new farming technology and infrastructure. This contrasts significantly with the development of off the coast mariculture, which has mostly consisted of advancing mariculture infrastructure for existing and well-established aquaculture species. It is likely that because of the high production costs, only a few species can be economically viable for offshore mariculture.

In temperate waters, there is more extensive commercial aquaculture in exposed locations farther from the coast for the mariculture of seabream and salmonids, but for salmon, however, producers have shown little interest to move into offshore mariculture. This limited interest relates to, among other things, a relatively good availability of sites for expansion in more protected areas and the interest for the industry to improve commercial returns through other less risky developments, such as improving husbandry, feed formulation, feed delivery and localization. Despite this, salmon farming in central Norway has, for example, found great economic incentives for moving farther from the coast by increasing the cage size and improving the infrastructure and logistics of the fish farms.

At present, however, even though the economic predictions from economic modelling studies presented in Table 5 are uncertain, a number of commercial or pilot-scale offshore mariculture activities for shellfish and finfish farming have progressed in tropical and temperate waters during the last decade, and further new initiatives are developing.

A high number of marine animals and plants have been farmed over a short time (Duarte, Marbá and Holmer, 2007), but few species as mentioned above are produced in large quantities. The evidence from recent years suggests that the concentration on a few species, and only a few "million tonnes/year" species, may not be fortuitous. There is a need for a careful examination of species selection for offshore mariculture, especially for those species where there are high expectations of their potential for

TABLE 5

Economic modelling studies for offshore mariculture production of finfish and shellfish

Species/group	Location and culture systems	Result (Economic viability)	Authors
Sea scallops (e.g. *Placopecten magellanicus*) and blue mussel (*Mytilus edulis*)	New England (USA); longline and seabed production.	With potential to be economically viable. Seabed seeding was most promising for scallop culture. Commercial mussel culture using submerged longlines was found to be economically viable and provided a sufficiently high market price. High risks of crop loss because of fouling and extreme weather conditions; significant initial capital investment was needed.	Hoagland, Kite-Powell and Jin (2003) Kite-Powell, Mogland and Jin (2003) Kite-Powell *et al.* (2003)
Mussels	Canada; longlines.	Not economically viable, due in large part to the slow growth of the shellfish in the cold waters.	Bonardelli and Levesque (1997)
Mussels, e.g. *Perna canaliculus*	New Zealand; longlines.	Offshore mariculture production was concluded to be marginal at best. Assessment studies were made by private mariculture companies in New Zealand, which operate some of the most efficient large-scale mussel farming systems in the world.	
Cobia (*Rachycentron canadum*), red snapper (*Lutjanus campechanus*), and red drum (*Sciaenops ocellatus*)	Gulf of Mexico; cage culture.	Economic modelling indicated that offshore mariculture of cobia, red snapper and red drum were unlikely to be economically viable unless the scale of the farm increased, landed prices increased and stocking densities were very high. Cobia showed the greatest potential.	Posadas and Bridger (2003)
Finfish species; cod, salmon and flounder	New England (USA); cage culture.	Modelling suggested that it would be economically viable, indicating the importance of the distance from shore, feed cost and maximum stocking density. Significant costs were associated with operating and maintaining cage systems, vessels, and staffing, emphasizing the importance of automation.	Kite-Powell *et al.* (2003)
Gilthead seabream (*Sparus* sp.)	Canary Islands (Spain) and the Mediterranean; cage culture.	Ongoing production activities are economically viable. Variable costs, i.e. feed and labour, made up approximately 50 percent of total costs, fixed costs were approximately 13 percent. The most economic scale was a large farm of 48 000 m^3. Financial returns were most sensitive to mortality, feed use and the commercial price for final product.	Gasca-Leyva *et al.* (2002) Gasca-Leyva, Leon and Hernández (2003a) Gasca-Leyva, Leon and Hernández (2003b) Gasca-Leyva *et al.* (2003)
Mutton snapper (*Lutjanus analis*)	Puerto Rico; cage culture (Ocean Spar SeaStation).	Could be profitable provided that the scale of production was increased significantly to reduce labour costs, and that the cost of the farming technology was lower.	Brown *et al.* (2002)
Atlantic salmon (*Salmo salar*)	Fish cage culture.	Production reached 1.4 million tonnes in 2011. Concluded to be economically viable for offshore, although this conclusion has often been questioned.	Ryan (2004) James and Slaski (2006) FAO (2012a)

future major increases in mariculture production. If the long-term goal for marine aquaculture is to fill an expected seafood deficit of many millions of tonnes per year, it may be necessary to focus on a few species that have demonstrably superior culture characteristics.

Finally, considering biosecurity requirements, a reasonable proposition may be that all new mariculture activities are to be based on only native marine species, but this may be unrealistic. It is noteworthy that all the "million tonnes/year" species in Table 3 are already farmed widely outside their native range. This poses a major challenge, and proper risk assessment and risk management must be in place in such new operations.

4. OPPORTUNITIES, TECHNICAL CONSTRAINTS AND FUTURE NEEDS OF OFFSHORE MARICULTURE

Offshore waters are generally more exposed to wind and waves, and therefore, require more advanced aquaculture technology and infrastructure in order to remain effective. Two approaches have emerged. First, there is the evolution of existing commercial mariculture technologies mostly through more robust construction of coastal mariculture systems making them suitable for offshore waters. These mariculture systems are being increasingly commercialized, with the higher infrastructure and operating costs offset by greater scale of production and the increased use of remote control technologies. Second, there is the development of novel offshore water mariculture technologies, which mostly involve large-scale structures that can be submerged to avoid the wind and wave exposure encountered in offshore situations. While many of these novel mariculture systems are only in the design stages or are being operated on an experimental basis, an increasing number are coming into commercial-scale production.

Most of this technological and commercial development is occurring in the cooler water regions of the world, where the majority of large-scale commercial mariculture production currently occurs, especially for finfish. However, there is significant potential for the development of mariculture in the world's tropical zone, with many countries within this zone now actively encouraging mariculture development. There are some examples of companies taking advanced commercial mariculture technologies, including open water technologies, into the tropical zone. In general, the tropical region of the world's oceans provides some significant advantages for aquaculture. Most importantly, the waters are warm and usually with a limited seasonal fluctuation, which can deliver very fast growth rates in species suited to these conditions. Advanced knowledge and greater experience of suitable tropical finfish species, such as cobia (*Rachycentron canadum*), will provide a stronger basis for advancing open-water mariculture in the tropical zone. Further advances could be achieved for developing nations in the tropical zone by encouraging the improvement of mariculture governance and planning, as well as assisting with technological and personnel capability in open-water mariculture. It is recommended that these areas should be the focus of future international initiatives in collaboration with developing nations.

4.1 Available technology and engineering for mariculture and the potential for offshore

Although culture methods for finfish, shellfish and macroalgae are quite different, the challenges of anchoring and operating at sea are common to all and there is a general need for engineering sophistication in the offshore environment. Important considerations include: (i) heavy-duty moorings in deep water; (ii) offshore systems for the containment of the aquatic crops; (iii) sea-going work boats fully equipped with cranes and crop harvesting and handling equipment; (iv) offshore feed storage and feed distribution systems; (v) automatic or partly automated feeding systems; (vi) mechanization as far as possible of all husbandry and maintenance tasks; (vii) remote monitoring and control systems; and (viii) development of large farms in order to generate economies of scale.

Offshore mariculture requires different or more sophisticated production technologies from those used in more protected areas. Some salmon farms are currently located in waters characterized by relatively high hydrodynamic energy, using HDPE cages located in off-the-coast locations. Although the farming technology developed for these salmonids is leading the development of finfish mariculture at the global level, it cannot be completely adopted for offshore mariculture, but many of the farming principles and components of these systems can, and these are being further developed to sustain offshore mariculture conditions.

A very wide range of designs and concepts have been promoted for finfish mariculture (Beveridge, 2004). A large number of these evolved from offshore oil and gas rigs, and some have promoted the use of adapted petroleum infrastructure (Hanson, 1974a; Hanson, 1974b; Ribakoff, Rothwell and Hanson, 1974; Stickney, 1997). These include bottom-supported platforms, such as the Texas towers, jack-up rigs and monopods, floating and semi-submersible platforms, including modified conventional ships and barges, as well as net pens supported between moored spar buoys. Fredheim and Langdan (2009) have published a comprehensive paper summing up recent advances in technology for off-the-coast and offshore finfish farming.

A frequent approach to overcoming the problem of wave stresses on offshore farming equipment has been to enclose and submerge the infrastructure either permanently or during periods of adverse weather conditions. This results in decreased stress on the infrastructure itself as water particle motion decreases exponentially from the sea surface to zero at a depth corresponding to half the wave length (Beveridge, 2004). In addition, submerging fish cages has the added advantage of avoiding or reducing conflicts with other water users, such as boat traffic. It can also help in avoiding surface jellyfish swarms and damage from collisions with floating debris (Beveridge, 2004; Ryan, Jackson and Maguire, 2007).

A large variety of offshore cages have been devised, built, tested and to some extent commercialized over the past 30 years or more (Beveridge, 2004). However, it appears that some submerged and semi-submerged cage designs are beginning to emerge as the most likely types to be commercialized more widely. The semi-submersible Farmocean sea cages (www.farmocean.se) were designed in Sweden and first used in 1986 and are now widely used, especially in Europe and the Mediterranean (Beveridge, 2004; Scott and Muir, 2000).

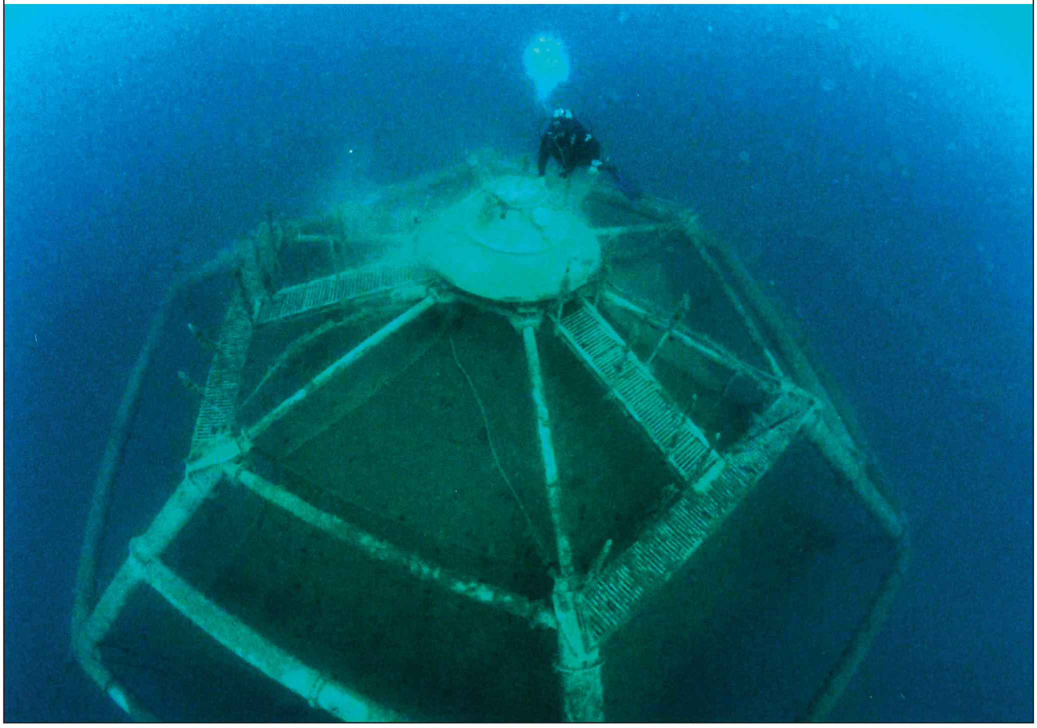
Submersible off-the-coast cages that have been widely used, especially in tropical regions of the world, are those produced by OceanSpar (www.oceanspar.com) (Baldwin *et al.*, 2000; Halwart, Soto and Arthur, 2007; James and Slaski, 2006) (Plate 1). OceanSpar cages have been used in Hawaii (the United States of America), Puerto Rico, Bahamas, in the Gulf of Mexico, Cyprus and New Hampshire (the United States of America). The Sadco-shelf is a rigid hexagonal cage design constructed of tubular steel that is fully submersible (www.sadco-shelf.sp.ru) (Ágústsson, 2004; Beveridge, 2004) (Plate 2). In the submerged position, the cage is reported to withstand waves over 15 m in height and current speeds in excess of 1.5 m/s. The main drawbacks of these farming structures are the initial high capital investment needed and the requirement for generally costly diver servicing. Furthermore, it has been noted that they still need to be fitted with more efficient feeding systems (Ágústsson, 2004; Halwart, Soto and Arthur, 2007; James and Slaski, 2006; Scott and Muir, 2000).

Several other robust submersible sea cages are available on the market that have been developed in Asia (China and Taiwan Province of China), including one specifically designed for farming flatfish with multiple bottom layers to facilitate the bottom dwelling behaviour of the cultured flat fish (Chen *et al.*, 2007; Chen *et al.*, 2008; De Silva and Phillips, 2007; Guo and Tao, 2004; Xu, 2004).

PLATE 1
Subsurface view of single-rim SeaStation

COURTESY OF OCEANSPAR LLC

PLATE 2
A fully submersible Sadco-Shelf E-Series rigid hexagonal cage with self-contained underwater feeding system



COURTESY OF SADCO SHELF LTD

In terms of bivalve aquaculture, commercial activities off the coast use the longline technology originally developed for nearshore farming operations, but with the utilization of stronger and heavier gear. However, the use of this technology in offshore waters remains problematic as a result of the increased strain loads of farm infrastructure, particularly during large wave conditions (Merino, 1997). In addition, the increased vertical movement in the farming structure due to wave motion can result in the detachment of the farmed stock such as for mussels that rely on byssus threads for their attachment to the farming structure. Lovatelli (1988) described in detail the structures used for the suspended farming of the Yesso scallop (*Pactinopecten yessoensis*) in Mutsu Bay in northern Japan using submerged longlines from which netting containers are hung and in which the scallops are cultured. Longline systems are adaptable to different farming situations and are well suited for growing crops that attach directly to ropes such as mussels and some macroalgae. Consequently, they have been adapted for offshore mariculture of mussels in the Mediterranean, Yellow Sea, North Sea, Atlantic Canada, New Zealand and northeastern United States of America.

Offshore mariculture of shellfish has been undertaken on an experimental scale at a number of locations in temperate regions where large-scale commercial shellfish farming is more prevalent (Bonardelli and Levesque 1997; Chambers *et al.*, 2003; Langan 2000a; Langan, 2000b). These have concentrated on submerging traditional suspended longline and pearl net culture systems to depths of 20 m below the sea surface to avoid the difficulties of retaining surface floats in exposed open waters, but with stronger mooring systems. This approach has worked well and survived the effects of high winds (100 km/h) and seas generated by a hurricane, as well as wave heights in excess of 6 m (Langan, 2000a; Paul, 2000). However, some difficulties have been encountered in maintaining the correct depth as the growing mussels add increased weight to the submerged floats. As a result, floats may collapse owing the increased water pressure from being pulled to greater depths (Chambers *et al.*, 2003). Besides the failure of floats, other problems with fouling and predation have been reported (Chambers *et al.*, 2003; Hampson *et al.*, 1999).

In the North Sea, the Alfred Wegener Institute in Germany and its partners have explored the combination of offshore mariculture of shellfish and seaweeds and offshore windmills for energy production (Buck *et al.*, 2006). The site selected, close to the lighthouse “Roter Sand” located offshore in the German Bight, southern North Sea, has strong tidal currents, waves that can reach 3–4 m in height and a current velocity of up to 2 m/s. There are also major offshore shellfish farming activities in the Yellow Sea and other regions of Southeast Asia. In some locations the shellfish longline and structures for farming macroalgae extend for more than four kilometres into offshore waters.

The majority of the global macroalgae production is undertaken in Asia, with China alone responsible for about two-thirds of the global production, some of which is produced in exposed waters (e.g. the integrated multitrophic mariculture of algae, bivalves and fish in the Yellow Sea). The farming technologies for the macroalgae are very similar to those used for shellfish, i.e. longline structures organized in such a way to ensure optimal supply of light and inorganic nutrients for the seaweeds. Because of the need for sunlight, the macroalgae farms tend to extend over large areas of surface waters and, thus, to some extent magnify the challenges of deploying mariculture equipment in the open sea. The requirement for light also means that submersion as a way of avoiding heavy seas is a much less suitable solution for macroalgae than it is for finfish and shellfish.

The amount of published information on offshore seaweed farming remains limited, and marine plant mariculture has generally not attracted a great deal of research or commercial attention in many developed countries (Buck and Buchholz, 2004). However, the current global interest in utilizing plant material for the production of renewable biofuels is drawing considerable attention to the potential for open-sea farming of fast growing macroalgae species in many parts of the world.

The offshore mariculture systems for shellfish and macroalgae are less complex than for fish and have mostly relied on adapting inshore farming systems to offshore conditions. This technology for offshore mariculture of shellfish and macroalgae is also more easily transferable to other locations and countries. However, the challenges for growing production from offshore mariculture of shellfish and macroalgae relate more to economic viability of the activity due to higher operating costs, and potentially lower productivity due to less availability of nutrients in many open sites.

Continuing innovation and development is enabling mariculture to move into more exposed waters farther from the coast and potentially opening up substantial new areas for mariculture production. While more development is needed before many of the emerging mariculture technologies are practical for commercial farming, there is a need to anticipate their eventual arrival and ensure that government regulators are prepared for the arrival of new technology.

4.2 Main operational challenges of offshore mariculture

Offshore mariculture engineering has made considerable progress over the last few decades; however, there is still a long way to go to advance offshore mariculture systems for finfish, shellfish and macroalgae into consistently commercially viable production systems. These systems need to include seeding, feeding, grading, harvesting, cleaning and monitoring of the farms, all of which have to be carried out in offshore environments often under difficult and dangerous conditions. Some economic modelling and initial commercial production systems strongly suggest that economic viability of commercial offshore fish farms can only be achieved if the installations are large enough with a production comparable with, or larger than, the largest existing off-the-coast fish farms currently in operation (i.e. >10 000 tonnes/year) and with even larger-scale installations for shellfish and macroalgae.

Feeding

Proper diet and daily feeding are critical to the efficient mariculture of healthy fish. Yet, in the open ocean, storms and high winds make regular feeding and observation of fish a substantial engineering and operational challenge. As a result, developing remotely operated systems for reliable feed delivery in an unpredictable environment has become a priority. Most feeding technologies currently employed in coastal and off-the-coast mariculture (e.g. salmon systems) may not be fully applicable in offshore conditions. Indeed, controlling remote feeding and monitoring of offshore farms from a nearby platform or an anchored barge may only be feasible for offshore locations where the weather is never too extreme. Common and well-tested feeding systems distribute feed pellets through individual floating pipes going from feed storage facilities (usually floating storage silos/barges) to individual cages. This technology will certainly need to be further developed if it is to be used in offshore mariculture operations, particularly in terms of designing a distribution system that can withstand sudden and prolonged adverse weather conditions.

Technical developments in this area are already under way with innovative feed storage, transportation and delivery prototypes that could be suitable for offshore aquaculture applications. For example, the University of New Hampshire in the United States of America has developed prototype systems for remotely operated feed buoys based on a cylindrical spar-shaped design that are suitable for exposed offshore waters. A structure of this kind, remotely controlled and potentially powered by solar or wave energy, will reduce both labour requirements and the frequency of trips offshore to deliver the feed, as well as allowing farms to be located farther away from the coast. These systems already allow land-based monitoring of the fish through underwater video, as well as the ability to check the position of the feed buoy and the control and monitoring of feeding operations.

