The development of offshore aquaculture: an economic perspective

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Knapp, G. 2013. The development of offshore aquaculture: an economic perspective. *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*. FAO Fisheries and aquaculture Proceedings No. 24. Rome, FAO. pp. 201–244.

ABSTRACT

This study offers an economic perspective on the potential future development of offshore aquaculture and its economic effects. Offshore aquaculture is still in its infancy. There is little publicly available economic information about offshore operations on which to base empirical economic analysis. More importantly, the limited experience with offshore aquaculture to date is not necessarily representative of the technologies, species and locations which will characterize offshore aquaculture in the future. Future offshore aquaculture will likely occur in many different environments, using many different technologies, at widely varying scales, with widely varying markets and costs. Given these uncertainties, this study does not offer definitive conclusions about the potential for offshore aquaculture and its economic effects. Rather, it focuses on presenting a theoretical economic framework for thinking systematically about economic questions associated with offshore aquaculture.

Economic potential for offshore aquaculture – Offshore aquaculture will develop to a significant scale if and only if it is profitable. Supply and demand analysis provides a useful theoretical framework for thinking about the conditions under which offshore aquaculture will be profitable, and why and how these conditions may change over time. In general, capital and operating costs are likely to be higher for offshore aquaculture than for inshore aquaculture. However, there may also be offsetting cost advantages to the extent that better water quality improves survival or growth rates or that larger scale operations are possible. Importantly, two of the largest costs of aquaculture – feed and juveniles – are essentially the same for offshore aquaculture as for inshore aquaculture. Because of higher capital and operating costs, offshore aquaculture may not be economically viable for species for which wild fisheries or inshore aquaculture can meet demand at prices lower than those needed for offshore aquaculture to be profitable. However, offshore aquaculture which is not currently profitable may become profitable in the future as a result of three broad mechanisms:

- *Increasing demand for fish*, causing prices to rise to levels which make offshore aquaculture profitable.

- *Declining costs of offshore aquaculture*, making offshore aquaculture more profitable.
- *Increasing costs and/or reduced production from wild fisheries and inshore aquaculture*, making them less able to meet demand.

Offshore aquaculture can be economically viable even if costs are higher than for inshore aquaculture and wild fisheries. What matters is not whether inshore aquaculture and wild fisheries can produce fish at a lower cost, but whether they can produce enough fish at a lower cost to keep prices below levels at which offshore farming is profitable. At its current scale and given current technology, offshore aquaculture is a relatively high-cost way of growing fish. Currently, offshore aquaculture is probably able to compete with inshore aquaculture only under limited circumstances, such as the following:

- When offshore weather and wave conditions are relatively mild, reducing the costs of building and operating offshore facilities relative to inshore aquaculture.
- When offshore farms enjoy significantly better water conditions than inshore farms, enabling faster growth or better survival.
- When offshore farms are able to supply market niches which cannot be supplied by inshore farms, for reasons such as lack of suitable sites, regulatory constraints, and transportation costs.
- When offshore farms are able to take advantage of cost-lowering synergies with other facilities or activities such as existing inshore farm facilities or offshore oil rigs.

Over time, however, the economic potential for offshore aquaculture is likely to grow, for several reasons:

- Growing population and income and changing tastes will increase world demand for fish, raising prices.
- The relative cost of offshore aquaculture, in comparison with inshore aquaculture, will decline, due to technological advances, experience and economies of scale.
- The relative values of competing uses of potential inshore farming areas will increase, reducing the availability of those areas for inshore farming.

Among the most important factors affecting the economic potential for offshore aquaculture will be:

- The extent and pace of technological development in areas such as remote monitoring, remote feeding, cage construction and the extent to which these technological developments can reduce costs and risks of offshore farming.
- The extent to which offshore farms are able to achieve better growth rates and survival than inshore farms.
- The extent to which offshore facilities face fewer conflicts with other activities than inshore farms.
- The extent to which offshore farming is able to develop to a level at which it begins to realize significant economies of scale and to spur the development of key supporting industries such as hatcheries, veterinary services, cage manufacture and processing.
- The extent to which enabling regulatory frameworks establish clear, stable and timely processes for permitting and regulating offshore farms.

It is possible to envision a very wide variety of types of offshore aquaculture developing in the future. Many different species could potentially be farmed profitably offshore, in many different places, using many different kinds of technologies, for many different markets. There is no single answer about the economic potential for these many types of offshore aquaculture and when they might become profitable. The answers vary for different species, locations and technologies. The world offshore aquaculture industry is still in its infancy. There has been only limited experience on which to judge its future potential. It is impossible to know with certainty what the long-run economic opportunities for offshore aquaculture may be. But it is reasonable to assume that they are real and substantial.

Market effects of offshore aquaculture – The market effects of offshore aquaculture will in general be similar to the market effects of any expansion of aquaculture production. These include effects on prices received by inshore farmers and fishers (and correspondingly on prices paid by consumers) and longer-term expansion of market demand potentially benefiting all producers. In the short run, growth in offshore aquaculture production will tend to lower fish prices by increasing the supply of fish, harming fishers and inshore farmers, but benefiting consumers. The extent to which different countries benefit from or are harmed by offshore aquaculture will depend on the extent to which their citizens are consumers of fish grown offshore, producers of fish grown offshore, or producers of fish which compete with fish grown offshore. Over the longer run, however, growth in offshore aquaculture production will tend to increase the world demand for fish as consumers become more familiar with fish; as fish become available in more locations, at more times and in more product forms; and, as offshore fish farmers engage in systematic marketing to expand demand. Increasing demand will tend to offset the effects of increasing supply on prices.

Economic impacts of offshore aquaculture – In general, because of the more difficult working conditions offshore and the higher cost of transporting workers to offshore facilities, offshore fish farms are likely to be more mechanized and have fewer people working on the farm sites per metric tonne of production than inshore farms growing the same species. Offshore aquaculture, like other kinds of aquaculture, will create jobs and income in many more places and industries than on fish farms. These will include both industries which supply fish farms with inputs (juveniles, feed, cages, veterinary services, etc.), as well as, industries which process, transport and distribute fish grown offshore. Thus, the potential economic impacts of offshore fish farming are much larger than the jobs and income created directly at offshore farming operations. These economics impacts will be spread over a far greater geographic area than the communities where fish farms are located or from which they are supported – and may extend too many other countries.

Economic implications of government policies for offshore aquaculture – Government leasing and regulatory policies are critically important for offshore aquaculture. Offshore aquaculture cannot and will not happen unless governments establish leasing and regulatory policies which give fish farmers the opportunity and incentive to invest in offshore fish farming. Just as importantly, without the potential for eventual economic benefit, companies will not invest in research on how to address potential engineering or other challenges for offshore aquaculture. Until actual offshore operations are in place, there is no opportunity to learn from experience about how to address the challenges. The surest way to ensure that no solutions are found for these challenges is to ban offshore aquaculture until they are found. The surest way to ensure that no benefits are realized from offshore aquaculture is to ban offshore aquaculture until the benefits are proven.

Having an enabling regulatory policy does not in any way imply that offshore aquaculture should not be regulated or that the environment should not be protected. On the contrary, strict regulations and environmental protection is not only consistent with, but essential for successful offshore aquaculture development. What is needed is not absence of regulation but clear, consistent and efficient regulation that provides clear guidelines for where and how offshore aquaculture will be allowed and addresses regulatory goals in a cost-effective way. To the extent practical, government leasing and regulatory policies should be clear and stable and should avoid unnecessary delay, site leases should be well defined and transferable and policies should regulate outcomes rather than inputs.

To the extent practical, regulatory institutions for offshore aquaculture should have clear responsibility and authority, should consider both costs and benefits of offshore aquaculture and should consider and balance local, regional and national interests.

Recommendations for FAO – FAO should encourage and facilitate the development of offshore aquaculture, but should not oversell it. The true test of whether, where and when offshore aquaculture is a good idea is the market. Although it seems highly likely that eventually large-scale aquaculture production will occur offshore, helping to meet food demands of a larger and wealthier world population, this does not necessarily mean that offshore aquaculture is currently economically viable on a large scale. That has yet to be demonstrated. At this stage the most appropriate strategy for FAO is to continue to collect and disseminate information about the potential for offshore aquaculture and to encourage its Member states to create enabling regulatory frameworks under which investors can test that potential. Probably the most effective role FAO can play is in helping governments (as opposed to the private sector) obtain information they need to understand the potential of offshore aquaculture and to plan for and promote its responsible development. FAO is well suited to help provide this information by doing things it does regularly and well, including support of technical studies by experts; hosting meetings for sharing information among technical experts and government officials; and facilitating efforts to discuss and establish consensus on international issues related to offshore aquaculture, such as the development of aquaculture in international waters.

INTRODUCTION

As aquaculture expands worldwide, there is growing interest in farming fish[1] further offshore. Although there are many technological and economic challenges in farming in more exposed environments, there are also many potential benefits, including more space, fewer conflicts with other uses of the marine environment and reduced impacts on the marine environment.

The development of offshore aquaculture raises many technical, biological, spatial, economic, legal, policy and livelihood issues of importance to FAO and its Member countries. FAO is conducting a project to collect global information on the potential for offshore aquaculture and to consider the issues which it raises. This study is one of a number of technical reviews conducted for this project.

This study offers an economic perspective on the development of offshore aquaculture and on selected issues raised by offshore aquaculture. It focuses on the question: *Why and how will offshore aquaculture develop and what economic effects will it have?*

Offshore aquaculture is still in its infancy. There is little publicly available economic information about offshore operations on which to base empirical economic analysis.

More importantly, the limited experience with offshore aquaculture to date is not necessarily representative of the technologies, species and locations which will characterize offshore aquaculture in the future. Future offshore aquaculture will likely occur in many different environments, using many different technologies, at widely varying scales, with widely varying markets and costs.

Given these uncertainties, this study does not offer definitive conclusions about the potential for offshore aquaculture and its economic effects. Rather, it focuses on presenting a theoretical economic framework for thinking systematically about why and how offshore aquaculture will develop and what its effects will be.

Challenges for economic analysis of offshore aquaculture

There are several fundamental challenges in economic analysis of how offshore aquaculture will develop and what its effects will be.

[1] Throughout this study, the term "fish" is used to refer to all potential aquaculture products, including finfish, shellfish, and marine plants.

First, as noted above, offshore aquaculture is still in its infancy. Only a tiny fraction of world marine aquaculture production currently occurs "offshore" in relatively exposed ocean environments. The limited experience with offshore aquaculture to date is not necessarily representative of the technologies, species, and locations which will characterize offshore aquaculture in the future. It is difficult to predict accurately how, when and where offshore aquaculture will develop in the future. The farther one looks into the future, the less certain one can be about the key factors which affect the development of offshore aquaculture: what aquaculture technologies may evolve, what the resulting cost structures may be for onshore, nearshore and offshore aquaculture and what prices of fish and other competing proteins will be.

The challenge of predicting why and how offshore aquaculture will develop and what effects it will have is analogous to the challenge one would have faced in 1929 – at the time of Lindbergh's flight across the Atlantic – in predicting why and how large-scale intercontinental air travel would develop and what effects it would have. The industry knows that offshore aquaculture is technically feasible. It seems likely that it will eventually occur on a large scale, driven by growing demand for food and fish, the limits to other ways of expanding food and fish production, and rapid and dramatic technological advances. What it is not known is what it will look like – any more than we could have envisioned 747s and Heathrow Airport at the time of Lindbergh's flight.

A second challenge for the economic analysis of offshore aquaculture is its likely future diversity. As with coastal marine aquaculture, many different species may be farmed, including finfish, shellfish and plants. Production may occur in many different environments, from tropical to subarctic, at widely varying distances from shore, with widely varying wind and wave conditions. Production may occur using many different technologies, at widely varying scales. Markets and costs may vary widely between species, regions, technologies and scales of production.

Thus, there is not a single answer about how offshore aquaculture may develop and what its effects will be, but rather many answers. It is as difficult to generalize about what "offshore aquaculture" will look like or what its effects will be as it would be to generalize about what "freshwater aquaculture" or "coastal marine aquaculture" look like or what their effects are.

A third challenge for the economic analysis of offshore aquaculture is that why and how offshore aquaculture develops and what its effects will be will depend critically on how it is regulated. How offshore aquaculture is regulated will directly affect where, how, when and at what cost it occurs. Regulatory regimes for offshore aquaculture may differ widely between countries – encouraging its growth in some countries and discouraging its growth in others. Thus, part of the answer to the question of why and how offshore aquaculture will develop and what its effects will be depends on how countries want offshore aquaculture to develop and what effects they want it to have.

Given these three broad challenges, this study does not offer definitive conclusions about the future development of offshore aquaculture and its economic effects. Rather, it frames a way of looking at economic questions raised by offshore aquaculture and offers general conclusions about the answers to the questions.

Defining "offshore aquaculture"

There is no commonly accepted definition for the term "offshore aquaculture." It is defined sometimes in terms of distance from shore, sometimes in terms of environmental conditions such as water depth or wave size or expected intensity of storms and sometimes in terms of legal jurisdiction. In theory, it could be defined in terms of a combination of these characteristics.

It would be difficult to arrive to a single definition of "offshore aquaculture" which would be useful for all purposes. Where it would be most useful to draw a dividing line between "inshore" and "offshore" aquaculture may vary depending on whether we are studying technological issues, environmental effects, or regulatory issues. Similarly, where it would be most useful to draw any of these dividing lines may vary between different countries and/or geographic regions.

For the purposes of this study, we define "inshore" and "offshore" aquaculture as follows:

Inshore aquaculture: Aquaculture in relatively protected locations close to shore.

Offshore aquaculture: Aquaculture in relatively exposed locations farther from shore.

These simple definitions suffice for addressing the broad economic questions considered in this study.

Fundamental conditions for the development of offshore aquaculture

It is assumed that two fundamental conditions must hold for the development of offshore aquaculture to a significant scale, which we refer to as the "economic condition" and the "political condition."

Economic condition: Offshore aquaculture will be developed to a significant scale only if it is profitable.

As with any other economic activity, private sector investors will not invest in offshore aquaculture unless they *expect* it to be profitable, and they will not continue to invest in it unless it actually *is* profitable.

In theory, unprofitable offshore aquaculture could develop if governments were willing to subsidize it, or invest in and operate government-owned offshore farms. Certainly, governments may invest in or subsidize experimental or small-scale offshore farming projects for purposes of research, demonstration, or pilot economic development programmes. However, it is assumed that most governments will not subsidize or invest in unprofitable offshore aquaculture at a large scale, partly because there would be little reason to do so and partly because they would not be able to afford doing it.

Political condition: Offshore aquaculture will develop only where there is an enabling regulatory framework which allows investors to undertake projects with a reasonable expectation that their investments in the farm and their fish will be secure and a reasonable degree of certainty about how the operation will be regulated.

Put simply, offshore aquaculture will not happen unless governments create the regulatory conditions under which it can happen. This same "political condition" holds for any economic activity and helps to explain the lack of investment and economic growth in countries with unstable political conditions and/or legal systems. We are not used to thinking about the importance of this "political condition" in countries with developed and stable political and legal systems, including property rights. But even in these countries, it is crucially important for economic activities in offshore waters where rights and conditions for economic activities are not yet defined.

Assumptions about offshore aquaculture

Much of the analysis in this study is based on four assumptions about how offshore aquaculture will *generally* differ from inshore aquaculture. The author assumes that in general, for any given geographic region, species and scale of operation, with currently available technologies, in comparison with inshore aquaculture: (1) offshore aquaculture will face a more challenging physical environment; (2) offshore aquaculture will have higher capital and operating costs per kilogram of production; (3) offshore aquaculture will have fewer significant effects on the marine environment; and (4) offshore aquaculture will create less potential for conflict with other users of the marine environment.

It is not assumed that these assumptions will always be true for all regions or species, only that they are generally likely to be true. Below, each assumption is discussed in greater detail.

1. Offshore aquaculture will face a more challenging physical environment – By definition, it is assumed that offshore aquaculture will occur in relatively exposed locations farther from shore. In general, these locations will have greater water depth and larger waves, posing greater challenges for the design of cages and feeding systems which can withstand these conditions. They will also be located at greater distances from shore-based support facilities, increasing the challenges of installing and operating farms, including stocking, feeding, monitoring and harvesting fish.

2. Offshore aquaculture will have higher capital and operating costs per kilogram of production – Capital costs will generally be higher because anchoring systems must be designed for greater depths and cages must be designed to withstand bigger waves. Operating costs will generally be higher because of the greater distances from shore-based facilities and the more challenging physical environment in which work must be done.

