A review of opportunities, technical constraints and future needs of offshore mariculture – temperate waters

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ABSTRACT

This paper reviews the status, investment and market considerations, and technical constraints to the development of offshore aquaculture in temperate regions of the world. It explores trends in production and discusses the importance of farming seafood products that are "affordable" if they are going to meet mass-market demand. In this respect, it notes that there are relatively few dominant (i.e. one million metric tonne/year) species and speculates on why this might be so. It reviews technical constraints to the future development of offshore aquaculture, among them engineering and operational challenges, questions of species selection, juvenile supply, aquatic animal health issues and the availability of suitable feed ingredients. It also considers issues of predator control, environmental impact and the critical importance of adequately trained people. It concludes by suggesting that offshore marine aquaculture will only develop to its full potential if enthusiasm for the idea is backed by an equal measure of political will. By presenting a long-range vision for this, the Food and Agriculture Organization of the United Nations (FAO) can help society to understand its benefits and make a case for it that cannot be denied.

INTRODUCTION

In 2006, worldwide production of fish, shellfish and marine plants from marine aquaculture was 36.2 million tonnes. This compares with 81.9 million tonnes harvested by the world's capture fisheries in the same year, for a combined total harvest of food from the oceans of 119.2 million tonnes (FAO, 2009). This represents about 1.7 percent by weight of man's total food supply.[1]

[1] Calculated by assuming total world food production of about seven billion tonnes (Global dataset of aquaculture production [quantity and value] 1950–2008. Released in March 2010, by the Fisheries and Aquaculture Statistics and Information Service, FAO).

In considering the future for offshore marine aquaculture, these figures prompt two observations and a question. First, marine aquaculture already contributes substantially to the world's ocean harvest, despite the fact that most of it occurs in nearshore waters. Second, though the oceans cover 70 percent of the Earth, we derive remarkably little of our food from them. Which prompts the question: is this inevitable and could the oceans be used to produce more of our food if we learned to farm offshore in some of the vast area that is available?

This is not a new idea. The possibility has been recognized by governments, industry and researchers since the 1960s, but progress has been slow due to technical challenges and to regulatory and political constraints in some countries. This paper considers opportunities for and technical constraints to offshore marine aquaculture in temperate waters, defined as those to the north and south of the Tropics of Capricorn and Cancer. The main countries presently engaged in aquaculture within this region are the People's Republic of China (northern part), Republic of Korea, Japan, Australia (southern part), New Zealand, Republic of Chile, United Mexican States (northern part), North America and Europe.

"Offshore mariculture" is a term that is not easy to define precisely. For the purposes of this discussion, it is defined as marine aquaculture that occurs in locations that are fully exposed on at least one quarter. In other words, farm structures have to be able to withstand the full force of an ocean storm should this occur. Since this applies to most of the oceans' surface, it embraces most of the future opportunity, but it also embraces large stretches of near shore waters along exposed coastlines and, realistically, this is where the first advances in offshore aquaculture will be made.

As well as technical challenges, offshore mariculture faces environmental, regulatory and financial constraints, which are the subject of other papers in this analysis. Insofar as solutions to all of them require political will, as well as science to solve them, creation by FAO of a coherent and imaginative vision for the future of offshore marine aquaculture will be helpful and this review is timely.

CURRENT STATUS

Table 1 summarizes global marine and brackish water aquaculture production in 2007 in terms of the major product categories. It shows that most production by weight (76.9 percent) consisted of marine plants and bivalve molluscs, while shrimp and finfish contributed most of the value (61.5 percent). Shrimp are mostly grown in the tropics in coastal ponds and are not considered further in this paper because, being tropical, they are outside its scope and they are unlikely candidates for offshore mariculture anyway.[2] By contrast, marine plants, bivalve molluscs and finfish are mostly grown in temperate waters and are candidates for offshore mariculture, and are the subject of the discussion that follows.

TABLE 1

Weight and value of the main marine and brackish water aquaculture product categories in 2007

Product category	Total production (mt)	Value (US$ '000)	Value/kg
Plants	14 784 148	7 504 680	0.51
Bivalve molluscs	12 848 400	12 642 221	0.98
Crustaceans	3 612 894	14 683 128	4.06
Finfish (brackish water + marine)	4 693 025	17 542 697	3.74
TOTAL	**35 938 467**	**52 372 725**	**1.46**

Source: Global dataset of aquaculture production (quantity and value) 1950–2008. Released in March 2010, by Fisheries and Aquaculture Statistics and Information Service, FAO.

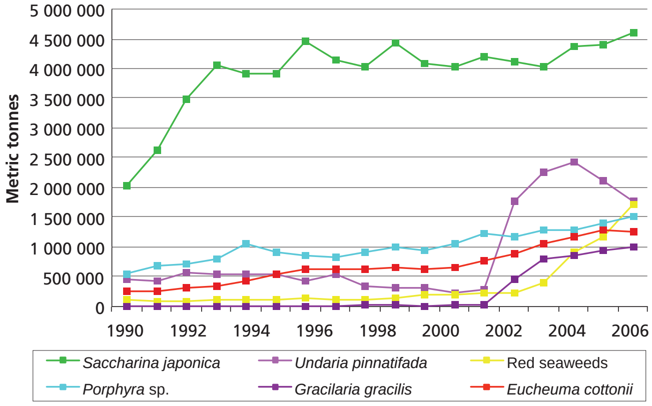
2 At least this would be the conventional wisdom. However, recent trials in the Sea of Cortez (Mexico) have shown surprisingly good performance of shrimp in cages, sufficient to encourage further development.

It is noteworthy that, in each category production is dominated by relatively few species with one species being highly dominant (Figures 1, 2 and 3). The Japanese giant kelp, *Saccharina japonica*, makes up 31 percent of all marine plants that are farmed, while *Crassostrea* species (mostly *C. gigas)* contribute 33 percent of all farmed molluscs, and Atlantic salmon (*Salmon salar*) contributes 30 percent of marine and brackish water farmed finfish, with salmonids in total contributing 39 percent. Collectively, the species or species groups represented in Figures 1, 2 and 3, contribute respectively 80.3 percent, 76.7 percent and 65.2 percent of all brackish water and marine plants, molluscs and finfish that are farmed worldwide.

This dominance of only a few species or species groups points to the idea that even though many hundreds of aquatic species have been domesticated by farming, only a few of them may have what it takes to become major farm species. If, for example, "major" is defined as exceeding one million tonnes per year production, only one finfish species out of hundreds that are farmed meets this definition, namely the Atlantic salmon, which dominates the finfish product category, like *Saccharina japonica* and *Crassostrea gigas* dominate the marine plant and mollusc categories. The significance of this is discussed further in the section on species selection.

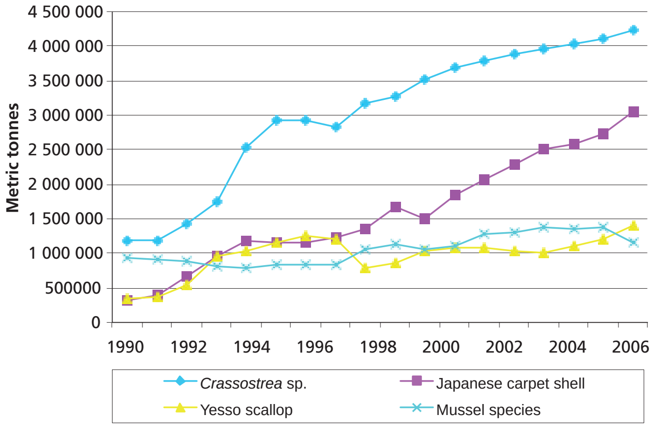
Figure 4 summarizes production trends for each of the major product categories since 1990 and shows how volume growth of marine aquaculture has been driven by plants and molluscs, in contrast to freshwater aquaculture, which has been driven by finfish. The significance of this is discussed in Section 3.2 below in the context of expected increases in future demand for seafood and how demand for different product categories will govern the nature of future offshore aquaculture industries.