Maintenance of mariculture systems

Maintenance of mariculture nets or line structures, and other labour-intensive activities, such as seeding, grading and harvesting, is much more difficult to undertake in an offshore setting than in protected waters. For example, in finfish mariculture, the stock sometimes needs to be corralled into a confined area of a sea cage so it can be harvested by lifting from the water or treated for disease in a more confined space. Corralling fish in sea cages is sometimes done by installing a fixed partition in the cage and rotating it at the surface so the fish are crowded into one segment. However, such simple techniques are more difficult or impossible in an offshore mariculture situation, such that alternative methods have to be developed for achieving the same end result.

Marine biofouling of structures and farm stock is a significant challenge for mariculture operations. For shellfish, mechanical cleaning on the deck of a boat is the most common cleaning method, sometimes combined with dipping in a fluid that kills some of the biofouling organisms. The method is basically identical for macroalgae. In finfish farming, the cleaning strategies include replacement of the fouled net with a clean one and washing of fouled nets onshore, air drying by lifting part of the net out of the water, or cleaning nets from the surface with specific equipments, and cleaning *in situ* by divers. These methods are often used in combination with coating, impregnating or constructing with net materials that deter fouling organisms. The physical removal of biofouling from offshore mariculture structures through scrubbing and scraping, high-pressure water blasting, and net changes will be problematic because of greater wind and wave conditions, and will therefore require the development of novel solutions. For example, the completely enclosed Aquapod (www.oceanfarmtech.com) enables the finfish cage to be rotated so that portions of the net are exposed to the air to help remove biofouling by drying out.

Research is in progress on new antifouling compounds and materials, some of which may have potential for application in offshore mariculture operations. These include: biological control (using natural grazers); new materials such as non-toxic antifouling coatings; electrical methods (e.g. generating biocides, pH shift); and new shellfish handling and immersion techniques (Chambers *et al*., 2006).

Monitoring and process control

Remote monitoring and control of mariculture operations, such as feeding fish, is rapidly becoming well established in coastal mariculture and off-the-coast mariculture. These remote systems have already become important in operating offshore mariculture systems and are ultimately likely to be a key part of their successful operation.

The monitoring and control systems of the production process may include:

- computer-supported management systems for individual cages of cultured fish;
- cameras for observation of fish feeding behaviour and health conditions that are positioned above, below and inside the cage;
- interactive system for planning, monitoring and controlling feeding;
- eco-sensors for the monitoring of feed losses;
- automated systems for removal of dead fish and the monitoring of growth and survival;
- integrated operational control systems that allow a wide range of remote operations.

The monitoring of the production environment may involve:

- temperature, salinity and oxygen sensors;
- water current velocity, wave conditions;
- light conditions.

The monitoring of the production system may involve:

- mechanical system integrity – condition of moorings;
- remotely operated vehicle (ROV) for net monitoring and undertaking maintenance tasks;

- predator exclusion mechanisms to safeguard the farms and the fish;
- surveillance for intruders or vandals;
- monitoring of fish health and growth using advanced computer vision and analyses systems.

The long-term goal for offshore mariculture should be to develop integrated farming systems that are mechanized and remotely controlled as much as possible. Above all, there must be emphasis on reducing the need for people and vessels to have to spend time travelling to offshore mariculture sites, and once there, working under difficult conditions at sea, especially if diving is involved. If offshore mariculture is to fulfil its promise and develop on a large scale, it must find ways to use people for oversight of mechanical and management systems rather than for physical performance of farm operations, which is the norm in most coastal mariculture.

Other mariculture operational issues

There are a number of operating aspects of offshore mariculture that will require the development of alternative methods than are currently used in coastal mariculture and off the coast mariculture. It is generally assumed that these challenges will be solved for actual species and for the specific mariculture technologies being developed for open waters. Some important operational aspects are: seeding and juvenile supply into offshore mariculture systems; harvesting and slaughtering; waste management; health and welfare; surveillance for predators, intruders and/or vandals; other aspects of biosecurity; and training of personnel for operation. Most of these challenges will be relevant for all types of farmed organisms, although the operational challenges for the mariculture of macroalgae is likely to be less demanding than for finfish.

Feeds for offshore mariculture

Shellfish and macroalgae extract the resources they need for growth from seawater, but all current candidate finfish species for offshore mariculture appear to be marine carnivores or omnivores, with a requirement for a dietary source of marine lipids, including highly unsaturated n-3 fatty acids (n-3 HUFA) and some fishmeal in their feeds (Tacon and Methian, 2008; Olsen, 2011). Recent developments have shown that the fishmeal component of fish feeds can be replaced to a large degree by proteins from agriculture plants (Tacon, Hasan and Metian, 2011). However, carnivorous fish species will continue to require a certain amount of n-3 HUFA in their diets. It is an ultimate long-term challenge for all types of mariculture to obtain new sources of n-3 HUFA for feed, and particularly DHA (22:6 n-3), an important component of a healthy human diet. Farmed macroalgae, cultured microalgae, other suitable single-cell biomass and transgenic oil crop plants that produce DHA and EPA are among the most likely new and renewable resources for these important lipids (Olsen, Holmer and Olsen, 2008; Duarte *et al*., 2009; Naylor *et al*., 2009; Nichols, Petrie and Singh, 2010; Olsen, 2011).

Animal production in both agriculture and aquaculture represent a pressure on available plant and animal resources that could otherwise be consumed directly by humans instead of being fed to the farmed animals. It could be suggested that with the increasing global population of humans over time, these plant and animal resources will be increasingly used for direct human consumption. However, the fish that are used for the production of fishmeal and fish oil are limited to the extent that they can be consumed directly by humans owing to their composition. However, aquaculture is currently the most efficient means for converting fishmeal and fish oil to acceptable forms of human food.

There appears to be potential for macroalgae to be grown and processed into major key ingredients for feeds for finfish so that mariculture can become self-sustaining with less interference with the current supply chain of food for humans (Duarte *et al*., 2009). Seaweed nutrients are protected by indigestible cell walls or chemically bound in a way that diminishes their potential nutritional value in the raw state. Indeed, processing or biorefining the raw plants to make the nutrients they contain more available may be the way to proceed to ensure progress in this challenging field.

4.3 Characteristics of the production environment and spatial potential for offshore mariculture

Kapetsky, Aguilar-Manjarrez and Jenness (2013) conducted a GIS-based global assessment of the status and potential for offshore mariculture development from a spatial perspective, tabulated in Appendix 1,[2] as inputs to the discussions of the current workshop and synthesis. The results of the assessment provide an indication of near-future global and national potential for the expansion of mariculture from present nearshore locations to offshore areas, and aim to stimulate much more comprehensive and detailed assessments of offshore mariculture potential at national levels. The part of the study on the present status of mariculture indicates large, unrealized offshore mariculture potential. Mariculture is widespread throughout all of the global climate zones except Antarctica. In all, 93 countries and territories practised mariculture during the period 2004–2008, but a further 72 (44 percent) were not yet practising mariculture. The intertropical zone and the northern temperate zone are the most developed global climate zones for mariculture. Several important mariculture nations span more than one climate zone, especially China, which is by far the world's leading producer. The intensity of mariculture production as measured in tonnes per kilometre of coastline is highly variable around the world, ranging from a fraction of a tonne in many countries up to 519 tonnes/km in China (Figure 7). About half of the mariculture nations have outputs of less than 1 tonne/km of coastline. Globally, the length of coastline available for mariculture is about 1.5 million km, with about 17 percent distributed among countries not yet practising mariculture. About one-half of inshore mariculture production consists of aquatic plants, but there is little production of plants offshore. Altogether, this evidence points to an apparent widespread underutilization of marine space for mariculture.

Another part of the study deals with offshore mariculture potential. The estimates for offshore potential are based on some key assumptions about the near-future development for offshore mariculture. Among these were that offshore mariculture will develop within economic exclusive zones (EEZs), will mainly use cages for finfish and longlines for mussels modified for offshore conditions, and will mainly employ species with already proven mariculture technologies and established markets. The assumptions set the stage for the establishment of analytical criteria and thresholds that are at the core of the spatial analyses. Thus, EEZs were used as spatial frameworks to define the limits of national offshore mariculture development.

The analytical criteria and corresponding thresholds used to define the technical limits on cages and longlines were depths (25–100 m) and current speeds (10–100 cm/s). Likewise, the criteria that defined the cost-effective area for development of offshore mariculture were cost limits on travel time and distance from shore to offshore installations (25 nm [46.3 km]) and reliable access to a port. This analysis showed that, relative to the entire EEZ area, near-future offshore mariculture is limited spatially by the need to tether cages and longlines to the seafloor (Figure 8). In this regard, the EEZ area is either currently too deep (88 percent) or too shallow (4 percent) for cages and longlines based on the depth thresholds of 25–100 m (Figure 9, upper pie chart).

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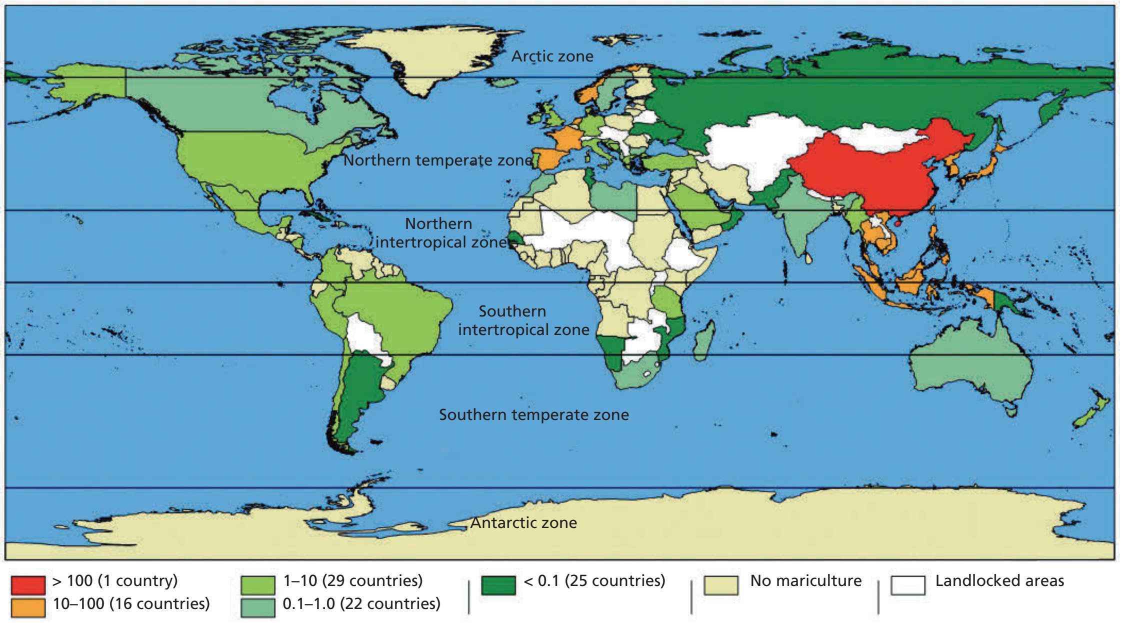
[2] Table A1 in Appendix 1 reports numbers of nations and aggregated areas meeting various criteria for the status and potential offshore mariculture.
Table A2 in Appendix 1 is a summary of status and potential of offshore mariculture by ranks of climate zones and by mariculture and non-mariculture nations (i.e. nations not yet practising mariculture).
Table A3 in Appendix 1 lists sovereign nations first in status and potential for offshore mariculture by surface area in each climate zone and by mariculture and non-mariculture nations.

FIGURE 7

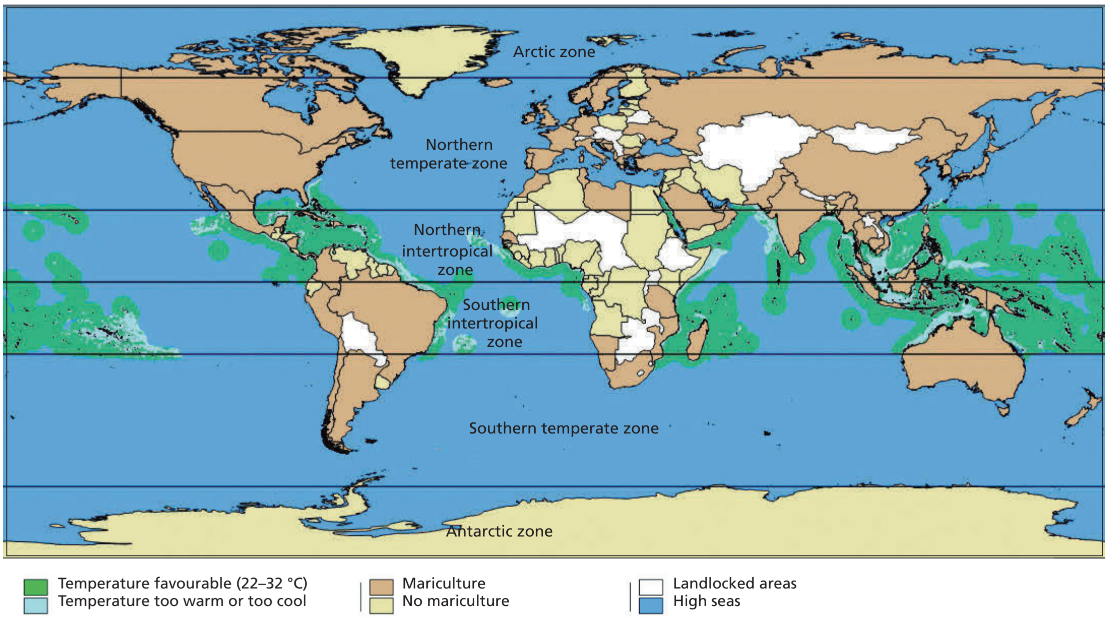
Intensity of mariculture production from 2004–2008 in tonnes per kilometre of coastline and numbers of countries in the range



Source: Kapetsky, Aguilar-Manjarrez and Jenness (2013).

FIGURE 8

Areas within EEZs with temperatures favourable for offshore grow-out of cobia



Source: Kapetsky, Aguilar-Manjarrez and Jenness (2013).

Moreover, in about 7 percent of the EEZ area, either depth is within the 25–100 m threshold or current speed is within the 10–100 cm/s threshold, but these thresholds do not occur together (Figure 9, upper pie chart). Thus, only about 1.4 million km^2 (0.87 percent) of the EEZ area remain where both depth and current speed are suitable for cages and longlines (Figure 9, bottom pie chart).

The physical and chemical characteristics of coastal seas and the open ocean are greatly influenced by latitude, continental shapes, major currents and ocean circulation. Seawater temperature and its spatial and temporal variability are critical for determining the species that are suitable for mariculture in offshore waters, but other factors (as indicated above) are also relevant. A major difference between tropical and temperate waters is the higher temperature and the smaller seasonal variability in the sea surface temperature in the tropics as illustrated by the vast areas within EEZs with temperatures favouring grow-out of cobia (22–32 °C) (Figure 9).

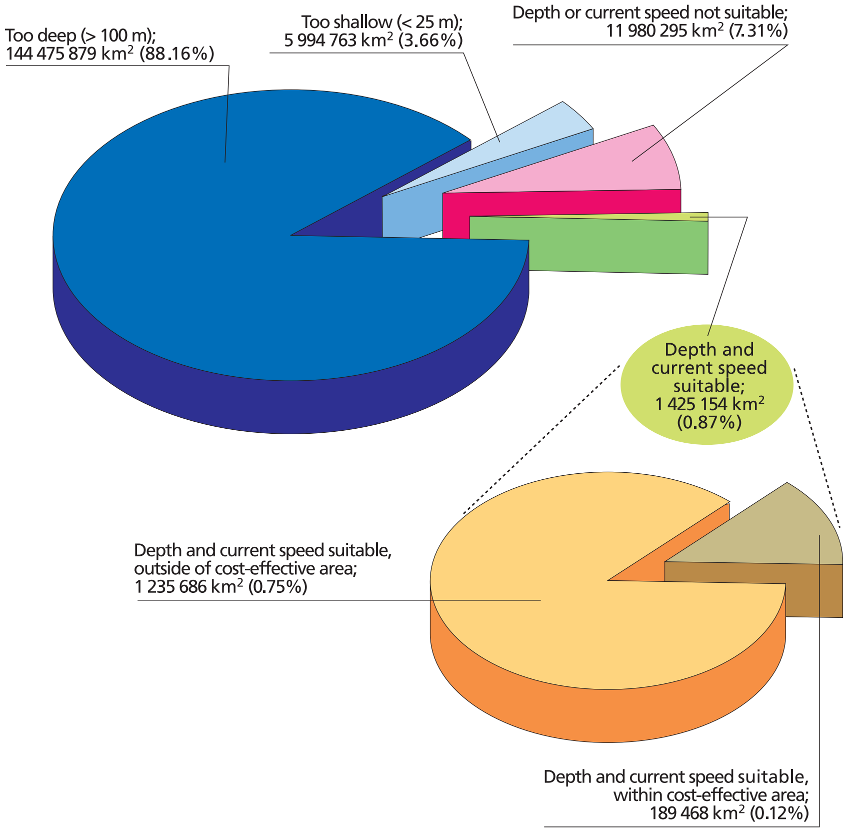
The areas span the globe in much of the Intertropical Convergence Zone and in small portions of the Northern and Southern Temperate Zones.

The potential of cobia for offshore mariculture development as well as of two other species that meet the culture system technology and market requirement criteria, Atlantic salmon and blue mussel (*Mytilus edulis*), was further assessed by integrating the areas with favourable grow-out temperatures with depths and current speeds suitable for submerged cages along with the cost effective area for development. Favourable grow-out of fish and mussels was defined by water temperature (22–32 °C for cobia, 1.5–16 °C for Atlantic salmon, and 2.5–19 °C for blue mussel). In the case of blue mussel, favourable growout was also assessed by food availability measured as chlorophyll-*a* concentration (>0.5 mg/m^3). Potential for offshore integrated multitrophic aquaculture (IMTA) of the latter two species was also analysed.

Scenarios using 5 and 1 percent of the area meeting all of the criteria for each of the three species showed that development of relatively small offshore areas could

FIGURE 9

Areas within EEZs relative to depths and current speeds suitable for sea cages and longlines and to the cost-effective area for development



Source: Kapetsky, Aguilar-Manjarrez and Jenness (2013).

TABLE 6

Extrapolated annual production from the aggregate areas suitable for the offshore mariculture of cobia, Atlantic salmon and blue mussel with 5 percent and 1 percent of the areas developed for offshore mariculture

Species	Assumed production rate[1] (tonnes/km^2)	Total area suitable for development (km^2)	5% developed		1% developed	
			Area (km^2)	Production (tonnes)	Area (km^2)	Production (tonnes)
Cobia	9 900	97 192	4 860	48 110 040	972	9 622 008
Atlantic salmon	9 900	2 447	122	1 211 265	24	242 253
Blue mussel	4 000	5 848	292	1 169 600	58	233 920
Total		**105 487**	**5 274**	**50 490 905**	**1 055**	**10 098 181**

[1] Nash (2004).

Source: Kapetsky, Aguilar-Manjarrez and Jenness (2013).

substantially increase overall mariculture production (Table 6). Improvements in culture technologies allowing for greater depths and increased autonomies, as well as the further development of free-floating or propelled offshore installations, would add greatly to the area with potential for offshore mariculture development.

This global assessment provides measures of the status and potential for offshore mariculture development from a spatial perspective that are comprehensive of all maritime nations and comparable among them. It also identifies nations that are not yet practising mariculture that have a high offshore potential. As FAO moves towards guiding the development of offshore mariculture through its regional fishery bodies and via technical assistance at national levels, more detailed assessments will need to be undertaken to determine the regions and countries that are most promising for development.

5. ENVIRONMENTAL INTERACTIONS OF OFFSHORE MARICULTURE

The most relevant environmental issues of offshore mariculture are those related to: (i) the biogenic waste and inorganic nutrients emission from fish farming affecting the water quality and the potential impacts on pelagic and bottom ecosystems (particularly sensitive habitats); (ii) escapees and genetic interactions with wild stocks; (iii) disease and use of chemical agents; and (iv) interaction with wild stocks and fisheries.

