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Aquaculture operations in floating HDPE cages

A field handbook

Cover photograph:
A floating marine finfish cage farm (Tabuk Fisheries Company) located off the Red Sea coast of Saudi Arabia in the northern coastal province of Tabuk. The HDPE cages are 19 m in diameter and fitted with anti-bird nets (Courtesy Francesco Cardia).

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Preparation of this document

The document has been funded and produced in the framework of the Technical Cooperation Programme between the Kingdom of Saudi Arabia and the Food and Agriculture Organization of the United Nations during the implementation of two unilateral trust fund projects, i.e. “Support to the Fish Farming Center (FFC), Jeddah, Saudi Arabia” and “Strengthening and supporting further development of aquaculture in the Kingdom of Saudi Arabia”.

The purpose of this manual is to provide a general overview of farming and management techniques needed to operate high-density polyethylene (HDPE) floating fish-culture cages, including the types of materials used, their technical specifications and operability.

The rationale behind this handbook is to contribute to the capacity building of technical staff on highly practical issues and the management of fish cage farms. Moreover, this publication provides entrepreneurs, managers and workers involved in cage farming with a reference manual where they can find a rich source of technical and biological information, ranging from farm installation to the entire production cycle. The handbook also includes technical tables, logbook examples and functional suggestions acquired from years of field experience, which is shared with the readers.

This publication is also addressed to administrations, institutional organizations and development agencies involved in planning, ruling, licensing, subsidizing, etc., with the main practical and technical issues of this relatively new branch of aquaculture being systematically described and explained.

Cage aquaculture is nothing but fish production using a (relatively) new technological system. Thus, many of the issues related to fish biology, pathology, feeding, etc., are shared with all other fish production systems. For this reason, the authors have focused as much as possible on practical and operational issues related to cage aquaculture, while readers are referred to more generic literature to obtain in-depth information on other and general aquaculture practices.

The handbook briefly covers some important topics such as work safety while others are not dealt with at all (e.g. working boats and cranes, diving technique and equipment) as specific technical competences are required to treat these topics adequately.

Finally, procedures and operations described in this manual aim to provide the reader with possible solutions to problems and issues that are usually encountered in the cage farms. Nevertheless, each procedure inevitably needs to be revised and adapted to each site condition, workers’ experience, and the availability of labour, equipment and auxiliary boats.

Abstract

Global aquaculture production has been steadily growing in recent decades, increasingly contributing fish and other edible aquatic organisms of commercial importance entering national, regional and international markets. The growing demand for such products has stimulated the development and expansion of aquaculture production systems both on land and in all waterbodies, covering technologies ranging from the production of seed material to ongrowing structures and other farming support facilities.

In recent decades, the aquaculture industry has also intensified its production output per unit area of space or volume, mainly to compensate, among other things, for the growing competition for land and water surfaces for other uses. The expansion of fish farming in the sea, also referred to as "mariculture", has happened as a result of several supporting factors. These include the acquisition of reproduction and ongrowing technologies for species of interest, and the development of physical structures to contain the cultured organisms. Modern marine cages, whether floating or submersible, represent one such development. These have evolved significantly from basic and rudimental systems to sophisticated and carefully engineered structures.

Many cage designs and models have been developed and are commercially available. Among these, high-density polyethylene (HDPE) cages are widely used, because of the versatility of the materials used, the relative simplicity in the performance of the various farming operations, and the comparatively limited investment capital required. Technological improvements of HDPE cages are evolving with the availability of new materials and the various equipment items needed to service all farming operations.

This manual focuses on technical aspects of HDPE cages; however, the introductory chapter covers the importance of proper site selection in terms of site exposure and environmental parameters that affect the well-being of the culture fish and affect farm structures. Proper siting of a cage farm is of paramount importance with regard to the overall technical and economic success of the commercial operation, and for reducing as far as possible the environmental footprint of the farm.

Prior to describing the characteristics of HDPE cages and elements making up a culture unit, the handbook describes the grid and mooring systems that support the fish cages. Information is provided on the components of the two systems, their technical specifications in relation to farm size as well as on-land assembling and sea installation procedures. A chapter focuses on the floating collar of the cage, describing the components that make up this key farming structure. The technical specifications and design options are provided for the key elements of the collar readily enabling the construction of structures that meet the needs of the operator and are suitable for the environment in which they will be placed. Technical information is then provided on the ropes, netting and net cage design and on determining the appropriate size and shape. Based on procedures developed over years of field experience, practical information on collar and net installation, net changing, maintenance and inspections technique is provided.

The final sections of this publication covers practical procedures related to the stocking of cages with seed material, feeding and managing the fish stock, as well as practical information on pre-harvesting and harvesting methods, fish handling and transportation. Some information is also provided on farm safety procedures, highlighting the potential risks when working on a cage farm either on the floating structures or underwater.

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Abbreviations and acronyms

ABW	Average body weight
ADCI	Association of Diving Contractors International
AED	automated external defibrillator
BL	breaking load
CI	condition index
CPR	cardiopulmonary resuscitation
DO	dissolved oxygen
FAO	Food and Agriculture Organization of the United Nations
FCR	feed conversion ratio
FFC	fish farming centre
FMG	full mesh gauge
FMKK	full mesh knot to knot
GPS	geographic positioning systems
HACCP	Hazard Analysis and Critical Control Points (system)
HDPE	high-density polyethylene
HMKK	half mesh knot to knot
HPPE	high-performance polyethylene
HSE	Health and Safety Executive
ID	identification
IDSA	International Diving Schools Association
IMCA	International Marine Contractors Association
K	condition factor
LED	light-emitting diode
MBL	minimum breaking load
MRS	minimum required strength
PA	nylon or polyamide
PE	polyethylene
PES	polyester
PET	polyethylene terephthalate
PN	nominal pressure
PP	polypropylene
PVC	polyvinyl chloride
ROV	remotely operated vehicle
SS	stainless steel
SDR	standard dimension ratio
SGR	specific growth rate
SWH	significant wave height
SWL	safe working load
WLL	working load limit
USD	US Dollar
UV	ultraviolet

UNITS AND SYMBOLS

Biological/statistical

CV	coefficient of variation
K	condition factor
RSD	relative standard deviation
W	biomass

Length, area, time, speed, volume, weight, concentration

mm	millimetre
cm	centimetre
m	metre
M	nautical mile (also NM)
km	kilometre
cm^2	square centimetre
m^2	square metre
km^2	square kilometre
s	second
min	minute
h	hour
Kn	knots (speed, equal to nautical miles per hour)
km/h	Kilometres per hour
cc	cubic centimetre (= ml)
m^3	cubic metre
ml	millilitre (= cc)
l	litre
mg	milligram
g	gram
kg	kilogram
mt	metric tonne (1 000 kg) (also written as tonne)
ppt	parts per thousand (also written as ‰)
ppm	parts per million
ppb	parts per billion (thousand million)

Nautical, oceanographic

DD	decimal degree
DMS	degree minutes seconds
DM	degrees decimal minutes
Hs	significant wave height (also SWH)
Tp	peak wave period
Tm	mean wave period
Vc	current speed

Other abbreviations and symbols

kWh	kilowatt-hour
N	Newton
kN	kilo Newton (= 1 000 Newton)
°C	degree Celsius
<	less than
>	greater than
n.a.	not analysed or not available (also written as N/A)
no.	number
Ø	diameter

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1. Introduction

Cage aquaculture has grown rapidly in recent decades and is currently undergoing swift changes in response to pressures from globalization and an escalating worldwide global demand for aquatic products. There has been a move towards clustering existing cages as well as towards the development and use of more intensive cage-farming systems. In particular, the need for suitable sites has resulted in cage aquaculture accessing and expanding into new untapped open-water culture areas such as lakes, reservoirs, rivers and coastal brackish and marine offshore waters.

In 2007, the Food and Agriculture Organization of the United Nations (FAO) published a report entitled *Cage aquaculture: regional reviews and global overview* (Halwart, Soto and Arthur, 2007). This report provides an assessment of the situation and future prospects of cage aquaculture around the globe, recognizing the importance of cage aquaculture and its key role for the future growth of the aquaculture sector. The regional reviews offer information on the history and origin of cage aquaculture, outlining major issues and challenges as well as highlighting specific technical, environmental, socio-economic and marketing issues that cage aquaculture faces and/or needs to address in the future.

The ever-increasing competition for land and water space, along with the growing market demand for marine fish and other sea products, as mentioned above, are some of the elements that are motivating the aquaculture engineering industry and entrepreneurs in the development of farming structures in open waters. In the past couple of decades, a variety of fish containment structures, typically referred to as fish cages, have been designed, tested and commercially produced. These structures vary in design, size and materials used as they are intended for diverse environments, ranging from relatively protected to highly exposed and dynamic sites, either as floating or submerged underwater structures and adopting a number of technological solutions to facilitate fish stock husbandry and management.

This technical manual focuses on the technical, structural and operational issues of high-density polyethylene (HDPE) floating cages, as they are currently widely used in modern industrial marine aquaculture in many parts of the world owing to the versatility of the materials used, the simplicity in the various farming operations and the relatively contained investment capital required (Plate 1). The main structural elements of these cages are the HDPE pipes, which can be assembled in various ways in order to produce collars of different sizes and shapes. The HDPE pipes, held together by a series of brackets with stanchions disposed throughout the entire circumference, form the floating collar ring, which is the main structure on which the fish net pen is secured. These gravity cages maintain the net pen shape and volume through a system of weights, also known as a sinker system, fixed at the bottom end of the net.

This manual provides the reader with highly practical and technical information on the design and components of a typical HDPE cage, on how to assemble a cage collar and on how to install a net pen. It also provides comprehensive information on the grid mooring system and installation. Finally, it presents information on farming operations, including maintenance and control of the farming structures, stocking of the farmed fish, feeding, harvesting and packaging, with a focus on practical aspects and routine management operations. The first chapter of this handbook highlights the importance of proper site selection in marine cage farming, briefly summarizing environmental factors such as wave exposure, water depth, oxygen levels, and water temperature, all of which influence farming operations and may determine the success of a fish cage farm if they have all been taken into due consideration during the planning stages of a business venture.

PLATE 1

Images of HDPE fish cages in calm waters (Tyrrhenian Sea, southern coast of Italy – top row), in rough waters (Atlantic Ocean, Canary Islands – middle row) and aerial view of two cage farm installations (Aegean Sea – bottom row)

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2. Site selection

Cage culture refers to an open aquaculture system where the rearing environment is the environment itself. As such, there are interactions between cages and the environment in both directions – cages affect the environment, and vice versa.

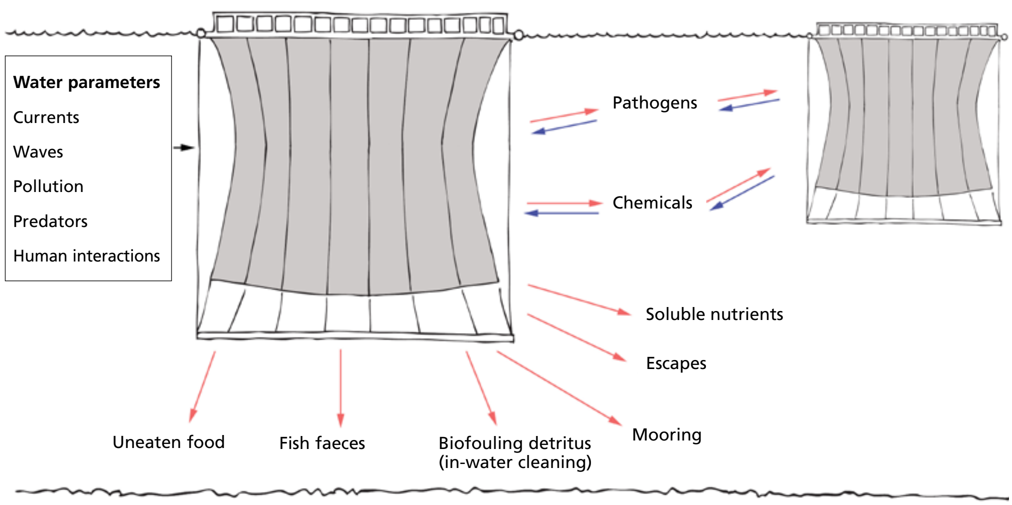
Moreover, one cage can have impacts on other cages because currents can transfer pests, pathogens and chemicals from one cage to another (or from one site to another). Within the site selection process, all possible interactions and their impacts on the cage aquaculture, including both environment and human related, should be evaluated and assessed in order to minimize threats, hazards and overexploitation (Figure 1).

Choosing a site in any fish farming operation is crucial because it influences economic viability. Site selection directly affects running costs, production, mortality and overall profitability. Compared with a land-based facility, sea cage aquaculture has less room for error regarding site selection, particularly as a wrong siting may result in the loss of the fish stock and cages.

A first general site characteristic is its exposure. This refers to the amount of wind and waves to which the site is subjected. An offshore and exposed site location will mean higher initial investments for cages, moorings and nets, higher costs of maintenance and greater risks, resulting in greater production costs. On the other hand, an exposed site will have a better hydrodynamism, with a resulting lower environmental impact, better fish welfare and a better product quality. A sheltered and protected site will be less exposed to waves and currents, which implies reduced maintenance and costs, but higher risks of significant environmental impacts are often associated with more sheltered sites for these very reasons.

Site exposure classification between offshore and nearshore is highly debated, and several definitions of offshore cage culture have been proposed so far. Some of these classification schemes are included in the following tables. Table 1 presents a classification proposed by FAO in 2009.

FIGURE 1
Diagram of the main interactions cage–environment–cage



Note: Blue arrows indicate external factors acting on structures and/or fish; red arrows indicate impacts of cages on the environment.

TABLE 1
Site classification proposed by FAO in 2009

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

Note: Hs = Significant wave height (Hs x 1.9 = Maximum wave height).

Source: Lovatelli, Aguilar-Manjarrez and Soto (2013).

Table 2 provides another possible classification, adapted from the Norwegian Standards (NS) NS9415-2003 on “Marine fish farms requirements for site survey, risk analyses, design, dimensioning, production, installation and operation”, which is based on significant wave height (Hs), peak wave period (Tp) measurements and degrees of exposure. The sites are ranked from A to E, where A refers to sheltered sites and E refers to very exposed, offshore sites.

TABLE 2
Norwegian site classification based on statistical parameters of waves

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

An additional possible classification (Table 3) proposed within the Norwegian Standards is based on the mid-current speed (Vc). Wave classes at the site are determined by metrics of significant wave height and wave period.

TABLE 3
Norwegian site classification: based on mid-current speed

Site classification (current classes)	Current speed (Vc) (m/s)	Site exposure level
a	0.0–0.3	Low
b	0.3–0.5	Moderate
c	0.5–1.0	Substantial
d	1.0–1.5	High
e	>1.5	Extreme

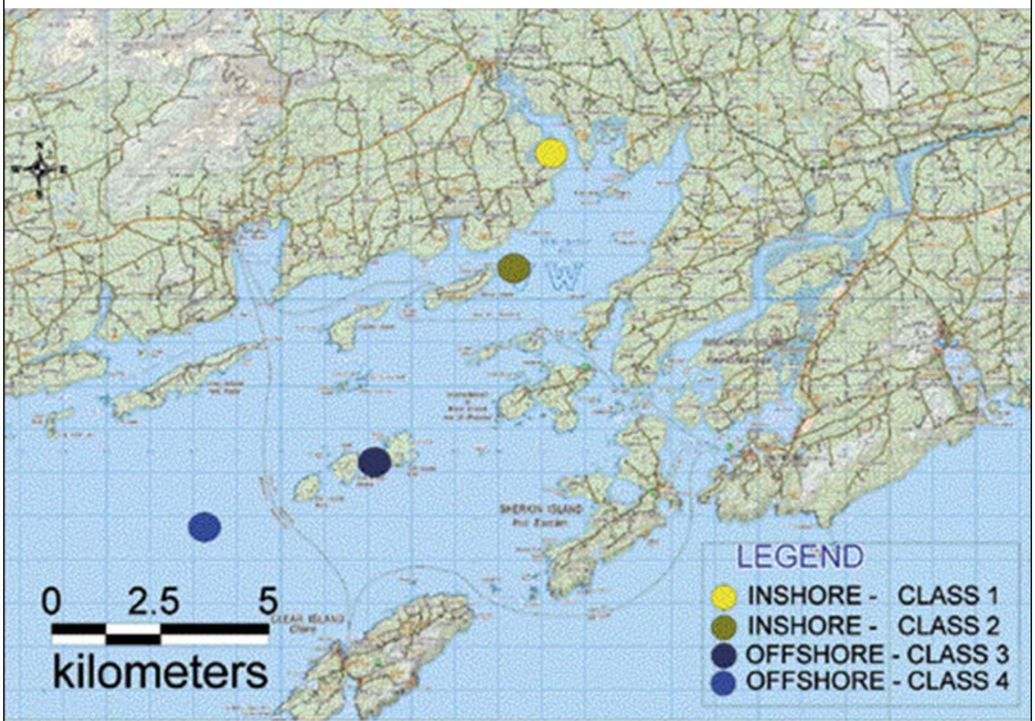
A further example of classification (Table 4 and Figure 2) was proposed at the “Farming the Deep Blue” conference held in Dublin, Ireland, in 2006. Here, the farm sites are classified into four classes where the exposure levels are matched with the cage technology used/recommended. In 2009, the Norwegian Standards moved to a similar classification scheme that considers the type of cage as well as the environmental conditions.

