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Construction and installation of hexagonal wooden cages for fish farming

A technical manual

Cover photograph:
A floating artisanal hexagonal wooden cage for fish farming (Courtesy of Fabrizio Piccolotti).

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FAO FISHERIES AND AQUACULTURE TECHNICAL PAPER

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Preparation of this document

This document was prepared following the implementation of the Food and Agriculture Organization of the United Nation of a projet in support of marine aquaculture development in the Republic of Djibouti.

During a series of field missions undertaken by the lead author, all the necessary materials for constructing a number of hexagonal wooden cages were assembled and cages were constructed and placed in the sea. The advantages of using locally available materials and the reasonable costs and ease of construction suggest the value of replicating this experience in other environments for the development of artisanal aquaculture. The basic knowledge and instructions provided in this manual are intended for present and future workers in aquaculture development dealing with the construction of small-scale artisanal floating cage for fish farming.

Abstract

This document is a practical guide that includes a list and the technical details of materials to construct a hexagonal wooden cage for fish farming, and its mooring system, for use in artisanal aquaculture. Instructions for assembling the various components are illustrated in detail, and technical guidelines for cage installation at the farming site are also described. This manual also offers basic advice on the choice of cage model and the components to be used based on the environmental, logistical and social conditions of the site. The physiological requirements of the species reared and their impact on production levels are discussed with the aim of providing the minimum information necessary for planning and setting up such an activity. This technical manual also explains that it is possible, using the illustrated cage model, to exploit environments that are more dynamic than those in which artisanal aquaculture traditionally operates. Additional technical information on the topics treated in the manual is provided in the appendixes.

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All the photographs were taken by the lead author.

Glossary

Anchor ring: strong iron ring to which a cable or a chain is attached (through a shackle).
Beacon: an object that indicates a hazard or serves as a marker.
Feed conversion ratio: this indicates the relationship between the quantity of feed consumed and the amount of growth, e.g. a value of 1.7:1 means that 1.7 kg of feed are needed to obtain a weight increase of 1 kg in biomass in fish farming.
Fetch: the distance at sea or on a water body across which the wind blows without encountering an obstacle.
Fouling: the spontaneous colonization of a submerged support structure by sessile organisms (algae, molluscs, crustaceans).
Hawser: a large rope (mooring rope or line) used for mooring or towing operations.
Launch: transferring a ship, a cage, etc. into water.
Hatchery: a structure designed to produce the eggs, larvae and fingerlings of fish or other commercial aquatic organisms.
Mark out: delineate a place by placing marker posts.
Moor: drop an anchor or a mooring post into the water to hold an object in place.
Mooring post (or sinker): a concrete slab or other heavy object, placed on the sea bed and connected by a rope or chain to a buoy or other floating object.
Pay out (a line): uncoil a mooring cable from a boat into the water.
Secchi disc: circular disc (about 20 cm in diameter) whose upper surface is divided into four equal parts painted alternately black and white. This is used to measure the penetration of light in water (its transparency). It is submerged at the end of a calibrated line until it disappears from view.
Shackle: A U-shaped piece of metal secured with a shackle pin or bolt across the opening; used to link two sections of a chain.
Specific growth rate: a technical term in fish farming to indicate the daily growth rate in terms of percentages.
Stocking: the process of putting fingerlings into a cage.
Stocking density: this indicates the quantity of fish (in kilograms) in relation to the volume of the cage (in cubic metres).
Teredo worms: bivalve molluscs (= lamellibranchs) with very long bodies, wormlike, that bore holes in wood submerged in seawater or brackishwater. Also known as shipworms.
Twine number: this indicates the size of the mesh twine and it is expressed in two figures (e.g. 201/70), the first of which indicates the linear weight of the primary fibre that makes up the twine (i.e. 210 is the weight in grams of a fibre 9 000 m long), while the second (in this case 70 but can range from 12 to 400) refers to the number of twisted fibres that constitute the net twine.
Uncoil: a marine term meaning to uncoil a cable that was coiled or rolled in the form of a circle.

1. Introduction

Aquaculture production may be practised on an industrial or artisanal scale in various aquatic environments.

The high capital investment characteristic of industrial aquaculture has allowed the installation of cages in exposed environments, offshore, with the help of high-level technology and usually through considerable investment inputs. However, artisanal aquaculture, using inexpensive, locally available and often recyclable materials, is traditionally carried out in highly sheltered areas where the hydrodynamic and meteorological conditions are hardly ever of an extreme nature. Conditions in such sheltered areas often entail a low water exchange rate in cages and the areas surrounding them, which gives rise to problems of environmental pollution and the loss of part of the aquaculture stock. Despite these limiting factors, the development of artisanal cage aquaculture in developing countries can contribute to providing protein for human consumption and also to creating employment in local communities.

The development of private initiatives, which should be backed by policies that favour and promote investment, are essential for the progress and consolidation of this industry. From a technical viewpoint, the major challenge for this development is an inadequate knowledge of the many biological and technical factors involved. The practice of cage aquaculture requires an in-depth knowledge of the aquatic environment, certain other environmental aspects and the biology of the species being reared. Familiarity with the breeding methods and the main technical factors involved in the production process is also necessary. Cage aquaculture has developed relatively recently and information on this subject is not adequately disseminated and shared.

The aim of this manual is to provide entrepreneurs, technicians (of private companies and relevant public and research institutions) and new entrants into this field with advice on the basic criteria for the evaluation of sites and the most suitable choice of cage model for various environmental conditions. Information on the relationship between the physiological requirements of the species and the culture environment (physicochemical, biological and hydrological aspects and the shape and model of cage adopted) is also provided.

Emphasis has been put on the detailed description of a hexagonal wooden cage (components, technical characteristics and operation, stocking volume available, etc.) and on the method for correctly assembling the various components. This model of cage is not as well known as the traditional square or rectangular forms but it is highly advantageous for use in sites that are not completely sheltered. The adoption of hexagonal cages, with their favourable hydrodynamic characteristics due to this geometric shape, makes it possible to establish fish culture farms in sites considered semi-exposed.

In fact, the adoption of this type of cage would make this activity possible in all coastal countries without sheltered areas, such as rivers or the archipelagos of Southeast Asia. In addition, the use of areas with better hydrodynamic conditions should make it possible to achieve higher levels of production of better quality fish.

Moreover, given that the aquatic environment is much more dynamic and offers many more variables than on-shore (land-based) locations, it is believed that the dissemination of prior experience in this field will help to develop the operational strategies and practical solutions that are essential for the success of certain operations. Thus, in this manual, the lead author has tried to share the fruits of his experience acquired during some 15 years of work at sea in the private sector as an aquaculture technician.

The chapters that deal with cage construction and their installation in the sea also contain practical advice on how to carry out these operations correctly.

This manual provides information and suggestions that can be used by both novices who have never been involved in this type of activity and professionals who can compare their ideas and technical solutions with those presented in this document. Indeed, the sharing of different experiences and ideas of each professional can continually help to improve upon the results already achieved.

2. Selection of site and suitable species

The main feature of cage aquaculture is that it is an "open system" where the interactions between the cage and the environment are reciprocal. The selection of a suitable site for cage installation must take into account the impact of the cage on the environment and *vice versa*. It is important to understand that the quality of the environment is the primary factor that influences aquaculture production (in terms of quality and quantity). Moreover, a careful evaluation of the environmental factors and an understanding of the dynamics that can affect the farming operations are essential for the successful planning of this activity (target species, potential production objectives, etc.). Before carrying out a study of the site, it is necessary to verify whether there is a national legal framework to regulate aquaculture production. A request for authorization to engage in marine culture in a public maritime area may be required in order to obtain a farming concession.

There may be bans on the use of certain species and of certain coastal areas (because of environmental pollution, use conflicts with other activities, protected marine areas, etc.). Restrictions on possible maximum production (in order to limit the emissions of polluting agents, particularly nitrogen and phosphate) may be imposed. Before the introduction of certain non-indigenous species, it may be necessary to consider applying a quarantine (to avoid the spread of pathogenic organisms).

Note: The lack of a legal framework, transparent procedures and easy access to the regulations are the main challenges to sustainable aquaculture development, especially in countries where this industry is less developed. The relevant regulations should not be considered as a constraint but rather a positive factor for the development of this industry. Measures to support this sector (e.g. investment incentives and access to credit) should be included in this legislation.

Table 1 summarizes the main advantages and disadvantages of fish farming in cages compared with land-based rearing (as far as small-scale aquaculture is concerned). Cage fish farming remains more profitable than land-based fish farming, although there are a few drawbacks.

2.1 SITE SELECTION

Cage farming must cope with the vagaries of environmental conditions. Thus, to minimize the risks associated with the farming structures, the species cultured, as well as those to the environment, site selection must follow a careful evaluation based on a feasibility study that considers various aspects of the proposed location.

TABLE 1
Main advantages and disadvantages of cage culture

Avantages	Disadvantages
Greater availability of suitable sites	Potential interference with the local fish population (possible transmission of parasites and pathogenic organisms, predators, introduction of various fish species into the cage)
Much better water exchange at no cost	Increased risks of theft and sabotage
Possibility of intensifying fish production (stocking density, increased rate of growth and survival)	Need for more skilled labour (for establishing the farm, feeding and maintenance)
Smaller initial investment	–
–	Life span of cages shorter than that of tanks or ponds
–	More risks associated with meteorological conditions in this dynamic environment

The feasibility study should take account of environmental, logistical and sociocultural factors. This chapter presents the main environmental factors and their impact on this aquaculture activity. Suggestions concerning the logistical and sociocultural aspects are also provided.

Environmental aspects

The environmental study comprises the following elements:
- bibliographic research;
- review of available data (provided by the government and/or research institutes);
- *in situ* analyses of physicochemical, geological and ecological factors; and
- consultations with local communities.

With regard to farming projects that involve the use of artisanal wooden cages, Table 2 summarizes the main factors to contend with in view of their impact on both the facilities and the species raised, and, where possible[1], acceptable values are given.

Hydrodynamic and geological factors

The hydrodynamic conditions, as well as the bathymetry and typology of the sea bed, must be assessed before selecting the most suitable cage model and mooring system. These factors also have an impact on the health and growth rate of the fish reared as they affect both the quantity and quality of production.

The optimal conditions should provide for a minimum distance of 2 m between the bottom of the net and the sea bed. This is to keep the fish being cultivated away from the organic matter loading under the cage, due to the accumulation of faeces and uneaten feed wastes. This organic matter is colonized by bacteria that, through decomposition, cause pollution of the water, and may create health problems for the fish in the cage. The potential environmental impacts on the sea bottom must be an important criteria for the proper siting of a fish cage. Placing cages above or near sensitive habitats such as seagrasses, coral reefs, seaweed beds, etc., that provide nursery areas and habitat to wild fish, must be avoided.

[1] For certain factors, maximum values do not exist because it is possible to adopt different technical solutions on a case by case basis. For others, the acceptability of a value depends on the physiology of the species cultivated.

TABLE 2
Principal factors, method of measurement and acceptable values

Hydrodynamic conditions	Measurement	Acceptable values
Wind speed	Available data, *in situ* measurement, interviews and observation	<10/15 knots
Current speed	Available data, *in situ* measurement, interviews and observation	>10 cm/s <1 m/s
Wave height	Available data, *in situ* measurement, interviews and observation	<1 m
Tidal range	Available data, *in situ* measurement, interviews and observation	–
Geological factors	**Measurement**	**Acceptable values**
Bathymetry	*In situ* measurement and observation	>5 m; <20 m
Typology of sea bed	*In situ* measurement and observation	Sandy
Distance to shore/closest landing	*In situ* measurement and observation	<2 km or the maximum distance for confortable care and servicing
Physicochemical factors	**Measurement**	**Acceptable values**
Water temperature	Available data and *in situ* measurement	–
Salinity	Available data and *in situ* measurement	–
Dissolved oxygen	Available data and *in situ* measurement	>3 mg/litre
pH	Available data and *in situ* sampling	–
Ecological and biological factors	**Measurement**	**Acceptable values**
Organic matter	*In situ* sampling and laboratory analysis	–
Suspended matter	*In situ* measurement	At least 1 m – Secchi disc
Phytoplankton	*In situ* sampling, laboratory analysis and satellite data	–
Presence of sensitive habitats	Visual exploration of the sea bottom	None
Other factors to consider	**Measurement**	**Acceptable values**
Fouling	*In situ* observation and interviews	–
Pathogenic organisms and predators	Bibliography and interviews	None
Sources of pollution	Available data, *in situ* measurement, interviews and observation	Absence of pollution
Coastal activities*	Observation and interviews	Absence of use conflicts

* Transport, fishing activities, military or commercial ports, protected marine areas, etc.

Note: Increasing the distance between the bottom of the net and the sea bed, will spread the faeces and wastes over a wider area and prevent an excessive concentration of organic matter at a single point, thus facilitating dispersal by the sea current. However, the presence of numerous cages in a relatively small area can have relevant cumulative impacts.

For example, in a site with a depth of 7 m, it is possible to place cages with nets 5 m high (which should ensure an acceptable stocking volume for artisanal aquaculture). However, a higher depth (>20 m) requires a larger mooring system, which will affect both the investment costs and its maintenance.

The sea current must have sufficient speed to disperse biological pollutants and fish catabolites, such as the ammonia excreted by the gills, to ensure adequate water exchange within the cage (not less than 10 cm/s). However, an excessive current speed (>1 m/s), in addition to increasing the stress on the cage (see also Chapter 3), causes a loss of feed, which – driven by the current – can be carried outside the net before the fish have time to eat it (worse feed conversion ratio + increase in pollution =

economic losses). Finally, a very strong current implies expenditure of energy for the fish, which have to swim to counter this phenomenon to the detriment of the growth rate, and a reduction in the volume of the net (despite the ballasts attached under the net) affecting the health of the aquaculture stock (see Chapter 4). Figure 1 illustrates the major interactions between the environment and the cage. The wind speed and wave height are closely related, as illustrated in Table 3.

Note: The presence of natural or artificial shelters such as islands, reefs or breakwaters in the surroundings can prevent the waves breaking on the cages.

In general, wooden cages are designed to be used in sheltered areas, as these types of structures are less suitable than those used in industrial aquaculture. The latter are constructed from metal or polyethylene, to withstand waves that are more than one metre high.

The hexagonal shape increases the resistance of the cage to dynamic stress (see Chapter 3) thus allowing the use of more exposed sites (Plate 1).

It should also be taken into account that adverse sea conditions can make it difficult to access the farm for maintenance and daily feeding of the fish. In this case, the risk of material damage is greater and the growth of the fish is severely affected, with an obvious impact on the return on investment. Thus, it is useful to assess the frequency of adverse weather conditions throughout the year, as it is often preferable to have a site where poor conditions occur with a greater intensity (although within acceptable limits) but less frequently.

Finally, knowledge of the typology of the sea bed (see Chapter 3) and tidal range helps in developing an appropriate mooring system.

