A Guide to

Marine Aquaculture

An introduction to the main challenges when establishing and managing marine aquaculture plants

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Table of content

Cover page photo: Sjømatrådet.

Introduction

Aquaculture is defined as the farming of aquatic organisms, including fish, mollusks, crustaceans and aquatic plants and to enhance the production process from spawning, production of juveniles, on-growing to harvest. Although a large number of species are being cultured, only a few species are candidates for commercial aquaculture.

In recent years we have seen substantial changes in the world market for fish. Aquaculture production has almost doubled since 2001 whereas production from fisheries has remained at the same level (Fig 1). The natural stocks are exploited to the limit and the future demand for fish products must be met by increasing the aquaculture production. It is therefore important to be able to continue to develop the aquaculture industry in a sustainable and economically feasible manner in the years to come.

In this guide the main focus is *on cold and temperate water* marine species including their many similarities, and the challenges the rise in spite of great differences in rearing conditions and geographic origins. Even salmon and trout which spawn

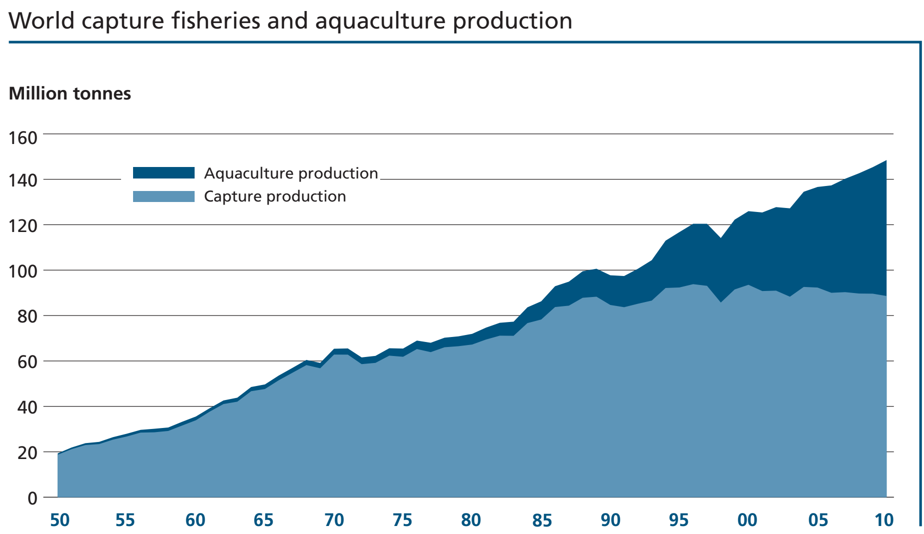


Figure 1: The total food fish production was 148 million tonnes in 2010. 88.5% was produced in China and only 4.3% in Europe. There is potential to increase production and efficiency in all areas (FAO).

and spend their first year in fresh water share a number of similarities with marine species. They are included in this guide because they are one of the leading examples of successful large scale production of fish. Production technology developed for salmon aquaculture was the basis for later attempts at farming of species like cod, halibut and even turbot in a number of European countries and is still used as a basic comparison for technical and biological issues.

The early stages of marine aquaculture

There is a large number of new species being farmed, but only relatively few have been successful over a long period of time. The criteria for succeeding are complex and usually a combination of biological and economical factors. Aquaculture is a relatively new industry in Europe; commercial cage culture only started in the second half of the 20th century with the salmon and trout industry. Hatching of juveniles, however, has a longer tradition as it has been used for restocking of rivers and lakes for recreational fishing. Capturing of mature fish before spawning has been practiced with species like salmon, cod and white fish to obtain artificially produced larvae. Using more extensive rearing methods like lagoons and ponds allowed larval production under conditions closely resembling the natural habitats, including algal blooms and production of natural zooplankton. Larvae or juveniles were released in the sea, lakes or rivers in an attempt to augment the natural populations. For commercial production it was necessary to intensify operations feeding of juveniles was started using live plankton of rotifers and artemia in intensive cultures. Production technology has moved indoors to be able to maintain full control of the production cycle.

Figure 2: A halibut juvenile facility in Norway.

The experiences from cage culture of salmon and trout were adapted to new species like cod, seabass and seabream in an attempt to duplicate the successful production of salmonids. In addition, land based production of the flatfishes halibut, turbot, and later sole had started. These species were high priced and it was therefore possible to justify the high investment costs. A number of criteria have to be fulfilled for the commercial cultivation of a species to succeed, including all stages of the production chain as well as price and market:

Main criteria for successful aquaculture:	
Market product demand	This means that the market already exists and is not met by wild fisheries or is easily replaced by other types of fish.
Species performance	The cultured fish should have the same acceptance on the market as the wild.
Production technology	The technology for producing the targeted species must be known and reproducible.
Markets	It is crucial to know where to sell the fish, especially if it is a local or international market.
Balance with commercial fisheries	An overproduction of wild catch will affect the prices and compete directly with the farmed product.
Production costs	The cost of producing the fish should be lower than the lowest market price

The result is only as successful as the weakest link in the production chain from broodstock to eggs, juveniles ongrowing and harvest. If the farmed production is in competition with wild fisheries of the same species, it has to be possible to produce and sell the fish at a lower price than the wild fish and the quality needs to be of a similar quality as the wild counterpart. In addition, the selling price has to be higher than the cost of production.