Existing data on the environmental effects of offshore mariculture are scarce and/or inadequate. The current state of knowledge must preliminarily be built based on the general knowledge and concepts resulting from existing and most relevant studies on mariculture (Holmer, 2013; Angel and Edelist, 2013). It is also important to have a fundamental understanding of the effective environmental risks of mariculture in open waters before properly adapted national regulations, international agreements and harmonized evaluation tools can be developed and/or proposed. The risk evaluation of offshore ABNJ mariculture should be made on a scale comparable with that already available for fisheries in international waters. There is already a general understanding in international law that activities that have a high risk of significant negative impact on marine ecosystems must be distinguished from those that most likely have minor impacts. It is therefore a challenge of science to suggest a robust, scientifically based management concept that clearly defines unacceptable impacts from those impacts that are minor and acceptable as a normal consequence of industrial activity.

It should be noted that other environmental interactions that may be important in coastal and nearshore mariculture operations may be of lesser concern in offshore farming activities, such as visual pollution, noxious odours and excessive noise interactions, owing mainly to the distance of the commercial activities.

5.1 Biogenic waste emission and inorganic nutrients

Pelagic ecosystems and water quality

There is in general a relatively poor understanding of how wastes from cage aquaculture systems disperse and affect the structure and function of the pelagic ecosystem (Cloern, 2001; Olsen *et al.*, 2006; Holmer, 2013; Angel and Edelist, 2013). Consequently, there is no clear scientific basis established for monitoring and managing environmental impacts for mariculture in open waters. It is primarily the inorganic nutrients such as ammonia and phosphate that may affect pelagic ecosystems, and the circumstances for protected and exposed mariculture sites is conceptually the same. The application of the precautionary approach principle has therefore been advocated because of the lack of scientific knowledge. However, it should be noted that a few assessment studies have identified serious impacts of mariculture activities on pelagic ecosystems (see Table 7).

According to the generic knowledge on nutrient point sources in marine waters, the following factors are important for offshore mariculture: (i) the size of the source, i.e. the specific release rate from the farm; (ii) the prevailing hydrodynamic forces, i.e. responsible for the dilution rate of the released nutrients and organic wastes; and (iii) the assimilation rate of nutrients and wastes into the natural food web.

Fish feeding is the primary driver of ecosystem impact as a result of biogenic wastes. Macroalgae and shellfish are not artificially fed, thus representing nutrient sinks, and hence are not further covered. The quantitative nutrient/waste emission from intensive aquaculture can be estimated by mass balance based on comprehensive statistical information on feed use and fish production combined with information on feed losses, contents of nitrogen (N) and phosphorus (P) in the feed and the fish, and assimilation efficiencies of the dominant N and P components of the feed (Olsen, Otterstad and Duarte, 2008; Olsen and Olsen, 2008; Reid *et al.*, 2009). For nutrients N and P, such estimates are particularly robust for N when feed losses are low, the natural feed supply to the aquaculture system is low, and the statistical information on production and use of feed is adequate for the purpose. The pelagic ecosystem is primarily exposed to the inorganic nutrient fraction. This approach is applicable to offshore mariculture as long as feed input, mortality and harvesting are carefully monitored.

Nutrient uptake and allocation in planktonic food webs and water hydrodynamics are the fundamental processes determining the assimilation capacity of the water column. Generally, if the dilution rate, mediated by the prevailing hydrodynamic conditions, ensures a dilution of the nutrient wastes to near natural concentrations before they affect phytoplankton and their grazers, negative environmental impacts are unlikely to occur, while the wastes may only stimulate natural production, which could possibly be regarded as a positive effect (Olsen *et al.*, 2007). Preliminary results obtained for typical off-the-coast salmon farms in central Norway have revealed that the ammonia uptake rate (biological assimilation) is much slower than the dilution rate at typical water current velocity rate of about 10 cm/s.

In general, there are no main differences, other than logistical ones, in assessing water column impacts of coastal and offshore mariculture farms. Moreover, this is valid across latitudes and weather conditions. The main assessment methods include dose estimation, waste dispersal (which can be simulated by 3D modelling) and impact evaluation based on dilution and biological assimilation rates. Other impact indicators suggested include enhanced ammonium (NH_4) concentration, growth responses in dialysis cultures and changes in the concentration of particulate nutrients (see Table 7).

Bottom ecosystems and sensitive habitats

In contrast to the poor understanding of the potential impacts on the water column, there is a relatively good scientific understanding on how particulate wastes, i.e. faeces and feed losses from mariculture, may disperse and ultimately accumulate in the sediments and benthic ecosystems below fish farms and in the immediate surrounding

TABLE 7

Overview of off-the-coast (OFC) and offshore (OFS) mariculture in different regions and its environmental impacts on water quality, sediment and benthic fauna

Species	Type	Location/region	Water quality	Sediment	Fauna (benthos)	Comment	Reference
Seabream/ seabass	OFS	East Mediterranean/ST	No impact	No data	No data	–	Basaran, Aksu & Egemen (2007)
Seabream	OFS	Canaries/ST	No data	Enhanced ON pools under cages	–	Low production	Dominguez *et al.* (2001)
Shellfish/ flounder	OFS	United States of America/T	No impact	No impact	No impact	Low production	Grizzle *et al.* (2003)
Atlantic tuna	OFC	West Mediterranean/ ST	No data	Enhanced OM pools and bacterial activity, reduced sediments	Disturbed community	–	Vezzulli *et al.* (2008)
Atlantic tuna	OFC	Adriatic/T	No impact	Enhanced P pools	No data	–	Matijevic, Kuspilic & Baric (2006)
Cobia	OFC	Puerto Rico/TR	No data	Enhanced ON pools under cages	No data	–	Rapp *et al.* (2007)
Salmon	OFC	Norway/B	No data	Increased sedimentation, increased P content	Increased production, abundance, biomass, reduction in diversity	230 m water depth - waste signals in bottom traps < 900 m away	Kutti, Ervik & Hansen (2007)
Salmon	OFC	Norway/B	No data	Reduced sediments <250 m, no change in OM pools except P	Increased production, abundance, biomass, reduction in diversity	230 m water depth	Kutti *et al.*, 2007; Kutti, Ervik & Hoisaeter (2008)
Seabream/ seabass	OFC	West Mediterranean/ ST	No impact	Enhanced OM pools under cages	Reduced species richness and abundance	Impact at 2 out of 5 farms	Maldonado *et al.* (2005)
Seabream/ meagre	OFC	West Mediterranean/ ST	No data	Enhanced OM pools under cages and downstream	Reduced species richness and abundance	–	Aguado-Gimenez *et al.* (2007)
Seabream/ seabass	OFC	Mediterranean/ST	No data	Enhanced P pools	Abundance shifts	Seagrass impacted	Apostolaki *et al.* (2007)
Seabream/ seabass	OFC	Mediterranean/ST	Nutrient availability enhanced up to 150 m	–	–	MedVeg project	Dalsgaard & Krause-Jensen (2006)
Seabream/ seabass	OFC	East Mediterranean/ ST	Transfer to higher trophic levels	No data	No data	–	Pitta *et al.* (2009)
Seabream/ seabass	OFC	Mediterranean/ST	–	–	Enhanced seagrass mortality	MedVeg project	Diaz-Almela *et al.* (2008)
Seabream/ seabass	OFC	Mediterranean/ST	–	Enhanced OM pools and bacterial activity, reduced sediments	–	MedVeg project	Holmer *et al.* (2007); Holmer & Frederiksen (2007)
Tuna	OFC	Mediterranean (Spain)/ST	No data	No change in OM pools	Disturbed community up to 220 m away	–	Vita *et al.* (2004)
Blue mussels	Coastal	Canada/B	No data	Enhanced OM pools and reduced sediments	–	–	Cranford, Hargrave & Doucette (2009)
Snapper/cobia	OFC	Puerto Rico/TR and Bahamas/ST	No impact	Enhanced ON pools under cages	–	Low production	Beltran-Rodriguez (2007); Benetti *et al.* (2006), (2008); Hincapié-Cardenas (2007)

TABLE 7 (CONTINUED)

Species	Type	Location/region	Water quality	Sediment	Fauna (benthos)	Comment	Reference
~40 species, cf footnote[1]:	OFC	China – 4 southern provinces/TR	No data (in English)	Enhanced OM , ON under cages in few reports	–	Large scale	Feng *et al.* (2005); Cao *et al.* (2007)
Pacific threadfin	OFS/TR	Oahu, Hawaii, United States of America/TR	No impact	OM enrichment	Disturbed faunal community up to 80 m from cages and altered microbial flora <300 m away	Low production	Helsley (2006); Lee, Bailey-Brock & McGurr (2006); Yoza *et al.* (2007)
Hawaiian yellowtail	OFC/TR	Big Is., Hawaii, United States of America/TR	No impact	No data	No data	>500 tonnes	N. Sims, personal communication, 2010
Cobia	OFC/TR	Viet Nam	No data	No data	No data	>500 tonnes	Merican *et al.* (2006)
Seabream/ seabass/red drum/siganids	OFC/TR	Mauritius	No data	No data	No data	Low production	Ministry of Agro-Industry and Fisheries of Mauritius (2007)
Red drum/ cobia	OFS/OFC	Réunion and Mayotte	No data	No data	No data	Low production	Dabaddie (2009)
Cobia	OFC	Belize	No data	No data	No data	Low production	Benetti *et al.* (2006), (2008)
Mostly cobia, also some tuna	OFC/OFS	Mexico, Brazil, Dominican Republic, Panama, Costa Rica, Ecuador	No data	No data	No data	Still low production or in different deployment phases	Stemler (2009); Benetti *et al.* (2008)
Barramundi	OFC	Australia	No data	No data	No data	Low prod	Rimmer (1995); Rimmer & Ponia (2007)
Barramundi	OFC	Papua New Guinea	No data	No data	No data	Low prod	Middleton (2004)
Sponge	OFS	Australia	No impact	No impact	No impact	Experimental	Duckworth & Wolfe (2007)
Seabream/ mullet	OFC	Oman	No data	No data	No data	Low production	Al-Yahyai (2009)
Red drum	OFC/TR	Martinique	No data	No data	No data	Low production	Dao (2003)

B: boreal; T: temperate; ST: subtropical; TR: tropical; ON: organic nitrogen; OM: organic matter; P: phosphorus

Note: "Low production" means <500 tonnes.

[1] Mostly cobia, amberjack, snapper, flounder, red drum and pompano; also seaweed and shellfish.

area (Tett, 2008). A quantification of the input is possible by using a mass balance method. It is also quite well understood how these accumulations of nutrient wastes distribute in sediments as a consequence of bottom topography, water current velocity, sediment structure and water depth (Cromey, Nickell and Black, 2002). Severe accumulations can cause major changes in the structure and function of benthic ecosystems locally, normally resulting in decreasing biodiversity and increased biomass of benthic heterotrophs (Pearson and Rosenberg, 1978; Soto and Norambuena, 2004). A consequence may be highly reduced conditions owing sulphide accumulation with a shift in decomposition of organic matter from fauna mediated to microbial processes, with inhibition of microbial processes such as nitrification and, secondly also denitrification (Holmer and Kristensen, 1992; Angel, Krost and Gordin, 1995). The result is high ammonium and phosphate release from sediments.

The following factors related to benthic impacts are considered important when moving mariculture to offshore sites: (i) the size of the particulate waste source, i.e. feed losses and particulate faeces; (ii) water depths and bottom topography; (iii) the specific hydrodynamic characteristics of a site (including surface and deeper water layers); (iv) the assimilation capacity of deep waters and benthic ecosystems; and (v) the presence of sensitive benthic habitats.

Feed losses can generally be reduced by using modern, camera and remote assisted feeding systems. Many of the commercially available systems can be used or adapted for offshore mariculture operations. The efficiency in the feed conversion ratio (FCR) is of paramount importance in both reducing the production costs and minimizing any environmental impact. In principle, feed losses can be almost totally eliminated in an optimal farming operation, and the only effective nutrient inputs to the environment would therefore be through the faeces and excretion, and these too could be minimized through optimizing feed composition and digestibility.

Water depths and water currents at the fish farm site and downstream will generally affect how widely sediments are distributed below and in the surrounding area of the farm. Bottom topography is also important, and locations over bottom ridges are presumably better than locations above the deepest holes in the seafloor. Depending on the depth and hydrodynamic characteristics of the farm site, filter-feeding organisms can remove some of the small particles before they reach the seafloor, but the majority of the larger particles, including uneaten feed pellets, will eventually reach the sediments. Enrichment of the benthic environment as a result of fast sinking particulate waste products from farms is considered to be one of the most significant impacts of mariculture (Hargrave, Holmer and Newcombe, 2008). Under exposed farming conditions, waste products can be dispersed over larger areas, but due to the fast sinking rates of feed pellets and faeces (Cromey, Nickell and Black, 2002; Magill, Thetmeyer and Cromey, 2006), the bulk of the sedimentation can generally be expected to occur in the immediate vicinity of the farms (i.e. within hundreds of metres).

The microbial processes will also respond to organic enrichment by enhancing their activity, and thereby increase the risk of hypoxia and reduced conditions in the sediments. Occurrence of hypoxia affects benthic fauna negatively, but areas where hypoxia occurs are frequently areas that are stagnant or with poor water exchange (Gray, Wu and Or, 2002). Thus, hydrodynamic factors are key processes determining whether or not hypoxia occurs. Offshore mariculture and off-the-coast locations should have less risk of hypoxia, although local hydrodynamic conditions and bathymetry have to be considered. Moreover, deep-dwelling benthic fauna, which are expected to be abundant in deep sediments, may suffer from hypoxia at higher oxygen concentrations, owing reduced conditions in the sediments (Hargrave, Holmer and Newcombe, 2008).

5.2 Sensitive benthic habitats

Moving aquaculture farther from the coast and to deeper waters will remove the pressure on coastal sensitive habitats, but there are probably other sensitive habitats at potential off-the-coast and offshore mariculture sites. Off-the-coast locations will probably include sensitive coastal habitats, especially in areas with clear water and deep light penetration, for example in the Mediterranean Sea, where seagrasses occur at 50–70 m water depths.

In general, there is a well-developed scientific background on benthic impacts from mariculture, including a number of impact proxies such as indicator species, diversity of species and groups, biomass of fauna, organic contents and biochemical measures, microbial status and aerobic conditions (Kalantzi and Karakassis, 2006; Brooks and Mahnken, 2003; Holmer, Wildish and Hargrave, 2005; Hyland *et al.*, 2005; Aguado-Gimenéz *et al.*, 2007; Hargrave, Holmer and Newcombe, 2008; Holmer, 2013; Angel and Edelist, 2013). There are various methods to measure these variables – established monitoring and management methods based on the scientific understanding of benthic impacts, including for example the MOM assessment method regularly used for large salmon farms (Hansen *et al.*, 2001) and dynamic simulation models like DEPOMOD (Cromey, Nickell and Black, 2002).

Among the main challenges ahead is to increase the knowledge on the typical benthic habitats to be expected under offshore mariculture sites and to test and verify the applicability of existing environmental monitoring procedures used for coastal and off-the-coast mariculture.

5.3 Escapees and genetic interactions with wild stocks

Escapes from fish farms are mainly caused by external forces (e.g. strong winds, waves, predators and vandalism, and inappropriate or poor farm management practices). The prevention of escapes remains primarily an engineering and management challenge. Escaped farmed organisms are generally considered to be a major problem, but the perception of the potential impacts to the environment differs among countries, also depending on the farmed species. The diverse consequences may include: (i) the potential genetic interference with wild stocks (regarded to be particularly harmful if the cultured stocks are larger than the natural ones and if the cultured stocks are selectively bred); (ii) the potential transmission of parasites and diseases; and (iii) the competition for space by which escapees outcompete natural populations (particularly negative if native species are outcompeted by non-native species).

Atlantic salmon has undergone selective breeding for generations, and it has been estimated that cultured numbers exceed those of wild fish (Cross *et al.*, 2008). In this case, major escapes of farmed salmon mixing with wild populations may produce negative effects (McGinnity *et al.*, 2003; McGinnity *et al.*, 2004). However, at present none of the many finfish candidates for offshore farming (see Table 4) have undergone the same breeding programme as salmon, which, besides, may not be a very well-suited candidate for offshore mariculture.

The issue of potentially large escapes from offshore mariculture activities is continuously discussed among many stakeholders, mainly owing to the fact that future offshore operations will most likely be large and placed in areas generally under rough weather conditions. Escapes from shellfish and marine plant mariculture cannot be excluded, but so far this has apparently not been regarded as a specific environmental hazard, at least when local species are farmed. Being offshore can minimize the risks by being far away from potential reproduction or settling areas.

5.4 Disease and chemical agents

Pathogenic bacteria, viruses and harmful parasites can be both introduced and transmitted through mariculture activities, including through escaped fish. Pathogens and parasites normally originate from wild fish or invertebrate populations (Diamant and Paperna, 1995), but may reach epidemic proportions in intensively cultivated cages, as in the case of sea-lice and salmon (Goldburg and Naylor, 2004; Naylor and Burke, 2005). Pathogens abound in all environments, but owing to the greater natural biodiversity in the tropics, there is also a larger diversity of disease agents (Avise, Hubbell and Ayala, 2008). In addition, the rate of infection is magnified owing to the naturally high ambient temperatures, which affect metabolic rates of hosts and pathogens alike, and their activity levels.

Proper health management of livestock throughout its life cycle, adequate waste management, efficient vaccines, proper handling of pharmaceuticals, and effective treatments and maintenance of the water quality (particularly oxygen levels) are important to maintaining farmed fish healthy and preventing the spread of disease to other farms and wild fish. The spreading of pathogenic bacteria and viruses between farms is correlated with culture density, vicinity of farms and the local patterns of water currents. Relocation of farms to offshore mariculture sites can therefore be expected to reduce spreading of disease and parasites between farms, whereas an increase in the size of the farms may increase the risk of outbreak and disease at a single farm. The spread of disease to and from wild migrating fish stocks will depend on distances to major migration routes, to feeding and spawning grounds, as well as the level of attraction of the wild fish to the cages. Disease introduction and transfer can also be a concern in shellfish and seaweed culture systems (Boyd *et al.*, 2005).

A variety of chemicals are used in mariculture, including disinfectants, antifoulants and veterinary medicines (Costello *et al.*, 2001; Read and Fernandes, 2003). Metals and other compounds may accumulate under cages (Dean, Shimmield and Black, 2007; Sutherland *et al.*, 2007), in benthic organisms, and may be transferred through the food chain (Lojen *et al.*, 2005). The impacts of antibiotics include effects on non-target organisms, effects on sediment chemistry and processes, and the ultimate development of antibiotic resistance (Beveridge, Phillips and Macintosh, 1997). The use of antifoulants may possibly increase in some offshore farming sites, whereas the use of medicines can be expected to decrease as a result of better environmental and culture conditions and larger distances between farms.

5.5 Interaction with wild stocks and fisheries

For offshore mariculture in the EEZ and ABNJ, it will be important to ensure that mariculture operations do not produce harmful interactions with wild migrating stocks. Mariculture farms may have considerable demographic effects on wild fish by aggregating large numbers in their immediate vicinity. Studies on seabream and seabass farms in the Mediterranean Sea have shown up to 30 different species of wild fish being attracted, with the aggregated biomass of wild fish at the majority of the investigated farm sites ranging between 10 and 40 tonnes (Dempster *et al.*, 2002, 2004, 2005). Similarly, large wild fish aggregations have been reported from fish farms in Greece (Thetmeyer, Pavlidis and Chromey, 2003) and the Canary Islands (Boyra *et al.*, 2004; Tuya *et al.*, 2006). Mussel rafts in the Mediterranean Sea (Brehmer *et al.*, 2003) are also known to aggregate wild fish, whereas cold-water farms in the North Atlantic attract fewer species (Dempster *et al.*, 2009). Large aggregates of saithe have been found around salmon farms showing a distinct morphology compared with natural fed species, with gadoid fish averaging over ten tonnes per salmon farm in Norway (Dempster *et al.*, 2009). In the Mediterranean, the wild fish are dominated by a few primarily planktivorous fish feeding on feed pellets gone astray. Also demersal fish are attracted to fish farms, although aggregations vary in numbers and species. Increased levels of parasites and disease in wild fish (and disease transfer from wild to farmed fish) are potential impacts of the dense and temporally persistent aggregations present in close proximity to large biomasses of caged fish hosting parasites and diseases (Dempster *et al.*, 2002).

