LARGE-SCALE CAGE FARM DEVELOPMENT GUIDELINES FOR THE PRIVATE SECTOR

by Patrick White

International aquaculture consultant to the U.S. Soybean Export Council

U.S. Soybean Export Council (Southeast Asia) Ltd
541 Orchard Road, #11-03 Liat Towers, Singapore 238881
Tel: +65 6737 6233, Fax: +65 6737 5849
Email: Singapore@ussec.org, Website: www.ussec.org

TECHNICAL BULLETIN
USSEC SEA 06/2021
AQ2021-17

LARGE-SCALE CAGE FARM DEVELOPMENT GUIDELINES FOR THE PRIVATE SECTOR

1. Introduction

In South-East Asia, cage culture has tended to develop as cluster of relatively small cages in sheltered bays, lakes reservoirs and rivers. This clustering is primarily a result of the limited site availability in sheltered coastal waters. The ever-increasing competition for land and coastal water space, along with the growing market demand for marine fish and other sea products are motivating the aquaculture industry to develop larger cage farms in open waters.

Fish cages vary in design, size and materials used as they are intended for diverse environments, ranging from relatively protected to highly exposed and dynamic sites, either as floating or submerged underwater structures and adopting a number of technological solutions to facilitate fish stock husbandry and management.

There are several definitions of coastal and offshore cage culture. Table 1 presents a classification proposed by FAO in 2009.

Table 1. Classification of cage culture as proposed by FAO in 2009

Feature	Coastal	Off the Coast	Offshore
Location/ hydrography	< 500 m from coast ≤ 10 m depth at low tide Within sight of land Usually sheltered	0.5–3 km from coast 10–50 m depth at low tide Often within sight of land Somewhat sheltered	> 2 km from coast Generally within continental shelf zones, possibly open ocean > 50 m depth
Environment	Hs usually < 1 m Short wind fetch Localized coastal currents, possibly strong tidal streams	Hs ≤ 3–4 m Localized coastal currents, some tidal streams	Hs 5 m or more, regularly 2–3 m, oceanic swells Variable wind periods Possibly less localized current effect
Access	100% accessible Landing possible at all times	> 90% accessible on at least once daily basis Landing usually possible	Usually > 80% accessible, landing may be possible, periodic, e.g. every 3–10 days
Operation	Regular, manual involvement, feeding, monitoring, etc.	Some automated operations, e.g. feeding, monitoring	Remote operations, automated feeding, distance monitoring, system function

Hs – Significant wave height

2. Site Selection and Assessment

Site selection involves identifying the most appropriate locations for individual farm development within aquaculture zones and comparing the biophysical characteristics of a prospective site, the needs of cultured fish and the proper functioning of aquaculture farms. Governments control siting through clear regulations that define the process for the allocation of sea space and requirements for licencing.

Site selection ensures that farms are located in a specific location, which enable the necessary production with the least possible adverse impact on the environment and society. Site selection is a process that defines what is proposed (species, infrastructure, and so on), estimates the likely outputs and impacts from that proposal, and assesses the biological and social carrying capacities of the site so that the intensity and density of aquaculture do not exceed these capacities and cause environmental degradation or social conflicts.

Site selection for individual farms within designated zones is normally led by private-sector stakeholders with direct interest in a specific aquaculture investment. The Government assists by defining clear site licencing, environmental impact assessment procedures and what is acceptable within the zones where the sites will be located.

The key steps in the site selection process are:

(i) assessment of suitability for aquaculture
(ii) detailed estimation of carrying capacity for sites
(iii) biosecurity planning and disease control
(iv) authorization arrangements

Farm sites that have poor site selection can lead to frequent outbreaks of anoxia, algal blooms including Harmful Algal Blooms, epidemic fish diseases and mass mortality (fish kills).

2.1. Site Selection Parameters and Factors Relevant to the Fish

Cage sites must have good water quality. Not only must the water be free of pollution, but the water should also meet the biological requirements of the farmed species. These criteria include appropriate temperature, salinity and dissolved oxygen (DO) necessary for the cultured species. The water should be free of excessive suspended solids, with limited occurrences of algal blooms and presence of diseased organisms. Sufficient seawater currents are necessary to ensure adequate water exchange, but too much current will add stress to the organisms and the equipment.

Water Temperature

Temperature has a direct influence on the metabolism of fish, and consequently on their oxygen consumption and rate of activity, as well as tolerance to ammonia and carbon dioxide levels. A sudden variation in temperature may be a source of stress to the fish and may facilitate disease outbreaks.

Salinity

Sites located close to river estuaries may have unsuitable salinity levels which can negatively influence feeding, the feed conversion ratio (FCR) and the specific growth rate. Significant salinity variations contribute towards stress, which may depress the immune system of the farmed fish, making them more susceptible to infections from parasitic organisms and other diseases.

Dissolved Oxygen

Dissolved oxygen (DO) is one of the most important parameters to consider when choosing a site. Oxygen requirements vary with species, stage of development and size of fish. The level of DO is influenced by temperature, and it directly influences the

FCR. The lower is the DO in the water, the higher the final FCR will be, which will result in higher feed costs.

Debris and Pollutants

Debris can damage the cages (net and structures) and pollutants can negatively affect the farmed fish stock causing mortalities or contaminating the fish.

Risks can be minimized by avoiding highly industrialized areas, although pollutants may also occasionally occur as a result of maritime traffic (e.g. oil spills and tank cleaning). River water may contain debris (plastic bags and bottles) or large floating objects (e.g. timber, driftwood) that may damage the net if brought onto the site by the current.

Suspended Solids and Turbidity

Rivers may bring high levels of suspended solids to the open sea. Turbidity is most likely to be caused by water run-off from land, or from currents or waves lifting silt deposits on the substrate. Farms should be situated in areas with relatively clear water. Sites that are prone to turbid water are not suitable for fish farming. Suspended solids should preferably be less than 5 mg/litre and should not exceed 10 mg/litre.

Algal Blooms

Plankton blooms can be catastrophic for fish farms, leading to large scale losses. When plankton blooms die and bacteria consume the algal mass, consumption of oxygen increases dramatically which can lead to local scale reductions in water oxygen concentration, which can affect fish stocks. When blooming, the microalgal species can cause an irritant to gill tissues, which reduces the capacity of the fish to take up oxygen from the water column. In some cases the blooming algal species may produce toxins and be toxic to fish.

Increasing eutrophication (including cumulative nutrient impact from aquaculture) together with climate change can contribute algal bloom development. Therefore sustainable carrying capacity of the site should be estimated and strict licence cap on production implemented to prevent nutrient levels exceeding the threshold concentrations that are linked with increased risk of algal bloom development.

Disease Organisms

Fish cage farmers can face pressure from native and exotic disease-causing organisms, or pathogens. Infection and disease can invade from multiple sources– water, wild fish or shellfish, newly-introduced farmed fish or shellfish, contaminated equipment, predators, human visitors and can interfere at all stages of production. Potential impacts include production losses from mortality events, loss of market access if certain pathogens are associated with the facility, aquaculture sector or region; and consequent inability to transport product to other farms or locations. These types of events frequently have crippling economic consequences. It is therefore prudent to have a buffer with other farms and implement a biosecurity plan to reduce the risk of introducing disease into the farm.

Water Depth

Water depth should be between 25 to 60m depth (water depth below the cages should be at least two net cage depths). This allows for good water exchange through the cages, allows spreading of particulate matter and still allows inspection of the moorings by divers.

Water Exchange

Particulate organic waste in the form of uneaten feed and faeces are usually the most significant impact to the environment.

This generally settles on the seabed near to the cages, provides a net input of organic carbon and nitrogen to the sediments, which can cause major changes in the benthic community and may exceed the environment's capacity to bioprocess this material. Therefore, floating cages should be located at sites where the water depth is sufficient to maximise water exchange and maintain sufficient depth below the net at low tide.

2.2. Site Selection Parameters and Factors Relevant For the Cages

Water Depth (Bathymetry)

Cage net depth should be no deeper than one-third of the site's depth to permit a wider and better dispersion of cage waste particulate. Diving deeper than 50 m will present a problem for professional divers for the inspection and repair of moorings.

Exposure (Wind and Waves)

The exposure of the site will influence the design and material used for cages, nets and moorings. The exposure is influenced by the distance to land (fetch), sea depth along the fetch, direction from where the wind blows, wind intensity, speed, direction and duration of wind, geometry of the seabed and coastal topography.

Wave Height

Waves account for approximately 20–25 per cent of the total forces affecting the mooring and the equipment.

Five factors influence the formation of wind-generated waves and work together to determine the size of waves;

- wind speed
- fetch distance (open water over which the wind has blown)
- fetch width
- time duration the wind has blown over a given area
- water depth

Table 2. Norwegian site classification based on statistical parameters of waves (NS 9415)

Site classification (wave classes)	Wave height (Hs) (m)	Peak wave period (Tp) (s)	Site exposure level
A	0.0 – 0.5	0.0 – 2.0	Low
B	0.5 – 1.0	1.6 – 3.2	Moderate
C	1.0 – 2.0	2.5 – 5.1	Substantial
D	2.0 – 3.0	4.0 – 6.7	High
E	> 3.0	5.3 – 18.0	Extreme

Significant wave height (Hs),
Peak wave period (Tp) measurements

Current speed

Current speed has a direct influence on the cages as it accounts for 70–75 per cent of total forces on a typical mid-size cage farm (i.e. with a production between 3 000–4 000 tonnes/year); it mainly affects;

- water exchange in the cage
- feed dispersion
- cage net weights and sinkers
- cage movements and fish transfers
- net shape and rearing volumes
- diving operations
- solid effluent dispersal distance.

Wind Speed

Wind accounts for approximately 5–10 per cent of the total forces on a cage mooring system, while the share increases in case of feeding barges. Wind can have a direct impact on cages and their activity by generating pull on the jump net, disturbing vessels moving around the farm and dispersing the feed pellets outside the cages.

Table 3. Norwegian site classification based on statistical parameters of current (NS 9415)

Site classification (current classes)	Current speed (Vc) (m/s)	Site exposure level
A	< 0.3	Low
B	0.3 – 0.5	Moderate
C	0.5 – 1.0	Substantial
D	0.0 1.5	High
E	>1.5	Extreme

mid-current speed (Vc)

Seabed Type and Slope

Seabed characteristics should be surveyed in order to classify the sediment type for anchor embedment. As a good anchor embeds itself deeply into the seabed, it is important to know whether drag embedment anchors ("plough" or "spade" anchors) or dead weight anchors (concrete blocks) are used will depend on the seabed characteristics.

Storms and Typhoons

Storms and typhoons are a risk mainly for the strong winds and for the resultant waves and currents generated in the sea. They mostly occur in the tropical-equatorial zones, mainly on the eastern coast of Asia (China and Japan). The typhoon belt is located above 10° latitude North and below 10 ° latitude South and affects north Philippines and Vietnam and North Australia. This typhoon risk may mean that submersible cage technology will need to be used.

Fouling

Fouling of nets with settlement of organisms. The main problem of fouling on cage nets is to reduce the size of the mesh opening, which reduces the speed with which water passes through the net mesh. Slow current through the net means oxygen is not being replaced as quickly as it is being used, especially during feeding, and oxygen concentration within the cage can reduce quickly and dramatically, creating stress for the fish and if not replaced quickly fish may die.

Fouling can have a physical effect on the caged fish through abrasion when fish come into contact with nets. Abrasion can open wounds that can be subject to secondary infection with bacteria, fungus and other disease vectors. Fouling will also increase the drag of the nets in water currents placing and increasing strain on the mooring system.

2.3. Legal and Environmental Regulation Criteria

Legal/Political Aspects

Although legal frameworks exist for aquaculture in all South-East Asian countries, there are many instances where uninformed, outdated or inappropriate regulatory regimes impede aquaculture development. Inconsistencies in the law can lead to an uncertain legal situation for cage farmers. Regulators are put in the conflicting position of promoting the development of the industry and regulating its effect on other uses of the land and sea.

Operators are sometimes forced to undertake activities while lacking adequate information or a complete understanding of laws and regulations. Conflicts and concerns often may be left unresolved. Legal constraints such as these detract from the stability and certainty that otherwise would facilitate sustainable aquaculture development, slowing or halting the growth of the industry.

- **Licencing.** Most countries have an administrative procedure based on prior approval by the Responsible Government Department for the setting up of aquaculture facilities. Usually, the authorization (in the widest meaning of the word) being granted is a licence to culture in a specific location and may define the size of the operation and species that can be cultured.
- **Environmental permitting.** Each country has some level of environmental concern and may require differing levels of environmental impact study and permit.