The development of the salmon industry in Norway

The salmon industry is one of the best examples of the successful development of an aquaculture species. When the initial development started in the early 1970s prices for wild salmon were high and wild fisheries for salmon were decreasing. A successful production in the early eighties created an interest in commercial salmon farming which resulted in a substantial growth leading the development of salmon farming as a commercially viable industry. The early industry experienced high market prices, but also high costs of production. In the mid eighties production had reached 50.000 tons and market price still remained high. Over the next 10 years market prices fell more than 50%. A lot of salmon farmers went bankrupt or had to close. The industry struggled with problems like high mortalities, poor smolt quality, insufficient equipment and poor knowledge of the nutritional requirement of the fish. In 1985 the cost of production was nearly as high as the export price. Intensive marketing programs which included value added products resulted in increasing demand again and the industry continued to grow.

Figure 3: Salmon farming in open cages. Photo: Marine Harvest.

Development of technology has improved all areas of production, including reduced risks and incidents leading to escapes and damaging to the facilities, better working conditions for the employees and better attention to the needs of the fish. Cost of production fell from 5 EUR/kg in 1990 to 2,5 EUR/kg in 1995. At the same time prices fell from 5,5 to 4,0 EUR/kg in a few years and the volumes increased. Feed production became more industrialized and specialized feed was developed for species, life stages and for special market segments. The quality of feed was developed to suit the nutritional requirement of the fish and technical quality was improved to reduce waste and improve digestibility. Today salmon has become a commodity which is dependent on the large volumes produced.

The high mortalities were caused by bacterial and viral diseases which threatened the industry from further growth. It was not until vaccines were developed for the most common bacterial diseases that the industry again started growing and in the early nineties all the salmon transferred to the sea were vaccinated. The industry has continued to develop and production has increased to more than 1 million tons a year. The cost of production has decreased to about one third of what it was in the early eighties and the market price has often had only a marginal profit, but the large volumes have allowed this to become a very profitable industry. Today salmon has a worldwide market.

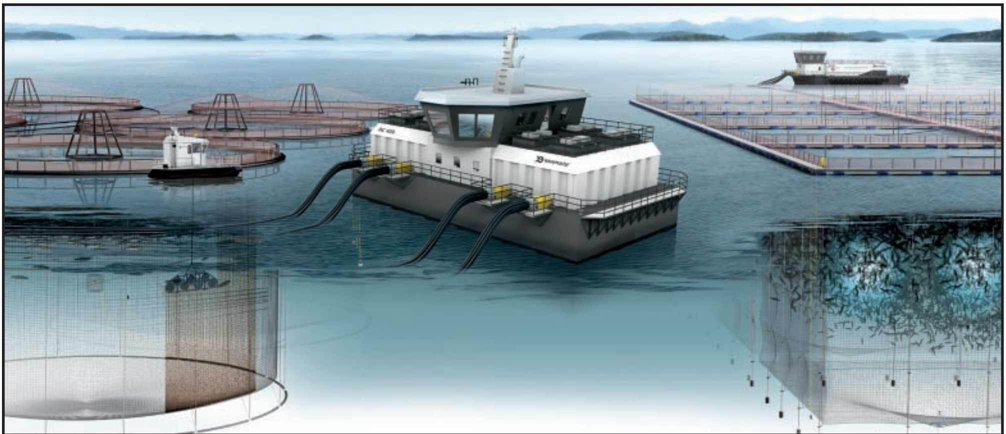


Figure 4: Modern cage farm showing both circular and steel cages. Both systems are being used today. A central feeding barge from Aquagroup is equipped with all the technical necessities to operate a cage farm. Each cage has its own supply of feed from the barge based on number and size of the fish, temperature and time of year (day length).

The production time of salmon from 100 gram to harvest size of 4 – 5 kg has been reduced from 3 years to 18 months. Better feed, breeding and technology has resulted in better growth and production systems that are based on all in all out principle that the whole cage is emptied for harvesting at one time. The use of larger cages allowed the production to increase in each cage and automatic feeders led to better growth and production time was decreased.

Marine species

The salmon industry led to the belief that other species could be developed for aquaculture using the same technology as salmon. The main difference is in production of juveniles. Contrary to salmon and trout which produce large eggs with a long embryonic period, most marine juveniles are dependent on live plankton for start feeding. Unlike salmon, the marine species like turbot, cod, halibut, bass and bream spend their whole life cycle in seawater and therefore their production is more simple than for the salmonids.