Offshore mariculture farms will presumably also attract large numbers of wild fishes, particularly as the farming operations are likely to be large, potentially increasing the availability of feed pellets lost in the immediate surroundings of the farm. This may be particularly the case in farms located close to the shore or near migratory routes and feeding and spawning grounds. A major concern of offshore mariculture farms is also the attraction of large predatory animals such as sharks and killer whales. On the Pacific coast of the United States of America and Canada, the Californian sea lion (*Zalophus californianus*), the harbour seal (*Phoca vitulina*) and the Steller sea lion (*Eumatopias jubatus*), interact with coastal fish farms by predating upon salmonids inside the cages and damaging netting in the process (Nash, Iwamoto and Mahnken, 2000). On the Atlantic coast, harbour seals and grey seals, *Halichoerus grypus*, cause similar problems (Nash, Iwamoto and Mahnken, 2000). In Chile, negative interactions of sea lions (*Otaria flavescens*) with salmon farms have been described (Sepulveda and Oliva, 2005). Sea-otters have also caused conflicts with production in specific regions.

Locating farms far away from marine mammal colonies is a good option and, thus, offshore aquaculture offers an opportunity to avoid interaction with them.

5.6 Integrated multi-trophic aquaculture

The ecological rationale of integrated multitrophic aquaculture (IMTA), which includes among others waste reclamation through trophic relationship and water quality maintenance through complementary functions of the farmed species, has recently attracted considerable interest from Western, as well as, other aquaculture nations (Chopin *et al*., 2001; Neori, 2008; Soto, 2009).

In the case of offshore mariculture, IMTA is being conducted by farming commercially valuable bivalves and macroalgae using longline systems installed in the vicinity of fish farms for these secondary crop species to take advantage of the wastes generated from the finfish. It has been demonstrated that bivalves close to the fish cages readily consume drifting faecal and feed particles; while in more distant locations, they will filter phytoplankton cells produced from inorganic nutrients released from the farm. The macroalgae may take advantage of the inorganic nutrients released, often a major waste from fish farms. The main driver of IMTA is the artificial feeding of finfish. Integrated multitrophic aquaculture farming may add value to the overall farming investment through the production of secondary crops, while at the same time mitigate any environmental impact through the reduction of waste dispersed. In other words, there is both an economic and an environmental drive for establishing IMTA operations.

In principle, IMTA in the sea is an environmentally friendly way of developing mariculture; however, an important question remains on the overall risks and achievable economic gains which may be very site-specific. In offshore mariculture locations, it is likely that food particles and nutrients disperse rapidly as a result of the hydrodynamic characteristic of the sea. Nevertheless, the rapid nutrient uptake capabilities of macroalgae may suggest that culturing macroalgae provide an additional economic incentive to go for such integrated development. IMTA driven by finfish cage culture may need to be further explored, considering that the growth of shellfish and macroalgae will also depend on the natural resources available in the ambient waters. The natural biological richness of the system or the capacity of the feed system to provide enough food for the extractive species is therefore fundamental for determining the economic potential of IMTA.

5.7 Minimizing environmental impacts

A risk assessment and environmental impact assessment and monitoring must always be in place before establishing offshore farms. FAO provides guidance that can be applied to the environmental concerns of offshore mariculture through different publications and guidelines including on health management for responsible movement of live aquatic animals (FAO, 2007), guidelines on the genetic resources management in aquaculture (FAO, 2008b), and on the ecosystem approach to aquaculture (FAO, 2010). Other relevant technical publications include global environmental assessment and monitoring of aquaculture (FAO, 2009) and understanding risk assessment and risk management in aquaculture (Bondad-Reantaso, Arthur and Subasinghe, 2008).

6. A VISION FOR THE FUTURE GLOBAL MARICULTURE INDUSTRY

Some relevant premises were agreed by the workshop participants: (i) there is a strong need for more seafood in the future; (ii) this seafood will partly need to come from mariculture in more exposed sites; (iii) there is a need to increase the harvest of marine organisms (wild and farmed) from lower trophic levels to minimize ecosystems impacts and ensure long-term sustainability while balancing these efforts with the global food and nutrition needs; and (iv) market forces alone cannot secure a balanced sustainable development. With such premises in mind, it is paramount to establish a clear vision for the future use of the global oceans for food production.

The overall vision for global mariculture in the twenty-first century is a "self-sustaining mariculture of quality and affordable seafood in harmony with the environment and its stakeholders". More specifically, some of the elements of the above vision would include:

- The twenty-first century will involve a "blue evolution" resulting in a rapidly increasing proportion of overall meat for human food being produced through coastal, off-the-coast and offshore mariculture.
- The feed resources for finfish will increasingly be derived from macroalgae and/or from other sources that are not taken from the human food chain, and thus the production trend will become more ecologically efficient and sustainable.
- Feed conversion rates are low, feed losses are minimized and escapes strongly reduced in all mariculture production.
- Mariculture production is undertaken in suitable areas where environmental impacts and stakeholder interactions and conflicts are minimized; the expansion of mariculture away from the ultimate shoreline to offshore locations becomes an important strategy to achieve this goal.
- An efficient national and international legal framework for mariculture is established.

The vision offers the following main political, scientific and industrial long-term challenges:

- There must be a strong political appreciation among key countries and international organizations on the importance of developing a robust and sustainable global mariculture industry that has the framework and capacity to facilitate the more rapid expansion of production in exposed open waters.
- Spatial planning with an ecosystem approach will need to be undertaken to identify the regions and countries that are most promising for offshore mariculture development, and to determine carrying capacities for maximum production and preservation of ecosystem services, including social carrying capacity.
- Suitable species must be identified and developed for offshore mariculture, because no particular finfish species that are currently in high production appear to be a clear candidate, and because most molluscs and macroalgae are currently not economically feasible for such production.
- Production systems, technology and operational procedures must be developed or improved, not through a revolution, but rather through an evolution, to allow production to be expanded to off-the-coast and offshore mariculture locations.
- New and more sustainable feed resources for fed-fish mariculture must be developed through long-term R&D efforts, and macroalgae have the potential to be an important raw material for feed ingredients.

- While feed pellets appear to be the most appropriate and environmentally friendly feed for off-the-coast and offshore mariculture aquaculture, the industry must install and apply modern feeding systems to minimize losses and secure feed conversion ratios well below 1.5 (dry feed supplied per wet weight produced).
- Science and industry must explore environmental impacts for off-the-coast and offshore mariculture and establish general principles for locating and monitoring this activity that are environmentally acceptable.
- Opportunities for minimizing environmental impacts while maximizing gains should be taken advantage of, such as the co-location of mariculture with offshore wind farms and oil and gas infrastructure.
- International collaboration and communication in developing offshore mariculture technology, best operational practice and regulatory frameworks will be critical for ensuring the rapid development of a sustainable global offshore mariculture industry.

The challenges of the vision are comprehensive, for science, society and industry, but no other issue is more important than to feed the world's populations in developing and developed countries in the twenty-first century. It is important for the global aquaculture industry to have a long-term roadmap towards its sustainability.

REFERENCES

Aguado-Gimenez, F., Marin, A., Montoya, S., Marin-Guirao, L., Piedecausa, A. & Garcia-Garcia, B. 2007. Comparison between some procedures for monitoring offshore cage culture in western Mediterranean Sea: Sampling methods and impact indicators in soft substrata. *Aquaculture*, 271: 357–370.

Ágústsson, G. 2004. *Design considerations and loads on open ocean fish cages south of Iceland*. University of Iceland. (M.Sc. dissertation).

Al-Yahyai, S. 2009. Sultanate of Oman: National review on marine cage aquaculture. *In* FAO/Regional Commission for Fisheries. *Report of the Regional Technical Workshop on Sustainable Marine Cage Aquaculture Development. Muscat, Sultanate of Oman, 25–26 January 2009*, pp. 45–72. FAO Fisheries and Aquaculture Report No. 892. Rome, FAO. 135 pp. (also available at www.fao.org/docrep/011/i0723e/i0723e00.htm).

Angel, D.L. & Edelist, D. 2013. Sustainable development of marine aquaculture off- the-coast and offshore – a review of environmental and ecosystem issues and future needs in tropical zones. *In* A. Lovatelli, J. Aguilar-Manjarrez & D. Soto, eds. *Expanding mariculture further offshore: technical, environmental, spatial and governance challenges, FAO Technical Workshop. 22–25 March 2010, Orbetello, Italy*, pp 173–200. FAO Fisheries and aquaculture Proceedings No. 24. Rome, FAO. 314 pp.

Angel, D.L., Krost, P. & Gordin, H. 1995. Benthic implications of net cage aquaculture in the oligotrophic Gulf of Aqaba. *European Aquaculture Society*, 25: 129–173.

Apostolaki, E.T., Tsagaraki, T., Tsapaki, M. & Karakassis, I. 2007. Fish farming impact on sediments and macrofauna associated with seagrass meadows in the Mediterranean. *Estuarine Coastal and Shelf Science*, 75: 408–416.

Avise, J.C., Hubbell, S.P. & Ayala, F.J. 2008. In the light of evolution II: Biodiversity and extinction. *Proceedings of the National Academy of Sciences of the United States of America*, 105: 11453–11457.

Baldwin, K., Celikkol, B., Steen, R., Michelin, D., Muller, E. & Lavoie, P. 2000 Open ocean aquaculture engineering – Mooring and net pen deployment. *Marine Technology*, 34: 53–58.

Basaran, A.K., Aksu, M., & Egemen, O. 2007. Monitoring the impacts of the offshore cage fish farm on water quality located in Ildir Bay (Izmir-Aegean Sea). *Tarim Bilimleri Dergisi – Journal of Agricultural Sciences*, 13: 22–28.

Beltrán-Rodríguez, D.M. 2007. Spatio-temporal variation in organic nitrogen and carbon in sediments associated with tropical submerged cage aquaculture. University of Puerto-Rico, Mayaguez Campus. 94 pp. (M.Sc. dissertation)

Benetti, D.D., Alarcón, J.F., Stevens, O.M., O'Hanlon, B., Rivera, J.A., Banner-Stevens, G. & Rotman, F.J. 2003. *Advances in hatchery and growout technology of marine fish candidate species for offshore aquaculture in the Caribbean*. 54th Ann. Gulf and Caribbean Fisheries Institute, Nov. 2001, Turks and Caicos. 54: 473–487.

Benetti, D., Brand, L., Collins, J., Orhun, R., Benetti, A., O'Hanlon, B., Danylchuk, A., Alston, D., Rivera, J. & Cabarcas, A. 2006. Can offshore aquaculture of carnivorous fish be sustainable? Case studies from the Caribbean. *World Aquaculture*, 37: 44–47.

Benetti. D.D., Clark, A. & Feeley, M.W. 1999. Feasibility of selected candidate species of marine finfish for cage aquaculture development in the Gulf of Mexico with novel remote sensing techniques for improved offshore systems monitoring. *In* R. Stickney, ed. *Third international conference on open ocean aquaculture*, pp. 103–119. Corpus Christi, USA, Texas A&M University.

Benetti, D.D., Matera, J., Alarcón, J.F., Feeley, M.W., Stevens, O.M., Banner-Stevens, G., Minemoto, Y., Rotman, F., Fanke, J., O'Hanlon, B. & Eldridge, L. 2002. Growth, survival and feed conversion rates of mutton snapper *Lutjanus analis* raised in floating net cages. *Journal of the World Aquaculture Society*, 33: 349–357.

Benetti, D.D., Orhun, M.R., Sardenberg, B., O'Hanlon, B., Welch, A., Hoenig, R., Zink, I., Rivera, J.A., Denlinger, B., Bacoat, D., Palmer, K. & Cavalin, F. 2008. Advances in hatchery and grow-out technology of cobia *Rachycentron canadum* (Linnaeus). *Aquaculture Research*, 39: 701–711.

Beveridge, M.C.M. 2004. *Cage Aquaculture*. Oxford, UK, Blackwell Publishing.

Beveridge, M.C.M., Phillips, M.J. & Macintosh, D.J. 1997. Aquaculture and the environment: the supply of and demand for environmental goods and services by Asian aquaculture and the implications for sustainability. *Aquaculture Research*, 28: 797–807.

Bonardelli, J.C. & Levesque, M. 1997. Economics of longline technology in offshore aquaculture and drift-ice environments; how to make or lose money? *In* Helsley, C.E., ed. *Open Ocean Aquaculture '97: Charting the Future of Ocean Farming*, pp. 225–238. Maui, USA, University of Hawaii.

Bondad-Reantaso, M.G., Arthur, J.R. & Subasinghe, R.P., eds. 2008. *Understanding and applying risk analysis in aquaculture*. FAO Fisheries and Aquaculture Technical Paper. No. 519. Rome, FAO. 304 pp.

Boyd, C.E., McNevin, A.A., Clay, J. & Johnson, H.M. 2005. Certification issues for some common aquaculture species. *Reviews in Fisheries Science*, 13: 231–279.

Boyra, A., Sanchez-Jerez, P., Tuya, F., Espino, F. & Haroun, R. 2004 . Attraction of wild coastal fishes to an Atlantic subtropical cage fish farms, Gran Canaria, Canary Islands. *Environmental Biology of Fishes*, 70: 393–401.

Brehmer, P., Gerlotto, F., Guillard, J., Sanguinede, F., Guennegan, Y. & Buestel, D. 2003. New applications of hydroacoustic methods for monitoring shallow water aquatic ecosystems: the case of mussel culture grounds. *Aquatic Living Resources*, 16: 333–338.

Bridger, C.J. 2004. The Gulf of Mexico Offshore Aquaculture Consortium. *In* C.J. Bridger, ed. *Efforts to develop a responsible offshore aquaculture industry in the Gulf of Mexico: A compendium of offshore aquaculture consortium research*. pp. 11–21. Ocean Springs, Mississippi-Alabama Sea Grant Consortium, USA.

Bridger, C.J., Costa-Pierce, B.A., Goudey, C.A., Stickney, R.R. & Allen, J.D. 2003. Offshore aquaculture development in the Gulf of Mexico: Site selection, candidate species, and logistic alleviation. *In* C.J. Bridger & B.A. Costa-Pierce, eds. *Open ocean aquaculture - from research to commercial reality,* pp. 273–283. Baton Rouge, USA, The World Aquaculture Society.

Brooks, K.M. & Mahnken, C.V.W. 2003. Interactions of Atlantic salmon in the Pacific northwest environment II. Organic wastes. *Fisheries Research*, 62: 255–293.

Brown, J.G., Goller, C.C., Peters, T.L., Olean, A., Vernon-Gerstenfeld, S. & Gerstenfeld, A. 2002. Economics of cage culture in Puerto Rico. *Aquaculture Economics & Management*, 6: 363–372.

Buck, B.H. & Buchholz, C.M. 2004. The offshore-ring: A new system design for the open ocean aquaculture of macroalgae. *Journal of Applied Phycology*, 16: 355–368.

Buck, B.H., Walter, U., Rosenthal, H. & Neudecker, T. 2006. The development of mollusc farming in Germany: past, present and future. *World Aquaculture*, 37(2): 66–69.

Cao, L., Wang, W., Yang, Y., Yang, C., Yuan, Z., Xiong, S. & Diana, J. 2007. Environmental Impact of Aquaculture and Countermeasures to Aquaculture Pollution in China. *Environmental Science and Pollution Research*, 14(7): 452–462.

CAWMA. 2007. *Water for food, water for life: A comprehensive assessment of water management in agriculture*. London, Earthscan; and Colombo International Water Management Institute.

Chambers, L.D., Stokes, K.R., Walsh, F.C. & Wood, R.J.K. 2006. Modern approaches to marine antifouling coatings. *Surface & Coatings Technology*, 201: 3642–3652.

Chambers, M.D., Howell, W.H., Langan, R., Celikkol, B. & Fredriksson, D.W. 2003. Status of open ocean aquaculture in New Hampshire. *In* C.J. Bridger & B.A Costa-Pierce, eds. *Open Ocean Aquaculture – From research to commercial reality*, pp. 233–245. Baton Rouge, USA, The World Aquaculture Society.

Chen, J., Guang, C., Xu, H., Chen, Z., Xu, P., Yan, X., Wang, Y. & Liu, J. 2007. A review of cage and pen aquaculture: China. *In* M. Halwart, D. Soto & J.R Arthur, eds. *Cage aquaculture – Regional reviews and global overview*, pp. 50–68. Rome, FAO. 241 pp. (also available at www.fao.org/docrep/010/a1290e/a1290e00.htm).

Chen, J., Guang, C., Xu, H., Chen, Z., Xu, P., Yan, X., Wang, Y. & Liu, J. 2008. Marine fish cage culture in China. *In* A. Lovatelli, M.J. Phillips, J.R. Arthur & K. Yamamoto, eds. *The Future of Mariculture: A regional approach for responsible development in the Asia-Pacific region*, pp. 285–299. FAO Fisheries Proceedings. No. 11. Rome, FAO. 325 pp. (also available at www.fao.org/docrep/011/i0202e/i0202e00.htm).

Chopin, T., Buschmann, A.H., Halling, C., Troell, M., Kautsky, N., Neori, A., Kraemer, G.P., Zertuche-Gonzalez, J.A., Yarish, C. & Neefus, C. 2001. Integrating seaweeds into marine aquaculture systems: a key towards sustainability. *Journal of Phycology*, 37: 975–986.

Cloern, J.E. 2001. Our evolving conceptual model of the coastal eutrophication problem. *Marine Ecology – Progress Series*, 210: 223–253.

Corbin, E. 2006. Offshore aquaculture. *Sea Technology*, 47: 7.

Costello, M.J., Grant, A., Davies, I.M., Cecchini, S., Papoutsoglou, S., Quigley, D. & Saroglia, M. 2001. The control of chemicals used in aquaculture in Europe. *Journal of Applied Ichthyology*, 17: 173–180.

Cranford, P.J., Hargrave, B.T. & Doucette, L.I. 2009. Benthic organic enrichment from suspended mussel (*Mytilus edulis*) culture in Prince Edward Island, Canada. *Aquaculture*, 292: 189–196.

Cromey, C.J., Nickell, T.D. & Black, K.D. 2002. DEPOMOD – modelling the deposition and biological effects of waste solids from marine cage farms. *Aquaculture*, 214: 211–239.

Cross, T., Burnell, G., Coughlan, S., Culloty, S., Dillance, E., McGinnity, P. & Rogan, E. 2008. Detrimental genetic effects of interactions between reared strains and wild populations of marine and anadromous fish and invertebrate species. *In* M. Holmer, K. Black, C.M. Duarte, N. Marba & I. Karakassis, eds. *Aquaculture in the Ecosystem*, pp. 117–154. Springer.

Dabaddie, L. 2009. Aquaculture in Africa. Media News update. (www.sarnissa.org/tiki-download_file.php?fileId=209).

Dalsgaard, T. & Krause-Jensen, D. 2006. Monitoring nutrient release from fish farms with macroalgal and phytoplankton bioassays. *Aquaculture*, 256: 302–310.

Dao, J.C. 2003. Aquaculture development of red drum (*Scianops ocellatus*) in Martinique and the French West Indies. *In* A. Lovatelli, R. Walters & R. VanAnrooy, eds. *Subregional workshop to promote sustainable aquaculture development in the small island developing states of the Lesser Antilles*, pp. 74–85. FAO Fisheries Report No. 704. Rome, FAO. 122 pp. (also available at www.fao.org/docrep/006/y4921e/y4921e00.htm).