TABLE 4
Marine cage site classification proposed at the "Farming the Deep Blue" conference

Site class	1	2	3	4
Conventional description (in relation to site exposure)	Sheltered inshore site	Semi-exposed inshore site	Exposed offshore site	Open-ocean offshore site
Cage type used	Surface gravity	Surface gravity	Surface gravity, anchor tension	Surface gravity, surface rigid, anchor tension, submerged gravity, submerged rigid

Source: Ryan *et al.*, 2004.

FIGURE 2
Site classification proposed at the "Farming the Deep Blue" conference



Source: Ryan, Mills and Maguire (2004).

The site classification examples provided above show how the classification of the site can be assessed using different considerations and objective observations, but that classification may differ depending on the method applied. In the end, exposure (and, consequently, current and wave height) is certainly the most relevant factor to be considered in offshore site classification regardless of the actual distance from the coast.

SITE SELECTION CRITERIA

There are different parameters and factors that need to be taken into consideration during the site selection process. These can be grouped into three categories (Table 5).

TABLE 5
Parameters and factors to be considered in the site selection process

Environmental parameters and factors relevant to the cultured organisms	Environmental parameters and factors relevant for the cages	Legal/logistic criteria
Temperature	Depth	Legal/political aspects
Salinity	Shelter (waves)	Access
Pollution	Sea bed	Security
Suspended solids	Current	Proximity to market
Algal blooms	Fouling	Traditional tenure rights
Disease organisms	Pollution	Lease permit process
Water exchange	-	-
Current	-	-
Fouling	-	-
Dissolved oxygen	-	-

Source: After Beveridge, 2004.

Environmental criteria for organisms

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

Dissolved oxygen

Dissolved oxygen (DO) is one of the most important parameters to consider when choosing a site. Oxygen requirements vary with species, stage of development and size of fish. The level of DO is influenced by temperature, and it directly influences the feed conversion ratio (FCR). The lower is the DO in the water, the higher the final FCR will be, which will result in higher feed costs.

The level of DO may also be influenced by algal communities. Diurnal photosynthesis increases DO, while nocturnal respiration decreases DO. The highest level of DO is in the late afternoon, and the minimum in the pre-dawn hours.

Algal blooms can dramatically influence the DO as mentioned above, but there is also a further reduction in DO when there is a change in oceanic conditions that causes algal blooms to suddenly die, or crash. With algae mortality, the decomposition of the biomass will lead to a DO decrease, sometimes reducing DO to zero.

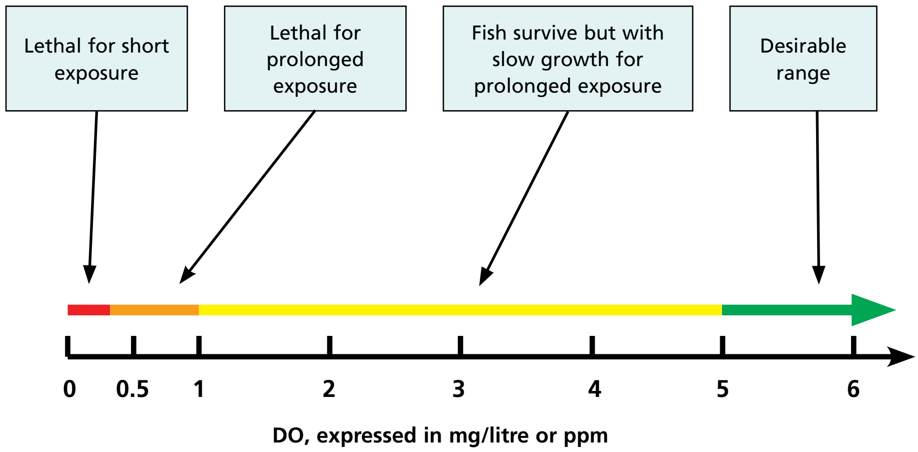
The level of DO is also influenced by fouling of the cage, because the growth of organisms on the net may reduce the water exchange. The level of DO may be reduced during feeding, but this is usually only temporary and normal values will return in a few hours.

As a generic reference, Swingle (1969) developed a DO scale for warm water fish species (see Figure 3):

- DO = < 0.3 mg/litre – fish die after short-term exposure;
- DO = 0.3–1 mg/litre – lethal for long-term exposure;
- DO = 1–5 mg/litre – fish survive, but growth is slow for prolonged exposure;
- DO = > 5 mg/litre – minimum for warm water fish species (fast growth).

Target species should be clearly identified before the site selection process, and their oxygen requirements researched in order to avoid selection of sites with insufficient DO for that species.

FIGURE 3
Dissolved oxygen (DO) effects on warm water fish



Source: After Swingle, 1969.

Pollutants

A variety of pollutants can damage the cages (net and structures) and can negatively affect the farmed fish stock causing mortalities or contaminating the fish to such a degree that the fish cannot be traded for human consumption.

Risks can be minimized by avoiding highly industrialized areas, although pollutants may also occasionally occur as a result of maritime traffic (e.g. oil spills and tank cleaning).

Cooling water effluents from power stations can also contain chemicals and biocides (e.g. chlorine, corrosion inhibitors, solvents and heavy metals) that may be lethal to the stocked fish.

Rivers may contain debris or large floating objects (e.g. timber, driftwood) that may damage the net if brought onto the site by the current.

Temperature

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

- Water temperature in coastal areas is influenced by freshwater influx from streams and rivers, which are influenced by seasonal variation in rainfall.
- Temperature range will be greater in shallower waters.
- Solar radiation received by a body of water is absorbed solely by the first few metres of water. If there is no mixing, the water will become stratified and the water column temperature may vary dramatically from the surface to the cage base.

Salinity

Salinity is the amount of dissolved salts in the water, usually expressed in parts per thousands (ppt or $^{o}/_{oo}$).

Unsuitable salinity levels can negatively influence feeding, the FCR and the specific growth rate (SGR).

Significant salinity variations contribute towards stress, which may depress the immune system of the farmed fish, making them more susceptible to infections from parasitic organisms and other diseases.

Estuaries are sites where salinity variations often occur, and they should be avoided if the fish species being cultured are sensitive to variations in this specific environmental parameter.

pH

The pH level is a measure of acidity. Pure freshwater has a neutral pH value (close to 7.0 at 25 °C). Values lower than 7 are acidic, while levels higher than 7 are basic or alkaline. pH is defined as a negative decimal logarithm of the hydrogen ion concentration in a given solution.

Seawater is soundly buffered against pH variation, and as such the pH is usually in the range of 8.0–8.2.

In freshwater, pH variations can occur owing to acid rain precipitation. This typically happens at the end of the winter months in areas where there is an abundance of melted snow flowing into the surrounding waterbodies.

Disease

Some pathogenic agents are present in the environment, especially if sites are located in polluted areas (e.g. harbours, near untreated sewage outlets, closed basins with poor water exchange). Bacterial diseases are often associated with poor water quality.

Some sites harbour intermediate or definitive hosts of parasites that can switch hosts from wild fish to farmed fish. This is not easy to evaluate *a priori*, although a laboratory specializing in fish diseases could advise on possible disease outbreaks in wild fish populations at the target site.

Turbidity

Farms should be situated in areas with relatively clear water. Suspended solids should preferably be less than 5 mg/litre and should not exceed 10 mg/litre. Turbid water is not suitable for fish farming for the following main reasons:

- Silt particles in turbid water contribute to fouling. When deposited on the net, they accelerate fouling by serving as a substrate for the growth of fouling organisms.
- The inability of the fish to see feed impacts feed efficiencies. Some fish also do not feed adequately when the water is turbid.
- Silt particles in large amounts can clog fish gills causing mortalities resulting from asphyxiation.

Turbidity is most likely to be caused by water runoff from land, or from currents or waves lifting silt deposits on the substrate.

Environmental factors on farmed structures

Along with the factors that may affect farmed fish, in the site selection process one must consider all those factors that can have an influence on the cage installation, barges and marine signals. It is essential to consider the following factors when choosing the cage model, in designing and constructing the mooring system, as well as in the selection of the service vessel:

- bathymetry or site depth (i.e. seafloor terrain and depth contours);
- current speed and direction;
- wind;
- wave height and period;
- sea bed (i.e. bottom type);
- storm and hurricane incidence.

Bathymetry

The water depth, in combination with the average current speed and direction, can determine the concentration of waste sediment in the area around the cages (see Figure 4).

Depth can also have the following impacts:

- Farm footprint: the greater the water depth, the larger the farm footprint will be, because the length of the mooring lines is usually three to five times the site's depth.
- Mooring design: site depth may influence the equipment and materials used for moorings, including their dimensions.
- Diving inspections: diving deeper than 50 m will present a problem for professional divers, who require specific training, and professional and expensive gear for working at greater depths. Although anchor inspection is not a routine procedure, this issue should be considered when selecting the site.
- Cage net depth: as a rule of thumb and depending on the current velocity, it should be no deeper than one-third of the site's depth and at least 15 meters should be left between the net base and the sea bed (at low tide), to permit a wider and better dispersion of cage waste particulate. Thus, a shallow site will result in the need to use short nets and, consequently, cage volumes will be smaller than in a deeper site.

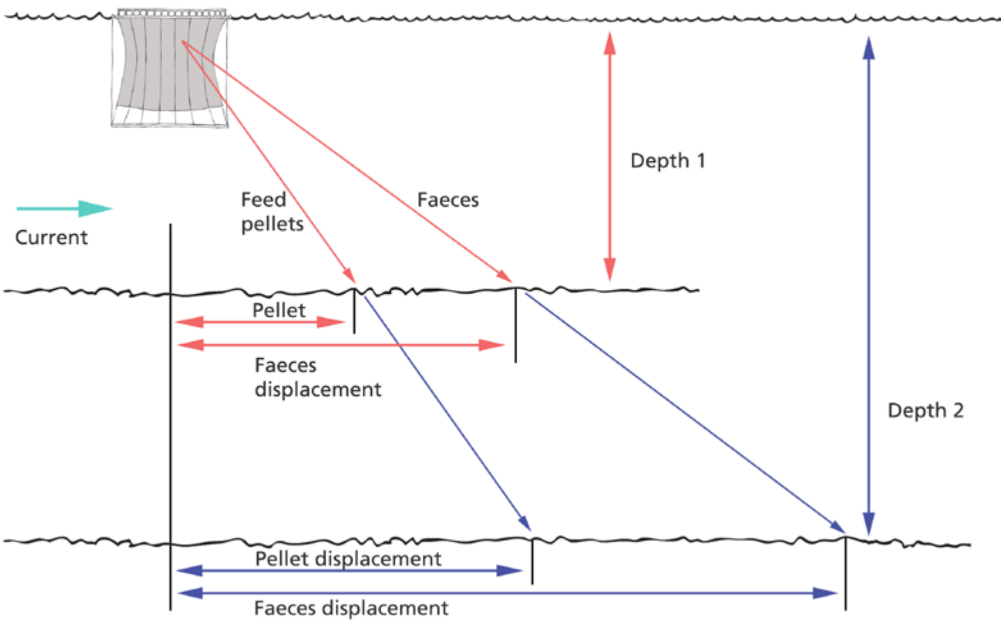
During any project development phase, the water depth should be studied on a marine chart and then properly verified through an extensive field survey. Bathymetric transects are a good way to survey the area and find the most suitable location, which should be, as far as possibly, flat and without rocks or coral formations that could provide points of tearing for the mooring lines.

A site survey can be also executed with the support of a dedicated depth scanner (e.g. portable 3D OLEX scanner) that can return comprehensive and detailed information on the seabed characteristics.

In many cases, the wave action in shallower waters (if not sheltered) is more violent. Shallower waters experience higher waves. A shallow site may be subjected to severe wave conditions, thus requiring stronger cage-net-mooring engineering than in locations in deeper water. Such conditions may also increase the probability of fish stock damage within the nets.

Note: A typical pitfall is to install a cage system too close to the shore both in terms of water quality and forces.

FIGURE 4
Influence of depth in solid waste displacement on the sea bed below cages



Note: Uneaten feed pellets have a higher density compared with faeces, thus their displacement will be more concentrated. Given a constant current, the deeper the site the larger the displacement will be, both for uneaten pellets and fish faeces.

Current speed and direction

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

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

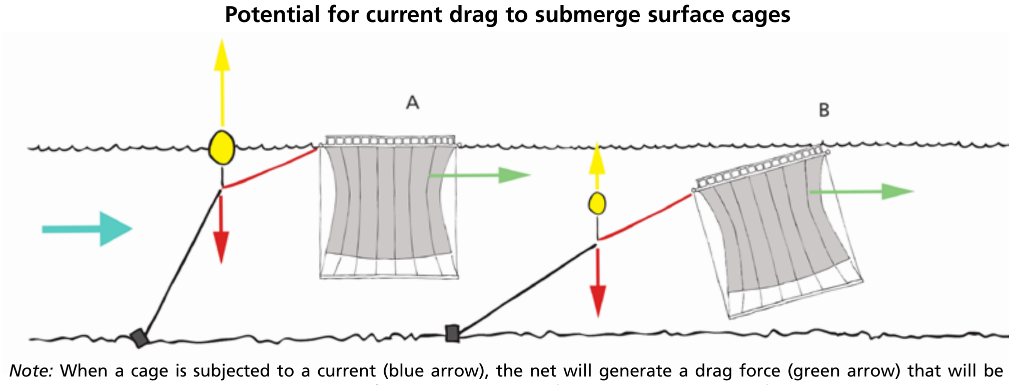
Current speed needs to be considered when designing the cage mooring system. Compensator buoys are sized according to the expected speed of the current registered on the site (Figure 5), as well as the dimensions of each of the components making up a mooring system. The net generates very strong drag forces because of the large area. When a net is heavily fouled, it can become an almost solid barrier to the current, increasing the load borne by the mooring system and potentially exceeding its weight-bearing limit.

Optimal current speed varies according to the cultured species and the mesh size of the cage nets. In the Mediterranean Sea the optimal current speed in cage aquaculture is generally between 10–20 cm/s and not exceeding 60 cm/s. In salmon aquaculture 25–50 cm/s is the optimal current speed and 75 cm/s is the maximum speed recommended. The Norwegian Standards NS9415 requires 50 cm/s as minimum input for determining the size of the mooring system and the elements to be used.

The prevailing direction of the current should also be considered, because this determines the area of effluent waste dispersal. A correctly sited farm will consider the location of sensitive habitats with respect to the site and current directions.

Data on currents is usually published in thematic nautical charts, and/or made available by marine authorities (e.g. navy, coastguard, ministry for merchant navy). In addition, a current buoy deployment (e.g. Nortec Doppler profiler) is highly recommended for each site to obtain site-specific details and to validate the chart data. Current data can be collected for a couple of moon cycles and then extrapolated for a 50 years return period.

FIGURE 5
Potential for current drag to submerge surface cages



Note: When a cage is subjected to a current (blue arrow), the net will generate a drag force (green arrow) that will be loaded on the mooring system. The buoys of the mooring system (known as mooring buoys) are subjected to a resulting downward pull (red arrows) generated by the cumulative effect of loads on the bridle (orange line) and mooring line (black line). This downward load is contrasted with the upward buoyancy (yellow arrows) (cage A). If the buoys are too small (cage B), buoyancy will be less than the downward load, and the buoy and the cage collar will become submerged in strong current conditions.