Note that the assumption is that offshore farms will have higher costs than inshore farms *with currently available technologies, for farms of a given scale*. As it will be discussed, it is possible that the relative costs of offshore farms could be lower with future (still-to-be-developed) technologies, or that large-scale offshore farms might benefit sufficiently from economies of scale to have lower units costs than smaller-scale inshore farms. In addition, if growth rates or survival rates are better at offshore farms, this would help to offset the relative operating cost differential of offshore farms.

A simpler basis for the assumption that offshore aquaculture will have higher costs is that most marine aquaculture to date has occurred inshore. If offshore aquaculture were possible at lower relative costs, it is likely that it would have developed to a relatively greater extent.

3. Offshore aquaculture will have fewer significant effects on the marine environment – By "significant" effects we mean effects which are measurable and which have measurable effects on the ecosystem. It is assumed that these effects will generally be fewer because with deeper water and stronger currents waste products will be dispersed over a greater area and are less likely to be sufficiently concentrated to have significant effects on the environment.

4. Offshore aquaculture will create less potential for conflict with other users of the marine environment – In general, diversity and intensity of other uses of the marine environment which might conflict with offshore aquaculture is likely to be relatively higher inshore, including in particular uses such as recreation, scenery (views of the coast enjoyed by local residents and tourists) and small-boat travel. Of course, there may also be conflicts with other uses occurring farther offshore, such as commercial fishing and larger-boat coastal navigation. It is only assumed that conflicts will generally be fewer for offshore aquaculture – not that this will be the case always or everywhere.

BASIC ECONOMICS OF AQUACULTURE

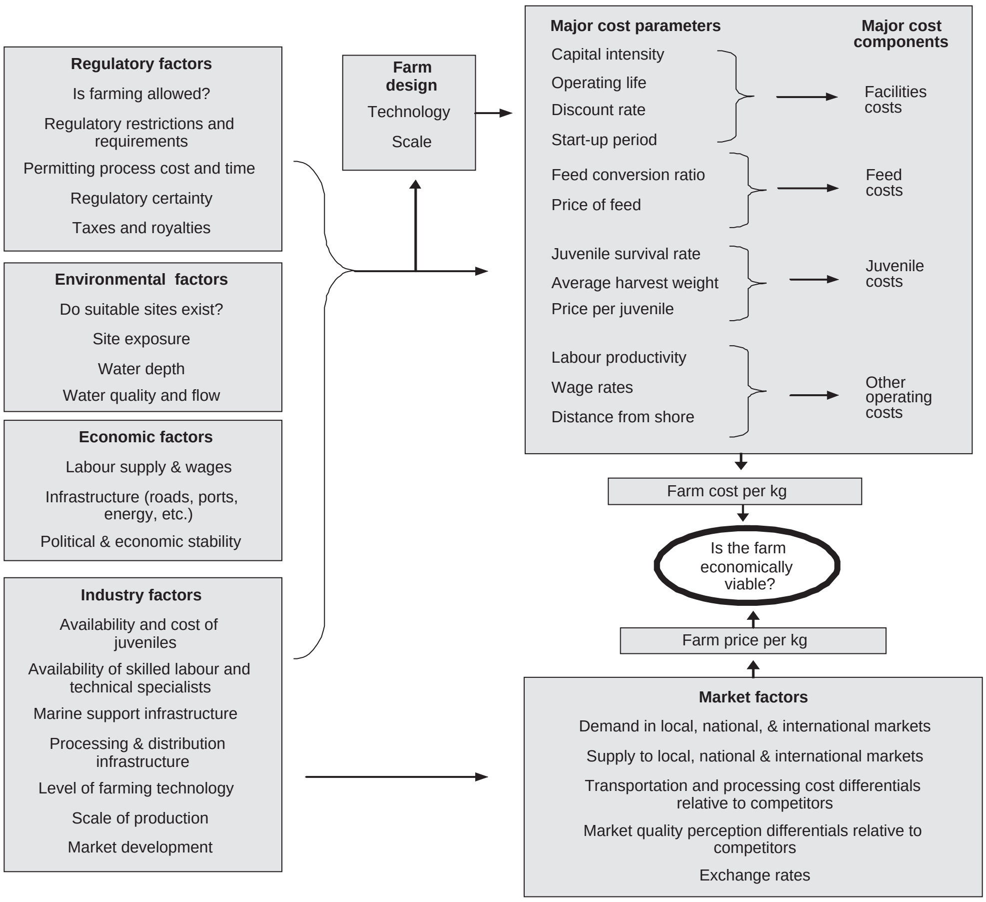
This paper begins by reviewing basic economics of aquaculture: how different factors affect costs, revenues and profitability or "economic viability" of a fish farm. To simplify the discussion, all costs and revenues are expressed on a per kg basis. This requires converting all costs and revenues incurred at different times – including one-time investment costs – into comparable costs and prices per kg.[2]

Figure 1 provides a conceptual framework for thinking about factors affecting the economic viability of a fish farm in a given location growing a particular species of fish. A fish farm is profitable if the average price per kg received for the fish exceeds the average cost per kg of producing the fish.

Major costs of fish farming

The cost per kg of producing fish may be divided into four major cost components: facility costs, feed costs, juvenile costs and other operating costs. Each of these cost components is determined by cost parameters, which are driven in part by the farm design. A wide variety of external factors – shown on the left side of the diagram in Figure 1 – drives both farm design and cost parameters. Some of the same and other external factors drive supply and demand conditions, which determine the price for which the farm can sell its fish.

FIGURE 1
Major factors affecting the economic viability of a fish farm



[2] A fish farm incurs costs and receives revenues over time. Prior to earning any revenues, a fish farm incurs initial one-time costs of planning, permitting and capital investments for cages and other facilities. These are followed by further investments in juveniles and feed. After the first grow-out period, the fish farm begins to earn revenues as the first fish are harvested and sold. Over the operating life of the farm, the farm continues to incur additional costs of juveniles and feed, as well as annual operating and maintenance costs. Analysis of the profitability and economic viability of a fish farm requires comparison of the stream of costs incurred over time with the stream of revenues over time. This may be done using standard methods of investment analysis. In general, a farm is economically viable if the net discounted value of expected revenues over time exceeds the net discounted value of expected costs over time (including the risk-adjusted cost of capital). Thus, profitability depends not just on total costs and revenues, but also on the timing of costs and revenues over the life of the farm, and the risk-adjusted cost of capital.

Facilities cost

A marine fish farm requires a variety of capital investments. The most significant investments are typically for cages, boats, feeding and monitoring systems, onshore facilities (docks, storage facilities and offices) and initial project planning (including design and permitting). For the purposes of this discussion, the cost of these investments is referred as "facilities cost." Any given total facilities cost of a fish farm may be converted into an equivalent annual facilities cost per year of production, which may be thought of as the annual equivalent payment that would be required to pay both principle and interest on a loan for the full cost of the investment over the lifetime of the investment.[3]

Facilities cost per kg is equal to:
(Equivalent annual facilities cost per year of production) / (annual production in kg)

The most important factors affecting facilities cost per kg include:

- Capital intensity: the total initial investment per kg of annual production.
- Discount rate: The risk-adjusted opportunity cost of capital for the project. Depending on how the project is financed, this may be either the interest rate which would be charged on a loan for the investment, or the rate of return which could be earned on an alternative investment of equivalent risk. For any given capital intensity, the higher the discount rate, the higher the facilities cost per kg.
- Operating life: the number of years with harvests to which facilities costs may be attributed. For any given capital intensity, the greater the number of years with harvests, the lower the facilities costs per kg.
- Start-up period: the period of time from when investments are made until harvests begins. For any given capital intensity, the longer the start-up period, the greater the facilities costs per kg.

Feed cost

Feed cost is one of the largest components of finfish farming costs. The most important factors affecting feed cost per kg of fish production include:

- Price of feed. This is the price per kg of feed purchased by the farm.
- Feed conversion ratio (FCR). This is the ratio of the total weight of feed eaten by a crop of fish (from the time they are purchased as juveniles to the time they are harvested) to the weight gained by the fish between stocking and harvest.

Feed cost per kg of fish is equal to:
(Price of feed) x (Feed conversion ratio)

Feed costs per kg of fish vary depending upon the type of feed, species, feeding technology and other factors affecting growth and survival rates of fish, including water quality.

In general, two opposing trends are likely to affect future feed costs per kg for marine aquaculture. The price of feed may increase as rising feed demand puts upward pressure on prices of fish meal and fish oil, which are major inputs to feed production. Rising prices of feed will increase farmers' incentives to reduce feed costs by improving feed conversion ratios. This may be done in a number of ways, such as reducing fish mortality, developing better feeds that fish are able to utilize more efficiently, improving the timing and method of feeding, utilizing more vegetable-based feeds

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[3] Financial analyses of fish farms often include "interest" and "depreciation." The concept of annual facilities cost as used here is approximately equal to the sum of interest and depreciation, with the assumption that interest and depreciation are identical for each year of facility life.

and shifting production from carnivorous species to non-carnivorous species. Future trends in aquaculture feeds costs per kg will depend on the relative strength of these opposing trends.

Juvenile cost

Juvenile cost is another important component of marine aquaculture cost. The most important factors affecting juvenile cost are:

- Price per juvenile. This is the delivered cost of individual juveniles purchased from a hatchery.
- Juvenile survival rate. This is the percentage of juveniles which survive to be harvested. It is equal to the inverse of the number of juveniles per harvested fish.
- Average harvest weight. This is the average weight of fish at harvest.

Juvenile cost per kg of fish harvested is equal to:
= (Price per juvenile) * (Juveniles per harvested fish) / (Average harvest weight)
= (Price per juvenile) / [(Juvenile survival rate) * (Average harvest weight)]

Key factors affecting fish farming costs

Fish farming costs vary widely depending upon the species being farmed and where and how it is farmed. In general, however, feed and juveniles represent the largest cost components for most types of finfish farming, while operating costs and facilities costs tend to represent a much smaller share of total cost, even for offshore farms.

This basic fact is important in considering the economics of offshore fish farming and its ability to compete with inshore farming. Although operating costs and facilities costs are likely to be higher for offshore farming, feed costs and juvenile costs are likely to be the same – or potentially lower, if offshore water quality and water flow are better.

The smaller the share of total costs represented by a particular cost element, such as facilities cost, the less significant the effect of an increase in that cost element in its relative effect on total cost. For example, suppose facilities costs and feed costs account for 10 percent and 50 percent of the total cost of an inshore farming operation, respectively. If facilities costs are 100 percent higher for an offshore farm, this represents only a 10 percent increase in total costs – which would be fully offset by a 20 percent decrease in feed costs.

Farm design

Some cost parameters are influenced by the farm design: the technology used by the farm and the scale of the farm. These include capital intensity, operating life, feed conversion ratio, juvenile survival rate and labour productivity. In general, as in other kinds of agriculture, fish farmers face a choice between capital intensity and other cost parameters. By increasing the capital intensity of the farm (which increases facility costs) farmers can achieve better feed conversion ratios, better juvenile survival rates and higher labour productivity (which lowers feed costs, juvenile costs and other operating costs).

The important point to recognize is that cost-minimizing design choices for offshore farming may differ from those for inshore farming and cost-minimizing design choices for offshore farms may differ from those for foreign offshore farms. For example, if labour costs more per hour for an offshore farm than for an inshore farm, an offshore farm is likely to use relatively less labour, thus, reducing the extent to which higher labour costs represent a cost disadvantage.

Regulatory factors

Regulatory factors directly affect the economic viability of fish farming – most obviously by whether farming is allowed at all, but also in numerous other ways.

Regulatory restrictions and requirements may limit farm design choices of scale and technology and may impose additional costs such as environmental monitoring. The permitting process may represent a significant cost which increases with the time required for permitting and the uncertainty associated with the outcome. Regulatory certainty – the likelihood that regulations will stay the same over the life of the farm – affects the risk associated with farming investments and the discount rate for facilities investments. Taxes and royalties represent additional direct costs.

Put simply, to a significant extent, the costs and economic viability of fish farming depends on how it is regulated. Favourable regulation cannot make a fish farm economically viable if environmental, economic, industry and market factors are unfavourable. But unfavourable regulation can keep a farm from being economically viable even if other factors are favourable.

Environmental factors

Key environmental factors affecting economic viability of a fish farm include site exposure, water depth and water flow. Exposure to waves and wind directly determine what kinds of cages and other farm equipment will work and the risks of farm damage and loss of fish. Water depth affects installation costs. Water depth, quality and flow affect feed costs and juvenile costs by affecting fish growth rates and mortality rates. Water depth, quality and flow also affect potential environmental effects of a farm and the extent to which these must be mitigated, either because it is in the farmer's own interest or because of regulatory requirements.

Economic factors

General economic conditions affect the costs and economic viability of a fish farm. Key economic factors include labour supply and wages, transportation infrastructure and availability and cost of utilities. Another critical factor is political and economic stability, including protection of property and basic rule of law.

Industry factors

The costs and economic viability of an individual fish farm are affected by a number of industry factors which depend on the scale and experience of the industry. As the scale of the fish farming industry within a region or nation grows, it creates a demand for specialized aquaculture support activities, such as hatcheries, veterinary services, fish transportation and processing. As the scale of these activities expands, this tends to lower costs and expand the types and scale of farming which is feasible. More generally, experience gained in farming drives technological change. Industry factors may be thought of as "feedback factors" affecting economic viability, in the sense that as an industry grows and gains experience, economies of scale and technological change help to lower costs and further expand the industry.

Market factors

Price is as important as cost to the economic viability of a fish farm. The price per kilogram received by a farm is driven by a wide variety of market factors interacting in complex ways. The effects of these factors can generally be described within the supply and demand framework presented below.

Which market factors are most important depends on the size of the market and the relative scale of competition. If a fish farm is supplying a market or markets which are also supplied with comparable fish of comparable quality from competing sources, the volume of competing supply and the prices offered by competitors are key factors influencing the price received by the farm. Put differently, the price depends on whether the demand for the fish is local, national or international and whether the competing supply is local, national or international.

Different factors also drive prices in the short-term (over the course of one or a few years) than over the long-term (the expected period of operation of a fish farm). In the short-term, prices are driven by the total supply available to the market given current production. Over the longer term, prices are driven by the capacity of producers to expand or contract production in response to higher or lower prices.

In national and international markets, competition typically occurs at the wholesale level, between fish which have undergone primary processing and been transported either to end-market locations or locations where further processing occurs. The price paid to a fish farm is driven not only by the wholesale price, but also by the costs of processing and transportation, which must be subtracted from the wholesale price. Put differently, whether a fish farm can be competitive is determined not just by the cost of growing the fish, but also by the costs of processing the fish and transporting it to markets. In considering whether a particular farming operation can be competitive, an important factor is how both processing costs and transportation costs to markets compare with those of competitors. A higher-cost farm can be competitive if its products can be processed at a lower cost or shipped to markets at a lower cost than for competitors.

Both processing and transportation costs depend in part on the scale of the industry. A pioneer fish farm in a location may face relatively high processing and transportation costs if the fish processing industry and transportation infrastructure is not well developed. As the industry grows in scale these costs may decline significantly, making fish farms relatively more competitive. Thus, some of the industry scale factors which affect the costs of a fish farm also affect the price paid to a fish farm, through their effects on the costs of processing and transportation.

A similarly important factor is the perceived quality of a farm's products compared with competing suppliers' products, as reflected in the relative prices buyers are willing to pay. A higher-cost farm can be competitive if its products can command a higher price than those of competitors.

COMPETITIVE DISADVANTAGES AND ADVANTAGES OF OFFSHORE AQUACULTURE

Relative to inshore aquaculture, offshore aquaculture has a number of potential competitive disadvantages (factors which tend to increase relative costs), but also certain potential competitive advantages (factors which tend to reduce relative costs). Potential competitive disadvantages include:

<u>Greater exposure</u>. Offshore aquaculture faces significant technical challenges and costs of constructing, installing, operating and maintaining cages and feeding and monitoring systems able to withstand wave and wind conditions in an exposed ocean environment. A more exposed environment also adds to the required sizes and construction and operating costs of support vessels. This increase in costs may be significantly reduced where there are synergies with existing or new offshore facilities built for other purposes, such offshore oil platforms or (as envisioned for the future) wave power generation installations.

<u>Higher support transport costs</u>. Offshore farms are (by definition) located farther from shore than onshore farms. In general, this will mean that fish, feed and workers will need to be transported over greater distances, adding to fuel and labour costs. Note, however, that locating a farm farther offshore does not necessarily imply a greater transportation distance, in comparison with available inshore sites. Depending on terrain, infrastructure development and the extent of the existing inshore farming industry, offshore facilities will not necessarily be farther from onshore support facilities such as docks and roads than available protected inshore sites. Put simply, it

may be shorter and quicker for a support vessel to travel five kilometres straight out to sea than eight kilometres up the coast or around a cape to the next bay.

