Lesson 1

PRODUCTIONS SYSTEMS

Aim: Explain general mariculture production systems

WHAT IS MARICULTURE?

This subject guide deals with the general selection and management of salt water species. The term "Mariculture" refers to a sub-category of Aquaculture that deals specifically with Marine Aquaculture.

According to the FAO the term "Mariculture" (in its present usage) may be defined as:

"The culture of marine organisms, both plants and animals, in an aquatic medium or environment which may be completely marine (sea), or sea water mixed to various degrees with fresh water. This definition would include both the sea and inland brackish-water areas. These can be freshwater or salt water organisms, or have development phases in both types of waters."

Fish that have development phases in both types of water are described as:

- **Anadromous fish:** are born in fresh water and spend most of its life in the sea. They return to fresh water to spawn. Salmon, smelt, shad, striped bass, and sturgeon are common examples.

- **Catadromous fish**: live in fresh water and enter salt water to spawn. Most of the eels are catadromous.

PURPOSES OF AQUACULTURE

Aquaculture is carried out to breed fish and aquatic organisms for the following purposes:

- Human Consumption
- Re-stocking purposes
- To breed lower quality "feed" fish for the fish feed and fish oil market
- "Put and Take" angling
- Ornamental (aquarium) fish
- To produce Pharmaceutical products – cosmetics, medicines, food additives etc.

TYPES OF OPERATIONS

Hatchery - produce fertile egg, larva or fingerlings
Nursery - nurse small larvae to fingerlings or juveniles
Grow-out - grow fingerlings or juveniles to marketable sizes

Mariculture production has an important role in providing for food security, and economic and social welfare, especially in rural areas of many countries. Mariculture also has some significant disadvantages as there are several environmental problems that are associated with it. Their extent depends on species, culture method, stocking density, feed type, husbandry practice, hydrodynamic site conditions and the sensitivity of the receiving ecosystem. In heavily populated coastal areas mariculture is in competition with other human activities for space and other resources. These other activities can for example be: fisheries, tourism, harbour operations, nature conservation and industry.

CLASSIFICATION OF CULTURE SYSTEMS

The kinds of aquaculture generally practiced use either *salt* or *freshwater* species, under either *extensive* or *intensive* production. Another over-lapping classification for aquaculture systems considers the origin of the main inputs to the system, water and nutrients. This classification defines three types of systems: *open*, *semi-closed* and *closed systems.*

Extensive Production (Ep)

An extensive production system involves the use of natural waters (i.e. oceans, saltwater estuaries, rivers, dams, lakes and various impoundments). It is a system where animals are stocked, allowed to spawn and increase in number and size.

Sometimes there will be some input in terms of water, fertilization, feeding and/or protection. Usually a simple stocking and harvesting routine is followed.

Extensive culture systems have been employed throughout the world since man learned to fish, particularly where there are shallow coastal lagoons, as in river deltas in the Tropics and Mediterranean areas (Nile delta, Rhone delta, lagoons and canals in the Adriatic Sea, Yucatan Peninsula coastal lagoons in Mexico, etc), and in more recent times when impoundments have been stocked for angling recreation.

This system is also employed for casual harvesting (i.e. non commercial) by rural communities. It is generally accepted that it is less expensive to produce a harvestable crop from an Extensive Production system than that from an Intensive Production system. Water is available at little cost, manpower needs are lower and the degree of expertise required from both the farmer and his workers is considerably less for extensive than intensive fish production.

The estuaries, ocean, lakes, and dams used for extensive production are usually large and have sufficient food and cover to support a large number of fish and allow them to grow reasonably quickly to a marketable size. However, they will grow more slowly than fish which are force fed under intensive conditions.

The mass of fish harvested is considerably less on a per hectare rating than under intensive production. Nutritional quality may be more variable also, depending on water quality and environmental conditions that determine fish food quality (climate variability, nutrient input to lagoons and dams, competition amongst species for the same food sources).

Intensive Production (Ip)

An intensive production system (IP) is managed to ensure optimum water conditions, feeding regimes and production of marketable flesh at all times. This is important for high production.

It requires a well designed and managed production unit so water flow, water quality, light intensity, oxygenation, waste build up, feed, predation, competition and most other factors affecting or limiting production are efficiently controlled, improved or otherwise manipulated. Reproduction can sometimes be initiated slightly out of season by manipulating water temperatures, oxygen and light intensity.

Pools, raceways or dams are typical units for intensive production. They are designed and constructed to offer the farmer as much control as possible, to circumvent problems and to improve any natural limitations. They also enable the farmer to determine exactly his marketable stocks and have them available whenever they are needed.

Intensive aquaculture for example may involve artificial spawning by means of hand stripping, with or without hormone stimulation. The ova (eggs) are hatched, and the young are raised, under protected and controlled conditions. They are regularly sorted and those of the same size are kept together. The weaker fish (those that would normally have died had they been in a natural habitat) are now a useable and marketable additional percentage.

In a hatchery, diseases that are often dormant in wild fish population may suddenly develop and spread quickly because of the large number of fish contained in a small amount of water. Epidemic proportions may be reached quickly. Treatment is imperative to ensure a suitable harvest and is often costly. However, most sicknesses can be quickly and efficiently treated.

To avoid the spread of disease, fish must be surveyed often, and procedures for fish health monitoring must be put in place.

Observation, experimentation and selection for improved breeding are usually extremely difficult where extensive production is practiced, but relatively easy in a hatchery or intensive farm. Selection for fast growth, good feed conversion, marketable characteristics and many other factors are usually done over a long period of time.