FIGURE 1
Trends in production of important marine and brackish water marine plant species since 1990 in tonnes



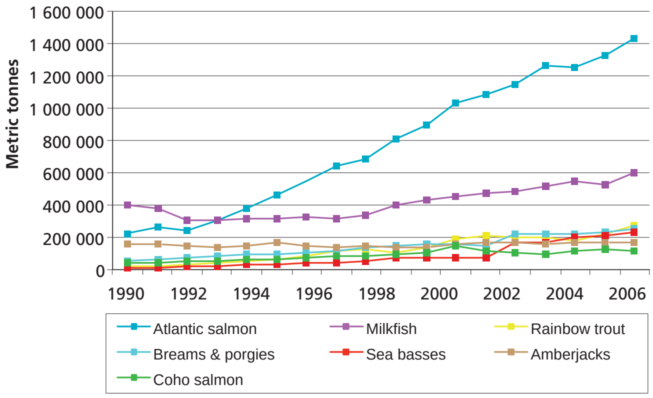
Source: Global dataset of aquaculture production (quantity and value) 1950–2008. Released in March 2010, by the Fisheries and Aquaculture Statistics and Information Service, FAO.

FIGURE 2
Trends in production of important mollusc species since 1990 in tonnes



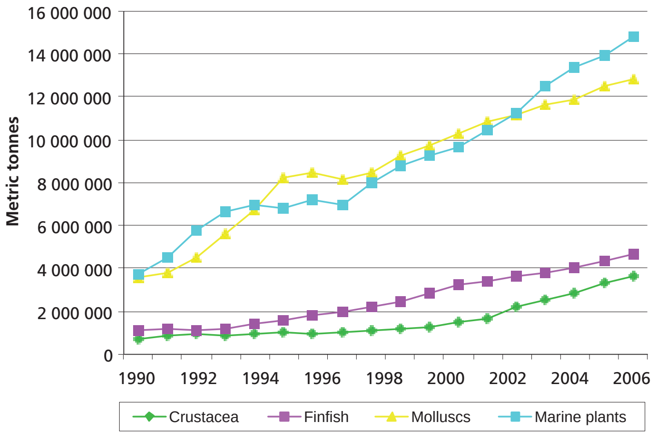
Source: Global dataset of aquaculture production (quantity and value) 1950–2008. Released in March 2010, by the Fisheries and Aquaculture Statistics and Information Service, FAO.

FIGURE 3
Trends in production of important marine and brackish water finfish species since 1990 in tonnes



Source: Global dataset of aquaculture production (quantity and value) 1950–2008. Released in March 2010, by the Fisheries and Aquaculture Statistics and Information Service, FAO.

FIGURE 4
Trends in production of the different categories of all marine aquaculture products since 1990 in tonnes



Source: Global dataset of aquaculture production (quantity and value) 1950–2008. Released in March 2010, by the Fisheries and Aquaculture Statistics and Information Service, FAO.

INVESTMENT AND MARKET CONSIDERATIONS

Investment

All successful mariculture, be it nearshore or offshore, for fish, molluscs or marine plants, requires clean water and must have shore-based infrastructure and services available to support it. Assuming these elements are in place, then the biggest challenge in moving offshore is how to design and install equipment that can withstand storm driven waves and currents and provide a safe working platform for farm workers. Though culture methods for finfish, bivalve shellfish and marine plants are quite different, challenges of anchoring and operation at sea are common to all and there is a general need for engineering sophistication in all offshore aquaculture. Some key considerations include:

- heavy-duty moorings in deep water;
- offshore systems for the containment or support of the aquatic crop;
- sea-going work boats equipped with cranes and fish pumps;
- offshore feed storage and feed distribution systems;
- mechanization of as many husbandry tasks as can be mechanized;
- remote monitoring and control systems; and
- development of large farms in order to capture economies of scale.

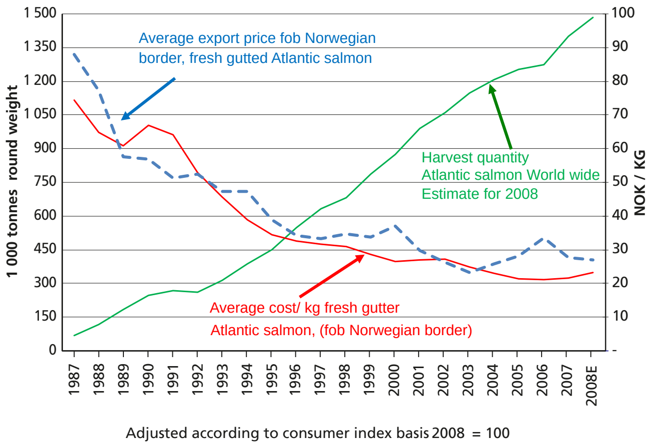
From FAO's standpoint, this need for engineering sophistication may have a bearing on how assistance programmes are structured, because the technology and investment will most likely have to come from developed countries; lack of both having been identified as bottlenecks by developing countries.

Market definition

Since technology development will be driven by actual and expected market demand for different types of seafood, it is helpful to consider the market before contemplating what technical challenges there may be. It is widely assumed that demand for seafood is running ahead of supply as production from the world's capture fisheries stagnate and the pace of aquaculture growth slows (FAO, 2009). But most discussion of this uses the terms "fish" or "seafood" to mean finfish, shrimp and molluscs collectively, while marine plants are usually excluded. Yet, it is clear from Table 1 and Figure 4 that the main products from marine aquaculture today are marine plants and bivalve molluscs, with shrimp and finfish comprising a relatively small proportion based on live weight. If offshore marine aquaculture is to play a role in bridging the gap between expected seafood supply and demand, what sort of seafood should it produce? Are each of the market categories freely substitutable one with the other, or are they categories that have their own market characteristics that will follow different paths?

From a resource use and technical point of view, marine plants and bivalve molluscs have the huge advantage that they do not have to be fed with compounded feeds, and this is a powerful incentive to increase their production. However, it is not certain that demand for them offers a comparable incentive. Marine plants are eaten widely in Asia, but not much in the rest of the world, while many bivalve molluscs tend to be speciality products eaten as starter dishes rather than as "centre of the plate" items. Moreover, the edible meat yield from bivalves is often quite low, so that production reported

FIGURE 5
Volume, cost and price trends of farmed salmon



Source: The Norwegian Seafood Export Council / Kontali. Myrseth, 2009.

on a live weight basis exaggerates their true food value. While these are broad generalizations with undoubted exceptions, the lack of clear definition between categories in market forecasts for seafood makes it more difficult to judge what market forces will drive future offshore aquaculture production. Put another way, better understanding of the exceptions and recognition of the need for category specific market development is an important part of trying to figure out what the best long-term opportunities for offshore marine aquaculture may be.

Demand for seafood is also price sensitive. Figure 5 shows how, as worldwide production of farmed salmon increased from about 75 000 tonnes to 1.6 million tonnes between 1987 and 2008, the selling price fell.

Arguably, price reductions are now starting to level off, but the point is that even at production levels of only a few hundred thousand tonnes per year, prices had to come down in order to encourage more people to buy salmon. Though it is widely assumed that aquaculture will have to produce many millions of tonnes of new seafood to keep pace with the expected demand, such assumptions are rarely accompanied by projections of the likely prices that consumers will be willing to pay for the extra volumes. Instead, there is often talk of "niche markets" and "high value species" that promise rich returns for those who can produce them. However, the lesson from salmon farming is that these markets are relatively small. If aquaculture is to produce the millions of tonnes of new seafood thought necessary, it will have to be priced to meet the value expectations of the mass market. Farmed salmon serves as a helpful benchmark in this regard.

More than "seafood"

It is also appropriate to consider the future for offshore mariculture in the wider context of overall global food supply. In a recent media release related to a Forum on "Feeding the World 2050", FAO stated "*Producing 70 percent more food for an additional 2.3 billion people by 2050 while at the same time combating poverty and hunger, using scarce natural resources more efficiently and adapting to climate change are the main challenges world agriculture will face in the coming decades.*" Duarte *et al.* (2009) emphasize similar concerns and discuss how marine aquaculture might be part of the solution. If offshore mariculture is to contribute to the alleviation of world hunger, what would it have to do?