Experimental spawning of cod for release in the coastal water had started as early as 1883 at the Institute of Marine Research(IMR) in Norway. Newly hatched larvae were released in coastal waters in an attempt to ensure recruitment to the stock of natural populations. Spawning of cod eggs for aquaculture purposes started about 1970 at the IMR which led to the beginning of a new aquaculture industry based on marine species like cod, halibut, turbot and wolfish. It turned out to be much more difficult than salmon and development was slow. The production of high quality juveniles is still one of the major constraints in the development of new cold-water species for aquaculture. Early experiences suggested that the on-growing stages are more straight forward for most species considered, and it is possible to take advantage of the technology and the services that have been developed for the salmon industry.

Cod

There was a great expectations for cod farming in Norway, Iceland and Scotland as well as in Atlantic Canada. The initial production was based on collection of wild zooplankton, but this method was later abandoned when the focus was large scale production independent of natural seasons. In early 2000 there was increasing interest from private investors from the salmon industry as well as the financial world and together with national and EU support more than 20 companies were involved in the cod industry. At most 20.000 tons were produced in 2008. High production costs combined with low market prices discouraged further development of the industry and by 2014 there are only a handful of producers left. In spite of better results including a national breeding program, better feed and vaccines the production has declined to less than 5.000 tons and very few juveniles are produced. The future for the cod industry is uncertain, yet some research is maintained, the national breeding program in Norway continues so it is still possible to continue aquaculture of cod at a commercial level.

Figure 5: Farmed cod. Photo: Sjømatrådet.

Figure 6: Farmed cod juveniles. Photo: Institute of Marine Research.

Turbot and halibut

These are species that have developed commercially largely due to their high value. The total annual production of turbot is about 15.000 tons worldwide, with the main producing countries Spain and Portugal. The production is landbased in traditional circular tanks in glass fiber or concrete. Juvenile production is intensive, using algae, rotifers and green water technique. Light manipulation of broodstock has allowed egg production all year. Breeding programs have resulted in better growth and currently turbot can be harvested before sexual maturation. Although production is labour intensive it has proven to be highly profitable.

The culture of halibut, another flatfish, has many similarities, but has not been as successful as turbot. The juvenile production is more complicated as it has a long post hatching stage before startfeeding can begin. Female halibut does not get sexually mature before it is at least 5 years which makes breeding programs difficult. Growth is slow and normally requires 4 – 5 years in ongrowing. Both cages and land based production is being used. Specialized cages have been developed for halibut with deep cages with stacks of shelving units placed within the cage (Figure 7).

Figure 7: Stolt Sera turbot farm in Galicia in Spain.

Although both halibut and turbot have been produced for more than 20 years in small amounts they have been relatively successful. Prices have remained high they have managed to be successful in small volumes. They are well recognized and high priced species with a good potential for aquaculture. They are flat fishes and mainly produced in landbased facilities , although halibut can be produced in specialized cages, but at a relatively high cost of production. It has benefited from a decline in the wild fisheries which has created a demand for these species. Both have been successful in obtaining a good reputation for the farmed fish.

Selecting species for aquaculture

A number of different factors are responsible for a successful aquaculture species. Some factors are biological whereas others are directly linked to technology and markets. When choosing a species it is necessary to have a good knowledge of the entire life cycle and the requirements at each stage in the production.

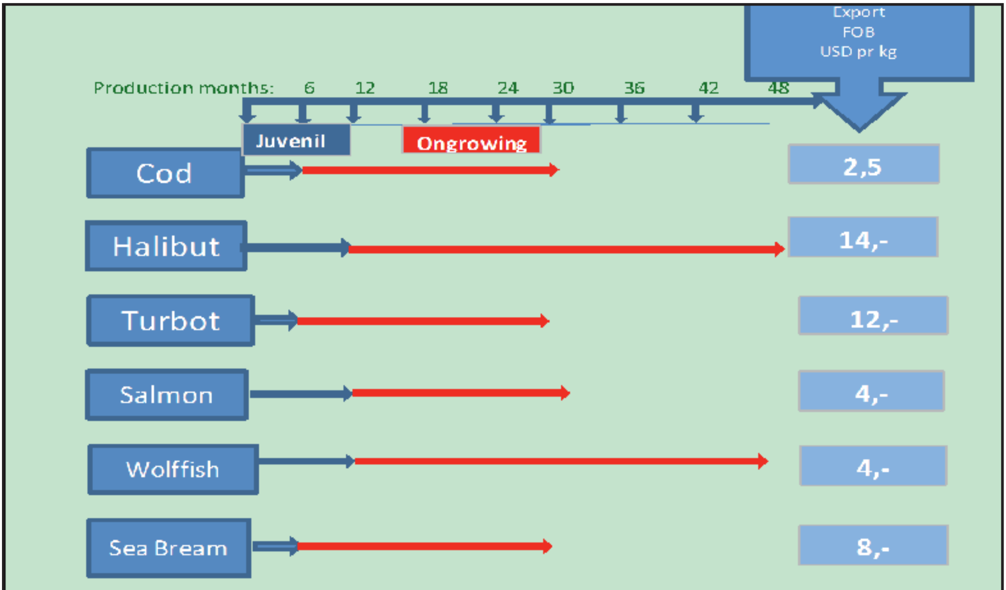


Figure 8: The figure compares the time of production of a few species. It is essential information both for the choice of species and the choice of technology. Some species like cod and turbot have a short juvenile stage and the juveniles are lower in price than juveniles with a long production time like salmon and halibut.