CLASSIFICATION BASED ON SYSTEM INPUTS

Open systems (Off-shore and Near-shore)

These systems use natural environments where aquatic organisms grow naturally in order to culture them. Water enters and leaves the system without the need of pumps, and most of the nutrients come with the water. Nutrients may be added in certain cases or for certain periods of time, as in salmon cage cultures. Open system advantages are: better water exchange and lower rate of diseases.

Offshore systems tend to involve fewer user conflicts compared to near shore systems.

The disadvantages of both systems are: higher quality variability and loss by predation and poaching.

Offshore systems have other disadvantages related to their exposed position including: equipment damage, mooring problems, net changing difficulties, accessibility in poor weather, higher capital cost, larger service cost, problems undertaking stock assessment and mortality checks, higher cost of insurance, and the need for trained personnel with offshore seamanship skills.

Semi-closed systems

Semi-enclosed systems are systems where water and nutrients are added to the system by means of controlled and man-made structures or effort. Water is circulated one or more times through the system, and then discharged.

These systems need additional equipments such as pumps and filters. The advantages are that environmental factors can be closely monitored and changed if need be, such as water flow, temperature, quality and oxygenation. Also nutrient input is matched as much as possible to the need of the population being fed, so fewer wastes are produced.

Disadvantages are the high costs for infrastructure and manpower. These systems are Intensive Production systems.

Closed systems (On-shore)

Closed systems are not as common as semi-closed systems, as they require high capital input, specialized structures and specialized staff to operate the system. They use mainly water tanks that in the majority of cases are circular.

Closed systems are used nowadays to produce eggs, larvae and juveniles, which are then sold to ‘fish growing’ farms. Closed systems are being tested in the salmon industry with success, although they have not been implemented fully, due to costs, equipment development and staff training.

Table 1.1: The common culture methods for each marine category:

Category	Culture method
Finfish	Cage culture Pen Culture Pond and raceway (flow through and reticulation systems) Sea ranching
Molluscs	Vertical or rack culture Hanging culture Bottom culture Land-based tank culture Sea ranching
Crustaceans	Pond culture Raceway culture Cage culture Sea ranching
Marine aquatic plants	Suspended culture (longline, raft, net) Bottom culture Tank culture
Echinoderms	Tank culture Cage culture Sea ranching

OPEN SYSTEMS CULTURE METHODS

CAGE (NETPEN) CULTURE

Mesh enclosures or cages, typically placed in coastal areas. The outside structures may be rigid or semi-rigid. The system design relies upon dilution as the solution to pollution. There is no effective barrier between the netpen interior and the ocean. Wastes are emitted directly into the surrounding waters.

The system design also creates the potential for farmed individuals to escape into the wild.

Fundamental design criteria should take into consideration accessibility, ease of maintenance and the safety of the complete system. The design and engineering of sea cage aquaculture production systems should give consideration to the following principle elements; the net or cage bag, frames, collars and supports, linkages and groupings, mooring systems, and access to water quality data.

Offshore Vs Near shore

Although numerous new opportunities seem to arise for offshore sea cage farming, a new set of constraints occurs, which are not at all encountered by near-shore sea cages.

The minimum size for juvenile fish to be stocked in such systems may be much larger than for inshore cages.

Rearing constraints may stem from the need for much more sophisticated technology for sorting, handling and harvesting of the fish.

Construction materials and operational procedures may have to take into account the species-specific behavioural requirements and peculiarities, adding to the operational costs (e.g. maintenance issues, weather conditions and material resistance, better surveillance techniques and remote control of feeding).

Advantages: Open sea farming encounters very different hydrodynamics to inshore and onshore farming, providing much better water exchange within cages and also much improved and rapid dispersion of wastes. The real difference between offshore versus inshore systems relates to reduced benthic deposition, with the actual benthic loading so small that measurable differences in terms of biodiversity indices may not be detectable.

Disadvantages: High cost of both the system purchase and its operation are critical factors. World-wide, there is a tendency towards larger production unit sizes and at a gradually increasing distance from the shore. The present trend is towards more exposed sites rather than to truly offshore systems. The main reason for this is because operating and infrastructure costs, as well as the infrastructure support systems, are similar to existing inshore farming systems. The initial investment costs may even be similar to those presently encountered for re-circulating systems.

Cage Design

Cages are generally categorised according to the nature of the structure used to support the holding net. This divides the designs into three major operational categories and two mechanical types:

Floating	flexible
	rigid
Semi-submersible	flexible
	rigid
Submersible	flexible
	rigid

Floating flexible cages

Rubber-hose cages: These types utilize rubber hoses originally designed for transferring oil between oil tankers and On-shore terminals. The primary commercial systems are those produced by Bridgestone and Dunlop.

Ocean spar net pens: The design is based on the cage net being held in shape by vertical spar buoys at each corner, which are in turn held apart through a tensioned mooring system. A variety of configurations is possible from squares through to polygons of 200 m circumference.

These systems are highly resilient to wave forces with long service life (>10 years), have relatively good impact resistance, have effective net hanging systems, allow for a variety of configurations, are relatively cheap at higher volumes and are the most widely used commercial offshore systems.

Floating Rigid

Rather than attempting to be wave compliant, these cage systems aim to be robust enough structurally to withstand wave action, and are generally of large, massive structure, usually steel construction, with varying degrees of ballasting, sometimes with mass concrete.

In addition, most types also attempt to build in a variety of features to facilitate management of the fish, such as feeding systems, harvest cranes, fuel stores and power generation, staff quarters, etc. Some systems are also self-propelling.