Wind

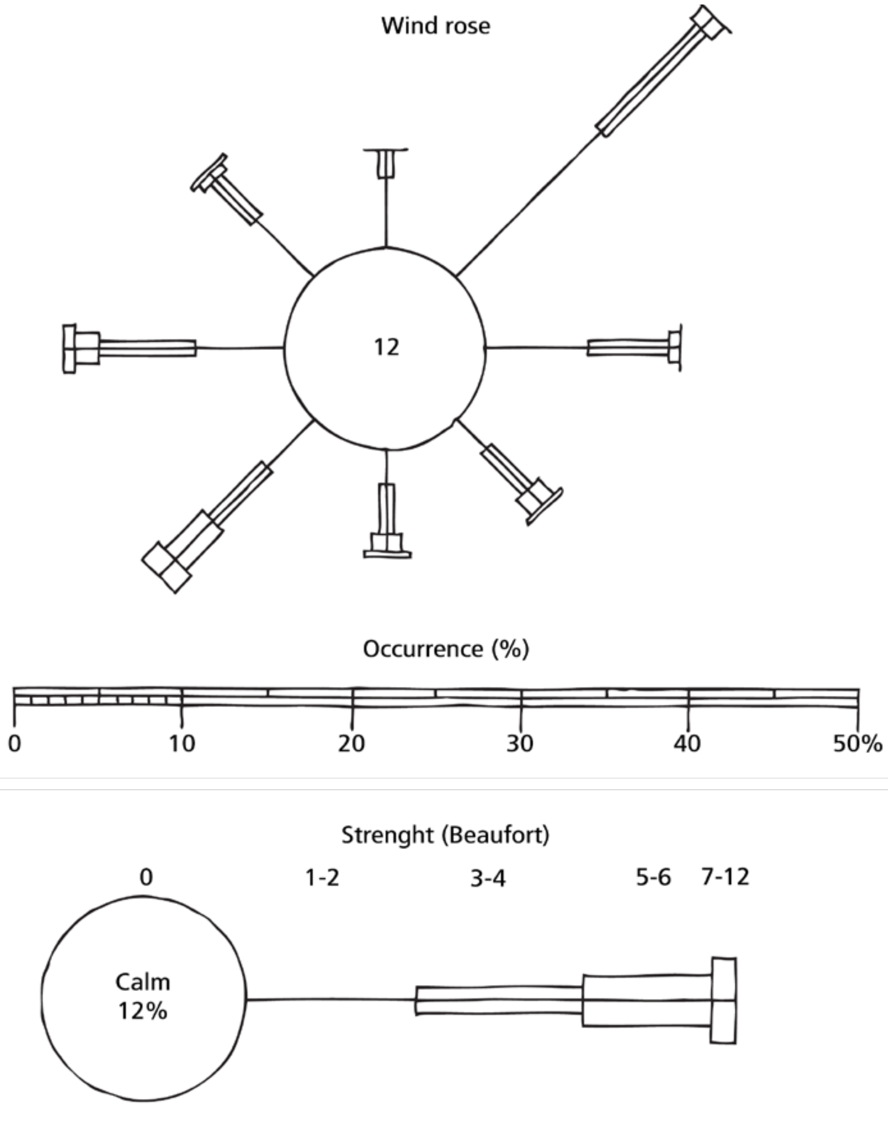
Wind accounts for approximately 5–10 percent of the total forces on a cage mooring system, while the share increases in case of feeding barges. Wind can have a direct impact on cages and their activity by generating pull on the jump net, disturbing vessels moving around the farm and dispersing the feed pellets outside the cages. For example, a plastic circular cage of 30 m diameter with a 1 m high jump net has an approximate wind-exposed surface area of 40 m². In a 40 knot wind, a single such cage can be subjected to 5 tonnes of wind pressure (R. Turner, Seawork Ltd, personal communication).

Wind can also have an indirect impact on cages, through wind-driven currents and wind-generated waves.

Data on wind are usually available at the relevant climate authorities, and can be analysed and summarized on a "wind rose" (see Figure 6). The wind rose is a graphical tool where statistical wind data records are reported at a particular location. It provides information on speed, direction and occurrence of the observed wind.

Wind is usually measured in knots, miles per hour (mph), or kilometres per hour (km/h) but a classification often used is the Beaufort Scale (Table 6), where a scale from 1 to 12 represents a range of possible wind force and subsequent sea conditions.

FIGURE 6
The wind rose represents the historical observations of wind at a specific location



Note: Each "arm" is the graphical representation of winds speed and direction (N, NE, E, SE, S, SW, W and NW). The length represents the occurrence, in percentage of observations, and the thickness represents the wind strength classes expressed in Beaufort (see Table 6).

TABLE 6
Beaufort scale values and descriptions

Force (Beaufort scale)	Equivalent speed			Description	Specifications for use at sea
	mph	knots	km/h		
0	0–1	0–1	0–1	Calm	–
1	1–3	1–3	1–5	Light air	Ripples with the appearance of scales are formed, but without foam crests.
2	4–7	4–6	6–11	Light breeze	Small wavelets, still short, but more pronounced. Crests have a glassy appearance.
3	8–12	7–10	12–19	Gentle breeze	Large wavelets. Crests begin to break. Foam of glassy appearance. Perhaps scattered.
4	13–18	11–16	20–28	Moderate breeze	Small waves, becoming larger; fairly frequent white horses.
5	19–24	17–21	29–38	Fresh breeze	Moderate waves, taking a more pronounced, longer form; many white horses are formed. Chance of some spray.
6	25–31	22–27	39–49	Strong breeze	Large waves begin to form; the white foam crests are more extensive everywhere. Probably some spray.
7	32–38	28–33	50–61	Near gale	Sea heaps up and white foam from breaking waves begins to be blown in streaks along the direction of the wind.
8	39–46	34–40	62–74	Gale	Moderately high waves of greater length; edges of crests begin to break into spindrift. The foam is blown in well-marked streaks.
9	47–54	41–47	75–88	Severe gale	High waves. Dense streaks of foam along the direction of the wind. Crests of waves begin to topple, tumble and roll over.
10	55–63	48–55	89–102	Storm	Very high waves with long overhanging crests. The resulting foam, in great patches, is blown in dense white streaks along the direction of the wind. The whole surface of the sea takes on a white appearance. The "tumbling" of the sea becomes more immense and shock-like. Visibility affected.
11	64–72	56–63	103–117	Violent storm	Exceptionally high waves (small and medium-size ships might be, for a time, lost to view behind the waves). The surface is covered with long white patches of foam lying along the direction of the wind. Everywhere, the edges of the wave crests are being blown into froth. Visibility affected.
12	73–83	64–71	118–133	Hurricane	The air is filled with foam and spray. Sea completely white with driving spray; visibility very seriously affected.

Source: Kemp, 2011.

Waves

Waves account for approximately 20–25 percent of the total forces affecting the mooring and the equipment on a typical mid-size cage farm (3 000–4 000 tonnes/fish/year). Five factors influence the formation of wind-generated waves:

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

All of these factors work together to determine the size of waves. The greater each of the variables is, the larger the waves are (apart for depth, as explained below). Currents also indirectly influence the wave formation, as winds against currents generate shorter and steeper waves.

Wave measurements and characteristics (Figure 7):

- wave height: measured from trough to crest (metres);
- wavelength: measured from the crests between two consecutive waves (metres);

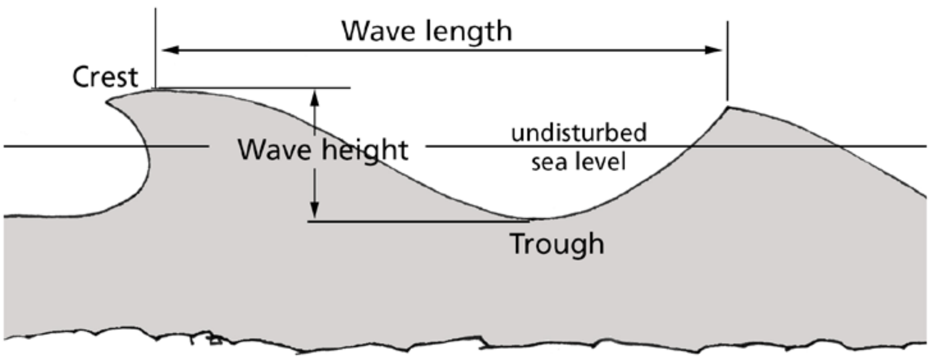
- wave period: the interval between the arrival times of consecutive crests at a stationary point (seconds);
- wave propagation direction: the direction of wave propagation measured in degrees from true North (0°), increasing in a clockwise direction.

The movement of waves across the sea surface in the deep ocean results in almost circular-shaped motions of water particles, called orbitals (Figure 8). Below the surface, orbitals gradually diminish with depth, up to a depth of half of a wave's length above which orbitals are not present. When waves approach the shore and the depth become lower that the half of the length of the waves, orbitals may reach the bottom. Friction between the bottom and the orbital's motion dissipates wave energy. The amount of dissipation depends primarily on orbital velocity and the rough quality of the sea bed. When the orbitals of a wave reach the bottom, the wave becomes steeper and eventually folds over as a breaking wave and surf. These bottom effects on waves are why waves have a greater steepness and become more destructive closer to shore.

The characteristic height of waves over a period is usually expressed as significant wave height (SWH or Hs), expressed in metres. Hs x 1.9 gives the maximum wave height over the period.

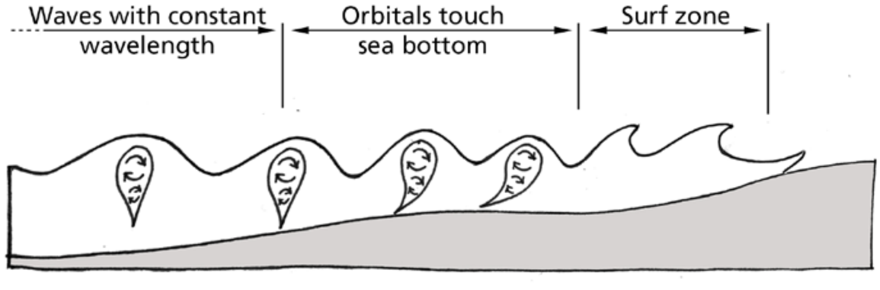
Given the measurement of the height of a given pool of waves, Figure 9 represents an average height (trough to crest) of the highest one-third of the waves in a given period (usually chosen in the range from 20 minutes to 12 hours).

FIGURE 7
Wave crest, trough and length



Source: ®The COMET Program – http://meted.ucar.edu/ (revised).

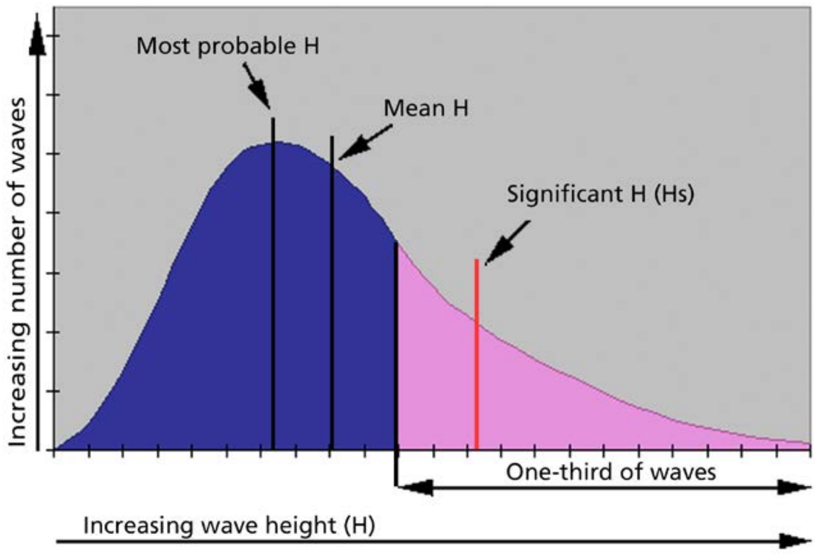
FIGURE 8
Wave orbitals and the effect of depth on wave behaviour



Note: With decreasing depth, orbitals touch the sea bed, and the wavelength and period decrease, while the wave steepness increases. In the surf zone, the waves collapse.

Source: ®The COMET Program – http://meted.ucar.edu/ (revised).

FIGURE 9
Statistical wave distribution in a given period



Note: Significant wave height is the average height of the highest one-third of the measured waves in a given period.

Other parameters for wave measurement are:

- Dominant wave period, in seconds, is the period between waves with maximum energy. In a given period, it is the time between the higher-energy waves.
- Average wave period, in seconds, of all waves during a 20-minute period.
- The direction from which the waves of the dominant wave period are coming. The units are degrees from true North, increasing in a clockwise direction, with North as 0 (zero) degrees and East as 90 degrees.

Fetch is the distance over which the wind blows in a constant direction and at a constant speed. While wind speed is the ultimate limiting factor of wave growth, growth is also limited by the size of the fetch region. Fetch size is constrained primarily by land masses.

There are smaller generated waves that are created out from the sides of the fetch region, while the predominant wind direction generates larger waves that spread out from the downwind end of the fetch.

In a selected site area, the fetch can therefore be quantified by degrees and length of the fetch, which is the distance of the site from the next coastline.

In particular there are two different fetch definitions:

- geographic fetch: the length of water over which a given wind might have blown;
- effective fetch: the length of area over which a given wind has actually blown.

Example of the connection between waves, wind and fetch length are given in Table 7.

TABLE 7
Example of calculated significant wave period and peak period in varying wind velocities and effective fetch length

Wind velocity (m/s)	Effective fetch length					
	3 km		10 km		30 km	
	Significant wave height (Hs) (m)	Peak wave period (s)	Significant wave height (Hs) (m)	Peak wave period (s)	Significant wave height (Hs) (m)	Peak wave period (s)
10	0.3	2.1	0.6	3.1	1.1	4.4
20	0.8	2.8	1.5	4.1	2.5	4.9
30	1.4	3.3	2.5	4.9	4.4	7.1

Source: Standards Norway, 2009.

Sea bed

Sea-bed characteristics should be surveyed in order to classify the sediment type for anchor embedment and to identify benthic communities.

This information will be crucial in evaluating the following:

- Mooring system:
  - Anchor type – whether drag embedment anchors ("plough" or "spade" anchors) or deadweight anchors (concrete blocks) are used will depend on the sea-bed characteristics.
  - Possible mooring abrasion points – in many cases, in order to maintain a necessary elasticity of the cage structure within the mooring system, for a potentially high wave climate, mooring lines longer than three/four times the site depth are required. Downstream mooring lines (or those on the side not exposed to the prevalent wind current or wave drag forces) may become very slack during storm or current action on the cages, and sink to where they rest on the sea bed. Although mud does not cause significant damage, sand or rocky areas in contact with the mooring lines can rapidly abrade them to a dangerous level. The use of non-compressible floats, secured to the lower end of the rope, or protected hard steel thimbles (tube-type thimbles; see Plate 10) for splices, can reduce this risk and lower maintenance costs.
  - Anchor deployment zones – irregularities in the sea bed may require a precise selection of suitable anchor deployment points, to avoid deployment of plough anchors on rocks (where the anchors will not embed) or of concrete blocks on hard clay (where the blocks may be dragged across the slippery surfaces).
- Sensitive habitats (live corals, seagrass meadows, nursery sites, etc.) should also be individually identified and mapped. The farm should be located downstream from these habitats, taking into account the current's prevailing direction.

As a good anchor embeds itself deeply into the sea bed, it is important to know more about the sea bottom than just its upper layer. Shells, weed and seagrass might prevent an anchor from taking hold. However, once through the upper layer, the anchor can dig itself into the lower sandy, mud, peat, cobble, stony or clay bottom layers, each with different holding characteristics. Common sea-bed compositions are usually reported in marine charts, using letters as symbols to indicate the type of sea bed. Table 8 provides a list of possible sea-bed compositions alongside the appropriate symbol used in the marine charts.

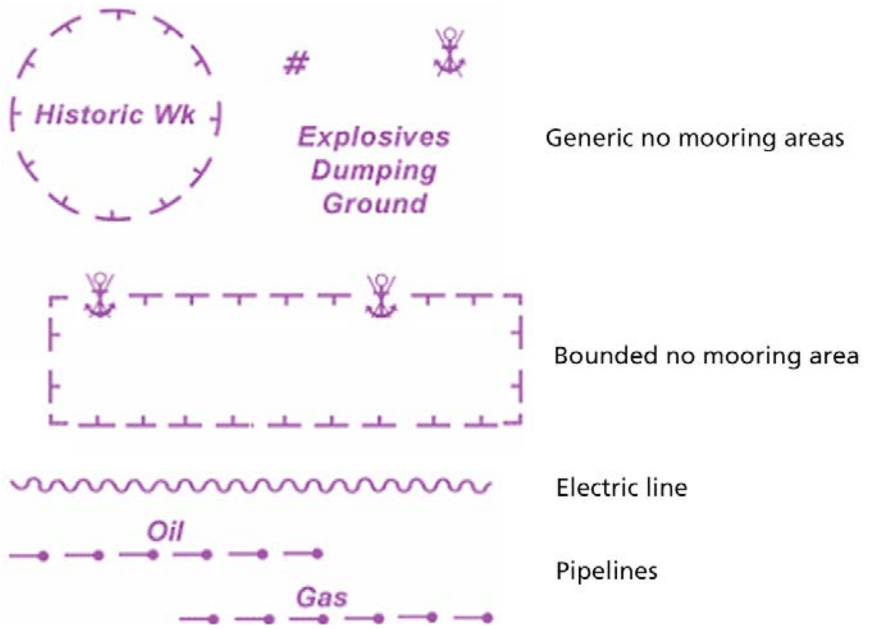
Thick mud, clay and sand will provide good holding, as will pebbles. Rocky, stones, corals will require a deadweight (gravity) anchor (i.e. concrete block).