Greater water depth. In general water depth is greater for offshore farms, and may in some cases be much greater – adding to the costs of mooring systems.

More difficult working conditions. Offshore farms will likely need to pay higher wage rates for workers able and willing to work in a harsher and riskier offshore environment and able to work with more complex technology of offshore farms. Note, however, that higher wage rates may be significantly offset by use of more capital-intensive and labour-saving technology such as remote feeding and monitoring systems.

Fewer industry-wide economies of scale. The costs of manufacturing cages and offshore feeding and monitoring systems depend upon the scale at which they are produced. Currently, far fewer cages and feeding and monitoring systems are being built for offshore farming than for inshore farming. Over time, as the scale of offshore investment expands, this will help to lower manufacturing costs for offshore cages and feeding and monitoring systems.

Less operating experience. For almost any economic activity, operating experience helps to identify better and cheaper ways to do things. Worldwide, there has been far less experience in building and maintaining offshore farms than for inshore farms. Over time, as more experience is gained with offshore farming, costs are likely to decline at a relatively greater rate for offshore farming than for onshore farming.

Less regulatory experience. In comparison with inshore aquaculture, there is a lack of experience with the regulation of offshore farming. Regulatory frameworks and effective methods for offshore farm monitoring and regulatory enforcement may not be in place. Potential jurisdictional and legal issues may not have been resolved. This lack of experience is likely to increase the difficulty, time, costs and risks associated with applying for offshore sites and meeting regulatory requirements. Over time, as more regulatory experience is gained for offshore farming, these costs are likely to decline until they are comparable with those for inshore farming.

Potential competitive advantages of offshore aquaculture, relative to inshore aquaculture, include the following:

Better water quality. Water quality is critical to successful fish farming. In general, offshore farms will have more water flow than inshore farms. Offshore farms are also less likely to be affected by pollution from land-based sources such as agricultural runoff. Better water quality contributes to better growing conditions for fish and is reflected in better feed conversion and survival rates, lowering costs of feed, juveniles and facilities and other costs (on a per kilogram basis).

Fewer conflicts with other activities. Because of their greater distance from shore, offshore farms are likely to have fewer conflicts with other economic and recreational uses of the environment. Reduced potential for conflicts with other activities may be reflected in fewer restrictions on farm size and greater economies of scale, as discussed below.

Fewer environmental impacts. Because of greater water flow and depth, offshore farms have less potential for concentration in the water or on the ocean bottom of fish faeces, fish feed or other farm residues. There is also less potential for interaction with species migrating close to shore or with concentrations of migrating anadromous fish. Reduced environmental impacts may be reflected in fewer restrictions on farm size and greater economies of scale.

Potential for greater farm economies of scale. Because of the greater availability of suitable large-scale farming sites and the potential for fewer regulatory restrictions on farm size, offshore farms have the potential to be larger, allowing for reduced costs through greater economies of scale.

Potential for shorter distances to markets. Because of reduced conflicts with other activities and greater availability of sites, it may be possible to locate offshore farms closer to markets (such as major cities) than is possible for inshore farming, reducing transportation costs and making it possible for fresher products to be delivered to markets.

WHAT WILL DRIVE THE DEVELOPMENT OF OFFSHORE AQUACULTURE?

> *"Offshore aquaculture is needed and will happen because the world will need more fish and only offshore aquaculture can meet that need."*

This is a familiar and plausible argument for the need for and inevitability of offshore aquaculture. By itself, however, this argument is incomplete. Offshore aquaculture is an economic activity which will be developed to a significant scale only if it is profitable. To understand how and why offshore aquaculture may develop, it needs to be understood how and why offshore aquaculture may become profitable in the future. How will the world's need for more fish, and the capacity of offshore aquaculture to supply that fish, translate into the economic signals that will make offshore aquaculture profitable and spur investment in offshore aquaculture?

A supply and demand modelling framework

Supply and demand analysis – a basic tool of economics – provides a useful framework for thinking about factors that may drive the future growth of offshore fish farming. Below the author first discusses a framework for modelling fish supply and demand. This framework is then used to discuss different mechanisms by which offshore aquaculture may become profitable and grow in scale over time.

Initial assumptions

For simplicity, it is assumed initially that there is only one species of fish and one global market for fish. Fish may potentially be produced in three ways: from wild (capture) fisheries, by inshore farming and by offshore farming. A regulatory framework exists under which investors may obtain secure rights to both inshore and offshore farming sites. Later, the implications of relaxing these assumptions are explored to allow for more species, more farming regions and more markets.

The subsequent discussion is illustrated with a variety of hypothetical supply and demand curves. What matters with these curves is only their slopes (how supply or demand changes as prices change) and their locations relative to each other (for any given price, relative supply or demand from different types of production). The reader should not be overly concerned with other details of how the curves are drawn. The purpose as intended by the author is not to illustrate actual supply or demand curves (which would vary widely for different species and locations) but rather broad economic principles affecting how fish are produced.

Inshore aquaculture supply curve

It is useful to begin the discussion of fish supply and demand with the fish supply curve from inshore aquaculture.

Each existing or potential inshore farming operation has an actual or expected production cost per kilogram. As discussed above, this includes the costs of facilities, feed, juveniles and other operating costs. These costs may vary between farms depending on their location, type of technology, scale of production and the costs of various factor inputs (labour, energy, etc.).

A farm is profitable (economically viable) if and only if the price it receives per kilogram is greater than or equal to the total cost of production per kilogram (including the risk-adjusted cost of capital). Although investors may invest in farms which turn out to be unprofitable, they will not continue to operate them over the long-term unless they are profitable.

As illustrated in Figure 2, the costs of all existing and potential inshore fish farms can be plotted on a graph, with costs per kilogram on the vertical axis and annual production on the horizontal axis arranged in ascending order of cost per kilogram. Plotted in this way, the total costs per kilogram form an inshore aquaculture supply curve. The supply curve shows the potential volume of fish production that would be profitable from inshore farms at any given price per kilogram. Put differently, it shows the price per kilogram that would be required for any given volume of production to be profitable.

Below price P_{min}^{I} no fish could be profitably produced. Above P_{min}^{I}, as the price increases the volume of fish which can be produced profitably increases, as less favourable inshore sites become profitable.

Wild fishery supply curve and offshore aquaculture supply curve

As illustrated in Figure 3, one may also think of "supply curves" for fish from wild fisheries and from offshore aquaculture. Each of these supply curves also shows, for any given price, the total volume of fish that could be profitably produced for that price within a given time period. In other words, it shows the price per kilogram that would be required for any given volume of production to be profitable.

The relative shapes of the three different supply curves reflect the different costs of production for each method of producing fish and how changes in price affect the volume which could be profitably produced. Wild fisheries can produce some fish at prices below the minimum price at which inshore aquaculture is profitable (P_{min}^{I}). However, the total volume of fish which can be produced by wild fisheries is limited by the capacity of the ocean to sustain wild harvests (as well as harvest restrictions imposed by managers). Thus, above a certain volume of fish which can be caught for relatively low cost the supply curve for wild fisheries begins to rise steeply and eventually becomes vertical. Put

FIGURE 2
Hypothetical inshore aquaculture supply curve

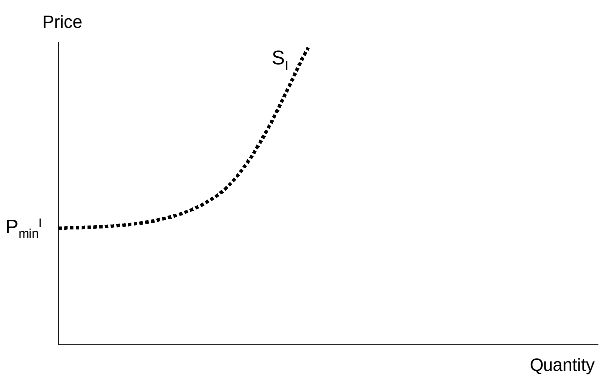


FIGURE 3
Hypothetical fish supply curves

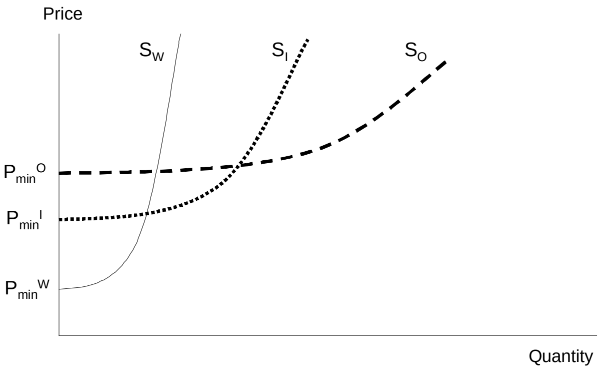


FIGURE 4
Hypothetical total fish supply curve

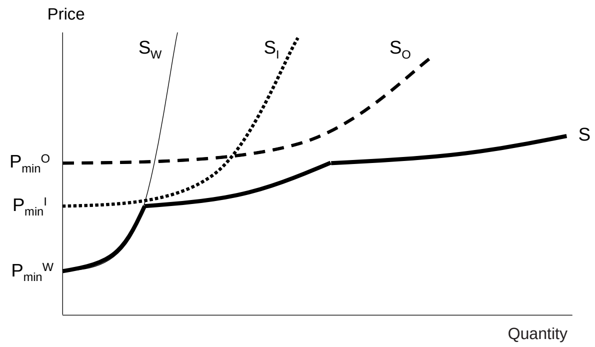
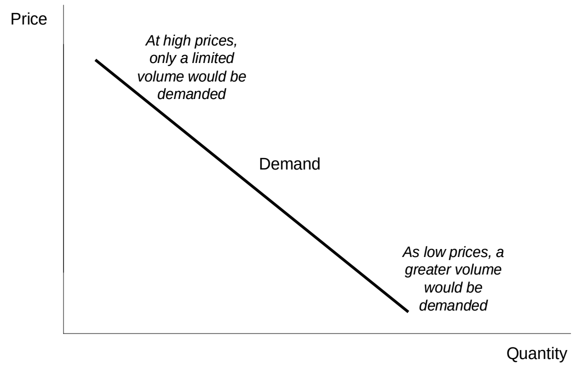


FIGURE 5
Hypothetical fish demand curve



differently, above a certain level of production even high prices cannot call forth additional production from wild fisheries.

In contrast, the minimum price at which offshore aquaculture production is profitable (P_{min}^{O}) is higher than for inshore aquaculture. However, at prices above this level it is possible to produce large volumes of fish, because of the very large number of sites which become available. Put differently, above a certain price level higher prices can call forth large increases in production from offshore aquaculture.

Total supply curve

As illustrated by Figure 4, the total fish supply curve S is the horizontal sum of the wild supply curve S_W, the inshore aquaculture supply S_I and the offshore aquaculture supply curve S_O. It shows, for any given price, the total volume that could be profitably produced from all three types of production. At low prices (between P_{min}^{W} and P_{min}^{I}) supply would come only from wild fisheries. At higher prices (between P_{min}^{I} and P_{min}^{O}) supply would come from both wild fisheries and inshore aquaculture. At still higher prices (above P_{min}^{O}) production would come from wild fisheries, inshore aquaculture, and offshore aquaculture.

Fish demand curve

As illustrated in Figure 5, a hypothetical fish demand curve may also be drawn. The demand curve shows the volume of fish that would be demanded by buyers at any given price per kilogram. Put differently, it shows the price per kilogram that would be required for buyers to demand (wish to buy) any given volume of production.

It is assumed that the demand curve is downward sloping, so that the lower the price, the greater the volume which buyers would wish to buy.[4] Only for simplicity, the demand curve has been drawn as linear (this is not essential to the analysis).

Equilibrium price and quantity

If one plots the fish supply and demand curves on the same graph, as illustrated in Figure 6a, then the price and quantity at which the curves intersect is referred to by economists as the “equilibrium” price and quantity. This is the only price for which the quantity fish producers would be willing to supply equals the quantity buyers would demand.

Economists argue that over time the actual price and quantity will tend to approach the equilibrium price and quantity. At a higher price, buyers would not be

[4] In some cases the demand curve may be horizontal or vertical. For example, the demand curve might be represented as horizontal if a large alternative source of production of the same fish (from other regions) were available to buyers at a particular price. In this case, buyer’s demand for fish from any given region would fall to zero above the price at which they could get it from other regions – and would become very large at prices lower than the price of fish from other regions. Alternatively, the demand curve might be represented as vertical if buyers always demanded exactly the same quantity of fish regardless of price.

willing to purchase all the fish that farmers would produce, causing a surplus of unsold fish. This would tend to cause the price to fall, which would cause farmers to reduce production and buyers to demand more. Similarly, at a lower price, buyers would want to purchase more fish than farmers would produce. Buyers would tend to bid up the price, which would cause farmers to increase production and buyers to demand less.

Figure 6b shows the same fish supply and demand curves as Figure 6a, but also shows the supply curves for each of the three methods of producing fish which together result in the total fish supply curve S. At the equilibrium price P, the supply from wild fisheries is Q_W and the supply from inshore fisheries is Q_I, which together add to total supply of Q. At the equilibrium price P, there is no production from offshore farms because – under these hypothetical supply and demand conditions – the equilibrium price is below the minimum price (P_{min}^O) at which any production from offshore aquaculture is profitable.

FIGURE 6A
Equilibrium price and quantity

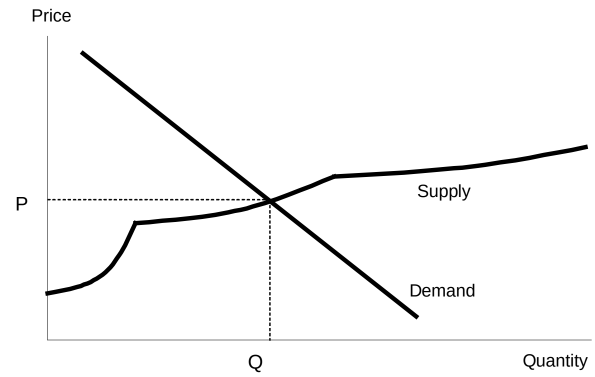
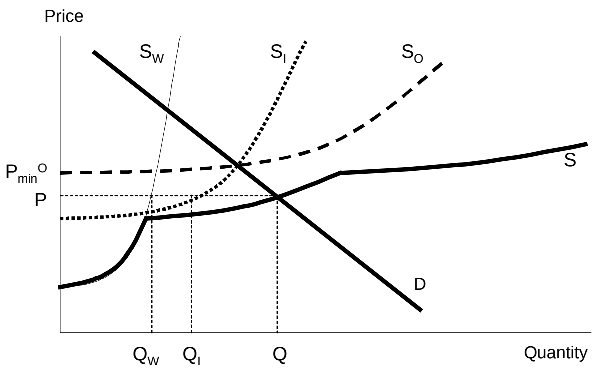


FIGURE 6B
Sources of supply at the equilibrium price



Mechanisms by which offshore aquaculture may become profitable

Figure 6b illustrates a situation in which the equilibrium price would be too low for offshore aquaculture to be profitable. In economic terms, the demand curve for fish intersects the supply curve at an equilibrium quantity Q which can be met by lower-cost inshore farms. Prices would not rise to the higher level necessary for higher-cost offshore farms to be profitable, because if they did, lower-cost inshore farms would increase production, causing a surplus which would drive prices back down. Put differently, *offshore farming will not be economically profitable if lower-cost inshore farms can fully meet demand at prices below the cost of offshore farming.*

Figure 6b represents the *current* economic situation for offshore production of many species in many countries. Given current demand for fish, current costs of production from offshore farming, and the prices at which fish can be supplied from wild fisheries and inshore aquaculture, offshore aquaculture production is not currently economically viable for many species because demand can be met at lower cost from wild fisheries and inshore production.

However, this does not mean that types of offshore aquaculture which are not currently profitable will never be profitable. Below, the author discusses three potential mechanisms by which offshore aquaculture which is not currently profitable may become profitable over time, by shifting either demand or supply. These mechanisms are summarized in Table 1.