2.4. Site Selection Parameters and Factors Relevant For the Environment

Sensitive Habitats

Cage sites should be located away from sensitive habitats such as live corals, seagrass meadows, nursery sites, etc. The farm should be located downstream from these habitats, taking into account the current's prevailing direction. If there are sensitive habitats close by then they should also be individually identified, mapped and regularly monitored during farm operation.

2.5. Carrying Capacity Assessment

Carrying Capacity tries to establish the maximum production that a site, zone or ecosystem can reasonably sustain in the long term. It can be defined under four categories, which are summarized as follows:

- **Physical carrying capacity** determines overall development potential based on physical features of the environment without consideration of limitations and regulations. It is the maximum number of farms that can be physically located within a water body.
- **Production carrying capacity** determines the maximum aquaculture production possible and is typically applied at site level, taking account of the likely feed use, FCR and other management activity to work out what level of production is possible at any given site.
- **Ecological carrying capacity** is the magnitude of production that can be implemented without leading to significant negative changes to the environment and the ecological processes, species, populations, communities and services.
- **Social carrying capacity** is the amount of aquaculture that can be developed without social conflict or impacts.

Conducting carrying capacity studies can be complex, for example to determine individual site and cumulative production from a number of farms in an aquaculture zone, while ensuring that ecological carrying capacity is not surpassed based on (typically) environmental quality standards.

2.6. Site Selection Parameters and Factors Relevant For the Operation of the Farm

Access and Logistics

The distance of the offshore cages from the shore is important as farms located far from shore will require additional time and cost for servicing (delivery of fry, feed and clean nets and collection of harvested fish and nets for cleaning).

The distance between the farm site and needed land facilities directly affects running costs. An excessive distance will cause:

- higher transfer times, and therefore less time for working on the farm;
- higher fuel costs;
- greater risks during fingerling transportation.

Distance can represent a limiting factor if an emergency occurs on the farm, e.g. in the case of accidents or damage to the nets. The time needed to respond should be as short as possible, and distance may be the limiting factor.

Daily Access to the Sea

It is important to select areas that are readily accessible in terms of installing cages and moorings into the sea, and transporting goods, services and transport people to and from the cage site as required.

There are a number of critical management activities that requires this daily access:

- Feeding the fish
- Check nets for holes
- Evaluated stock health and welfare
- Undertake repairs and general maintenance
- Change nets
- Ensure the security of the site and fish
- Emergency access to ensure that repairs can be carried out in the event that damage occurs from wind and wave action, collision, predator attack or malicious damage.

Access to Facilities and Infrastructure on Land

As well as environmental and management issues related to distance from shore, there are other parameters where distance from site is also a consideration, in particular:

- Proximity of harbour/jetty for boat anchorage, staff and equipment loading and unloading
- Proximity to shore base offices and storage facilities for feed, equipment and staff offices
- Access to roads for transport
- Access to processing facilities, where these are not locally integrated
- Electricity and potable water supply services
- Proximity to the market, for local sale
- Proximity to main airport/ports, for exports.

Feed, Fry Supply and Services Close By

The farm should be located close to hatchery and nursery facilities, repair and maintenance workshops for boats, vehicles as well as machinery (boat and vehicle engines, ice machine, processing equipment etc.)

Good Road and Sea Connections

If possible, the farm should be located close to good road, sea and air connections which will reduce time and cost for delivering inputs for the farm and distribution of farm products to the local markets.

International/Tourist Airport

The freight costs can be reduced by being located close to international airports and particularly popular tourist destinations as tourist planes have low freight usage and so may offer cheaper rates.

Coast Guard

It is an advantage for the farm to be located close to coast guard facilities and an agreement made with them to monitor boat traffic close to the cages (especially at night)

Security

Depending on the location, theft and poaching can pose a great threat to fish farms. Security measures should be taken to safeguard the fish and facilities at sea with lights, alarms, dogs, guards, etc. as losses can have severe business repercussions.

Minimizing Conflicts with Other Users

Aquaculture in coastal areas can coexist happily with other users of the marine environment, possible conflicts with people legitimately conducting fishing and sport fishing, transport of goods, bunkering, tourism and diving tourism and others that are visible uses of the marine environment and may be taking place in areas that are also suitable for aquaculture.

The other users of the coastline should be considered in order to minimize the risk of negative interactions occurring in performing cage farming duties. Such issues include:

- **Fisheries communities**. Conflicts with the fishery can arise mainly for space competition. There could be areas traditionally exploited by local fishermen communities that might be suitable for aquaculture, leading to competing usage and need for compromise.
- **Proximity to Touristic areas**. Aquaculture can generate conflicts with tourism both on land and at the sea particularly with tourist hotels.
- **Proximity to other aquaculture activities.** Background bacterial levels can increase around fish cages and water quality can also be affected locally and could cause problems for neighbouring farms that are using the same water resource. A buffer zone should be required also between cage farm licences, and between cage farm licence and inland aquaculture facility outlets.
- **Other Industrial activities**. The discharges and the outlets coming from heavily industrialized areas may lead to a deterioration of water quality.

3. Selection of Cage Technology

Conventional cage technology. Floating High Density Poly Ethylene (HDPE) collars for cages are suitable for semi exposed sites (up to 3m wave height).

Figure 1. Tracks of typhoons during the last 40 years

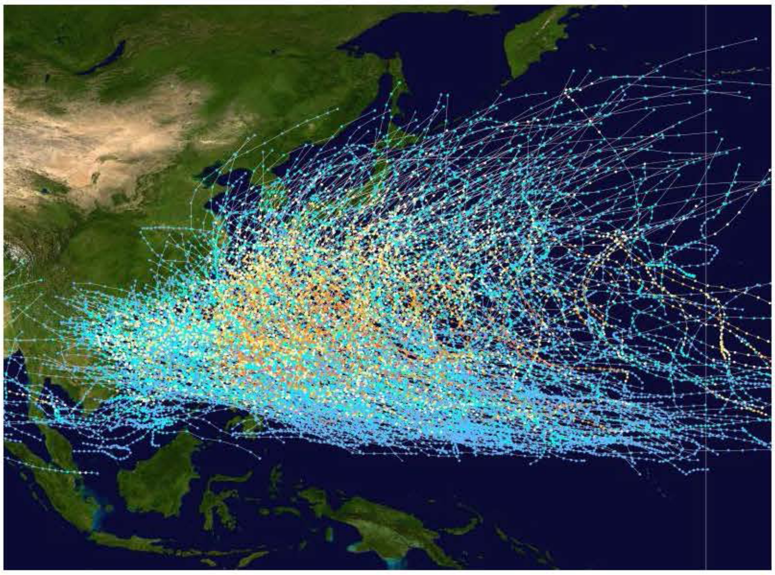


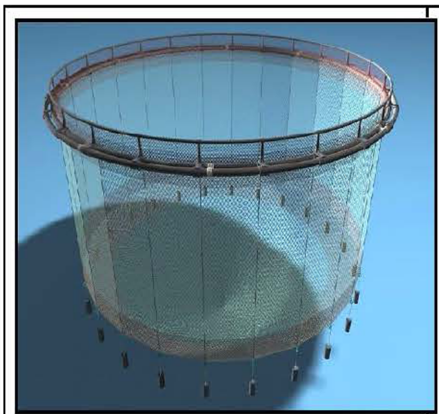
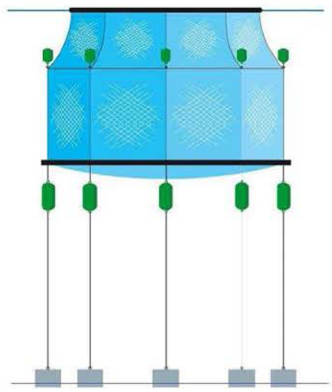
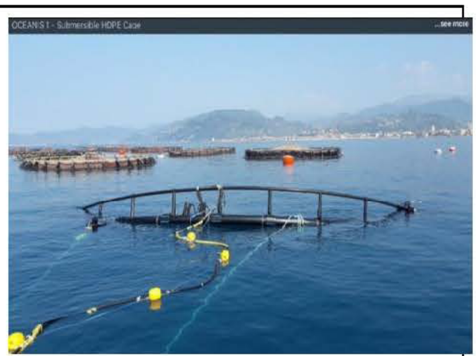
Table 4. Offshore technology in relation to classification of exposure

Class	1	2	3	4
Conventional Description (In relation to site exposure)	Sheltered Inshore Site	Semi-Exposed Inshore Site	Exposed Offshore Site	Open Ocean Offshore Site
Cage Type Used	Surface Gravity	Surface Gravity	Surface Gravity, Anchor Tension	Surface Gravity, Surface Rigid, Anchor Tension, Submerged Gravity, Submerged Rigid

Types of Offshore Cage Technology

For sites that are fully exposed or suffer from occasional typhoons should consider the use of tension leg or frameless cages (which can move freely with the stresses) or sinking cages which can be lowered below the water surface and avoid the strong wave action.

Figure 2. Types of offshore cages

		
Conventional cage technology	Tension leg technology	Sinking cage technology

Floating Cages

High density polyethylene (HDPE) cages are the most popular ones used worldwide. The HDPE pipes can be assembled in various ways in order to produce collars of different sizes and shapes. There are many HDPE cage supplier companies (Floatex, Corelsa, PolarCirkle, Fusion Marine, etc). These cages are often composed of two (sometimes three) rings of HDPE pipe 20-35 cm diameter. The rings are filled with polystyrene. There are a number of stanchions on the pipe to hold the net. The bottom of the net has weights and sometime a sinker tube to maintain the shape.

Advantages: versatility of the materials; net changing simple; frequent visual check of the fish; relatively cost-effective (especially for bigger cages).

Disadvantage: complicated mooring system requiring frequent checking and maintenance. Time is required to submerge the submergible models and constant weather forecast checks are required.

Tension Leg Cages

These cages are made of a net kept in shape by submerged buoys and a submerged rigid frame. The mooring system is composed of six bottom concrete blocks located vertically under each cage. The top of the cage is fitted with a circular HDPE collar to ensure access and feeding. During adverse weather conditions the cage will submerge entirely causing a loss in the rearing volume. The nets are fitted with a zip which allows the removal of the top portion of the cage during fish harvesting and to allow positioning of the net on a larger HDPE floating collar.
Advantage: simple design and automatic response to adverse sea conditions; cost-effective; small bottom area occupied by the mooring system; easy to repair; few components requiring maintenance; very low visual impact.
Disadvantage: closed cage and poor visual check of the fish; small surface for feeding; difficult to change the nets.

Submersible Cages

Submersible cages are also used to avoid storm effects at the water's surface, as well as minimizing conflicts with navigation. These cages have been designed in various shapes, but they all require some type of system for raising or lowering the entire structure within the water column. This may involve the use of ballast/flotation chambers incorporated into the cage structure, or a combination of cables and pulleys attached to anchors and floats. Submersible cages also use the same structure to support both the containment net (on the internal surface) and the predator netting (on the exterior). Harvesting takes place at the water's surface, and some submersible cages can be partially collapsed to allow for crowding of harvestable fish to facilitate their removal.
Advantage: can submerge during adverse sea conditions; net changing simple; frequent visual check of the fish;
Disadvantage: many components requiring maintenance; Higher purchase price.

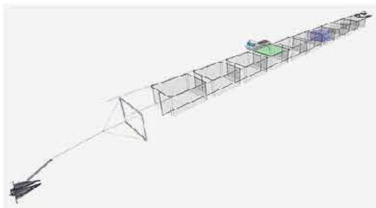
Different Design of Cages

There are many different cage designs that have been developed by the different equipment suppliers in the different countries.

Table 5. Different designs of offshore cages

 Bridgestone cage – flexible surface collar	These types of floating cages are designed for severe offshore conditions. Bridgestone and Dunlop provide cages made by assembling rubber oil hoses with junctions flanged together. Iron stanchions are clamped on the hoses to allow the net to hang. The cages have a square, hexagonal or octagonal shape. Square cages can be assembled in multiple cage modules. **Advantages**: modular nature of the components permits a variety of configuration; extremely resistant; suitable for exposed sites; long durability. **Disadvantage**: limited external walkway; expensive at lower volumes.