Aquaculture for stocking / restocking

Aquaculture for purposes of stocking/restocking is the process of producing juveniles for release into the sea, lakes or rivers of depleted or overfished species. Although the main focus in this guide has been culturing of juveniles for aquaculture purposes, culturing of juveniles can be used to restore depleted stocks or as a means of more extensive sea ranching.

There are several considerations to make when releasing fish to rivers or the sea. The individuals reared for stocking should be of high quality in order to be able to compete in the wild. Stocking of fish should be done when conditions are favorable and feed abundant, normally in the spring when plankton blooms and fish larvae will provide feed for the fish. Temperatures should be within optimal range for the species. In cold temperatures the metabolism will be slower and less feed is needed, but at subnormal temperatures the fish will lose their appetite and mortalities will occur. Similarly, if the temperatures are too high, it increases the risk of diseases. Handling stress is reduced in cooler water but will cause delayed, high mortality in warm water.

Before releasing fish to the sea it is essential to evaluate the suitability of the fish. Young larvae have low survival rates in the wild and larvae reared in captivity will be even less likely to survive. The two main reasons are predation from larger fish and availability of feed to grow. Small larvae do not swim long distances and will need to have the feed available where they are. Experience from Norwegian release of cod juveniles rather than larvae showed a recapture of nearly 20%.

Other factors like the ability of the released fish to adapt to wild conditions are important. Cultured individuals are often less well adapted to natural habitats than wild fish and therefore less likely to survive.

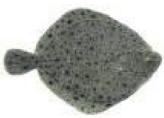
Stocking is mostly used as enhancement technique for depleted stocks in inland waters. FAO reports on the following major types of stocking:

- compensation to mitigate a disturbance to the environment caused by human activities;
- maintenance to compensate for recruitment overfishing;
- enhancement to maintain the fisheries productivity of a water body at the highest possible level;
- conservation to retain stocks of a species threatened with extinction.

In Europe the most common species for stocking / restocking are common carp (*Cyprinus carpio*), rainbow trout (*Oncorhynchus mykiss*), salmon (*Salmo salar*) and in some areas pike (*Esox lucius*) and white fish (*Coregonus lavaretus L.)***.** Stocking programmes are also used to support recreational fisheries.

Aquaculture species in Europe

Fish is completely reliant on the quality of the water where they live. They are dependent on the water for respiration, feed, growth and excretion of waste. To a great extent water determines the success or failure of an aquaculture operation. Species have different requirements concerning water quality in cultured conditions which reflect the conditions where they are found in the wild. It is therefore important to understand the natural requirement of the species before choosing the species for aquaculture. The most common species used for aquaculture have been well described in the literature and it is advisable to have a thorough understanding of these requirements before making a choice of what species of fish to culture. In this guide we have chosen 10 species which are produced commercial today and made an evaluation of their production based on a number of criteria.

Major aquaculture species in Europe					
Common name	Picture	Scientific name	Major aquaculture countries	Annual world production (tonnes) FAO	Market
Salmon		*Salmo salar*	Norway, Scotland, Chile	1,5 mill	Global market
Trout		*Oncorhynchus mykiss*	Worldwide	0,7 mill	Global market
White fish		*Coregonus huntsmani*			Local markets
Turbot		*Psetta maximus*	Spain, Portugal, France, Turkey	80.000	European market
Wolf fish		*Anarhichas spp.*	Norway	< 1	Export potential
Halibut		*Hippoglossus hippoglossus*	Norway, Canada, Scotland, Iceland	2	North European market
Cod		*Gadus morhua L.*	Norway, Scotland, Canada	20	Global market
Sea bream		*Sparus aurata*	Mediterranean countries, Turkey	140.000	Global market

Sea bass		*Dicentrarchus labrax*	Mediterranean countries, Turkey	120.000	Gloabla market
Sole Picture: wikipedia		*Solea solea*	Spain, France, UK	120	Market potential

Site selection and environment – the main challenges

Site selection in aquaculture is essential for a successful outcome. Regulations for site selection are based on long term performance of the site taking into account, risks of disease, accumulation of feces and interference with other industries. It is essential to perform an integrated assessment of the site according to both national and EU regulations. For the farmer a location with good water quality, sufficient shelter and optimal temperature is likely to give better growth and reduce the risk of mortality. A bad site for the fish farm is likely to give problems in a number of different ways that will affect the outcome of the production.