These systems are designed with rigid framework elements providing only limited movement or volume change in response to external loads.

Normally with steel frame structures, these contain adjustable buoyancy elements to raise or lower the system. With a more rigid structure it may also possible to add service facilities such as feeders, potentially developing self-contained systems. Primary examples of these cage types include the Farmocean cage and the Ocean Spar Sea Station.

A variant of the open floating cage is the fully enclosed Fish Containment Reservoir (i.e. SARGO).

Unlike traditional net pens that are open to the sea, these cages completely isolate their fish crop from surrounding waters. Each solid wall reservoir is fabricated from a reinforced fiberglass or composite plastic resin that is impervious to corrosion and highly resistant to bio fouling from barnacles, anemones, and similar marine organisms.

This feature changes the aquaculture process from planting juvenile fish in a “fenced-off” portion of the sea, into an industrial process where system inputs, outputs and internal operations are fully managed.

This controllable approach is successfully used in land-based sites. These floating systems are essentially a floating variant of the land-based systems.

Semi-submersible and Submersible cages

These cages are able to be submerged for periods of time below the higher energy regimes of surface waters. They offer the advantage of being lighter and simpler structures which, if submerged appropriately during poor sea conditions, tend to incur far less exposure and hence physical stress.

The reduced movement also potentially reduces possible damage to fish stocks or motion stress. As with floating systems there are two structural classes: flexible and rigid (with similar design consequences).

HANGING (SUSPENDED) CULTURE

This method is used in shell fish culture and includes variations of raft and long line culture:

Raft culture

Raft culture is similar in many respects to longline culture, except that the raft commonly swings on a single mooring (Figure 1). As with longline culture, ropes are suspended from the raft. This technique has far less scope for mechanisation; most harvesting is done by hand and the operation generally smaller in scale than longlining.

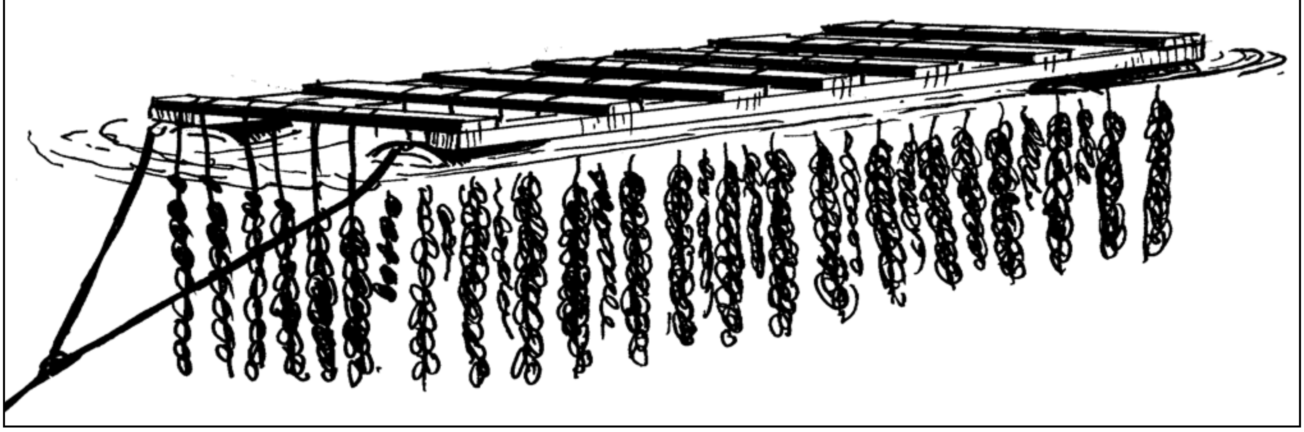
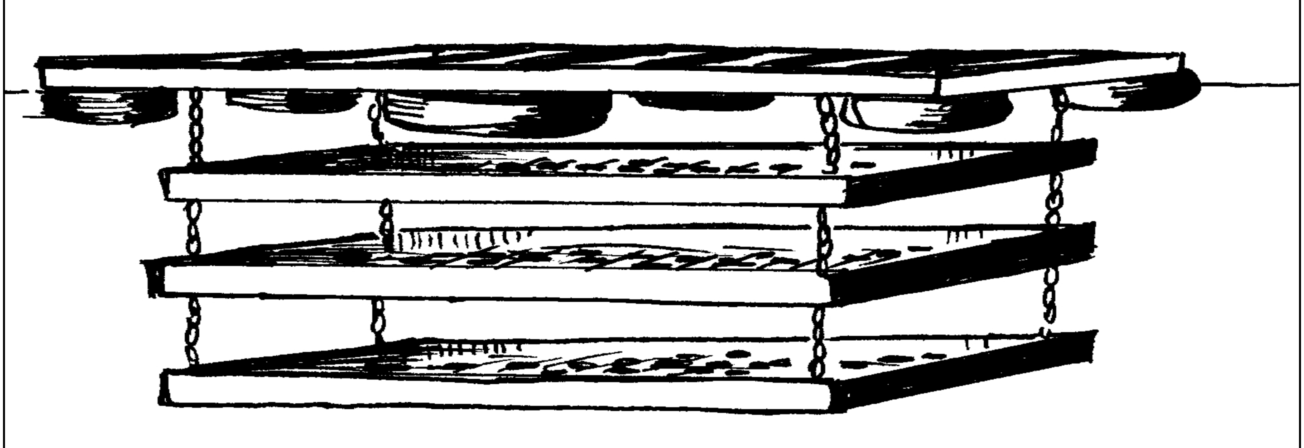


Figure 1- RAFT CULTURE - Suspended Culture Strings

A variation of this method is suspended trays (Figure2)

Figure 2 - RAFT CULTURE - Suspended Trays



Long-line culture

The long-line culture is a modification of raft culture. This method is mainly used for offshore culture.