In round numbers, the total weight of food produced in the world today is about seven billion tonnes. Of this, roughly six billion tonnes are plants and one billion tonnes are animal products, a ratio of 6:1. The same ratio for all of the world's aquaculture is about 1:3 and for the world's capture fisheries, it is 1:53. These ratios suggest that we need to look mostly to plants, not animals, for solutions to the challenges of global food supply and, for offshore mariculture, this means marine plants or seaweeds.

The People's Republic of China grows most of the marine plants in the world today- about 9.8 million tonnes out of a world total of 15 million tonnes. Of the 9.8 million tonnes, about four million tonnes is the brown kelp *Saccharina japonica,* which was farmed in 41 000 hectares of coastal waters in 2004 (Chen, 2006). Assuming kelp is 80 percent water, this gives a dry weight production of plant matter of 19.5 tonnes/hectare. Extrapolating, that means that six billion tonnes (the weight of plants produced each year by agriculture) could be grown in 308 million hectares of ocean space, which is less than one percent of the ocean's total surface. In fact, because conversion to dry weight of *Saccharina* skews this calculation in favour of agriculture, the area of ocean required to grow an exactly comparable amount of plant biomass is probably substantially less than one percent.

That is important. If there really are concerns about how it is going to be possible to feed everyone in 2050, the idea that the world's production of plant biomass might be doubled by farming marine plants in less than one percent of the oceans is surely one that should be taken seriously. Moreover, since seaweeds can be grown without using land or freshwater, and even without fertilizers in some places, farming them should be taken even more seriously. Large-scale seaweed farms might also be used to remove excess nutrients that cause phytoplankton blooms and other problems in some coastal waters.

Market opportunities

The above suggests that offshore mariculture offers three general opportunities. First, there will be a need for more finfish because demand is expected to increase and fish landings from the world's capture fisheries will remain stagnant. In so far as many fish have intrinsic market value (Table 1), this suggests that commercial incentives to develop and expand farming of finfish offshore will be strong and will encourage continued development, though the end products will have to be "affordable" if large volumes are to be produced.

Second, there will be similar incentive to develop offshore farming of shellfish, though this may be confined to a limited number of species such as mussels and scallops, which have broad market appeal and may be best suited to floating methods of culture. In addition, there will be environmental incentives to encourage bivalve shellfish farming because they feed themselves, being the only means we have to harvest the vast natural phytoplankton productivity of the sea.

Third, there is apparent potential to increase the production of marine plants, but little immediate market incentive to do so. Left to market forces alone, this is an opportunity that might go unrealized and a question for FAO and the national governments it advises is, should their respective natural resource agencies intervene to encourage development? It is not hard to imagine western consumers accepting the idea of "marine vegetables" that offer nutrition, variety, value and a food source that leaves a gentle footprint on the Earth (MacArtain *et al.*, 2007). In turn, this would provide a market incentive to farm them and, as techniques were perfected and volumes built, this could lead to the development of other uses such as animal feed ingredients (Yoshimatsu *et al.*, 2005) or biofuel (Aisawa *et al.*, 2007; Chynoweth, 2002; Roesijadi *et al.*, 2008).

Presently, there is interest in several western countries in the idea of integrated multi-trophic aquaculture (IMTA) where marine plants and shellfish are grown "downstream" of marine fish farms in order to reuse some of the wastes (nutrients) that they release. Because these projects will produce limited quantities of marine plants, it is to be hoped this may inspire parallel programmes to develop markets for them. However, though IMTA may offer a practical way to introduce the idea of farming marine plants, it is really looking at it the wrong way round. They should be a primary source of biomass, as in agriculture, not a secondary product used to clean up wastes. The vision for this form of offshore aquaculture should be bigger, and a focus on demonstrating and promoting the food value of marine plants for people would seem to be the most likely way to get such a vision accepted. In this respect, an American company has recently trademarked the name "*Kelp – the Virtuous Vegetable*™" (Ocean Approved Inc.; www.oceanapproved.com), which illustrates the imagery that could be used in promotional efforts.

TECHNICAL CONSTRAINTS

Offshore mariculture presents numerous technical challenges, many of which have been faced and met in nearshore aquaculture, albeit in less challenging circumstances. They range from engineering challenges to species selection and juvenile supply, to matters relating to environmental impact and environmental service costs. For offshore mariculture to succeed on a scale that makes a meaningful impact on human seafood supply, answers are needed to all of them. However, the transition from nearshore to offshore will be gradual and answers will evolve over time. Sometimes people talk about a "blue revolution" in the context of marine aquaculture, but development of aquaculture offshore will be evolutionary rather than revolutionary and aquaculture's needs and significance might be better understood by critics if it was to be explained as a "blue evolution", with adaptation and improvement that will continue indefinitely. The important thing for all to realize is that this involves trial and error and unless there is tolerance for error, such evolution cannot occur.

Engineering

The two biggest engineering challenges in offshore mariculture are storm events at sea and the cost of anchoring equipment at depth. Mooring with traditional multi-anchor systems becomes expensive at anything much more than 75 m of depth and this greatly restricts where offshore farms may be located. Single point mooring systems have the potential to increase the range of depth options, though they are not used much presently and they prompt justified concern about dependence on just one mooring line. However, their use would expand the range of possible offshore site options and their further development is an engineering priority.

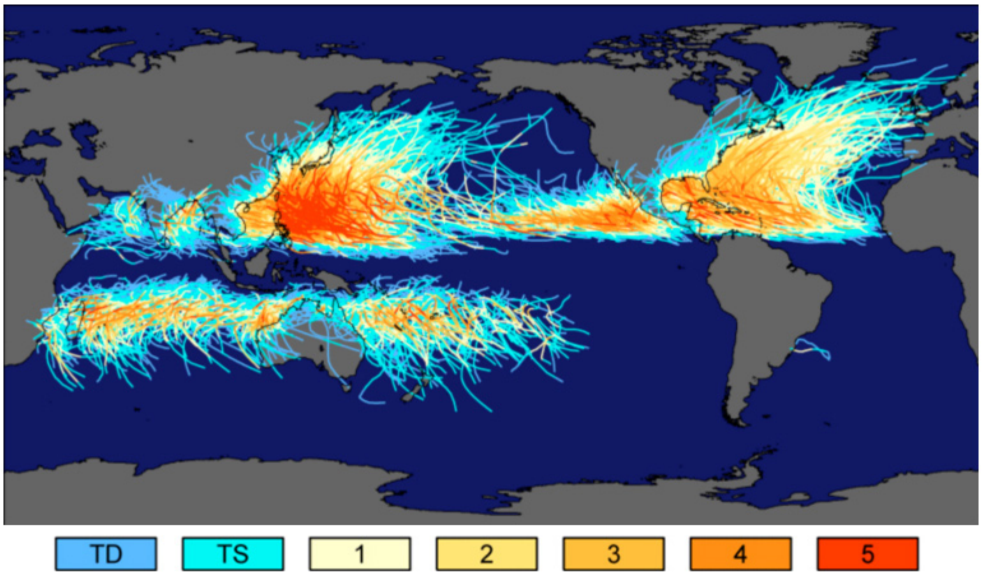
Eventually, for open ocean aquaculture to achieve its full potential and if the constraints imposed by depth are to be overcome, self-positioning, free-floating systems must be developed. Initial work on concepts has been started at the Massachusetts Institute of Technology (Handwerk, 2009), though this is very preliminary and it will likely take many years yet before commercial prototypes are available. Meantime, there are many shallow water areas in the world where offshore mariculture can be started, and it is best for now to concentrate effort there and accept the limitations imposed by moorings. The immediate engineering challenge, therefore, is waves created by ocean storms and there are two most probable solutions.