In the early years of salmon farming in Norway, the sites were often selected based on convenience and accessibility to the shore rather than the best growing condition for the fish. The need to be protected from exposure to strong waves and winds had a higher priority than the long term effect on the sea bottom under the cages. Today the criteria for the location of a salmon cage are very strict. In addition to meeting the requirements for water quality for optimum production, it is required to have a plan which shows that the effluent water does not have a long term negative affect on the environment.

Choosing the site for aquaculture will be strongly influenced by the intensity of the culture and the type of production - cage culture or land based production. Cage culture is reliant on the available ambient temperatures which can fluctuate throughout the year but is also influenced by tidal changes and diurnal variations. Cages are usually more exposed to extreme weather which can affect both the equipment and the fish.

Technological development of cages and equipment for cage culture has allowed new and more exposed sites to be used for aquaculture.

Figure 9: Circular cages for salmon farming. Photo: Sjømatrådet.

Some species have part of their production cycle on land to produce large size juveniles. This will reduce the production time in the sea. For halibut which has a total production time of 4 – 5 years, the time in a land based facility extends far beyond the juvenile stage when the fish is produced until 1 – 1,5 kg on land before being transferred to cages in the sea. This can reduce the total production time with as much as a year compared to having the whole production in the sea. Sea bass and seabream are species that are transferred to cages < 5 g. This needs special attention the first few months to make sure all get access to feed. Generally transfer of small fish has the risk of high losses in the beginning. As fish are transferred from tanks they are not used to the large environment in a cage and special attention is needed the first few months.

Weather it is land based or sea based the most important factor is the water quality. Poor water quality will always have a negative affect on the production, either in causing mortality or a negative by affecting fish growth and development. In land based operations care should be taken that water has sufficient oxygen, either through oxygenation of the water or directly to the tanks. In addition removal of CO2 needs to be done to prevent conditions that are toxic to the fish.

Environmental conditions

The aquaculture industry is regulated by strict laws which prohibit the industry from affecting its environment. In addition, there are requirements as to what environmental conditions need to be fulfilled for it to be suitable for aquaculture purposes. The environmental factors are evaluated before permission is given for a fish farm and is based on national legislation. The factors take into consideration the discharge of nutrients, carrying capacity of the site and the impact it will have on the benthic environment. The effect of the spread of potential diseases are considered and the risk of pollution from nearby industry.

Operational procedure should include a plan for follow up of the environmental effects of the fishfarm. A monitoring plan should cover the consequences of the spread of diseases both directly from the farm, through discharges from the fish and by fish escaping from the farm. Build up under the cages can be caused by faeces from the fish and feed spill from overfeeding the fish. A long term build up under the cages can seriously damage the benthic fauna in the vicinity of the farm. Fish escaping from cages is an unintentional release of fish to the environment and is often considered a genetic pollutant to the environment.

Land based production

For land based facilities, the first requirement is sufficient availability of land with good access to the sea. Weather circular tanks or raceways are used, land based aquaculture require large areas and measures the production per m2 contrary to sea cages which use the volume of water and measure the production per m3. A land based commercial facility therefore requires a large area and should be as low as possible to avoid the cost of having to lift water too high. Usually the water intake is from a depth where temperature and oxygen fluctuations can be avoided. It is also an advantage to avoid algal growth in the water intake which means that the source should so deep that the sunlight does not reach.

Land based production is when all or part of the production cycle is on land using water pumped from a water source as the sea, lakes rivers or lakes and removing wastes to allow the fish to thrive and grow. The amount of water used is dependent on whether flow through or recirculation systems are used.

New production technology and water treatment has renewed interest in land based aquaculture. Traditionally landbased production was dependent on the availability of water for flow through systems. New recirculation technology (RAS) has made landbased production with limited production capacity possible both in fresh and salt water. Production in large facilities with high capacities can now produce efficiently with regard to energy and costs and at the same time have an environmental focus. Technology for removal of CO2 is making production in high densities possible.

Juveniles are most commonly produced in landbased hatcheries. Small hatcheries can efficiently supply juveniles for a single farm, while large commercial hatcheries can offer juveniles for sale to on growing farms.

A commercial hatchery normally includes facilities for broodstock, egg production and start feeding of larvae. Many species require start feeding on live feed and the hatchery has to be able to have a production of live feed.

Hatcheries are based on pumping water from a water source, either a lake, the sea or rivers, which has a steady supply of water and being located near the water source is important for removal of wastes and CO2. As investment costs are high it is essential to plan for efficient use of space and facilities. All year production requires full control over the water quality including temperature. It is essential to have good knowledge of the water source whether it is fresh or sea water hatcheries. The demand for water increases as the fish grows and it is necessary to have good knowledge of the water source all through the year as both the quality and quantity of water may fluctuate.

For some species like sea bream, turbot, halibut and cod it is common to have additional facilities for broodstock and egg production in addition to tanks for start feeding. A facility for cod and sea bream juveniles will have a production capacity of 10 – 25 million juveniles and a high technological production based on 2 – 4 cycles. Concrete or glass fiber tanks of various sizes are commonly used in most hatcheries either circular or raceways. Care should be taken that the location has sufficient water for maximum operation. In addition it is necessary to have a good recipient for the waste water from the farm.