The basic feature of a long-line unit is a series of styrofoam floats arranged in a row. The long-line is secured at each end with two anchors. These support a large number of sea weed (figure 3) or culture droppers (figure 4). The number of droppers used varies with hydrological and biological conditions but is normally in the order of 400-500 per (double headline) longline. The longline can be used to hang chaplets, pocket panels, lantern baskets or spat collectors.

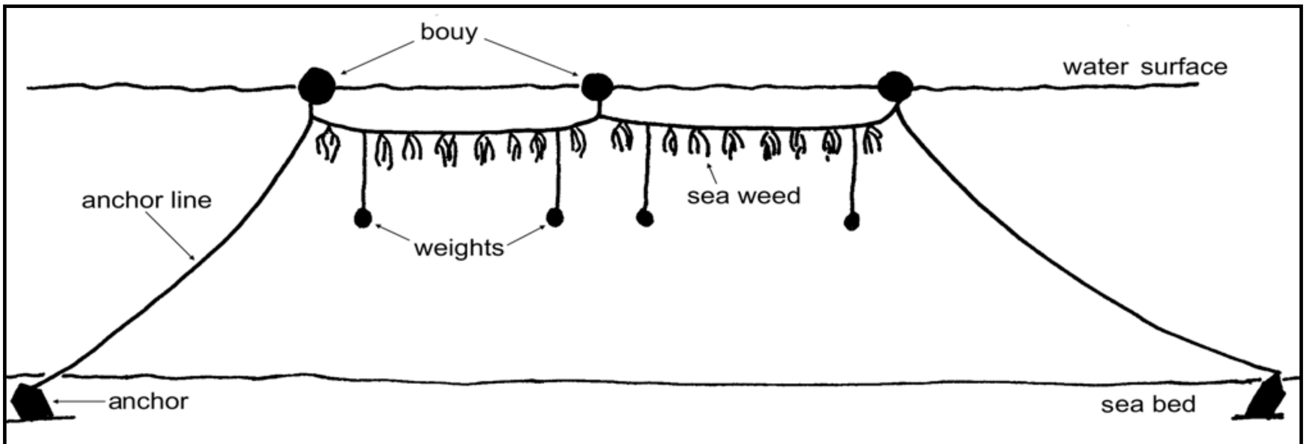


Figure 3 - LONGLINE CULTURE - Sea Weed

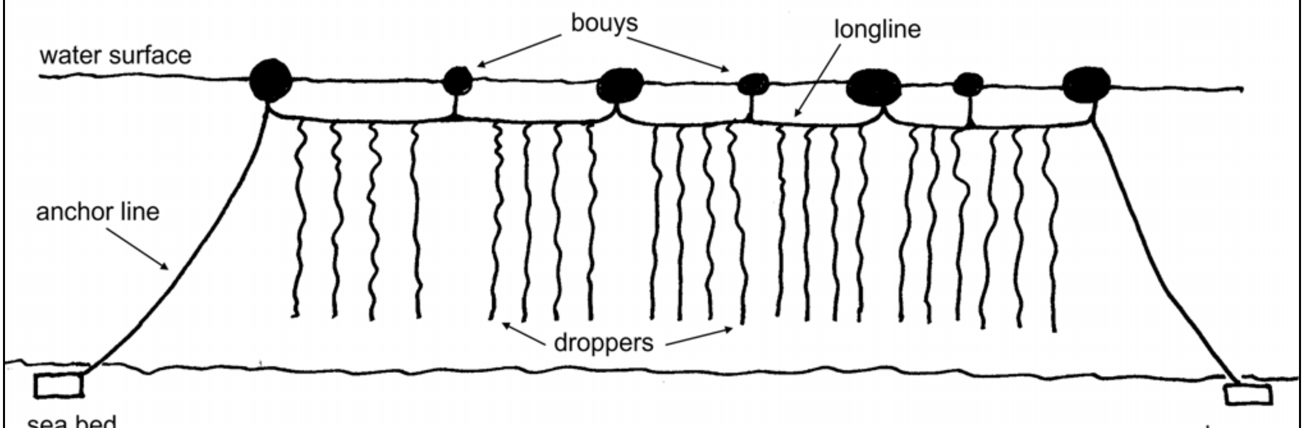


Figure 4 - LONGLINE CULTURE - (i.e. mussels)

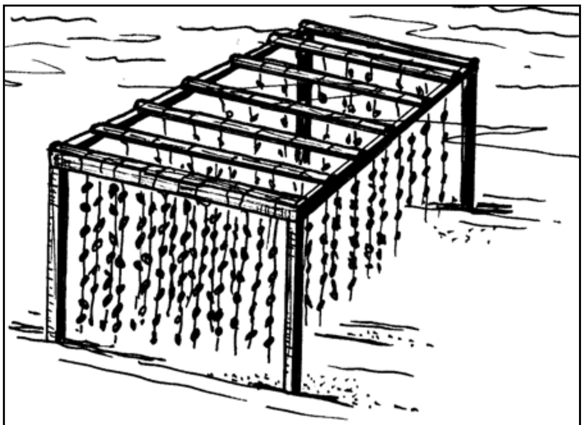


Figure 5 - RACK CULTURE - Culture Strings

VERTICAL OR RACK CULTURE

The rack method is a shallow water adaptation of the hanging culture method.