FIGURE 1

Major interactions between the cage and the environment

Notes: The arrows pointing towards the cage show the impact of external factors on the cage and the fish reared. The arrows pointing away from the cage show the impact on the environment. The arrows pointed at each end indicate mutual interactions between the cage, the environment and the other surrounding cages

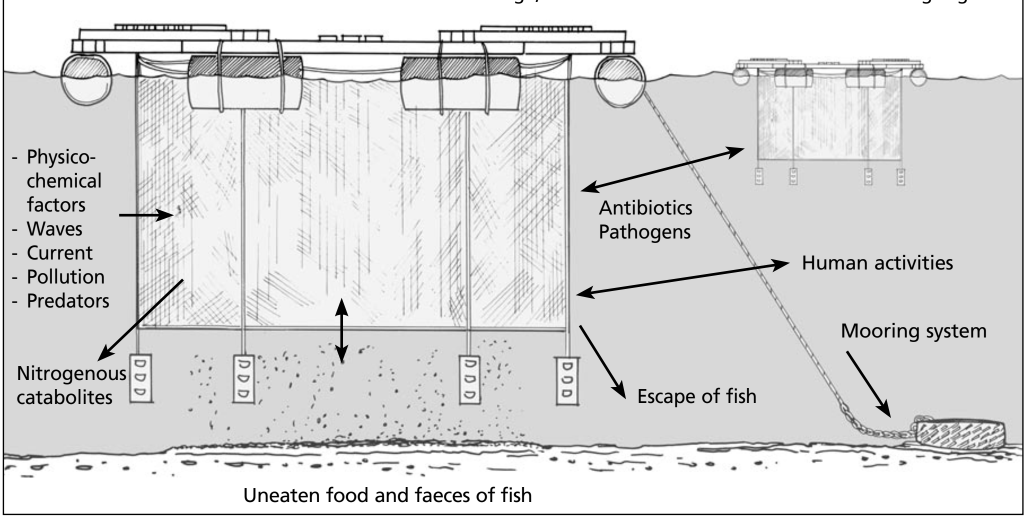


TABLE 3
Relationship between the wind speed and the swell

Beaufort scale	Wind speed (in knots)	State of the sea	Wave height (m)
0	<1	Without ripples	–
1	1–3	With small ripples	0.10
2	4–6	With small waves	0.30
3	7–10	Waves with white foam crests	1.00
4	11–16	Larger and larger waves, more frequent white foam crests	1.50
5	17–21	Moderate waves, many foam crests, some sea spray	2.50
6	22–27	Some waves begin to form, the white foam crests are everywhere and more extensive	4.00
7	28–33	The sea rises, presence of breaking waves	5.50
8	34–40	Waves of average height and great length, all the crests break	7.50
9	41–47	High waves, the crest of waves unfurls in billows	10.00
10	48–55	Very big waves with long crests, the entire surface of the sea becomes white, visibility reduced	12.50
11	56–63	Waves of exceptional height, the surface is covered with beds of foam, visibility greatly reduced	16.00
12	64	The air is filled with foam and sea spray, the sea is entirely white with foam, visibility very severely affected	>16.00

Source: Nardone, 2001.

Physicochemical, ecological and biological factors

It is vital to determine the physicochemical, ecological and biological factors of the site in order to ascertain their compatibility with the species to be cultured.

To be compatible with an environment, a species must find the right conditions for its survival and which meet its physiological requirements.

Given that these conditions differ from one species to another, it is impossible to indicate universal optimal values, as a site may be suitable for one species and be completely unsuitable for another.

Note: In general, marine fish are more demanding than freshwater species, which can be raised in poorer quality environments (notably, less-oxygenated waters and with more suspended matter).

For each factor, there is a range of values within which it is possible for a species to survive. Within this range exists what is known as the optimal value, which ensures maximum well-being, high growth rates, low mortality rates, high production and a better quality product. As the variables are numerous, it is possible that in a given environment not all the factors considered will provide optimal conditions for a given species. It can thus be said that a particular species may be successfully cultivated if it strikes the best balance between the more favourable and less favourable environmental conditions, helping to achieve a good cultivation potential (growth rate, feed conversion ratio, survival rate, etc.).

It is important to remember that all fish are ectothermic (cold-blooded) animals. **Temperature** is thus one of the most important factors because it regulates the metabolism (e.g. level of appetite of the fish and consequently the growth rate)

PLATE 1
(a) Five hexagonal wooden cages placed in an exposed site in the Republic of Djibouti; (b) hexagonal cages, unitary and modular structures in an exposed site in Viet Nam; (c, d) square cages in modular structures in two highly protected bays in Viet Nam

and thereby influences the fish production level. It would never be profitable to rear fish in an environment where the temperature is close to limiting values for the species (even if all the other conditions are optimal).

Attention: Sudden temperature changes should be avoided because they are stressful to the fish and can have negative effects on their immune system. Sea currents, industrial discharges and/or rise in water levels of rivers can cause sudden temperature changes.

Similarly, **dissolved oxygen** is very important for the well-being of the fish; it affects their health, appetite, feed conversion rate and resistance to diseases. Moreover, a well-oxygenated environment is of better quality in many respects (less risk of production of hydrogen sulphide, major biodiversity, etc.) and helps to achieve the highest stocking densities.

Salinity indicates the concentration of mineral salts in the water (notably sodium, Na). The **pH** measures the acidity or basicity of the water. Although various species have different requirements with regard to these two parameters and a different tolerance to their variation, a generalization can be made according to the two major categories, namely marine fish and freshwater fish. As in the case of oxygen, sudden variations need to be avoided.

An excessive quantity of **suspended matter** and **phytoplankton** can cause health problems for the fish. The first will cause branchial irritations and encourage the presence of pathogenic organisms and parasites, while the second – by consuming a lot of oxygen during the night – can cause asphyxia of the cultured fish. In addition, phytoplankton and suspended matter, in reducing visibility, can make it difficult for the fish to locate the feed and thereby lead to feed wastage.

Excessive plant biomass (phytoplankton and macroalgae) can also be dangerous because the dying cells settle at the bottom and their decomposition by bacteria reduce the dissolved oxygen in the surrounding environment.

Attention: When the available oxygen is finished, the decomposition of organic matter is caused by anaerobic bacteria, which, in using up the sulphur instead of oxygen, cause the production of hydrogen sulphide, which is very toxic for the animal species.

Fouling constitutes a major problem facing cage fish farmers whether at industrial or artisanal level. It is caused by sessile marine organisms (especially algae, but also crustaceans and molluscs) that infest all the cage components and the mooring system, thus affecting both the structures and the fish cultured. The weight of the net can be doubled because of fouling, which alters the balance between the force of gravity and the buoyancy of the cage. Moreover, by clogging the meshes, it increases the resistance to the swell and sea current, which exposes the structures (cages and mooring system) to major stress. By preventing or reducing water circulation and exchange inside the cage, as well as the removal of organic matter (faeces and uneaten feed), fouling can lead to a reduction in dissolved oxygen in the farming environment and, consequently, a sharp reduction in growth and the occurrence of health problems and partial mortality of the aquatic stock.

Attention: Owing to excessive infestation from fouling, damage to the structures and holes in the net occur more frequently (risk of partial or even total loss of fish).

In a natural environment, there is a risk of infection caused by **pathogenic organisms**. The fish around the cages may be carriers of germs, often harmless for wild fish, but very infectious in farming conditions (high stocking density and intensive feeding leads to stress, which makes the fish less resistant to infections).

The proximity of sources of pollution, as a result of human activities (industry, agriculture, animal breeding, maritime traffic, etc.) and sewers, can cause the build-up of pathogens and/or the contamination and, in some cases, death of the farmed fish. Furthermore, infected fish may be unfit for consumption.

Attention: This build-up, which may be occasional, might not be recorded on a constant basis during the year. Monitoring and assessment of anthropomorphic activities in the surrounding areas can help to anticipate the risk of pollution. In case of doubt, it is recommended to take frequent samples (for laboratory analysis).

Note: The presence of bacteria known as faecal coliforms, especially the species *Escherichia coli*, is used to detect the sources of pollution by faecal matter.

Logistical and sociocultural factors

Logistical factors, such as the type of infrastructure around the site (Plate 2), are of major importance, especially:

- the road network for the delivery of materials, fingerlings and marketable fish, as well as for easy access to the site by the staff;
- availability of ports or piers or hauling places for the launching of cages and boats;
- availability of a land base for the construction, establishment and management of the future farm (offices, storage of materials, production of ice, preparation of feed for the fish, etc.); and
- electricity and water supplies (or generators and freshwater wells, if necessary).

PLATE 2

(a) Freshwater well, (b) ice-making machine, (c) generator, (d) space outside for construction work

The sociocultural factors involve the following considerations:

- the hostility of local communities (risk of burglary, sabotage, vandalism);
- use conflicts for space (fishing areas, tourism, maritime traffic, presence of other similar enterprises, etc.);
- the availability of human resources (qualified technicians, labour) or training opportunities;
- the interest and availability of communities present to convert to fish farming; and
- the creation of employment.

2.2 SELECTION OF SUITABLE SPECIES

The most suitable species for fish farming are to be found first among the indigenous species. There are two basic reasons for preferring native species:

- their presence in the natural environment assures their physiological compatibility with the environmental conditions of the site; and
- the protection of the ecosystem.

The introduction of non-indigenous species exposes the environment to the risk of disturbance and, for this reason, it is often prohibited. The escape of carnivorous fish can alter, sometimes dramatically, the food chain with repercussions on the entire ecosystem. Moreover, the risk of importing related pathogenic organisms that can be transmitted to wild populations must be seriously taken into consideration. The introduction of non-native species is admissible only with the permission of the relevant authorities and after a quarantine period and all other necessary assessments (see Arthur, Bondad-Reantaso and Subasinghe, 2012). In addition, the transport of fingerlings by road, air or sea requires high-level technology and/or entails costs that are too high for small-scale artisanal aquaculture.

Taking account of these general principles, the main factors to be considered during the species selection process are listed below.

Economic aspects: cost and benefit analysis

The economic aspects include:

- **Sale price/production cost ratio.** This must ensure a satisfactory profit margin. The production cost depends on both the principal technical farming parameters (feed conversion ratio, growth rate, survival rate, total production, number of cages, etc.) and farm management (monitoring, maintenance, feed strategy, etc.), and for this reason it may be different for two farms with similar environmental and logistical conditions.

Attention: A feasibility assessment (technical, economic and environmental) is a fundamental step prior to cage building and mooring. A farmer must indeed make sure that he has enough production volume (this includes the number of cages needed) and benefits to account for its expenditures (including initial investment, seeds, feed, fuel, servicing, minimal infrastructure, work force, etc.).

- **Market potential.** This consists in evaluating the supply/demand ratio so as to establish the annual marketable production and on this basis assess the economic viability of the project. The expected production may be earmarked for the local market or export (in this case, make sure that you are able to comply with the hygienic standards imposed by the importing country).
- **Marketable fish size.** A large marketable size can make the production cycle too long and affect the profitability of the operation (the growth rate being inversely proportional to the age of the fish and their size).

Physiological aspects

The physiological aspects are linked to the biology and ecology of the species considered, such as:

- **Biophysical compatibility** between the species and the site. Several chemical and physical factors should be taken into consideration to assess the physiological compatibility of a species with the environment (see Table 1). The optimal situation will be a blend of the two that ensures good cultivation performance (growth, survival, etc.).
- **Life style.** The farming conditions (volume, size, siting of cages) must correspond to the life style of the species. For example, pelagic fish are not suitable for small cages, while benthic species, which are generally associated with the sea bed, are not appropriate for floating cages. However, certain demersal species that do not need large spaces can thrive in this farming system. Tolerance to high stocking densities depends on the gregarious/solitary nature of the species.

Note: On this subject, there is a significant difference between marine fish culture in ponds and fish culture in cages, as the latter makes it possible to increase the culture density (as in the case of groupers). Moreover, it has been observed that groupers and barramundi perch (*Lates calcarifer*) respond better to feeding when they are at a higher density (FAO, 1988).

- **Adaptability to feeding system.** The growth of the cultivated stock depends on the feed provided, be it industrial feed or low-value fish cut up into small pieces (Plate 3). Certain species do not accept this type of feed, thus it is impossible for them to be successfully cultured.

Technical aspects

The technical aspects to be considered imply prior knowledge and understanding of the production cycle and include:

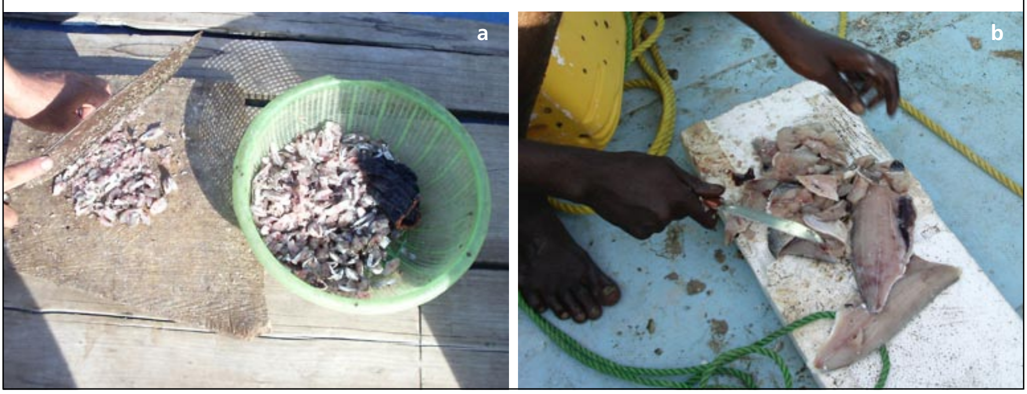
- **Production potential.** The most important factors that determine the potential of a species being reared are the growth rate, the feed conversion ratio, and stocking density.
- **Supply of fingerlings.** This is a most important aspect and constitutes the main drawback to the development of this industry in some countries (notably African countries). The regular stocking of cages is assured when

the artificial breeding of fingerlings in hatcheries is well understood. There is also a type of aquaculture based on the capture of wild juveniles (see Lovatelli and Holthus, 2008). In this case, it is necessary to use the appropriate capture methods while assessing the risk of depletion of the resources (FAO, 2011). In both cases, the source of procurement of the fingerlings should be as close as possible to the farm in order to avoid injuries and stress to the fish and the high cost of unduly prolonged transportation.

- **Food supply.** Carnivorous fish can be reared where there is good-quality pelleted feed, available or produced locally at competitive prices. Low-value fish and animal by-products (e.g. scraps of filleted fish) are widely used in small-scale aquaculture particularly in many Asian countries where these resources are available (FAO, 2011; and Plate 4).
- **Resistance and tolerance.** These characteristics help the fish to tolerate the farming conditions better. Certain species are more tolerant to high stocking densities and handling (during sorting operations, harvesting, etc.), less susceptible to diseases and more resistant to critical conditions, such as low

PLATE 3
(a) Cobia (*Rachycentron canadum*) juveniles fed with low-value fish; (b) example of feed used

PLATE 4
Preparation of feed: (a) chopped fish in Viet Nam; (b) filleting of low-value fish in Africa



dissolved oxygen levels and sudden variations in various parameters (oxygen, temperature, salinity, etc.).

- Mastery of **culture techniques.** Prior knowledge of the production cycle of the species (which implies knowledge of the biology and behaviour during the cultivation process) is an advantage and reduces the risk of failure.