Growth in demand

Higher-cost offshore aquaculture will be able to compete with lower-cost inshore aquaculture and wild fisheries if demand increases sufficiently that the limited volume which can be produced at lower costs from wild fisheries and inshore farming cannot

TABLE 1
Mechanisms by which offshore aquaculture may become profitable

Mechanism	Potential driving factors	Change in demand or supply curves	Effects on price and total fish production	Figures illustrating effects
Growth in demand	Growth in world population Growth in per capita incomes, particularly in newly developing countries Increasing awareness of health benefits of seafood Marketing by the aquaculture industry Constraints to the ability of agriculture and freshwater aquaculture to meet growing food demand, including constraints on availability of land, fertilizer and water	Outward shift in the demand curve for fish	Increase in price Increase in production	7a, 7b
Reduction in offshore costs	Technological advances in cage design, remote control and monitoring technology, anchoring and feeding systems, etc. Reduction in permitting costs and political risks as regulatory frameworks are created and governments and industry gain experience with offshore aquaculture Economies of scale as offshore production increases	Downward shift in the offshore aquaculture supply curve	Decrease in price Increase in production	8a, 8b, 8c
Reduction in alternative supply	Increased demand for other uses of inshore waters resulting in reduced availability of inshore sites Increased regulatory restrictions on inshore farms to reduce environmental impacts	Inward shifts in the wild fisheries and/or inshore aquaculture supply curves	Increase in price Decrease in production	9a, 9b, 9c

fully meet demand. A wide variety of factors could cause a growth in demand for fish. These include (but are not limited to) growth in world population; growth in per capita incomes, particularly in newly developing countries; increasing consumer awareness of health benefits of seafood; marketing by the aquaculture industry; and constraints to the ability of agriculture to meet growing food demand.

FIGURE 7A
Effects of growth in demand

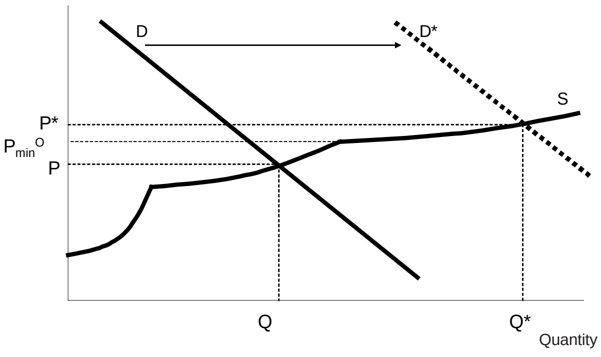
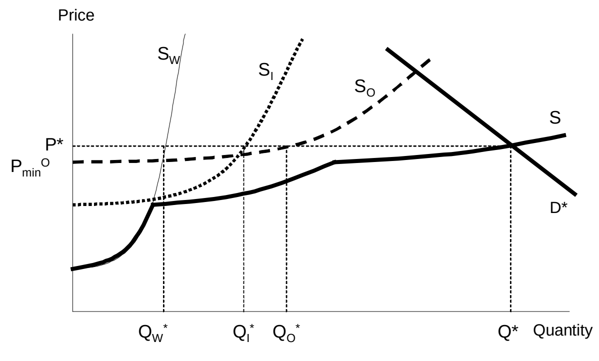


FIGURE 7B
Effects of growth in demand



As illustrated in Figure 7a, growth in demand would cause the demand curve for fish to shift outward from D to D*. This shift in demand causes the equilibrium price to rise from P to P*, above the minimum price P_{min}^{O} at which offshore aquaculture becomes profitable. Total world fish production rises from Q to Q*.

As illustrated in Figure 7b, at the new equilibrium price P*, quantity Q_W* is produced from wild fisheries, quantity Q_I* is produced from inshore aquaculture, and quantity Q_O* is produced from offshore aquaculture.

Reduction in offshore costs

Offshore aquaculture will be able to compete with wild fisheries and inshore aquaculture if costs for offshore farming decline sufficiently that offshore aquaculture becomes profitable at prices at which demand cannot be fully met by wild fisheries and inshore farms. Such a reduction in cost might occur, for example:

because of technological advances in cage design, remote control and monitoring technology, anchoring systems, feeding systems, etc.; reductions in permitting costs and political risks as regulatory frameworks are created and governments and industry gain experience with permitting and regulation of offshore aquaculture; and economies of scale as offshore production increases.

As illustrated in Figure 8a, a reduction in offshore costs would cause the offshore aquaculture supply curve to shift downward from S_O to S_O*, showing that any given volume can be supplied for a lower price. There is a corresponding downward shift in the total supply curve from S to S*.

As illustrated in Figure 8b, the downward shift in the total supply curve from S to S* results in an increase in the total equilibrium quantity produced from Q to Q* and a decrease in the equilibrium price from P to P*.

As illustrated in Figure 8c, at the new, lower equilibrium price P*, quantity Q_W* is produced from wild fisheries and quantity Q_O* is produced from offshore aquaculture. There is no production from inshore aquaculture, for which costs have not changed and for which (in this extreme example) the minimum cost of production is now higher than for offshore aquaculture.

FIGURE 8A
Effects of a reduction in offshore costs

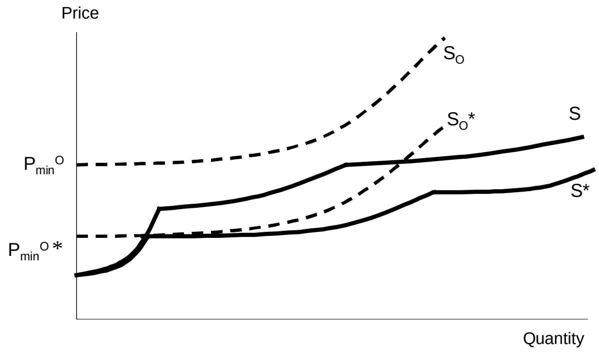


FIGURE 8B
Effects of a reduction in offshore costs

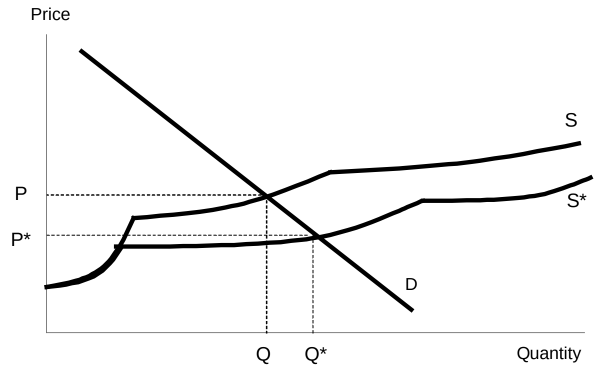
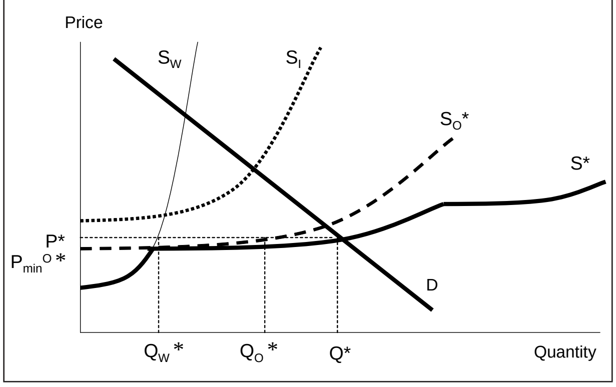


FIGURE 8C
Effects of a reduction in offshore costs



Reduction in alternative supply

Offshore aquaculture will be able to compete with wild fisheries and inshore aquaculture if the quantity which can be supplied by wild fisheries and inshore aquaculture at any given price declines sufficiently so that wild fisheries and inshore farms cannot meet demand, causing prices to rise. This might occur, for example, due to increased demand for other uses of inshore waters resulting in reduced availability of inshore sites, or increased regulatory restrictions on inshore farms to reduce environmental impacts.

As illustrated in Figure 9a, a reduction in supply from wild fisheries and inshore aquaculture would cause the wild fisheries supply curve to shift inwards from S_W to S_W* and the inshore aquaculture supply curve to shift inwards from S_I to S_I*. There is a corresponding inward shift in the total supply curve from S to S*.

As illustrated in Figure 9b, the inward shift in the total supply curve from S to S* results in a decrease in the total equilibrium quantity produced from Q to Q* and an increase in the equilibrium price from P to P*.

As illustrated in Figure 9c, at the new, higher equilibrium price P*, quantity Q_W* is produced from wild fisheries, quantity Q_I* is produced from inshore aquaculture,

FIGURE 9A
Effects of a reduction in alternative supply

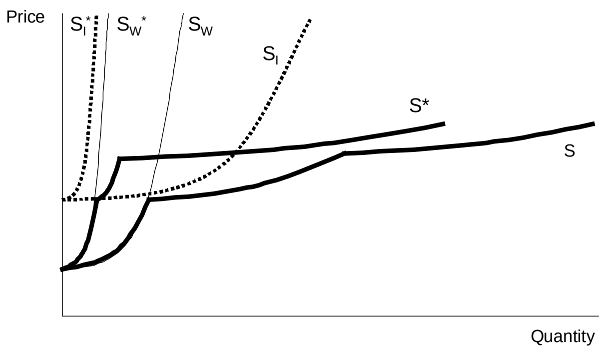


FIGURE 9B
Effects of a reduction in alternative supply

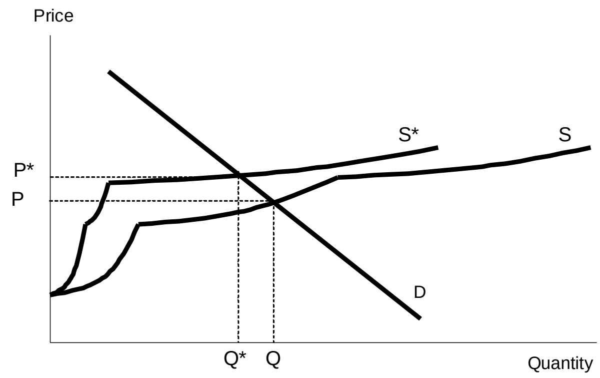
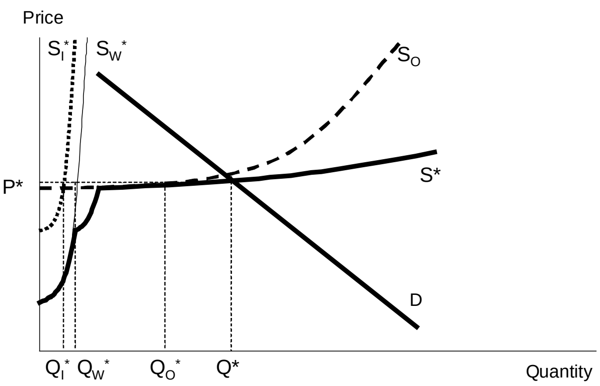


FIGURE 9C
Effects of a reduction in alternative supply



and quantity Q_O* is produced from offshore aquaculture. Production from wild fisheries and inshore aquaculture declines while production from offshore aquaculture increases.

Combined effects of multiple mechanisms

Offshore aquaculture is most likely to become profitable not as a result of any one of the three mechanisms discussed above occurring singly, but rather as a result of all three mechanisms occurring simultaneously. This is illustrated in Figure 10, as a result of simultaneous shifts in demand and supply curves. Growth in demand has caused the demand curve for fish to shift outwards from D to D*. Reductions in offshore costs and reductions in alternative supply have caused the supply curve to shift from S to S*.

The combined result of these shifts is an increase in the total equilibrium production of fish from Q to Q* and (in this example) an increase in the equilibrium price from P to P*. Note, however, that under different assumptions about relative changes in demand and supply the equilibrium price might fall rather than rise.

Modelling supply and demand for multiple regions

Thus far, it has been assumed that there are global supply and demand curves for fish and a global equilibrium price for fish. In reality, of course, the world consists of many different countries (and regions within countries) with widely varying supply and demand conditions for fish. These countries (and regions within countries) represent different markets for fish, which are connected to varying extents by trade.

Suppose two countries (A and B) have different supply and demand conditions for a particular species of fish. As illustrated in Figure 11a, if there is no trade, then the equilibrium price in Country B (P^*_B) would be higher than the equilibrium price in Country A (P^*_A).

As illustrated in Figure 11b, if there is trade between the two countries and the cost of transportation is zero, then the equilibrium price would be the same in both countries – because no buyer would be willing to pay more for fish from one country than the other and no seller would be willing to sell fish for less in one country than the other. In Country A, both the price (P**) and production (Q^{**}_A) would be relatively higher than they would have been without trade. In Country B, both the price (P**) and production (Q^{**}_B) would be relatively lower than they would have been without trade.

FIGURE 10
Combined effects of growth in demand, reduction in offshore costs, and reduction in alternative supply

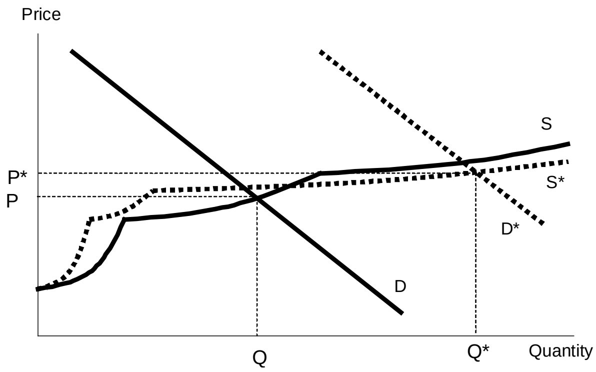


FIGURE 11A
Price and production without trade

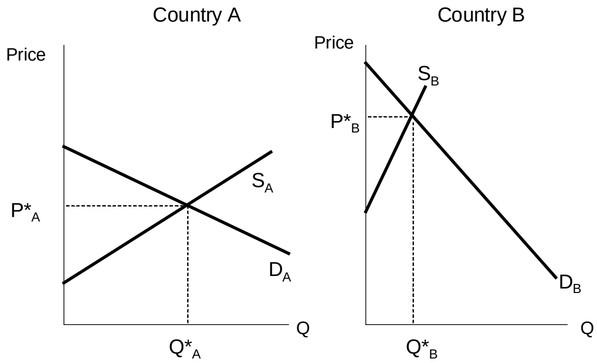
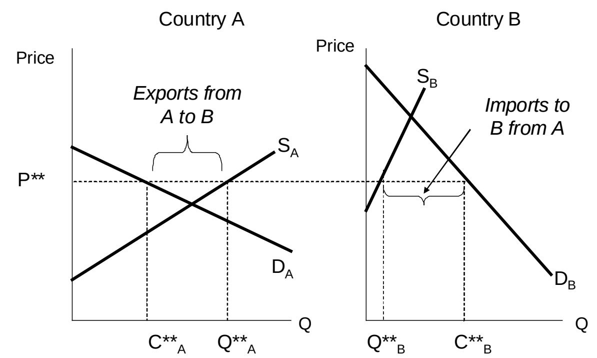


FIGURE 11B
Price and production with trade and zero cost of transportation



As illustrated in Figure 11c, if there is trade between the two countries, but there is a cost for transporting fish between the two countries, then the equilibrium price will differ between countries, but not as much as it would have differed without any trade. The difference between the price P^{**}_B in Country B and the price P^{**}_A in Country A will equal the cost of transportation - because buyers in Country B are indifferent between paying a higher price for domestically produced fish or paying a lower price in Country A plus the cost of transporting the fish from Country A to Country B.

Put simply, costs of transportation (and other barriers to trade) may allow fish prices to differ between countries and region, while the potential for trade limits the extent to which prices differ.

There are in fact significant costs to transporting fish between countries (or regions within countries). In addition, for certain kinds of fish products (particularly fresh products), quality declines with transportation time and distance, which from an economic point of view may also be considered a "cost" of transportation. Countries may also impose a variety of additional barriers to trade, such as tariffs. For all of these reasons, there is not a single global price for fish of a given species. Rather, there are differences in fish prices between countries - although these differences are not as great as there would be without trade.

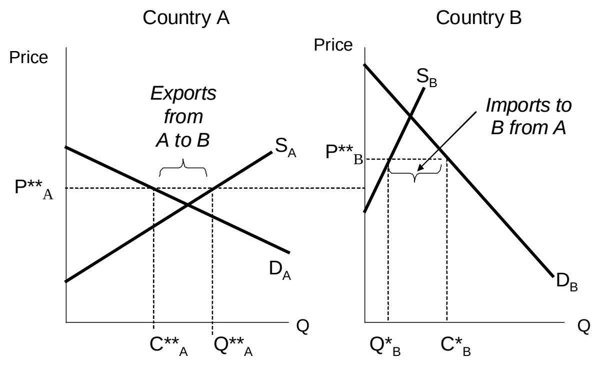
Differences between countries in the economic viability of offshore aquaculture

The economic viability of offshore aquaculture may differ between countries (and regions within countries) for two broad reasons: (a) costs may differ; and (b) prices may differ.

Costs of offshore aquaculture may differ between countries and regions for a variety of environmental, economic and policy regions. In general, all else equal, costs will be lower and offshore aquaculture will be more economically viable in countries and regions in which:

- The offshore environment is more favourable, with shallower water and less exposure to storms, waves, currents, etc.
- The support infrastructure is better developed, with established facilities for juvenile production, fish processing, fish transportation, veterinary services, etc.
- A skilled labour force is available.

FIGURE 11C
Price and production with trade and a positive cost of transportation



- An enabling regulatory system exists with clear regulatory policies.
- There is political and economic stability and the rule of law.