 Platform cage – resists waves by strength of structure	These structures are square or hexagonal in shape and hold 7-8 net cages. The platforms are provided with sinking systems that permits buoyancy control. The platform building is divided in two floors (ground floor: packaging area, cold store and ice room; 1st floor: staff lodgings, kitchen/canteen, meeting room). It is moored by a single line which allows the structure to freely rotate over a large water surface to better disperse fish waste. The power is supplied by two generators. **Advantage**: excellent logistic; possibility of feeding with any sea condition; constant visual check of the fish; supposedly a highly durable structure. **Disadvantage**: high initial investment cost; high maintenance costs; net changing difficult; extremely high visual impact.
 FarmOcean cage – semi-submersible, reduced surface exposure	These cages are defined as semi-submergible rigid cages designed with a rigid steel framework. The net is fixed inside the main floating hexagonal frame and its shape is maintained by a sinker tube attached to the bottom. Each cage is moored through three main radial lines. A feed system is usually placed on the top of the floating frame storing feed; energy is supplied by solar panels. A winch on the top of the steel frame lifts the sinker tube together with the bottom of the net to simplify the harvesting process. **Advantages**: suitable for exposed sites; integrated feeding system; stable holding volume. **Disadvantage**: high initial capital costs; complicated access when harvesting; net changing difficult; high maintenance costs; high visual impact.
 Aquapod – geodesic sphere, submersible	The Aquapod is a cage in which farmers can put their fish and then leave it adrift in the sea. The vessel's engines are used occasionally but only to correct the course of the floating fish farm -- so it minimises the amount of diesel that is used. The pods are stocked with fingerlings. The cage is made out of a brass mesh that eliminates biofouling to minimise both drag and the need for cleaning the cages.

 SeaStation cage – central spar and rigging, submersible	System components include anchors, mooring lines, fish pens, sensors, cameras, and feeding systems; producers can select optional operational equipment such as stocking nets and nursery nets, treatment, bathing, harvesting and data collection systems. The SeaStation can enclose a similarly shaped "nursery net" inside the net pen. Once the fry have grown out to the appropriate size, this net is removed. The sea stations stay submerged during most of the grow-out period, the fish are fed under water—which makes it challenging to evenly distribute the feed by using a water-delivered feeding system that includes a disperser inside the cage that distributes the pellets.
 Sadco Shelf cage – rigid frame, submersible	This Russian company produces and distributes two types of steel cages both of which are submersible. A tubular structure holds a completely closed net kept in shape by a sinker tube connected to the main structure through steel cables. On the top of the cage a waterproof integrated feeding system is installed and equipped with an underwater video system remotely controlled. These cages are designed for exposed sites in offshore conditions. Advantage: suitable for all site (also very exposed); resistant and durable; low visual impact; no reduction in the culture volume also in strong current conditions. Disadvantage: difficult to change nets (in the Sadco series); expensive at low volumes; automatic feeder still being properly tested.
 Subflex cages – submersible SPM flexible net cage system	Ocean's Subflex ("submerged flexible") system, developed in Israel has flexible cages that can be submerged underwater when there are strong currents and waves. SUBflex can be submerged, in merely 10 minutes. It has a submersible single-point mooring (SPM) system, with a series of cages lined up in a row. Each cage is individual and its possible to disconnect and separate it as required. 

Cage Design and Material

High Density Polyethylene (HDPE) pipes are widely used as the main material for the construction of offshore floating cages. HDPE pipes are an excellent material for cage construction because they are durable, flexible, shockproof, resistant to ultraviolet (UV) light and require relatively little maintenance, if installed correctly.

The diameter of the pipes will determine the buoyancy of the cage collar. The more exposed the site, the more buoyancy will be needed (e.g. more weight will be needed to maintain the cage volume) and, therefore, the pipe diameter will need to be larger.

The bracket or stanchion is a structural element of the cage collar that binds the pipes together to form the cage collar. There are four main categories of brackets:

- welded plastic
- roto-moulded plastic
- injection moulded plastic
- metal.

The bracket design may include two or three seats for the main floating pipes. On the top of the stanchion, a seat is available where the handrail is placed. The brackets may be equipped with specific attachment points for the net and sinker system, which can be secured with lines or ropes.

3.1. Selection of Mooring and Net Type

Due to competition for space in sheltered sites, ever stricter environmental regulations and the desire for cost reduction, there is a trend towards using bigger, offshore cages.

The consequences of these trends are:

- Production in rougher conditions
- Higher risk due to the increased value of fish
- Fewer possibilities for inspection and maintenance

This requires high reliability of the net cages i.e. the capability to retain fish avoiding therefore the risk of escape.

The reliability of the net cages depends on the following factors:

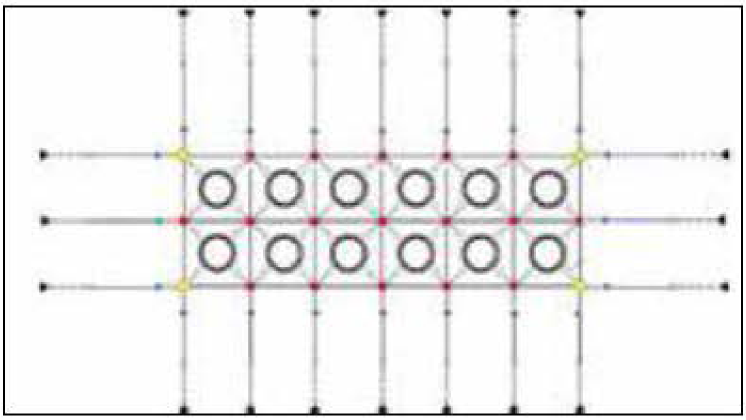
- Mooring design and materials
- Netting design and material including breaking strength
- Cage design and materials

3.2. Mooring Design and Grid System Installation

A complex system of anchors, chains, cables and buoys is usually required to hold offshore cages in place. Depending on the location and the typical weather and sea conditions, these systems may take the form of single attachments or complex webs. Mooring with traditional multi-anchor systems becomes expensive at more than 75 m of depth and this greatly restricts where offshore farms may be located.

The most commonly used mooring system for large High Density Polyethylene (HDPE) circular cages is a square-shaped grid system held on the seabed with an array of mooring lines. It is a dynamic system; all of the components keep the structures moored to the seabed and are designed to dampen the forces generated by the wave motion.

Figure 3. Layout of a mooring grid



The mooring system is divided in two main groups of components, the mooring lines and the grid system: In a grid system, the cages are not moored separately one from the other but are instead aggregated in modules.

The most common modules in offshore sites are composed of 12 or 20 cages, installed in two parallel rows. 6 x 2 or 10 x 2 unit grid systems are preferable in exposed sites with strong currents and waves.

Mooring system design depends on the number of cages that will be moored, as well as the number of mooring lines. The ratio between the number of cages and number of moorings is a useful indication of how securely the cages are moored as well as of the relative cost.

Anchors. Different types of anchors are suited to various types of substrate. Multipurpose plough anchors used for sandy or muddy bottoms. The holding capacity for these anchors ranges from 20 to more than 50 times the weight, when installed in mud-silt or compacted sand. Alternatively concrete blocks can be installed and the weight of concrete must be proportional to the drag forces to which it is subjected. These anchors can range in weight from 1 to 5 tonnes.

3.3. Net Design and Materials

The design of the nets is based on cage design, site characteristics, production plans and the operator experience at that location. Net shape and roping must be designed according to the structure of the main cage components (floating collar, stanchion/brackets, sinkers, sinker tube, etc.) to which the net will be fixed. Nets for circular floating cages generally consist of a vertical wall, mounted on a base net (the cage floor). The vertical wall is further divided into a submerged part (more or less corresponding to the net depth) and a jump net, which is the portion of the wall out of the water, from the waterline to the handrail.

The most common synthetic polymers for nets and ropes are

- **Nylon or polyamide (PA)**. Nylon is the most commonly used fibre in cage aquaculture. Netting for cages, mooring lines and lines used for attaching the net to the collar are mostly made with nylon. Nylon has poor resistance to UV light and will deteriorate, thus all the equipment made with this fibre must be properly stored away from direct sunlight. The longer nylon nets or ropes are exposed to UV light, the greater the decrease in breaking load and overall strength, resulting in a higher risk of structural breakages.
- **Polyester (PES)**. Polyester has very good resistance to UV light, so it is commonly used for nets that have to be exposed to the sunlight, such as bird nets mounted above the cages, and anti-abrasion net panels around the waterline of the cage. Compared with nylon, Polyester (PES) is about 20–25 per cent heavier (to achieve the same breaking load), but PES has the advantage of not absorbing water, whereas nylon can absorb up to 10 per cent of water.
- **Polypropylene (PP)**. Polypropylene netting is not commonly used in cage net manufacturing, but is instead often used for predator nets (commonly for bird protection nets).
- **High-performance polyethylene.** High-performance polyethylene fibre, such as Dyneema™ or Spectra™ has increasingly been used in aquaculture, mainly for net production. The main characteristics of this fibre are the reduced elongation (3.5 per cent at breaking load) and the exceptional breaking load compared with other fibres of the same thickness.

Polyester and polypropylene fibres can be braided together to create netting with the combined characteristics of the two polymers.

Norwegian Standards NS-9415 provides advice on the minimum technical specifications of cage nets according to cage dimensions.

Table 6. Dimension classes of cages (NS-9415)

Net depth from waterline base (m)	Circumference (m)							
	≤ 49	50–69	70–89	90–109	110–129	130–149	150–169	> 170
0–15	I	II	III	IV	V	V	VI	0
15–30	II	II	IV	IV	V	VI	VII	0
30–40	III	III	IV	V	V	VI	VII	0
> 40	0	0	0	0	0	0	0	0

4. Selection of Fish Species

The selection of fish species (and fish strains) is key to the profitability of the business. Asian fish species that;

- are suitable for culture at high density cages
- have sufficient fry supply (availability and batch size)
- have fast growth rate at ambient temperatures
- have low FCR
- have good survival
- adhere to Local Legislation in terms of the use of exotic species

It is important to select species that have strong market demand and price. In addition it is important to know the market product form (live fish, whole fish, fillets, etc.). It is important to have a cost-effective delivery system to get the fish to market (boat, road, air) and to calculate the cost to the market (local, regional and or international markets)

4.1. Potential Aquaculture Species

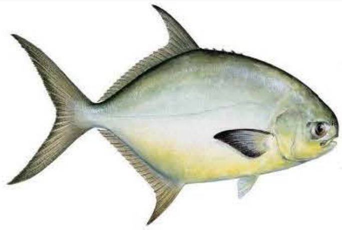
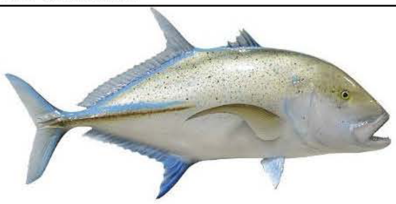
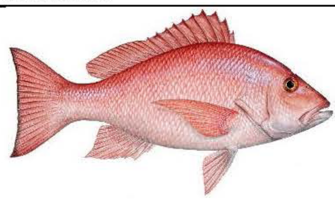
There are a number of potential species that can be cultured. Brackish water and marine farming is dominated by a few commercially produced species. Brackish water species include milkfish, tilapia, and barramundi (Asian seabass). In the case of marine farming which is almost entirely cage farming, the leading species are those that have been farmed are Japanese amberjack, Japanese seabass and more recently the production of emerging marine species such as groupers and pompano.

A wide range of other species are cultured, including pompanos, rabbitfish, threadfins, croakers, drums, gobies, puffers, scorpion fishes and others. Many of these species are grown at least on an occasional basis in marine cages.

Cobia (*Rachycentron canadum*)

Cobia is increasingly being cultured in more subtropical and tropical waters, including in Taiwan Province of China, China, Malaysia and Viet Nam. Production, while still small, has increased significantly over the past three years. Most production currently comes from China and Taiwan Province of China and totalled around 40 000 tonnes in 2015 (FAO, 2017). Production of this fast-growing (to 6 kg in the first year) species is set to expand rapidly, not only in Asia but also in the Americas.

Table 7. Some potential species for culture in offshore cages

		
Asian Seabass	Short fin pompano	Milkfish
		
Giant trevally	Amberjack	Red snapper
		
Cobia	Threadfin	Red drum

Asian seabass (*Lates calcarifer*)

Barramundi production in Asia was estimated by FAO in 2015 at around 57 000 tonnes. The biology of seabass is also very suitable for large-volume farming. It is able to tolerate and grow in a wide range of salinities. It is a relatively hardy species that tolerates crowding and has wide physiological tolerances. The high fecundity of female fish provides plenty of material for hatchery production of fry. Hatchery production of seed is relatively simple. Barramundi feed well on pelleted diets, and juveniles are easy to wean to pellets.