3. Choice of cage model

3.1 BASIC CRITERIA

The choice of cage model is a key step in the design and operation of an aquaculture farm. It is based on economic and technical considerations, as well as the requirements of the species being raised.

The various cage models are different in terms of their materials, shape and dimensions.

A farm can consist of several independent cages or modular structures, which permit savings to be made on the materials used (and also the mooring system) and can have management benefits (e.g. the fish feeding operations are simplified) (Plate 5).

PLATE 5

(a) Circular cage in high density polyethylene tubes (HDPE) used in small-scale aquaculture in Viet Nam; (b) example of a dual cage system, floating structure in HDPE and wooden frame to support the net; (c) the movements of the workers from one cage to another during feeding operations is easier with modular structures; (d) sorting and examination of the fish stock in modular hexagonal cages

In small-scale artisanal aquaculture, the most frequently used cages are constructed from wood because it is a material that is easily available and relatively cheap. This chapter discusses the main factors that influence the choice of the most suitable cage model for the different potential sites.

Economic factors

Owing to the fact that the socio-economic environment in which artisanal cage culture takes place often has a bearing on the possible initial investment, the main considerations should be the following:

Cost and availability of materials used. The main cage structure can be constructed from a variety of materials, such as wood, polyethylene, galvanized iron or steel.

Wooden components have the advantage of being more affordable than the other materials and they can be obtained locally, thus without any shipping or forwarding costs. Similarly, the other cage components, the floating system and mooring system, can be made from local materials, often recycled materials (see Chapter 4; Table 5), that are also reasonably priced and have readily available spare parts.

If necessary, the components can be adapted to meet construction requirements or to offset the unavailability of certain materials locally. Plate 6 gives an example of the production of 20 cm-long bolts by a blacksmith, from a threaded rod of 2 m (as it was impossible to find bolts of this length locally).

As concerns the nets, given the crucial role they play and the expertise necessary to make them, they can initially be ordered from specialized suppliers. Local workers (e.g. fishers) could then try to reproduce the same type of net required.

Simplicity of construction and maintenance. Relatively simple structures constructed from local materials make it possible to use local labour (workers, blacksmiths, carpenters, etc.) both for construction and maintenance, as machines or sophisticated techniques are not required for joining the various components. This provides a double advantage: a smaller financial outlay, and the creation of employment in the local communities (Plate 7).

Stocking volume. This volume is determined by the dimensions of the net (volume = surface × height; see also Appendix 1) which, in demarcating the space in which the fish live, influences the potential production for each cage. In general, it can be affirmed that by increasing the dimensions of the cages, the unit cage volume costs are reduced.

The cost per cubic metre of cage volume is reduced as the size increases (the limit is reached when the dimensions of the cage make it necessary to use more sophisticated materials). Thus, a cage of 100 m^3 is less expensive than two cages of 50 m^3, while achieving the same production (if water exchange is not a limiting factor; see the next paragraph). The cost of the cage should therefore be considered

PLATE 6

(a) Cutting a threaded rod into pieces; (b) welding of the nut to form the head of the bolt; (c) 20 cm bolt obtained; (d) iron bolts, bars and plates made by a blacksmith

PLATE 7

Assembling of components by local workers

in relation to the weight of the fish produced (and to its market value). Moreover, larger units have the advantage of having fewer cages with the same total farm volume (and thus more or less the same production), saving on the materials used and on the cost of management and maintenance.

However, with large cages, if the net is torn (in the event of an accident, action by predators, etc.), the losses are greater. In addition, routine maintenance and certain management activities, such as net changing or fish sorting, can become much more complicated (and require more sophisticated and costly resources).

Technical factors

The experience gained to date in artisanal cage culture has made it possible to exploit diverse environments (rivers, lakes, lagoons and the sea) with different environmental and hydrodynamic characteristics.

Various models have been designed, based on how the different structures react to these characteristics.

A cage model is characterized by its shape, size and volume.

Shape – Most existing cages are square, rectangular, circular or polygonal in shape. Circular cages have a more favourable surface/perimeter ratio (Figure 2) and for which the same volumes can be obtained while saving on the materials used (more beneficial cost/volume ratio, while also considering that being lighter in weight, they require a simplified mooring and floating system; see Chapter 4).

Another important feature of circular cages is that they are more resistant to dynamic stress, which makes them better suited to less sheltered sites.

As it is difficult to construct a circular cage from wooden materials, hexagonal cages (such as the one described in detail in this manual) have been designed. They have similar hydrodynamic characteristics (the hexagon is the geometric shape closest to a circle with a number of sides) and they can be constructed from wooden materials (beams or planks). Moreover, the mooring of the service boat alongside the latter cages is easier than flanking circular ones, while the movement of the workers is safer due to the relative stability of the hexagonal cages.

However, square and rectangular cages have certain advantages that make them preferable in sheltered areas, such as:

- ease of construction;
- possibility of producing large modular structures; and
- a higher water exchange rate within the nets (Figure 3).

Size – The resistance of a cage to dynamic stress caused by the swell and sea currents is also determined by its dimensions. Wooden cages provide greater resistance to stress induced by the swell and currents when they are smaller in size (with cages made from polyethylene, because of the elastic nature of the materials, the resistance increases when they are large-sized). The choice of the most suitable size (just as that of volume) depends on the characteristics of the site. In sheltered sites, the cage size can be increased, while in exposed sites, small cages are more suitable.

FIGURE 2
The perimeters of four different cage models with the same surface area

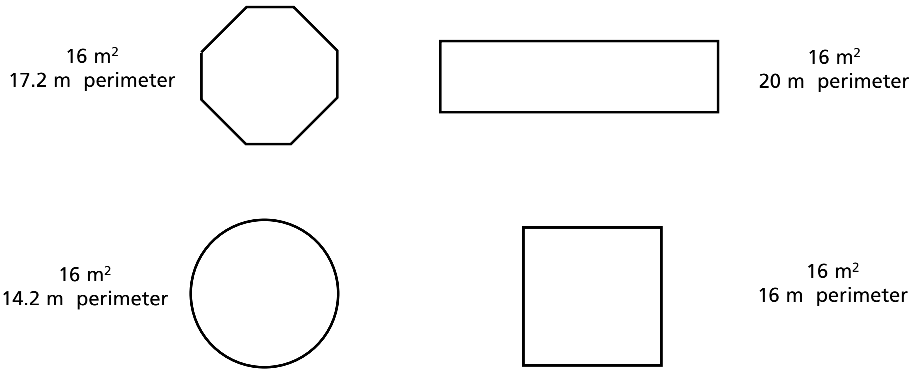
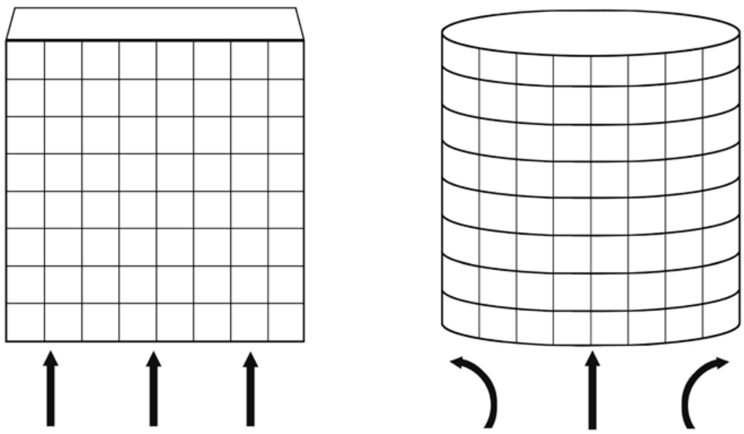


FIGURE 3
Water exchange is better in square and rectangular cages than in cylindrical ones (of the same volume and mesh length)

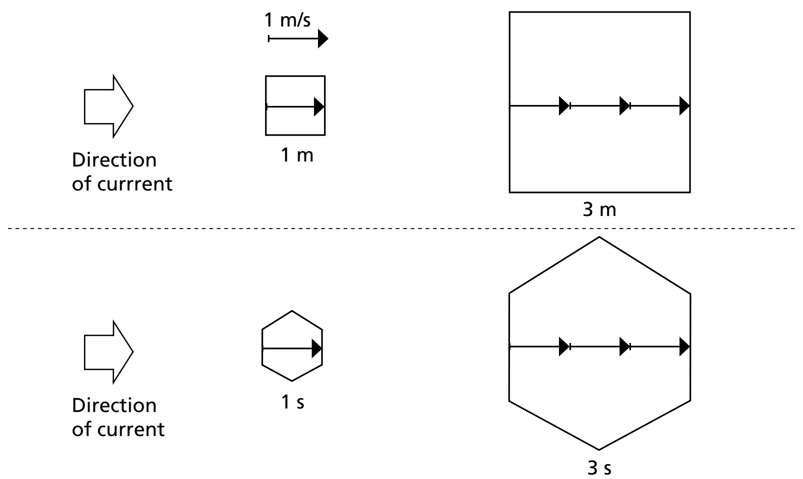


Volume – The water exchange inside the cage is inversely proportional to the volume of the net and depends on the speed of the current and the distance between the opposite walls, as illustrated in Figure 4.

The level of dissolved oxygen is strictly related to the water change by the sea current (the movement of the fish also has an influence on the flow of water inside the cage). In a site with low hydrodynamics, the dissolved oxygen rate can become a limiting factor, and the increase in volume can give rise to water quality problems inside the cage.

All conditions being equal, small cages make it possible to increase the stocking density considerably (e.g. 200 kg/m^3 of fish can be obtained in a cage of 1 m^3, but only 25 kg/m^3 in a cage of 100 m^3).

FIGURE 4
For the same current speed, complete water exchange inside the cage occurs more frequently in smaller cages



On the other hand, small volume cages often induce a loss of feed, which is carried outside the cage by the current before the fish are able to eat it (the feed conversion ratio is adversely affected).

Note: Determining the suitable shape, size and volume of a cage is also important for meeting the requirements of the fish, in particular their swimming and feeding habits (good swimmers, demersal species, use of the water column, ability to feed at the bottom rather than on the surface, etc.), and thus ensuring the well-being of the fish reared. The selection of the right cage helps to reduce sanitary problems and competition among the stock while ensuring a high production of better quality fish, as well as lower production costs.

Evaluating the economic and technical aspects and the requirements of the species being raised make it possible to determine the most suitable cage model.

Table 4 simplifies and schematizes the relationship between the wooden cage model and the environment where the farming operation takes place.

In the selection of the farm site and species, as already discussed, the choice of the cage can also result from a compromise between a number of different variables. In any given location, some conditions will be favorable while others will not.

TABLE 4
Relationship between the characteristics of a site and the most suitable cage model

Characteristics of site	Cage model		
	Shape	Size	Volume
Sheltered	Square/rectangular	Large Modular structures possible	Large
Exposed	Circular/hexagonal	Small	Small
Good quality (high level O_2)	All 4 suitable	Large	Large
Lower quality (low level O_2)	Square/rectangular	Small Modular structures possible	Small

4. Components of a hexagonal wooden cage

This chapter describes the technical details of a hexagonal wooden cage.

This cage model, less well known than square and rectangular cages, but widely used in Southeast Asian countries and in some African lakes or rivers, can be used for fish culture in semi-exposed sites.

The components of this type of cage, and the tools necessary for its construction, are listed in Table 5.

The selection of the components depends on economic and technical factors (availability and cost of materials, equipment necessary, labour, etc.), based on the criteria discussed in Chapter 3.

Plate 8 shows three hexagonal cages installed in the Republic of Djibouti.

An evaluation of the selection of the different components, the role they play and their relationship with the environmental conditions of the site is also provided in this chapter. Finally, other alternatives are briefly illustrated.

PLATE 8
Hexagonal cages placed in an exposed site

TABLE 5

Materials necessary for a hexagonal wooden cage

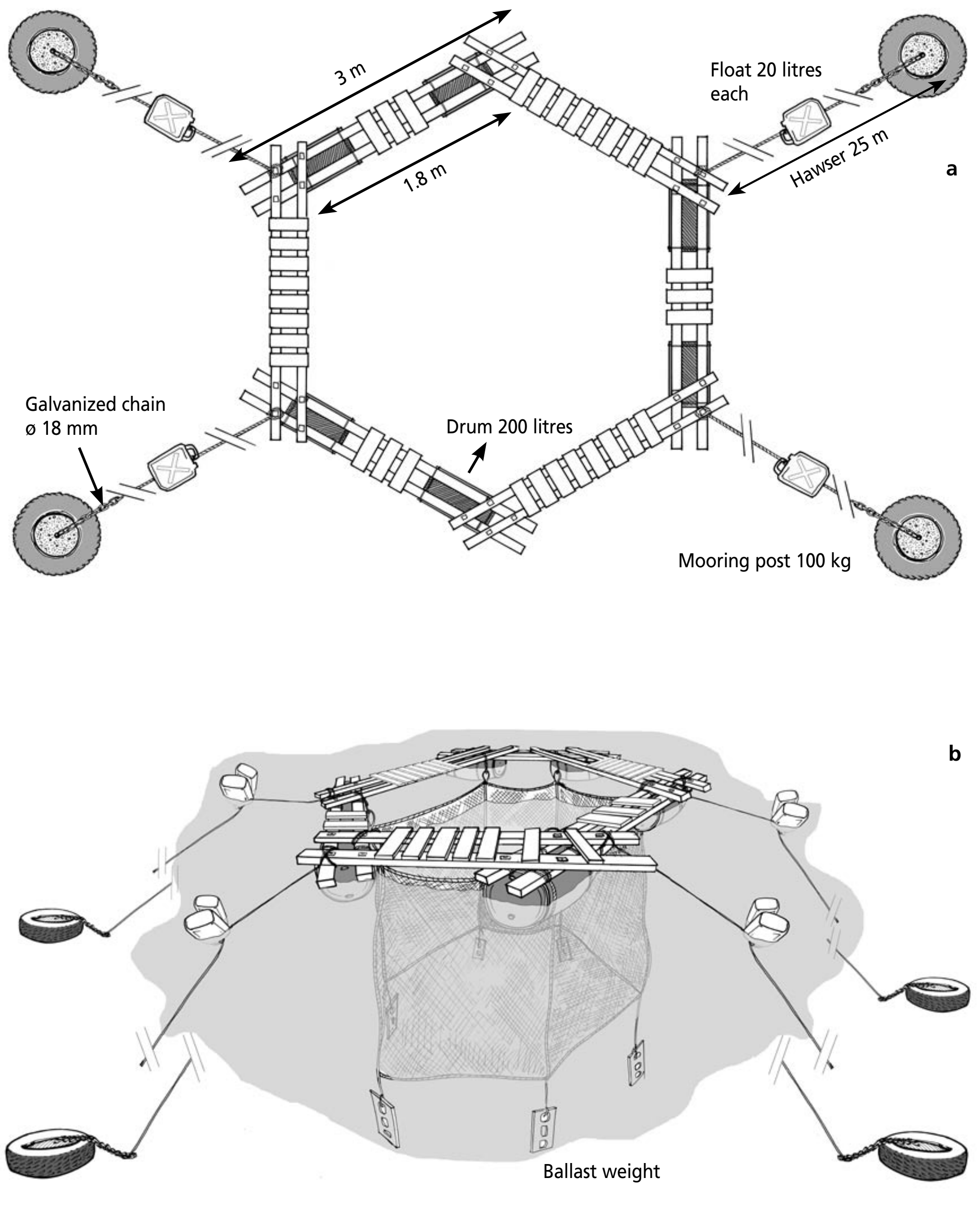
a) Main structure made of wood			
	Component	**Dimensions**	**Quantity**
a1	Beams made of eucalyptus wood	Length = 3 m Width = 13.5 cm Thickness = 6.5 cm Weight = 10 kg	12
a2	Planks made of eucalyptus wood	Length = 50 cm Width = 15 cm Thickness = 2 cm	40
b) Floating system			
	Component	**Dimensions**	**Quantity**
b1	Plastic drum	Diameter = 60 cm Height = 80 cm Volume ≈ 220 litres	6
c) Mooring system			
	Component	**Dimensions**	**Quantity**
c1	Used tyres	Type = R/14 Diameter = 55 cm Height = 20 cm	4
c2	Chain	Diameter = 18 mm Length = 1.5 m	4
c3	Iron bar	Diameter = 18 mm Length = around 4 m	1
c4	Iron bar	Diameter = 18 mm Length = about 50 cm	12
c5	Cement	Bags of 50 kg	1.5
c6	Polyester ropes (hawsers)	Diameter = 24 mm Length* = 25 m	4
c7	Floats	Volume = 20 litres	8
d) Ropes			
	Component	**Dimensions**	**Quantity**
d1	Corde	Diameter = 10 mm Reel of 100 m	1
d2	Corde	Diameter = 8 mm Reel of 100 m	2
d3	Corde	Diameter = 5 mm Reel of 100 m	2
e) Hardware			
	Component	**Dimensions**	**Quantity**
e1	Bolts	Diameter = 16 mm Head = 23 mm Length = 20 cm	24
e2	Screws	Suitable for bolts of diameter = 16 mm	24
e3	Washers	Suitable for bolts of diameter = 16 mm	24
e4	Iron plates	5 × 5 × 0.5 cm thick	24
f) Nets			
	Component	**Dimensions**	**Quantity**
f1	Nylon net	Hexagon of 1.7 m wide and 5 m long	1
g) Ballasts for the net			
	Component	**Dimensions**	**Quantity**
g1	Iron plate	Weight = 7 kg	6
h) Tools			
	Component	**Dimensions**	**Quantity**
h1	Drill	Of the appropriate power to drill a hole in the beams	1
h2	Adjustable spanner	No. 23, appropriate for the screws and head of the bolts	4
h3	Claw hammers	40 cm long	2
h4	Nails	N° 5	1.5 kg
h5	Adhesive tape	–	1
h6	Tape measure	3 m long	1
h7	Old inner tubes	Not important	3
h8	Glue for the caps of drums	Silicone-based	1 tube
h9	Shovels	Appropriate for mixing cement	2