To construct a rack for oysters (for example), wooden poles are driven into the bottom, two to four metres apart.

These uprights are connected by horizontal poles. The horizontal poles support the suspended strings of cultch (chaplets), which are placed about 30 cm apart (see figure 5).

Other systems combine rack and tray techniques where young oysters are spread across wire mesh and raised to maturity. Racks are used extensively for spat collection and the growth of young oysters and mussels. A variety of suspension methods are available.

BOTTOM CULTURE

Bottom sowing

The simplest of shellfish culture methods. What is basically required is that the sea bottom of the farm be hard. Otherwise, the shells get buried and lost in the mud. This method has been used mainly in the intertidal zones. Alternatively, simple wire or plastic nesting trays can be suspended above or set on stable substrate.

Cultch lines

Another method of bottom culture is where cultch lines are suspended just above an unstable substrate (see diagrams 6 and 7 below)

Figure 6 - BOTTOM METHOD - Oysters

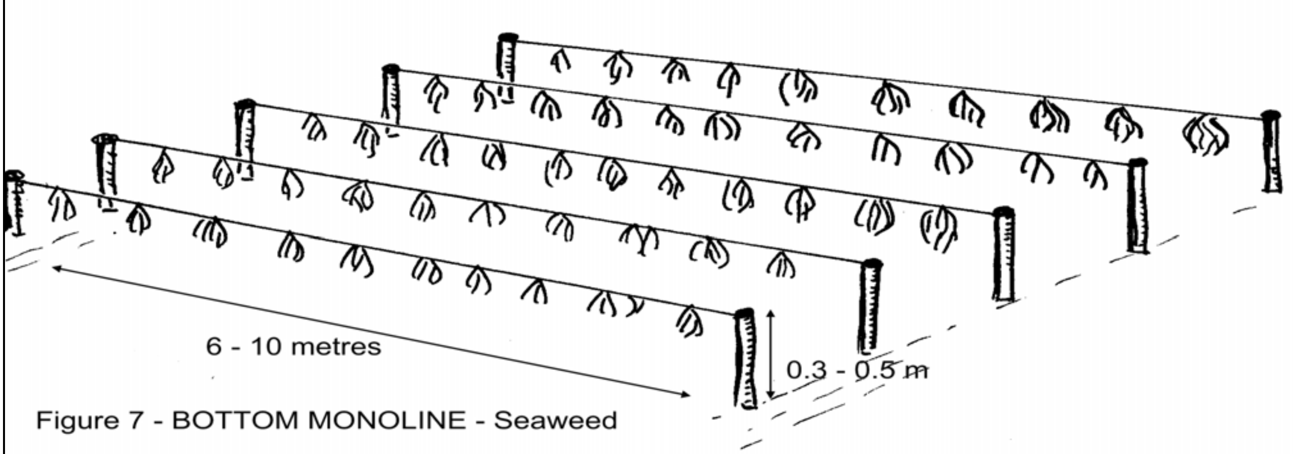


Figure 7 - BOTTOM MONOLINE - Seaweed

STONE CULTURE

Stones are used as collecting materials in an intertidal zone where the bottom is soft. A lot of attention must be paid to selecting the growing site. The bottom must be “combed” or raked to make it smooth before setting the collecting materials (stones).