Milkfish (*Chanos chanos*)

Milkfish production in Asia was estimated by FAO in 2015 at around 990 000 tonnes. Philippines is the largest producer with 235,000 tonnes. The majority of the production is from marine fish cages. Fry is still collected from the wild but the majority of fry is now produced in the hatchery.

Groupers (*Epinephalus* spp.)

Grouper production in Asia was estimated by FAO in 2015 at around 150 000 tonnes. The majority of this grouper production still relies on the collection of fry, fingerlings and juvenile fish from the wild. Grouper culture is continuing to expand rapidly in Asia, driven by high prices in the live fish markets of Hong Kong SAR and China, the decreasing availability of wild-caught product due to overfishing.

The main species that are cultured are;

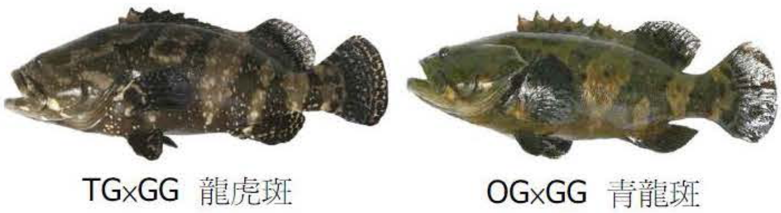
- Mouse grouper *Cromileptes altivelis*
- Tiger grouper *Epinephelus fuscoguttatus*
- Orange spotted grouper *E. coioides,*
- Malabar grouper E. *malabaricus,*
- *Hong Kong grouper E. akaara,*
- Giant grouper *E. lanceolatus,*

- Potato grouper *E. tukula,*
- Areolate grouper *E. areolatus,*
- Greasy grouper *E. tauvina*
- Camouflage grouper *E. polyphekadion*

Main hybrid species

E. fuscoguttatus x E. lanceolatus
E. coioides x E. lanceolatus

Figure 4. Grouper Hybrid crosses



E. coioides x E. fuscoguttatus
Cromileptes altivelis x E. fuscoguttatus

Figure 5. Grouper hybrid crosses

Amberjacks and other Carangids (*Seriola* spp.)

The Japanese amberjack (*Seriola quinqueradiata*) is one of the main marine fish species cultured in Asia, comprising 4.4 per cent of total brackish and marine finfish production, with just under 140 000 tonnes produced in 2015 (FAO, 2017). Nearly all of this production comes from Japan, where production has been relatively stable since the 1980s. Most if not all these fish are cultured in cages.

Other carangids that are becoming popular for culture are snubnose pompano (*Trachinotus blochii*) with 110,000 tonnes production and silver pomfret (*Pampus argenteus*).

Snubnose pompano (*Trachinotus blochii*)

The long fin pompano or snub nosed pompano is the native pompano species in SE Asia and is found occurring naturally from southern Japan, South to Australia. It is the most common available species for farming due to its long/year round spawning. Long fin pompano grows a little slower (1-2 months) than short fin if targeting 500 - 600 g market size. Long fin pompano reach sexual maturity at 1.5 kg (25-30 cm) and reach maximum size of 4 kg. In common with other fish the growth rate slows and FCR becomes higher after sexual maturity. Long fin pompano can be spawned all year.

Kingfish (Seriola dumerili and lalandi)

Kingfish is part of the Carangidae family of jacks and yellowtails and has a circum-global distribution in warm to tropical waters of the Pacific and Indian ocean. Farmed kingfish grow quickly in captivity, reaching 3-4 kg in 18 months and 6 kg in 2.5 years. FCR's vary between 1.2 and 1.8 depending on temperatures and culture systems. Farmed kingfish has primarily sold to the Japanese restaurant market for consumption as sashimi.

5. Optimal Cage and Farm Size

Most nursery cage facilities being used in South-East Asia are small HDPE circular cages with a diameter between 6 and 10 m diameter. Grow-out cages use larger HDPE circular cages with a diameter between 15 to 22 m diameter. The production capacity for the grow-out cages are 30,000 kg for 15m diameter cages and 60,000 kg for 20m diameter cages (culturing milkfish). It is possible to change nets by hand for cages less than 20 m diameter.

The break-even farm size for reef fish production is between 300 - 500 tonnes/yr depending on species. The optimal farm size is calculated to be between 2,500 to 3,000 tonnes/yr.

Figure 6. Different cage sizes

6. Hatchery

There are large variety of hatcheries being used to supply fry and fingerlings for offshore cages.

There are independent hatcheries that do not have grow-out facilities that produce multi-species in tanks (ID). These hatcheries sell fry to farming companies that on-grow the fry to market size. There are hatcheries that are integrated with the cage grow-out facilities.

These hatcheries use intensive hatchery techniques culturing algae, rotifers and hatching Artemia and feeding these to the larvae.

Typically these hatcheries use water that has been pumped from the sea (flow through) and then sterilized using chlorine or other disinfectants and then pumped to the culture tanks.

Other hatcheries use recirculated water systems which have the advantage of using less water and conserving heated water which is used as a strategy to reduce disease breakout. There are pond-based hatcheries that are supplying both integrated cage production as well as selling to other independent cage farmers often on a contract growing basis with the offer to buy back the market sized fish.

Figure 7. Different inputs required for hatchery production of fry

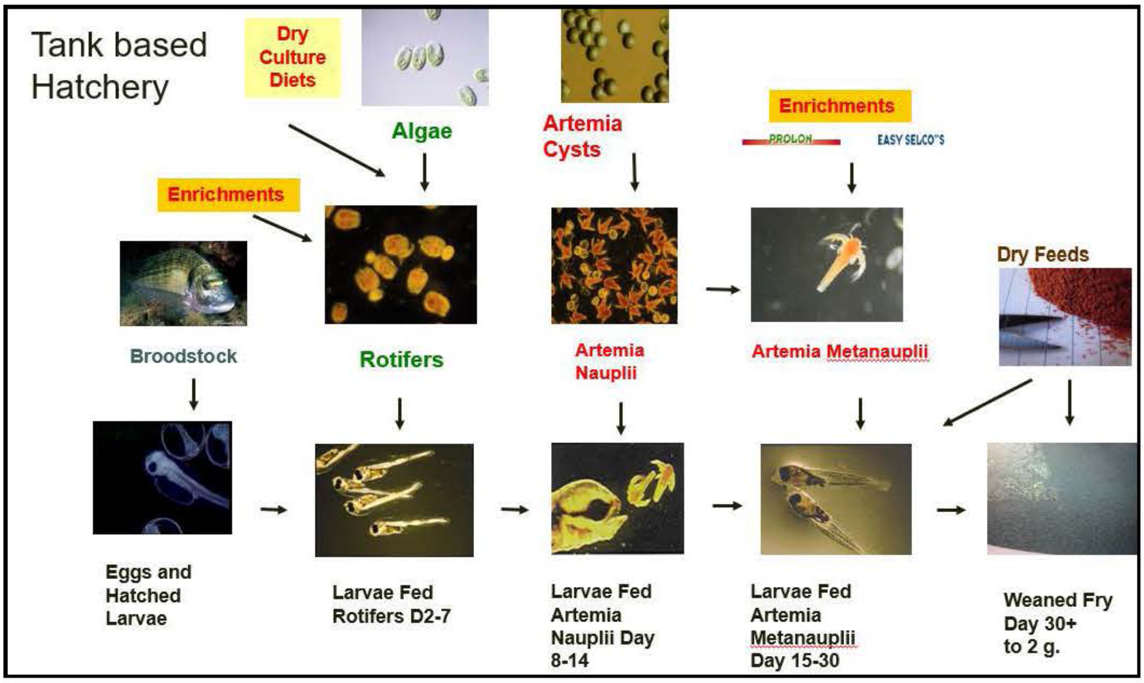


Figure 8. Hatchery production of fry in ponds

In countries where there are limited private hatcheries, the pioneer large scale cage farmers have to rely on fry produced from Government Research facilities.

Some producers have selected particular strains of species such as the Singapore and Australian strain of Asian sea bass. In some cases, they hybridise the strains or hybridise species (tiger grouper *Epinephelus fuscoguttatus* and the giant grouper *Epinephelus lanceolatus*). The larger companies have genetic broodstock management programs to prevent inbreeding. There are genetic selection programs for barramundi in Vietnam, Australia and Singapore and some work has been undertaken in China for Groupers.

A high priority is to maintain good broodstock biosecurity. This is undertaken either by keeping the broodstock in a separate location or maintaining strong biosecurity measures inside the broodstock holding tanks.

The main limitations are that there are a limited number of species produced in the hatchery and that the batch size is relatively small. It is necessary to produce at least 75,000 fry in one batch as this batch will then need to be graded into three batch sizes of 25,000 fingerlings and stocked into cages.

Large cage farming companies should have integrated hatcheries to allow them control over species produced, quality of fry and number of fry. This allows control of production without having to rely on other hatchery producers.

The hatchery can be sized larger than immediate requirements so that excess fry can be sold to other farmers to grow-on under contract. This allows another income stream, reduction in fry production cost, allow the farm to select the best fry and allows for quick expansion of the production in the future.

It is recommended to produce at least three species as this allows flexibility to produce according to market demand and price. If possible the water supply for the hatchery should be from a beach well or borehole so that water is filtered before pumping to the hatchery.

There should be continuous treatment of inlet water with Ozone (O_3 at around -350 mV ORP) followed by treatment by UV and activated carbon filter rather than batch treatment with chlorine/UV, Vircon, etc. This will reduce the need for large water storage tanks and will disinfect water of the majority of bacteria, parasites and some viruses. There should be the ability to heat seawater to 30'C to prevent the symptoms of some diseases. If is recommended that this be undertaken using solar power where possible (plastic sheeting over tanks).

Live feed (algae, rotifers, Artemia) should be enriched with lipids, and vitamins to improve quality of the fry and surface skimmers used to reduce deformity (lack of swim bladder). The hatchery should be designed so that the batch size is between 75,000 to 150,000 to allow grading into three sizes (small, medium and large) before being stocked in nursery tanks or nursery cages.

There should be regular disease testing using Polymerase Chain Reaction (PCR) on broodstock and batches of fry and hatcheries should have a genetic management plan to prevent inbreeding.

7. Nursery Phase

The benefits of undertaking a nursery phase rather than stocking fry directly into cages is to increase survival rate, reduce FCR and reduce time the fish are in cages (reduce risk).

It is recommended to nurse the fry from 2g to 50 to 75g size on shore in tanks or ponds before stocking the fingerlings into cages at sea. This can be undertaken in earthen or plastic lined ponds or in tanks with flow through water or recirculated water systems.

It is recommended to use Raceways or rectangular tanks to allow regular in-tank grading (every 3 – 7 days). Where possible, borehole water should be used to ensure stable water quality (reduce suspended solids, stable water temperature, etc.) however care should be taken as borehole water can be low in oxygen and high in Carbon dioxide and Nitrogen.

It is recommended to use Recirculated Aquaculture System (RAS) to reduce water requirement and allow stronger biosecurity. Batches of fingerlings should be regularly tested for the major diseases.

It is recommended that the production of fingerlings in the nursery is based on an All-in All-out plan as this allows the dry-out of the nursery facilities between batches to reduce the risk of disease.

It is recommended to use of high quality feeds to ensure good growth rate and high survival. Fry should be fed at least 8 times per day (every 2 hours) and fingerlings between 4 and 6 times per day. Fish should be vaccinated twice. Fry should be dip vaccinated at 2g before leaving the hatchery and then fingerlings vaccinated by injection at 50g before being transferred to the nursery cages at sea.

Fingerlings should be regularly sampled for size and health ever 2 weeks and should be graded and counted before transfer to nursery cages.

Nursery Cages (50g to 200g)

It is recommended that the fingerlings are then transferred from the onshore nursery to dedicated small nursery cages at sea. These nursery cages should be HDPE cages and can be square 10m x10 m x 5 m deep or round cages with a diameter of 6 m to 10 m. The nursery cage nets should be changed regularly as fish grow in size.

Fingerlings should be fed at least 4 x/day by hand and the feeding rate should be changed weekly and should be regularly sampled (size and health) at least monthly and they should be graded and counted before being transferred to grow-out cages.