* the length depends on the bottom depth – it should be between 3 and 5 times the depth.

4.1 CAGE MODEL

This cage consists of a double wooden hexagon with an outer length of 3 m and an inner length of about 1.8 m, on which a hexagonal net is attached. The mooring system is composed of 4 concrete mooring posts of about 100 kg each. Figure 5 shows the top view and side view of the cage.

FIGURE 5
(a) Top view; (b) side view of the cage



For the purpose of providing a detailed description of the cage, the four principal structural parts are discussed separately below.

The frame

The frame of the cage consists of a sturdy structure assembled from 12 beams made of eucalyptus wood and joined by 24 galvanized iron bolts (see Table 5 for the dimensions of all the components).

Each side of the hexagon is composed of two parallel beams that are 35 cm apart such that by nailing the wooden planks on top of them, a 50 cm walkway is obtained (the walkway should allow the management staff to move easily around the cage). This distance also makes it possible to place the plastic drums firmly underneath the beams, thus ensuring a better cohesion of the structure (Figure 5, Plate 9 and see Chapter 5).

PLATE 9
(a) Detail of the walkway; (b) feeding of fish

The role of this frame is to:

- provide support to the net (which takes the shape of the frame);
- ensure hydrodynamic characteristics suited to the environment;
- provide suitable points where the mooring lines can be securely tied;
- permit the mooring of the service boat; and
- allow the aquaculturist to work easily above the structure.

Four of the six corners of the hexagon constitute safe, strong and equidistant points where the mooring lines can be attached (see Figure 5).

Note: The dimensions of the wooden elements and, consequently, the related nuts and bolts can vary, within certain limits, depending on the materials available locally. The wood used should be strong enough; different types of wood can be used depending on availability and cost. The length of the side of the hexagon can vary slightly depending on the beams available. These facts apply to all the components of the cage, while ensuring that the frame conforms to the standards set based on the criteria discussed in this manual, as well as in other publications on this subject.

The total weight of the frame is about 200 kg (it is important to know this detail in order to set up the floating system and the mooring system correctly (see below).

Options

The same hexagonal structure can be constructed from iron. This material is strong and is more resistant to damage but is susceptible to corrosion when it is exposed to water for a long time (particularly saltwater or brackish water). However, iron-based cages require specialized labour (blacksmith) and equipment (welding equipment) to construct and maintain them. In addition, it is impossible to undertake minor repairs without towing the cage to land.

Steel or polyethylene cages are more resistant, but the cost of materials and construction is very high, which does not make them suitable for small-scale artisanal aquaculture.

The flotation system

The buoyancy of the cage is assured by using six empty plastic drums of about 220 litres, with a diameter of 60 cm and a height of 80 cm. Each drum has a buoyancy of about 200 kg. The total buoyancy of the system is 1 200 kg (see Appendix 1 for the calculation of the volume and buoyancy of an object).

Respecting the geometry of the cage and construction diagram (see Chapter 5), the six drums are placed underneath the three lower sides of the hexagon, two on each side. This provides the needed buoyancy, adequate stability in water and a uniform waterline.

To attach the drums to the beams, a polyester rope of 5 mm in diameter is used (for the length of the rope see Chapter 5; all the knots mentioned in this manual are illustrated in Appendix 2). Larger twines can also be used depending on the location of the site. A nylon fishing line can be used provided that it is at least 2 mm in diameter.

The role of the floating system is to:

- maintain the wooden structure above the water to prevent it from getting wet (which would cause increase in weight, reduction in buoyancy and decrease in durability) and being infested with teredo worms or shipworms (which would weaken the wood and reducing its durability);
- maintain the upper part of the net (the roof) at a level sufficiently high above the water to prevent colonization by fouling, which by blocking the meshes would make the delivery of feed more difficult or even impossible; and
- ensure the buoyancy and stability of the structure in order to allow routine activities to be carried out smoothly.

The total buoyancy required depends mainly on the weight of the cage. In general, it is necessary to ensure a buoyancy of about twice the total weight, while taking into consideration the wooden structure, the net, the ballasts under the net, the weight of the operators, the weight of the fish (at the time of harvesting) and fouling, which, as it gradually increases, can reach to twice the weight of the net and other components.

In determining the total buoyancy required, it should be considered that:

- Inadequate buoyancy can reduce the resistance of the structure to prevailing hydrodynamic forces; it makes mooring and work on the structure more difficult or impossible. Finally, in the event of accidental loss of a single float the cage can sink straight to the bottom, thus leading to the loss of the batch of fish.
- Excessive buoyancy is a setback because a cage that is too buoyant is easily buffeted by the movement of the water surface. Consequently, the vertical movements are more abrupt and extensive, thus increasing the risk of damage to the cage and ripping of the net. The stability of the operators working on the cage is also reduced.

The plastic drums have the following advantages:

- They ensure optimal buoyancy.
- They are light and easy to handle, which facilitates their installation and replacement, if necessary.
- Unlike iron drums, they do not suffer corrosion and they require less maintenance.
- They are generally available locally at an affordable price.
- Their flexibility makes it easy to tie them securely to the structure.

Options

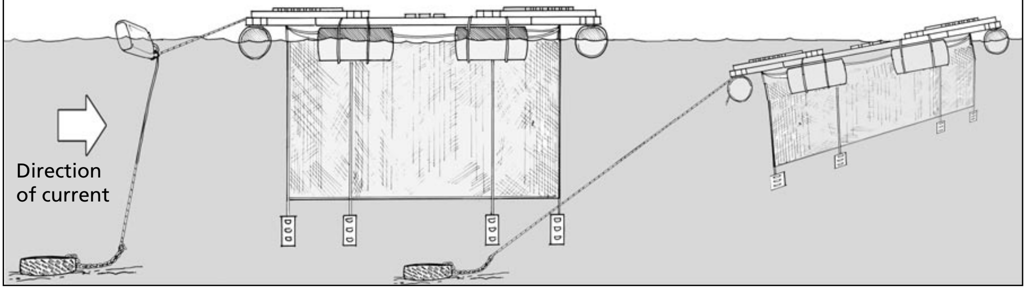
- Iron drums, but they are heavier, less buoyant in an equal volume of water, and susceptible to corrosion due to the galvanic current (less durability).
- Polystyrene in general, but it is less resistant, some pieces can break off, it absorbs water gradually, and thus the weight increases and buoyancy diminishes.

The mooring system

The mooring system envisaged for this cage consists of:

1) Four concrete mooring posts of 100 kg each (see Appendix 3 for the exact composition of the concrete and characteristics of the mooring posts).
2) Four pieces of chain with a chain size of 18 mm and a length of 1.5 metres (one for each mooring post; see Chapter 5). In general, the chains of a mooring system play the role of a shock absorber (being composed of several links, the spread of the force caused by the heavy swells is absorbed all along the chain). Moreover, the chain prevents the rubbing of the hawser on the concrete (when it is not stretched by the hydrodynamic forces), reducing the risk of the rope breaking (see Figure 1 and Figure 5).
3) Four hawsers, with a diameter of 24 mm and a length of 25 m, that constitute the mooring lines. The mooring lines connect the cage to the mooring posts. The appropriate diameter and length depend on the strength of the wind, current, swell, size of the cage and depth of the water. The breaking load of

FIGURE 6
How floats prevent accidental immersion of a cage
When the cage is subjected to the thrust of an excessive current, the floats, in resisting their vertical thrust, prevent one side of the cage from accidental immersion. Moreover, they absorb the force induced by the surge thus avoiding excessive tensions on the points where the mooring lines are tied to the beams



a rope depends on the fibre that it is made of and its diameter. Appendix 4 indicates the breaking loads of different types of rope in comparison with their diameter.

4) Eight floats of 20 litres. The role of the floats is to absorb the heavy swells of the sea (to spread the surge strength). In addition, they prevent the side of the cage exposed to the current from becoming submerged by the thrust of an excessive current (Figure 6).

The mooring system serves to hold the structure in place and prevent it from drifting with the current, wind or surge. To ensure its effectiveness, the appropriate dimensions should be determined by considering three main factors:

a) The total weight of ballast required. In the case of a concrete mooring post, the total weight of the ballast should be at least one and a half times the weight of the structure (cage and net). On soft bottoms (sandy, muddy), the mooring post is thus better secured and the system more efficient.

Attention: The available technical resources should be taken into account. For example, where no crane is available, the mooring posts should not exceed a certain weight so that they can be moved by hand. In this case, if the total weight of four mooring posts is insufficient to ensure the effectiveness of the system, their quantity can be increased (e.g. two mooring posts can be used for each mooring line, making eight in total).

b) The length of each mooring line. The hawsers must be three to five times longer than the depth to ensure more effective elastic absorption of heavy swells.

Note: The length of the hawsers determines the points where the mooring posts must be placed, or the surface occupied by the mooring system at the bottom of the sea. Appendix 5 explains how to calculate the location of the mooring posts.

c) A study of the main local hydrodynamic parameters gives an indication of the necessary diameter of components such as the hawsers and chains. In the event of extreme conditions, all the components should be above the normal dimensions (weight of mooring posts, diameter of hawsers, volume and/or number of floats).

Options

A viable alternative is to use anchors instead of mooring posts. The choice between the two is determined by availability and especially the cost.

In general, anchors are more expensive and it is important to choose the model that is most suitable for the sea bed. However, the weight of a mooring system by anchorage can be considerably smaller than one that uses mooring posts.

For ballast, large stones can be used, but for the same weight, they are more cumbersome and less adhesive. Moreover, because of their uneven shape there are no points where ropes can be securely tied.

The net

The net, by delimiting the space where the fish live, determines the stocking volume. The volume depends on the dimensions of the net (surface × height), the height of the net being dependent on the height of the water column. It is advisable to leave a minimum of 2 m between the bottom of the net and the bottom of the sea (or a lake or a river, etc.), so that the sea current can remove the cage wastes while preventing the fish from being too close to the bacterial fauna that colonize these wastes.

More detailed information on the nets usually used and their technical features is provided in Box 1. See also Figure 7.

The net envisaged for the cage described in this manual is a hexagonal net with sides of 1.7 m and 5 m high (which varies depending on the depth). It determines a stocking volume of 37.5 m^3 (see Appendix 1 for the calculation of the surface area and volume of a hexagonal cage). The stocking density, which is the biomass produced per cubic metre, depends on the species cultured. Assuming an average of 30 kg/m^3 in a tropical environment (for average and large volumes), such a cage can produce about 1 125 kg of fish per production cycle.

Figure 7 gives an example of the appropriate net for this cage with all the required features.

A design like this one can be sent to a supplier when placing an order.

In Plate 10, the difference between a knotted net and a knotless net is illustrated.

Given the cost of the net and importance of the choice of the most suitable mesh (see Box 1), Table 6 indicates the relationship between the mesh size and weight of the fish. This ratio depends on the species reared, particularly its morphological characteristics. The table refers to groupers.

Ballast weights of 7 kg each are provided at the six corners of the bottom of the net (see Figure 1 and Figure 5), in order to maintain the same shape under

BOX 1

Main features of the fish farming net

Nets used for aquaculture are generally obtained from specialized suppliers because of the expertise needed for their production. The main technical features of such nets are:

- The net shape – The net always takes the shape of the cage on which it is mounted. The perimeter is slightly smaller to prevent the net rubbing against the frame, which would inevitably create holes in the net. The height, which determines the stocking volume, is a more variable factor and depends primarily on the sea depth but also on other technical factors.
- The materials – The net can be made from various synthetic fibres, such as nylon, polyester and polypropylene. Nylon, which is highly resistant, is the most widely used because of its superior breaking load and durability. However, it is more expensive and less resistant when exposed to ultraviolet rays.
- The twine number – The twine number is the size of the net twine. It is expressed in two figures, for example 210/70. The first indicates the linear weight of the primary fibre that makes up the twine while the second corresponds to the number of fibres making up the net twine. A higher twine number (e.g. 210/86) means a higher breaking load and higher weight (reflected in the cost of the net).
- Knotted or knotless – These two different types relate to the technique used in making the net. The second is preferable in order to prevent the fish from becoming injured by rubbing themselves against the walls of the cage. Moreover, knotless nets provide better protection against colonization from fouling (i.e. less surface available for organisms to settle on).
- The mesh shape and size – The shape may be square or hexagonal as this does not significantly affect either the cost or the behaviour of the net in water. However, the mesh size is very important. It depends on the size of the fish being reared and it influences the water circulation in the cage and the dynamic resistance to the sea current. For the same volume, a close-meshed net is heavier and thus more expensive (given that the weight is one of the factors that determine the cost of the net).