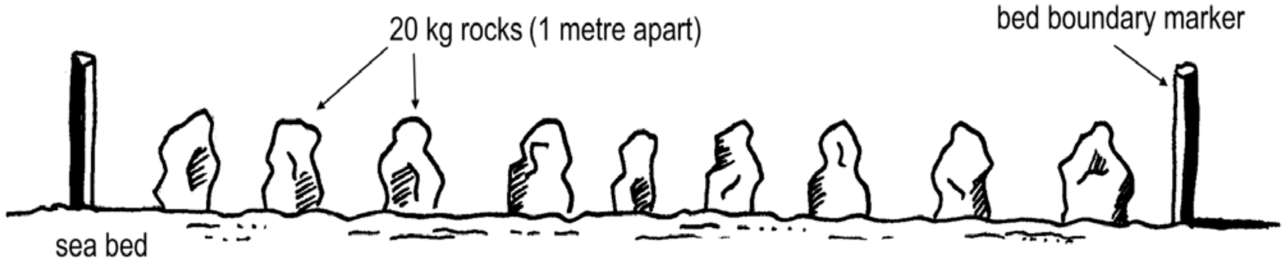


Figure 8 - STONE CULTURE - Oysters

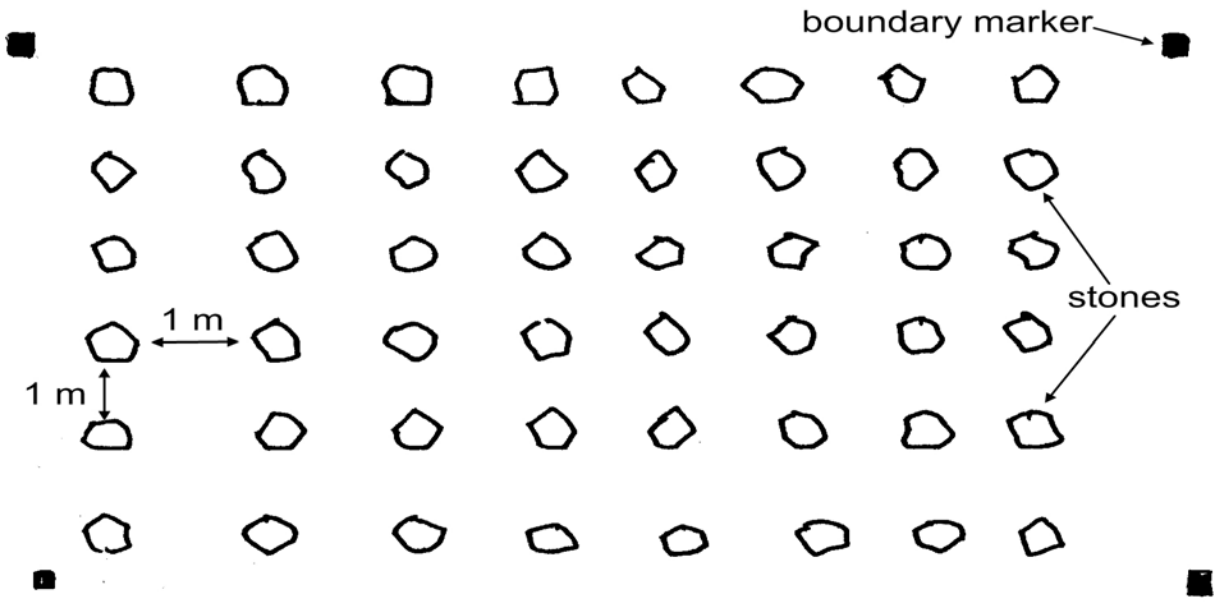


Figure 9 - STONE CULTURE - Ground Plan

STAKE CULTURE

To use this method, the ground must have a smooth bottom and be located in protected coastal areas with little influence of wind and waves. One method involves driving stakes into the substrate, the cultch is either strung vertically or horizontally (Figure 10) between stakes.

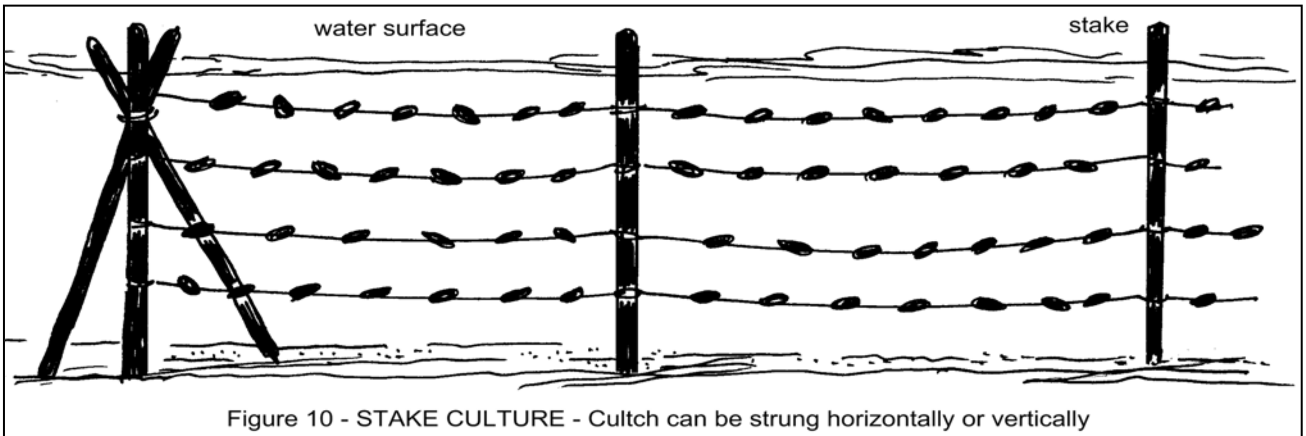


Figure 10 - STAKE CULTURE - Cultch can be strung horizontally or vertically

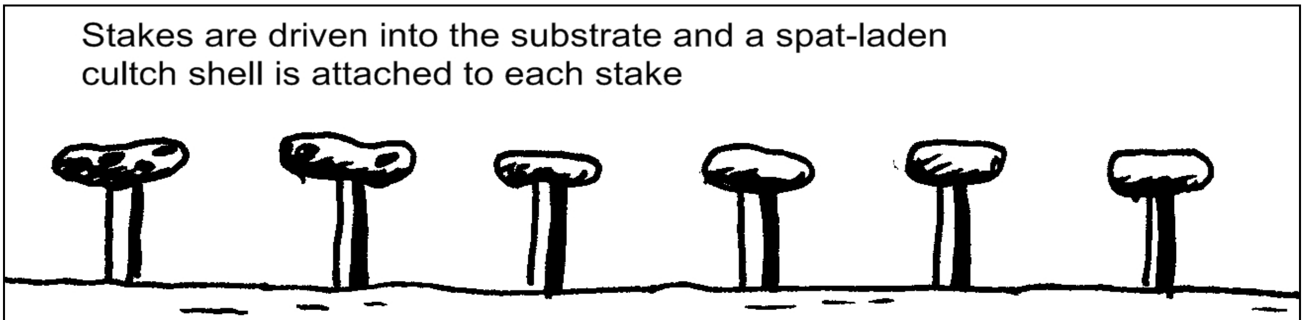


Figure 11 - STAKE CULTURE - Oysters

Another method suitable for oysters is to use stakes made out of pine trees, oak, concrete, PVC, bamboo or other materials.

Spat-laden shells are attached to the stakes (figure 11 above).

The advantage of this method is that the facilities for culture are easy to establish. This method is particularly useful in areas with soft bottoms that would not allow bottom culture.

UMBRELLA CULTURE

Shell fish are attached to ropes or wire and suspended from a central post radiating to anchors like spokes on a wheel, thus taking the shape of an umbrella (figure 12).