Prices paid for fish grown offshore may differ between countries and regions if demand relative to supply varies between countries and regions. In general, all else equal, prices will be higher and offshore aquaculture will be more economically viable in countries and regions in which:

- Population, income and consumer preferences create strong demand for fish relative to available domestic supply.
- Available domestic supply from wild fisheries and inshore aquaculture is limited.
- Costs are high for transporting fish from other countries or regions, or there are other barriers to trade which add to costs of importing fish.
- Costs are low for transporting fish to other countries or regions and there are few barriers to trade impeding fish exports to other countries which add to costs of exporting fish.

Summary: What will drive the development of offshore aquaculture?

Offshore aquaculture will develop to a significant scale if and only if it is profitable. Supply and demand analysis provides a useful theoretical framework for thinking about the conditions under which offshore aquaculture will be profitable and why and how these conditions may change over time.

In general, capital and operating costs are likely to be higher for offshore aquaculture than for inshore aquaculture. However, there may also be offsetting cost advantages to the extent that better water quality improves survival or growth rates or that larger scale operations are possible. Importantly, two of the largest costs of aquaculture - feed and juveniles - are essentially the same for offshore aquaculture as for inshore aquaculture.

Because of higher capital and operating costs, offshore aquaculture may not be economically viable for species for which wild fisheries or inshore aquaculture can meet demand at prices lower than those needed for offshore aquaculture to be profitable. However, offshore aquaculture which is not currently profitable may become profitable in the future as a result of three broad mechanisms:

- Increasing demand for fish, causing prices to rise to levels which make offshore aquaculture profitable.
- Declining costs of offshore aquaculture, making offshore aquaculture more profitable.
- Increasing costs and/or reduced production from wild fisheries and inshore aquaculture, making them less able to meet demand.

Offshore aquaculture can be economically viable even if costs are higher than for inshore aquaculture and wild fisheries. What matters is not whether inshore aquaculture and wild fisheries can produce fish at a lower cost, but whether they can produce enough fish at a lower cost to keep prices below levels at which offshore farming is profitable. Note that agriculture – farming of wheat, rice, beef, poultry, etc. – occurs worldwide in countries and environments with vastly different costs of production and not just in the lowest-cost countries and environments.

In general, neither inshore nor offshore aquaculture is likely to be profitable for species for which supply from wild fisheries is low-cost, year-round, reliable and abundant relative to demand. However, for species for which wild fisheries are unable to meet these conditions, competitive opportunities will be created for inshore and offshore aquaculture to be profitable.

At its current scale and given current technology, offshore aquaculture is a relatively high-cost way of growing fish. Currently, offshore aquaculture is probably able to compete with inshore aquaculture only under limited circumstances, such as the following:

- When offshore weather and wave conditions are relatively mild, reducing the costs of building and operating offshore facilities relative to inshore aquaculture.
- When offshore farms enjoy significantly better water conditions than inshore farms, enabling faster growth or better survival.
- When offshore farms are able to supply market niches which cannot be supplied by inshore farms, for reasons such as lack of suitable sites, regulatory constraints and transportation costs.
- When offshore farms are able to take advantage of cost-lowering synergies with other facilities or activities such as existing inshore farm facilities or offshore oil rigs.

Over time, however, the economic potential for offshore aquaculture is likely to grow, for several reasons:

- Growing population and income will increase world demand for fish, raising prices.
- Technological change is likely to lower the relative cost of offshore aquaculture relative to inshore aquaculture. As in all industries (including inshore aquaculture) there will be a learning curve for offshore aquaculture. Over time, experience will help to identify ways to reduce costs. Economies of scale will help to bring down costs as the offshore industry expands and offshore operations expand in size.
- Growing population and income will increase relative values of competing uses of potential onshore and inshore farming areas, reducing the availability of those areas for inshore farming.

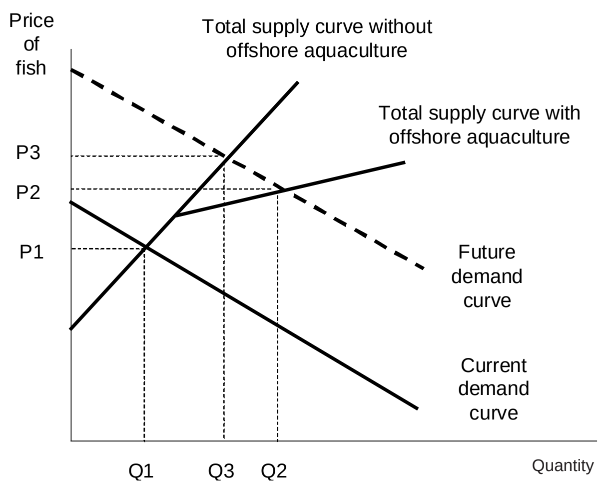
Among the most important factors affecting the economic potential for offshore aquaculture will be:

- The extent and pace of technological development in areas such as remote monitoring, remote feeding, and cage construction, and the extent to which these technological developments can reduce costs and risks of offshore farming.
- The extent to which offshore farms are able to achieve better growth rates and survival than inshore farms.
- The extent to which offshore facilities face fewer conflicts with other activities than inshore farms.
- The extent to which offshore farming is able to develop to a level at which it begins to realize significant economies of scale, and to spur the development of key supporting industries such as hatcheries, veterinary services, cage manufacture, and processing.
- The extent to which enabling regulatory frameworks establish clear, stable and timely processes for permitting and regulating offshore farms.

It is possible to envision a very wide variety of types of offshore aquaculture developing in the future. Many different species could potentially be farmed profitably offshore, in many different places, using many different kinds of technologies, for many different markets. There is no single answer about the economic potential for these many types of offshore aquaculture and when they might become profitable. The answers vary for different species, locations and technologies.

The world offshore aquaculture industry is still in its infancy. There has been only limited experience on which to judge its future potential. It is impossible to know with certainty what the long-run economic opportunities for offshore aquaculture may be. But it is reasonable to assume that they are real and substantial.

FIGURE 12
Effects of growth in fish demand



MARKET EFFECTS OF OFFSHORE AQUACULTURE

What are the potential effects of offshore aquaculture on world seafood markets? How will different groups and countries be affected? In previous sections, supply and demand analysis has been used to discuss factors that may drive the future growth of offshore aquaculture. Next supply and demand analysis can be used to examine potential market effects of offshore aquaculture.

Causes vs. effects of offshore aquaculture

It is important to distinguish between the *causes* and *effects* of offshore aquaculture. *Causes* are the changes in fish supply and demand curves which may make offshore aquaculture economically viable. *Effects* are the differences in prices and production that may occur with offshore aquaculture compared with those which would occur without offshore aquaculture.

For example, suppose the *cause* of offshore aquaculture is a growth in demand. As illustrated in Figure 12, the growth in demand from the current demand curve to a higher future demand curve causes the price to rise from P1 to P2 and causes total production to increase from Q1 to Q2. At the higher price level P2, part of total production is now from offshore aquaculture. Thus, the increase in demand caused an *increase in price* which made offshore aquaculture possible.

Suppose, however, that offshore aquaculture had not been an option. Without offshore aquaculture, the total supply curve would have been the steeper "total supply curve without offshore aquaculture." The increase in demand would have caused the price to rise even higher to P3, while causing production to rise only to Q3. Because the equilibrium price, P2, with offshore aquaculture is lower than the equilibrium price, P3, without offshore aquaculture, the *effect* of offshore aquaculture is to lower the price compared to what it would have been without offshore aquaculture.

In summary, then, the *cause* of offshore aquaculture might be an increase in demand resulting in higher fish prices, but the *effect* might be to keep fish prices from rising as much as they would without offshore aquaculture. Put differently, the *effects* of offshore aquaculture will be how future prices and production vary from what they would be without offshore aquaculture – not how they vary from today's prices and production.

Similarity of market effects for offshore and inshore aquaculture

What will distinguish offshore aquaculture from other types of marine aquaculture – at least in the near term – are the environments in which it takes place, the technologies needed to operate in those environments, and (potentially) the leasing and regulatory framework needed to operate. In contrast, initially there are not likely to be significant differences between offshore and inshore aquaculture in the species of fish which are grown, the products made from them, and where they are sold.

In some situations, offshore aquaculture may enjoy certain market advantages relative to inshore aquaculture. For example, offshore aquaculture might benefit from larger scales of production, closer location to major markets, or better environmental conditions potentially allowing fish to be grown to different sizes or to attain better quality. These conditions may in some cases be what make offshore aquaculture competitive.

In general, however, the market effects and issues for offshore aquaculture are generally likely to remain similar to those for inshore farming of the same species, as offshore farming grows to account for a larger share of production. Put differently, the market effects of offshore aquaculture will in general be similar to the market effects of any expansion of aquaculture production. These include effects on prices received by inshore farmers and fishers (and correspondingly on prices paid by consumers), and longer-term expansion of market demand potentially benefiting all producers.

FIGURE 13
Changes in consumer and producer surplus with additional sources of supply

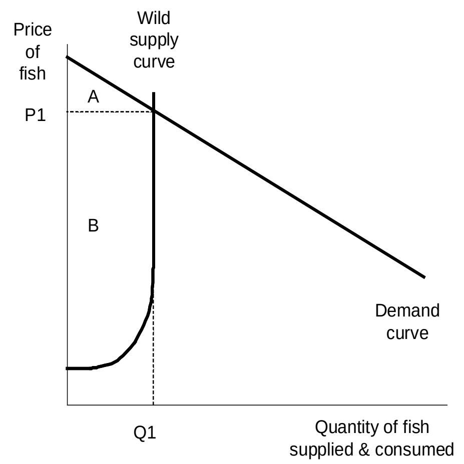


Figure 13A: Supply is only from wild fish

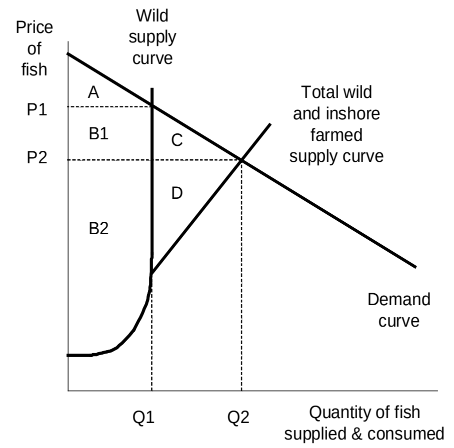


Figure 13B: Supply is from both wild fish and inshore aquaculture

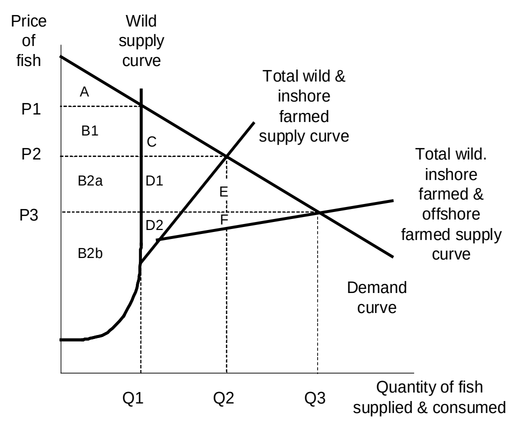


Figure 13C: Supply is from wild fish, inshore aquaculture, and offshore aquaculture

Potential market effects of growth in aquaculture supply on consumer and producer surplus

We may illustrate how different groups might be affected by additional supply from inshore and offshore aquaculture, and the net effects on society, as changes in what economists refer to as "consumer surplus" and "producer surplus". For simplicity, it is assumed initially that there is no change in demand for fish as supply increases (we relax this assumption later in our discussion).

Suppose that initially all fish supply is from a wild fishery. The supply curve for fish shows the total volume of fish offered for sale at any given price (Figure 13a). It is assumed that the supply curve is initially upward sloping, and becomes vertical at the maximum annual quantity available from the wild fishery. It is assumed total wild catches are limited by regulation rather than by fishing effort (which could potentially cause higher prices to result in lower catches over time).

The intersection of the wild supply curve with the demand curve determines the equilibrium price P1 and the equilibrium quantity sold Q1. At this price, the area of the graph labelled A shows what economists refer to as "consumer surplus": the difference between what consumers would have been willing to pay for fish (as shown by the demand curve) minus the price P1 that they actually pay. Similarly, the area of the graph labelled B shows what economists refer to as "producer surplus": the difference between the revenue received by wild fish producers and the revenue for which they would have been willing to supply the fish.

Consumer surplus is a measure of net benefits to consumers from the fishery. Producer surplus is a measure of net benefits to fishers from the fishery. The total net benefits to society from the fishery – the difference between what consumers would have been willing to pay and what it costs to produce the fish – are represented by the area A + B.

Now suppose that inshore aquaculture provides a new source of fish supply in addition to wild fish. For simplicity it is assumed initially that the farmed fish and wild fish are perceived in the market as identical species of identical quality. The effect of the development of inshore aquaculture is to shift the supply curve to the right, to the new "total wild and inshore farmed supply curve" (Figure 13b). This new total supply curve is the horizontal sum of the wild supply curve and an upward sloping inshore farmed supply curve (which is not shown in the graph).

As supply shifts from the old "wild supply curve" to the new "total wild and inshore farmed supply curve," the equilibrium price falls from P1 to P2, and the equilibrium quantity supplied and consumed increases from Q1 to Q2. Note that because the wild supply curve is depicted as vertical over this part of its range, there is no effect on the volume of wild fish supplied.

At the new equilibrium, consumer surplus is now represented by the sum of areas A, B1 and C, while producer surplus is now represented by the sum of areas B2 and D.

How are different groups affected by the introduction of inshore aquaculture (assuming there is no change in demand)?

- Wild fishers are harmed because their prices fall. Their producer surplus declines from area B to only area B2, or by an amount represented by area B1.
- Inshore fish farmers benefit from the opportunity to earn profits. They earn producer surplus represented by area D.
- Consumers benefit because their prices fall. Their consumer surplus increases from area A to areas A + B1 + C.

Total benefits to society increase from areas A + B to areas A + B1 + B2 + C + D. Areas C + D represent an increase in net benefits to society from inshore aquaculture, which are respectively the consumer surplus and producer surplus from inshore aquaculture. However, there is a redistribution of the benefits of the wild fishery from fishers to consumers by an amount represented by area B1. Put simply, in the short run, if inshore aquaculture depresses the price of wild fish, wild fishers lose and consumers gain by an equivalent total amount.

Note that the relative scale of these effects on fishers, consumers and fish farmers depend upon the assumptions we make about the shape of the supply and demand curves. In particular, if demand is highly "inelastic" (the demand curve slopes steeply downward, so that changes in supply cause big changes in price), the market effects of inshore aquaculture will be much greater than if demand is highly "elastic" (the demand curve is relatively flat, so that changes in supply cause only small changes in price).

Because there are far fewer fishers than consumers, the effects upon individual fishers are far greater than the effects on individual consumers. As the price falls, an individual fisherman may see a very large drop in his income. An individual consumer will experience a correspondingly large drop in the price of the fish she buys, but this will not be anywhere as significant for her overall welfare as the loss of income is for the fisherman.

Now suppose that offshore aquaculture provides yet another new source of fish supply in addition to wild fish and inshore aquaculture. Again, for simplicity we assume that all fish are perceived in the market as identical species of identical quality. The effect of the development of offshore aquaculture is to shift the supply curve still further to the right, to the new "total wild inshore farmed and offshore farmed supply curve" (Figure 13c). This new total supply curve is the horizontal sum of the wild supply curve and upward sloping inshore farmed supply and offshore farmed supply curves (which are not shown in the graph).

As the total supply curve shifts still further outwards, the equilibrium price falls from P2 to P3, and the total equilibrium quantity supplied and consumed increases from Q2 to Q3. At the new lower price, the volume of fish produced from inshore aquaculture is lower, but is more than made up for by the volume of fish produced from offshore aquaculture.

At the new equilibrium, consumer surplus is now represented by the sum of areas A, B1, B2a, C, D1 and E, while producer surplus is now represented by the sum of areas B2b, D2 and F.

How are different groups affected by the introduction of offshore aquaculture in the short run (assuming there is no change in demand)?

- Wild fishers are harmed because their prices fall. Their producer surplus declines from area B2 to only area B2b, or by an amount represented by area B2a.
- Inshore fish farmers are harmed because their prices fall. Their producer surplus declines from area D to only area D2.
- Offshore fish farmers benefit from the opportunity to earn profits. They earn producer surplus represented by area F.
- Consumers benefit because their prices fall. Their consumer surplus increases from area A + B1 + C to area A + B1 + C + B2a + D1 + E.