Other elements are necessary for the preparation of a net. These are:

- Horizontal support ropes (or top, middle and bottom ropes) – There are generally two or three of them (three if the cage has a guardrail), one at the bottom of the net and one at the higher end. The diameter depends on the net size and mesh.
- Vertical support ropes – The number depends on the shape of the net. They serve to increase the resistance to forces induced by sea surges. Moreover, they support the weight of ballasts attached to the bottom of the net, which makes it easy for the net to maintain the appropriate shape.
- Connetions or fastening loops – These are extensions from vertical ropes, at both the higher and lower end, that serve to fix the net to the cage and to attach the ballasts to the bottom. They can be replaced by loops made of rope in order to facilitate the fixing process.

the strength of the current. The current strength can cause the net to become deformed, which, by severely reducing the cage volume, can cause stress and injuries, and even the death of the fish.

FIGURE 7
Design of a net with all the technical specifications

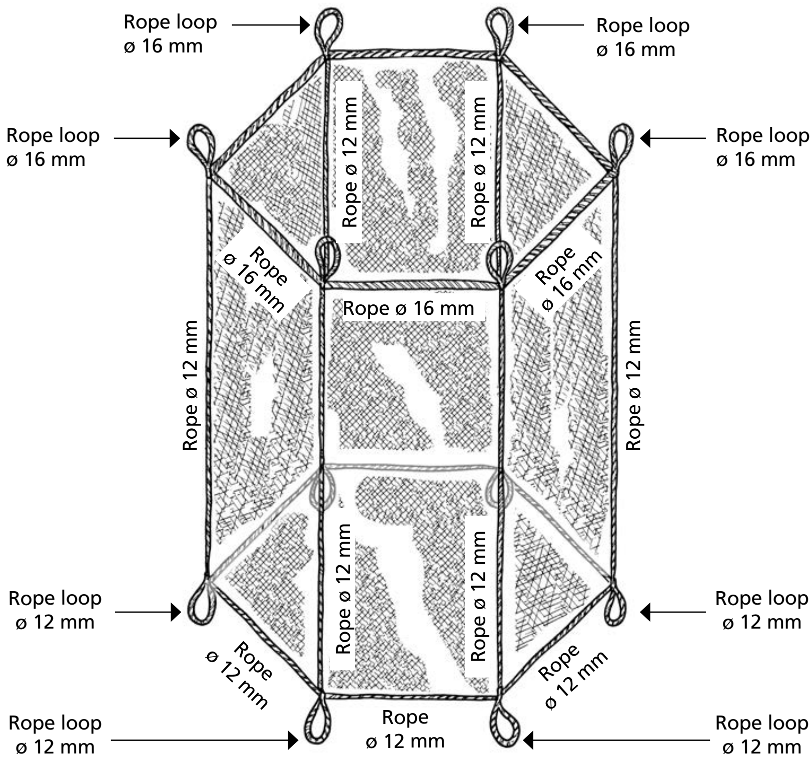


PLATE 10
a) Knotted net; (b) knotless net

TABLE 6
Relationship between fish size (groupers) and net mesh

Phase	Length (cm)	Weight (g)	Net mesh (mm)
1	3–7	7	8
2	15–20	100	20/22
3	25–30	300	25
4	35–40	700	30

Options

Rigid metal or plastic nets can be used, but they are not suitable for an environment with strong hydrodynamic conditions and for average and large fish rearing volumes.

Nets can be sewn by people with the necessary know-how (e.g. fishers), by cutting and sewing nets that can be bought locally (e.g. trawls) and with the appropriate characteristics (dimensions, mesh size, twine number, etc.)

Attention: Given the crucial function of the net, it is preferable to choose one of good quality even if it is more expensive, especially as a good-quality net can be used for several production cycles (after cleaning and maintenance), while paying off the initial investment.

5. Cage construction

The cage construction process should be preceded by a careful examination of all the materials (components and appropriate tools, see Chapter 4; Table 5) to verify their conformity with the required technical features. This check should preferably be made when the supplies are delivered. In fact, it often happens that certain components may not be available at the time needed and have to be ordered by the suppliers based on the specifications provided (e.g. dimensions, weight, number).

Attention: The assembly site where construction takes place is often far from the location of the suppliers. An unsuitable component that cannot be used can delay work for a long time.

The second stage involves the transfer of materials to the assembly site for construction of the cage. The desired features of this assembly site are:

- Availability of a warehouse to store the cage components, tools and equipment from theft and bad weather.

Attention: Certain components (notably the net) could be damaged by rats and/or insects.

- Availability of electricity to connect the necessary electrical equipment (such as the saw and drill). In the absence of mains electricity, a generator can be used as an alternative solution.
- Availability of space outside; there must be sufficient space for the construction of the cage. Moreover, the land must be flat to allow for the movement of the cage components and facilitate assembling. The construction area must be as close as possible to the cage installation site (as its dimensions could make transportation difficult), and protected from the sun, wind and rain (Plate 11) as far as possible.

The next stage involves the organization of the work and identification of the most suitable places for each operation. For example, to prepare the mooring posts, provision must be made for space to mix the cement and arrange the tyres to be filled with fresh concrete (see the following section and Plates 12–17).

The procedure for constructing a hexagonal wooden cage and its mooring system, divided into three key steps, is covered in the following paragraphs. For the technical details of the materials (components, ropes, bolts and nuts, etc.) to be used, see Chapter 4 and Table 5.

PLATE 11
A flat open area is required for the construction of cages

5.1 PREPARATION OF THE MOORING POSTS

1) Line up the old tyres on plastic bags or cardboard, as indicated in Plate 12.
2) Set up two stands (using cans, stumps, etc. if necessary) at the two ends of the lined-up tyres. Place an iron bar (Ø = 18 mm) on the two stands and ensure that it is firmly attached and does not move (Plate 13).
3) Using the iron bar, hang a chain segment above each tyre making sure that the last three or four chain links are located in the centre of the tyres (the chain can be temporarily attached to the iron bar with a piece of string if necessary) (Plate 14).
4) Pass the iron bars (50 cm) through the three or four chain links in the middle of each tyre, as shown in Plate 15.

PLATE 12
Old tyres used for the construction of concrete blocks lined up on used plastic bags

PLATE 13
The drums of the floating system are initially used in the preparation of the mooring posts

5) Mix the cement, sand and water in the proportions indicated in Appendix 3 and use the mixture to fill the tyres (Plate 16).
6) Leave the cement to dry, taking care to sprinkle water on it for the number of days required for it to harden (the sprinkling of water three or four times a day is advisable if the weather is hot) (Plate 17).

Note: By means of this system, one can avoid using shackles to attach the chains to the anchor ring and save on costs, especially as the shackles tend to split up in the water and constitute a weak link in the mooring system.

Thus prepared, the mooring posts constitute the first part of the mooring system. The elements to be added are the mooring lines. The procedure for tying the mooring lines to the chains, an operation done during the installation of the cage in the sea (lake, river, etc.), is discussed in Chapter 6.

PLATE 14
Arrangement of chains

PLATE 15
Crossed iron bars in the tyres

PLATE 16
The tyres are filled with concrete

PLATE 17
Mooring posts prepared and left to dry

5.2 FIXING OF THE WOODEN STRUCTURE

A detail of the completed cage with specific dimensions is illustrated in Figure 8.

All the tools needed for this operation are shown in Plate 18.

7) Arrange on the ground the six beams that represent the three lower sides of the double hexagon, making sure that the two parallel beams on each side are 35 cm apart (Plate 19).
8) Arrange the six beams that represent the three upper sides on top of the three lower sides in order to obtain a regular hexagon (Plate 20).
9) Check that the six inner sides of the double hexagon are of equal length (about 1.8 m). Move the beams as necessary until a regular hexagon is obtained (Plate 21).

FIGURE 8
A corner of the cage and the distance between the components

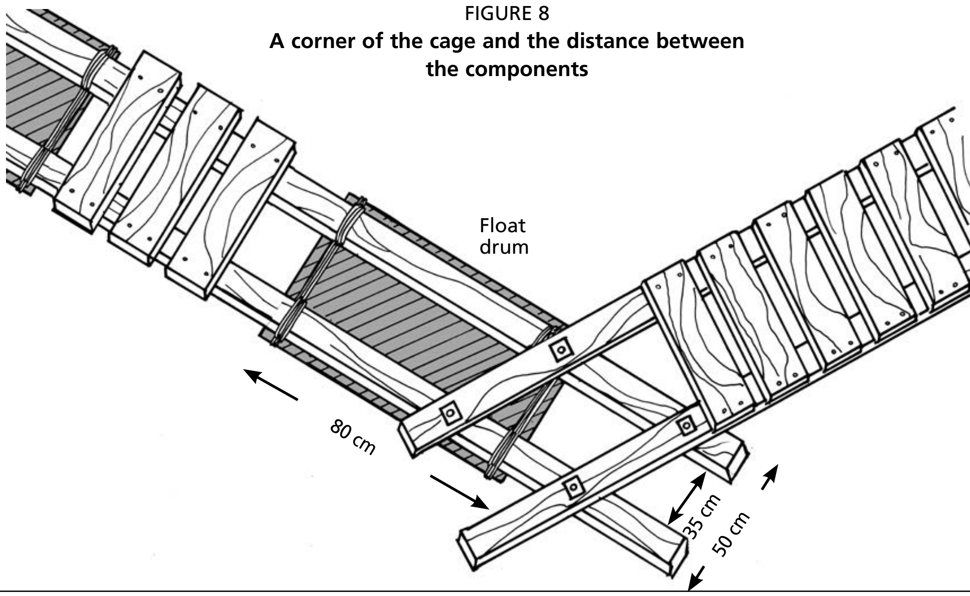


PLATE 18
Tools required for cage assembly

PLATE 19
(a) Arrangement of the first lower beams;
(b) verification of the distance between the parallel beams

10) Use a drill (bit Ø = 16 mm, the holes corresponding to the diameter of the bolts) to make the 24 holes (4 in each corner) where the beams are superposed. These holes constitute the 24 points for insertion of the bolts (Plate 22).
11) Insert the 24 bolts with their washers and iron plates in the 24 holes (Plate 23 and Figure 9).

Note: Sections 10 and 11 can be combined. In fact, in order to avoid the situation where, after drilling the 24 holes, the holes of the upper beams do not correspond to the lower beams (owing to accidental knocks, vibrations during perforation, etc.), it is sensible to insert the bolts (with their iron plates and washers) each time a hole is drilled.

PLATE 20
Arrangement of upper beams

PLATE 21
Verification of the length of the internal sides

Attention: When the bolts are inserted, take care not to damage their threads (especially if they are inserted with a hammer and if the supporting surface is hard), as this would make it difficult afterwards to screw the nut underneath.

12) Raise a corner of the hexagon, place an object (old tyre, stump, stone, etc.) underneath it and screw the four nuts (with their washers) onto the four corresponding bolts. The bolts and nuts should be tightened with two adjustable spanners. Repeat this process for all six corners (Plate 24).
13) Remove the supporting object described above and nail the 50 cm planks between the parallel beams of each upper side (it is necessary to wait for the floats to be assembled (see Section 5.3) before nailing the boards onto the lower sides) in order to obtain the walkway (see Figure 8).

PLATE 22
(a) Drilling of holes in the beams; (b) the holes for the insertion of the bolts are ready

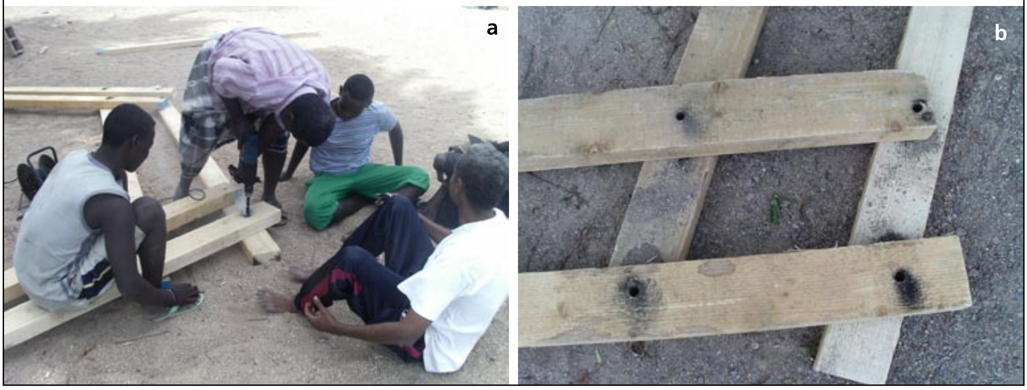


PLATE 23
(a) Bolt insertion; (b) all four bolts properly inserted in the first corner

FIGURE 9
Schematic drawings illustrating the correct insertion of the bolts, iron plates and washers

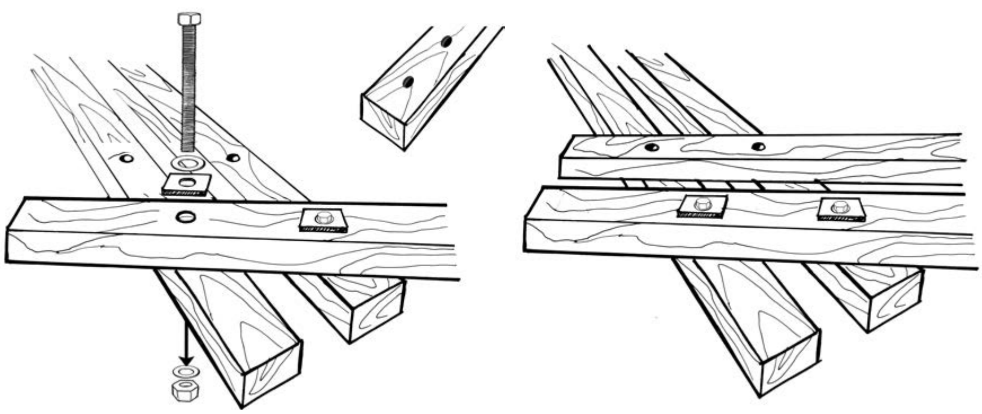


PLATE 24
Tightening of screws

5.3 PREPARATION OF THE FLOATATION SYSTEM

14) Spread some glue on the screw caps of the drums and tighten them in order to make them completely watertight (Plate 25).
15) Tie two pieces of rope (Ø = 5 mm) of about 8 m in length to each end (lower and upper) of the 6 drums, in order to have 4 loose ends that will be eventually used to fix the drums to the wooden frame. On each side of the drum the two loose rope ends should be positioned opposite to one another (use the knot type (i) illustrated in Appendix 2) (Plate 26).
16) Place the six drums under the hexagonal wooden frame structure, with two under each lower side (Plate 27).
17) Tie the drums to the beams with the four ropes of Ø = 5 mm (see point 15 above) using the knot type (ii) shown in Appendix 2 (Plate 28).
18) Nail the planks onto the lower sides of the hexagon so as to fill the spaces between the two drums (see Figure 8).