8. Grow-Out Systems

Fish should be grown in round HDPE cages or typhoon proof cages depending on location. Cages with a diameter 15m and net depth of 10m can produce a maximum of 30 tonnes per cycle and cages with a diameter of 20m and net depth of 12 m can produce a maximum of 60 tonnes per cycle (for milkfish, other species may be less).

Divers should inspect nets daily to check nets for any holes and make necessary repairs and collect dead fish. Feeding should be undertaken by feed blower at least 2x/day. Feeding rate should be adjusted weekly or every 10 days. Fish should be sampled regularly for size and health (at least monthly)

Due to the large biomass of fish in one cage, it is recommended to undertake partial harvest using a seine net and to harvest directly into insulated tubs containing ice slurry. When necessary, it is recommended to use polyculture of species to assist with;

- Calming behavior (coral trout and humpbacked grouper)
- Feeding trigger (addition of pompano or milkfish)
- Net cleaning (rabbitfish)

8.1. Grow-Out Facilities and Equipment At Sea

Transport boats are an important part of day-to-day operations, moving fingerlings for stocking, supplies, fuel, equipment, personnel and their provisions and harvested fish. Boats must be properly sized to meet the demands of the operation, but no larger than necessary to efficiently move materials and personnel.

It is recommended to use specialized boats for;

- People (medium size and fast). Special designed boats, made entirely of High Density Polyethylene (HDPE), a virtually indestructible material and maintenance free.
- Security (small and fast)
- **Floating pontoons.** Floating pontoons which can be used for temporary storage of feed, accommodation for night staff, and diving gear storage can also be made of High Density Polyethylene, and therefore maintenance free.
- Work boat with crane (feed, nets, fry, harvest)

8.2. Other Cage Farming Equipment

Bird nets. Cormorants, seagulls and other birds of prey may represent a threat to the farmed fish. These predators can take many fish if the fish are small. Cormorants are a particular problem, as they perch on newly stocked cages for long periods. Moreover, birds can cause damage to fish of marketable size such that the fish can no longer be sold.

The most efficient way to prevent bird predation is to cover the open top of the cage with a bird net. This net should have a large mesh size (e.g. 100 mm) and be mounted with a rope running along the perimeter of the cage. Additional diagonal cross ropes may be added for strength.

Navigational buoys. Navigational Buoys for boundary concession area or marine danger alert, completed of International Association of Lighthouse Authorities certified marine lights.

9. Operational Aspects

Fish feeding systems. The development of efficient equipment and feeding routines and techniques is a priority to enhance technical and financial success, especially because feed accounts for such a large percentage of the operating budget. Efficient feeding can also reduce environmental impacts. When a cage farm is in a relatively exposed site, the safe and reliable operation of feeding systems becomes particularly important.

The most common options for feed distribution are;

- **Hand feeding**. The principal advantage of hand feeding is that farmers can closely monitor the appetite of their fish and, consequently, can adjust the amount of food provided. Hand feeding also increases the farm workers' attention to fish behaviour, which can signal possible disease outbreaks or other problems at an earlier stage. Hand feeding is labour intensive and time-consuming. Therefore, it may be very difficult on large farms, or expensive in terms of labour costs.
- **Feed cannons**. Feed cannons reduce the manual work involved with hand feeding. This can be considered a semi-automatic feeding system; the feed is often delivered by hand into the feed cannon, while the distribution is mechanized. The simplest systems consist of a small feed hopper (100 litres) fitted with an air blower or water pump powered by a diesel, gasoline or hydraulic motor that distributes the feed.

Farms should try to improve their feeding efficiency and optimize feed conversion factors to increase profits and to decrease nutrient and organic matter loses. This can be achieved by using better formulated and quality feeds (higher digestibility, better binders) and improved feeding strategy to reduce overfeeding.

Stock Health Monitoring

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

Good health management practices include:

- Good fish husbandry, which is an all embracing term to mean good water conditions and feed, moderate stocking densities, clean cages, prompt mortality removal, careful handling, etc. It is fundamental good aquaculture practice and there are examples of farms where, if such practices are followed diligently, treatments for fish health problems are rarely needed.

- Biosecurity, which includes obvious things like not bringing diseased juveniles on to a farm, disinfection of equipment that has been used on another farm, and care in harvesting to ensure no spillage of blood. It may also include single year class stocking and area management agreements with neighbouring farms so that all of them stock, harvest and fallow on the same schedule.
- Stocking of large juveniles that are in the peak of condition when they are stocked. Too little is known yet about how to measure and manage the physiological condition of juveniles reared in hatcheries.
- Use of vaccines, which have proved their efficacy against bacterial diseases. Vaccines are also available now for virus diseases.

Grading

Fish cage farmers will need to grad their stock at various stages of the life cycle. Regular grading helps to avoid discrepancies in fish sizes and consequent bullying of smaller fish, which can result in runting, i.e. poor growth induced by stress.

The market will generally pay a higher price for the larger grades. Also, fish at a higher average weight have a lower unit cost of production because the juvenile cost is spread over a greater weight. Thus, selling smaller fish, which are more expensive to produce and fetch a lower price, is doubly disadvantageous to the fish farmer.

Normal grading procedure either involves ‘passive grading’, (sweep nets fitted with slatted panels through which the smaller fish can escape back into the cage), or pumping fish across a grading grid on the deck of a service vessel.

Mortality Removal

Even a relatively low natural mortality rate will result in a number of dead fish which would have to be disposed of in any given week.

Mortality removal on conventional farms is carried out either by scuba divers or by in-cage passive collection systems. The most likely use a combination of these methods, and would rely for the most part on passive collection systems. In these systems, the bottom of the fish cage is sloped towards a pocket that holds a container (mortality sock) into which dead fish gradually tumble as tidal currents ebb and flow. The cages would have one of these passive collectors located in the centre of each one. The containers will need to have a capacity of at least 100 kg.

On a regular basis or as weather allow, farm workboats haul the containers to the surface for emptying. At this stage, divers would also carry out inspection visits to each cage and gather any mortalities that have missed the collection system.

Parasites

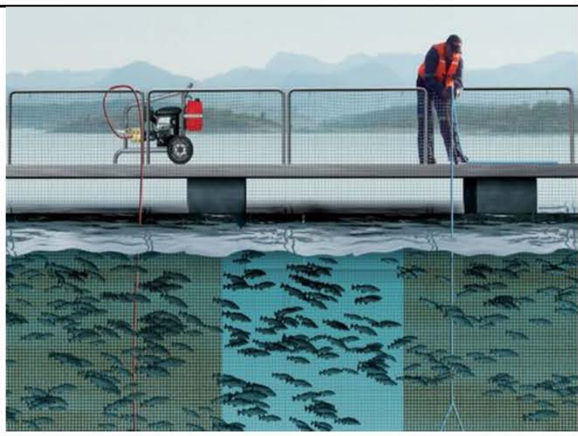
Sea lice, a type of parasite that attaches to fish and feeds on tissue and blood, is one of the most significant diseases in cage farming. Sea lice do not directly cause death in infected fish, instead the deep erosions they create result in loss of tissue for human consumption, chronic stress (which leads to loss of growth), and vulnerability to other pathogens that can cause illness and death.

Antiparasitics used to treat sea lice have been linked to reduced populations of wild aquatic animals, especially crabs, lobsters and other crustaceans that are biologically similar to sea lice. Emamectin benzoate (EB, trade-name SLICE®) is currently the one product for treatment of sea lice infestation. Vaccine development efforts have shown some progress, but no sea lice vaccines are currently available for commercial use. Even with vaccination, other chemotherapeutic agents may be required, which can contribute to pollution and toxicity.

Biofouling

Marine biofouling is another aspect of marine aquaculture that demands attention and controlling which is often labor intensive. It tends to be site specific in relation to intensity and species and varies with season. The farms should have a dedicated team and equipment for the cleaning of nets. The net cleaning equipment can comprise onshore drum net cleaner with associated net drying and net mending space and net store or using an in-cage net cleaner.

Table 8. Different support equipment for offshore cage culture.

	
Drum net cleaner	In-cage net cleaner

Feeding of grow-out cages should be undertaken using a boat or barge with feed blower (air or water) for grow-out cages.

	
Feed blower	Feed delivery boat

It is important that the sea licensed area should be large enough to ensure at least a minimum distance of 200m to the neighboring fish farm so that the farm can manage biosecurity and environmental impact.

Predator Control

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

Since finfish are already contained in cages, entry of predators is a matter of making sure that the cage meshes are strong enough to resist them, and this is not always easy with large predators that can tear holes in nets. For this reason, special predator nets are often used that provide an added layer of protection around the main fish containment net. However, these provide another surface for marine fouling, which reduces water flow and adds to the drag coefficient of farm structures. In some circumstances adding predator netting around the mortality collection section of the net is sufficient.

System Monitoring

There is a need to monitor certain farm functions including:

- mechanical system integrity – condition of moorings, attachments, nets, etc.,
- stock condition, behavior and health,
- feed consumption in the case of finfish,
- stock mortality,
- water quality,
- presence of predators

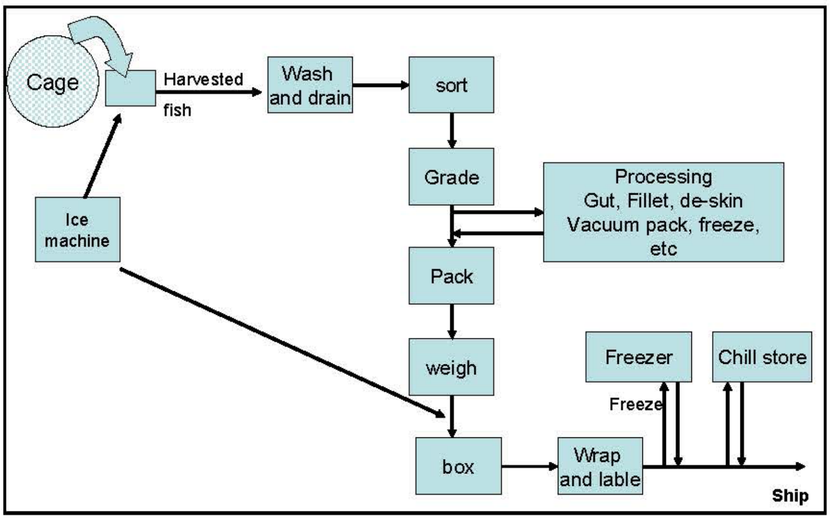
Surveillance

With modern technology, most of these things can be done using probes, robots and cameras that can be controlled and tracked remotely. They all have to be able to run off a battery and be robust enough to work in offshore conditions.

Security of the fish and cages at sea during the night can be problematic, therefore it is recommended to use infrared CCTV with alarm. Infrared security cameras have the capability to capture video in low light and no light (0 Lux) areas. Infrared cameras have IR LEDs positioned around the outer edges of the camera lens.

Packing and Processing

The fish should be drained, sorted for deformities then graded into size. If the fish are to be sold fresh on ice for the local market then the fish will be packed into PE boxes with ice, weighed and labelled. If the fish are to be sold fresh on ice for the export market then the fish should be packed into polystyrene boxes with ice, weighed and labelled. The packing and processing should follow the following flow;



The packing facility should have the capacity to pack and process the average daily harvest in one shift. However, in practice there will be peaks and troughs of production, and possibly the need to supply orders much larger than this on any one particular day. Peaks in production should be managed by having additional shifts.

The packing and processing facility should comprise of at least two production lines containing;

- Sorting area,
- grading table
- packing table
- weighing and labelling table
- Live fish packing area with oxygen supply
- Ice machine (5 t/day capacity for fresh water ice)
- Chill store (+ 4 °C)
- Freezer store (-20 °C)
- Associated labs and offices
- Loading and unloading bays

If processing equipment is required for export of fish, additional equipment will need to be added comprising;

- Filleting or gutting table
- Blast freezer
- Vacuum packer

10. Grow-out Facilities and Equipment on Land

Equipment at the shorebase site usually should include a crane, a generator, diesel storage, bulk feed storage and distribution, a workshop with full complement of tools, diving bottle compressor, fish culture equipment such as nets and graders, harvest tub storage and other miscellaneous gear. Most offshore operations will require an office/administrative facility on shore near the dock being used by the transport boat(s) to facilitate logistics and sales. This site can also serve for warehousing of regularly-used supplies, fuel and back-up equipment.