De Silva, S.S. & Phillips, M.J. 2007. A review of cage aquaculture: Asia (excluding China). *In* M. Halwart, D. Soto & J.R. Arthur, eds. *Cage aquaculture – Regional reviews and global overview*, pp. 18–48. Rome, FAO. 241 pp. (also available at www.fao.org/docrep/010/a1290e/a1290e00.htm).

Dean, R.J., Shimmield, T.M. & Black, K.D. 2007. Copper, zinc and cadmium in marine cage fish farm sediments: An extensive survey. *Environmental Pollution*, 145: 84–95.

Dempster, T., Fernandez-Jover, D., Sanchez-Jerez, P., Tuya, F., Bayle-Sempere, J., Boyra, A. & Haroun, R.J. 2005. Vertical variability of wild fish assemblages around sea-cage fish farms: implications for management. *Marine Ecology – Progress Series*, 304: 15–29.

Dempster, T., Sanchez-Jerez, P., Bayle-Sempere, J.T., Gimenez-Casalduero, F. & Valle, C. 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., Sanchez-Jerez, P., Bayle-Sempere, J.T. & Kingsford, M. 2004. Extensive aggregations of wild fish at coastal sea-cage fish farms. *Hydrobiologia*, 525: 245–248.

Dempster, T., Uglem, I., Sanchez-Jerez, P., Fernandez-Jover, D., Bayle-Sempere, J., Nilsen, R. & Bjorn, P.A. 2009. Coastal salmon farms attract large and persistent aggregations of wild fish: an ecosystem effect. *Marine Ecology – Progress Series*, 385: 1–14.

Diamant, A. & Paperna, I. 1995. Protozoan diseases of fish in Mediterranean marine aquaculture. 2nd European Congress on Protistology and 8th European Conference on Ciliate Biology, July 21–26, Clermont Ferrand, France. *European Journal of Protistology*, 31: 402–476.

Diana, J.S. 2009. Aquaculture production and biodiversity conservation. *BioScience*, 59: 27–38.

Diaz-Almela, E., Marba, N., Alvarez, E., Santiago, R., Holmer, M., Grau, A., Mirto, S., Danovaro, R., Petrou, A., Argyrou, M., Karakassis, I. & Duarte, C.M. 2008. Benthic input rates predict seagrass (Posidonia oceanica) fish farm-induced decline. *Marine Pollution Bulletin*, 56: 1332–1342.

Dominguez, L.M., Calero, G.L., Martin, J.M.V. & Robaina, L.R. 2001. A comparative study of sediments under a marine cage farm at Gran Canaria Island (Spain). Preliminary results. *Aquaculture*, 192: 225–231.

Duarte, C.M., Marbá, N. & Holmer, M. 2007. Rapid domestication of marine species. *Science*, 316: 382–383.

Duarte, C.M., Holmer, M., Olsen, Y., Soto, D., Marba, N., Guiu, J., Black, K. & Karakassis, I. 2009. Will the oceans help feed humanity? *BioScience,* 29(11): 967–976.

Duckwoth, A.R. & Wolff, C. 2007. Bath sponge aquaculture in Torres Strait, Australia: Effect of explants size, farming method and the environment on culture success. *Aquaculture*, 271: 188–195.

FAO. 1995. *Code of Conduct for Responsible Fisheries*. Rome. 41 pp.
(also available at ftp://ftp.fao.org/docrep/fao/005/v9878e/v9878e00.pdf)

FAO. 2006. *The state of world aquaculture 2006*. FAO Fisheries Technical Paper No. 500. Rome, FAO. 134 pp. (also available at www.fao.org/docrep/009/a0874e/a0874e00.htm).

FAO. 2007. *Aquaculture development. 2. Health management for responsible movement of live aquatic animals.* FAO Technical Guidelines for Responsible Fisheries No. 5, Suppl. 2. Rome. (also available at www.fao.org/docrep/010/a1108e/a1108e00.htm).

FAO. 2008a. *Report of the FAO Expert Workshop on the Use of Wild Fish and/or Other Aquatic Species as Feed in Aquaculture and its Implication to Food Security and Poverty Alleviation, Kochi, India, 16–18 November 2007*. FAO Fisheries Report No. 867. Rome. 29 pp. (also available at: www.fao.org/docrep/fao/011/i0263e/i0263e.pdf).

FAO. 2008b. *Aquaculture development. 3. Genetic resource management*. FAO Technical Guidelines for Responsible Fisheries No. 5, Suppl. 3. Rome. (also available at ftp://ftp.fao.org/docrep/fao/011/i0283e/i0283e.pd).

FAO. 2009. *Environmental impact assessment and monitoring in aquaculture*. FAO Fisheries and Aquaculture Technical Paper No. 527. Rome. 57 pp. Includes a CD-ROM containing the full document (648 pages) (also available at www.fao.org/docrep/012/i0970e/i0970e.pdf).

FAO. 2010. *Aquaculture development 4. Ecosystem approach to aquaculture*. FAO Technical Guidelines for Responsible Fisheries No. 5, Supplement 4. Rome. 53 pp. (also available at www.fao.org/docrep/013/i1750e/i1750e00.htm).

FAO. 2012a. *The State of World Fisheries and Aquaculture 2012*. Rome. 209 pp. (also available at www.fao.org/docrep/016/i2727e/i2727e.pdf).

FAO. 2012b. Global dataset of aquaculture production (quantity and value) 1950–2010. Fisheries and Aquaculture Statistics and Information Service (also available at ftp://ftp.fao.org/FI/CDrom/CD_yearbook_2010/root/food_balance/section1.pdf).

Feng, Y.Y., Hou, L.C., Ping, N.X., Ling, T.D. & Kyo, C.I. 2005. Development of mariculture and its impacts in Chinese coastal waters. *Reviews in Fish Biology and Fisheries*, 14: 1–10.

Field, C.B, Behrenfeld, M.J., Randerson, J.T. & Falkowski, P. 1998. Primary production of the biosphere: Integrating terrestrial and oceanic components. *Science*, 281: 237–240.

Fredheim, A. & Langan, R. 2009. Advances in technology for offshore and open ocean aquaculture. *In* G. Burnell & G. Allen, eds. *New technologies in aquaculture: Improving production efficiency, quality and environmental management*, pp. 914–944. Cambridge, UK, Woodhead Publications.

Gasca-Leyva, E., León, C.J., Hernández, J.M. & Vergara, J.M. 2002. Bioeconomic analysis of the impact of location on gilthead seabream (*Sparus aurata*) cultivation. *Aquaculture*, 213: 219–232.

Gasca-Leyva, E., León, C.J. & Hernández, J.M. 2003. Management strategies for gilthead seabream (*Sparus aurata*) cultivation in floating cages in the Mediterranean Sea and Atlantic Ocean. *In* C.J. Bridger & B.A. Costa-Pierce, eds. *Open ocean aquaculture – from research to commercial reality*, pp. 341–351. Baton Rouge, USA, The World Aquaculture Society.

Gasca-Leyva, E., León, C.J. & Hernández J.M. 2003b. Management strategies for seabream *Sparus aurata* cultivation in floating cages in the Mediterranean Sea and Atlantic Ocean. *Journal of the World Aquaculture Society* 34, 29–31.

Gasca-Leyva, E., León, C.J., Hernández, J.M. & Vergara, J.M. 2003. Bioeconomic analysis of the impact of location on gilthead seabream (*Sparus aurata*) cultivation. *In* C.J. Bridger & B.A. Costa-Pierce, eds. *Open ocean aquaculture – from research to commercial reality*, pp. 325–339. Baton Rouge, USA, The World Aquaculture Society.

Goldburg, R. & Naylor, R. 2004. Future seascapes, fishing and fish farming. *Ecology*, 3: 21–28.

Gray, J.S., Wu, R.S.S. & Or, Y.Y. 2002 . Effects of hypoxia and organic enrichment on the coastal marine environment. *Marine Ecology – Progress Series*, 238: 249–279.

Grizzle, R.E., Ward, L.G., Langan, V., Schnaittacher, G.M., Dijkstra, J.A. & Adams, J.R. 2003. Environmental monitoring at an open ocean aquaculture site in the Gulf of Maine: Results for 1997–2000. *In* C.J. Bridger & B.A. Costa-Pierce, eds. *Open Ocean Aquaculture: From Research to Commercial Reality*, pp. 105–117. Baton Rouge, USA, The World Aquaculture Society.

Guo, G.X. & Tao, Q.Y. 2004. Offshore cage culture technique in China and its development prospects. *Scientific Fish Farming*, 7(9): 10–11.

Halwart, M., Soto, D. & Arthur, J.R. 2007. *Cage aquaculture: regional reviews and global overview*. Fisheries Technical Paper No. 498. Rome, FAO. 241 pp. (also available at www.fao.org/docrep/010/a1290e/a1290e00.htm).

Hampson, G., Hoagland, P., Kittelsen, A. & Paul, W. 1999. *Submerged coastal offshore mussel aquaculture system (SCOMAS); biological aspects of suspended near bottom growth near the benthic turbidity zone.* Woods Hole, USA, Department of Biology, Woods Hole Oceanographic Institution.

Hansen, P.K., Ervik, A., Schaanning, M., Johannessen, P., Aure, J., Jahnsen, T. & Stigebrandt, A. 2001. Regulating the local environmental impact of intensive, marine fish farming. II. The monitoring programme of the MOM system. *Aquaculture*, 194: 75–92.

Hanson, J.A. 1974a. A national mariculture program. *In* J.A. Hanson, ed. *Open sea mariculture; perspectives, problems and prospects*, pp. 375–396. Stroudsburg, USA, Dowden, Hutchinson & Ross, Inc.

Hanson, J.A. 1974b. Quo vadis? *In* J.A. Hanson, ed. *Open sea mariculture; perspectives, problems and prospects*, pp. 359–374. Stroudsburg, USA, Dowden, Hutchinson & Ross, Inc.

Hargrave, B.T., Holmer, M., & Newcombe, C.P. 2008. Towards a classification of organic enrichment in marine sediments based on biogeochemical indicators. *Marine Pollution Bulletin*, 56: 810–824.

Helsley, C.E. 2006. Environmental observations around offshore cages in Hawaii. *In* C.S. Lee & P.J. O'Bryen, eds. *Open Ocean Aquaculture – Moving Forward*. Honolulu, USA Aquaculture Interchange Program (AIP) Workshop. 4 pp.

Hincapié-Cardenas, C. 2007. Macrobiofouling on open-ocean submerged aquaculture cages in Puerto Rico. University of Puerto Rico, Mayaguez Campus, Mayaguez, Puerto Rico (MSc thesis).

Hoagland, P., Kite-Powell, H.L. & Jin, D. 2003. *Business planning handbook for the ocean aquaculture of blue mussels*. Woods Hole, USA, Marine Policy Center, Woods Hole Oceanographic Institution.

Holmer, M. 2013. Sustainable development of marine aquaculture off-the-coast and offshore – a review of environmental and ecosystem issues and future needs in temperate zones. *In* A. Lovatelli, J. Aguilar-Manjarrez & D. Soto, eds. *Expanding mariculture farther offshore: technical, environmental, spatial and governance challenges. FAO Technical Workshop, 22–25 March 2010, Orbetello, Italy.* pp. 135–171. FAO Fisheries and Aquaculture Proceedings No. 24. Rome, FAO. 314 pp.

Holmer, M. & Frederiksen, M. S. 2007. Stimulation of sulfate reduction rates in Mediterranean fish farm sediments inhabited by the seagrass Posidonia oceanica. *Biogeochemistry*, 85: 169–184.

Holmer, M. & Kristensen, E. 1992. Impact of marine fish cage farming on sediment metabolism and sulfate reduction of underlying sediments. *Marine Ecology – Progress Series*, 80: 191–201.

Holmer, M., Marba, N., Diaz-Almela, E., Duarte, C.M., Tsapakis, M. & Danovaro, R. 2007. Sedimentation of organic matter from fish farms in oligotrophic Mediterranean assessed through bulk and stable isotope (delta C-13 and delta N-15) analyses. *Aquaculture,* 262: 268–280.

Holmer, M., Wildish, D. & Hargrave, B.T. 2005. Organic enrichment from marine finfish aquaculture and effects on sediment processes. *In* B.T. Hargrave, ed. *Environmental Effects of Marine Finfish Aquaculture*, pp. 181–206. Springer, Berlin.

Hyland, J., Balthis, L., Karakassis, I., Magni, P., Petrov, A., Shine, J., Vestergaard, O. & Warwick, R. 2005. Organic carbon content of sediments as an indicator of stress in the marine benthos. *Marine Ecology – Progress Series*, 295: 91–103.

James, M.A. & Slaski, R. 2006. *Appraisal of the opportunity for offshore aquaculture in UK waters*. UK, Department for Environment and Rural Affairs and Seafish.

Kalantzia, I. & Karakassisa, I. 2006. Benthic impacts of fish farming: Meta-analysis of community and geochemical data. *Marine Pollution Bulletin.* 52: 484–493.

Kapetsky, J.M., Aguilar-Manjarrez, J. & Jenness , J. 2013. *A global assessment of potential for offshore mariculture development from a spatial perspective*. FAO Fisheries and Aquaculture Technical Paper No. 549. Rome, FAO. 181 pp. (also available at www.fao.org/docrep/017/i3100e/i3100e00.htm).

Kite-Powell, H.L., Hoagland, P. & Jin, D. 2003. Economics of open ocean grow-out of shellfish in New England: Sea scallops and blue mussels. *In* C.J. Bridger & B.A. Costa-Pierce, eds. *Open ocean aquaculture – from research to commercial reality*, pp. 293–306. Baton Rouge, USA, The World Aquaculture Society.

Kite-Powell, H.L., Hoagland, P., Jin, D. & Murray, K. 2003. Open ocean grow-out of finfish in New England: A bioeconomic model. *In* C.J. Bridger & B.A. Costa-Pierce, eds. *Open ocean aquaculture – from research to commercial reality*, pp. 319–324. Baton Rouge, USA, The World Aquaculture Society.

Kutti, T., Ervik, A. & Hansen, P.K. 2007. Effects of organic effluents from a salmon farm on a fjord system. I. Vertical export and dispersal processes. *Aquaculture,* 262: 367–381.

Kutti, T., Hansen, P. K., Ervik, A., Hoisaeter, T. & Johannessen, P. 2007. Effects of organic effluents from a salmon farm on a fjord system. II. Temporal and spatial patterns in infauna community composition. *Aquaculture*, 262: 355–366.

Kutti, T., Ervik, A. & Hoisaeter, T. 2008. Effects of organic effluents from a salmon farm on a fjord system. III. Linking deposition rates of organic matter and benthic productivity. *Aquaculture*, 282: 47–53.

Langan, R. 2000a. Open ocean culture of blue mussels. *Mytilus edulis* using submerged longlines. *In World Aquaculture*. Nice, France, World Aquaculture Society. 365 pp.

Langan, R. 2000b. Submerged longline culture of blue mussels (*Mytilus edulis*) at an open ocean site in the Gulf of Maine. *Journal of Shellfish Research*, 19: 575.

Lee, H., Bailey-Brock, J. & McGurr, M. 2006. Temporal changes in the polychaete infaunal community surrounding a Hawaiian mariculture operation. *Marine Ecology – Progress Series*, 307: 175–185.

Liao, I.C. 2003. Candidate species for open ocean aquaculture: the successful case of cobia *Rachycentron canadum* in Taiwan. *In* C.J. Bridger & B.A. Costa-Pierce, eds. *Open ocean aquaculture – from research to commercial reality,* pp. 205–213. Baton Rouge, USA, The World Aquaculture Society.

Lojen, S., Spanier, E., Tsemel, A., Katz, T., Eden, N. & Angel, D.L. 2005. d^{15}N as a natural tracer of particulate nitrogen effluents released from marine aquaculture. *Marine Biology*, 148: 87–96.

Long, R. 2007. *Marine resource law*. London/Dublin/Toronto/Hong Kong, Thomson Round Hall.

Lovatelli, A. 1988. *Status of scallop farming: A review of techniques*. FAO Document SF/WP/87/1. 22 pp. (also available at www.fao.org/docrep/field/003/AB714E/AB714E01.htm).

Magill, S.H., Thetmeyer, H. & Cromey, C.J. 2006. Settling velocity of faecal pellets of gilthead seabream (*Sparus aurata* L.) and seabass (*Dicentrarchus labrax* L.) and sensitivity analysis using measured data in a deposition model. *Aquaculture*, 251: 295–305.

Maldonado, M., Carmona, M.C., Echeverria, Y. & Riesgo, A. 2005. The environmental impact of Mediterranean cage fish farms at semi-exposed locations: does it need a re-assessment? *Helgoland Marine Research*, 59: 121–135.

Marra, J. 2005. When will we tame the oceans? *Nature*, 436: 175–176.

Matijevic, S., Kuspilic, G. & Baric, A. 2006. Impact of a fish farm on physical and chemical properties of sediment and water column in the middle Adriatic Sea. *Fresenius Environmental Bulletin*, 15: 1058–1063.

McGinnity, P., Prodohl, P., Ferguson, K., Hynes, R., O'Maoileidigh, N., Baker, N., Cotter, D., O'Hea, B., Cooke, D., Rogan, G., Taggart, J. & Cross, T. 2003. Fitness reduction and potential extinction of wild populations of Atlantic salmon, *Salmo salar*, as a result of interactions with escaped farm salmon. *Proceedings of the Royal Society of London Series B-Biological Sciences*, 270: 2443–2450.

McGinnity, P., Prodohl, P., Maoileidigh, N.O., Hynes, R., Cotter, D., Baker, N., O'Hea, B. & Ferguson, A. 2004. Differential lifetime success and performance of native and non-native Atlantic salmon examined under communal natural conditions. *Journal of Fish Biology*, 65: 173–187.

Merican, Z. 2006. Marine finfish cage culture - Industry Review. *Aqua Culture Asia Pacific*, 2(2): 22–24.

Merino, G.E. 1997. Considerations for longline culture systems design; scallops production. *In* C.E. Helsley, ed. *Open ocean aquaculture '97: charting the future of ocean farming*. pp. 145–154. Maui, USA, University of Hawaii.

Middleton, I. 2004. Commercial barramundi *Lates calcarifer* farming with rural villagers along the north coast of Madang, Papua New Guinea. *In: Proceedings of Australasian Aquaculture 2004, Sydney Convention Centre, Sydney, Australia*. 206 pp.

Miller, F.P. 2008. After 10,000 years of agriculture, whither agronomy? *Agronomy Journal*, 100: 22–34.

Ministry of Agro Industry & Fisheries (Fisheries Division). 2007. *Potential for sustainable aquaculture development in Mauritius*. Port Louis, Mauritius. 11 pp.

Muir, J. 2004. Offshore Mariculture System Options. Lecture delivered at the CIHEAM Advanced Course on Offshore Mariculture, Zaragoza (Spain), 17–22 May 2004.

Nash, C.E. 2004. Achieving policy objectives to increase the value of the seafood industry in the United States. The technical feasibility and associated constraints. *Food Policy*, 29: 621–641.

Nash, C.E., Iwamoto, R.N. & Mahnken, C.V.W. 2000. Aquaculture risk management and marine mammal interactions in the Pacific Northwest. *Aquaculture*, 183: 307–323.

Naylor, R. & Burke, M. 2005. Aquaculture and ocean resources; raising tigers of the sea. *Annual Review of Environment and Resources* 30: 185–218.

Naylor, R.L., Hardy, R.W., Bureau, D.P., Chiu, A., Elliott, M., Farrell, A.P., Forster, I., Gatlin, D.M., Goldburg, R.J., Hua, K. & Nichols, P.D. 2009. Feeding aquaculture in an era of finite resources. *Proceedings of the National Academy of Sciences USA*, 106(36): 15103–15110.