Total benefits to society increase from areas A + B + C + D to areas A + B + C + D + E + F. Areas E + F represent an increase in net benefits to society from offshore aquaculture, which are respectively the consumer surplus and producer surplus from offshore aquaculture. However, there is again a redistribution of the benefits from wild fishers and inshore aquaculture producers to consumers by an amount represented by area B2a + D1. Put simply, to the extent that offshore farming lower fish prices, fishers and inshore fish farmers stand to lose but consumers stand to gain.

Again, note that the relative scale of these effects on fishers, consumers and fish farmers depend upon the assumptions made about the shape of the supply and demand curves. In particular, if demand is inelastic (the demand curve slopes down steeply), offshore aquaculture may have big effects on prices; while if demand is elastic (the demand curve is relatively flat), offshore aquaculture may have only small effects on prices.

Again, because there are far fewer fishers and inshore farmers than consumers, the effects upon individual fishers and inshore farmers are far greater than the effects on individual consumers.

Relative effects of offshore aquaculture on different countries

The preceding analysis considered the potential market effects of offshore aquaculture on fishers, inshore and offshore fish farmers and consumers without regard to the question of where they live. In general, fishers and inshore fish farmers stand to lose from offshore aquaculture (because their prices fall), while offshore fish farmers stand to gain (from the opportunity to earn profits) and consumers stand to gain (because fish prices fall).

Given the fact that fish are traded widely, the effects of offshore aquaculture of a particular species may vary widely between countries depending on the relative extent to which their populations include fishers who catch the species, inshore farmers who grow the species, offshore farmers who would grow the species and consumers who eat the species.

Table 2 shows sixteen potential "scenarios" for combinations of these different groups which might live in a country. A country will clearly gain from offshore aquaculture of a species if it has no fishers or inshore farmers who produce that species, but it has offshore farmers of and/or consumers of that species (Scenarios 2, 3 and 4). Similarly, a country will clearly lose from offshore aquaculture if it has no offshore farmers or consumers of the species, but it has fishers and inshore farmers of the species

TABLE 2

Change in net benefits to a country from domestic or foreign offshore farming of a species

Scenario	Groups which are included in the population of the country				How groups are affected by domestic or foreign offshore farming of the species				Change in net benefits to the country from domestic or foreign offshore farming of the species
	Fishers who catch the species in capture fisheries	Inshore farmers of the species	Offshore farmers of the species	Consumers of the species	Fishers	Inshore farmers	Offshore farmers	Consumers	
1									No effect
2				X				Gain	Gain
3			X				Gain		Gain
4			X	X			Gain	Gain	Gain
5		X				Lose			Lose
6		X		X		Lose		Gain	Uncertain*
7		X	X			Lose	Gain		Uncertain
8		X	X	X		Lose	Gain	Gain	Uncertain*
9	X				Lose				Lose
10	X			X	Lose			Gain	Uncertain*
11	X		X		Lose		Gain		Uncertain
12	X		X	X	Lose		Gain	Gain	Uncertain*
13	X	X			Lose	Lose			Lose
14	X	X		X	Lose	Lose	Gain	Gain	Uncertain*
15	X	X	X		Lose	Lose	Gain		Uncertain
16	X	X	X	X	Lose	Lose	Gain	Gain	Uncertain*

* Scenarios in which consumers stand to benefit from lower prices and expanded supply, but fishers and/or inshore farmers stand to lose from lower prices.

(Scenarios 5, 9 and 13). For other scenarios, the change in net benefits to the country is uncertain: it depends on the relative scale of and effects on groups which stand to lose and groups which stand to gain.

More generally, as with inshore aquaculture, different offshore producing countries and firms will compete with each other in international markets. The countries where investment first occurs may enjoy competitive advantages deriving from economies of scale in farming, juvenile production, processing, distribution and many other land-based support activities. However, over time they may face competition from new lower-cost producing companies taking advantage of established technologies. As has occurred with inshore aquaculture, this may lead to financial difficulties for higher-cost producing countries, trade disputes, and direct and indirect trade barriers.

Potential market effects of growth in aquaculture supply on consumer and producer surplus with growing demand

The preceding analysis assumed that the demand for fish was unchanged by the introduction of aquaculture. However, over time introducing new supply from inshore and offshore aquaculture is likely to increase demand for fish, shifting the demand curve out.

There are several reasons for which new supply from aquaculture is likely to increase fish demand over time. First, at any given time, demand for fish reflects consumers' tastes and preferences, which in turn reflect their past consumption experiences. If a particular fish species is expensive, consumers who have not eaten it in the past are less likely to buy it in a store or order it in a restaurant. As the price falls, consumption increases, as illustrated by the increase in consumption from Q1 to Q2 in Figure 13b and from Q2 to Q3 in Figure 13c. Part of the increase in consumption is because new consumers try the fish. As these new consumers become familiar with and develop a taste for the fish, over time they may be willing to pay a higher price for it than they would have previously.

Second, consumer demand for fish is limited by its availability in stores and restaurants. Even if consumers like a fish and are willing to pay a high price for it, they will not buy it if it is not in their local stores or on their local menus. As aquaculture supply expands, fish are offered for sale in more geographic locations, in more kinds of stores and restaurants and at more times of the year, thus increasing the total demand at any given price.

Third, fish farmers engage in marketing in a systematic effort to increase demand. They recognize that their economic success depends critically on expanding the market for their products. Marketing by fish farmers is not just advertising to consumers. Rather, it is a systematic approach to understanding and responding to the needs of both consumers and store and restaurant buyers, reflected in (for example) product forms, quality standards, packaging, timing and volume of fish deliveries, long-term contracts, supply guarantees, payment terms, etc. (Note that without competition from aquaculture, wild fishers have less incentive to engage in marketing, particularly when prices are high, because they are limited by nature in the volume of fish that they can supply and cannot expand their total production).

Figure 14 illustrates potential longer-run effects of an increase in fish demand as aquaculture grows. With expanded demand, the price increases back from P3 to P4 and the quantity of fish supplied and consumed increases from Q3 to Q4.

The increase in demand benefits all producer groups:

- Fishers producer surplus increases by an amount represented by area I.
- Inshore fish farmer's producer surplus increases by an amount represented by area J.
- Offshore fish farmers' producer surplus increases by an amount represented by areas K + L.

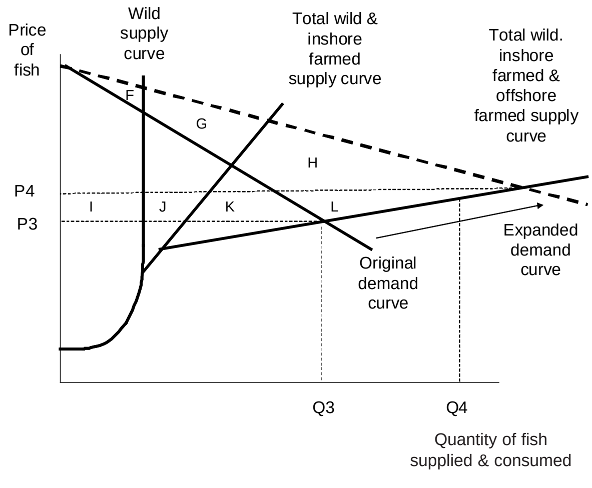
Some consumers lose from the increase in demand but others benefit. As the price rises from P3 to P4:

- Those consumers whose demand was represented by the original demand curve and who had previously been purchasing fish for the lower price P3 experience a loss of consumer surplus represented by areas I + J + K.
- New consumers (as well as former consumers who enjoy fish more) experience an increase in consumer surplus represented by areas F + G + L.

The increase in demand increases total benefits to society by an amount represented by areas F + G + H + L. Higher demand also reduces the extent to which aquaculture results in a shift of net benefits from fishers to consumers.

Thus, over the long-term, if growth in aquaculture supply (from offshore aquaculture or any other kind of aquaculture) is accompanied by growth in demand, there will be smaller effects on previous wild and farmed producers. If the increase in demand is sufficiently high there may be no long-term effect on the price and existing producers may not be harmed at all – or could even be helped.

FIGURE 14
Potential longer-run effects of increase in fish demand due to aquaculture



Potential market differentiation of offshore fish

The preceding discussion assumed that consumers view all fish of a given species as identical – so that changes in supply from any given source (such as offshore farming) can affect prices for producers from other sources (such as wild fisheries).

However, another potential change in demand which may arise over time as a result of aquaculture – including offshore aquaculture – may be a differentiation in consumer demand for different sources of supply, such as between wild and farmed fish or between fish farmed inshore and fish farmed offshore.

As total world production of fish expands and more consumers in more places eat more fish in more product forms, both buyers (e.g. retailers and food service operators) and consumers may come to perceive differences between fish of the same species produced in different ways, resulting in price premiums for some fish from some origins and price discounts for others. For example, following the emergence of large-scale salmon farming, some (not all) consumers came to perceive some (not all) species of wild salmon as superior to farmed salmon, thus, tending to offset in part the effects of increased farmed salmon supply on wild salmon prices.

It is possible (although far from certain) that similar market differentiation could emerge over time for fish grown in offshore farms. For example, if fish grown in offshore farms came to be perceived as "cleaner" or more "environmentally responsible" this could increase demand for offshore-grown fish relative to inshore-grown fish, increasing the market impacts on inshore-grown fish.

The importance of marketing

As with inshore aquaculture, marketing will be critical for the future of offshore aquaculture – for individual firms engaged in offshore aquaculture, for countries with offshore aquaculture, for species grown on offshore farms – and more broadly for all fish producers.

Without marketing to ensure growth in demand, increases in aquaculture production – inshore of offshore – will tend to lower prices, eventually to levels at which expanded (or even existing) production levels are no longer profitable. Only by continuing to expand demand can production continue to rise. For example, the vast growth in salmon production over the past three decades has been possible only because salmon farmers have greatly expanded demand: salmon is now consumed in far more countries, by far more people, in far more product forms.

Note that effective marketing will be particularly important for "new" species which may be found to be suitable for offshore farming but which are not farmed in significant volumes onshore. The greater the share of total production of a species that offshore aquaculture represents, the greater the potential for incremental offshore production to have significant market effects.

Summary: market effects of offshore aquaculture

In the short run, growth in offshore aquaculture production will tend to lower fish prices by increasing the supply of fish, harming fishers and inshore farmers but benefiting consumers. The extent to which different countries benefit from or are harmed by offshore aquaculture will depend on the extent to which their citizens are consumers of fish grown offshore, producers of fish grown offshore, or producers of fish which compete with fish grown offshore.

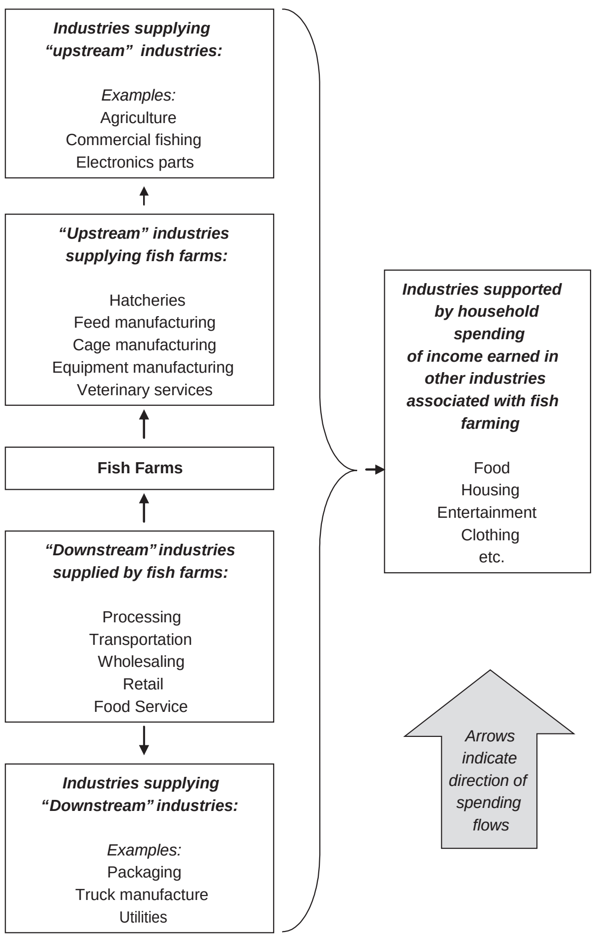
Over the longer run, however, growth in offshore aquaculture production will tend to increase the world demand for fish as consumers become more familiar with fish; as fish become available in more locations, at more times, and in more product forms; and as offshore fish farmers engage in systematic marketing to expand demand. Increasing demand will tend to offset the effects of increasing supply on prices.

ECONOMIC IMPACTS OF OFFSHORE AQUACULTURE

What will the economic impacts of offshore aquaculture be? How many people will offshore aquaculture employ, in what kinds of jobs, and earnings what kind of incomes?

The starting point in answering these questions is to recognize that fish farming, regardless of where or how it is done, creates jobs and income in many more places and industries than on fish farms per se. Figure 15 provides a simple categorization of industries which depend in some way on fish farming. We may group these industries into six categories:

FIGURE 15
Industries associated with fish farming



- <u>Fish farms</u>. These are aquaculture operations growing fish or shellfish.
- <u>"Upstream industries" supplying fish farms</u>. These are industries from which the fish farms purchase direct inputs. Among the industries which account for the greatest share of fish farm purchases are hatcheries, feed manufacturing and cage and equipment manufacturing.
- <u>"Downstream" industries supplied by fish farms</u>. These are industries in the distribution chain from fish farms to consumers, including processing, transportation, wholesaling, retail and food service.
- <u>Industries supplying upstream industries</u>. These are industries from which the "upstream" industries purchase inputs. For example, the feed manufacturing industry purchases raw material for making fish feed from both the agriculture and the commercial fishing industries.
- <u>Industries supplying downstream industries</u>. These are industries from which the "downstream industries purchase inputs. For example, the processing industry purchases boxes from the packaging industry.
- <u>Industries supported by household spending</u>. These are industries throughout the entire economy that are supported by spending of household income earned in the other industries.

Clearly the nature and degree of association with fish farming varies widely among these different categories of industries. There are only a few industries which would disappear entirely without fish farming, such as farm cage manufacturing. However, there are many industries, across many sectors of the economy – which benefit in some way from fish farming.

Figure 15 helps to illustrate two simple, but important points. First, the economic impacts of fish farming are larger – potentially much larger – than those which occur at fish farms. The employment created by aquaculture cannot be counted simply by adding up the jobs at aquaculture companies.

Second, the economic impacts of fish farming are spread over a far greater geographic area than the communities where fish farms are located or from which they are supported. While the hatchery supplying a fish farm may be located relatively near the farm, the company manufacturing the cage or the restaurant selling the fish may be located thousands of miles away.

One indicator of the relative significance of "upstream industries" in aquaculture production is the share of purchased product inputs in the gross output value of aquaculture. As shown in Table 3, purchased inputs accounted for 69 percent of total gross output value of Canadian aquaculture in 2005, and feed purchases alone accounted for 31 percent. The shares of different inputs varied between provinces, reflecting different mixes of species in total production.

Viewed in a different way, gross value added in Canadian aquaculture was only 31 percent of gross output in 2005. Thus, more than two-thirds of gross output value was generated in other "upstream" industries.

Adding up how many people work on actual fish farms and what they earn is a relatively straightforward process. Speculating about how many people might work on future offshore fish farms is also relatively straightforward (although highly uncertain given uncertainty about the future scale and characteristics of the industry). However, it is far less straightforward to measure the full economic impacts, across all industries, of existing fish farms – or to project the potential full economic impacts of future fish farms.

One approach for estimating economic impacts of an industry is input-output analysis, which calculates economic impacts using assumptions about inter-industry purchases per dollar of output of an industry. These may then be used to calculate three types of economic impacts: "direct," "indirect," and "induced." Applied to fish farming, "direct impacts" are those occurring within the fish farming industry; "indirect" impacts are those driven by purchases of the fish farming industry from other industries and "induced impacts" are those driven by household spending of income created by direct and indirect impacts. Each of these types of impacts is typically measured in three ways: annual average employment, wage and salary income and sales or "output."

Input-output analysis typically measures only the impacts of an industry and its associated upstream activities. If one wishes to measure the impacts of the "downstream" activities of processing and distributing farmed fish, the same approach may be applied to estimating the direct, indirect and induced impacts of these industries (net of those associated with fish production).