At the end of these steps, the cage is completed and ready to be launched. It can be placed along the edge of the sea (river, lake, etc.) or on the pier of the port to be later towed to the installation site (see Chapter 6) (Plate 29).

PLATE 25
a) Spreading of glue; (b) tightening of the screw cap

PLATE 26

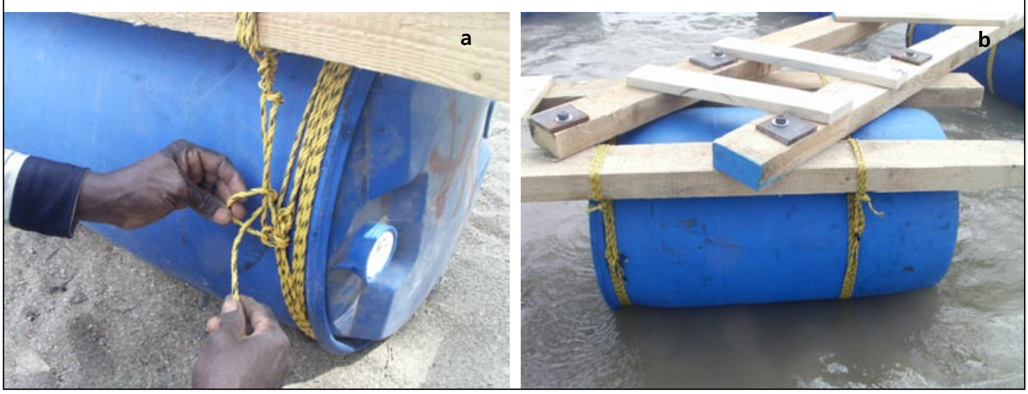
(a) Fixing the first rope on one end of the drum; (b) fixing the third (top left) rope to the drum, with the bottom right still to be added

PLATE 27

Installation of drums under the cage

PLATE 28

(a) Tying of drum to the beam; (b) drum securely tied with the four ropes to the cage



The cage can easily be carried by four or five people (Plate 30).

PLATE 29
(a) Completed cage ready for use; (b) cage ready to be towed to the installation site

PLATE 30
Completed cage being hand-carried across the beach

6. Cage installation at the farming site

The following paragraphs discuss the procedure for placing in the sea (lake, river, etc.) a fish farming cage, such as the one described in the previous chapter.

In general the installation of fish cages is preceded by marking the boundaries of the farm site in order to avoid future accidents, particularly from boats navigating through the area. All boat traffic and other commercial activities such as artisanal and industrial fishing, transportation of goods and persons, etc., should be prohibited in the vicinity of the farm. The legislation in force in each country should provide the technical specifications of the required beacons (e.g. height, shape, type of lighting signals and their period of validity and scope).

A marine farm is marked by four buoys anchored to the bottom by mooring posts of adequate size, positioned at the four corners of its boundary. Following the same outline used to illustrate the construction of the cage, the cage installation in the sea is also divided into four different stages.

Box 2 describes the features of a site (as well as the resources used) in the Republic of Djibouti, where a farm composed of five hexagonal cages (constructed in line with the procedures described in this manual) has been established.

BOX 2

Principal features of the Loyada site, Djibouti

The site selected for the establishment of a marine farm, composed of five hexagonal wooden cages, is located in the south of the Republic of Djibouti near the border with the Somali Republic.

A feasibility study based on environmental factors (meteorology, hydrodynamism, local fauna, etc.) and on logistical and social aspects was conducted before placing the cages in the sea.

The town of Loyada has a small border outpost from where the military personnel, using a small boat, control maritime traffic, which is an advantage because the marine farm is under constant surveillance thanks to their presence.

A community of artisanal fishers living in Amerdjog (a neighbouring village), fish with mesh nets and a line fishing system with about ten small boats 5–6 m long equipped with outboard motors of 25–40 hp. The Loyada fish factory, built beside the beach, produces the ice necessary for fishing trips, which can last 2–3 days. It also serves as a meeting point for the fishers and a landing site for fish (mostly destined for the market in the city of Djibouti).

Although there is no visible shelter and the fetch is considerable, an analysis of historical data and surveys carried out within the local community have established that, because of the presence of a coral reef offshore, the waves are never higher than 1.0–1.5 m. The prevailing

BOX 2 (continued)

winds during the year come from the east/northeast, but their speed is never excessive (maximum 5–6 knots). In July and August, a blistering wind, called Kahmsin, blowing from the northwest desert zone at up to 40–50 knots causes discomfort to the population of the country. However, coming from the landward side, this wind, although it can prevent fishers from going to sea, does not produce waves large enough to damage the cages.

To obtain the depth suitable for the establishment of the farm, a site was selected at a distance of about one nautical mile (1 852 m) from the coast, with a depth of 7 m (at low tide, the tidal range being almost 80 cm) and a muddy sea bed.

These two conditions are favourable for mounting cages with nets 5 m deep and a mooring system composed of concrete mooring posts. Moreover, this site is not a fishing area so there are no conflicts with fishers. Immediately after this bathymetric line, the presence of the reef provides a shelter that prevents breaking waves from striking the cages.

No historical data on sea currents are available, and assessments have been based both on reports from local fishers and direct observations. The current speed seems to be perfectly compatible with the proposed fish farming project (small-scale artisanal fish farming) as it has never been less than 10 cm/s, which allows sufficient water exchange in the cages and ensures the removal of the faecal matter and catabolites of the fish being cultured. The maximum speed does not exceed 1 m/s, which prevents the deformation of the cage nets (causing a marked reduction in the rearing volume) and the loss of feed during the feeding of the fish stock.

The water temperature is between 25 °C in winter and 30 °C in summer, the salinity ranges between 36‰ and 38‰ and the dissolved oxygen level (which is 6 mg/litre) determines the composition of the very rich local fauna, which mainly consists of demersal species, groupers, snappers, red mullets, etc., and grey mullets (highly appreciated by the local market) and large and small pelagics (notably Spanish mackerel, carangids, tuna, barracudas, sardines), as well as dolphins and certain species of sharks (which constitute a danger for fish farming operations as they are potential predators).

The target rearing species are to be found among the demersal fish, especially groupers. The stocking of cages began with about 200 groupers of 180 g (with the present fishing systems being used, it is difficult to capture small-sized specimens) caught in the surrounding waters. Feeding trials have been successfully carried out by providing the grouper juveniles in the cages unmarketable low-value fish, chopped into small pieces.

The five cages were constructed with the support of three technicians from the Department of Fisheries (DoF) of the Ministry of Agriculture of Djibouti and some fishers who were selected from the local community to provide labour. The cages were placed in the sea by the same team using a boat belonging to the DoF, equipped with a 40 hp outboard motor.

The management of these first trials has been entrusted to two fishers, selected from the local community, under the supervision of technicians from the DoF, who will be mainly responsible for the collection of key technical data and parameters (e.g. the feed provided, feed conversion ratio, specific growth rate, and mortality rate) in order to complete the feasibility study with the necessary technical and economic assessments pertaining to the fish cage farming operation.

All the operations described below require a small boat (5–6 m) equipped with an outboard motor (25–40 hp), assuming the small-sized cages used in artisanal aquaculture.

6.1 MARKING OF MOORING POINTS

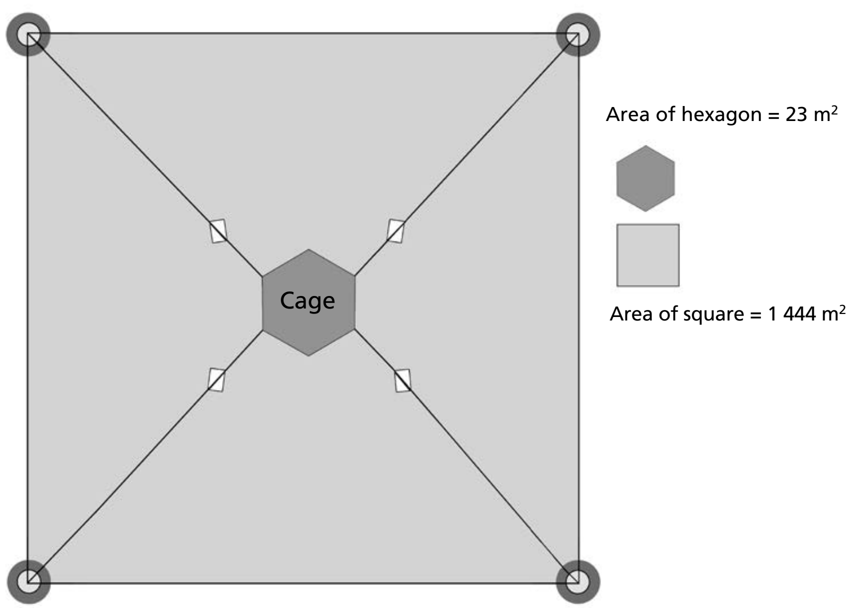
Cage installation is always preceded by the deployment of the mooring system in the water. As indicated in Chapter 4, the mooring system occupies more space at the bottom of the sea than that occupied by the floating cage (as this area is not visible from the surface), and respecting this geometric detail is very important in order to ensure the effectiveness of the system.

The cage correctly installed should be at the centre of a square whose four corners are represented by the mooring posts (Figure 10). Appendix 5 explains how to calculate the location of the mooring posts and the length of the sides of the square.

In order to position the mooring posts correctly, the points where they are to be placed have to be previously marked. The procedure for marking the four corners of the square is as follows.

1) Prepare four provisional marker buoys by using four ropes (Ø = 8 mm) each with one end of the rope attached to a weight of about 10–15 kg and the other to a float (e.g. an old empty 20-litre plastic drum). The length of the four ropes must be slightly longer (by about 1 m) than the water depth at the installation site. In addition, prepare four guide ropes of the same length (see Appendix 5 for calculating the lenght of the guide ropes) as the side of the square shown in Figure 10 (these ropes will provide the distance that should separate the mooring posts, equal to the side of the square; see Figure 11).

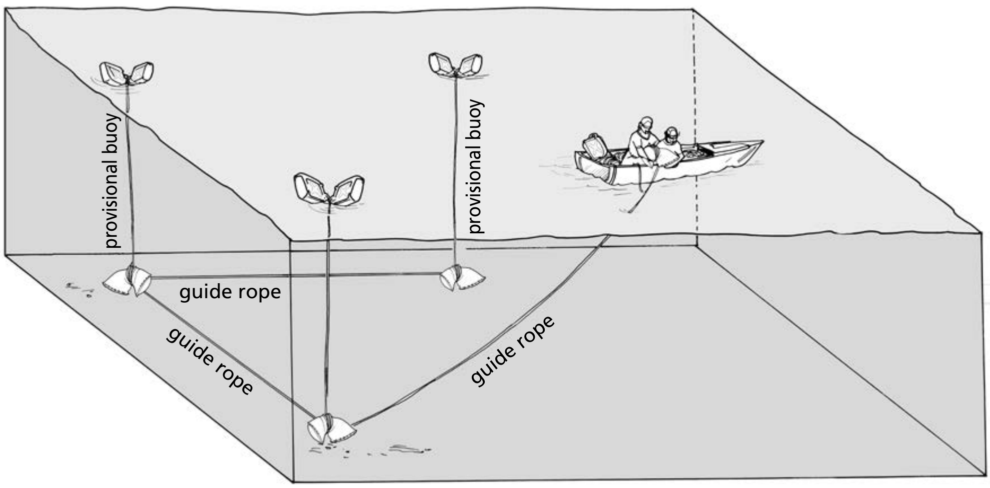
FIGURE 10
The area occupied by the mooring system in relation to that of the cage



2) Connect the two weights using the first guide rope (Figure 11).
3) When the first corner of the square is reached (determined visually within the farming site), place the first provisional marker buoy in the sea. Move with the boat until the first guide rope becomes fully stretched and then place the second mooring buoy, taking care to first attach the second guide rope.
4) Move with the boat, so as to form a right angle (90°) with the first side of the square, until the second guide rope is entirely released, and then place the third mooring buoy in the water after tying the third guide rope.
5) Repeat this process for the last marker buoy to be placed in the water.

Note: In this phase, the operators use the first marker buoys installed as visual markers to obtain the square desired. It is possible to move the mooring buoys with an auxiliary rope tied to the weights and pulled by the boat in the direction desired, in order to adjust their position as necessary.

FIGURE 11
Installation of provisional marker buoys at the cage farm site



At the end of these five steps, the four corners are now marked. The corners can be marked one day or a few days before the mooring posts are placed in the sea. However, it would be better not to wait too long because the provisional marker buoys could move or be lost as a result of the current, the surge or because of inquisitive persons or thieves (Plate 31).

6.2 PREPARATION OF MOORING LINES

The elements that connect the cage to the mooring posts are the mooring lines. Each mooring line consists of a rope whose characteristics (in terms of material, diameter and length) depend on the hydrodynamic conditions and bathymetry of the site.

PLATE 31
Provisional marker buoys delimiting the farm site

To prepare the mooring lines, it is necessary to:

6) Uncoil the rope. The ropes are often delivered in large coils (100 m or more). To uncoil them properly take hold of the inside end (never the outside one!) located in lower part of the roll and draw it out holding the end (taking care to uncoil the rope in a counter-clockwise direction) until the entire line is uncoiled (Plate 32).

Attention: A roll of rope that is not properly uncoiled will form loops that will prevent the entire line uncoiling by forming an entangled mess. To uncoil the rope correctly, it can also be rolled up in a clockwise direction to keep the reel intact.

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7) Measure and cut the rope to obtain the length required for each mooring line, taking care to roll adhesive tape around the part desired, before cutting, to prevent the ends from opening (Plate 33).

Attention: Take care to leave enough rope to tie the ends on the cage and on the chain link of the mooring post (several metres may be needed; it is advisable to do several trials before cutting the rope).

PLATE 32

(a) Coiled rope on delivery; (b) reach in and take hold of the inside end; (c) draw it out holding the rope end; (d) pull out the entire length of the rope

PLATE 33

Protection of the rope with adhesive tape

8) When the rope is stretched out on the ground, the points where the mooring line will be tied to the cage should be marked. Use the first line prepared as a guide to mark the same points on the other three lines. This procedure helps to obtain four identical lines and a perfectly balanced mooring system (Plate 34). In addition, mooring the cage will be easier.
9) Tie one end of the mooring line to the last link of the chain segment of the mooring post using knot type (ii) illustrated in Appendix 2. Protect the knots to prevent them rubbing against the successive link (e.g. using strips obtained by cutting old inner tyre tubes), as shown

in Plate 35. Repeat this process for the other three mooring lines (the mooring lines can be tied to the chains before or after loading the mooring posts onto the boat depending on the space and means available).

10) Coil the mooring lines, forming a circle clockwise (Plate 36). This is important because during mooring the rope must be uncoiled without becoming entangled (see below).

The mooring system is now ready for deployment on the site.