The shorebase should be close to a proper jetty so that fry, harvesting tubs, nets and feed can be easily loaded into boats to take to the cages and unload dirty nets, harvested fish. The farm should have a dedicated onshore service facility of at least 1 ha comprising

- Net cleaning, net mending area and store
- Feed store capable of storing at least two 40 ft container deliveries (50 tonnes)
- Equipment store and workshop
- Processing and packing facility and flake ice machine

Net washer. Dirty nets from the cages should first be washed in a net washer. The automatic net washer is a rotary washing drum in robust stainless steel and is often supplied with a wastewater tank in hot dip galvanized steel and a steel gate as a protection. Available in 7, 10 and 20 m3 drum volume. The system provides washing cycles of automatic timed rotation of about 20 minutes each. The net will be lifted into the net washer using a crane and jib.

Net maintenance area and store: Clean nets from the net washer should be placed on a frame to dry. Once the net is dried, maintenance and net repairing should be carried out and then the net should be folded and then stored in the store.

Food store: The fish feed should be stored in an insulated building (roof, floor and walls). The store should be large enough to store sufficient feed 1 month.

Maintenance workshop: Maintenance workshop for mechanical, plumbing and electrical repairs, including stores for spare parts and replacement equipment.

Packing and processing building: In the packing and processing room, all the operations related to the grading, weighing, packaging of the harvested fish are located.

The building has to be located away from the other buildings in order to keep away any kind of contaminant during the fish packaging. Most of the building should be thermo-insulated and air-conditioned.

Administration area: The main offices (administration, sales, purchasing, farm management) should be placed in a separate building close to the entrance to the site.

Floating Jetty. The shore base should have a jetty with fixed crane to support the sea operations. The jetty should reach a depth of 4 to 5 meters at the end. The jetty should be constructed at the start of the project to allow the installation of the moorings, nets and cages. The jetty can also be used to hold the seawater intake pipes for the hatchery and nursery.

11. Farm Management

Farm management (supply procurement, inventory, human resources, fish husbandry, financial, marketing, logistics, and scheduling) are all critical to the success of an offshore aquaculture operation. This requires a well-considered management structure, as well as a disciplined corporate culture with regard to information sharing and collaboration. Monitoring, evaluation and reporting are also important aspects of offshore aquaculture management, and requirements for these activities are often incorporated into permits and financing agreements.

It is recommended to use dedicated aquaculture farm management software linked to a comprehensive fish data collection system This allows good analysis of;

- Fish performance and productivity
- Cost of production
- Prediction of feed requirement and harvesting size and date

Table 9. Informal perceptions of key risk areas prior to and post the field review

Risk category	Prior to field visit	Re-based, post visit	Rank
Market - oversupply, price decline	20%	19%	1
Feed - quality, cost, feed-security	15%	15%	2
Disease	10%	14%	3
Environmental problems	10%	13%	4
Scaling up	10%	13%	4
Husbandry (ge FCR, output delivery)	10%	9%	6
Management generally	10%	6%	7
Socio-political risk local & national	10%	6%	7
Other	5%	6%	7
	100%	**100%**	

11.1. Risk and Mitigation of Risk

Biosecurity

The main risk of disease is from bringing new biological material into the farm. This generally occurs when fry are purchased for stocking or broodstock and eggs purchased for the hatchery. Therefore, there should be a strict protocol to have health checks made on all new biological material before they are brought into the farm, these fish should be placed in quarantine for at least 2 weeks and if they are found not to be suffering any disease then they can be allowed into the farm. This is particularly important for the viral diseases.

It recommended that the farm develops and implements a number of management plans including;

- Biosecurity plan to reduce the risk of disease. This need to include;
  - People. Control of visitors to sensitive areas on the farm particularly if they have visited other fish farms recently. There should be biosecurity zones in the shorebase. High level biosecure areas - broodstock, live feed production. Medium level biosecure areas, Fry and fingerling production.
  - Equipment. Farm equipment should washed with detergent, rinsed with clean water and dried regularly and especially if it passes from the cages and the shorebase.
  - Cars and boats. There should be a wheel wash and car spray for all vehicles entering
  - Biological material. Any new biological material entering the farm (eggs, fry, fingerlings, etc.) should be held separately in quarantine facilities for at least 2 weeks to test and treat any diseases before release into the farm.

- Medication and vaccination

  One of the biggest risks in any fish farming venture is the loss of stock due to disease. Hence it is very common practice on larger farms to employ an in-house fish pathologist, who routinely takes samples of fish from the cages to check for the presence of diseases organisms and thereby recommend/carry out any remedial action required in order to avoid a serious disease outbreak. Given that the locators operators will, at least initially, have little previous aquaculture experience, such a service is considered essential. Hence a small fully equipped laboratory will be required, which should be staffed by a trained technician.

During the fry-rearing period, various forms of preventative medication and treatments may have to be administered. These can either take the form of medicated feed fed to the fish, chemicals added to the water or vaccines given to the fish at an early age.

It has been found that fry health is improved by closing each section for one to two weeks between each batch production and cleaning and sterilising all the tanks.

It is proposed to give the fry a full vaccination treatment against the most common diseases (Vibrio and Pasteurella) at a size of 2 grams by dip vaccination and again at 10 grams with a final booster given at 50 gram size by injected vaccination.

- Insurance

It is recommended that during the first two years of operation, insurance be taken out to cover the greatest risks. The cost of the insurance depends on the scale of risk, the value at risk and the excess (the amount of loss that is absorbed by the farmer). Insurance companies will not insure fish until they have been weaned on to dry feed.

Most aquaculture insurances can be assigned to one of two types of coverage, which are called “All Risks” or “Named Perils”.

- The title ”All Risks” is somewhat misleading, given the fact that no insurance company in the world covers all conceivable risks. Both formulations merely describe different concepts from which the insurance products are derived. “All Risks” is based on the hypothesis that all risks are initially covered, after which individual hazards are then gradually excluded. The premium is reduced with each excluded hazard.

- In the "Named Perils" approach, the reverse is true, because nothing is covered at the start and then, step by step, a concept for certain risks which the insurance company agrees to bear is developed. Depending on the type and scope of a policy, "All Risks" insurances are on average 10 to 15 per cent more expensive than "Named Perils".

The typical premium for aquaculture insurance is 3.9% of average fish value in the water with an excess of 15%.

Insurance can cover

- Offshore and onshore farms, grow-out operations and hatcheries
- Pollution
- Theft of stock
- Predation
- Storm, lightning, tidal wave, collision
- Structural failure of equipment
- Deoxygenation of water
- Other changes in water including salinity
- Disease
- Fire, lightning, explosion, earthquake
- Mechanical breakdown or electrical breakdown at onshore farms
- Aquaculture equipment
- Boats, moorings, cages and feed barges

Typical insurance taken out by farms are

- Malicious damage
- Equipment failure
- Business interruption

The cost for insuring against disease outbreak or low production are normally too expensive.

- Security
  One of the dangers of farming in remote areas is the risk of theft. Therefore, strong security is recommended, especially at nights and weekends from security lookout posts.

  There should be a security guard at each cage cluster equipped with a search light and small generator. The shore base should also be fenced around its perimeter.

Other

- Environmental management plan. There should be regular monitoring of water quality (close to the cages and hatcher/nursery effluents) and sediment quality under and close to cages.
- Emergency power generator.

11.2. Better Management Practices (BMP)

BMPs are a practical and economically feasible way to reduce adverse environmental impacts of aquaculture at the farm level and also at larger scale, and so reduce conflicts with fisheries. Implementing BMPs requires action from both the Government (in the form of better policy, regulation, enforcement, and planning and management procedures) and industry (through BMPs). However, BMPs must consider the monitoring and adaptive management of the added impacts of many farms, and therefore the need to consider the aquaculture zone and/or watershed scale. BMPs can involve, for example, more efficient ways to reduce feed losses and to improve FCRs, therefore reducing the nutrient release to waterbodies. They can also involve practices that minimize the risks of escapees from farms, the spread of diseases and so on. BMPs are generally developed as the first step towards the certification of individual farms and clusters of farms.

11.3. Fish Farm Certification

In order to enter certain markets or sell to certain buyers, it may be necessary for the farm to certified. The application of certification in aquaculture is now viewed as a potential market-based tool for minimizing potential negative impacts and increasing societal and consumer benefits and confidence in the process of aquaculture production and marketing.

Fish farm certification considers a range of issues relevant including:

a) animal health and welfare
b) food safety
c) environmental integrity
d) socio-economic aspects associated with aquaculture

The main certification schemes for fish cage farms are

- The Aquaculture Stewardship Council sets individual standards for best environmental and social aquaculture performance for 12 specific species
- The Global Aquaculture Alliance uses the Best Aquaculture Practice standards and covers issues related to food safety as well as environmental and social sustainability
- The Global Partnership for Good Agricultural Practices (GlobalGAP) covers issues related to food safety as well as environmental and social sustainability. The initiative is a member-based initiative open to producers, suppliers, retailers and the food service industry.

11.4. Product Traceability for Exported Product

In order to enter certain markets or sell to certain buyers, it may be necessary to implement strict product traceability. Traceability is defined by the Codex Alimentarius Commission as "the ability to follow the movement of a food product through specified stage(s) of production, processing and distribution". Traceability therefore facilitates knowledge regarding the identity, history and source of a product. Traceability can allow operators to guarantee the safe origin of their product, and to take appropriate actions (such as withdrawal or recall), if food is found not to be safe.

In the case in the EU, the general principles and requirements of food law that requires all food business operators, feed producers and primary producers of animals to have in place a "one-up and one-down" traceability system.

The Code of Federal Regulations requires importers to the U.S. to maintain records that identify the immediate sources of their foods. They must maintain these records for at least two years and make them available to the US Food and Drug Administration within four hours, if requested.

11.5. Farm Staff Health and Safety

There are a number of risks for aquaculture workers, including electrical shock, drowning, slips, trips, falls, sprains and strains, accidents with machines, exposure to chemicals, night work and exposure to fish medication. Divers are particularly exposed to decompression illness and other diving risks, falls from boats and cages. A farm should undertake systematic hazard identification, education, training and prevention and robust tracking and reporting of injuries and illnesses.

Trained Personnel

All forms of aquaculture require specialized skills and additional skills are required offshore for navigation and safe working practices. The production crew would comprise management, fish health experts, maintenance craftsmen, commercial divers and professional seafarers. Given the combination of a difficult work environment and complex technologies, all of these staff will have to be highly trained specialists.

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

Social Responsibility

The farm should have some social responsibility programmes including;

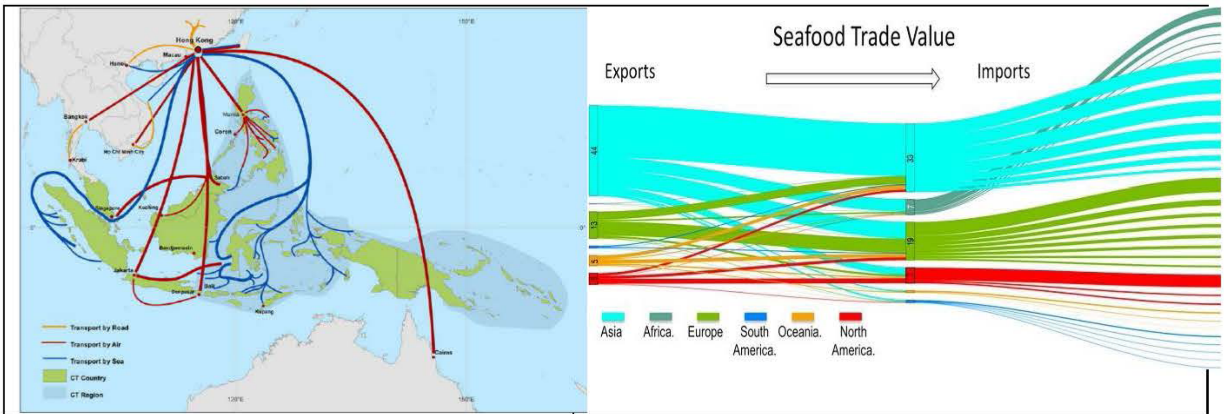
- Staff training scheme. Staff should undergo regular technical training as well as for safety at sea, first aid, hygiene and biosecurity.
- Incentive scheme for workers. It is recommended to have a staff incentive scheme based on fish productivity (survival, FCR, etc.)
- Close cooperation with local community. There should be proactive cooperation with the local community and neighbours in order to maintain good relations.