Neori, A. 2008. Essential role of seaweed cultivation in integrated multi-trophic aquaculture farms for global expansion of mariculture: an analysis. *Journal of Applied Phycology*, 20: 567–570.

Nichols, P.D., Petrie, J. & Singh, S. 2010. Long-chain omega-3 oils: An update on sustainable sources. *Nutrients*, 2: 572–585.

O'Hanlon, B., Benetti, D.D., Stevens, O., Rivera, J. & Ayvazian, J. 2003. Recent progress and constraints towards implementing an offshore cage aquaculture project in Puerto Rico, USA. *In* C.J. Bridger & B.A. Costa-Pierce, eds. *Open ocean aquaculture – from research to commercial reality*, pp. 263–268. Baton Rouge, USA, The World Aquaculture Society.

Olsen, L.M., Holmer, M. & Olsen, Y. 2008. *Perspectives of nutrient emission from fish aquaculture in coastal waters – Literature review with evaluated state of knowledge*. Project No. 542014. The Fishery and Aquaculture Industry Research Fund (also available at www.fiskerifond.no/files/projects/attach/fhf-nutrients_and_aquaculture.pdf).

Olsen, Y. 2011. Resources for fish feed in future mariculture. *Aquacult. Environ. Interact.*, 1: 187–200.

Olsen, Y., Agusti, S., Andersen, T., Duarte, C.M., Gasol, P., Gismervik, I., Heiskanen, A-S., Hoell, E., Kuuppo, P., Lignell, R., Reinertsen, H., Sommer, U., Stibor, H., Tamminen, T., Vadstein, O., Vaqué, D. & Vidal, M. 2006. A comparative study of responses in planktonic food web structure and function in contrasting European coastal waters exposed to experimental nutrient addition. *Limnology & Oceanography*, 51: 488–503.

Olsen, Y., Andersen, T., Gismervik, I. & Vadstein, O. 2007. Protozoan and metazoan zooplankton-mediated carbon flows in nutrient-enriched coastal planktonic communities. *Marine Ecology – Progress Series*, 331: 67–83.

Olsen, Y. & Olsen, L.M. 2008. Environmental impact of aquaculture on coastal planktonic ecosystems. *In* K. Tsukamoto, T. Kawamura, T. Takeuchi, T.D. Beard Jr. & M.J. Kaiser, eds. *Fisheries for Global Welfare and Environment*, pp. 181–196. 5th World Fisheries Congress, Terrapub.

Olsen, Y., Otterstad, O. & Duarte, C.M. 2008. Status and future perspectives of marine aquaculture. *In* M. Holmer, K. Black, C.M. Duarte, N. Marbà & I. Karakasis, eds. *Aquaculture in the Ecosystem*, pp. 293–319. Springer.

Paul, W. 2000. *An offshore mussel aquaculture experiment*. Woods Hole, USA, Woods Hole Oceanographic Institution.

Pearson, T.H. & Rosenberg, R. 1978. Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. *Oceanography and Marine Biology: Annual Review*, 16: 229–311.

Percy, D.R., Hishamunda, N. & Kuemlangan, B. 2013. Governance in marine aquaculture: the legal dimension. *In* A. Lovatelli, J. Aguilar-Manjarrez & D. Soto, eds. *Expanding mariculture further offshore: technical, environmental, spatial and governance challenges, FAO Technical Workshop. 22–25 March 2010, Orbetello, Italy*, pp. 245–262. FAO Fisheries and aquaculture Proceedings No. 24. Rome, FAO. 314 pp.

Pitta, P., Tsapakis, M., Apostolaki, E. T., Tsagaraki, T., Holmer, M. & Karakassis, I. 2009. “Ghost nutrients” from fish farms are transferred up the food web by phytoplankton grazers. *Marine Ecology–Progress Series*, 374: 1–6.

Posadas, B.C. & Bridger, C.J. 2003. Economic feasibility of offshore aquaculture in the Gulf of Mexico. *In* C.J. Bridger & B.A. Costa-Pierce, eds. *Open ocean aquaculture – from research to commercial reality*. pp. 307–317. Baton Rouge, USA, The World Aquaculture Society.

Rapp, P., Ramirez, W.R., Rivera, J.A., Carlo, M. & Luciano, R. 2007. Measurement of organic loading under an open-ocean aquaculture cage, using sediment traps on the bottom. *Journal of Applied Ichthyology*, 23: 661–667.

Read, P. & Fernandes, T. 2003. Management of environmental impacts of marine aquaculture in Europe. *Aquaculture*, 226: 139–163.

Reid, G.K., Liutkus, M., Robinson, S.M.C., Chopin, T.R., Blair, T., Lander, T., Mullen, J., Page, F. & Moccia, R.D. 2009. A review of the biophysical properties of salmonids faeces: implications for aquaculture waste dispersal models and integrated multi-trophic aquaculture. *Aquaculture Research*, 40: 257–273.

Ribakoff, S.B., Rothwell, G.N. & Hanson, J.A. 1974. Platforms and housing for open sea mariculture. *In* J.A. Hanson, ed. *Open sea mariculture: perspectives, problems and prospects*, pp. 295–333. Stroudsburg, USA, Dowden, Hutchinson & Ross, Inc.

Rimmer, M. 1995. The challenges of agricultural production and food security in Africa. *Journal of Southern African Studies*, 21: 165–167.

Rimmer, M.A. & Ponia, B. 2007. A review of cage aquaculture: Oceania. *In* M. Halwart, D. Soto & J.R. Arthur, eds. *Cage aquaculture – Regional reviews and global overview*, pp. 208–231. FAO Fisheries Technical Paper No. 498. Rome, FAO. 241 pp. (also available at www.fao.org/docrep/010/a1290e/a1290e00.htm).

Rotman, F.J., Benetti, D.D., Alarcón, J.F., Stevens, O., Banner-Stevens, G., Matzie, W., Feeley, M.W., Zimmerman, S., O'Hanlon, B. & Eldridge, L. 2003. Advances in aquaculture technology of mutton snapper (*Lutjanus analis*) and greater amberjack (*Seriola dumerili*), two candidate species for offshore grow-out. *In* C.J. Bridger & B.A. Costa-Pierce, eds. *Open ocean aquaculture – from research to commercial reality*, pp. 215–221. Baton Rouge, Louisiana, USA, The World Aquaculture Society.

Ryan, J. 2004. *Farming the Deep Blue*. Dublin, Ireland, Sea Fisheries Board and Marine Institute. 160 pp.

Ryan, J., Jackson, D. & Maguire, D. 2007. *Offshore aquaculture development in Ireland; next steps*. Dublin, Ireland, Board Iascaigh Mhara Technical Report (Irish Sea Fisheries Board) and the Marine Institute.

Scott, D.B.C. & Muir, J.F. 2000. Offshore cage systems: a practical overview. *In* J.F. Muir & B. Basurco, eds. *Mediterranean offshore mariculture*, pp. 79–89. Options Méditerranéennes: Série B. Etudes et Recherches; n. 30. Advanced Course of the CIHEAM Network on Technology of Aquaculture in the Mediterranean on "Mediterranean Offshore Mariculture", 1997/10/20-24, Zaragoza (Spain). Saragossa, Spain, Centre International de Hautes Etudes Agronomiques Méditerranéenes:.

Sepulveda, M. & Oliva, D. 2005. Interactions between South American sea lions *Otaria flavescens* (Shaw) and salmon farms in southern Chile. *Aquaculture Research*, 36: 1062–1068.

Soto, D. ed. 2009. *Integrated mariculture: a global review*. FAO Fisheries and Aquaculture Technical Paper No. 529. Rome, FAO. 183 pp. (also available at www.fao.org/docrep/012/i1092e/i1092e00.htm).

Soto, D. & Norambuena, F. 2004. Evaluation of salmon farming effects on marine systems in the inner seas of southern Chile: a large-scale mensurative experiment. *Journal of Applied Ichthyology*, 20: 493–501.

Stemler, C. 2009. *Open sea aquaculture in Panama: An assessment of cobia production by pristine oceans*. Smithsonian Tropical Research Institute. The McGill Panama Field Study Semester. 29 pp.

Stickney, R.R. 1997. Offshore mariculture. *In* J.E. Bardach, ed. *Sustainable aquaculture*, pp. 53–86. New York, USA, John Wiley & Sons, Inc.

Sutherland, T.F., Petersen, S.A., Levings, C.D. & Martin, A.J. 2007. Distinguishing between natural and aquaculture-derived sediment concentrations of heavy metals in the Broughton Archipelago, British Columbia. *Marine Pollution Bulletin*, 54: 1451–1460.

Tacon, A.G.J. & Halwart, M. 2007. Cage aquaculture: a global overview. *In* M. Halwart, D. Soto & J.R Arthur, eds. *Cage aquaculture – regional reviews and global overview,* pp. 1–16. Fisheries Technical Paper No. 498. Rome, FAO. 241 pp. (also available at www.fao.org/docrep/010/a1290e/a1290e00.htm).

Tacon, A.G.J. & 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.

Tacon, A.G.J., Hasan, M.R. & Metian, M. 2011. *Demand and supply of feed ingredients for farmed fish and crustaceans: trends and prospects*. FAO Fisheries and Aquaculture Technical Paper No. 564. Rome, FAO. 87 pp. (also available at www.fao.org/docrep/015/ba0002e/ba0002e.pdf).

Tett, P. 2008. Fish farm wastes in the ecosystem. *In* M. Holmer, K. Black, C.M. Duarte, N. Marbà & I. Karakasis, eds. *Aquaculture in the Ecosystem*, pp. 1–46. Springer.

Thetmeyer, H., Pavlidis, A. & Chromey, C. 2003. *Interactions between wild and farmed fish*. The Meramed project, Newsletter 3.

Tuya, F., Sanchez-Jerez, P., Dempster, T., Boyra, A. & Haroun, R.J. 2006. Changes in demersal wild fish aggregations beneath a sea-cage fish farm after the cessation of farming. *Journal of Fish Biology,* 69: 682–697.

UNCLOS. 1982. *United Nations Convention on the Law of the Sea of 10 December 1982*. 208 pp. (also available at www.un.org/depts/los/convention_agreements/texts/unclos/UNCLOS-TOC.htm).

Vezzulli, L., Moreno, M., Marin, V., Pezzati, E., Bartoli, M. & Fabiano, M. 2008. Organic waste impact of capture-based Atlantic bluefin tuna aquaculture at an exposed site in the Mediterranean Sea. *Estuarine Coastal and Shelf Science*, 78: 369–384.

Vita, R., Marin, A., Jimenez-Brinquis, B., Cesar, A., Marin-Guirao, L. & Borredat, M. 2004. Aquaculture of Bluefin tuna in the Mediterranean: evaluation of organic particulate wastes. *Aquaculture Research*, 35: 1384–1387.

Wilson, S. 2004. Sustainable aquaculture: an organizing solution in international law. *Thomas Jefferson Law Review*, 26: 491–492.

Xu, J.Z. 2004. Wave-resistance cage culture technique in deep sea. *Scientific Fish Farming*, 4(6): 10–11.

Yoza, B.A., Harada, R.M., Nihous, G.C., Lib, Q.X. & Masutania, S.M. 2007. Impact of mariculture on microbial diversity in sediments near open ocean farming of *Polydactylus sexfilis*. *Ecological Indicators*, 7: 108–122.

Appendix 1

ESTIMATES OF STATUS AND POTENTIAL FOR OFFSHORE MARICULTURE

The status and potential for offshore mariculture was estimated by Kapetsky, Aguilar-Manjarrez and Jenness (2013) on the basis of surface areas and numbers of nations that meet various criteria. The technical criteria include water depths (25–100 m) and current speeds (10–100 cm/s) suitable for sea cages and longlines. The economic criterion is the cost-effective area for development, that is the area within 25 nm of a servicing port. Temperature identifies areas favourable for the growout of cobia (22–32 °C), Atlantic salmon (1.5–16 °C) and blue mussel (2.5–18 °C). For the latter, favourable growout is also defined by chlorophyll-*a* concentration (>0.5 mg/m^3).

The status and potential of offshore mariculture development are tabulated in three ways:

1. by numbers of nations and aggregate surface areas meeting various criteria (Table A1);
2. by ranks[1] of climate zones (Table A2);
3. by first ranked nations in each climate zone (Table A3).

In the tabulations, a distinction is made between nations in which mariculture is already developed or "mariculture nations" and those not yet practising mariculture or "non-mariculture nations". For reasons of economy of space many of the results presented in the tables are not discussed in the text of this Appendix; however, the results often relate to the text in other sections of this global synthesis or to the review papers that support this synthesis. For example, defining offshore mariculture is one of the topics of the synthesis, and depth is one of ways that mariculture zones can be defined. In this regard, Table A1 under the topic "Zones and Maritime Claims" provides the areas corresponding to the various depth zones. Four of the review papers in these proceedings deal with various aspects of offshore mariculture by climate zones. In this regard, Table A2 ranks offshore mariculture potential by climate zone based on the surface area meeting criteria and combinations of criteria. In the same vein, Table A3 identifies the first-ranked nation meeting the criteria and combinations of criteria in each climate zone based on the amount of surface area with potential.

Mariculture countries for the purposes of this study are those listed in the FAO aquaculture production statistics as having mariculture production originating from the marine environment in one or more years.

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[1] A rank classification for suitability was set from 1–5 (i.e. 1 least suitable, and 5 most suitable) based on the amount of surface area meeting criteria.

TABLE A1

Summary of the status and potential for offshore mariculture development by numbers of nations and aggregate area meeting criteria

Present status of mariculture production

	Mariculture nations		**Non-mariculture nations**		**Total**	
Production	Nations and territories	Mean production (tonnes) 2004–2008	Nations and territories	Production (tonnes) 2004–2008	NA	NA
	93	29 976 736	72	0		

Present status of mariculture intensity

Mariculture intensity	**Nations and territories**	**Production (tonnes/km coastline)**
	93	–
Mean	–	15
Median	–	1
Maximum	–	520

Present status of mariculture coastline length

Coastline length	**Mariculture nations**		**Non-mariculture nations**		**Total**	
	km		km		Nations	km
	80	1 472 111	83	302 548	163	1 774 659

Notes:

Non-mariculture nations are maritime nations not yet practicing mariculture.

The results by Kapetsky, Aguilar-Manjarrez and Jenness (2013) are not discussed in Annex 1, but presented herein as relevant to Annex 1 and various review papers in these proceedings. For additional details and in depth analysis see Kapetsky, J.M., Aguilar-Manjarrez, J. & Jenness, J. 2013. *A global assessment of offshore mariculture potential from a spatial perspective*. FAO Fisheries and Aquaculture Technical Paper No. 549. Rome, FAO.

The differences in the number of nations and territories between mariculture production and intensity versus coastline length are attributed to the fact that two different spatial data sets were used (i.e. the number of countries/territories varied between these data sets). The FAO statistical database contains production attributes assigned to country and territory names. It reports production from some territories separately from their associated sovereign nations. In contrast, coastline length was derived for this study using GIS methods from a different set of country and territory associations in digital format in which each coastline is a spatial object from which its length becomes an attribute. The differences have been taken into account in estimating mariculture intensity.

Zones and maritime claims

	Mariculture nations		**Non-mariculture nations**		**Total**	
	EEZs	Area (km^2)	EEZs	Area (km^2)	EEZs	Area (km^2)
Area of Exclusive Economic Zones	189	131 361 870	77	32 627 206	266	163 989 076

Zones and Maritime claims	Nations	Area (km^2)	Nations	Area (km^2)	Nations	Area (km^2)
Territorial Sea		20 750 899		4 587 804		25 338 704
Contiguous Zone		4 969 506		724 344		5 693 850
Economic Zone		118 730 541		23 774 037		142 504 578
Fishing Zone		12 404 048		69 008		12 473 056
Total	78	156 854 994	79	29 155 194	158	186 010 188

Mariculture zones defined by depth	Nations	Area (km^2)	Nations	Area (km^2)	Nations	Area (km^2)
1–10 m		2 010 632		260 325		2 270 956
Off the coast (10–50 m)		11 163 661		789 506		11 953 167
Offshore (50–150 m)		8 552 668		808 162		9 360 829
>150 m		109 597 945		30 405 078		140 003 023
Total	83	131 324 906	67	32 263 070	158	163 587 976

Technical feasibility for cages and longlines and cost-effective area for development (area 25 nm from a servicing port)

Technical feasibility and cost-effective area for development	Mariculture nations		Non-mariculture nations		Total	
	Nations	Area (km^2)	Nations	Area (km^2)	Nations	Area (km^2)
Depths suitable for cages and longlines (25–100 m)	82	12 405 003	71	1 000 446	153	13 405 449
Current speed suitable for cages (10-100 cm/s)	77	84 244 659	69	16 790 002	146	101 034 662
Depths (25–100 m) and current speeds (10–100 cm/s) suitable for cages and longlines	73	1 234 771	65	190 383	138	1 425 154
Cost-effective area for development	79	5 119 018	74	1 015 430	153	6 134 448
Cost-effective area for development and depths and current speeds suitable for cages	69	146 820	52	42 648	121	189 468

Note:
The varying numbers of nations reflect the fact that differing numbers of nations meet the various depths, current speed, cost-effective distance and other thresholds of the Kapetsky, Aguilar-Manjarrez and Jenness (2013) study. What is important here is the absolute number of nations that meet various criteria, not the relative numbers.