The first is to locate farms in parts of the world where storm events are rare and the spacial review that is a parallel part of the present proceedings will be especially helpful in this respect (Kapetsky, Aguilar-Manjarrez and Jenness, 2012). Figure 6 is a map that shows where major tropical storm activity is concentrated in the world and shows how the search for suitable locations might begin to be narrowed down.

More detailed mapping is required to pinpoint areas that are all or mostly free of both major and minor storms. The Mediterranean coast of the Kingdom of Spain is an example of such an area where a number of farms are anchored in locations with exposure to the east of several hundred kilometres. Finfish farms like the one shown in Figure 7, have operated there with conventional floating plastic high density polyethylene (HDPE) cages for several years without any major weather damage.

However, benign weather is not the only driver for offshore aquaculture development. Good coastal infrastructure and ready access to markets are equally important, and there are many parts of the world, including the west coast of Europe, most of the United States of America, including the State of Hawaii, and the Republic of Korea, where these offer good reasons to develop the industry, despite potentially stormy weather. This has stimulated development of new designs of offshore cages that can withstand major storm events. Concepts range from submersible, rigid framed structures to flexible, floating support collars that ride rather than resist the waves (Figure 8) and there is enough experience now to think that offshore farming in these areas is possible, though cost and operational practicality are still constraints (Loverich and Forster, 2000; Forster, 2008).

FIGURE 6
Storm tracks at sea to show where tropical storms are concentrated



Source: http://mapscroll.blogspot.com/2009/05/visualizing-global-warming.html

FIGURE 7
Culmarex SA finfish farms off the east coast of Spain

COURTESY OF CULMAREX SA

There are similar challenges in the offshore farming of bivalve shellfish and marine plants. Lovatelli (1988) described 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 placed (Figure 9). Longline systems are naturally ocean compliant and are well suited to growing crops that attach directly to ropes such as mussels and some marine plants. Consequently, they have been adapted for the offshore farming of mussels in the Mediterranean, Atlantic Canada, New Zealand and northeastern United States of America (Langan, in preparation) and are used extensively in Asia for farming the kelp *Saccharina japonica* (Figure 10).

In this respect, aquaculture methods for the offshore farming of bivalve shellfish and marine plants are relatively further advanced than they are for finfish and more

FIGURE 8
Examples of offshore finfish cages

COURTESY OF ACQUA AZZURRA SPA

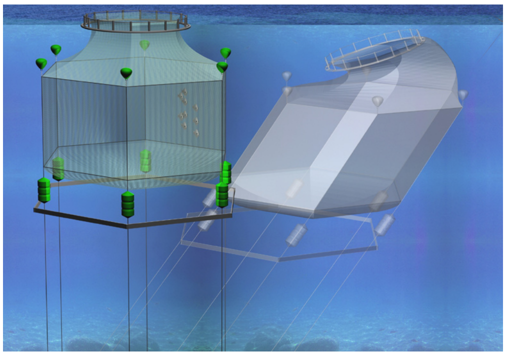
Bridgestone cage – flexible surface collar

COURTESY OF ITTICA OFFSHORE DEL TIRRENO SPA

Platform cage – resists waves by strength of structure

COURTESY OF ACQUA AZZURRA SPA

FarmOcean cage – semi-submersible, reduced surface exposure



COURTESY OF REFA MED

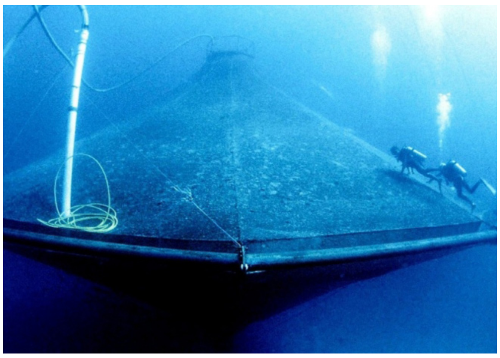
Refa Med Tension Leg cage – flexible, float tensioned moorings

COURTESY OF OCEAN FARMS TECHNOLOGIES INC

Aquapod – geodesic sphere, submersible

COURTESY OF FRANCESCO CARDIA

Sadco Shelf cage – rigid frame, submersible



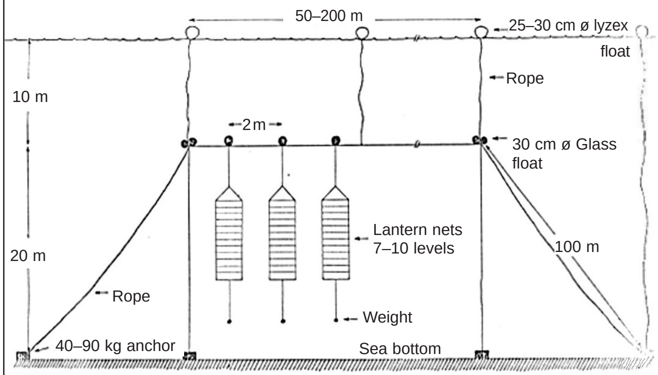
COURTESY OF OCEANSPAR LLC

SeaStation cage – central spar and rigging, submersible

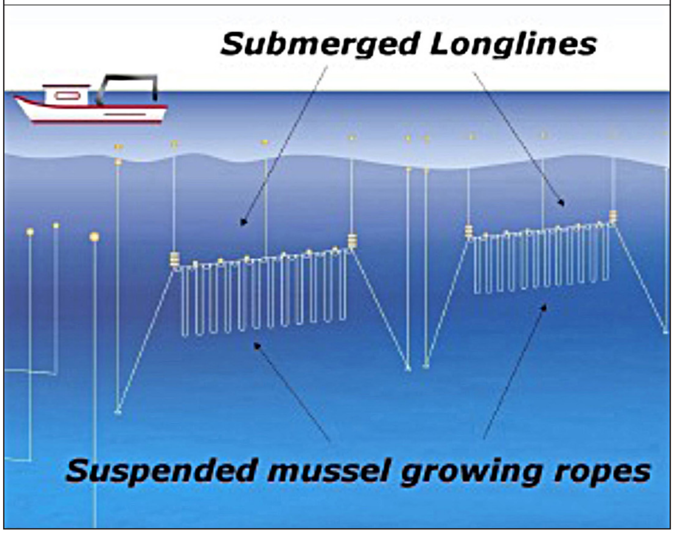
COURTESY OF SUBFLEX LTD / ANAT LYNN

Subflex cages – submersible single-point mooring flexible net cage system

FIGURE 9
Longline culture of scallops and mussels



Source: Lovatelli, 1988.



COURTESY OF UNIVERSITY OF NEW HAMPSHIRE

immediately adaptable for technology transfer to developing countries. The difficulties with them may relate more to the cost of production and selling prices for the products than to engineering feasibility. In addition, marine plants have to be able to capture light, so farms for them tend to occupy greater surface area than farms for finfish or shellfish and this will magnify equipment challenges in the open sea. This requirement for light also means that submersion, as a way of avoiding heavy seas, is a less likely solution for marine plants than it is for finfish and bivalves.

From a historical point of view, it is worth noting that between 1968 and 1990 a programme in the United States of America that became known as the U.S. Marine Biomass Program, was one of the first serious attempts to test the offshore farming of marine plants. It was conceived by Howard Wilcox who, with others, dreamt of ocean food and energy farms that would produce marine plant biomass that could then be processed, like terrestrial crops, into multiple food and energy products. Given impetus by the first world oil crisis of the 1970s, it became mostly a bioenergy project and was funded generously by the United States Department of Energy and related agencies. Chynoweth (2002) summarizes the work in considerable detail and describes how it eventually petered out as oil flowed freely again in the 1980s and early 1990s and a sense of crisis lapsed into complacency. A more recent review (Roesijadi *et al.*, 2008) looked at this work in the context of current enthusiasm for biofuels, as well as other possible uses for marine biomass and concluded that higher value applications, such as the direct use of marine plants as food for people, offered the most immediate opportunities for development.