The sea bed might be unusable for anchorage, or anchoring may be forbidden for reasons other than sea-bed nature, such as the presence of cables, telephone lines or pipelines, explosive dumping areas, or historical shipwreck sites (Figure 10). These limitations should be indicated on the nautical chart or enquiries can be made to the coastguard on this issue.

TABLE 8
Symbols used in standard nautical charts to indicate sea-bed composition

Symbol	Bottom type	Symbol	Bottom type
S	Sand	P	Pebbles
M	Mud	St	Stones
Cy, Cl	Clay	Rk, Rky	Rock, rocky
G	Gravel	Ch	Chalk
Co	Coral	Sh	Shells
Cb	Cobbles	Wd	Weed
Sn	Shingle	S/M	Two layers (e.g. sand over mud)

FIGURE 10
Graphic key on standard marine charts indicating "no mooring" areas



Storm and hurricane incidence

Storms and hurricanes, or cyclones or typhoons, are meteorological phenomena that can represent a risk mainly for the strong winds and for the resultant waves and currents generated in the sea. They mostly occur in the tropical-equatorial zones, in the area delimited by the two tropics, but they can extend their incidence into the North Atlantic (United States of Amercia and Canada) as well as the North Pacific, mainly on the eastern coast of Asia (China and Japan).

Hurricanes are classified with the Saffir-Simson hurricane wind scale (Table 9).

TABLE 9
Saffir-Simson hurricane wind scale

Category	Wind speeds	Impact
One	33–42 m/s, 64–82 knots, 74–95 mph, 119–153 km/h	Very dangerous winds will produce some damage
Two	43–49 m/s, 83–95 knots, 96–110 mph, 154–177 km/h	Extremely dangerous winds will cause extensive damage
Three	50–58 m/s, 96–112 knots 111–129 mph, 178–208 km/h	Devastating damage will occur
Four	58–70 m/s, 113–136 knots, 130–156 mph, 209–251 km/h	Catastrophic damage will occur
Five	≥70 m/s, ≥137 knots, ≥157 mph, ≥252 km/h	Catastrophic damage will occur

Source: Saffir, 1973.

The occurrence of hurricanes in a selected area should be carefully evaluated in order to perform an accurate siting and an adequate mooring calculation if the likelihood of having these phenomena is considered high.

Different cage models, other than floating, may be considered in the areas where there is a high incidence of hurricanes, such as submersible cages that are more suitable for extreme weather conditions.

Other criteria

Logistics

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

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

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

Available infrastructures at cage-site locations should be identified in order to evaluate possible advantages or disadvantages connected to the site's position. These may include:

- roads;
- piers/harbours/jetties;
- available work space on land;
- storage or warehouse availability.

Other coastal uses

The use of coastlines, activities carried out on them or the different occupations of those working on the coast should be considered in order to minimize the risk of negative interactions occurring with other coastal users in performing cage-farming duties. Such areas include:

- port areas or infrastructures;
- dumping points and underwater outlets along the coast;
- areas of interests for tourism (residential, beaches);
- archaeological sites;
- traditional fishing areas;
- artificial reefs;
- other aquaculture facilities;
- areas of military interest.

NAUTICAL CHARTS

A nautical chart is a graphic representation of a maritime area and adjacent coastal regions. Sometimes nautical charts are not available, or very inaccurate, or available only at large scale; in this case a site survey is critical to identify the correct cage system site and orientation.

The key characteristic of the chart is that the depiction of land/sea areas is to scale, thereby providing a tool for accurate measurements of heights, depths and distances. The scale of a chart is defined as the ratio of a set distance on the map to its corresponding distance on real land/sea.

For example, on a chart with a scale of 1:100 000, each centimetre measured on the chart will be equal to 100 000 cm (or 1 000 m or 1 km) as measured on the ground.

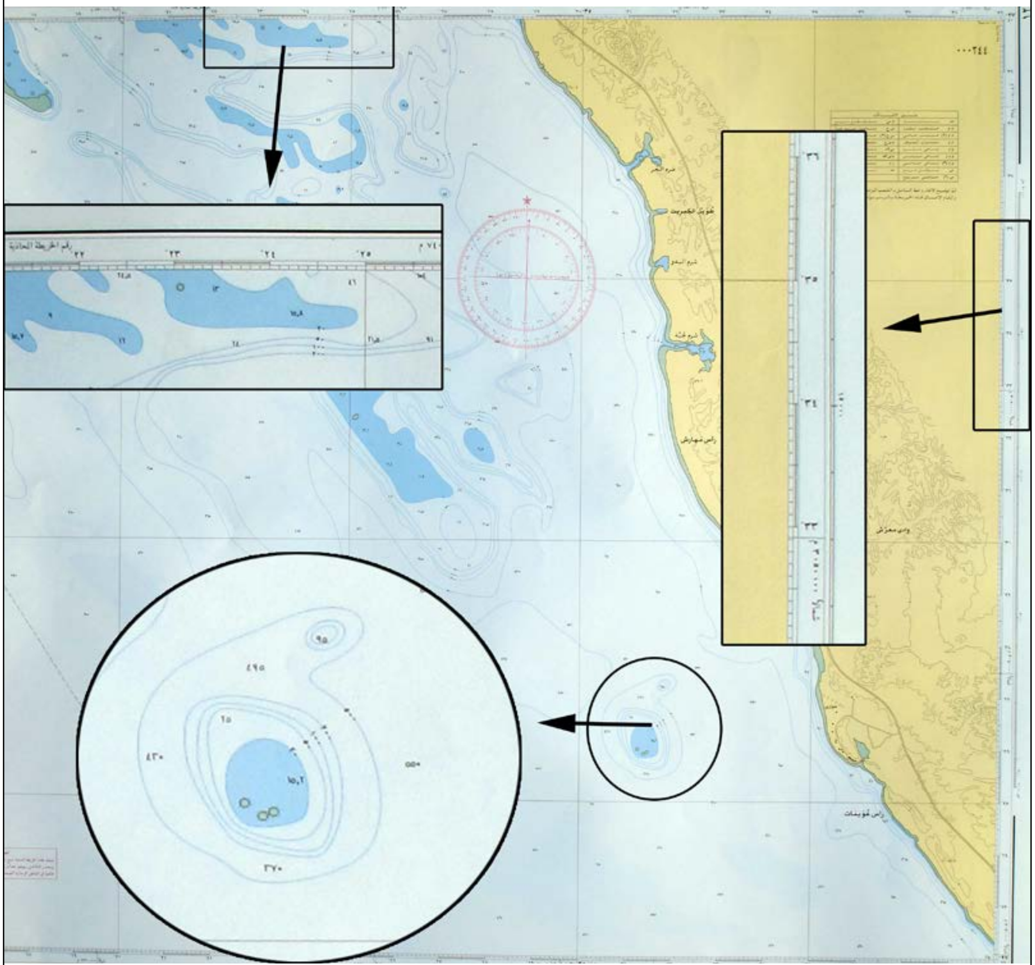
The latitude scale, which runs vertically along both sides of the chart, indicates North and South, and the longitude scale running horizontally along the top and bottom of the chart indicates East and West (Figure 11).

One of the most useful aspects of a nautical chart is the depiction of the depth and bottom characteristics through numbers, colour codes and bathymetric contour lines.

Geographical coordinates

Latitude and longitude represent the geographical coordinates, and the combination of these two components specifies the position of any location on the planet.

FIGURE 11
Interpreting a navigation chart



Note: Latitude and longitude are reported on the scales alongside the chart edges (in the picture the rectangular highlights). Bathymetric contour lines are associated with different colour areas for shallower waters (in the picture, the circular shape).

There are several formats for writing geographic coordinates, but all methods list latitude first and longitude second. The following are valid and acceptable ways to write geographic coordinates:

– DMS degrees: minutes: seconds (32° 30’00” N, 12° 30’00” E)
– DM degrees: decimal minutes (32° 30.0’ N, 12° 30.0’ E)
– DD decimal degrees (32.5000° N, 12.5000° E)

In the geographic positioning systems (GPS), units can be set to a specific format, but the most commonly used formats are DMS and DM. Sometimes, it is necessary to convert between these different methods of recording geographic position. There are 60 seconds in one minute, and 60 minutes in one degree. North latitude is positive (+) while South latitude is (-); East longitude is positive (+), West longitude is negative (–).

3. Mooring and grid system installation

Farm installation requires specific technical skills and a high level of specialization of the staff engaged. In most cases, the installation work benefits from the help of external qualified diving or marine engineering companies.

The first step is to identify an adequate area of land to use for staging and storage, ideally close to the farm site identified.

This phase includes developing a working relationship with the authorities (harbour and/or municipal) and obtaining the necessary authorizations (for the occupancy of public area, for moving loads and for towing some components from the harbour to the farm site).

The free area on land should have the following characteristics:

- a surface large enough to allow the construction of the cage and the use of a forklift;
- access to electricity;
- potential to leave materials and equipment safely without running the risk of theft (if possible, in a locked storehouse).

Sites meeting these requirements can be found in most port areas. A shaded area should be provided for nylon equipment (nets, ropes, etc.) in case a prolonged stocking is expected before installation (ultraviolet [UV] radiation degrades nylon).

All the farm components, equipment, gear and necessary materials will be stocked in this area, where one may work more readily than on a boat or underwater. Cage components need to be assembled on land, and they require a great deal of space.

NAVIGATIONAL BUOYS

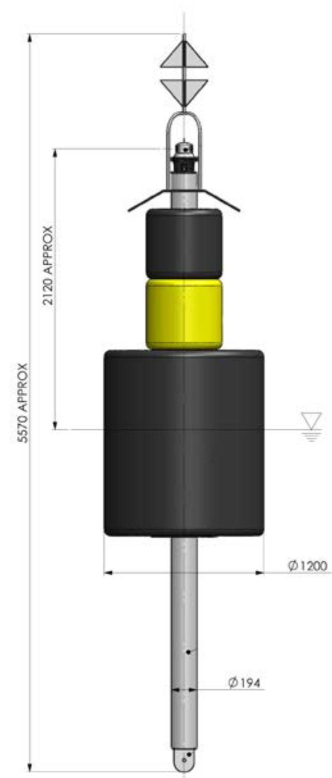
Usually, the first components that are installed are the marker buoys that designate the farm perimeter as per the licence. One marker buoy is placed on each corner of the farm site (Figure 12).

Technical characteristics

A wide range of navigational buoys are available on the market, including both hot-dip galvanized steel and rotomoulded polyethylene. A generic component list of a navigational buoy system includes:

- Concrete blocks: One of these anchors is used for each buoy, with a weight appropriate for the buoy depending on buoyancy and site characteristics, equipped with at least an 18 mm steel ring for attachment.
- Galvanized steel connecting chain: The chain connects the concrete block to the buoy, and should have a length 1.5 times the site depth and a diameter appropriate to the size of the buoy.
- Shackles: Two shackles are needed for each buoy; one to connect the chain to the concrete block, and the other to connect the chain to the buoy.

FIGURE 12
Navigational buoy technical drawing and dimensions (Unit: mm)

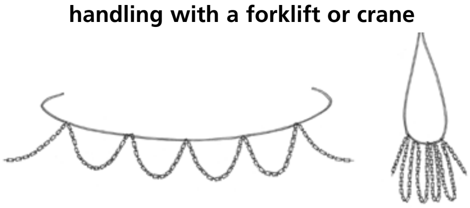


COURTESY OF: FLOATEX SRL

FIGURE 13
Marine lantern of 1 M (top), 2 M (middle) 3 M (bottom) visible range

COURTESY OF: SEALITE PTY

FIGURE 14
Chains can be bunched with a rope passed through every 20–30 links, to permit easy handling with a forklift or crane



- Swivel: The buoy should be free to rotate around its own axis.
- Navigational buoy: The buoy should be highly visible, and equipped with a radar-reflector device and marine lantern.

Modern marine lanterns (Figure 13) are equipped with several light-emitting diode (LED) lights, which provide bright lights with minimal power usage. They should be bright enough to be seen from a long distance, as required by local regulations. These types of lanterns usually have solar panels to recharge the batteries and are relatively maintenance-free.

Navigational buoys are generally yellow, but some regions require special cardinal buoys in which each buoy has a different colour sequence in order to be easily recognized.

Material assembly on land

The buoy assembly (concrete block, shackle, chain, shackle and buoy) should be prepared on land.

One end of the chain is connected with a shackle to the buoy's pad eye on the lower part of the buoy.

Both the buoy with the chain and the concrete block are loaded on board the vessel. The free end of the chain is connected to the concrete block's pad eye with a shackle.

Chain can be bulky and unwieldy to handle. One method for easier handling is to bundle the chain by passing a stout rope through every 20–30 links as shown in Figure 14, resulting in numerous coils, which reduces the chain's length. This method can be used for any chain deployments discussed in this manual.

Deployment

Once at the deployment point (determined with the aid of a GPS) the rope keeping the chain "bunched" is removed. The next steps are:

- The buoy is craned into the water, and the boat begins to move forwards, towing the buoy.
- Once at the exact point for deployment, the chain is deployed overboard, the concrete block is lifted up by the crane's hook using a rope sling, and held out over the water. The rope sling is cut.
- The concrete block will sink until the buoy is in position (Figure 15).

GRID SYSTEM AND MOORING SYSTEM

The mooring system used with the HDPE circular cages is a square-shaped grid system held on the sea bed with an array of mooring lines.

It is a dynamic system; all of the components keep the structures moored to the sea bed, and are designed to dampen the forces generated by the wave motion.

The mooring system is divided in two main groups of components, the mooring lines and the grid system (Figure 16):

- The mooring lines include the anchors, ground chains, ropes and related shackles, and buoys.
- The grid system includes the frame ropes, mooring buoys, connector rings or plates, bridles, and related shackles.

In a grid system, the cages are not moored separately one from the other, but are instead aggregated in modules.

The most common modules in offshore sites are composed of 6, 8 or 12 cages, installed in two parallel columns. Larger modules are also used in sheltered sites, including some larger systems of up to 36 cages in a 3 × 12 grid system, but there may be concerns on the possible oxygen availability and total loads on the mooring components.

Six or eight unit grid systems are preferable in exposed sites with strong currents and waves.

System design depends on the number of cages that will be moored, as well as the number of mooring lines. The ratio between the number of cages and number of moorings is a useful indication of how securely the cages are moored as well as of the relative cost. A farming module with a smaller number of cages will have a relatively higher number of mooring

FIGURE 15
Navigational buoy mooring scheme: the buoy is moored to a concrete block by a chain. A portion of the chain should lie on the sea bed to permit the vertical movement of the buoy with the waves

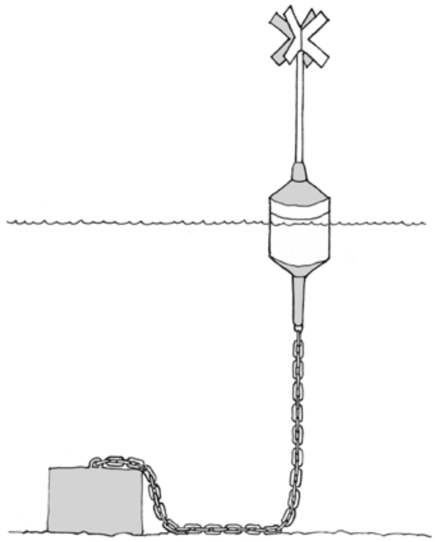
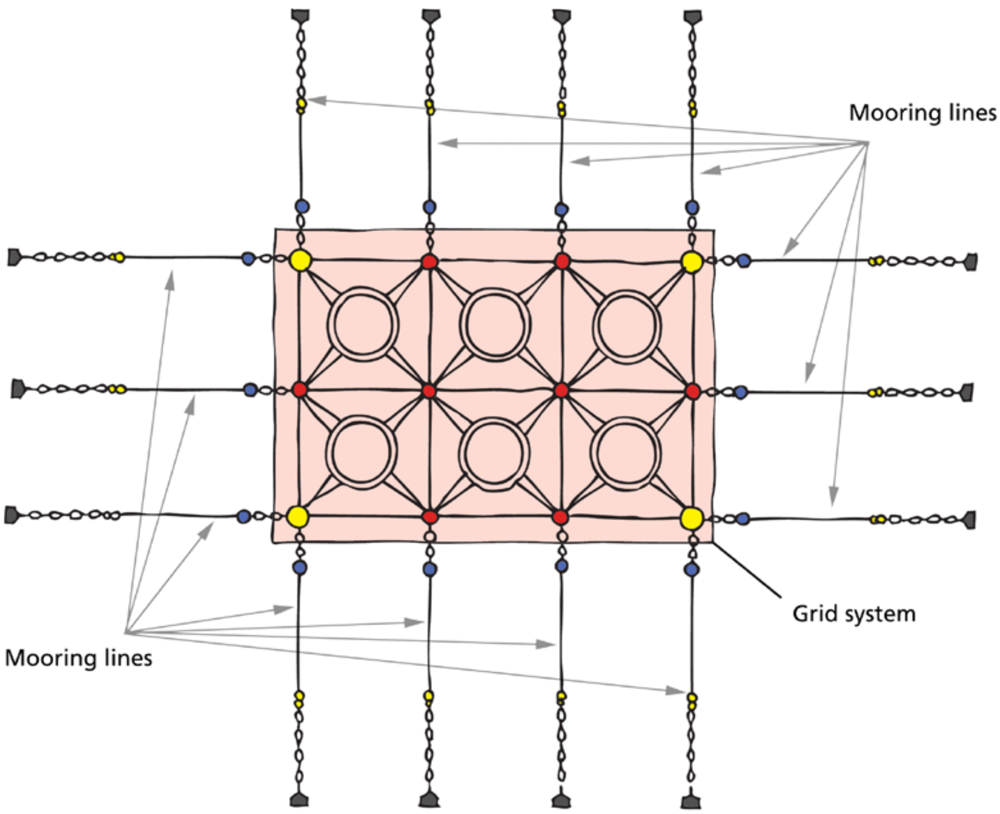


FIGURE 16
Grid system and mooring lines in a framing module of six cages



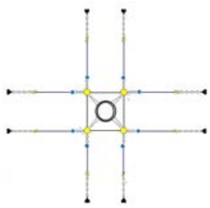
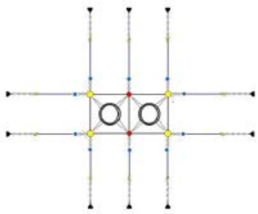
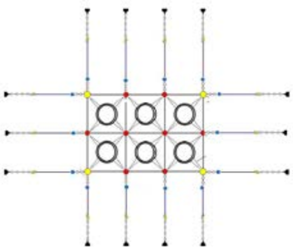
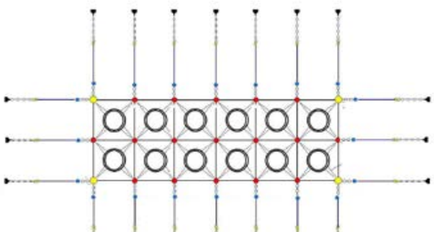
lines per cage (Table 10). This is preferred in a highly exposed site because a greater number of anchors will hold each cage more securely. On the other hand, in a sheltered site larger modules can be used where the mooring system would benefit from an economy of scale, requiring relatively fewer anchors and subsequent lower installation costs. Table 10 is a guide and additional mooring lines can be added as required to reinforce the farming module, particularly those situated in exposed sites.