Other requirements are connected to infrastructure like access to land or sea transport and electric supply. In addition it is necessary to consider natural elements like flood and wind exposure which can affect the operation. An advantage is also to be close to the on growing facilities to avoid high transport costs and unnecessary stress on the fish.

Figure 10: Landbased facility for production of smolt. Photo: Marine Harvest.

Land based on growing production is normally seen for high priced species which can justify a high production cost. Flat fish like turbot, halibut and sole are good candidates for land based production. With their quiet behaviour and high price they perform well on land. Water is usually pumped into a heather tank which ensures a steady supply to the individual production units. Farms should be located close to the water source to avoid high pumping costs.

Open cages

For a number of species like salmon, trout, bass and bream open cages are the most common and cost efficient way for salmon production. Except for its size, floating cages for farming of fish remains basically the same. Whereas cages originally were homemade from made of wood today steel cages or PVC is the most common material used. The early cages were functional because they were usually placed in sheltered locations and close to a shore base. As the demands grew for larger cages, companies were established that produced complete cage solutions which included cages and moorings in either plastic or steel. The purpose of increasing cage sizes was a more efficient production. Larger cages placed greater demand on the equipment. Today the larges cages have a production volume between 20.000 – 40.000 m3. This means that a single cage can contain approximately half a million fish, although the number of fish is usually much less. Because of the large sizes, accidents caused by weather damage or human failure can have detrimental effects both for the companies and the environment. In 2005 an accident resulted in an escape of 500.000 fish from a single farm in Norway. A national technical standard now regulates the requirements for cage systems. This standard is now being included in the International Organization for Standardization (ISO).

Figure 11: Circular cage farm from Turkey.

Steel cages are most commonly used in protected areas and includes 6 – 12 square or rectangular individual cages connected together by a central steel gangway as well as gangways around each individual cage. Large cage systems usually includes a working barge which includes the feeding systems, storage and operational units. The advantage with this system is a good work platform which allows efficient working conditions for the various operations. Each cage is usually 24 x 24 or 30 x 30 meters, although they can be as large as 40 x 40 meters. Nets are adapted to the individual site or farm, but 20 – 30 m deep nets are the most common size. Rectangular cages have a flat bottom whereas nets for circular cages have a tapered bottom which also gives additional volume.

Circular cages are lower in cost and better suited for exposed sites. The circular cages are commonly 160m in circumference and with a dept of 30 meters it can have a production of 1100 tons in a single cage. The size of a circular cage is 40 times bigger than it was in 1985 and constructed to withstand the most extreme storms. Circular cages are normally placed in a grid of 1 – 3 rows of cages. To operate a circular cage is dependent of a well equipped working boat.

Figure 12: Circular cage. Photo: Marine Harvest.

The number of fish in a cage has increased and was in 2010 between 150.000 – 250.000 fish. As the fish is growing the cages are usually split in two before the fish reaches harvesting size.

Feed is by fare the most important single cost and technology related to feed and feeding is therefore of major importance for the farmer. Each cage is normally equipped with a camera that lets the operator observe the fish behavior and records the feeding of the fish. In addition feeding is regulated for each cage according to recommended feeds for the size of fish. A sensor will register the feed which passes by at every moment and the information used to regulate the amount of feed that goes into the cage. This way the fish will always have feed available as long as it will eat, but also makes sure that feed is not wasted to the environment.

No matter what type of technology is used, the choice of location is important, both for the farmer and to avoid any environmental problems. The location must have the best possible water quality for stable production as well as having a carrying capacity which allows the water quality to remain in a stable without being influenced by nutrient buildup or wastes from fish and pollutants.

Selection of sites for salmon farming is based on the following criteria:

- Shielding from waves, ice, and strong water current and wind that can damage the cages
- Suitable and stable temperatures for the selected species based on year round knowledge
- Stable salinity and oxygen levels. Seasonal variation may have a negative affect on feed uptake and cause unnecessary stress on the fish.
- Good water current in all dept levels. Water exchange has to occur both diagonally and horizontal.
- Sufficient depths under the farm to prevent sedimentation build up under the cages. The seabed under the cages will affect algal growth, water nutrients and the environment surrounding the farm.
- Care should be taken to consider possible effects from nearby industry, commercial fisheries and predators.
- Long term carrying capacity of the production has to be evaluated.

Specialized cages

With development of marine species like cod and halibut there is a new demand of specialized cages. Fig…. shows the cage system developed for halibut using stacks of shelves to increase the are in the cages. The shelves are developed by Aqualine and 3 stacks of 7 shelves will increase the area in the cage by 60 %.

For species like cod, which are in the early phase of production, cages are usually smaller to allow better control with the production. Cod is often released in cages at a smaller size than salmon and therefore has different requirements to the cages and nets.