Operations

Though engineering solutions for the offshore containment of aquaculture crops have been shown to be feasible, there is still a long way to go to integrate them into safe, large-scale operating systems where all the key tasks involved in aquatic husbandry are done cost efficiently. These include feeding, grading, harvesting, cleaning and monitoring of farm functions, all of which have to be done at sea under conditions that may often be difficult and dangerous. Lack of such an integrated capability is the main reason that salmon farmers have held back from expanding offshore up to now, leaving the burden of offshore development to less experienced farmers of new aquaculture species in locations where sheltered sites are not available and where the potential for high selling prices justifies the risk. As a result, progress has been slower than it might have been, had salmon farming companies been more involved.

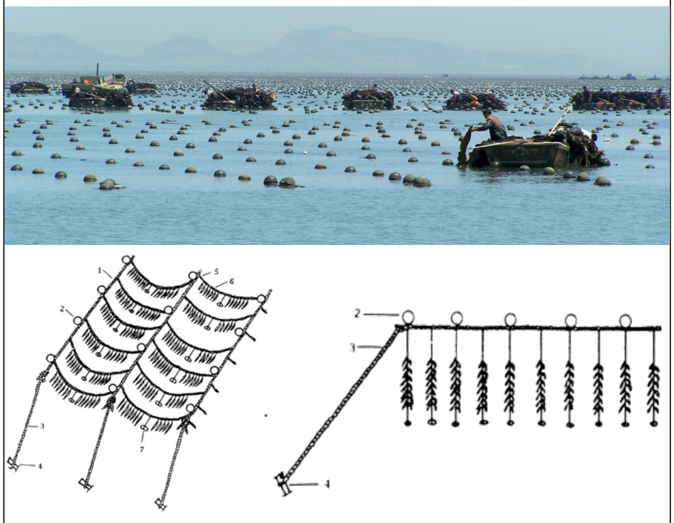
Feeding and livestock handling

However, progress has been made. The University of New Hampshire, for example, has built a prototype, ocean compliant feed storage and feeding system (Figure 11), that promises to deal with one of the biggest challenges, namely the routine operations involved in transporting feed to a fish farm and feeding the fish. When this is fully mechanized, remotely controlled and, potentially, solar or wave powered, it will reduce both the labour requirements on the farm and the frequency of trips needed to deliver feed.

Grading and harvesting are also labour intensive activities that are more difficult to do offshore, especially if there is much wave activity. For finfish, this usually means that they first have to be crowded so they can be graded or moved into the harvest system. For shellfish, it means lifting them on to the deck of a boat so they can be worked on there. Crowding fish in offshore 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. Though it is not done yet, it also seems that it would be feasible to tow cages inshore for harvesting, if a system was designed for easy detachment and reattachment of moorings.

In all cases, the less stock handling that has to be done the better. It is always difficult, weather dependent and stressful on the stock. One strategy to eliminate the need for grading is to stock farms with juveniles that are large enough and sufficiently well-graded that they do not need to be sorted again until they are harvested.

FIGURE 10
Farming of marine plants in China



Source: Chen, 2006; FAO, 1989.

COURTESY OF CHEN JIAXIN

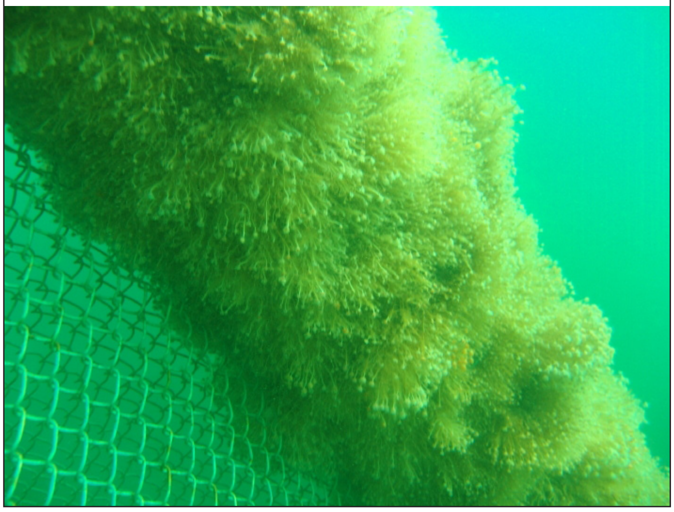
FIGURE 11
A 20-tonne prototype ocean farm feeder

COURTESY OF UNIVERSITY OF NEW HAMPSHIRE

Marine biofouling

Marine biofouling is another aspect of marine aquaculture that demands attention and controlling which is often labour intensive. It tends to be site specific in relation to intensity and species and varies with season. For bivalves, 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. In finfish farming, 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 *in situ* with a surface or diver operated net cleaning device. These methods are often used in combination with net coating materials that deter fouling organisms; cuprous oxide being the most commonly used active ingredient.

FIGURE 12
The copper nickel mesh is suspended from a HDPE pipe, which is extensively fouled in contrast to the mesh which is not



COURTESY OF RICHARD LANGAN

Another interesting antifouling strategy for certain designs of finfish cage is to rotate them at the surface, thereby, allowing sections of the net to dry in turn so that fouling organisms die before they have a chance to grow significantly. In order to do this, the cages must be completely enclosed and designs such as the Aquapod™ and SeaStation™ (see Figure 8). These type of cages are well suited to this fouling removal method. Fully enclosed cages that can be submerged may also be able to be moved between different depths as a way to disorient fouling organisms.

Any methods for fouling control that require handling of the stock or gear will be more difficult to do offshore than nearshore and much more difficult if there is any sort of wave activity. For this reason, impregnation or coating of nets or lines with materials that deter fouling has important advantages, except that there is concern about the use of copper based materials because of potentially toxic effects on non-target organisms. Research is in progress on alternative anti-fouling compounds including natural antifouling metabolites derived from marine plants (Center for Marine Biotechnology and Biomedicine [CMBB], undated), materials that inhibit biofouling physically and on netting material made from a copper nickel alloy. While the latter is still based on copper, it does not slough particles into marine waters like cuprous oxide based coatings and its intrinsic strength may confer other benefits (Figure 12). The Collective Research on Aquaculture Biofouling (CRAB) Project in Europe is another effort to find new solutions for marine biofouling (CRAB, 2006).

System monitoring

Finally, there is a need to monitor certain farm functions including:

- mechanical system integrity – condition of moorings, attachments, nets, etc.,
- stock condition, behaviour and health,
- feed consumption in the case of finfish,
- stock mortality,
- water quality,
- presence of predators, and
- surveillance for intruders or vandals.

With modern technology, most of these things can be done using probes, robots and cameras that can be controlled and tracked remotely. Even things like fish health may be susceptible to remote monitoring, one day, using micro tags that monitor and transmit data about physiological functions. However, they all have to be robust enough to work in offshore conditions, so sophisticated probes and electronics alone will not be enough.

Cumulatively, all of the above operational tasks come under the heading of what farmers call "husbandry" and the long-term goal for offshore mariculture should be to integrate them into farming systems that are mechanized and remotely controlled as far as possible. Above all, there must be emphasis on reducing the need for people to have to work under dangerous conditions at sea, especially if diving is involved, because it is inherently dangerous and expensive. 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 systems rather than physical performance of farm operations as is the case now.

Species selection

Over the last 50 years several species have been selected as especially good candidates for marine aquaculture and have become dominant (Table 2). These are the “million tonne per year” species, or species groups. There are 12 of them, which in total make up 70.8 percent of production from all of marine and brackish water aquaculture. Nine of them are temperate water species and six of them are marine plants. Because they have been so successful, it is important to understand why. Some of their key attributes include:

- they are good to eat, or have value for chemical extraction in the case of some of the marine plants;
- general tolerance of farm conditions can mean natural resistance to parasites and disease, tolerance of handling and crowding, ready acceptance of dry feed for fed species, or a calm behavioural demeanour that curbs stress;
- ready availability as seed stock from either hatcheries or natural settlement;
- they are fast growing, or relatively fast growing;
- adaptability to farming outside, as well as within their native range;
- in most cases, they have been genetically improved by selective breeding, extending their advantages even further over new candidate species; and
- edible meat yield, or recovery, of fed species is high enough to make production of value added products economically feasible.