If the grid system has more than eight cages, the forces generated by current or waves may strain the grid, causing it to sag in the middle (Figure 17). For this reason, if it is not possible to reduce the number of cages, the central mooring lines should be doubled and cross-linked, i.e. requiring the installation of additional anchors (Figure 18).

Furthermore, in order to reinforce the corner points of the grid system it is possible to install "corner anchors" on one or more sides (Figure 19). These additional mooring lines reduce stress on the grid corners caused by the currents and waves flowing in from those directions.

The mooring system can be installed using single or double mooring buoys. The first option is mainly used with a floating cage system, while the second option is used with submersible cages or in case of high-energy sites. In the case of a submersible cage

TABLE 10
Square grid systems showing different number of cages and mooring lines (if no additional mooring lines are added to reinforce the system)

Farm module	No. cages	No. mooring lines	No. mooring lines/cage
	1	8	8
	2	10	5
	6	14	2.33
	12	20	1.66

system, the submerged cages use the grid as a hanging frame while submerged, so a double line of mooring buoys is needed (the first on the mooring lines, and the second on the grid corners). The double-mooring buoy system could also be used with large cages, or in high-energy sites where additional buoyancy is necessary.

FIGURE 17

A grid system deformed by forces generated by current or waves

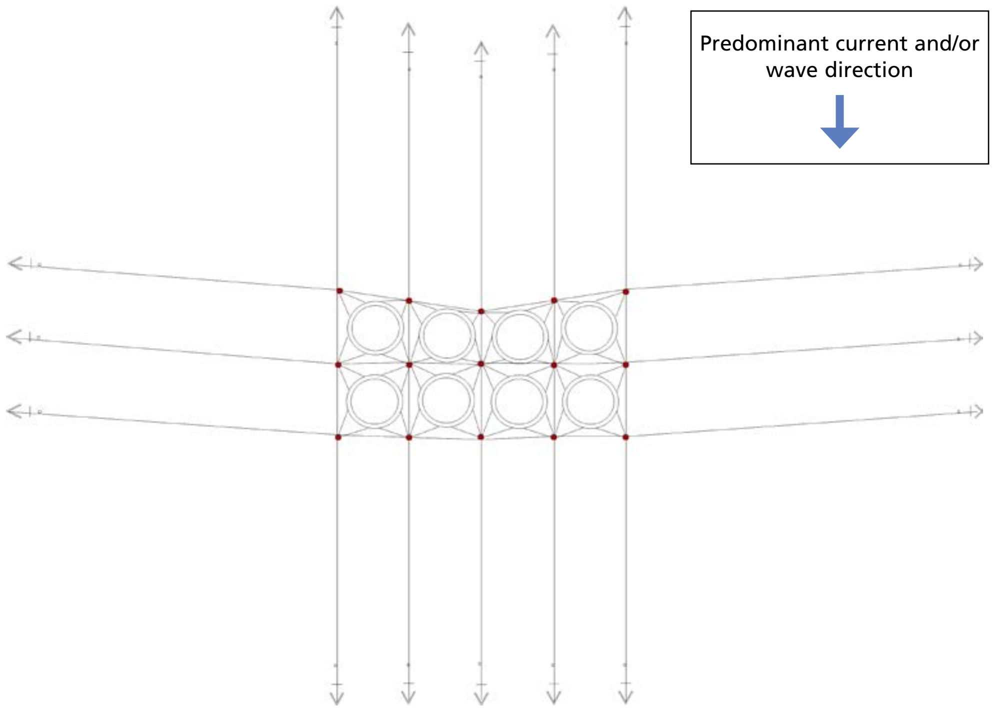


FIGURE 18

A grid system with the central mooring lines doubled

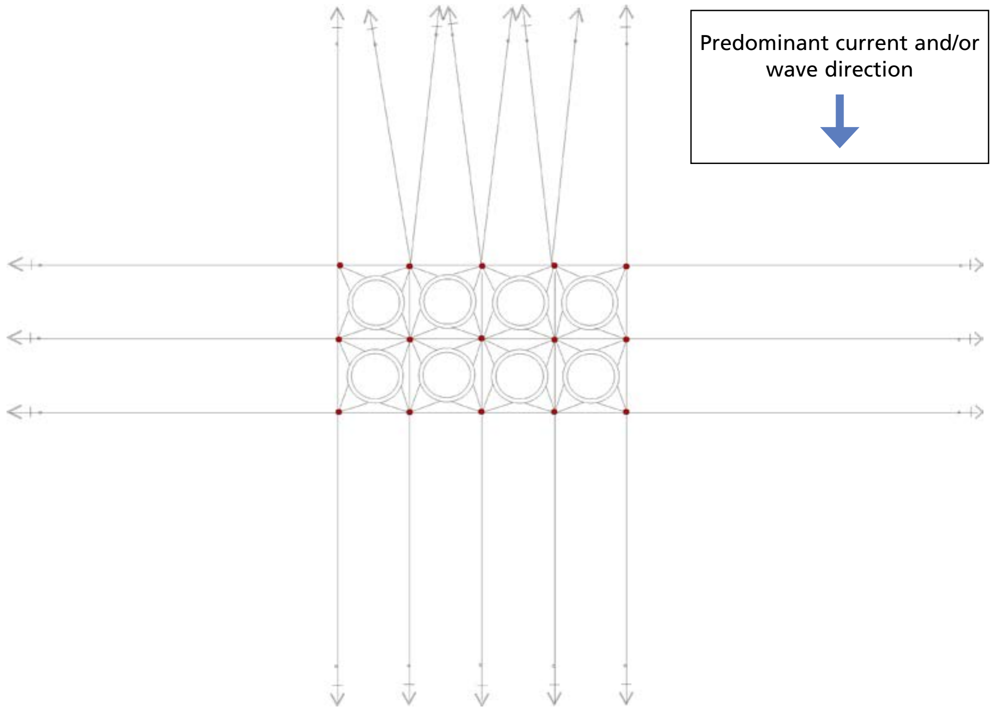
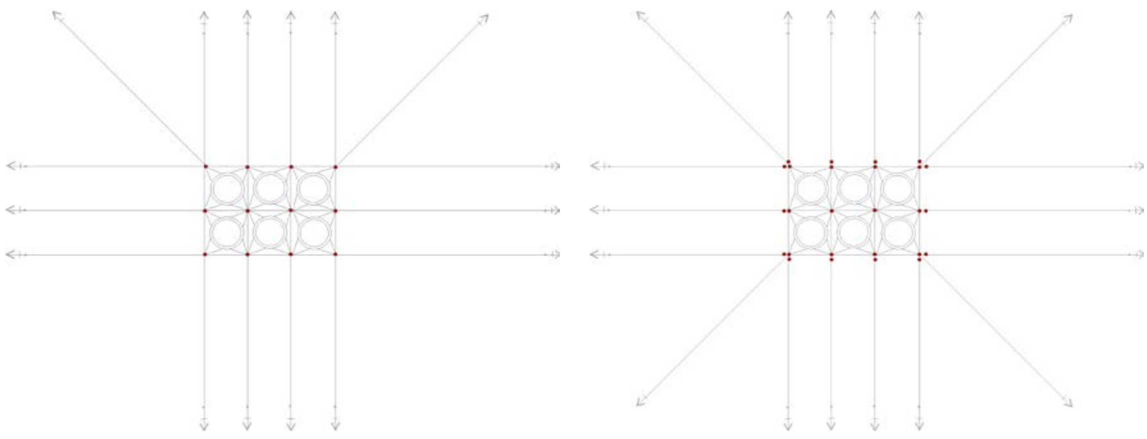


FIGURE 19
A grid system with additional corner mooring lines

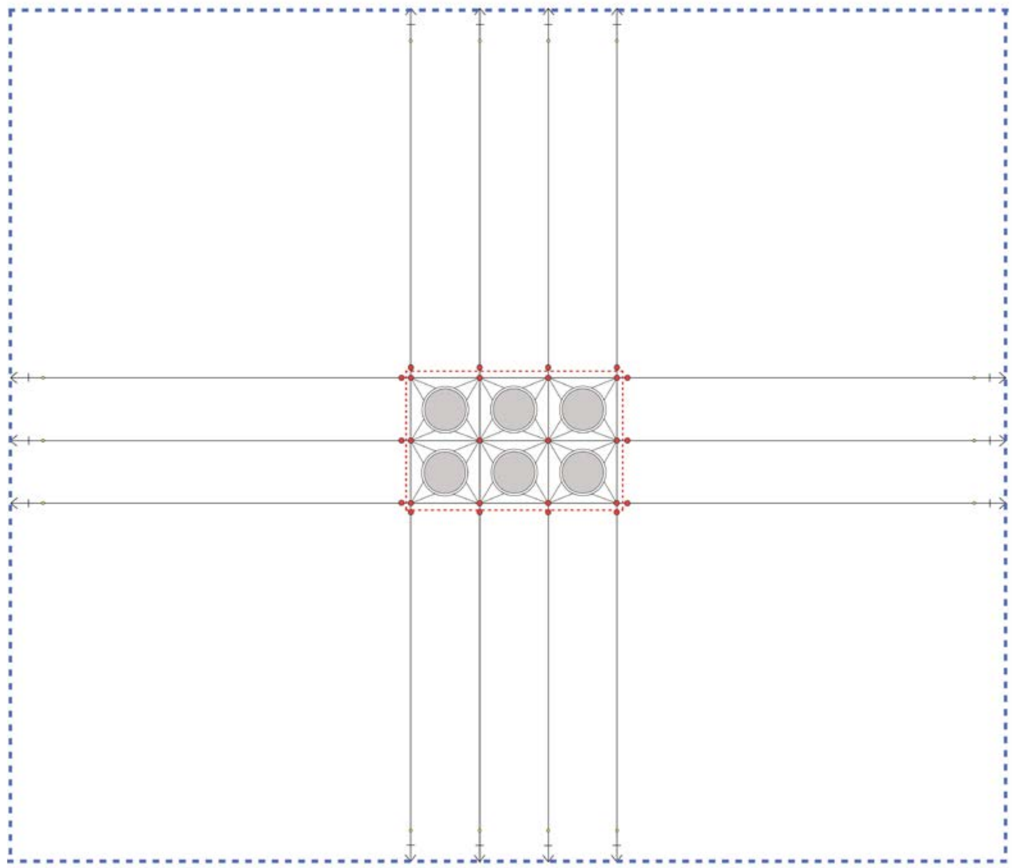


Schematics and details of a double buoy mooring system are presented in Appendix 1.

Farm footprint

The actual surface area occupied by a cage farm system is called the farm footprint (Figure 20). The total area of an HDPE cage system is much larger than the visible floating components. The floating components (buoys and cages) will occupy the smaller area of the grid system, while a much larger area underwater will be occupied by the mooring lines.

FIGURE 20
Surface area occupied by a cage farm system



Note: Surface area occupied by the floating components (red dotted area) and the actual farm footprint (blue dotted area). The proportions of the area are based on a farm site 30 m deep (with each square of the grid system 30 m long).

This is important in evaluating the licence or lease area dimensions, and the safety "no fishing zone" around the licensed area.

To calculate this footprint, a mooring line length of at least 4–4.25 times longer than the site depth should be used. This is because the maximum loading power of anchors is generated by the angle of 9–12° between the anchor and the mooring line. Thus, the dimensions of the grid system, plus 4–4.25 times the depth of the site (for each side of the grid system) will give the actual dimensions of the footprint.

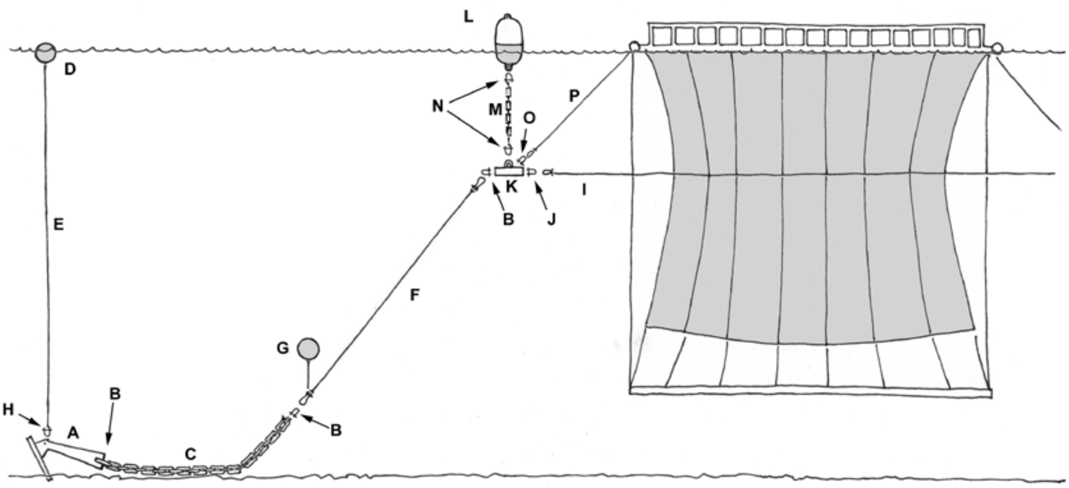
Mooring and grid components

The components of a single mooring line are detailed in Table 11, with components for a grid system presented in Table 12. In both these tables, a reference to Figure 21 is provided for each component.

The sizes of the components are for a 3 × 2 grid system module, with cages of 20 m in diameter in a medium-energy site (Hs 2.5 m), 25 m deep.

Is recommended that all the components of the mooring system must be certified by the supplier for the declared Safe Working Load (SWL).

FIGURE 21
Schematic drawing of components constituting the mooring line and grid system in a single buoy mooring system



Note: The figure is not-to-scale and it only refers to Tables 10 and 11 for the key to the letters.

TABLE 11
List of components of a single mooring line (typical example only, sizes and dimensions may vary according to site and mooring analysis)

Mooring system components	Quantity	Reference (Figure 21)
Anchor: 800 kg embedment type (sand or mud ground)	1	A
Shackle: bow-type with bolt and pin rated for 12.5 tonnes SWL[1]	3	B
Ground chain: diameter 38–42 mm. Total weight approx. 1 tonne	1	C
Anchor marker buoy: 10 litre buoyancy	1	D
Anchor marker line (crown line, or tripping line): polysteel rope of 37 m length and 36 mm diameter	1	E
Mooring rope: polysteel rope of diameter 48 mm, 3–4 strands, length 100 m. Also splicing, steel thimble and oval ring #22 mm at one end	1	F
Deep water buoy: 10 litre buoyancy	1	G
Shackle: bow-type with bolt and pin rated for 8.5 tonnes SWL	1	H

[1] SWL = safe working load.