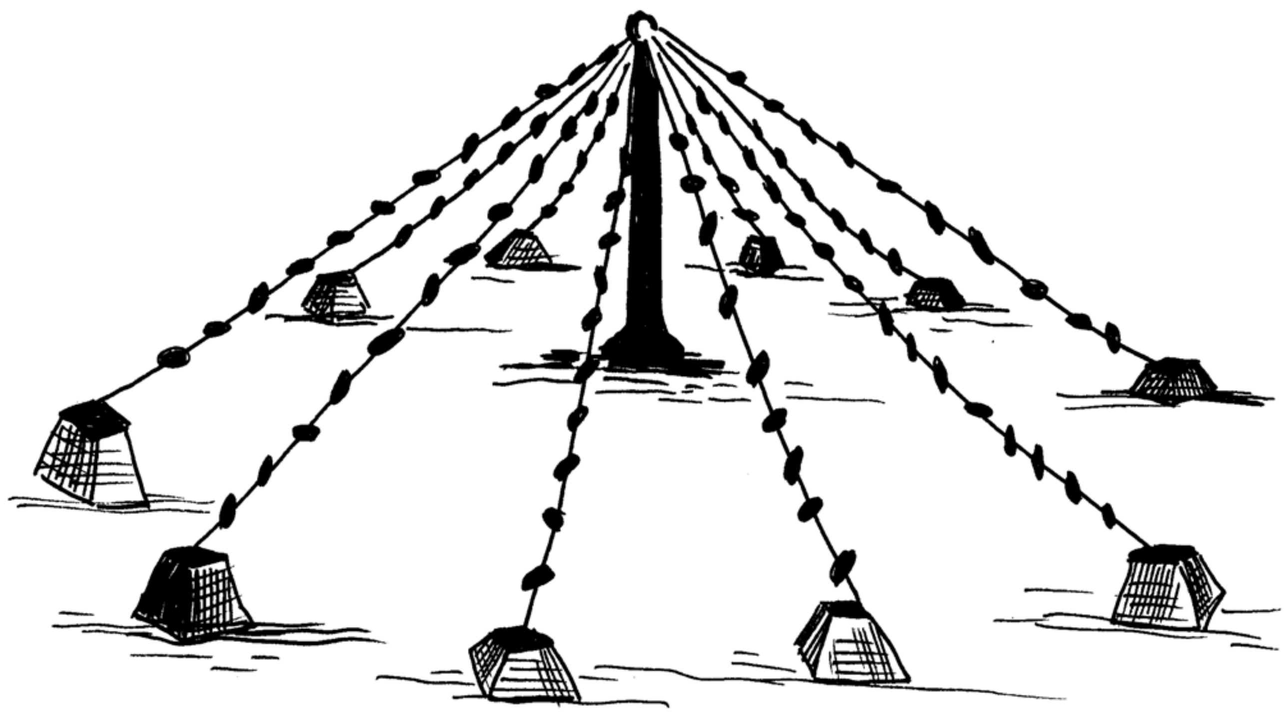


Figure 12 - UMBRELLA CULTURE

The Culture lines are secured by stakes or anchors.

NET CULTURE

Pearl nets (figure 14), pocket panels and lantern nets (figure 13) are used extensively in suspended pearl culture systems.

Figure 13 - LANTERN NET - Oyster Culture

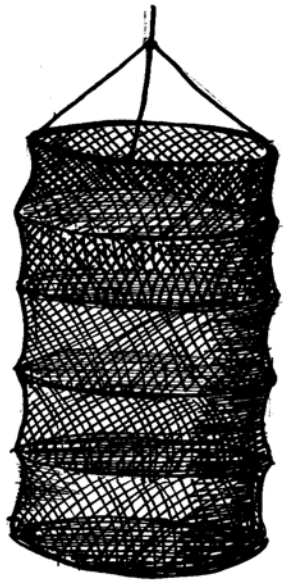
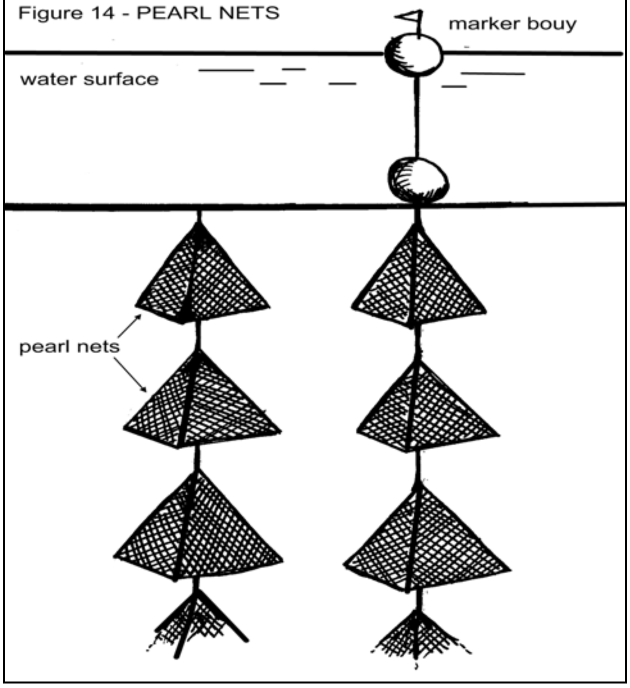


Figure 14 - PEARL NETS



SEMI-ENCLOSED SYSTEMS

Flow through tank systems

Flow-through tanks are similar to recirculating tanks except that flow-through systems allow water to enter and exit through tanks and holding areas.