This prompts several questions about species selection for the future:

- Is this concentration on only a few species fortuitous or is it because, like corn, rice and wheat, or chickens, pigs and cows, they have special farm attributes?
- Do any of the new species that are being tested in aquaculture have characteristics that will allow them to become similarly dominant?
- Are there species that are waiting to be “discovered” for aquaculture? If they have the right characteristics, these need not be species that are well known in fisheries or the market.
- If really good species for aquaculture are limited in number, will it be necessary to transfer those that are good further outside their native range? If so, what precautions are needed? FAO’s Technical guidelines on aquaculture certification minimum substantive criteria # 49 address this question by saying that “*exotic*

TABLE 2
The “million tonne per year” species and species groups in marine and brackish water aquaculture

Marine plants	Scientific name	Production in 2007 (mt)
Japanese kelp	*Saccharina japonica*	4 613 104
Wakame	*Undaria pinnatifda*	1 765 470
Red seaweeds	Red seaweeds	1 728 475
Laver (Nori)	*Porphyra*	1 510 634
Zanzibar weed	*Eucheuma cottonii*	1 247 945
Warty *Gracilaria*	*Gracilaria gracilis*	1 003 892
Molluscs		
Pacific oyster	*Crassostrea gigas*	4 233 829
Japanese carpet shell	*Ruditapes philippinarum*	3 044 057
Yesso scallop	*Pactinopecten yessoensis*	1 412 797
Mussels	Several species	1 163 448
Shrimp and finfish		
White legged shrimp	*Penaeus vannamei*	2 296 359
Atlantic salmon	*Salmo salar*	1 433 030
TOTAL		**25 453 040**

Source: Global dataset of aquaculture production (quantity and value) 1950–2008. Released in March 2010, by the Fisheries and Aquaculture Statistics and Information Service, FAO.

species are to be used only when they pose an acceptable level of risk to the natural environment, biodiversity and ecosystem health", which is reasonable, but does not specify what "low risk" means (FAO, 2011).

- Even within their native range, should aquaculture species be selectively bred, given concerns about interbreeding with wild stock? FAO's criteria, cited above, are silent on this.
- What about farming transgenically modified (GMO) species? There is no need of them presently, but will this change, as it is changing in terrestrial agriculture?

The evidence from recent years suggests that the concentration on only a few species may not be fortuitous. Numerous species of aquatic animals are farmed in many parts of the world and some have been farmed for many years on quite a large scale, but they have not broken through to the million tonne per year level. The criteria for species selection in aquaculture should be reviewed, especially for those species where there are such high hopes. It is easy to be enthusiastic about seafood variety and upscale market niches but, if the long-term goal for marine aquaculture is to fill an expected seafood deficit of millions of tonnes per year, maybe this can only be done if we find and focus on a few species that have demonstrably superior culture characteristics.

Also, based on the record, it is at least a reasonable proposition that if all new aquaculture activities are to be based on farming only native species, progress will be slower than if they are not. It is noteworthy that, all the "million tonne per year" species in Table 2 are already farmed widely outside their native range. For this reason, it would be helpful if the risks posed by new species introductions and/or genetically improved aquatic stocks were better understood. By encouraging such work, FAO could help to ensure that absence of scientific information does not become a reason to hold otherwise valid and potentially important aquaculture development back.

FAO could also encourage research into the production of all female and sterile farm stocks. Triploid oysters and rainbow trout are used routinely now in commercial farming but triploidy has not yet worked so well in other aquatic farmed species. A new project in Europe (www.salmotrip.stir.ac.uk) will re-look at the feasibility of growing triploids of Atlantic salmon, earlier attempts having been unsuccessful. In the Kingdom of Norway, a project to test performance of triploid Atlantic salmon over the full production cycle put smolts to sea in the fall of 2009. Preliminary results show better growth in freshwater, but an increase in deformities (M. Dalen, personal communication, 2009).

Juvenile supply

For the dominant marine aquaculture species listed in Table 2 juvenile supply need not be a limitation. Hatchery or natural seed collection practices are well established and can be replicated as needed. Juvenile supply is a bigger constraint for some of the newer species of interest because hatchery capacity is limited and/or the hatchery rearing process is less reliable. Availability of established, domesticated broodstock of some of these species may also be a limitation. There are three general ways in which juveniles (seed) are produced, examples of which are shown in Figure 13.

i. They are captured from the wild. This is still standard practice for mussel and scallop seed where it is not considered threatening to wild populations. However, it is of ecological concern where it is still done in certain shrimp farming situations, and for yellowtail farming in Japan and tuna farming worldwide, and it is being phased out.
ii. Production in fertilized ponds where blooms of phytoplankton and zooplankton provide feed for larvae hatched from eggs in a hatchery. This method is used extensively in Asia and is successful in producing a wide variety of species. An advantage is that juveniles can feed on a variety of natural plankton, though there is little or no control of what species these are.
iii. Production in modern hatcheries where phytoplankton, rotifers and *Artemia* are provided as feed and where all other aspects of the rearing process are controlled as

FIGURE 13
Examples of hatchery and nursery systems

Seedling hatchery for the giant kelp *Saccharina japonica* in Yantai, China

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Salt water pond for producing marine finfish in southern China

COURTESY OF JOHN FORSTER

A modern marine finfish hatchery for European seabass and gilthead seabream in Spain

COURTESY OF RICHARD PRICKET

A marine finfish nursery for European seabass and gilthead seabream in Spain

COURTESY OF RICHARD PRICKET

closely as possible. Such control is an advantage compared to open ponds, but the limited range of live feeds may be inadequate for some species and may compromise juvenile quality.

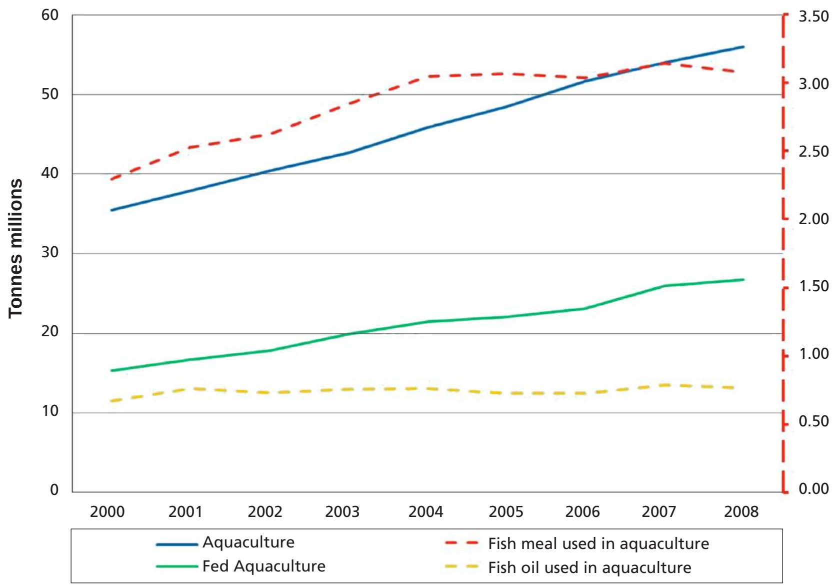
In all cases, the optimum size at which juveniles should be stocked in offshore farming facilities is still open to question. There is a natural inclination to want to do this as early as possible when the juveniles are small, because growing them larger in land-based facilities can be costly and transporting them to the cages becomes more costly as they get bigger. However, very small juveniles or seedlings may be more vulnerable to disease and parasites than larger ones. One of the reasons why salmon farming may have been successful is that the salmon life cycle requires that fish be kept in hatcheries until they reach 60–120 g live weight before transfer to salt water as smolts. Eventually, this may prove to be the best production strategy for all species in offshore farms, where it will be simplest to stock large seedlings, or juveniles, and harvest them when they have reached market size without any handling or sorting during the rearing process.