Environments favourable for growout integrated with technical criteria and the cost-effective area for development

Temperatures and chlorophyll-a concentrations suitable for favourable growout; depths (25–100 m) and current speeds (10–100 cm/s) suitable for cages and longlines

	Mariculture nations		Non-mariculture nations		Total	
	Nations	Area (km^2)	Nations	Area (km^2)	Nations	Area (km^2)
Cobia temperature range 22–32 °C	44	658 031	40	135 907	84	793 938
Atlantic salmon temperature range 1.5–16 °C;	14	30 566	0	0	14	30 566
Chlorophyll-a >0.5 mg/m^3	95	6 2376 545	54	717 804	149	6 994 349
Blue mussel temperature 2.5–19 °C and chlorophyll-a >0.5 mg/m^3	15	29 960	0	0	15	29 960
IMTA temperature 2.5–16 °C and chlorophyll-a >0.5 mg/m^3	9	14 590	0	0	9	14 590

Cost-effective area for development (area 25 nm from a servicing port), temperatures suitable for favourable growout, depths (25–100 m) and current speeds (10–100 cm/s) suitable for cages and longlines

	Mariculture nations		Non-mariculture nations		Total	
	Nations	Area (km^2)	Nations	Area (km^2)	Nations	Area (km^2)
Cobia temperature range 22–32 °C	42	66 188	38	31 004	80	97 192
Atlantic salmon temperature range 1.5–16 °C	6	2 447	0	0	6	2 447
Blue mussel temperature 2.5–19 °C and chlorophyll-a >0.5 mg/m^3	11	5 848	0	0	11	5 848
IMTA temperature 2.5–16 °C and chlorophyll-a >0.5 mg/m^3	6	1 202	0	0	6	1 202

Locations that minimize competing and conflicting uses while taking advantage of possible complementary uses of marine space as illustrated by marine protected areas

	Mariculture nations		Non-mariculture nations		Total	
	Nations	Area (km^2)	Nations	Area (km^2)	Nations	Area (km^2)
Marine protected areas (MPAs) worldwide	93	3 533 612	51	296 957	120	3 830 569
Suitable inside MPAs for cobia offshore mariculture (temperature suitable; depths and current speeds suitable)	31	44 863	12	2 092	43	46 955

TABLE A2

Summary of potential for offshore mariculture by rank (from 1 to 5) of climate zones and by mariculture and non-mariculture nations based on aggregated surface area meeting criteria in each climate zone

Ranking: 1 least potential, to 5 highest potential

Criteria	**Arctic**	**Northern temperate**	**Intertropical**	**Southern temperate**	**Antarctic**
Present status of mariculture					
Production					
Mariculture (1)	3	2	1	4	0
Coastline length					
Mariculture	3	1	2	4	0
Non-mariculture	3	2	1	5	4
Mariculture intensity					
Mariculture	3	1	2	4	0
Zones and maritime claims					
Area of Exclusive Economic Zones					
Mariculture	4	2	1	3	0
Non-mariculture (2)	0	4	1	3	2
Maritime claims *Territorial Sea + Contiguous Zone*					
Mariculture (3)	3	2	1	4	5
Non-mariculture	0	2	1	5	4
Mariculture zones defined by depth *Off the coast (10–50 m) + Offshore (50–150 m)*					
Mariculture	3	1	2	4	0
Non-mariculture	0	2	1	4	3
Technical feasibility and cost-effective area for development					
Depths for cages and longlines (25–100 m)					
Mariculture	3	2	1	4	0
Non-mariculture	0	2	1	4	3
Current speed for cages and longlines (10–100 cm/s)					
Mariculture	4	3	1	2	0
Non-mariculture	0	4	1	2	3
Depths and current speeds suitable for cages and longlines					
Mariculture	4	2	1	3	0
Non-mariculture	0	2	1	3	4
Cost-effective areas (area 25 nm from a port)					
Mariculture	4	1	2	3	0
Non-mariculture	0	2	1	3	0
Cost-effective areas (area 25 nm from a port and depths and current speeds suitable for cages)					
Mariculture	4	2	1	3	0
Non-mariculture	0	2	1	3	0

TABLE A2 – CONTINUED

Environments favourable for growout: temperature and chlorophyll-a concentration suitable, depths (25–100 m) and current speeds (10–100 cm/s) suitable for cages and longlines	**Arctic**	**Northern temperate**	**Intertropical**	**Southern temperate**	**Antarctic**
Cobia temperature range suitable (22–32 °C)					
Mariculture	0	2	1	3	0
Non-mariculture	0	2	1	0	0
Atlantic salmon temperature range suitable (1.5–16 °C)					
Mariculture	3	2	0	1	0
Non-mariculture (4)	0	0	0	0	0
Blue mussel temperature and chlorophyll-a suitable (2.5–19 °C ; >0.5 mg/m^3)					
Mariculture	3	2	0	1	0
Non-mariculture	0	1	0	0	0
IMTA temperature and chlorophyll-a suitable (2.5–16 °C ; >0.5 mg/m^3)					
Mariculture	3	2	0	1	0
Non-mariculture	0	1	0	0	0

Environments favourable for growout and within the cost-effective area for development: temperature and chlorophyll-a concentration suitable, depths (25–100 m) and current speeds (10–100 cm/s) suitable for cages and longlines	**Arctic**	**Northern temperate**	**Intertropical**	**Southern temperate**	**Antarctic**
Cobia temperature range suitable (22–32 °C)					
Mariculture	0	2	1	3	0
Non-mariculture	0	0	1	0	0
Atlantic salmon temperature range suitable (1.5–16 °C)					
Mariculture	3	1	0	2	0
Non-mariculture	0	0	0	0	0
Blue mussel temperature and chlorophyll-a suitable (2.5–19 °C ; >0.5 mg/m^3)					
Mariculture	3	1	0	2	0
Non-mariculture	0	0	0	0	0
IMTA temperature and chlorophyll-a suitable (2.5–16 °C ; >0.5 mg/m^3)					
Mariculture	3	1	0	2	0
Non-mariculture	0	0	0	0	0

Locations that minimize competing and conflicting uses while taking advantage of possible complementary uses of marine space as illustrated by marine protected areas	**Arctic**	**Northern temperate**	**Intertropical**	**Southern temperate**	**Antarctic**
Marine protected areas (MPAs)					
Mariculture	3	1	2	4	5
Non-mariculture	0	3	1	2	4
Cobia suitable for temperature; cage and current speeds suitable inside MPAs					
Mariculture	0	2	1	3	0
Non-mariculture	0	2	1	0	0

Notes:
(1) There is no mariculture in the Antarctic Zone; (2) There are no non-mariculture nations in the Arctic Zone; (3) Some mariculture countries have territorial claims in the Antarctic Zone; (4) No ports are listed for the Antarctic Zone in the World Port Index (National Geospatial-intelligence Agency, 2009).

TABLE A3

Sovereign nations ranked first in surface area for offshore mariculture potential in each climate zone by mariculture and non-mariculture nations

	Mariculture nations					Non-mariculture nations				
	AZ	NTZ	ITZ	STZ	AaZ	AZ	NTZ	ITZ	STZ	AaZ
Present status of mariculture										
Production	Canada	China	China	Chile	–	–	–	–	–	–
Coastline length	Canada	Canada	Indonesia	Chile	–	–	Denmark (1)	Bangladesh	Antarctica	–
Mariculture intensity	Norway	China	China	Chile	–	–	–	–	–	–
Zones and maritime claims										
Area of Exclusive Economic Zones	Russia	United States of America	France	France	–	–	Egypt	Micronesia (Federated States of)	Antartica (2)	–
Maritime claims	–	–	–	–	–	–	–	–	–	–
Territorial Sea + Contiguous Zone	Canada	Canada	Indonesia	Australia	United Kingdom	–	Iran (Islamic Republic of)	Ecuador	Uruguay	–
Mariculture zones defined by depth	–	–	–	–	–	–	–	–	–	–
Off the coast (10–50 m) + Offshore (50–150 m)	Russia	United States of America	Indonesia	Argentina	–	–	Iran (Islamic Republic of)	Venezuela (Bolivarian Republic of)	Antarctica (3)	–
Technical feasibility and cost-effective area for development										
Depths for cages and longlines (25–100 m)	Canada	United States of America	Indonesia	Argentina	–	–	Iran (Islamic Republic of)	Venezuela (Bolivarian Republic of)	Antarctica	–
Current speed for cages and longlines (10–100 cm/s)	Denmark	United States of America	France	France	–	–	Egypt	Micronesia (Federated States of)	Antarctica	–
Depths and current speeds suitable for cages and longlines (25–100 m; 10–100 cm/s)	United States of America	United States of America	Indonesia	Australia	–	–	Egypt	Venezuela (Bolivarian Republic of)	Uruguay	–
Cost-effective area for development (area 25 nm from a port)	Norway	United States of America	Indonesia	Australia	–	–	Finland	Nigeria	Antarctica	–
Cost-effective area for development (area 25 nm from a port with depths and current speeds suitable for cages (25–100 m; 10–100 cm/s)	United States of America	Taiwan Province of China	India	Australia	–	–	Finland	Nigeria	Uruguay	–

Notes:

(1) Denmark figures prominently in the NTZ due to its association with Greenland; (2) Territorial claims in Antarctica are not identified in the Flanders Maritime Institute spatial database; (3) The Global Maritime Database identifies claims in Antarctica.

Terminology: AZ = Arctic Zone; NTZ = Northern Temperate Zone; ITZ = Intertropical Zone; STZ = Southern Temperate Zone; AaZ = Antarctic Zone.

TABLE A3 – CONTINUED

Sovereign nations ranked first for offshore mariculture potential by surface area in each climate zone and by mariculture and non mariculture nations

	Mariculture					No mariculture				
	AZ	NTZ	ITZ	STZ	AaZ	AZ	NTZ	ITZ	STZ	AaZ
Present status of mariculture										
Environments favourable for growout: temperature and chlorophyll-a concentration suitable, depths (25–100 m) and current speeds (10–100 cm/s) suitable for cages and longlines										
Cobia temperature range 22–32 °C	–	United States of America	Indonesia	Madagascar	–	–	Egypt	Venezuela (Bolivarian Republic of)	–	–
Atlantic salmon temperature range 1.5–16 °C	Norway	United States of America	–	Chile	–	–	–	–	–	–
Blue mussel temperature 2.5–19 °C and chlorophyll-a >0.5 mg/m^3	Norway	Denmark	–	Argentina	–	–	Poland	–	–	–
IMTA temperature 2.5–16 °C and chlorophyll-a >0.5 mg/m^3	Norway	United States of America	–	Argentina	–	–	–	–	–	–
Environments favourable for growout and within the cost-effective area for development: temperature and chlorophyll-a concentration suitable, depths (25–100 m) and current speeds (10–100 cm/s) suitable for cages and longlines										
Cobia temperature range 22–32 °C	–	United States of America	India	Madagascar	–	–	–	Nigeria	–	–
Atlantic salmon temperature range 1.5–16 °C	Norway	United States of America	–	New Zealand	–	–	–	–	–	–
Blue mussel temperature 4–18 °C and chlorophyll-a >1mg/m^3	Norway	Denmark	–	New Zealand	–	–	–	–	–	–
IMTA temperature 2.5–16 °C and chlorophyll-a >0.5 mg/m^3	Norway	United States of America	–	New Zealand	–	–	–	–	–	–
Locations that minimize competing and conflicting uses while taking advantage of possible complementary uses										
Marine protected areas (MPAs)	Denmark	United States of America	Kiribati	Australia	–	–	–	Ecuador	–	–
Cobia suitable for temperature, cage depth and current speeds suitable inside MPAs	–	United States of America	Australia	South Africa	–	–	Egypt	Micronesia (Federated States of)	–	–

Notes:

(1) Denmark figures prominently in the NTZ due to its association with Greenland; (2) Territorial claims in Antarctica are not identified in the Flanders Maritime Institute spatial database; (3) The Global Maritime Database identifies claims in Antarctica.

Terminology: AZ = Arctic Zone; NTZ = Northern Temperate Zone; ITZ = Intertropical Zone; STZ = Southern Temperate Zone; AaZ = Antarctic Zone.

Annex 2 – Workshop agenda

AGENDA AND TIMETABLE

	Monday, 22 March
14:00–16:00	Welcome note, introductions and adoption of agenda Initiative objectives and goals Technical review – temperate – **J. Forster** Technical review – tropical – **A. Jeffs** Environment review – temperate – **M. Holmer**
16:00–16:30	***Coffee break***
16:30–18:00	Environment review – tropical – **D. Angel** GIS spatial analysis – **J. Kapetsky** Remote sensing – **J. Aguilar-Manjarrez**
	Tuesday, 23 March
08:30–10:30	Economic & marketing review – **G. Knapp** Case Study I – Kona Blue – **N. Sims** Case Study II – Salmon farming in Chile – **A. Alvial** Policy and Governance review – **D. Percy**
10:30–11:00	***Coffee break***
11:00–12:30	Preliminary issues and actions identified for possible inclusion in the FAO global offshore mariculture development initiative – **Y. Olsen** Formation of Working Groups and review of TORs
12:30–14:00	***Lunch break***
14:00–16:00	Working Group I – Technical issues Economic and marketing issues Working Group II – Environmental issues Policy and governance issues
16:00–16:30	***Coffee break***
16:30–18:00	Working Group I – Cont'd Working Group II – Cont'd

Wednesday, 24 March	
08:30–10:00	Working Group I – Cont'd Working Group II – Cont'd
10:00–10:30	***Coffee break***
10:30–12:30	Working Group I – Cont'd Working Group II – Cont'd
12:30–14:00	***Lunch break***
14:00-15:30	Presentation of main conclusions and recommendations from the Working Groups and follow-up discussion – **Chairpersons / Participants** Working Group I
15:30–16:00	***Coffee break***
16:00–17:00	Working Group II

Thursday, 25 March	
09:30–10:30	Feedback and presentation of the draft FAO global offshore mariculture development initiative – **Y. Olsen / FAO**
10:30–11:00	***Coffee break***
11:00–12:30	Workshop follow-up actions Closing remarks
12:30–14:00	***Lunch break***
15:00	Departure for Rome

Annex 3 – List of participants

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Annex 4 – Profiles of experts

EXPERTS

Adolfo ALVIAL – General Director of Adolfo Alvial Asesorías S.A., a consultancy company based in Chile providing support to the aquaculture sector, with emphasis in salmon farming. He is also President of the Business Incubator company INER Los Lagos, Member of the Directory Board of the Regional Agency for economic development, member of the Technical Council of the Technological Institute of Salmon of the Chilean Salmon Farming Association (SalmonChile), member of the Global Aquaculture Alliance Salmon Technical Committee. He has been Director of Marine Harvest – Chile Area, Director of the Technological Institute of Salmon, Director of the Aquaculture Division of Fundación Chile, Secretary General of the Arturo Prat University (former university of Chile – Iquique), and Director of the Marine Science Department at the same university. He has undertaken several research projects related to phytoplankton ecology in northern and central Chile, and on El Niño impacts on pelagic fisheries and aquaculture. He has been in charge of new aquaculture business developments in Chile, such as turbot, abalone, hirame, halibut, Chilean sole, hake and white sturgeon. He has published numerous papers in national and international science journals. Furthermore, Mr Alvial has produced a number of reports for private clients, including national and foreign governments, mostly on aquaculture, but also on environmental management and ecotourism. Adolfo Alvial has supported several aquaculture pioneer companies in Chile in salmon, abalone, and turbot production. His areas of expertise also include coastal zone management, integrated management systems in aquaculture and environmental monitoring and forecast systems in coastal waters.

Dror ANGEL – Senior researcher at the Recanati Institute for Maritime Studies and lecturer at the Departments of Marine Biology and of Maritime Civilizations at the Charney School of Marine Sciences, University of Haifa, Israel. He is also the head of the new International MA Programme in Maritime Civilizations at the same university. Dror, a Ph.D. in Biological Oceanography from the City University of New York, has been working in the field of aquaculture and marine ecology for the past 20 years. In addition to studying the interactions of aquaculture with the environment, Dr Angel has examined a number of different options, including artificial reefs and integrated aquaculture to ameliorate aquaculture effects, and to make the activity more environmentally acceptable and economically sustainable. In recent years, he has been involved in numerous efforts by FAO and the International Union for Conservation of Nature (IUCN) to apply the ecosystem approach to aquaculture and to establish applicable guidelines for the industry. Although he is primarily an ecologist, Dr Angel's recent activities have included an examination of the factors that affect public attitudes and opinion, coastal management, policy, and, ultimately, decision-making. Dr Angel has participated in numerous national and international research projects focusing on mariculture and has carried out research in different parts of the world. He has published numerous scientific publications on aquaculture-environment related topics in peer-reviewed journals and in books.

Francesco CARDIA – Dr Cardia is an aquaculture consultant, primarily working for private companies operating cage aquaculture activities. He graduated in 1993 from the University of Rome in Natural Sciences and Ecology and, in 2002, obtained his Ph.D. in Parasitology from the Veterinary faculty of the University of Turin, with a thesis on marine finfish parasitosis in Italian cage farms. Following this, he worked for five years at an inland freshwater aquaculture farm (cyprinids, reproduction, selection and ongrowing). From 1998 to 2003, he gained field experience in marine cage aquaculture while working full-time as a production manager with intensive cage farms producing European seabass and gilthead seabream. During the aforementioned period, he undertook a research activity together with the Chair of Parasitology of the "Tor Vergata" University in Rome. In 2002, he commenced his consulting activity in Italy, providing several cage farm companies with technical and biological advisory support, focusing on farm project and start-up, production planning, maintenance planning, traceability, and quality improvement. Since 2004, Dr Cardia has also been working as a consultant with FAO, and he continues to be involved in several activities, mainly related to cage aquaculture practices.

John FORSTER – President of Forster Consulting Inc., which has provided advice on aquaculture to private/public sector clients since 1994. Links to recent work for the United States and the Canadian Governments are: aquaculture.noaa.gov/pdf/econ/3.pdf; aquaculture.noaa.gov/pdf/econ/12.pdf; dfo-mpo.gc.ca/csas/Csas/Publications/SAR-AS/2008/SAR-AS2008_001_E.pdf. Specific areas of interest include development of offshore aquaculture, the future for large-scale farming of seaweed, and the application of commercial disciplines learned in salmon farming to new aquaculture opportunities. From 1994–2005, Dr Forster was also President of Columbia River Fish Farms, a company that he founded and developed to become the largest producer of steelhead rainbow trout in Northern America before it was sold in 2005. Previously, from 1974 to 1994, Dr Forster worked in technical and management positions for Stolt Sea Farm Washington Inc., which farmed salmon and sturgeon in the United States of America, and Shearwater Fish Farming Ltd., which farmed rainbow trout in the United Kingdom of Great Britain and Northern Ireland and provided services to aquaculture clients worldwide. Dr Forster began in aquaculture in 1965 with the Ministry of Agriculture Fisheries and Food (MAFF), the United Kingdom of Great Britain and Northern Ireland, working in research on the mass culture of prawns and the design of marine water reuse systems. Dr Forster has served on the Fisheries, Marine Fisheries Advisory Committee (MAFAC) of the National Oceanic and Atmospheric Administration (NOAA) (from 2002 to 2008), as well as a Board Director of Aquaculture without Frontiers, The Washington Fish Growers Association, and Chairman of the Global Aquaculture Alliance's Salmon Technical Committee.

Enrica FRANCHI – A researcher at the Laboratory of Lagoon Ecology, Fisheries and Aquaculture a research branch of the Polo Universitario Grossetano, a private consortium associated with the University of Siena. She was awarded a Ph.D. in Environmental Sciences and is currently a contract professor of Aquaculture and Ecological Restoration at the University of Siena. She has been working in the field of marine ecology and aquaculture for the last 15 years. Her research expertise is mainly concerned with the interaction of aquaculture on the environment and testing methods such as biodepuration, phytodepuration and integrated aquaculture to minimize negative impacts of aquaculture on the environment. Her most recent project was modelling the impact of aquaculture wastewater on the water quality of the receiving basin. Dr Franchi has participated in several European Union (Member Organization) and Italian sponsored projects on aquaculture and environment-related issues and has authored and co-authored numerous publications in peer-reviewed journals.

Marianne HOLMER – Head of Institute and Full Professor in Marine Ecology at the Institute of Biology, University of Southern Denmark. She has a Ph.D. in Marine Ecology from Odense University (now University of Southern Denmark). Her research expertise is primarily in marine benthic ecosystems in coastal zones and off-the-coast areas with particular focus on the ecosystem approach to management of marine aquaculture. Her primary area of research interests are impacts of disturbance on coastal and open-sea ecosystems, with marine aquaculture as a case study of organic enrichment. Her scientific publications (96) are all peer-reviewed, and published in well-recognized journals. She has edited one Springer book (*Aquaculture in the Ecosystem*, 2008) and written 11 book chapters. She has coordinated several European Union (Member Organization) projects on marine aquaculture, and participated in several other European Union (Member Organization) and national projects on aquaculture. She has research experience from Europe, Africa, Asia, Australia and North America through a series of short- and longer-term research projects in these areas. She is an appointed member of the Danish National Board for Oceanology and is an active member of the European Aquaculture Technology and Innovation Platform (EATIP). She teaches terrestrial and marine ecology and biological oceanography at all university levels.

Andrew JEFFS – An Associate Professor of Marine Science at the University of Auckland in New Zealand, where he teaches aquaculture. He is also a Director of Two Fathom Ltd., an aquaculture and marine environmental consultancy based in New Zealand. He has undertaken aquaculture research and consultancy work in many countries including Australia, Belize, the Caribbean, Viet Nam, Malaysia, Fiji and the United States of America. For ten years he was an aquaculture scientist for New Zealand's national aquaculture research institute, leading their major research programmes and subsequently becoming an executive manager for the institute. He played a major role in forging new working relationships with commercial aquaculture operators and with indigenous Maori for progressing aquaculture research and development. Prior to this, he was a senior officer for the New Zealand Government, responsible for coastal management, and was involved in establishing some of the first marine protected areas in New Zealand. He has published more than 100 papers in international science journals and in excess of 300 reports for commercial clients, mostly on the aquaculture of a wide range of species, including spiny lobsters, fishes, abalone, sea cucumbers, geoduck, mussels and oysters. His research and consulting efforts have resulted in many commercial outcomes, including the development of practical lobster holding and aquaculture diets, commercial lobster seed harvesting technology in New Zealand, pilot commercial spiny lobster farms in New Zealand and overseas, and mussel broodstock conditioning technology.