TABLE 3
Estimated share of selected expenditures in gross output value of Canadian aquaculture, 2005

	Newfoundland (%)	Prince Edward Island (%)	Nova Scotia (%)	New Brunswick (%)	Quebec (%)	Ontario (%)	British Columbia (%)	Canada total (%)
Purchased product inputs	**59**	**24**	**47**	**75**	**40**	**43**	**74**	**69**
Feed	28	–	24	29	–	24	38	31
Eggs and fish for growout	7	8	7	10	2	5	3	6
Processing services	4	2	0	4	0	–	10	6
Goods transportation/storage	4	1	2	2	1	1	7	4
Energy	2	2	2	1	8	3	2	2
Maintenance/repairs	2	3	1	–	3	1	3	3
Insurance premiums	–	0	1	2	1	0	2	2
Rental/leasing expenseses	1	2	0	1	1	1	1	1
Professional services	2	1	1	1	2	1	1	1
Therapeutants	–	–	2	1	–	–	2	2
Gross value added (factor cost)	**33**	**76**	**53**	**25**	**59**	**57**	**27**	**31**
Salaries/wages	11	37	17	12	19	17	11	13
Finfish share of production volume	61	0	64	94	25	100	87	75

Source: Calculated from value-added account data in Statistics Canada, Aquaculture Statistics 2005, Catalogue No. 23-222-XIE. Estimates were based on taxation data and a sample of 148 establishments. Blank cells indicate estimates were not available.

A significant challenge for input-output analysis is that it requires extensive data on inter-industry purchases. This is particularly a challenge for marine aquaculture, partly because it relies heavily on purchases from other industries and partly because it is a relatively new industry for which relatively few data are available.

Kirkley (2008) developed an input-output model for the purpose of estimating potential economic impacts of the United States of America's offshore aquaculture. For each species, the model required specific assumptions about the scale of the operation and different kinds of expenditures such as farm installation costs, vessel maintenance, feed costs, etc. The model then calculated direct, indirect and induced impacts generated by the farming operation, as well as "downstream" activities.

Table 4 summarizes the relative shares of estimated direct, indirect and induced employment impacts of farming and downstream activities. The estimated direct employment impacts of fish farming accounted for between only 11 percent and 19 percent of the projected total employment impacts of farming from all upstream and downstream activities, as well as induced activity in the rest of the economy. As shown in the fourth row, the total impacts attributable to farming (as opposed to downstream activities) represented only 27 percent to 38 percent of total impacts.

Thus, the potential total employment and income impacts of offshore fish farming are much larger than those which would occur at the farming operations alone – potentially five to ten times larger. Put differently, simply adding up jobs and wages at the farms would greatly underestimate the total economic impacts created by offshore farming.

Note that as with the market impacts discussed earlier, the employment and income impacts of offshore aquaculture would not necessarily occur fully or even primarily within the countries where the offshore farms are located. For example, to the extent the feed or cages are manufactured in a different country, or the fish are transported to and sold in a different country, the economic impacts may occur in other countries. Put differently, in an increasingly globalized economy, economic activity anywhere may have indirect and induced economic effects in many other countries.

Table 5 shows Kirkley's projections of employment impacts per thousand metric tonnes of annual production for each species. The important point is not the specific impacts projected for any particular species (which depend on numerous assumptions about the scale and technology of each farming operation), but that there is wide variation between species in the scale of potential economic impacts associated with a given production volume. This is to be expected, given the fact that technologies of fish farming vary widely depending upon what species is being farmed and how it is being farmed.

TABLE 4
Share of estimated employment impacts of potential offshore aquaculture operations

	Blue mussel (%)	Sea scallop (%)	Cod (%)	Atlantic salmon (%)	Winter flounder (%)
Farming direct	11	11	15	14	19
Farming indirect	4	1	10	6	7
Farming induced	13	16	12	16	12
Farming total	**27**	**29**	**36**	**35**	**38**
Downstream direct	43	3	38	38	37
Downstream indirect	3	2	2	2	2
Downstream induced	26	26	24	24	23
Downstream total	**73**	**71**	**64**	**65**	**62**
Combined direct	53	54	52	52	56
Combined indirect	7	4	12	8	9
Combined induced	39	42	35	40	35
Combined total	**100**	**100**	**100**	**100**	**100**

Source: Full-time and part-time employment impacts estimated for different types of United States of America offshore aquaculture operations by Kirkley (2008).

TABLE 5

Estimated employment per thousand metric tonnes of annual production in potential United States of America offshore aquaculture operations

	Blue mussel	Sea scallop	Cod	Atlantic salmon	Winter flounder
Farming direct	11	155	70	36	146
Farming indirect	4	18	47	15	53
Farming induced	13	218	56	43	91
Farming total	**29**	**391**	**173**	**93**	**290**
Downstream direct	45	588	180	101	284
Downstream indirect	3	32	12	6	18
Downstream induced	28	360	113	63	178
Downstream total	**76**	**980**	**305**	**170**	**480**
Combined direct	56	743	250	136	430
Combined indirect	7	50	58	21	71
Combined induced	41	578	169	106	268
Combined total	**104**	**1370**	**477**	**263**	**770**

Source: Full-time and part-time employment impacts estimated for different types of United States of America offshore aquaculture operations by Kirkley (2008).

Table 6 shows estimates of annual average employment in aquaculture per thousand metric tonnes of production, for various regions and species, from a number of different sources. The estimates are for inshore marine aquaculture and onshore aquaculture, which likely differ in their employment impacts from those of potential future U.S. offshore farms. The definitions of "employment" and the methodologies used to derive the estimates of employment vary considerably between sources.

TABLE 6

Selected estimates of aquaculture employment, various species and regions

Species	Region	Year	Source and notes*	Live weight (mt)	Estimated employment	Estimated employment per '000 tonnes
All aquaculture	Newfoundland	2005	1	8 163	200	25
	Prince Edward Island			18 921	620	33
	Nova Scotia			8 917	250	28
	New Brunswick			37 657	1 250	33
	Quebec			1 215	155	128
	Ontario			4 000	150	38
	British Columbia			73 195	1 275	17
	CANADA TOTAL			**152 068**	**3 900**	**26**
All aquaculture	Austria	1997	2	4 274	379	89
	Belgium			1 471	112	76
	Denmark			38 250	698	18
	Finland			16 365	809	49
	France			211 205	10 342	49
	Germany			59 069	3 193	54
	Greece			54 947	2 711	49
	Ireland			35 101	1 275	36
	Italy			211 919	4 923	23
	Netherlands			97 640	564	6
	Portugal			8 781	1 452	165
	Spain			233 693	7 851	34
	Sweden			6 523	480	74
	United Kingdom			128 525	2 705	21
	EU TOTAL			**1 107 763**	**54 029**	**49**
All aquaculture	Europe	1998	3	1 315 000	57 000	43
Salmon	N. Brunswick	2000	4	29 100	1 683	58
Salmon	Maine	2002	5	6 695	240	36
Salmon	Scotland	1997	6	99 197	1 647	17
Salmon	Scotland	2002	7	143 000	1 552	11

TABLE 6 (CONTINUED)

Species	Region	Year	Source and notes*	Live weight (mt)	Estimated employment	Estimated employment per '000 tonnes
Salmon & trout	Norway	2000	8	488 839	3 631	7
		2005		645 387	3 054	5
Species other than salmon & trout	Norway	2000	8	1 439	400	278
		2005		11 507	606	53
Catfish	Mississippi	2001	7	172 789	3 000	17

*Sources and notes are listed below.

General notes: To the extent possible, employment data are estimates of full-time-equivalent employment in fish farming (excluding upstream or downstream impacts, including processing). The kind of employment data collected and/or estimated varies between studies. See notes for individual sources for additional details.

1) Fisheries and Oceans Canada. 2006. Canadian Aquaculture Industry, 2004-2005: Key Figures. www.dfo-mpo.gc.ca/Aquaculture/ref/kf0405_e.htm

2) MacAlister Elliott and Partners, Ltd. 1999. Forward Study of Community Aquaculture: Summary Report. Prepared for European Commission Fisheries Directorate General. Note: Species mix varies widely between EU countries. Employment estimates are for full-time-employment in production.

3) Commission of the European Communities. 2002. A Strategy for the Sustainable Development of European Aquaculture. Brussels 19.9.2002, COM(2002) 511 final. Note: Reported production volume is for 2000. Estimated 1998 employment was "at least 80 000 full or part-time workers, equivalent to 57 000 full-time jobs" (see page 4).

4) Stewart, Len (Aquaculture Strategies, Inc.) 2001. Salmon Aquaculture in New Brunswick: Natural Development of Our Marine Heritage. Prepared for New Brunswick Salmon Growers Association Aquaculture Strategies. Note: Estimated person-years employment includes 157 in hatcheries, 624 in growout, 537 in processing, 240 in direct services, and 125 in "selling, administration and other." 77.3 percent of jobs were full-time, 9.6 percent were part-time, and 13.1 percent were seasonal.

5) O'Hara, Frank, Charles Lawton and Matthew York (Planning Decisions, Inc.). 2003. Economic Impact of Aquaculture in Maine. Prepared for the Maine Aquaculture Innovation Center. Note: Includes employment at three companies producing 6 800 tonnes of salmon annually of "over 240 full-time workers" in "freshwater and ocean farming operations, processing plants, and administrative and sales positions."

6) Highlands and Islands Enterprise and The Scottish Office. 1998. The Economic Impact of Salmon Farming, Final Report. Prepared by Public and Corporate Economic Consultants (PACEC) and Stirling Aquaculture. 124 pp. Employment is estimated FTE employment in smolt production and salmon production. The study estimated that additional FTE employment of 4 777 is created in "processing, supplier and induced."

7) Scottish Executive, 2004. Scottish Economic Report: March 2004. Scottish Salmon Farming. www.scotland.gov.uk/library5/finance/ser04-16.asp. Note: Estimates are for FTE employment of 1 552 in smolt and salmon farming. Additional FTE employment of 4 728 for salmon farming, 1 024 for farming suppliers, and 520 for processing suppliers.

8) Statistics Norway. 2007. Fish Farming 2005. www.ssb.no/nos_fiskeoppdrett. *Note:* Includes employment in hatcheries.

9) Hanson, Terrill, Stuart Dean, and Stan Spurlock. Economic Impact of the Farm-Raised Catfish Industry on the Mississippi State Economy. Department of Agricultural Economics, Mississippi State University. Note: Includes only employment in catfish production. Additional employment of 3 671 was reported in catfish processing. Production of 172 789 tonnes is volume of catfish processed in Mississippi, USA.

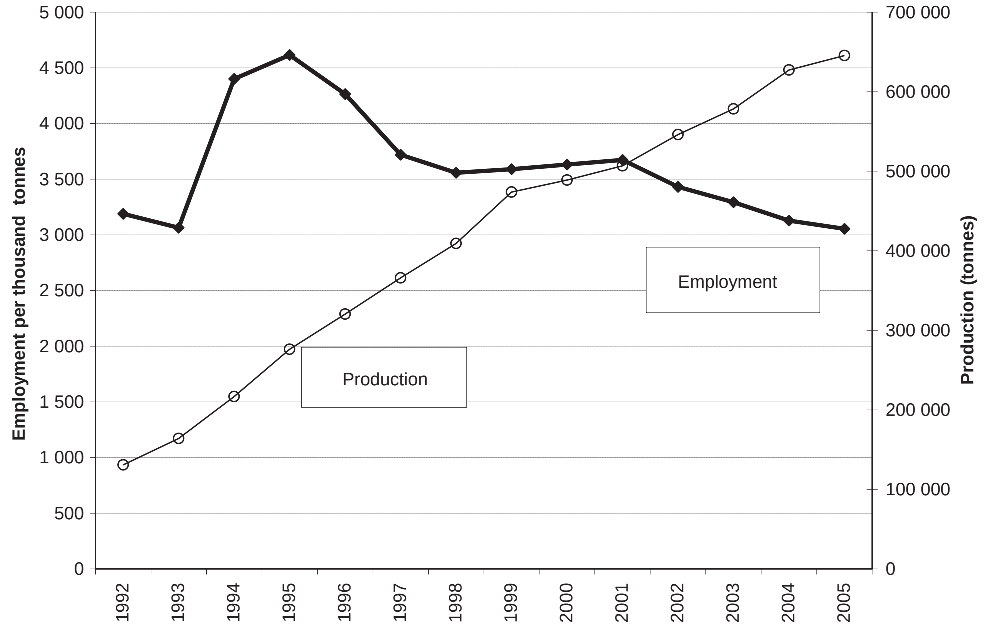
The employment estimates are only for direct employment in fish farming. As discussed above, total employment created by aquaculture in these regions, after accounting for indirect and induced upstream impacts of upstream and downstream activities, is likely much larger – potentially five to ten times as great.

The employment impacts associated with a given volume of aquaculture production vary widely depending upon the species, region and technology and scale of production. In general, labour productivity is much higher in large-scale salmon farming, resulting in the creation of fewer direct farming jobs per thousand metric tonnes of production than smaller-scale farming of other species.

Norwegian salmon and trout farming – probably the most labour-efficient large-scale aquaculture in the world – creates about 5 direct farming jobs per thousand tonnes of production. In contrast, aquaculture in general, reflecting smaller-scale production of a mix of finfish and shellfish species, tends to create between 20 and 50 direct farming jobs per thousand tonnes of production.

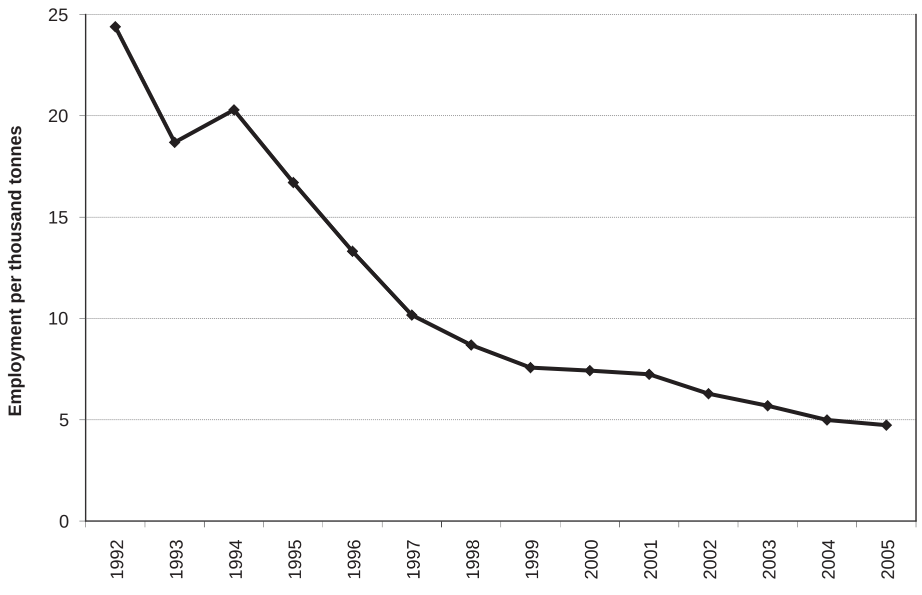
Detailed cost and employment data compiled annually for the Norwegian aquaculture industry help to illustrate the basic point that the number of jobs created by fish farming depend upon scale, technology and economics. Between 1992 and 2003, Norwegian salmon and trout production more than quadrupled while total employment in Norwegian salmon and trout farming declined (Figure 16a). As a result, employment per thousand metric tonnes of salmon and trout production fell from 24.4 to 5.7 (Figure 16b) – reflecting a dramatic increase in labour productivity as the scale of the industry increased.

FIGURE 16A
Norwegian salmon and trout aquaculture: total production and total employment



Calculated from data in Statistics Norway, *Fish Farming 2005*.

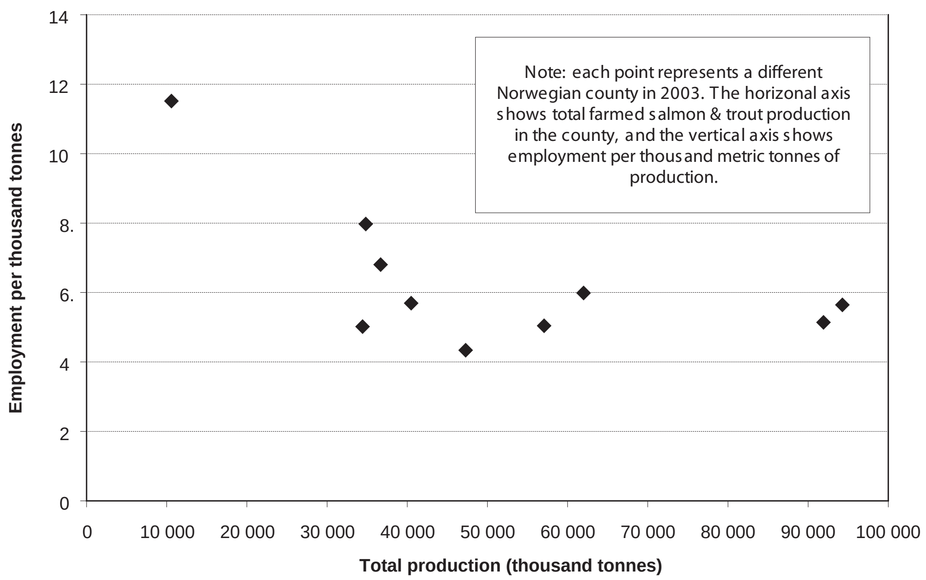
FIGURE 16B
Norwegian salmon and trout aquaculture: total production and total employment



Calculated from data in Statistics Norway, *Fish Farming 2005*.