PLATE 34
Preparation of four identical mooring lines

PLATE 35
Sequence for correctly tying the mooring line to the chain link and protecting it from rubbing against the chain

PLATE 36
(a) Coiling the mooring line; (b) coiled mooring line ready to be lowered into the water

6.3 INSTALLATION OF MOORING POSTS AND MOORING OF THE CAGE

Before deploying the mooring posts and towing the cage to the farming site, it is advisable to organize the space on the boat properly. It is often useful to arrange pallets on the hull in order to protect the boat from any damage and from where the mooring posts will be simply pushed into the water without the need to lift them up. The operation will be faster (a sure way to deploy them correctly at the point desired) and there will be less risk of accidents to the operators.

11) Load the four mooring posts onto the boat so as to ensure a balanced weight (Plate 37).
12) Upon arriving at the places previously marked (see Point 3 above in Section 6.1), it is important that all the mooring posts/mooring lines should be deployed in their proper place (Plate 38).

Attention: During this operation, the mooring posts will sink very rapidly to the bottom of the sea, violently dragging the chain and mooring line. Great care must be taken not to become entangled in the chain or the loops in the rope.

PLATE 37
(a) Mooring posts correctly arranged on the boat; (b) mooring lines being tied to the chain

Note: As the hawsers are buoyant (polyester is less dense than water), they are highly visible and can be retrieved when the cage has to be moored.

PLATE 38
Lowering the mooring posts into the sea

13) Tow the cage using two ropes as shown in Plate 39. Tie the ropes to two adjacent corners of the hexagon, making sure they are of the same length, in order to spread the towing force over at least two points. Using a suitable length (at least 15–20 m) of the towing ropes and a moderate boat speed help to absorb the shocks induced by the movements of the sea.
14) Maneuver the boat until the cage is at the centre of the square marked by the mooring posts. When approaching this point from the direction opposite that of the current and the wind, it is easier for the operators to tie the mooring lines to the cage.
15) Retrieve the hawsers (jump into the sea if necessary) and tie them to four opposite corners of the cage using the points previously marked (Point 8 above). Use knot type (ii) described in Appendix 2 (Plate 40).

PLATE 39
(a) Tying the two towing ropes to two adjacent corners; (b) towing of the cage

16) Fix the 20-litre floats on the hawsers (two on each hawser) at about 3 m from the cage, using pieces of rope of 8 mm in diameter. For this purpose, use the knot type (v) illustrated in Appendix 2 (see Chapter 4, Table 5, and the Section on "The mooring system").

PLATE 40
Mooring of the cage

The cage is thus properly moored and ready for the net to be attached (Plate 41).

6.4 ATTACHMENT OF THE NET

Before the net is attached, open the package and spread the net on a flat surface in order to check its conformity with the geometry, size, twine number (see Glossary) and mesh size required. Also check to ensure that there are no holes, damage or manufacturing defects (Plate 42).

Note: There is generally a label on the nets delivered by the suppliers with the technical specifications and a registration number (Plate 42d). Keep this label for management purposes (record of farm components) and for any future disputes (some defects could appear after attachment of the net onto the cage).

PLATE 41
Moored cages ready for the net to be attached

After checking the conformity and integrity of the net, the next stage is to:

17) Cut six pieces of rope with a diameter of 10 mm and a length of 3 m and tie them to the six upper corners of the net using the loops placed for this purpose, as shown

PLATE 42

(a) Net delivered with its identification label; (b) examination of net before it is fixed onto the cage; (c) net roof; (d) label with the technical specifications and registration number

in Plate 43 and in Appendix 2 (knot [iv]). These ropes are used for fixing the upper part of the net onto the beams of the cage (see Point 22 below).

18) Prepare six ballast weights of about 7 kg and tie them to six pieces of rope of a diameter of 10 mm and a length of about 50 cm (Plate 44).
19) Fold and roll up the net beginning with the bottom in order to have the upper part and the six ropes within reach during its attachment to the cage, and load it onto the boat (Plate 45).
20) Place the folded net on the walkway of the cage and place three or four persons all around the hexagon (see Figure 12).
21) Lower the net into the water by holding the six ropes and pulling so that each rope is close to a corner of the cage (Figure 13).
22) Tie the six ropes to the corners of the hexagon (see Appendix 2 for the knots to use). Adjust the distance between the net and the cage so that about 30 cm of the upper part of the net is above the water (Plate 46).
23) Raise the inner sides of the net until the six lower corners are just below the surface and tie the six ropes with the 7 kg ballast weights (see Point 18 above) to the loops provided. Lower all the six ballast weights into the sea so that the net, because of its weight, can assume its fully stretched hexagonal shape (Plate 47).

PLATE 43
Knots used for tying the ropes to the loops of the net

24) Sew the roof of the net on.

At the end of these stages, the cage is ready for stocking with juveniles of the target species.

PLATE 44
Ballast weights to be tied to the bottom of the net after it is attached to the cage

PLATE 45
Three nets ready to be installed loaded onto the boat

FIGURE 12
First phase of attachment of the net

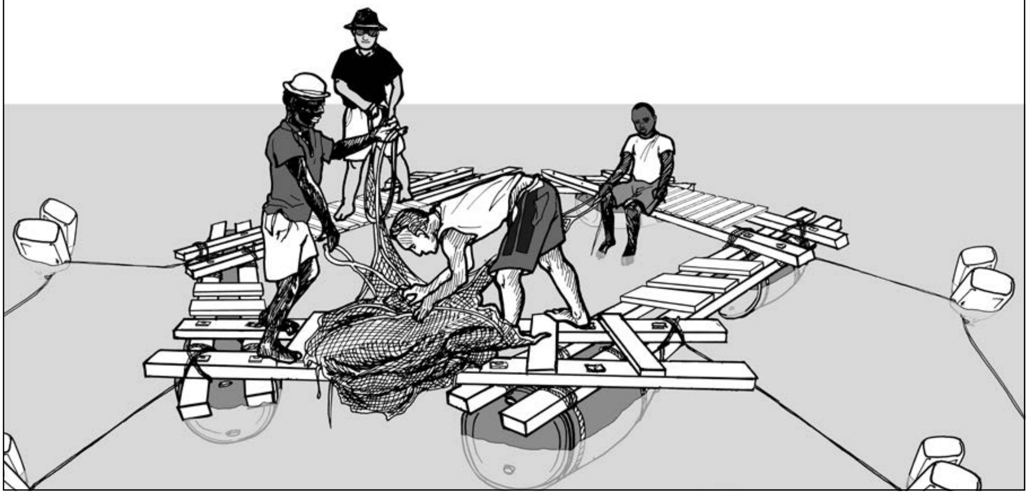

FIGURE 13
Second phase of attachment of the net

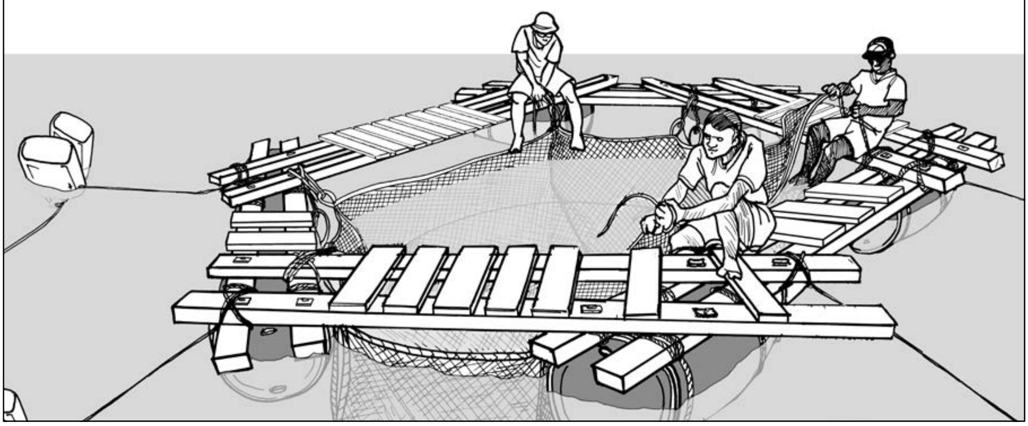

PLATE 46

(a) First phase of attachment of the net; (b) second phase of attachment of the net

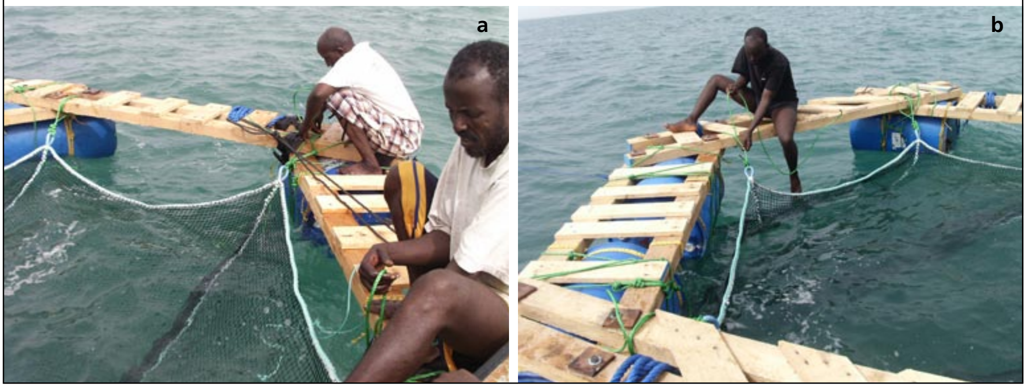

PLATE 47

(a) Corner of the net fully stretched by the ballast; (b) iron plate used as a ballast; (c) wall of the cage fully stretched after attachment of the ballasts; (d) fixing of the net completed

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Appendix 1

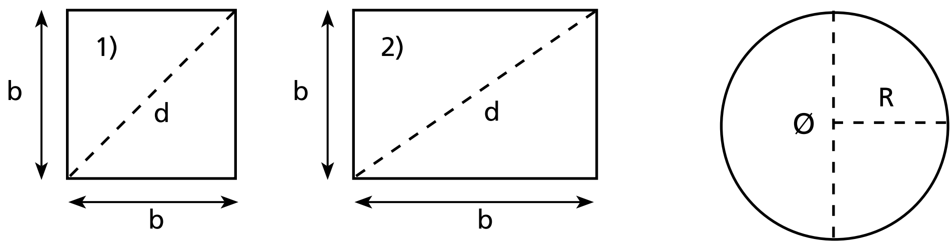
CALCULATION OF THE SURFACE AREA, VOLUME AND BUOYANCY OF A BODY

It is necessary to know the volume of the net, which is strictly related to the biomass that can be cultured and, therefore, the production that can be obtained.

It is therefore important to know how to determine the surface area and volume of a geometric figure such as a square, a rectangle, a circle and a hexagon, because most existing cages have these shapes.

Figures A1.1 and A1.2 illustrate the formulae for calculating the surface area of a square, a rectangle, a circle, a triangle and two regular[1] polygons (pentagon and hexagon[2]).

FIGURE A1.1
Formulae for calculating the surface area of a square, a rectangle and a circle



1) Area: $b \times b = b^2$
$(d = b\sqrt{2})$

2) Area: $b \times h$
$(d = \sqrt{b^2 + h^2})$

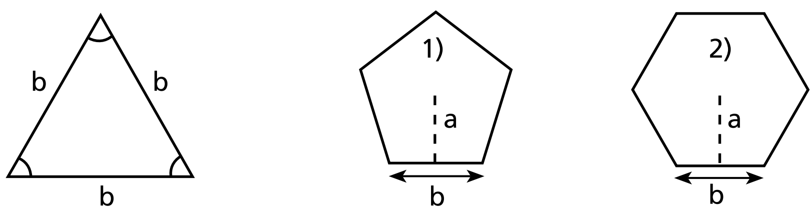
Perimeter: $2\pi R = \pi Ø$

Area: $\pi R^2 = \frac{\pi Ø^2}{4}$

$\pi = 3.14$

Source: Prado, 1988.

FIGURE A1.2
Formulae for calculating the surface area of a triangle, a pentagon and a hexagon



Area: $\frac{b^2\sqrt{3}}{4}$

C = Perimeter

1), 2) Area: $C \times \frac{a}{2}$

C 1) = $5 \times b$

C 2) = $6 \times b$

To calculate $a = (\sqrt{3} \times b)/2$

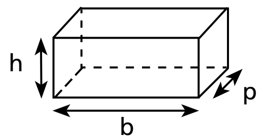
Source: Prado, 1988.

1 Regular = equilateral and cyclic (all corners lie on a single circle).
2 A hexagon is made up of six isosceles triangles.

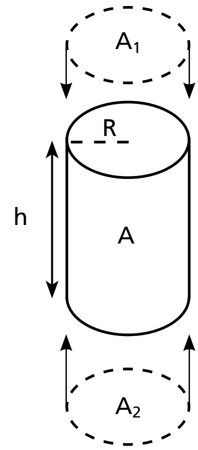
For a hexagon, as for other geometrical figures, the volume is obtained by multiplying the surface area by the height, according to the general rule:

Volume = surface area × height

FIGURE A1.3
Volume of a rectangle and a cylinder



Volume: b x p x h



Surface circumference (A): $2\pi R \times h = \pi Ø \times h$

Total surface, (A tot): $2\pi R \times (R + h) = (A)+(A^1)+(A^2)$

$= \pi Ø \times \frac{Ø}{2} + h$

Volume: $\pi R^2 \times h = \frac{\pi Ø^2}{2} \times h$

Source: Prado, 1988.

Attention: Take into account the units of measurement; if the surface area and height are calculated in metres, the corresponding volume is expressed in litres.

The equivalence ratio between these parameters is as follows:

1 cubic metre (m^3) = 1 000 cubic decimetres (dm^3) = 1 000 000 cubic centimetres (cm^3)
1 litre (l) = 1 000 cubic centimetres (cm^3) = 1 cubic decimetre (dm^3)

1 cubic metre (m^3) = 1 000 litres (l)

Determining the volume of a body is also essential for calculating the buoyancy and for establishing whether a body floats or sinks and, in the first case, what its vertical thrust is.

Figure A1.4 illustrates the calculations to be done.

FIGURE A1.4

Force of gravity and vertical thrust

G_a (kgf) = weight of body in the air

G (kgf) = Volume of body (m^3) × d (density of body in kgf/m^3)

F (kgf) = upward vertical thrust

F (kgf) = volume of body (m^3) × dw (density of water in kg/m^3)

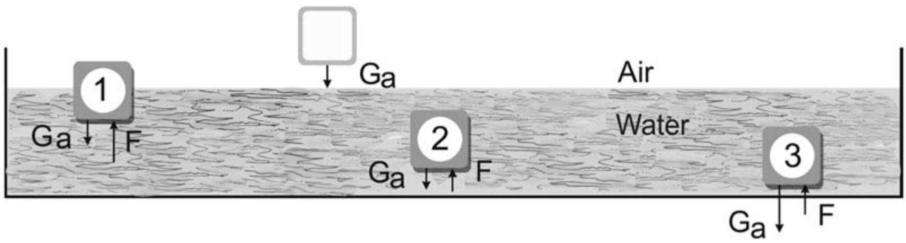
G_w (kgf) = weight of body in the water

G_w (kgf) = weight of body in the air (kgf) – vertical thrust (kgf)

G_w (kgf) = $G_a - F$

$$G_w \text{ (kgf)} = G_a\left(1 - \frac{1^*}{d}\right)$$

* 1 for freshwater, 1,02 for sea water.