The entering water is treated for bacteria, parasites and diseases. The out-going water should be subject to treatment to remove solid wastes and other treatments as prescribed by local environmental laws. These systems are similar to recirculating systems except that they are found where reliable water sources are available.

Hard-walled, free-standing tanks are made from a range of different materials including concrete, aluminium, reinforced plastic, and fibreglass. They are also available in a range of shape such as square, circular or polygon. Soft-walled systems are made of plastic.

CLOSED SYSTEM AQUACULTURE (CAS)

Reticulation (Recirculating) systems

A recirculation aquaculture system (RAS) can be defined as a “system that recycles and renovates water for the culture of aquatic organisms”.

Historically, recirculation was thought of as recycling ≥ 95% of the water volume per circuit through the system (i.e. rearing tank and filter), with ≤ 5% new water added per circuit and many circuits per day.

However, RAS are now described, not by water replacement per pass, but by replacement per day, e.g. 10% per day.

Recirculating tanks are usually located where land and water is limited.

Tanks came in a variety if sizes, with circular tanks often used because of their self-cleaning properties. Polygon tanks are space efficient. The tanks are scalable and modular. This allows a producer the flexibility of adding units without interrupting production in existing tanks.

RAS have to grow fish rather than just hold them, so it is the amount of food that can be fed that is important, rather than the stocking density.

The efficiency of RAS is determined by the ability to cope with the wastes derived from the feed, so food load is the main consideration when designing and predicting the capacity of a system.

Filtration systems should remove solid wastes, convert ammonia and nitrite to nitrate, add oxygen, remove CO2, maintain an acceptable pH and control pathogens. Each stage of filtration systems must have sufficient capacity and not become overloaded, which can then impact downstream processes.

CO2 removal is often overlooked as newer oxygenation systems (as opposed to older aeration systems) do not remove CO2. For every 1 Kg of oxygen used, 1.4 Kg of CO is produced and, if it accumulates in the water, can prevent oxygen transport within the fish.

Equipment: Modern RAS typically have various components for renovating water during a cycle:

- a top outlet from the culture tank to a drum filter to remove suspended solids
- a bottom drain from the culture tank leading to a swirl separator to remove larger solids (uneaten food, faeces)
- a biofilter for ammonia and nitrate conversion
- an air blower to remove CO2
- oxygen (and ozone) addition
- an ultraviolet source to destroy the ozone
- addition of make-up water before return to the culture tank

Advantages: lower water demands, limited space requirements, possible shift away from the sea front, reduced water discharge, predator exclusion, independence from external conditions, isolation from the natural environment, avoidance of escapees, improved bio-security because of isolation from external contamination and possible water treatment at the outlet, and limited chemical use.

Disadvantages: require high capital investment and is energy demanding. The present technology concentrates effluents, but does not remove all the nitrogen and they are released near-shore undiluted. The transformation of soluble compounds into particulate matter demands space (e.g., treatment through algae pond in a secondary loop), and solids, in the form of sludge, have to be disposed of on land. Phosphates and heavy metals accumulate in this system and are difficult to remove, limiting the use of this organic material for crops.

Raceways

Raceways are either recirculating or flow through. Raceways are long structures, made from either concrete, plastic or steel. Some are several hundred metres in length. Recirculating raceways are entirely land-based and can be single-level or stacked to increase the units of production per metre floor space. Water flows through these systems, remaining in one spot for only a short period of time. They have a low water volume to container surface area. This system suits species such as trout that thrive in a simulated stream flow or flat fish (i.e. flounder or sole) that require large surface areas.

Inland Ponds

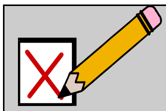
These ponds and channels can be lined with mud or membranes. The system is similar to tank and raceway culture but production is carried out in large earthen ponds and channels.

COMBINED SYSTEMS

Integration of mariculture into a managed mix of coastal resources use can be carried out in different ways:

1. One approach is at the biological level through co-culture between species, including fish and/or shellfish and/or micro/macro algae, and in various combinations of species at different trophic levels.

2. Another option is to combine various mariculture technologies, for example, onshore culture systems (e.g., flow-through or recirculation systems) to produce either juveniles and/or market-sized fish (most likely medium-sized specimens for specific markets) in conjunction with near-shore or offshore sea cages for on-growing and fattening to much larger-sized products which can target different markets (vertical integration).



SELF ASSESSMENT
Perform Self Assessment Test 1.1
If you answer incorrectly, review the notes and try the test again.

SET TASK

Investigate three different mariculture enterprises (preferably in your locality or region). Determine what types of systems are used in these different enterprises. Try to obtain some literature (e.g. brochures or magazine articles), which describe the ventures. The 3 different enterprises may be found any of the following ways:

- Search the internet for Mariculture Farm web sites or articles about specific aquaculture farms. Telephone Book
- Contact a Tourism Authority in your state (Mariculture farms may provide guided tours for tourists. You may be able to obtain brochures on farms in your locality).
- Contact your local government fisheries department. Some enterprises (e.g. Hatcheries) may be operated by government departments and may be open to the public. You may find brochures available to potential buyers of young animals.

If possible, visit these companies and gather as much information as possible.

Note: We understand that farm visits are not always possible or encouraged. In some countries there are issues with poaching (theft) and farms are secured with armed guards to protect against entry. In other cases, licensing and Occupational Health and Safety laws may prevent actual farm visits.

You can still complete the task by conducting an internet search (a hypothetical farm “visit”) to find information on materials that are used to contain fish or other species. Gather information on materials characteristics, uses, durability, costs and maintenance. Organize the information in a comparative table.

ASSIGNMENT
Complete Assignment 1