Figure 13: Sterling White Halibut farm. The cages are 30 meter deep with stacks of shelves. Feeding is done in the centre and fish will swim out and feed. The annual production is 1000 tonnes. Photo: Marine Harvest.

For a number of species like salmon, trout, bass and bream open cages are the most common and cost efficient way for production. No matter what type of technology is used, the choice of location is demanding. The location must have the best possible water quality for stable production as well as a carrying capacity which allows the water quality to remain stable without being influenced by nutrient build up or wastes from fish and pollutants.

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Closed cages

A third alternative which is being developed is closed systems in the sea. Problems like salmon lice and escapes have increased the interest in development of new technology for closed large scale production. For large volume species like salmon, trout and sea bass and sea bream closed cages might be an alternative. It requires less investments that land based facilities, does not take up valuable land area and the pumping cost of water is much less than on land. New concepts are currently being tested out (fig.) and it is yet to be seen if it can maintain requirements for low production costs.

Figure 14: Aquafarm Equipment's new closed cage for aquaculture is being tested in full scale. Researchers shall monitor the fish health, water quality and optimize the temperature, oxygen concentration, and water flow. Also the mechanical and structural parts of the system shall be tested thoroughly.

Production from eggs to harvest

Life cycle stages

The different stages in the fish life cycle represent the stages of biological development Each stage has specific requirements regarding rearing conditions, feed, disease control and feed. The length of each stage varies between species and reflects the natural habitats in which they live.

Figure 15: The stages in the life cycle of the fish have different biological and technological requirements. Good knowledge of the life cycle is necessary to provide the best aquaculture conditions.

For aquaculture to be possible, it is necessary to have control of the whole life cycle in captivity. Fig. 15 describes a typical production cycle. High quality eggs are necessary to produce larvae with good potential for growth and survival. Knowledge and availability of the appropriate feed requirements will enhance the growth potential of a strong and healthy fish. Good environmental conditions will ensure good growing conditions and good management and technology will ensure optimal farming conditions.

The following is a description of the different stages in the production and the major requirements necessary regardless of the species.

Broodstock and egg production

In the early stages of aquaculture development, we were dependent on the availability of naturally produced eggs or fry for culturing purposes or even the collection of wild sexually mature broodstock for spawning. For salmon this was done for a long time, believing that the wild brodstocks had the best condition for producing high quality eggs. In Scotland this was done as late as the nineties where every generation was obtained from the wild. In cod aquaculture, broodstock was selected from the cages. In some Asian countries milk fish (*Chanos chanos*) production depend on collection of fry to stock tanks or ponds. The reason for this is to keep costs down, but high mortalities and uneven quantity and quality is likely to keep costs high.

The aquaculture of eels (*Anguilla anguilla*) is dependent on collection of glass eels because it is not possible to obtain eggs for juvenile production in captivity.

Requirements broodstock:	
Wild broodstock	Domesticated broodstock with selection of good individuals for high quality eggs and sperm. Can be difficult to feed in captivity.
Farmed broodstock	Specialized nutritional requirements to ensure spawning and good fertilization rate. Potential for different spawning groups.
Male – female ratio	Usually higher number females than males. 70 – 30 ratio
Natural spawners or stripping	Species dependent. Natural spawning and fertilization of cod, wrasse and haddock. Turbot and halibut are stripped.
Disinfection of eggs	Eggs should be disinfected before incubation to prevent growth of bacteria and fungus. Time of disinfection important.
Egg collection	Egg collection immediately after fertilization. Siphoning of tank surface for pelagic spawners or removal of bottom substrate for bottom spawners.
Nutrition	Special attention need to be paid to broodstock nutrition.

Good broodstock management is essential for good quality eggs and juveniles. Good knowledge about the requirements of nutrition of broodstock is prerequisite for successful production of eggs and juveniles. Poor egg quality will not only result in problems in the gonadal development, but may also affect quality and growth potential of juveniles and later on in the on growing stage.

The eggs are spawned and developed separately from the spawning fish. Most marine fish have pelagic eggs (eggs floating free in the water mass) and eggs are fertilized outside the fish. Some species brood the eggs until they hatch, like lump sucker where the male keeps guard of the eggs after spawning. In wolf fish, the egg surface is sticky after fertilization and the eggs stick together in the shape of a ball and the female guards them with thier body until they hatch.

In aquaculture most species are stripped of eggs and sperm and fertilized artificially.

Although species like cod eggs that are spawned in captivity will be fertilized by the males, it is becoming more common to strip the eggs in order to keep a record of the parental lineage and which individuals eggs and sperm come from.

Eggs are kept in incubators for the egg to develop under optimal conditions for the species. Demersal eggs like cod, turbot, bass and bream are kept in circulation, whereas salmon, trout and wolf fish are kept in tanks where they rest on the bottom until hatching. Most species will not protect their eggs and rely instead on spawning large number of eggs for their survival. The time it takes for the eggs to hatch is measured in day degrees (DG). It is the number of days multiplied with the temperature. As an example cod eggs will take 70 day degrees to hatch which could mean either 23 days at 3°C or 10 days at 7°C.