12.Seafood Marketing

Most seafood trade is Asia to Asia but also to Europe, Africa and N. America. China is now a net importer of seafood and the market is expected to grow rapidly. It is recommended that production is market led with a clear target market in terms of season, fish market size, product form (live, fresh or frozen), product processing (whole, gutted, filleted, etc.), packaging (boxed, vacuum packed, etc.) and if possible a market agreement in place at the start of production.

Live fish was transported mainly by boat but recently, Indonesia has restricted transport of live fish to only Indonesian owned vessels. The majority of live fish is now shipped by air. Therefore it is advantageous if the farm located close to international airport with high level of tourist flights and destinations Bali, Singapore, Phu Quoc, Penang).

Figure 9. Seafood distribution and trade



Live fish transport routes to Hong Kong	Sea food trade

It is recommended that production should be market led and if possible have a seafood processor or fish trader as business partner. If possible, production should be aimed at supplying China and Taiwan with product they cannot compete with (e.g. winter sales of pompano).

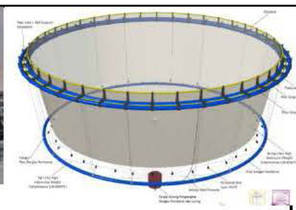
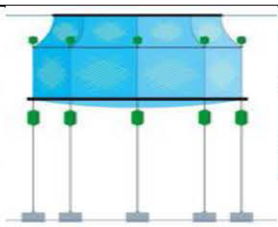
New opportunities are opening for the use of internet trading of seafood products for example Alibaba e-market for seafood.

Aquaculture Certification

There are a number of certification schemes such as the Aquaculture Stewardship Council and Global Aquaculture Alliance that aim to promote environmental sustainability and social responsibility using market mechanisms at the farm scale. In this way, the environmentally certified farms credibly demonstrate that their production practices are non- polluting, non-disease transmitting, and/or non-ecologically threatening. Certification primarily is aimed at farmers who are exporting their products rather than supplying local markets. Therefore, there is a need to create local and national incentives for certification and labelling; for example, this is followed in China, to make local consumers more aware so they can choose environmentally friendly products.

13. Cage Farm Investment Costs

Offshore aquaculture requires very high initial investments. But the very nature of offshore aquaculture production suggests the potential for economies of scale as well. Securing high quality inputs, such as feed and fingerlings, is crucial to the success of any aquaculture enterprise, but the need to program growth cycles, harvests and net maintenance make the timing of fingerling and feed purchases a critical aspect of management in offshore aquaculture. As a result, vertically integrated companies dedicated to offshore aquaculture have emerged in various regions including Norway, Scotland, the Mediterranean, Chile and Australia and New Zealand. These corporations control crucial inputs to allow for smoother operations on the cages themselves, and to respond more quickly to market demands. A brief analysis was made of capital cost requirement of different types of cage technology

			
HDPE cages from Europe	HDPE cages from Indonesia	Tension leg cages from Europe	Sinking cages from Indonesia

The costs were as follows;

Key equipment for 2,000 tonnes	**Europe US$**	**SE Asia US$**	**Europe US$**	**SE Asia US$**
Diameter 22m cage collars and sinker ring	548,000	960,000	2,055,000	2,400,000
Cage nets	274,000			
Moorings	335,000	335,000		335,000
Bird nets and floats	17,000	17,000		
Navigation lights	15,000	15,000	30,000	30,000
Supervision of installation	60,000	20,000	28,000	10,000
Harvesting cage			19,000	
Freight	80,000	25,000	35,000	15,000
Total	1,329,000	1,372,000	2,167,000	2,790,000
% higher cost	Base cost	3%	63%	110%

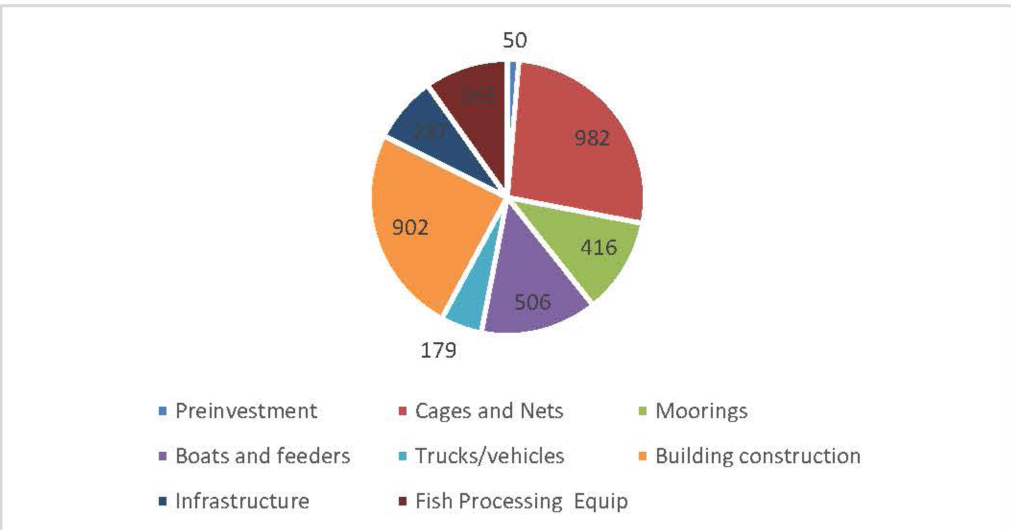
A comparison of capital cost requirements were made for a fully integrated fish farm with hatchery, nursery, grow-out, processing and packing. The capital costs for the different production technology is given in the table below.

Total Capital Cost (US$)	2,500t Floating	2,500t Floating	2,500t TLT	2,500t Sinking
Cages, net and moorings	1,400,000	1,400,000	2200000	2,800,000
Equipment at sea	800,000	800,000	800,000	800,000
Shore base facilities	2,340,000	2,340,000	2,340,000	2,340,000
Shore base equipment	2,340,000	2,340,000	2,340,000	2,340,000
Hatchery	1,050,000	1,050,000	1,050,000	1,050,000
Work boats	1,235,000	1,235,000	1,235,000	1,235,000
Trucks and vehicles	455,000	455,000	455,000	455,000
Contingency (5%)	481,000	481,000	521,000	551,000
Total capital costs	10,101,000	10,101,000	10,941,000	11,571,000

Generic Capital Costs

The generic capital costs for an offshore cage farm with a size of between 2,000 and 3,5000 tonnes per year using conventional floating cages is around US$ 3,700 per tonne of production. A breakdown of the costs is given below.

Capital Cost	US$ per tonne of production
Pre-investment	50
Cages and Nets	982
Moorings	416
Boats and feeders	506
Trucks/vehicles	179
Building construction	902
Infrastructure	287
Fish Processing Equip	363
Total	3,684

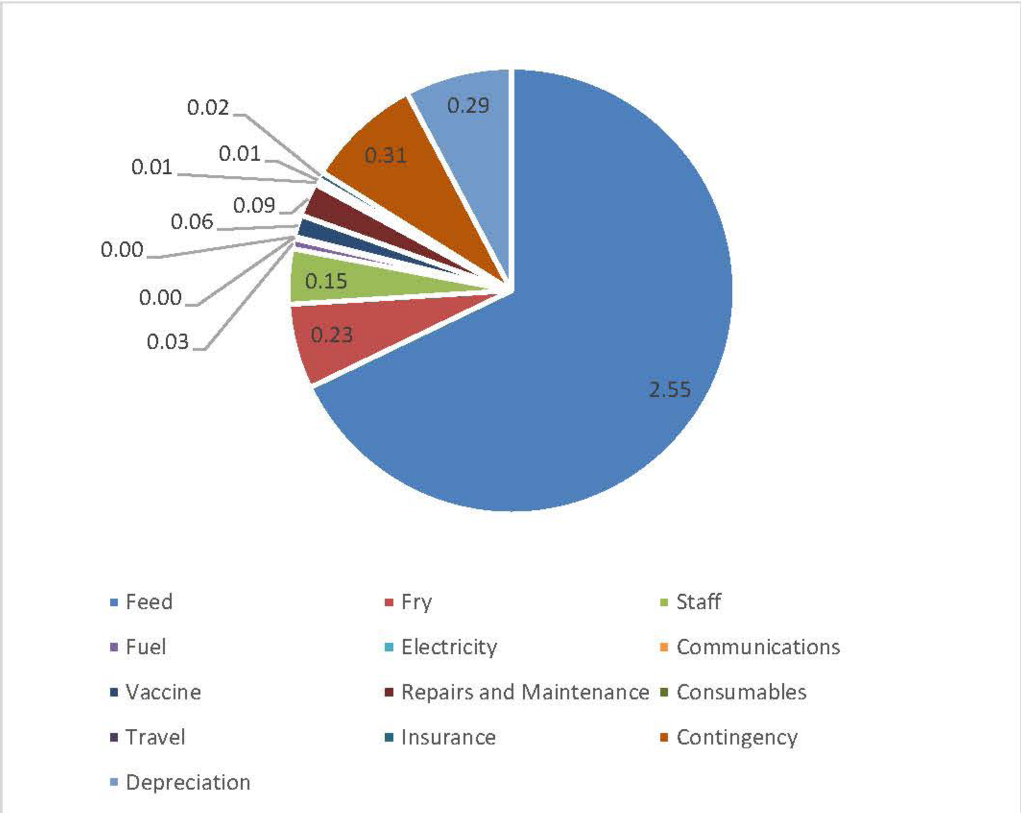


In addition to the capital costs, there is requirement for working capital which is the expenditure on production costs before harvest and sale of the production and can be quite considerable additional investment.

Generic Operational Costs

The generic operational costs for an offshore cage farm growing high value fish species per year using conventional floating cages is around US$ 3.75 per kg of production. A breakdown of the costs is given below.

Feed	2.55
Fry	0.23
Staff	0.15
Fuel	0.03
Electricity	0.00
Communications	0.00
Vaccine	0.06
Repairs and Maintenance	0.09
Consumables	0.01
Travel	0.01
Insurance	0.02
Contingency	0.31
Depreciation	0.29
Production cost	3.75



14. Environmental Impact

There are a number of environmental impact risks are widely recognized as important. These risks include;

- genetic consequences of escaped fish,
- disease and pathogen amplification and retransmission,
- consequences of nutrient input,
- interactions with wild animals.

Genetic Consequences of Escaped Fish on Wild Fish

The farming of non-native species poses a greater environmental risk than farming of native species. However native species can be subjected to genetic selection programs or unintended selective pressures in hatcheries, and thus even aquaculture-reared native fish may pose some level of genetic risk to wild fish, should they escape.

Nutrient Output to the Environment

The effects of nutrient inputs from aquaculture on marine ecosystems are probably the best understood of the environmental concerns, at least at small scales. Existing models of nutrient dispersion (for example, Depomod/Tropomod) are scientifically robust and readily available. In addition, data from other farming systems (for example, salmon farming) are also readily available. What is unclear is the fate of nitrogen and phosphorus in different systems and under different oceanographic and hydrographic conditions. In short, we have a poor understanding of when nutrient inputs can be viewed as food ("good") and when they should be viewed as waste ("bad"). It is difficult to satisfactorily address these concerns in advance of aquaculture development; therefore, scaled and cumulative impacts of nutrient inputs will need to be closely monitored during development.

The impacts of uneaten fish feed and fish waste on the local environment and ecosystem can be separated into near-field impacts on sediments and the water column, and far-field impacts on the ecosystem. There is a gradient of impacts with greater nutrients and waste proximate to the farm and diluted further from the farm. The distance waste travels varies based on fish stocking density, feeding rates and siting issues such as water depth and water velocity or currents. The impacts of marine cage culture on water quality and primary production of local biota are from nutrient enrichment in the water column up to 100 meters of the farms (near-field effects) but not at greater distances. These nutrients were consumed by local biota.

Far-field ecological effects can occur in intensively farmed area over time with impacts being variable and depend on farm siting, density of farms and the strength of local regulations. Far-field effects of the release of nitrogen and phosphorus with associated chlorophyll-a concentrations steadily increasing. In ongoing monitoring of production areas is needed to ensure that near-field and far-field impacts are not damaging ecosystems and aquatic organisms.

Interactions with Wild Animals

Fish cages will act as fish-aggregating devices and will attract predators and cage farming may put these animals at risk if not proactively addressed (for example, collision, entanglement and predation effects).

14.1. Regular Monitoring Surveys

Monitoring is often designed at the end of the Environmental Impact Assessment (EIA) and is part of the EIA statement. The monitoring protocol proposes what type of indicators should be used to monitor the impact of the farm at various points in time.