1	2	3
Vertical thrust greater than weight of the body in the air.	Vertical thrust equal to weight of the body in the air.	Vertical thrust less than weight of the body in the air.
The difference "weight of body in the air – vertical thrust" is negative.	The difference "weight of the body in the air – vertical thrust" is nil.	The difference "weight of body in the air – vertical thrust" is positive.
Body (1) **floats**.	Body (2) is in **equilibrium** in the water.	Body (3) **sinks**.

Source: Prado, 1988.

Appendix 2

KNOTS

The knots used for the construction and installation of the cage described in this manual are illustrated in the following figures.

I. Clove hitch knot

The clove hitch belongs to the category of tightening knots (see Figure A2.1 and Plate A2.1).

FIGURE A2.1
Tying of a simple and double half-hitch knot

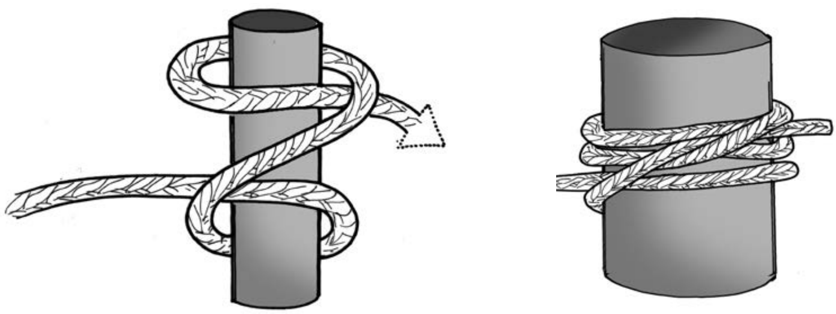


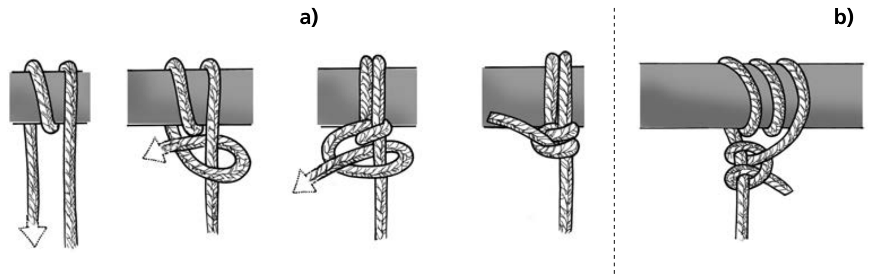
PLATE A2.1
Detail of a drum, with a rope of diameter 5 mm, ready to be fixed to a beam

This knot is used to tie the ropes of 5 mm diameter to the drums of the floating system. This knot can be repeated several times.

II. Round turn and two half hitches knot

This knot is the most commonly used and the most reliable for tying a rope under high tension to a fixed point. Figure A2.2 illustrates how this knot is tied.

FIGURE A2.2
(a) Tying of two round turns and two half hitches; (b) tying of three round turns and two half hitches



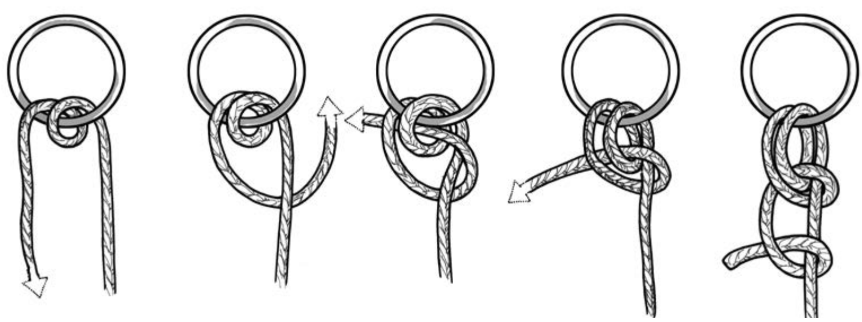
This knot is used for:

a) Tying the drums of the floating system to the beams. In this case, several round turns and half hitches are made.
b) Tying the mooring lines to the beams of the cage when the cage is placed in the sea.
c) It can also be used to tie the mooring lines to the chain of the mooring posts. A viable alternative can be the use of the Anchor bend knot (see below).

III. Anchor bend knot

This is the best way to tie an anchor ring to the mooring line, and it has the advantage of preventing the rope from rubbing against the iron. Figure A2.3 illustrates how this knot is tied.

FIGURE A2.3
Tying of an anchor bend knot



The drawback is that it can be used only if the chain link is sufficiently large to allow the rope to be passed twice round without being superimposed.

IV. Slip knot

This knot is useful when ropes of small diameter are used. Its distinguishing feature is that it tightens up as the tension applied increases. Figure A2.4 illustrates how this knot is tied.

This knot is used to:

a) tie the ropes to the net loops;
b) tie the ballast weights that are placed underneath the frame after being fixed on the cage.

V. Taut-line hitch knot

It is used to tie a rope to another tight rope. Figure A2.5 illustrates how it is tied.

This knot is used to tie the 20-litre floats to the mooring lines.

FIGURE A2.4
Tying of a slip knot

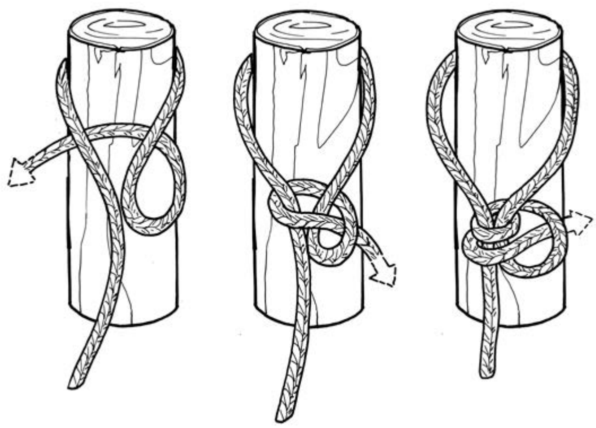
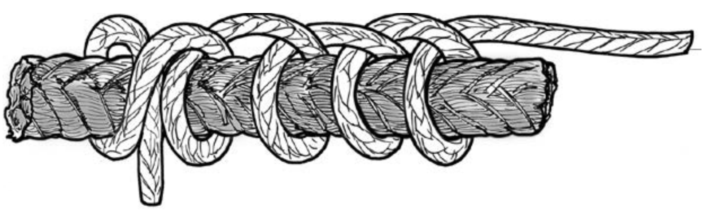


FIGURE A2.5
Tying of a taut-line hitch knot



Appendix 3

COMPOSITION OF CONCRETE

The concrete to make the mooring posts is prepared from cement, sand, gravel and freshwater. To prepare good quality concrete, these ingredients should be mixed using the right proportions and the drying process should be done in the appropriate manner. When the mixing and hardening are done properly, concrete blocks that are waterproof and that have maximum resistance are obtained.

In general, whatever the quantity of concrete desired, the proportions to be used are as follows:

- 1 part of cement;
- 1.5 parts of sand (particle size 0.5 mm);
- 2 parts of gravel (size 15 mm); and
- 0.5 parts of freshwater.

While assuming that a bag of cement normally weighs 50 kg, in the following example, the instructions for obtaining 450 kg of concrete, needed to make four mooring posts of around 110 kg each, are provided.

Attention: Upthrust (buoyancy) reduces the weight of the mooring posts in water. For a density of 2.2, this weight in water represents 53 percent of that in the air.

The quantities of the ingredients needed to obtain 450 kg of concrete are:

- 100 kg of cement;
- 150 kg of sand (particle size 0.5 mm);
- 200 kg of gravel (size 15 mm); and
- 50 litres of freshwater (25 litres per bag of cement).

The way to mix these ingredients is as follows:

1) Spread the sand over a flat surface to obtain a circular shape.
2) Place two bags of cement onto the sand.
3) Break open the bags with a spade to release the cement.
4) Mix the sand and cement and add the gravel.
5) Make a circular shape out of this mixture and dig out the base as shown in Plate A3.1.
6) Add water as the components are mixed until a homogeneous mixture is obtained.
7) Pour this mixture into four old tyres lined up on top of four empty bags (or cardboard boxes).
8) Leave the concrete to dry, taking care to sprinkle water on it from time to time (3–4 times a day if the weather is hot).

PLATE A3.1
Mixing concrete

To ensure maximum strength, the hardening process must last several days, and to prevent the concrete from cracking it must be kept wet at all times. One of the methods used is to cover the mooring posts with gunny (coarse sacking), which is moistened throughout the drying process.

Calculation of the volume of the concrete

It is necessary to know the volume of the concrete in relation to its weight in order to calculate the adequate size of the tyres (or, more generally, of the containers) to be filled.

The formula used for the calculation is: $d = m/V$
d = density measured in kilograms/litre;
m = mass measured in kilograms;
V = volume measured in litres.

Given that the density of the concrete is 2.2 kg/litre and the mass of each mooring post is 110 kg, then the corresponding volume is:

2.2 kg/litre = 110 kg/V (litre) or V = 50 litres

A tyre 55 cm in diameter with a thread of 20 cm gives a volume of about 50 litres.

When preparing the mooring posts, remember that the shape plays a crucial role in increasing the stability (for a given mass).

Flat mooring posts have a better sticking surface compared with the volume of cube-shaped ones, which ensures a much better stability.

Appendix 4

TECHNICAL CHARACTERISTICS OF ROPES

The following table illustrates the tensile strength of different types of ropes, in relation to their diameter.

Ropes

Ropes made from synthetic fibres

Diameter mm	Polyamide (PA)		Polyethylene (PE)		Polyester (PES)		Polypropylene (PP)	
	kg/100m	A[1] kgf[2]	kg/100m	A[1] kgf[2]	kg/100m	A[1] kgf[2]	kg/100m	A[1] kgf[2]
4	1.1	320	–	–	1.4	295	–	–
6	2.4	750	1.7	400	3.0	565	1.7	550
8	4.2	1 350	3.0	685	5.1	1 020	3.0	960
10	6.5	2 080	4.7	1 010	8.1	1 590	4.5	1 425
12	9.4	3 000	6.7	1 450	11.6	2 270	6.5	2 030
14	12.8	4 100	9.1	1 950	15.7	3 180	9.0	2 790
16	16.6	5 300	12.0	2 520	20.5	4 060	11.5	3 500
18	21.0	6 700	15.0	3 020	26.0	5 080	14.8	4 450
20	26.0	8 300	18.6	3 720	32.0	6 350	18.0	5 370
22	31.5	10 000	22.5	4 500	38.4	7 620	22.0	6 500
24	37.5	12 000	27.0	5 250	46.0	9 140	26.0	7 600
26	44.0	14 000	31.5	6 130	53.7	10 700	30.5	8 900
28	51.0	15 800	36.5	7 080	63.0	12 200	35.5	10 100
30	58.5	17 800	42.0	8 050	71.9	13 700	40.5	11 500
32	66.5	20 000	47.6	9 150	82.0	15 700	46.0	12 800
36	84.0	24 800	60.0	11 400	104.0	19 300	58.5	16 100
40	104.0	30 000	74.5	14 000	128.0	23 900	72.0	19 400

[1] A = Breaking load (dry rope).
[2] kgf = Kilogram-force.

Source: Prado, 1988.

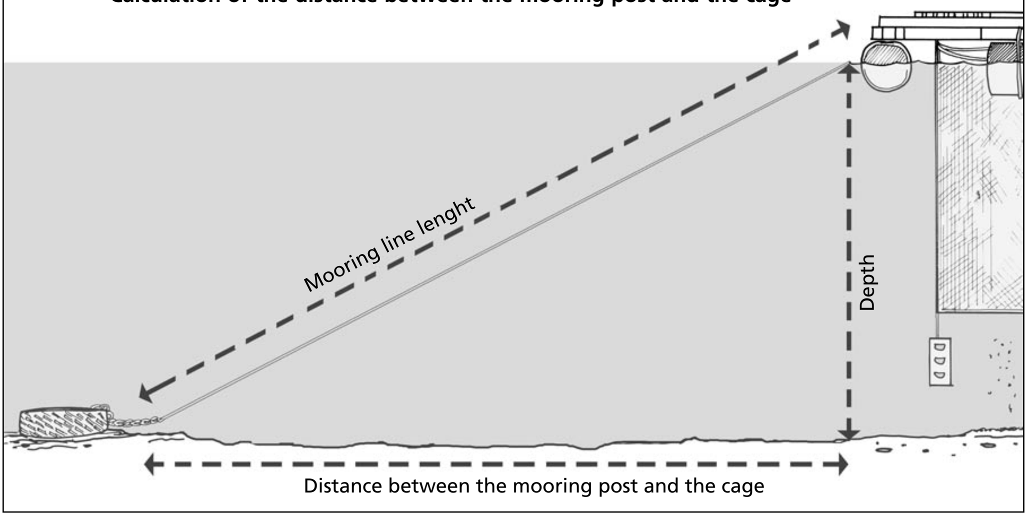
Appendix 5

CALCULATION OF LOCATION OF THE MOORING POSTS

The length of the mooring lines should be three to five times the water depth.

This means that the exact distance of the mooring posts from the cage is represented by the side forming the right angle (a cathetus or commonly known as a "leg") of a right triangle whose hypotenuse is constituted by the mooring line and the other cathetus is represented by the depth of the water column (see Figure A5.1).

FIGURE 5A.1
Calculation of the distance between the mooring post and the cage



Assuming that the depth of the site is 7 m (at high tide), a suitable mooring line should be between 21 m (7 × 3) and 35 m (7 × 5). The choice of length, ranging between these two extremes, also depends on the exposure of the site, meaning the hydrodynamic characteristics (the length will be longer in the event of extreme conditions).

In the example given in this manual, the length chosen is 25 m. Thus, by the Pythagorean theorem (i.e. "In a right triangle, the square of the length of the hypotenuse is equal to the sum of the squares of the lengths of the two catheti") it is possible to calculate the distance between the mooring post and the cage by the formula:

$$\text{Cathetus}^2 + \text{Cathetus}^2 = \text{Hypotenuse}^2$$

or $$7^2 + x^2 = 25^2 \rightarrow x^2 = 625 - 49 \rightarrow x^2 = 576 \rightarrow x = 24\text{ m}$$

The mooring posts should be placed 24 m away from the cage. Moreover, they represent the angles of a square in the middle of which the cage is moored.

It is possible to know the length of the diagonals of this square by considering that they are equal to twice the distance between the mooring post and the cage (24 m) and twice the side of the hexagon (3 m).

This means that the diagonal desired is $24 + 3 + 3 + 24 = 54$ m

Knowing the diagonal of a square, we are able to calculate the length of its side by the formula:

Length = diagonal/$\sqrt{2}$

or lenght = $54/1.4 = 38$ m

The cage is located in the middle of a square with a side 38 m long.

This document is a practical guide that provides a list and technical details of the materials to be used for constructing a hexagonal wooden cage, together with its mooring system, for fish farming within the framework of artisanal aquaculture. The instructions for assembling the different components are illustrated in detail, and the technical guidelines for cage installation at the farming site are also described. The basic knowledge and instructions provided in this manual are intended for those working in aquaculture development.