James McDaid KAPETSKY – Founder and Secretary-Treasurer of Consultants in Fisheries and Aquaculture Sciences and Technologies, Inc., Wilmington, the United States of America, that has been in business since 1999. As a Senior Fisheries Resources Officer in the FAO Inland Water Resources and Aquaculture Service (now the Aquaculture Branch) he specialized in promoting the use of GIS, remote sensing and mapping applications in aquaculture and inland fisheries beginning in the early 1980s. After retirement in 1999, he continued working in the same subject area, mainly on contract with FAO, but with other assignments with the United States Agency for International Development and Hatfield Consultants Ltd. In recent years he has focused on spatial approaches to improving estimates of marine aquaculture potential, particularly in the open ocean. Dr Kapetsky is an editor of GISFish, an FAO portal on spatial tools in fisheries and aquaculture (www.fao.org/fishery/gisfish/index.jsp), author of book chapters on GIS in aquaculture and inland fisheries, respectively, and a co-author with Dr J. Aguilar-Manjarrez of a number of FAO and other publications. Those dealing directly with marine aquaculture include a recent symposium presentation entitled "Spatial data needs for the development and management of open ocean aquaculture" (www.csc.noaa.gov/geotools/sessions/Thurs/ H08_Kapetsky.pdf), an FAO Fisheries Technical Paper "*GIS Remote Sensing and Mapping for the Development and Management of Marine Aquaculture*", a symposium proceedings "*Spatial perspectives on open ocean aquaculture potential in the US eastern Exclusive Economic Zones*" and a Fisheries and Aquaculture Technical Paper No. 549 entitled "*A global assessment of offshore mariculture potential from a spatial perspective*".

Gunnar KNAPP – Dr Knapp is a Fisheries Economist at the University of Alaska Anchorage. He earned both a B.A. in Economics (1975) and a Ph.D. in Economics (1981) from Yale University. Since 1981, he has been on the Faculty of the University of Alaska Anchorage's Institute of Social and Economic Research (ISER), where he has held the rank of Professor of Economics since 1992. Dr Knapp has undertaken a wide variety of research related to fisheries markets, fisheries management, the seafood industry and the aquaculture industry. Much of his work has focused on the Alaska salmon industry and changes in world salmon markets and the Alaska salmon industry resulting from the development of salmon farming. He has also studied: markets for Alaska pollock, herring, halibut, and cod; effects of the implementation of catch-share fisheries management systems in the Alaska halibut and crab fisheries; and effects of fisheries management on safety in the fishing industry. Dr Knapp recently authored two chapters of a study on "Offshore Aquaculture in the United States: Economic Considerations, Implications & Opportunities" for the United States National Oceanographic and Atmospheric Administration (NOAA) aquaculture programme, which examined the economic potential for and economic impacts of United States offshore aquaculture. Dr Knapp also teaches an Internet-based University of Alaska distance education course on fisheries economics and markets. Dr Knapp is an active participant in the International Institute of Fisheries Economics and Trade (IIFET) and the North American Association of Fisheries Economists (NAAFE) and was a founding member of NAAFE.

Yngvar OLSEN – Professor at Norwegian University of Science and Technology (NTNU), Trondhjem Biological Station, from 1995 till present. He has, since 2006, acted as Director of the Strategic Marine Focus Area at NTNU, responsible for facilitating, coordinating, and directing marine research at the university. He was earlier a senior scientist at SINTEF and is now a senior advisor at SINTEF Fisheries and Aquaculture. Professor Olsen has 25 years' experience within the main research field of aquaculture and marine plankton, including: live feed technology for marine fish larvae, lipid nutrition and first feeding of marine larvae, marine phyto- and zooplankton interactions, food web dynamics, trophic cascades, biochemical composition, nutrient cycling, and coastal eutrophication. He has published about 110 papers in international peer-reviewed journals. Scientific interests are marine juvenile production, coastal eutrophication, and environmental interactions with aquaculture. Besides his academic and research activity, Professor Olsen has been, among others, a member of the Board of Directors and a Vice President of the World Aquaculture Society (2002–2006). He has been involved in the organization of several WAS and European Aquaculture Society conferences. He acted as President of Norwegian Board for Cooperation in Marine Sciences (2001–2005). He is currently Co-chair of the Thematic Area Environmental Interaction with the Environment in the European Aquaculture Technology and Innovation Platform (EATiP) and a member of the Scientific Advisory Board of the German Leibniz Institute of Marine Sciences (IFM-GEOMAR), Kiel, Germany (2004–2012).

David PERCY – Borden Ladner Gervais Professor of Law at the University of Alberta. He holds an MA degree in Jurisprudence from Oxford University and an LLM degree from the University of Virginia. He has been a Visiting Scholar at Stanford, Virginia and the Centre for Socio-Legal Studies at Oxford and worked as a Visiting Research Scientist at FAO in Rome. He teaches Contracts, Natural Resources Law and Energy Law. He has published the leading works on Water Law in Alberta and in Canada. He acted as counsel to the Federal Inquiry on Water Policy in Canada in 1987 and worked on drafting the Alberta Water Act from 1989 to 1996. He has published three books on water law and advised governments and government agencies in six Canadian jurisdictions on water law matters. He is currently Co-Chairperson of a committee advising the Minister of Environment on water allocation issues in Alberta. David Percy's work in water law led him to develop an interest in aquaculture. In 2000–2001, David was seconded to work for FAO on problems of aquaculture in five African countries. During his period of leave, he co-authored (with Nathanael Hishamunda) a work on the Promotion of Sustainable Commercial Aquaculture in sub-Saharan Africa. In 2002, he worked as a consultant for FAO on Aquaculture Law in Namibia. In this capacity, he drafted the Aquaculture Act of Namibia (with Annick VanHoutte, FAO Senior Legal Officer, and led a national consultation on the legislation when it was in draft form. In 1995, Mr Percy won the WPM Kennedy Award for outstanding merit in Canadian Law teaching, and in 1996 he won the Rutherford Award for excellence in undergraduate teaching at the University of Alberta. In 2000, he received the Tevie H. Miller Award for Teaching at the Faculty of Law.

Neil SIMS – Co-founder and CEO of Kampachi Farms, LLC, an aquaculture research and development company based in Kona, Hawaii, the United States of America, and La Paz, Mexico. Kampachi Farms is developing commercial production of sashimi-grade Cabo Kampachi (*Seriola rivoliana*, longfin amberjack) in Mexico and other regions of the world, and is researching offshore technologies, alternative feedstuffs and new fish species for culture. Neil was also co-founder and President of Kona Blue Water Farms, the first United States integrated marine fish hatchery and open ocean mariculture operation, off Hawaii's Kona Coast, which produced more than 1 350 kg/week of longfin amberjack from an offshore site. He is Founding President of the Ocean Stewards Institute, a trade association that advocates for rational, considered development of offshore mariculture. He obtained a B.Sc. in Marine Biology/Zoology (James Cook University, Australia, 1980) and an M.Sc. in Zoology (University of New South Wales, Australia, 1990). From 1983 to 1988, he led the establishment of the Fisheries Research Division of the Cook Islands Ministry of Marine Resources, working in research and management of subsistence fisheries, and artisanal fisheries for pearl shell, *Trochus*, giant clams and finfish. At the same time, he led the research and development supporting the growth of the black pearl culture industry in the Cook Islands. Since 1993, he has been based in Hawaii, where he has led more than 40 federally funded research projects in aquaculture development, primarily focused on pearl oyster and marine fish hatchery development and open-ocean mariculture. He has led commercial ventures in Australia, Hawaii and the Marshall Islands, and has consulted for private companies, governments and regional agencies throughout the South Pacific and Southeast Asia. From 2001 to 2004, he led the development of breakthrough hatchery technology for "difficult-to-rear" marine fish, such as groupers, snappers and trevallies, which evolved into the pioneering open-ocean mariculture operation.

Piergiorgio STIPA – An aquaculturist by profession, with practical knowledge gained in different countries. He has worked on shrimp farming in Albania, and fish hatcheries and mariculture farms in Greece and Italy for more than 15 years. He is currently the technical head of both a marine cage offshore fish farm and a land-based pond fish farm in the Mediterranean (Italy). The farms are part of a wider commercial group selling top-quality fish (European seabass, gilthead seabream and meagre) in the European market with the brand "Fish from Orbetello". Mr Stipa has a background in marine biology (he graduated in 1992 at the University of Rome) and has conducted research activities in Italy and in the United States of America (Stanford University). He is a commercial and fishing captain, being a former Italian Navy officer, and has served one year in a commercial fishing boat in the Indian Ocean. He has a commercial diving licence, with more than 10 years experience in offshore cage installations and diving operations. He has also worked and collaborated with International Organizations such as the United Nations Industrial Development Organization (UNIDO) and FAO, promoting training in environmental and aquaculture matters in countries such as Nigeria and Viet Nam. At regional level, he has collaborated in several research projects focusing on fish and mollusc farming technologies and fish quality improvement. He has recently been involved in promoting marine aquaculture activities on the island of Palawan (the Philippines), with local entrepreneurs. Nowadays, his main interests are offshore fish farming and practical applications on submerged cages and remote feeding systems.

FAO EXPERTS

José AGUILAR-MANJARREZ – Ph.D. (1992–1996) and M.Sc. (1991–1992) in Aquaculture (Aquaculture Planning and GIS) from the University of Stirling in the United Kingdom of Great Britain and Northern Ireland. He graduated in Oceanography in 1989 from the Faculty of Marine Sciences in Ensenada, Baja California, Mexico. He has worked for the FAO Fisheries and Aquaculture Department for 14 years, first as a visiting scientist (1996–1998), then as a consultant (1998–2000) and since 2001 as an Aquaculture Officer in the Aquaculture Branch (FIRA). His responsibilities at FAO-FIRA cover two different areas: GIS-related activities, and assistance to field projects on rural aquaculture in a number of countries in Latin America and Africa. Activities specific to GIS have broadly included: (i) the development of methodologies, technical papers, reviews and training materials on GIS applications to aquaculture such as FAO Fisheries Technical Paper. No. 458 (www.fao.org/docrep/009/a0906e/a0906e00.htm); (ii) the construction of georeferenced information systems such as GISFish (www.fao.org/fishery/gisfish); and (iii) the formulation, implementation and review of field projects that have a GIS and/or remote sensing component. His main current interest is in GIS and remote-sensing approaches for estimating the potential for offshore mariculture.

Nathanael HISHAMUNDA – He holds a B.Sc. in Agronomy and an Engineer of Agriculture degree from the National University of Rwanda, an M.Sc. in Fisheries and Aquaculture from Auburn University, Alabama, the United States of America, and a Ph.D. in Agricultural Economics with a specialization in Agricultural Policy, Trade and International Development from the same institution. He began his carreer as Head of Aquaculture Extension within the Rwanda Ministry of Agriculture, Livestock and Forestry in 1984. In 1986, he led the Rwanda National Aquaculture Service until he left to pursue his higher education in 1992. While at Auburn University, he served as a Research and Teaching Assistant in Agricultural Trade and Policy and in Aquaculture and Fisheries Economics, from 1993 to 1999. He joined FAO in 1999 as a Fishery Planning Analyst and currently leads the Aquaculture Economics and Policy Group, which deals with complex and diverse issues of national, regional and global importance, and coordinates the Branch assistance to FAO Members in the areas of aquaculture socio-economics, policy, planning and governance. With more than 50 publications, he has produced leading works on aquaculture economics, aquaculture policy and governance and aquaculture and food security. He has prepared aquaculture development policies and strategies, national aquaculture development plans and has contributed to the preparation of legal and regulatory frameworks for sustainable aquaculture development for numerous countries in Africa.

Jiansan JIA – He has been working with FAO as Chief of the Aquaculture Branch since 1998. Before joining FAO, he worked for the Government of China for more than 20 years, holding several leading positions with provincial and central government authorities, in both national and international agriculture, fisheries and aquaculture development (e.g. Director General, China National Corporation for International Cooperation in Agriculture, Livestock and Fisheries; Director General, International Cooperation, Ministry of Agriculture; Executive Vice-President, China National Fisheries Corporation; Deputy Director General, Bureau of Fisheries; Vice Governor, Wujiang County, Jiangsu Province). During the past 12 years, he has devoted himself to sustainable development of aquaculture at global and regional levels by leading the FAO Aquaculture Branch based in Rome. He was one of the leading organizers of the Conference on Aquaculture in the 3rd Millennium held in Bangkok in 2000, and promoted the establishment and advancement of the FAO's Committee on Fisheries (COFI) Sub-Committee on Aquaculture. Mr Jia was the Co-Chair of the International Organizing Committee of the Global Conference on Aquaculture 2010.

Blaise KUEMLANGAN – He has been a Legal Officer in the Development Service of the Legal Office of FAO since 1996. He holds a Masters (LLM) in International and Comparative Law, Kent School of Law, Chicago, and a Bachelor of Laws (LLB) from the University of Papua New Guinea. Prior to joining FAO, he was a Senior Legal Officer with the State Solicitors Office of the Papua New Guinea Attorney General's Department, where he provided legal advice and assistance to government agencies including the Department of Foreign Affairs, Civil Aviation, Trade and Industry, Environment and Conservation and Fisheries and Marine Resources. He was also involved in fisheries enforcement, including the prosecution of offences. In the FAO Legal Office, he specializes in the international law of the sea in the field of fisheries and the development of national fisheries and aquaculture law through technical advice and field assistance to FAO Members in many regions of the globe. He has drafted or contributed to the review and development of the aquaculture laws of many developing countries. His typical annual work includes the provision of assistance and advice on the legal aspects of fisheries and aquaculture normative work, projects and consultations of FAO's Department of Fisheries and Aquaculture.

Alessandro LOVATELLI – A marine biologist and aquaculturist, he obtained his B.Sc. and M.Sc. degrees at the universities of Southampton and Plymouth (the United Kingdom of Great Britain and Northern Ireland), respectively. His first experience with FAO dates back to 1987, working as a bivalve expert attached to an FAO/UNDP regional project. His subsequent FAO assignment was in Mexico, working on a regional aquaculture development project funded by the Italian Government. From 1993 to 1997, he worked in Viet Nam, Somalia and then again in Southeast Asia. In Viet Nam, he headed the aquaculture and fisheries component of a large European Union (Member Organization) project developing, among other activities, ten regional aquaculture demonstration, training and extension centres. In Somalia, he acted as the lead aquaculture and fisheries consultant for the European Commission. Following an additional year in Viet Nam as one of the Team Leaders under the Danish-funded Fisheries Master Plan Project, he was recruited by FAO as the Aquaculture Advisor attached to the FAO-EASTFISH project based in Denmark. In 2001, he once again joined the FAO Department of Fishery and Aquaculture in Rome. The main activities he is currently focusing on are marine/offshore aquaculture development, transfer of farming technologies and resources management. Mr Lovatelli has coordinated and co-authored numerous FAO technical reviews and papers, mainly focused on marine aquaculture development.

Doris SOTO – Obtained her B.Sc. in Limnology from the University of Chile in 1975 and her Ph.D. in Ecology (aquatic ecology/food webs) in the Joint Doctoral Program between San Diego State University and University of California in Davis, the United States of America, in 1988. She worked as a Professor at the Fisheries and Oceanography Department at Austral University in Puerto Montt, Chile, until 2004. She was also an Adjunct Scientist at the Institute of Ecosystem Studies in Millbrook, New York (the United States of America) from 1999 to 2005. Up to 2005, she was involved in research activities on aquaculture environmental management and nutrient cycling of salmon farms and other aquaculture systems, both in freshwater and marine environments. She has carried out research to evaluate the effect of escaped salmon and trout on aquatic ecosystems. She joined FAO in 2005, where she has been leading the development of a framework for an ecosystem approach to aquaculture. She is the focal point for climate change impacts on the aquaculture sector. She has conducted extensive fieldwork in Latin America and worked with FAO partners in the Mediterranean Sea on various aspects of mariculture and the environment. She has published numerous scientific papers and reports, and has led different types of projects.

Rohana SUBASINGHE – A Senior Aquaculture Officer at the Fisheries and Aquaculture Department of FAO. He is specialized in aquaculture development and aquatic animal health management. Since his graduation in 1980 from the University of Colombo, Sri Lanka, he has worked in all parts of the world, with most experience in Asia. He joined FAO in 1994 and took responsibility in implementing numerous projects on aquaculture and aquatic animal health at national, regional and international levels. Among others, at FAO, he is also responsible for analysis of trends in aquaculture development globally. A former teacher at the University of Colombo and the Universiti Putra Malaysia, Mr Subasinghe earned his Ph.D. at the University of Stirling. He has been responsible for initiating major policy changes in aquatic health management in relation to aquaculture in Asia and globally. He currently serves as the Technical Secretary to the Sub-Committee on Aquaculture of the Committee on Fisheries (SCA-COFI) of FAO, the only global intergovernmental forum on aquaculture.

Diego VALDERRAMA – He holds a B.Sc. in Marine Biology from the Universidad Jorge Tadeo Lozano (Colombia), an M.Sc. in Aquaculture/Fisheries from the University of Arkansas at Pine Bluff (UAPB) (the United States of America), and a Ph.D. in Environmental and Natural Resource Economics from the University of Rhode Island (the United States of America). His expertise is in the economics of aquaculture and marine resources. In addition to numerous peer-reviewed articles, he has co-authored three book chapters on aquaculture economics issues. As a Master's student, he investigated the production economics of shrimp farming in Central America, catfish farming in the southeast of the United States of America, and the economics of aquaculture effluent regulation. His doctoral work examined a variety of issues in marine resource economics. His work has also addressed the economic potential and implications of offshore aquaculture development in the United States of America. In 2009 and 2010, he joined FAO as an Aquaculture Officer (Economics) in the Fisheries and Aquaculture Department, where he contributed to the Department's work on social and economic aspects of policy and strategy development to ensure sustained livelihoods for all beneficiaries in aquaculture. He is currently an Assistant Professor at the Food and Resource Economics Department at the University of Florida (the United States of America), where he teaches and conducts research on marine resource economics and international economic development.

Annex 5 – Group photograph

From left to right: Alessandro Lovatelli, José Aguilar-Manjarrez, John Forster, Jia Jiansan, Doris Soto, Dror Angel, Blaise Kuemlangan, James McDaid Kapetsky, Adolfo Alvial, Neil Anthony Sims, Marianne Holmer, Francesco Cardia, Nathanael Hishamunda, Andrew Jeffs, Diego Valderrama, Enrica Franchi, Yngvar Olsen, David R. Percy, Gunnar Knapp, Piergiorgio Stipa (missing: Rohana Subasinghe).

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Expanding mariculture farther offshore

Technical, environmental, spatial and governance challenges

FAO Technical Workshop
22–25 March 2010
Orbetello, Italy

This document contains the proceedings of the technical workshop entitled "Expanding mariculture farther offshore: technical, environmental, spatial and governance challenges" held from 22 to 25 March 2010, in Orbetello, Italy, and organized by the Aquaculture Branch of the Fisheries and Aquaculture Department of the Food and Agriculture Organization of the United Nations (FAO). The objective of this workshop was to discuss the growing need to transfer land-based and coastal aquaculture production systems farther off the coast and provide recommendations for action to FAO, governments and the private sector. Offshore mariculture is likely to offer significant opportunities for food production and development to many coastal countries, especially in regions where the availability of land, nearshore space and freshwater are limited resources. The workshop report highlights the major opportunities and challenges for a sustainable mariculture industry to grow and further expand off the coast. Furthermore, it recommended that FAO should provide a forum through which the potential importance of the sea in future food production can be communicated to the public and specific groups of stakeholders and to support FAO Members and industry in the development needed to expand mariculture to offshore locations. This publication is organized in two parts. The proceedings include the workshop report, and an accompanying CD–ROM containing six reviews covering technical, environmental, economic and marketing, policy and governance issues, and two case studies on highfin amberjack (*Seriola rivoliana*) offshore farming in Hawaii (the United States of America) and one on salmon farming in Chile.