It usually focuses on environmental parameters.

Environmental Monitoring Programme and Surveys

The environmental monitoring results support decision makers as well as the producer himself with an estimation of the size of the impacts (extent and severity) and ways to improve management and regulate the activity. The input of phosphate and nitrate to the environment and the environmental impact of a farm will depend on three factors, namely:

- The frequency, direction and strength of water currents in the area, indicating the rate at which the water mass is renewed around the installation. A 1000-tonne fish farm can have less impact than a 100-tonne fish farm if placed in a position where currents and depth provide better dispersion in the environment.
- The phase of the production cycle. In summer, Mediterranean species develop their greatest need for feed during the year; hence the spillage at this time will be greater than in January.
- The management practices. Good feeding and disease prophylaxis procedures have low impacts on the environment.

In monitoring the environmental effects of aquaculture, as in all studies on environmental change, data are collected at various points in time and are compared with original, pre-development data as well as with contemporary reference data. This will show changes over time due to the impacts, and natural environmental change will also be taken into consideration. Survey techniques vary but generally require the following (adapted from Telfer and Beveridge, 2001):

- **A baseline definition**: based on data collected before development. Baseline monitoring refers to the measurement of environmental parameters during a pre-project period for the purpose of determining the nature and ranges of natural variation and to establish, where appropriate, the nature of change. This provides essential background ecosystem data for subsequent comparison. The survey may be both spatial and temporal, providing pre-development data on the natural environment and its changes throughout the proposed development area. Such data can aid in the design of an appropriate monitoring study, focusing, for example, on the areas which are most relevant for investigating change in a particular environment. The survey will also answer important management questions for the developer: in this case, will the site support aquaculture?
- **A monitoring survey**: the collection of post-development data provides information on the actual impacts, in relation to the contemporary reference and baseline data. Once interpreted, the results may be used directly for management decisions by both fish farmers and environmental regulators by ensuring adherence to Environmental Quality Standards (EQSs) and acceptable zones of effect. Care should be taken in designing the monitoring study so that data are generated to answer the questions posed by all users of the data.
- **Compliance monitoring** takes the form of periodic sampling and/or continuous measurement of environmental parameters, levels of waste discharge or process emissions to ensure that specific regulatory requirements are observed and standards met;

In general, the protocol for monitoring is based on previous knowledge of the existing zone and will take into consideration:

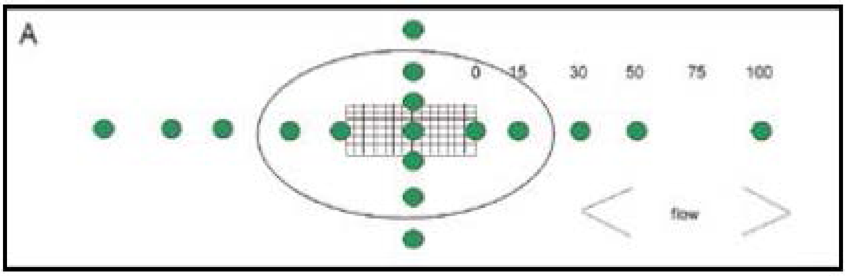
- Frequency of sampling,
- Position of sampling stations,
- Method of sampling water or sediments,

- Method of analysis of the samples taken to measure the determinants.

Sampling strategies usually attempt to maximize data collection per expended effort, which normally entails the use of transects aligned with the direction of principal current flow rather than a less efficient but more statistically rigorous random sample or grid approach.

Transects and specific station protocols are particularly good at allowing detailed investigation of gradients from a discharge point, as illustrated in Figure 10.

Figure 10. Potential locations for sampling station to detect gradients from a marine fish cage. (from Telfer and Beveridge, 2001)



The various parameters monitored are similar to those measured during the EIA. They usually consist of the following:

A. Visual Observations

Based on special in situ transect sections and/or video transect analysis, these observations describe the following:

- Real distance of sedimentation impacts (from faeces, remnants of feed pellets or trash fish);
- Superficial state of the sediment due to organic concentration below or around the cages;
- Signs of ecosystem changes below or around the farm due to the presence or absence of *Beggiatoa* bacteria on anoxic sediments, the number and type of wild species below and around the cages (e.g. fishes, octopus, pelagic/benthic fishes and detrital invertebrates), or a reduction of macroscopic life;

Status of corals and seagrass beds (in terms of quality and extent).

B. Water Column Measurements

Maintenance of water quality is critical to the health of the cultured stock so important culture parameters such as water temperature, salinity, pH and dissolved oxygen, levels inside sea cages will be monitored regularly, usually on a daily basis. Parameters such as total dissolved solids and concentrations of nitrogen and phosphorus will be monitored as required by the monitoring program.

Measurements are taken of temperature, salinity, dissolved oxygen, optical properties (turbidity, suspended solids, Secchi disk transparency), nutrients (phosphorus, ammonium and nitrogen) and chlorophyll-a. Various studies show that the follow-up of dissolved oxygen and other elements in the water is not very useful since no measurable change is identifiable beyond 50m from the cage and the high dispersion capacity of the water does not reflect the impact of the farm on the Mediterranean.

C. Sediment and Bottom Community Measurements

Particulate wastes tend to settle to the sediments creating a 'footprint' effect usually distributed in the direction of the main current flow (Beveridge, 1996). The benthic environment beneath and surrounding the sea cages or close to the effluent outflow point should be monitored biologically (e.g. macrofauna abundance and species diversity), chemically (i.e. the composition of elements in sediment) and physically (e.g. the particle size of sediment and video footage/photo comparisons).

Distribution of the soft substrate in the area should be measured, with data on granulometry, redox potential, organic and mineral content, free sulphides and *Beggiatoa* percentage, and the presence or absence of pellets and food. Where appropriate, pollutants may be studied, based on the EIA results. In addition, seagrass quality and density should be described, based on specific transect protocols.

Benthic communities are usually described using bioindicators as key elements in the analysis of the bottom reactivity of the farm since they are the species or groups of species that provide evidence for a specific environmental factor. Besides identification, data on species richness, abundance, biomass and diversity (using the Shannon index) should also be produced.

Measurements of sediment and bottom community species are highly relevant since they incorporate all the elements from the production farm, such as impact on photosynthesis, transformation in the sediment or trends towards anoxia. Because of this, it is also the topic that has been most studied up to now (FAO/GFCM, 2004).

Control Sites

The water quality and benthic quality at the farm should be compared to unimpacted sites (control sites). The control sites will be located approximately 500 metres from the farm boundary.

D. Cumulative Effects Measurements

In some cases, albeit rarely up to now due to the complexity and cost of the task and the lack of experience, cumulative effects studies are requested. The first trial studies are often carried out by regional or central Government agencies to analyse possible synergies or cumulative effects such as the maximum stocking rate, based on simulations using data from the EIA.
e. Interference with other users.

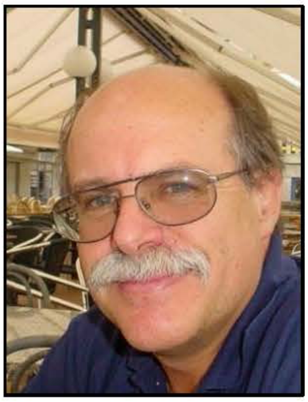
A small section concerns monitoring of conflicts and relations with other users. In general this section is not very complete or well researched by the monitoring consultancy or researchers.

Reporting

Environmental reporting requirements depend on the National regulations but are likely to include the following:
The ongoing Environmental Monitoring Report shall contain:

- Farm name and location
- aquaculture licence number
- name of person / organisation conducting environmental assessment;
- Environmental monitoring sample collection methods, sample analysis methods and results;
- data summarised in tables and graphs
- an interpretation of the data providing an integrated understanding of the results plus any unusual results highlighted
- recommendations in regard to compliance with management triggers
- a copy of the raw data attached as appendices and provided electronically in spreadsheets a map of the farm site with all sample points, reference points and survey transects, including their coordinates

About the Author



Patrick White is a specialist in fish hatchery and fish production, responsible planning and sustainable management of aquaculture, Climate Change impacts on aquaculture and the impact of aquaculture on the environment. He has over 42 years of experience in the aquaculture sector and has worked in Africa, the Mediterranean, the Middle East, and most often in Asia and the Pacific Region in countries such as the Philippines, Thailand, Vietnam and Indonesia. He has worked in aquaculture research, in the commercial fish farming sector as well as an aquaculture consultant. For the last 15 years he has specialised in:

- Production optimisation (improved feeding strategy, development of BMPs, etc).
- Environmental management of aquaculture (carrying capacity estimation, environmental impact – water quality and sediments, etc).
- Site selection and zoning.

He has undertaken many projects for the FAO and World Bank, led EU research projects, undertaken development projects funded by NORAD and DANIDA. He was a major contributor to the development of the FAO Ecosystem Approach to Aquaculture Development and FAO/WB Zoning Siting and Area Management strategies.

He has worked with USSEC on responsible planning and management of shared water bodies and the promotion of large scale offshore cage culture. He has helped arrange cage culture industry tours for groups of South East Asian stakeholders in Turkey, Norway, Malta and Greece.

Soy In Aquaculture Program

This technical paper was created through the USSEC Soy In Aquaculture (SIA) program and the USSEC Southeast Asian Regional Program. USSEC works with target audiences in Southeast Asia and globally to show the utility and benefits of using United States soybean products in aquaculture diets.

The SIA program replaces the Managed Aquaculture Marketing and Research Program (the AquaSoy Initiative, funded and supported by the United Soybean Board and American Soybean Association) which was designed to remove the barrier to soybean meal use in diets fed to aquaculture species.

The objective of the SIA is to optimize soy product use in aquaculture diets and to create a preference for U.S. soy products in particular, including but not limited to U.S. soybean meal, soybean oil, soybean lecithin, and "advanced soy proteins" such as fermented soy and soybean protein concentrate.

This paper follows the tradition of USSEC to provide useful technical materials to target audiences in the aquaculture industry.

For more information on soybean use in aquaculture and to view additional technical papers, please visit the Soy-In-Aquaculture website at www.soyaqua.org.

U.S. Soybean Export Council Headquarters

16305 Swingley Ridge Road, Suite 200
Chesterfield, MO 63017, USA
TEL: +1 636 449 6400
FAX: +1 636 449 1292
www.ussec.org

USSEC INTERNATIONAL OFFICES

USSEC AMERICAS
Carlos Salinas
REGIONAL DIRECTOR – AMERICAS (AM)
U.S. Soybean Export Council
16305 Swingley Ridge Road, Suite 200
Chesterfield, MO 63017-USA
CSalinas@ussec.org
TEL: +52 331 057 9900

USSEC GREATER CHINA
Xiaoping Zhang
REGIONAL DIRECTOR - GREATER CHINA
U.S. Soybean Export Council
Suite 1016
China World Office #1
China World Trade Center
No. 1 Jianguomenwai Avenue
Beijing 100004
People's Republic of China
XPZhang@ussec.org
TEL: +86 106 505 1830
FAX: +86 106 505 2201

USSEC NORTH ASIA
Rosalind Leeck
SENIOR DIRECTOR - MARKET ACCESS AND REGIONAL DIRECTOR - NORTH ASIA
16305 Swingley Ridge Road, Suite 200
Chesterfield, MO 63017
RLeeck@ussec.org
TEL: +1 314 304 7014
FAX: +1 636 449 1292

USSEC SOUTH ASIA
Kevin Roepke
REGIONAL DIRECTOR - SOUTH ASIA
16305 Swingley Ridge Road, Suite 200
Chesterfield, MO 63017-USA
KRoepke@ussec.org
TEL: +1 314 703 1805

USSEC GREATER EUROPE, MIDDLE EAST/NORTH AFRICA
Brent Babb
REGIONAL DIRECTOR - GREATER EUROPE AND MIDDLE EAST/NORTH AFRICA (MENA)
16305 Swingley Ridge Road, Suite 200
Chesterfield, MO 63017
BBabb@ussec.org
TEL: +1 636 449 6020
FAX: +1 636 449 1292

USSEC SOUTHEAST ASIA AND OCEANIA
Timothy Loh
REGIONAL DIRECTOR - SOUTHEAST ASIA
U.S. Soybean Export Council
541 Orchard Road
#11-03 Liat Towers
Republic of Singapore 238881
TLoh@ussec.org
TEL: +65 6737 6233
FAX: +65 737 5849