Most eggs rely on their yolk sack for their first feed after hatching. The yolk sac is directly attached to the intestine of the larvae which will take up nourishments directly. As the yolk sac gets smaller the larvae must be able to catch their prey and this is a very critical stage in the life of the fish. Even though the natural spawning usually occurs when the availability of feed is abundant, it is not always the case and the larvae has only a short time to find feed before it dies. In aquaculture, the larvae are introduced to tanks with sufficient live feed and the chances of survival is higher than the wild.

Requirements egg production:	
Fertilization	Sperm quality needs to be checked before fertilization. Non fertilized eggs need to be removed radidly.
Embryonic development	Following the embryonic development with a microscope gives a good indication of egg quality.
Incubation	Incubation of eggs keeps eggs in good condition and avoids desiccations: Maintain good water quality throughout incubation period.
Temperature requirements	Regulating temperature of the incubation within the optimal temperature range will allow production planning for better timing of startfeeding.
Hatching	Eggs should be transferred shortly after hatching to ensure best possible environment.

Startfeeding and production of fry

Most marine larvae are fed shortly after hatching. Small larvae like turbot, cod, sea bass and bream are startfed with rotifers whereas larger fish like halibut are fed on the larger artemia. Some species like wolfish and salmon which have a long incubation period of the eggs will start directly on formulated feed which is a great advantage for the hatcheries which will have one less live production to worry about. Live algae is sometimes used in connection with start feeding, either as feed for the zooplankton or for the benefit of the larvae. The algae provide shade in the startfeeding tanks which will resemble the natural conditions of the larvae. In many instances, live algae are being replaced by fresh algae paste and even clay.

Requirements startfeeding:	
Time of startfeeding	Dependent on embryonic development of mouth and intestine. Good biological knowledge of species required. Size of larvae and mouth indicates feed size.
Nutritional requirements	Live feed or formulated feed requirements dependent on species. Rotifers and artemia used as live feed, Some species start directly on commercial micro feeds. Sufficient feed must be available at all times.
Growth potential	The high growth potential of early stages requires high densities of feed at all times.
Tank requirements	Tanks must reflect natural environment with respect to feed, temperature, light and water flow.
Grading	Early grading usually gives larvae improved growth potential.

Transfer to ongrowing facilities

For the hatcheries it is important to get juveniles ready for sale at the smallest possible size. When the larvae are properly weaned to dry feed and have a good and steady growth rate they are ready to be transferred to the final grow out or a temporary nursery facility. Some producers have specialized in nursery production to receive small juveniles and intensify the production for a number of months and sell it as large juveniles to producers that want large juveniles usually for cages. The smaller fish have usually a higher growth rate than the larger fish and the total production time can be reduced by utilizing this growth potential.

Grow out

The grow out stage should primarily be focused on feeding the fish and maintaining good water conditions. Feed represents the biggest cost in the grow out stage and care should be taken to ensure that the fish are in good conditions at all times and have a good appetite. Fast growing fish like salmon often need to be graded sometime during the production when densities in the cages or tanks get too high.

Requirements ongrowing:	
Feeding	The availability of good quality feed based on nutritional requirements.
Remove dead fish	Dead fish can cause infections to the fish and should be removed frequently. Mortalities due to disease outbreaks must be investigated.
Water quality	Good water quality is essential for good growth and health status.
Grading	Grading is necessary when densities are too high or size differences too big.
Harvesting	Planning of harvesting is necessary for good management. Starving the fish before harvesting will give better quality and hygiene to the end product.

Fish health

Identifying and preventing diseases caused by parasites and infectious pathogens is crucial to successful aquaculture business. A good knowledge of the causes of diseases and mortalities can be essential for good aquaculture management. Mortalities can be due to diseases, poor management or escapes. Mortalities due to disease can be the main reasons for bad economic results regardless of aquaculture species.

A number of factors can cause diseases in fish. Good health management, including good knowledge can reduce the effects of disease outbreak and preventive measures can reduce the effects of disease outbreaks. Good water quality strengthens the resistance to disease, especially water temperature and oxygen conditions. High densities of fish may cause stress and facilitate the spread of disease and should be considered when planning the production. Different species and life stages are susceptible to different diseases. Outbreaks may occur when the fish is stressed and outbreaks may occur during sexual maturation or when the fish is exposed to handling.

Figure 16: Fish veterinarian checking fish health at cod farm.

The infection pressure of specific diseases vary according to disease, condition of the fish and time of year. Viruses, bacteria and parasites have different abilities to cause disease outbreaks. Some organisms are species specific, but others can infect a wide range of fish. Symptoms of diseases varies and will cause varying degrees of mortality.

Vaccine development is one of the most important measures for disease prevention. Vaccines are developed for all the major bacterial infections for most commercial aquaculture species. Due to its success the use of antibacterial measures can be reduced and the effects of disease outbreaks minimized.

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