Note: The total number of components required is obtained by multiplying the quantities below by the actual number of mooring lines (see also Table 10).

TABLE 12
List of equipment for a 3 × 2 cages grid system (typical example only, sizes and dimensions may vary according to site and mooring analysis)

Grid system component (3 × 2 cages)	Quantity	Reference (Figure 21)
Grid rope: polysteel rope of diameter 48 mm, 3–4 strands, length 40 m. Also splicing, steel thimble and oval ring #22 mm at one end	17	I
Shackle: bow-type with bolt and pin rated for 8.5 tonnes SWL[1]	34	J
Corner plates or ring: section diameter 28 mm	12	K
Mooring buoy: 950 litre buoyancy	12	L
Buoy chain: diameter 16 mm, length 3 m	12	M
Shackle: bow-type with bolt and pin rated for 4.75 tonnes SWL	24	N
Connections to cage	**Quantity**	**Reference (Figure 21)**
Shackle: bow-type with bolt and pin rated for 6 tons SWL	24	O
Bridle: polysteel rope of diameter 36 mm, 3–4 strands, length 10 m. Also splicing, steel thimble and oval ring #16 mm at one end	48	P

[1] SWL= safe working load.

Note: Tables 11 and 12 are only to be used as a reference. Size and dimensions of all components must be properly calculated according to the actual characteristics of the farm site selected. Lengths of the mooring lines in the tables are only suitable for a site with a water depth of 25 m. The total length of a mooring line must be at least 4–4.25 times the site depth, or longer if specified by the cage supplier. The size of each component must be properly calculated, according to site characteristics, cage size and cage design.

Mooring points

Different types of anchors are suited to various types of substrate. Plate 2 shows multipurpose anchors used for sandy or muddy bottoms. These are the most commonly used anchors in farm mooring (Figure 22). In the event of rocky sea bottoms or unsuitable environmental conditions of the site, rock pins may be considered as mooring points in case anchors or concrete blocks (see below) cannot be employed (Plate 3).

PLATE 2
Plough anchors

COURTESY OF: A. CIATTAGLIA

PLATE 3
A rock pin fixed to a rocky shore

COURTESY OF: AKVA GROUP ASA

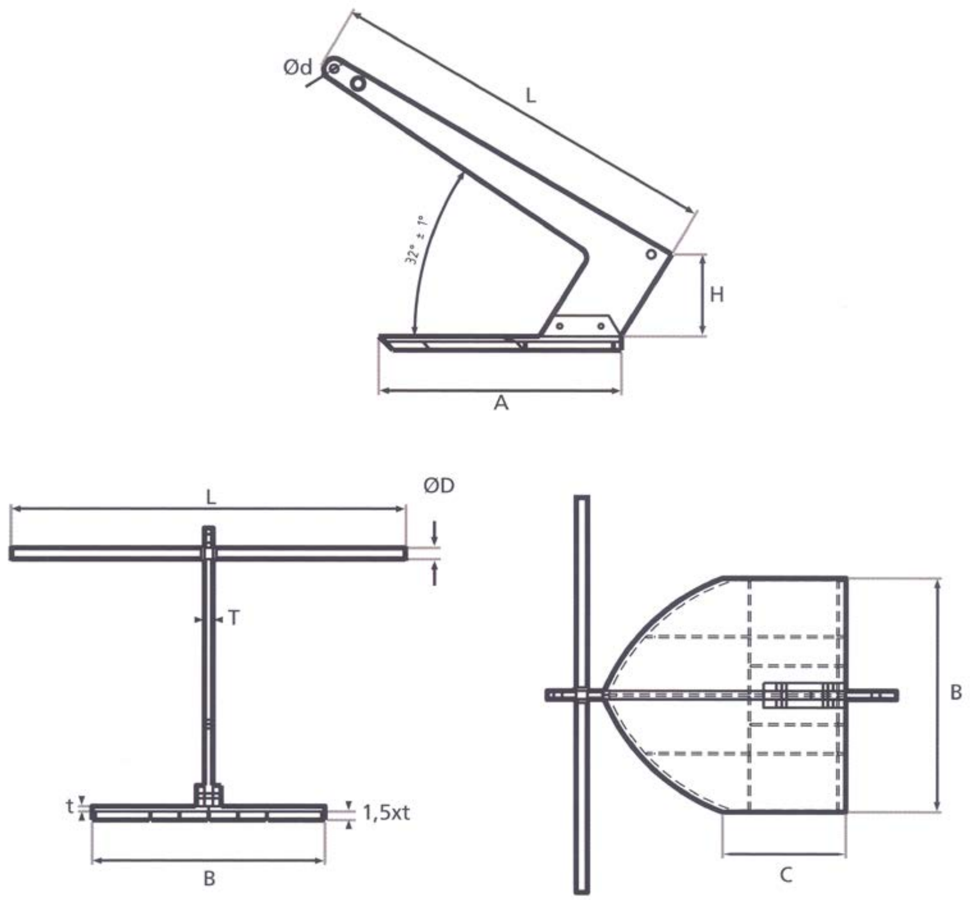
The holding capacity for these anchors ranges from 20 to more than 50 times the weight, when installed in mud-silt or compacted sand.

Alternatively, or in combination with the anchor, concrete blocks can be installed (Plates 4–8). As a mooring, the weight of concrete must be proportional to the drag forces to which it is subjected. These anchors can range in weight from several hundred kilograms to 10–20 tonnes.

In some cases, a concrete block may include a through-hole for the insertion of a safety chain for lifting and manoeuvring of the block, and for additional safety in the mooring. The upper steel ring will generally be 30–40 mm thick and is subjected to heavy abrasion by the continuous friction of the mooring shackle. If the ring fails, the safety chain can still hold the mooring in place.

The shape of the concrete block is also important. A broader concrete profile is always preferable to a narrower footprint, to improve adhesion to the sea bed. If the block has a convex bottom, it will increase the adhesive power to the sea bed by creating a suction effect, particularly in soft sand or muddy substrates.

FIGURE 22
Example of plough anchors – technical drawing and dimensions



	FLUKE				SHANK				STOCK
Weight	A	B	C	t	T	L	H	Ød	ØD
kg	mm	mm	mm	mm	mm	mm	mm	mm	mm
300	1 030	945	550	20	34	1 650	1 650	50	50
500	1 290	1 220	650	22	40	2 100	2 100	50	60
700	1 400	1 280	700	28	45	2 350	2 350	60	60
1 000	1 560	1 480	780	30	50	2 590	2 590	60	70
1 500	1 760	1 690	890	39	60	2 865	2 865	60	80
2 000	1 970	1 840	940	40	65	3 000	3 000	75	90
2 500	2 100	1 980	970	45	70	3 200	3 200	80	95
3 000	2 200	2 070	1 050	50	75	3 355	3 355	85	100

COURTESY OF: SOTRA MARINE AS

PLATE 4
Iron frame used for industrial concrete block building

COURTESY OF: A. CIATTAGLIA

PLATE 5
Wooden mould ("form") for building concrete blocks in the field

COURTESY OF: F. CARDIA

PLATE 6
Detail of the stud link chain used in the wooden form. Note the two iron bars added on the lower link

COURTESY OF: F. CARDIA

PLATE 7
Once the wooden form is filled with concrete, and the block has hardened, the form can be removed and the block left to dry for a few days

COURTESY OF: F. CARDIA

PLATE 8
Concrete block deployment. The concrete block is lifted into place using the boat's crane or lift bags

COURTESY OF: A. CIATTAGLIA

Chains

Two different types of chains are used in cage aquaculture: studless chains and stud link chains. The two types differ by the presence (stud link) of a stud in the centre of each link (Figure 23).

The size of a chain is commonly indicated using the diameter of the section of the link expressed in millimetres (mm), Ø in Figure 23. In this manual, this value is used to indicate a chain size.

Studless chains are mostly used as connection elements between mooring components, such as buoys and corner plates or rings of the grid system. In these cases, the link diameter does not usually need to exceed 14–16 mm.

New chains, of high-strength steel (such as grade 60 or 80), are recommended. Table 13 provides some technical specifications of studless chains of different diameters.

TABLE 13
Characteristics of studless chains (indicative)

Diameter (Ø) (mm)	B × A (mm)	Safe working load (tonnes)	Breaking Load (tonnes)	Weight (kg/m)
7	21 × 10.5	1.2	6.1	1.1
10	40 × 15	2.6	12.6	2.2
13	52 × 19.5	4.3	21.2	3.7
16	64 ×24	6.4	32.2	5.6
19	76 × 28	9.0	45.4	7.1
22	88 × 33	12.0	60.0	10.0

Stud link chains have a higher safe working load (SWL) and are commonly heavier than studless chains, given equal length and Ø (see Tables 13 and 14).

The ground chain is usually of a stud link type. It is often tarred to ensure it lasts longer in the marine environment. The size can range from 38 to 42 mm thickness (with a weight of about 30–35 kg/m), up to 50 mm (with a weight of about 50–60 kg/m).

The ground chain, connecting the anchor and the mooring rope is primarily used to provide weight to the mooring line, in order to keep the angle between seafloor and the mooring line within the desired range, between 9° and 12°.

Shackles

Shackles are used to connect mooring ropes, chains and anchors (Figure 24).

The SWL capacity in tonnes is usually used to identify the size of shackles.

Shackles can be U-shaped or omega-shaped (Figure 24). Omega-shaped shackles are the most common because they can accommodate a greater number of connections.

Shackles can be locked with one of the following main systems:

- clevis pin and screw-thread, where the pin is locked with a wire or welded shut to prevent the nut from loosening (Figure 24a and Figure 25).
- round pin without screw-thread, but with a cotter-pin (Figure 24b).
- bolt and nut + cotter-pin, to prevent the loosening of the nut (Figure 24c).

Stainless steel cotter-pins are strongly recommended.

The second locking system described above is the less preferred for mooring connections, as the cotter-pin may corrode as a result of the galvanic current generated in the system.

FIGURE 23
Studless and stud link chains (Ø = diameter)

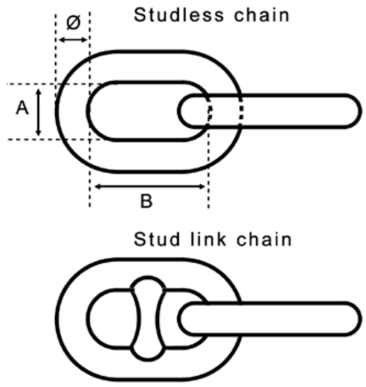


TABLE 14
Stud link chains: weight per metre (indicative)

Diameter (Ø) (mm)	Weight (kg/m)
16	6.0
19	7.9
22	10.9
25	14.2
29	17.9
32	22.3
33	24.6
34	26.9
38	32.1
42	37.0
44	42.8
48	49.3
51	55.5
54	62.7
58	70.3
60	78.2

FIGURE 24
Types of shackles. Top row: omega-shaped. Bottom row: U-shaped. (a) Shackles with clevis pin and screw-thread. (b) Shackles with pin without screw-thread and with cotter-pin. (c) Shackle with bolt and nut + cotter-pin

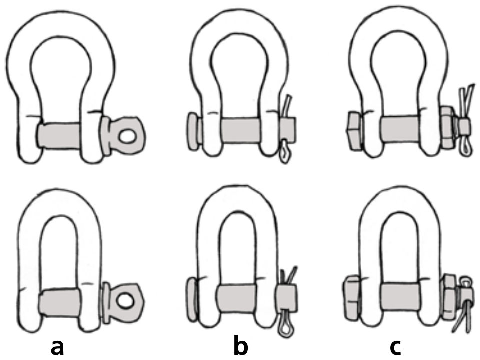


FIGURE 25
Shackles with clevis locked with a wire

Deep water buoys

The deep water buoys are made with a rigid material based on polyethylene or polyvinyl chloride (PVC). These components are used to lift the connection point between the chain and rope in the mooring line to avoid abrasion of the line when it comes in contact with the sea bed (Plate 9).

These floats can also be used as anchor markers at the surface end of the tripping line.

Thimbles

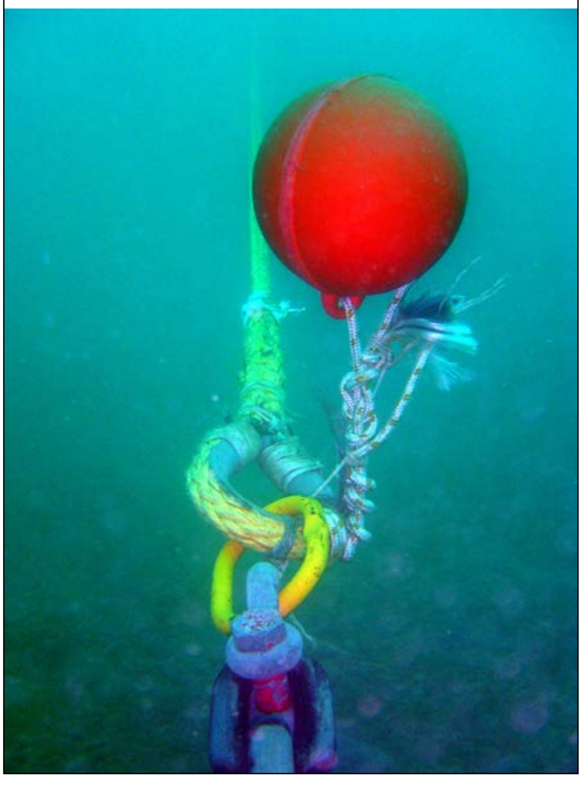
Thimbles are generally made of hot-dip galvanized steel, and are used to reinforce the rope loop (eye splice) where it is connected to metal equipment (shackles, rings, etc.), and thus where it is subjected to heavy abrasion. Thimbles can markedly reduce wear on the rope.

Thimbles used for moorings are usually either "tube-type" or "open-type" (Plates 10 and 11).

Tube-type thimbles reduce the possibility of the splice becoming undone over time, and provide more protection to the spliced rope. However, they are heavier and more expensive.

Thimbles are fixed to the rope through an eye splice. Splicing is a knotting procedure that provides for minimal loss of rope tensile strength. Each knot weakens the rope. A simple knot can reduce the effective breaking load of a rope by 55 percent compared with the original rope specifications, while a splice results in a reduction of only 5 percent (Prado, 1990). In a mooring line eye-splice, the rope strands are braided back

PLATE 9
Deep water buoy installed on a mooring line



COURTESY OF: F. CARDIA

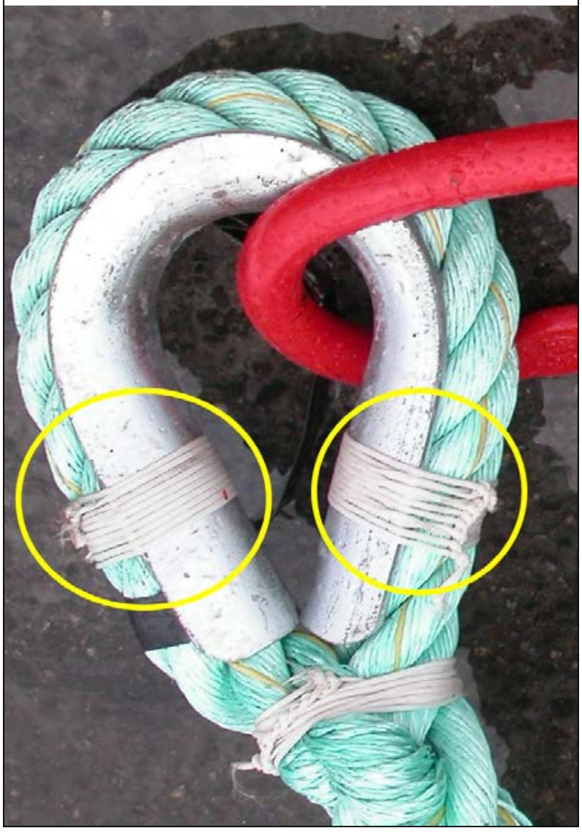
PLATE 10
Thimble – tube-type

COURTESY OF: A. CIATTAGLIA

PLATE 11
Thimble – open-type

COURTESY OF: A. CIATTAGLIA

PLATE 12
Open thimbles showing binding to prevent twisting within eye splice



COURTESY OF: A. CIATTAGLIA

upon themselves at least four times, to provide the greatest splice strength.

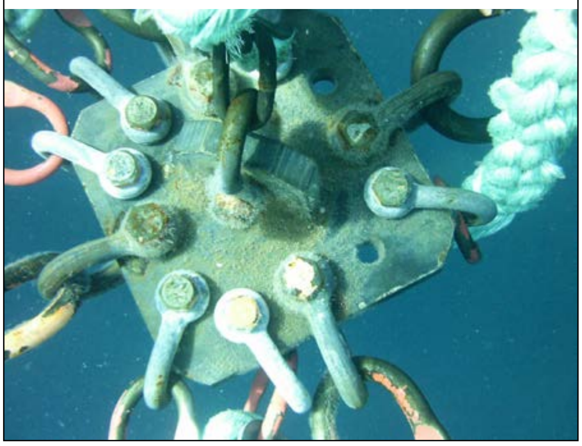
Open thimbles should be fixed with two bindings, as shown in Plate 12. This will avoid thimble rotation inside the eye loop once the rope becomes stretched under load.