A reliable supply of good quality juveniles is obviously a vital precursor to any offshore marine farming activity. Where capacity does not exist, FAO assistance with the establishment of captive broodstock and the construction and operation of hatcheries and nurseries could be a valuable part of any support programme. This could also include help with breeding programmes to select stocks with favourable farm characteristics.

Feeds

Though there is concern about the high level of use of fishmeal and fish oil in some aquaculture feeds, availability of these ingredients does not constrain offshore farming presently, because there is so little offshore production. However, this will not be so indefinitely and research to find alternatives is necessary and is now showing

FIGURE 14
Global aquaculture growth and use of fishmeal and fish oil from 2000–2008



Source: Shepherd, 2009.

results (Turchini, Tortensen and Wing-Keong, 2009; Tacon and Metian, 2008). This is illustrated by the fact that there has been little or no increase in the global use of fishmeal and fish oil in aquaculture feeds in recent years, despite of increases in the worldwide aquaculture production (Figure 14).

However, people are now beginning to question whether any feed ingredient that could be eaten directly by humans should instead be fed to farm animals and there is concern about pressure to produce more of these ingredients because it may lead to new environmentally damaging agricultural development. FAO could help in this area in two ways.

The first is to become much better than we now are at life cycle assessment (LCA), because it holds the promise of being able to make objective comparisons of efficiency between different food producing activities. From a feed efficiency point of view, there are reasons to think that when aquaculture is compared in this way with intensive animal farming on land it may show up rather well. For example, as poikilotherms, aquatic livestock burn less energy than terrestrial livestock in order to grow and, therefore, produce less greenhouse gases (GHGs). However, full LCA requires accounting not just for energy and GHGs, but for all resource and environmental service inputs, as well as the food value derived from them. Studies such as The Global Salmon LCA (Ecotrust, 2010), Ellingsen and Aanodsen (2006), Ayers and Tyedmers (2008) or Pelletier *et al.* (2009) are helpful starts, but there is a long way to go yet before shrimp and finfish farmers might be able to make an unequivocal case for their businesses based on demonstrated life cycle efficiency.

This gets to the heart of present discussion about sustainability. This word is now used so widely in all kinds of different contexts that its meaning has become blurred. It has become a concept rather than a measurable, comparative attribute, and it is used carelessly to claim sustainability for human activities that are clearly not sustainable in the long-term. "*You can't manage what you can't measure*" is a business cliché and LCA is the best tool there is presently by which some measure of sustainability might be made. A LCA methodology that allowed comparative measurement of ecological efficiency between different food producing processes, including aquaculture, would help to bring objectivity to discussion that is now often subjective and may lead us in wrong directions.

The second is the idea that marine plants might be grown and processed into feeds for finfish so that marine aquaculture could become self-sustaining. In the raw state, seaweed nutrients are protected by indigestible cell walls, or are chemically bound in a way that diminishes their potential nutritional value. Processing or bio-refining the raw plants to make the nutrients they contain more available may be a solution. Japanese scientists are leaders in this field using fermentation and enzyme digestion to release spheroplasts and chloroplasts from *Porphyra* that led to improved survival and nutrient retention, when included in feeds for black and red seabream at three percent and five percent, respectively (Khan *et al.*, 2008; Kalla *et al.*, 2008). Though these are low levels of inclusion, perhaps they point to how marine plants might be used in aquaculture feeds in future, in turn providing the market incentive to increase the farming of them.

Stock health

Diseases and parasites are serious threats in all aquaculture. Offshore, they may be less of a threat than nearshore due to better water quality conditions, though they may also be harder to control. However, it is essential that adequate treatment methods are developed and available for the inevitable occasions when they will be needed. This applies mostly to finfish and there are several preventative and treatment approaches, all of which are used in nearshore aquaculture and some of which will be usable offshore. They include:

i. Good fish husbandry, which is an all embracing term to mean good water conditions and feed, moderate stocking densities, clean cages, prompt mortality removal, careful handling, etc. It is fundamental good aquaculture practice and there are examples of farms where, if such practices are followed diligently, treatments for fish health problems are rarely needed.
ii. Bio-security, which includes obvious things like not bringing diseased juveniles on to a farm, disinfection of equipment that has been used on another farm, and care in harvesting to ensure no spillage of blood. It may also include single year class stocking and area management agreements with neighbouring farms so that all of them stock, harvest and fallow on the same schedule.
iii. Selection of species that are naturally resistant or are less vulnerable to stress induced disease because they adapt well to farm conditions.
iv. Stocking of large juveniles that are in the peak of condition when they are stocked. Too little is known yet about how to measure and manage the physiological condition of juveniles reared in hatcheries.
v. Inclusion of pre- and probiotics and immunological stimulants in feeds. Today, many claims are made for various substances, some no doubt exaggerated, but there seems to be an emerging consensus that this approach is helpful (Fish Farmer, 2009).
vi. Use of vaccines, which have proved their efficacy against bacterial diseases in salmon. Vaccines are also available now for virus diseases like Infectious Salmon Anemia (ISA) and for some other finfish species. Since they may also be effective against certain parasites, this is a field where there is almost unlimited scope for improvement and it is a priority.
vii. Medication, either in the feed or administered as a bath treatment. Use of antibiotics and other medicines in feed is an environmental concern in aquaculture, especially if it leads to overuse. However, it is and likely always will be one of the tools that fish health professionals need to use. Bath treatments for external and gill parasites are also important fish health management tools, but they may be difficult to administer offshore.
viii. Selective breeding of naturally resistant strains. The Norwegian Institute for Food Fisheries and Aquaculture Research reported recently that some strains of salmon

are more easily infested with sea lice than other strains and breeding from them could save the salmon farming industry millions of dollars a year (Nofima, 2008). Work has also been done to breed salmon strains that are naturally resistant to the Infectious Pancreatic Necrosis virus (IPN) (Aquagen, 2008).

ix. Changing cage depth, or simply providing very deep nets so that fish have a choice where they swim, may help in some circumstances. This has been used to avoid the effects of phytoplankton blooms on salmon farms in British Columbia (Canada) and there are reports that it may also help with control of sea lice.

Most of these approaches come under the heading of prevention rather than treatment and they apply to shellfish and marine plants even more so than they do to finfish because vaccine and medication options for them are not available. For this reason, species selection and selective breeding for stocks that have natural resistance to disease is important. For example, the success of *Crassostrea gigas* as a farmed oyster in Europe is in large part due to its greater resistance to the protozoan parasite, *Bonamia,* to which the native oyster *Ostrea edulis* is susceptible (FAO, 2004).

Predators

In aquaculture, as in agriculture, predation on farm stocks by wildlife is a problem unless protective measures are taken. The problems and solutions tend to be species and region specific and there is general concern about reliance on lethal methods of control, especially of avian and mammalian predators.

Since finfish are already contained in cages, entry of predators is a matter of making sure that the cage meshes are strong enough to resist them, and this is not always easy with large predators like sea lions that can tear holes in nets. For this reason, special predator nets are often used that provide an added layer of protection around the main fish containment net. However, these provide another surface for marine fouling, which reduces water flow and adds to the drag coefficient of farm structures. In some circumstances also, because predator nets are difficult to change and have larger meshes, farmers tend to leave them in the water for extended periods of time, when they may create habitat for transitional stages of certain fish parasites.

Predator nets will be even more problematic to use offshore where handling of all farm gear is more difficult. Therefore, alternative strategies are needed and the most likely is the use of materials for the primary fish net that are stronger than nylon and strong enough to resist predators with a single barrier. New materials such as Kikko Net (www.fukuina.com/netting/kikko_net), Dyneema® (www.dsm.com) and Aquagrid® (www.aquagrid.net) are now used in some nearshore cages and, though more expensive, are likely to become the preferred primary netting materials in offshore cages. There are also cages such as the Aquapod™ (see Figure 8), which are clad in predator resistant, plastic coated metal mesh.