Norwegian aquaculture data also help to illustrate that even farming of the same species in the same country may have different job impacts in different locations – likely reflecting differences in industry scale. As shown in Figure 17, there were significant differences between Norwegian counties in the employment per thousand metric tonnes of production in 2003.

FIGURE 17
Norwegian salmon and trout aquaculture: total production and total employment



Calculated from data in Statistics Norway, *Fish Farming 2005*.

In general, because of the more difficult working conditions offshore and the higher cost of transporting workers to offshore facilities, offshore fish farms are likely to be more mechanized and have fewer people working on the farm sites per tonne of production than inshore farms growing the same species. Put differently, where it is possible to replace offshore workers with machines, offshore farm operators are likely to try to do so. This effect will be amplified to the extent that offshore farms are larger scale than inshore farms.

However, some parts of offshore fish farming operations may employ more labour than inshore operations producing comparable species and volumes. For example, because of generally longer distances from shore facilities to farms, offshore farms may create relatively more jobs in transporting fish, feed, equipment and people to and from farms.[5]

Clearly the employment in offshore aquaculture will depend upon the volume of offshore aquaculture production, the mix of species which are farmed and the scale and technology of individual farming operations. However, given observed levels of employment in existing capital-intensive inshore aquaculture, is possible to make reasonable estimates about the potential scale of total employment which might be created by any given level of offshore production.

Table 7 shows the potential total employment implied by different combinations of three assumptions:

- Total annual production. The table shows implications of annual production from 50 000 to 500 000 tonnes.
- Direct farming employment per thousand tonnes. The table shows implications of direct employment ranging from five jobs per thousand tonnes (large-scale highly efficient Norwegian salmon and trout farming) to 50 jobs per thousand tonnes (averages across all aquaculture in some regions).

[5] Note that locating a farm farther offshore does not necessarily imply a greater transportation distance from shore facilities. Depending on terrain and infrastructure development, the distance from a shore facility straight out to an offshore farm may be shorter than the distance along the coast to a suitable inshore farming site.

- Ratio of total employment to direct farming employment. The table shows implications of between two and ten total jobs per direct farming jobs. Note that the lower assumption would exclude "downstream" employment created in transportation, wholesaling, retail and food service.

TABLE 7
Potential employment created by offshore aquaculture implied by different combinations of assumptions

	Assumed direct farming employment per thousand tonnes	Assumed annual offshore production (tonnes)		
		50 000	100 000	500 000
Direct farming employment only	5	250	500	2 500
	20	1 000	2 000	10 000
	50	2 500	5 000	25 000
Assuming 2 total jobs per direct farming job	5	500	**1 000**	**5 000**
	20	**2 000**	**4 000**	**20 000**
	50	**5 000**	10 000	50 000
Assuming 5 total jobs per direct farming job	5	1 250	**2 500**	**12 500**
	20	**5 000**	**10 000**	**50 000**
	50	**12 500**	25 000	125 000
Assuming 10 total jobs per direct farming job	5	2 500	5 000	25 000
	20	**10 000**	20 000	100 000
	50	**25 000**	50 000	250 000

Note: Relatively more likely combinations of assumptions are shown in **bold**.

On average, the jobs created in offshore aquaculture are likely to be higher-skilled and higher-paying than the jobs in onshore and inshore aquaculture for similar species. These jobs will include, for example, operation and maintenance of vessels and remote monitoring and feeding facilities and fish nutrition and fish health specialists.

As with other higher-skilled and higher paying jobs, not all of the new jobs created by offshore aquaculture will necessarily be taken by current residents of those communities nearest offshore aquaculture facilities. The industry is likely to seek the most qualified employees it can find from a broader regional or national pool of workers with the requisite skills. However, local communities may be able to influence local hiring through training programmes or tax incentives. Local training or hiring requirements could potentially be incorporated in enabling regulations for offshore aquaculture.

Commercial fishers would be well skilled for and could potentially work in many of the jobs that might be created by offshore aquaculture, particularly those that involve vessel operations, maintenance of offshore operations and transportation of fish. However, some (but not all) kinds of offshore aquaculture – particularly large-scale corporate farms – may involve a very different working environment than commercial fishing. Some but not all fishers and other coastal community residents would welcome these job opportunities.

In considering the types of jobs created by offshore aquaculture, it is important to keep in mind the point emphasized earlier in this chapter that most of these jobs will not be working on offshore farms or working for offshore aquaculture companies. Rather, most of the jobs will be in a wide variety of upstream and downstream activities such as hatcheries, feed manufacturing, soybean farming (for feed ingredients), cage manufacturing, software development (for remote monitoring systems) and fish processing and distribution.

ECONOMIC IMPLICATIONS OF GOVERNMENT POLICIES FOR OFFSHORE AQUACULTURE

In the previous section, how economic factors may affect offshore aquaculture development was examined – assuming that government policies provide an enabling regulatory framework for offshore aquaculture. In this section, we examine how

TABLE 8
Selected government policies affecting the offshore aquaculture development

Category	Selected key issues
Leasing policies	Is there a process by which farmers may lease offshore sites?
	How predictable is the process?
	How long does it take?
	How legally secure are sites?
	How flexible are permitted uses of sites?
	Can sites be transferred?
	What do sites cost?
Regulatory policies	What regulations does government impose on offshore farmers?
	How costly are the regulations?
	What is the process for developing regulations?
	How stable and predictable are the regulations?
	What are the objectives of the regulations?
	How efficient are the regulations? Could the same objectives be achieved at lower cost?
Other policies	How is offshore aquaculture taxed?
	What kinds of subsidies are available for the offshore aquaculture industry?
	To what extent and in what ways does government support offshore aquaculture research, education and marketing?
	What are trade policies towards farmed fish?
	What infrastructure (roads, ports, etc.) does government provide in areas with offshore aquaculture potential?

government policies may affect the offshore aquaculture development assuming that economic factors are favourable.

A wide variety of government policies may affect the development of offshore aquaculture. These policies may be grouped broadly as leasing policies, regulatory policies and other policies (Table 8).

Leasing and regulatory policies are critically important for offshore aquaculture. Offshore aquaculture cannot and will not happen unless governments establish leasing and regulatory policies which give fish farmers the opportunity and incentive to invest in offshore fish farming.

Just as importantly, without the potential for eventual economic benefit, companies will not invest in research on how to address potential engineering or other challenges for offshore aquaculture. Until actual offshore operations are in place, there is no opportunity to learn from experience about how to address the challenges. The surest way to ensure that no solutions are found for these challenges is to ban offshore aquaculture until they are found. The surest way to ensure that no benefits are realized from offshore aquaculture is to ban offshore aquaculture until the benefits are proven.

Having an enabling regulatory policy does not in any way imply that offshore aquaculture should not be regulated or that the environment should not be protected. On the contrary, strict regulations and environmental protection is not only consistent with but essential for successful offshore aquaculture development. What is needed is not absence of regulation but clear, consistent and efficient regulation that provides clear guidelines for where and how offshore aquaculture will be allowed and addresses regulatory goals in a cost-effective way.

Principles for efficient offshore aquaculture policies

A basic economic principle is that government aquaculture policies should be efficient: they should not impose unnecessary costs in achieving any given regulatory objectives. Put differently, government indifference to regulatory efficiency has the potential to significantly slow the development of aquaculture. Economic theory suggests that basic conditions for efficient offshore aquaculture policy include:

- Policies should be clear and stable. Regulatory uncertainty – the risk that planned offshore investments will not be approved or that regulations may change and impose additional costs and/or delay – reduces incentives for firms to invest in aquaculture.

- Policies should avoid unnecessary delay. The longer the time from when an investment is made to when an economic return is realized, the lower the rate of return on the investment. To the extent possible, government should respond rapidly to applications for leases and operating permits.
- Site leases should be well defined and transferable. Leases should be *well defined* so that farmers have a clear understanding of how and for what period of time they will be able to use a site. They should be *transferable* so that they will be operated by the most efficient farmers, who are able and willing to pay the most for the sites.
- Policies should regulate outcomes rather than inputs. If the goal of regulation is to achieve a certain outcome (such as maintaining water quality or limiting escapes), to the extent possible government should allow industry to seek the most cost-effective way to achieve the outcome rather than mandating a particular way of achieving it.

Principles for offshore aquaculture regulatory institutions

Policies affecting offshore aquaculture may be developed by a wide variety of government institutions: executive, legislative and judicial agencies and bodies at local, regional, national and international levels of jurisdiction. What kinds of institutions have authority and responsibility to develop policies affecting offshore aquaculture will affect what kinds of policies are developed.

In general, offshore aquaculture is more likely to develop if regulatory institutions have the following characteristics:

- Clear responsibility and authority. There should be clear responsibility and authority for the development of leasing and regulatory policies for offshore aquaculture policy. If no agency has both responsibility and authority to develop these policies, they will not be developed and offshore aquaculture will not happen.
- Balance of perspectives. Institutions should provide a mechanism for society to consider and balance both costs and benefits of offshore aquaculture. If agencies are only concerned with minimizing any costs or risks of aquaculture, the simplest way to do so will be to not allow it.
- Appropriate jurisdiction. Policy authority should be at levels which can consider and balance local, regional and national interests.

Challenges for offshore aquaculture

Because it is new, offshore aquaculture may face several significant policy hurdles. These include lack of an established leasing and regulatory framework; lack of clearly defined responsibility and authority for creating a leasing and regulatory framework and lack of existing stakeholder groups with a strong interest in supporting offshore aquaculture. In contrast, groups which oppose offshore aquaculture may be well established and may have agency support.

Overcoming these challenges will require that offshore aquacultures supporters make the case effectively that offshore aquaculture can be environmentally sound and economically beneficial. FAO can play a role in supporting the development of responsible offshore aquaculture by collecting, analyzing and disseminating information about the technical feasibility and potential environmental and economic benefits of offshore aquaculture.

EMPIRICAL ECONOMIC ANALYSIS OF OFFSHORE AQUACULTURE

To move beyond theoretical analysis such as that presented in this paper to empirical analysis of the prospects for or implications of offshore farming of particular species in particular locations requires the development of models based which explicitly incorporate data and assumptions about variables such as expected costs and prices and relationships such as fish growth functions and market supply and demand. Such models may range from simple spreadsheets, based on rules-of-thumb assumptions about expected average costs and prices, to complex models incorporating assumptions about factors such as feed conversion ratios, fish growth rates, and the timing of capital expenditures. In general, more complex models may be used to address more complex questions but require more assumptions, cost more to develop and may be harder to understand.

Empirical economic analyses of offshore aquaculture have several potential benefits for industry and government:

<u>Systematic thinking</u>. Economic models require systematic thinking about costs and revenues. This is difficult when farms do not yet exist for which costs and prices can be observed, but it is still essential.

<u>Sensitivity analysis</u>. Models provide a tool for testing the implications of changes in key assumptions such as feed costs or growth rates. In thinking about economic viability, what is important is not just using the best available assumptions, but also thinking about the range of uncertainty in model outputs associated with uncertainty about key assumptions.

<u>Optimization analysis</u>. Investors face numerous choices in the design of a fish farm, such as scale. Economic models can be used to explore tradeoffs between different design choices and to examine the implications of how farms are regulated.

<u>Economic impact analysis</u>. Economic models of farming operations can provide the starting assumptions for analysis of economic impacts of offshore farming, such as the jobs and income which might be created by offshore farming, both directly and indirectly.

Most of the publicly available empirical economic models for offshore aquaculture have been developed by universities and research institutions in the United States of America. They cover a range of species and geographic regions, e.g. Atlantic cod, sea scallops and blue mussels in the Northwest Atlantic (Jin, Kite-Powell and Hoagland, 2005; Kite-Powell, Hoagland and Jin, 2001); finfish in the Gulf of Mexico (Posadas, Bridger and Costa-Pierce, 2001); Pacific threadfin in Hawaii (Kam, Leung and Ostrowski, 2003); bluefin tuna in the U.S. East Coast (Shamshak and Anderson, 2009); snapper in Puerto Rico (Brown *et al*., 2002); rock bream in the Republic of Korea (Lipton and Kim, 2007); and gilthead seabream in the Canary Islands and the Mediterranean (Gasca-Leyva *et al*., 2001).

In general, these models describe the biological, environmental, economic, and regulatory conditions under which offshore aquaculture may become profitable. A useful contribution of FAO to the development of offshore aquaculture might be to assist in the development of prototype empirical economic models for species and geographical regions for which information is lacking. Industry and governments alike could use the results of these analyses in planning for particular types of offshore farms. Over time, as more experience is gained in offshore aquaculture and more data are collected from actual operations, empirical analysis will become relatively easier and cheaper.

RECOMMENDATIONS FOR FAO

What lessons may be drawn from this economic analysis about how FAO can best support the responsible development of offshore aquaculture? This analysis is concluded with three broad recommendations.

1. FAO should encourage and facilitate the development of offshore aquaculture, but should not oversell it.

The true test of whether, where and when offshore aquaculture is a good idea is the market. Although it seems highly likely that eventually large-scale aquaculture production will occur offshore, helping to meet food demands of a larger and wealthier world population, this does not necessarily mean that offshore aquaculture is currently economically viable on a large-scale. That has yet to be demonstrated.

At this stage the most appropriate strategy for FAO is to continue to collect and disseminate information about the potential for offshore aquaculture and to encourage Member states to create enabling regulatory frameworks under which investors can test that potential.

2. Probably the most effective role FAO can play is in helping governments obtain information they need to understand the potential of offshore aquaculture and to plan for and promote its responsible development.

Typically, private sector companies considering specific offshore aquaculture development opportunities have needs for detailed and specific information about potential sites, technologies, species and markets. FAO is not in a position to provide this kind of specific information at the needed level of detail. Private sector fish farmers and consultants can best develop this information themselves.

In contrast, governments, which will play a critical role in establishing an enabling regulatory framework for offshore aquaculture have a significant need for information on what kinds of offshore aquaculture might have potential, its potential benefits and costs and how they can best plan for and promote its responsible development.

FAO is well suited to help provide this information by doing things it does regularly and well, including:

- Support of technical studies by experts.
- Hosting meetings for sharing information among technical experts and government officials.
- Facilitating efforts to discuss and establish consensus on international issues related to offshore aquaculture, such as the development of aquaculture in international waters.

Specific activities that could be particularly helpful include:

- Periodic studies demonstrating that offshore aquaculture is technically and economically feasible and environmentally sound, based on case studies of actual operations.
- Development of prototype empirical economic models of offshore aquaculture for particular species and/or geographical regions.
- Development of examples of permitting and regulatory guidelines for offshore aquaculture which could be used as starting points by governments.
- Facilitating technical training of government officials responsible for key decisions affecting offshore aquaculture.
- Collecting data on offshore aquaculture production, by country and species. Note that this would require developing definitions of "offshore," or potentially multiple "offshore zones," based on objective indicators such as distance from shore. Until this is done, it will be difficult to know the extent to which offshore aquaculture is actually developing. Initially, while offshore aquaculture remains in an early stage of development and while definitions remain unclear, it may not be possible to develop formal data series, but periodic surveys of member countries could provide indicators of the approximate scale of current or expected future production.

3. Analyses of markets and marketing specifically for offshore aquaculture should not be a priority for use of FAO resources at this time.

Clearly, markets are important for offshore aquaculture. As discussed earlier, offshore aquaculture will develop on a significant scale only for species for which demand is sufficiently strong to support prices high enough that offshore farming is profitable at volumes which cannot be satisfied by production from lower-cost sites. But what FAO can do either to create this demand or help entrepreneurs learn about market opportunities is relatively limited.

Seafood markets are dynamic and can change fast. Markets develop in part because producers invest significantly in developing them. Market information, about who may be willing to buy different products and what they are willing to pay for them is valuable and often proprietary. There is intense competition for markets within the seafood industry, both among countries and often among different firms within countries. Typically, industry and national organizations are likely to be more effective in collecting detailed market information and developing marketing strategies to best take advantage of the opportunities.

FAO and its associated institutions (Eurofish, Infofish, etc.) presently have a variety of programmes and efforts which play a useful and effective role in developing and disseminating market information and in assisting with marketing efforts, primarily at the level of initial market information gathering and development. These efforts should continue. But there are no obvious *new* market-related activities which should be a high FAO priority for facilitating offshore development at this time.

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