Corner plates

Corner plates are used to connect the different parts of the grid system. They come in many shapes and sizes. Mooring plates are the main connecting points of the whole grid structure where all components come together and are locked with shackles: the grid system, the mooring lines, the buoy chains and the cage bridles (Plates 13 and 14).

Plates are usually square-shaped, with sufficient holes for the shackle pins to be inserted. At times, steel rings are used instead of corner plates as shown in Plate 15 (see next section).

PLATE 13
Corner plate, 12 holes. Four are used to connect the main mooring lines; eight are used to connect the mooring bridles for the cages



COURTESY OF: F. PICCOLOTTI

PLATE 14
Corner plate, eight holes. Four are used to connect the main mooring lines; four are used to connect paired mooring bridles for the cages

COURTESY OF: AD.AQ. SRL

PLATE 15
A steel ring used in a mooring grid in place of a corner plate

COURTESY OF: A. CIATTAGLIA

PLATE 16
Circular steel ring used as connecting element in the grid system

COURTESY OF: F. CARDIA

PLATE 17
Elliptical steel ring

COURTESY OF: A. CIATTAGLIA

Steel rings

Hot-dip galvanized steel rings are used at intersections in the mooring system. Round-shaped rings are used where different grid-lines intersect (Plate 16).

Oval-shaped or elliptical rings (Plate 17) are inserted into steel thimbles in order to avoid using larger more expensive elements (e.g. shackles and thimbles) when connecting elements of similar breaking loads. Plate 18 shows connections within the mooring array.

Mooring systems without shackles are sometimes used in sheltered sites. These systems have large iron rings (Plate 19) on the grid corners, where the grid and mooring ropes are connected through a “lark’s head” or “bow anchor” knot (Plates 20 and 21). This prevents wear and tear of the metals and reduces maintenance costs. It is necessary to use only high-quality ropes that can be securely tightened; ropes made of polyester or nylon are recommended. Polysteel can be too slippery a material for these purposes.

Buoys

There is a wide range of sizes and shapes of mooring buoys available on the market (Plate 22). These are generally described by their buoyancy, expressed in kilograms or volume (in litres). The buoyancy in kilograms of a buoy is equivalent to the volume of the buoy minus its weight in kilograms.

The outer material is often rotationally moulded polyethylene, and the filling is usually polyurethane foam or polystyrene.

In most buoys, a steel bar (about 30–40 mm thickness) runs through the main buoy body to

PLATE 18
Steel rings used for connecting eye spliced ropes with thimbles through a pair of shackles. Another shackle then connects the circular ring to the corner plate

COURTESY OF: A. CIATTAGLIA

PLATE 19
Steel ring used as a corner plate. This component permits the rope to be knotted directly to the steel ring without using shackles

COURTESY OF: F. CARDIA

PLATE 20
Grid lines connected with anchor bends to a steel ring. The upper rope is connected to the buoy

COURTESY OF: N. KEFERAKIS

connect the two opposite attachment rings and add strength. More recently, full plastic HDPE buoys have also been produced to reduce galvanic corrosion problems.

Ropes

Ropes are the main components of the mooring system, and are used for both the mooring lines and grid system lines.

The most common rope material used is polysteel or danline, a blend composed of polypropylene and extruded polyethylene. This combination provides a line of the same weight and price as polypropylene, but with a tensile strength more than 25 percent higher.

Polyester or nylon ropes can also be used, but these are more expensive, and have much more stretch when placed under load. Stretching in the lines can cause major problems in the mooring grid.

Mooring system installation

This section describes a possible procedure for installing a 3 × 2 cage mooring system.

Note: The following procedure is intended only as an example. Any deployment will need to consider different arrangements according to the working team, available service boat and mooring dimensions.

This example is provided considering a grid system where corner palates and shackles are used (see Plates 13 and 14); procedures for deploying grid systems with rings (see Plate 15) may have different steps and operational sequences.

Before installation, the correct mooring system orientation must be determined. This is

PLATE 21
Steel ring connected to grid lines and cage bridles

COURTESY OF: F. CARDIA

PLATE 22
Buoys of different sizes stored on a harbour pier

COURTESY OF: A. CIATTAGLIA

a critical factor for the best performance from the mooring equipment. The orientation is generally planned according to the main or dominant current and/or wave direction. If no other reasons exist, the grid should be oriented to ensure the best possible oxygen supply to the farmed fish and the largest number of mooring lines holding the farm against the predominant currents and waves (Figure 26).

To describe the mooring system installation, a six-cage module system comprised of three groups of two cages is used as an example (Figure 27):

- three main central lines (red lines);
- eight grid lines (green lines);
- eight side mooring lines (blue lines).

FIGURE 26

Preferred orientation of the mooring system with reference to the predominant current and/or wave direction

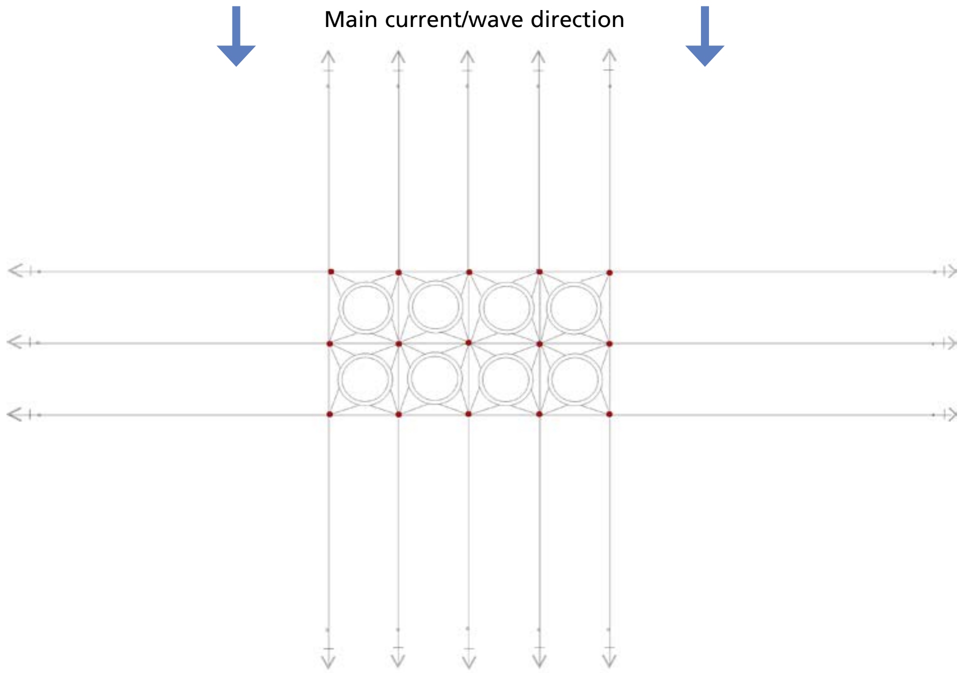
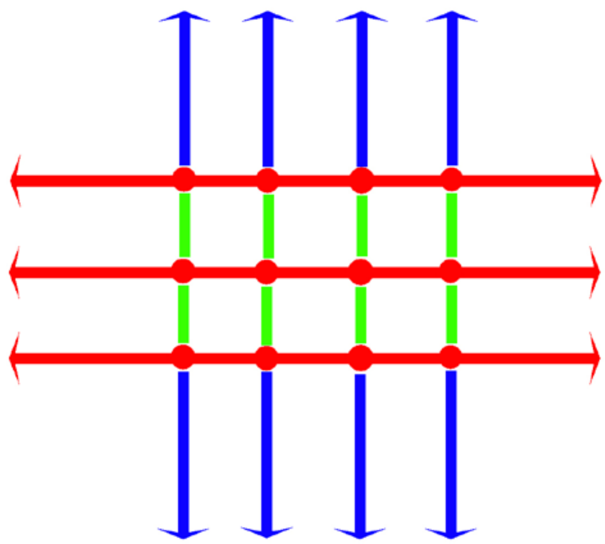


FIGURE 27

Mooring system: main central lines (red), side mooring lines (blue) and grid ropes (green)

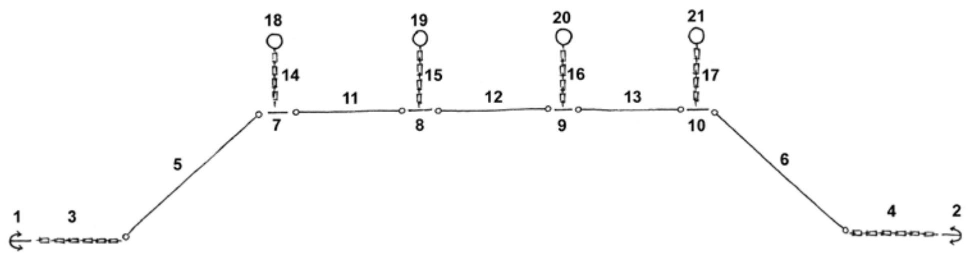


Each one of these groups will be deployed in succession and assembled together at sea.

Each main central line as shown in Figure 28 will be made up of two mooring lines (components 1–3–5 and 2–4–6), plus a portion of the grid system (components 7–21).

The connections among the various elements are always made through adequately sized shackles.

FIGURE 28
Main central line and its components (simplified drawing)



Anchors: 1, 2
Bottom chains: 3, 4
Ø 48 mm mooring line ropes (with thimbles at the two ends): 5, 6
Rings or plates: 7, 8, 9, 10
Ø 48 mm grid ropes (with thimbles at the two ends): 11, 12, 13
Buoy chains: 14, 15, 16, 17
Buoys: 18, 19, 20, 21

Assembling of components on land

The assembly work begins on land

First, the ropes must be uncoiled and unrolled in the correct manner. If a coil is unrolled without following the correct procedure, the rope will twist and knot and this can weaken the rope. The correct procedure is to place the coil on an axle or spool, so it can spin freely, and then take the bitter end of the rope (free end) in one's hands, and walk away from the coil so that it comes directly off the coil without twisting. All rope must be unrolled in this manner, including mooring lines, grid lines and bridle lines.

Assembly starts by connecting the various elements of the first main central line (numbering as referred to in Figure 28).

1. The rope (5) is linked to the plate (7); then three of four plates (7–9) are connected through the grid ropes (11), (12) and (13). All the elements are then connected one to each other as in Figure 28.

In this way, a portion of main line is assembled and properly set out in a coil on a pallet. Plates (or rings) must be left outside the coil to ensure easy access.

Care must be taken to wind the line onto the pallet in reverse order so that the first element to be deployed is at the end of the coil. This ensures ease of deployment.

2. The steel plate (10) is linked to mooring rope (6) and this portion is coiled onto a second pallet.

The pallets are then loaded aboard the deployment vessel.

These are the elements that together with two anchors and their respective bottom chains will compose a main mooring line.

Similarly to point 1, the assembled components are set out in coils on a pallet.

The 12 surface buoys and their respective buoy chains are connected, and then loaded aboard the deployment vessel. The chains can be bunched with a rope, as described above for navigational buoy installation (Figure 14).

The final on-land stage consists of preparing the anchors and their respective ground chains, which will similarly be bunched.

Boat loading

The deployment vessel should ideally be equipped with a crane, with a hydraulic drum, and should have adequate haulage power. Speed is a secondary consideration.

The most important dimension characteristic of the deployment vessel is the available space on the deck. The deck will require sufficient room to load the following components:

- two anchors;
- two ballast chains;
- two tripping lines;
- the pallets (as described in the previous section);
- surface buoys with their respective buoy chains.

The precise layout of the elements on deck is very important. Once the first anchor is deployed, it will drag out all the other elements. Therefore, each mooring component has to be free to move without becoming entangled or snagged on the boat's fittings. Once the components are placed aboard, they will be connected together, and each major line is assembled into two sections, to facilitate the deployment:

First major line section:

- Connect the bottom chain (3) to the anchor (1).
- Connect the tripping line with the anchor.
- Connect the end of the bottom chain to the thimble of rope (5), which is on the top of the pallet with the line.
- Connect the three buoy chains to the three plates, which are in view on the pallet coiled with the line.

Second major line section:

- Connect the bottom chain (4) to the anchor (2).
- Connect the tripping line with the anchor (2).
- Connect the end of the bottom chain to the thimble of rope (6) which is on the top of the pallet with the coiled line.
- Connect the buoy chain (17) to the plate (10).

All the above connections have to be made using correctly sized shackles.

Once these operations have been completed, the first major line's components, from anchor (1) to anchor (2) are connected into two separate sections, and are ready to be deployed.

Installation at sea

Major line installation

For the installation at sea, it is useful to employ an additional smaller boat as a support vessel to recover buoys, to retrieve lift bags and scuba divers, and to assist with the surface buoy alignment.

The mooring system must be placed in a previously determined position inside the licence area. This means that the anchors must be installed at predetermined points, to ensure the correct geometry of the grid system. A GPS is used to identify the exact location for positioning the anchors. These are marked with temporary marker buoys. Each one of these markers is composed of: (i) a small-sized weight (5–10 kg); (ii) a rope of the same length as the water depth; and (iii) a small float (easily visible on the surface). These markers can then be accurately placed and/or be easily moved, if necessary.

The first anchor (anchor 1) is released onto the predetermined point, and the boat moves at a moderate speed forward so that the mooring line, including the buoys connected to the plates, are placed in sequence into the water.

The boat is then manoeuvred close to the line previously paid out into the sea, coming from the opposite direction. The second major line section is then deployed, starting from the anchor.

To complete the first major central line's installation, the two lines are then joined, connecting the grid rope (13) to the plate (10).

It is very important that the distance between the two anchors is less than the distance they will occupy at the end of installation. In such a way, the line remains loose (not tight) and the last connection (between the grid rope [13] and the plate [10]) can be easily completed.

All the elements of the first major central line are thereby connected.

The same procedure is used to install the other two major central lines, aligned parallel to the first line.

Before proceeding with the installation of the side lines, the three lines are put under tension by hauling on the anchor crown line, or tripping line, so that the anchors assume their final position.

Note: The plough anchors should not be dropped to the sea bottom (free fall) but carefully lowered with the use of a drum-winch to reduce the risk of the anchors landing upside down.

Grid lines and side mooring line installation

Once the three major lines are installed, the plates are connected with the grid mooring lines (green lines in Figure 27). Scuba divers are used for this task. The vessel can facilitate this work by hauling on the lines to bring the two plates closer to each other, for easier connection of the lines.

In order to complete the grid system deployment, the side mooring lines (blue lines in Figure 27) are then installed.

The deployment points for the anchors are previously identified with the "provisional marker buoys". The components (anchor, chain, tripping line, shackles and rope) of the lines can be loaded separately, and assembled aboard before the launch.

Procedure for deployment of the anchors:

- Release each anchor on the pre-established point.
- Move the boat towards the grid system buoy where the mooring line is to be connected.
- Once at the buoy, the boat is moored to the buoy, and scuba divers connect the shackle at the end of the line to the plate.
- The operation is repeated for the other lateral lines on the same side and then for the mooring lines on the opposite side.

Post-installation tightening and check

The tightening of the lines after deployment is important in ensuring that the grid is square and that all the anchors are sharing the loads evenly.

For the tightening operation, a V-shaped towing rope can be arranged on the boat's stern.

The tripping lines of all the grid's anchors can then be hauled with this towing rope.

The three anchors of the major central lines on the same side of the grid system are the first to be tightened.

As a consequence of the anchor's haulage, the corresponding surface buoy starts to move, and as the tension increases, it starts to gradually submerge.

The correct alignment of the buoys can be verified by the support boat, which is moored on the buoys themselves, and provides directions to the main boat during the tightening.

By observing the buoyancy of the buoys, it is possible to assess the correct tension applied to the anchor by the boat, and to instruct the boat to stop pulling when the anchor is correctly positioned. If the line is too loose, the buoys will float too much; if the line is too tight, the buoys will sink and be too far submerged.

This operation is then repeated on the other anchors of the major central lines on the short opposite side of the grid, and then on the other mooring side lines.

Is recommended to inspect the following points before proceeding with the cage installation by divers or preferably with the use of a remotely operated (underwater) vehicle (ROV):

- The anchors are not upturned and are embedded correctly.
- The ropes are correctly arrayed, and are not coiled or knotted, which would reduce their strength.
- All the connecting shackles are correctly installed and are in the correct position.

Following deployment, it is useful for the farm management to number all the grid plates with plastic tags. This will help staff to keep clear records of possible anomalies or problems that require follow-up.

Numbered grid plates also simplifies record-keeping for maintenance purposes.

Before cage collar installation, the bridle lines are connected to the plates.

The mooring and grid system are now properly installed and ready for the fish cages to be deployed.