Shellfish predators are mostly smaller than those that prey on finfish and include a number of invertebrates such as starfish, crabs and snails. Farmers often protect shellfish against them by enclosing the farm stock in plastic net bags or tubes, or in nylon "pearl" or "lantern' nets". As in finfish farming, these materials attract marine fouling and this must be cleaned, which is more difficult to do offshore. Since most bivalve shellfish need protection when they are small, a preferred strategy for offshore production may be to use nursery farms for the early vulnerable stages, only transferring them to offshore structures when they are predator resistant. This same idea was discussed earlier in the context of juvenile finfish supply.

With regards to marine plants, numerous organisms such as sea urchins and herbivorous fish graze on them and they may damage small-scale cultures or slow growing seaweed species. For example, grazing by large halfmoon perch destroyed kelp plants within a few days at one experimental California location where kelp farming was being tested as part of the US Marine Biomass Program (North, 1987; Chynoweth, 2002). Ask (undated) also notes that slow growing seaweed species grown in nearshore farms for carrageenan production are vulnerable to predation by *Siganus* sp., which nip the growing tips of the seaweed thallus, reducing the plant growth for a week or more until the plant heals itself. Predators do not seem to be a problem in large-scale production of fast growing seaweeds where growth greatly exceeds grazing demand.

Environmental impact

Environmental issues in offshore mariculture are discussed separately in this FAO review and therefore it is inappropriate to go into detail here. However, it is appropriate to note that campaigns against the development of offshore aquaculture, conducted mostly based on environmental concerns, have held development of the industry back. This is especially so in the United States of America that might otherwise have provided technical leadership. Therefore, environmental issues and concerns about offshore aquaculture are a serious constraint to its development. It would be helpful if FAO could offer international perspective on this by weighing precautionary concerns about environmental impact against precautionary measures that must be taken to assure future human food supply.

Integrated multi-trophic aquaculture (IMTA) is considered by some to be a possible solution to some environmental concerns though, in reality, it responds only to the release of nutrients and this is probably one of the lesser environmental concerns offshore. Development and evaluation of IMTA should be encouraged, but it should not be assumed an improvement until it is fully tested. There are questions, for example, about biosecurity risks in creating verdant habitat close to fish farms and about the design of farms for marine plants in offshore conditions, which, until they are proved seaworthy, might be more of a hazard than a help. Evaluation should also consider simply allowing released nutrients to be assimilated naturally in the marine ecosystem. It is not obvious why growing marine macrophytes close to finfish farms as part of a multi-trophic system would be considered preferable to natural growth of phytoplankton further away, unless their production pays for itself both economically and in terms of life cycle costs such as energy consumption.

Trained offshore personnel

All forms of aquaculture require specialized skills and additional skills are required offshore for navigation and safe working practices. Fishers have the latter skills and, if they are willing, are almost certainly capable of learning aquaculture skills. However, this involves a change of mindset and most likely a change in status from independent owner operator of a fishing boat to employee of an aquaculture company. It cannot be assumed that such changes are easily made and, therefore, training programmes that understand this and work to achieve the transition will help offshore aquaculture to develop more surely.

A constraint is that because there are so few offshore aquaculture facilities operating worldwide it will be difficult to provide trainees with practical experience and development of demonstration offshore farms would be helpful in this respect. Such farms have been instrumental in demonstrating many new farming technologies and it seems likely that they could be equally helpful in developing and demonstrating methods for offshore mariculture.

CONCLUSION

In 2003, The Economist began an editorial about ocean aquaculture with this: *"If modern agriculture was invented today, it probably wouldn't be allowed"* (The Economist, 2003). Of course, agriculture was invented thousands of years ago and the gradual, evolutionary development of modern agriculture since then, aided by land ownership laws that put the rights of the land owner on an equal footing with society, has been generally accepted.

The circumstances in which ocean aquaculture is being invented are quite different. Our present well-being in the developed world means that production of more food from the sea is not a necessity in the same way that agriculture was necessary, while development of new technologies today happens so quickly that the consequences of mistakes can be more serious. Moreover, society is beginning to understand the importance of balancing human needs with those of the ecosystem and, as the "owner" of the ocean space that would be farmed, it is the sole arbiter of how it should be used; there being no private ocean ownership laws to provide counterweight.

So, an undeniable case for ocean mariculture has not yet been made and until it is, the political will needed to encourage it will be undermined by public ambivalence and even hostility. All of the technical constraints discussed above can be overcome if society decides that offshore mariculture is something it needs. On the other hand, if it decides it is something it can do without, the obstacles may begin to seem insurmountable. FAO can help make the case by standing back from national squabbles about resource allocation, market competition and coastal conservation, to look at the Earth and its people as one and to present a long range, global vision of what ocean aquaculture might accomplish and might look like, say, 100 years from now. This would put ideas for development in context and provide scope and direction to programmes designed to test them. This paper has highlighted the following questions that might be addressed in creating such a vision.

Marine plants

There is a huge apparent potential to increase our vegetable biomass supply by greatly expanding the farming of marine plants. As noted, the present ratio of plant to animal production in all of aquaculture 1:3. If instead, this was 6:1, as it is for terrestrial agriculture, we should now be producing 270 million tonnes of marine plants per year, instead of 15 million tonnes per year. Therefore, a key question is, should transition to plant based, self-sustaining marine aquaculture be part of the long-term vision for ocean farming and, if so, is there merit in pointing out how little of the oceans' surface would be needed to achieve it?

Market definition

People talk of a future seafood supply deficit, but is this of marine plants, bivalve molluscs, shrimps, finfish, or all of these and, if the latter, in what proportion? Better definition of the future market mix will help to clarify what a future marine aquaculture industry must do in order to meet demand.

Competitive value

If offshore aquaculture is to contribute substantially to human well-being, its products must offer competitive value. The history of the farmed salmon industry illustrates the importance of this as production volumes build. This makes it extremely important to select species for aquaculture with attributes that make competitive pricing possible.

Which species?

Today, only 12 aquaculture species, or species groups, are produced at a level of more than a million tonnes per year, and the record of accomplishment of developing "new" species is mixed. Is it possible that the excitement that accompanies seafood in all its varieties will mislead us into thinking it can all be farmed when, in fact, it may not be possible to duplicate such variety at a cost that meets mass-market expectations of value? Moreover, might this mean that like chickens, pigs and cows on land, offshore mariculture will be driven by relatively few species that are farmed worldwide?

Industry critical mass

The efficiency needed to make aquaculture products affordable will depend on large-scale development and industry concentration. This will allow the establishment of service companies that help to make primary producers more efficient. The need for this critical mass gives advantage to those countries that already have well established near shore aquaculture industries, and may make it even harder to start offshore mariculture in some developing countries. How can this handicap be overcome?

Ecological efficiency

Should ecological efficiency be factored in to future projections of market mix? If so, what information is needed in order to be able to decide on the best balance? An important part of this is determining the long-term implications of producing animals that are fed on feeds made from ingredients that could also be food for people. Equally important is determining the "carrying capacity" of marine waters to support increased aquaculture production. Overall, it means more definitive Life Cycle Assessment. Is such analysis capable of providing the precision needed to make good decisions about a future product mix?

Help for developing countries

The engineering, financing and management demands of offshore mariculture will likely necessitate corporate investment and mean that it is driven by technology and companies from developed economies. What role can developing countries play in this and how can they be helped to participate? Might publicly sponsored demonstration farms serve as R&D platforms, training locations and as a less threatening way than commercial development to introduce the offshore aquaculture idea?

Is it necessary?

Finally, do we really need to find ways to increase the food yield from the oceans in order to sustain human well-being, or is it an ecological extravagance? In the developed world, we have reached a state of well-being where such a question can be asked. A long- range vision for ocean aquaculture must not only be able to answer it affirmatively, but must be able to show also how it can be done in balance with the marine ecosystem and in a way that is less intrusive than agriculture has been on land.

Offshore mariculture will only develop if enthusiasm for the idea is backed by an equal measure of political will. By addressing these questions and developing a long-range vision, FAO can help society to understand its benefits and make a case for it that cannot be denied.

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