4. HDPE cage components

High density polyethylene (HDPE) pipes are widely used as the main material for the construction of floating cages. High-density polyethylene is a class of plastic resins obtained by polymerizing ethylene gas. Pipes made of HDPE are widely available because they are commonly used for liquid and gas transfer (irrigation systems, gas pipelines, etc.). Moreover, HDPE pipes are an excellent material for cage construction because they are durable, flexible, shockproof, resistant to ultraviolet (UV) light and require relatively little maintenance, if installed correctly.

HDPE CAGE CHARACTERISTICS

HDPE pipes

Types of HDPE

There are several different HDPE materials used for pipes; those used for cage construction are mainly PE80 or PE100. These codes, according to ISO 4427, relate to the minimum required strength (MRS) of the pipe, measured after 50 years at a temperature of 20 °C, and expressed in Bar:

- PE 80 (= MRS 8.0);
- PE 100 (= MRS 10.0).

PE 80 indicates an HDPE grade where the pipe will rupture at a pressure of at least 8.0 N/mm, over a 50 year service life at 20 °C. In the case of the PE 100 pipe, the pressure would be at 10.0 N/mm. This means that, assuming we have pipes of the same dimensions, pipes made of PE 100 material may function at a higher operating pressure than pipes made of PE 80.

The density of PE 80 is slightly lower than that of the PE 100, with specific-gravity values of 0.945 g/cm^3 and 0.950 g/cm^3, respectively.

Therefore, a cage built with PE 100 HDPE will be more rigid and stronger than a cage made with PE 80 HDPE, assuming both pipes are of the same dimensions, and slightly less flexible in handling dynamic loads.

Diameter of pipes

The external diameter of HDPE pipes used for cage building is usually expressed in millimetres. The diameter of the pipes will determine the buoyancy of the cage collar. The more exposed the site, the more buoyancy will be needed (e.g. more weight will be needed to maintain the cage volume) and, therefore, the pipe diameter will need to be larger. Brackets will be sized according to the pipe's diameter (see section on brackets below).

Pressure is not a characteristic relevant for cage construction. However, HDPE pipes are produced with different pressure-resistance grades (PN grades), which indicate the pressure of water, in bars, that the pipe can sustain at 20 °C. Different PN grades imply a different pipe wall thickness and, consequently, cage weight, strength, resistance and flexibility. Therefore, the higher the pipe PN is, the thicker will be the pipe wall thickness.

Many HDPE pipe manufacturers use the "standard dimension ratio" (SDR) as a method of rating the piping. The SDR is the ratio of pipe diameter to wall thickness and can be expressed as follows:

$$SDR = D / s$$

Where:

D = pipe outside diameter (mm);
s = pipe wall thickness (mm).

Example: A pipe with an SDR of 9 and a diameter of 250 mm will have a wall thickness of 27.8 mm.

With a high SDR ratio, therefore, the pipe wall will be thinner. As such, a high SDR pipe has a lower pressure rating, and a low SDR pipe has a higher pressure rating.

When used to build circular cages, HDPE pipes are limited by their torsion. Generally, the minimum radius to close and weld a round cage is approximately 25 times the pipe's external diameter. This means that a 250 mm pipe can be bent in a circle of no less than about 6.25 m radius before kinking (250 × 25 = 6 250 mm). This calculation varies according to the pipe wall thickness and air temperature. Table 15 provides the bending radius for HDPE pipes with different standard dimension ratio (SDR).

TABLE 15
Bending radius of HDPE pipes

Standard dimension ratio (SDR)	Bending radius (maximum recommended)
9	20 × outside diameter
11	23 × outside diameter
13	25 × outside diameter
21	27 × outside diameter

Tables 16 and 17 provide some of the technical details, such as the thickness of the pipe wall, weight per metre of pipe, and buoyancy per metre of HDPE PE 80 and PE 100 for those PN numbers and pipe diameters most often used in cage construction.

Example: A double pipe cage, having a circumference of 60 m, made with 250 mm diameter pipes of HDPE PE100 and PN 16 types, will have a buoyancy (without considering the weight of brackets and handrail) of 3 924 kg (60 m × 2 pipes = 120 m × 32.7 kg = 3 924 kg).

TABLE 16
HDPE PE 80 pipe characteristics

Pipe size Ø (mm)	HDPE PE 80 pipes											
	PN 6.3			PN 10			PN 12.5			PN 16		
	SDR 21			SDR 13.6			SDR 11			SDR 9		
	T (mm)	W (kg × m)	B (kg × m)	T (mm)	W (kg × m)	B (kg × m)	T (mm)	W (kg × m)	B (kg × m)	T (mm)	W (kg × m)	B (kg × m)
110	-	-	-	8.1	2.6	6.9	10.0	3.2	6.3	12.3	3.8	5.7
125	-	-	-	9.2	3.4	8.9	11.4	4.1	8.2	14.0	4.9	7.4
140	-	-	-	10.3	4.2	11.2	12.7	5.1	10.3	15.7	6.1	9.2
160	7.7	3.7	16.4	11.8	5.5	14.6	14.6	6.7	13.4	17.9	8.0	12.1
180	8.6	4.7	20.7	13.3	7.0	18.4	16.4	8.5	17.0	20.1	10.1	15.3
200	9.6	5.8	25.6	14.7	8.6	22.8	18.2	10.4	21.0	22.4	12.5	18.9
225	10.8	7.3	32.4	16.6	10.9	28.8	20.5	13.2	26.6	25.2	15.9	23.8
250	11.9	9.0	40.1	18.4	13.5	35.6	22.7	16.3	32.8	27.9	19.5	29.6
280	13.4	11.3	50.2	20.6	16.9	44.6	25.4	20.4	41.2	31.3	24.4	37.1
315	15.0	14.3	63.6	23.2	21.3	56.6	28.6	25.7	52.2	35.2	30.9	47.0
355	16.9	18.1	80.8	26.1	27.0	71.9	32.2	32.6	66.3	39.7	39.3	59.6
400	19.1	23.0	102.6	29.4	34.2	91.4	36.2	41.5	84.1	44.7	49.8	75.8
450	21.5	29.0	130.0	33.1	43.4	115.6	40.9	52.5	106.4	50.3	63.0	96.0
500	23.9	35.9	160.4	36.8	53.5	142.8	45.4	64.8	131.5	-	-	-

Note: Ø = pipe diameter in mm; T = wall thickness in mm; W = weight of pipes in kg/m; B = buoyancy in kg/m; SDR = standard dimension ratio; PN = nominal pressure.

TABLE 17
HDPE PE 100 pipes characteristics

Pipe size Ø (mm)	HDPE PE 100 pipes											
	PN 6			PN 10			PN16			PN 25		
	SDR 26			SDR 16.8			SDR 11			SDR 7.3		
	T (mm)	W (kg × m)	B (kg × m)	T (mm)	W (kg × m)	B (kg × m)	T (mm)	W (kg × m)	B (kg × m)	T (mm)	W (kg × m)	B (kg × m)
110	-	-	-	6.6	2.2	7.3	10.0	3.2	6.3	15.1	4.5	5.0
125	-	-	-	7.4	2.8	9.5	11.4	4.1	8.1	17.1	5.8	6.4
140	-	-	-	8.3	3.5	11.9	12.7	5.1	10.3	19.2	7.3	8.1
160	6.2	3.0	17.1	9.5	4.5	15.6	14.6	6.7	13.4	21.9	9.5	10.6
180	6.9	3.8	21.7	10.7	5.7	19.7	16.4	8.5	16.9	24.6	12.1	13.4
200	7.7	4.7	26.7	11.9	7.1	24.3	18.2	10.5	20.9	27.4	14.9	16.5
225	8.6	5.9	33.9	13.4	8.9	30.8	20.5	13.3	26.4	30.8	18.9	20.9
250	9.6	7.3	41.8	14.8	11.0	38.1	22.7	16.4	32.7	34.2	23.3	25.8
280	10.7	9.1	52.5	16.6	13.8	47.8	25.4	20.5	41.0	38.3	29.2	32.4
315	12.1	11.6	66.3	18.7	17.5	60.4	28.6	25.9	52.0	43.1	36.9	41.0
355	13.6	14.6	84.3	21.1	22.2	76.7	32.2	32.8	66.1	48.5	46.8	52.1
400	15.3	18.6	107.1	23.7	28.1	97.5	36.3	41.7	83.9	54.7	59.5	66.1
450	17.2	23.5	135.5	26.7	35.6	123.4	40.9	52.8	106.2	61.5	75.3	83.7
500	19.1	28.9	167.3	29.7	44.0	152.2	45.4	65.1	131.1	-	-	-

Note: Ø = pipe diameter in mm; T = wall thickness in mm; W = weight of pipes in kg/m; B = buoyancy in kg/m; SDR = standard dimension ratio; PN = nominal pressure.

Brackets

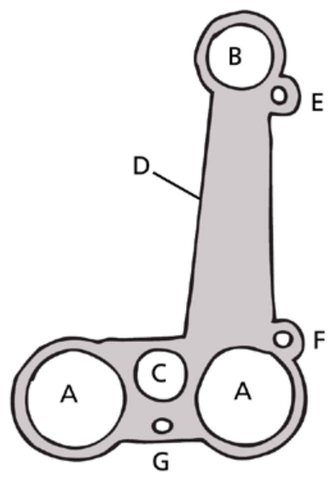
The bracket is a structural element of the cage collar that binds the pipes together to form the cage collar (Figure 29). Bracket robustness is essential to cage reliability. The bracket design may include two or three (sometimes even four) seats for the main floating pipes as shown in (A) in Figure 29. Additional spaces for walkway pipes may be available (C). On the top of the stanchion (D), a seat is available (B) where the handrail is lodged. The brackets may be equipped with specific attachment points for the net (E and F) and sinker system (G), which can be secured with lines or ropes. This last point (G) may also be used to attach a perimeter safety chain that can act as additional security to prevent the collar breaking apart in heavy seas.

A wide range of brackets are available from different net cage manufacturers, and the design should be chosen taking into consideration the site exposure and the required strength of the cage.

There are four main categories of brackets: welded plastic, rotomoulded plastic, injection moulded plastic, and metal.

Welded plastic brackets are made with HDPE pipes and HDPE components welded together (Plate 23). This type of bracket is usually very robust, although all components must be properly welded together to ensure durability. If the cages are to be installed in an exposed site, the design should avoid butt-welded points on the stanchion (see handrail supports – Plate 24),

FIGURE 29
Standard bracket scheme (two floating pipes, side elevation)



Notes: A) main floating pipe seats; B) handrail pipe seat; C) additional walkway pipe seat; D) stanchion; E) top-rail/handrail/jump net rope attachment point; F) waterline rope attachment point; and G) sinkers or sinker tube attachment point or seat for perimeter safety chain.

because these welds represent weak points on the stanchion element, which are subjected to fatigue by the continuous movement of waves.

Rotational moulded plastic brackets are probably the most widely used in floating HDPE cages (Plates 25 and 26). They are produced with the "rotational

PLATE 23
HDPE bracket made with welded HDPE pipes, reinforced on the base of the stanchion

COURTESY OF: A. CIATTAGLIA

PLATE 24
HDPE brackets made with welded HDPE pipes, mounted on a cage. Note the butt welds on the stanchion (red arrows), which are less robust

COURTESY OF: F. CARDIA

PLATE 25
PE brackets produced with the rotational moulding technique

COURTESY OF: F. CARDIA

PLATE 26
A PE bracket produced by rotational moulding, prior to installation

COURTESY OF: F. CIATTAGLIA

moulding" industrial manufacturing technique, where the mould of a single bracket is filled with plastic (PE or HDPE), and then heated to the plastic's melting point. As the mould is rotated, the melted plastic is dispersed uniformly to the walls of the mould. The mould is then cooled, opened and the plastic bracket is removed and ready. These types of brackets are not solid plastic, and the thickness of the plastic and the design itself are the key structural characteristics affecting their robustness. Depending on the design, the weight of these elements can range from 15–20 kg (for lighter models) up to 50 kg (for the most robust models). Some models are filled with expanded polyurethane resin to increase robustness and prevent deformities.

Injection moulded plastic brackets (Plate 27) are produced by a different process from that described above. Injection moulded brackets are made by feeding polyethylene plastic (PE or HDPE) into a heated barrel, where it is mixed and then injected into a mould, where it cools and hardens. Injection moulded brackets are solid components, and so are very robust, but heavier than those produced by rotational moulding.

PLATE 27
Injection moulded plastic bracket

COURTESY OF: AKVA GROUP AS

Metallic brackets were widely used in the past, but with the increased use of plastic brackets, the former brackets are now primarily used in more sheltered sites (Plate 28). However heavy duty steel brackets are being produced by some manufacturers (e.g. Aqualine, Norway). Metallic brackets are usually made of galvanized iron (zinc-plated), with either welding or bolting of the components together. Metal brackets may be cheaper than plastic brackets, but their use is not recommended for exposed sites because of two major constraints. Rusting (galvanic corrosion) may affect their reliability over time, and the plastic pipes may be damaged by continuous abrasion against the metal components.

PLATE 28
Disassembled components of a galvanized steel bracket

COURTESY OF: A. CIATTAGLIA

Some brackets are specially designed to be used as a temporary support when an original bracket fails. These supplementary brackets can be installed directly on-site, by being mounted onto the pipes while the cage is in operation (Plates 29 and 30).

Dismountable brackets are a provisional, temporary solution, and the original bracket should be replaced as soon as possible. The replacement of brackets with original brackets is usually carried out on land, as the procedure includes cutting the HDPE pipes, removing the broken bracket, inserting the replacement bracket, and then re-welding the pipes into a complete collar.

PLATE 29
Dismountable bracket – disassembled

COURTESY OF: AD.AQ. SRL

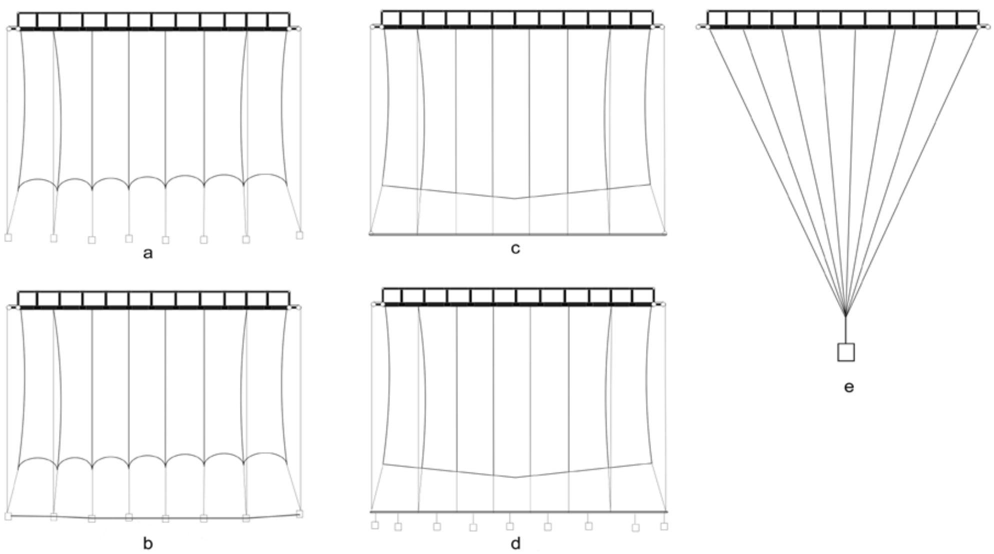
PLATE 30
Dismountable bracket – assembled

COURTESY OF: AD.AQ. SRL

Sinkers and sinker tube

Cage nets need to be weighted down to maintain the cage's volume in variable currents. There are two main methods of weighting down a net: using multiple sinkers (or weights), or using a single sinker tube. Some combinations and modifications of these two systems are also used (see Figure 30).

FIGURE 30
Different sinker systems



Notes: a) single sinker; b) single sinkers linked through a connecting rope; c) sinker tube; d) sinker tube with additional weights e) tapered net with a single sinker.

COURTESY OF: A. CIATTAGLIA

Multiple sinkers are a commonly used method to weight down a net (see Plates 31–36). Several weights, usually one for each bracket, are fixed to the outermost pipe of the cage collar with a rope. This rope can be attached either onto the pipe or onto the bracket (if the bracket is designed with an attachment point). The rope should be a few metres longer than the cage net wall. The net is attached either onto the sinkers (Plate 31) or onto the sinker ropes (Plate 35) with lines running from the base rope of the net cage.

The weight of each sinker will depend on the net's dimensions, mesh size, and the site's environmental characteristics. Faster currents and larger waves require heavier weights.

Sinkers are commonly made of concrete (Plates 31, 32 and 36). These can be readily made by filling a piece of PVC pipe with concrete, into which is immersed a section of

PLATE 31
Concrete sinkers – correct installation

COURTESY OF: F. CARDIA

PLATE 32
Concrete sinkers installed incorrectly: the vertical sinker rope is too short and the net is hanging from the sinkers

COURTESY OF: F. CARDIA

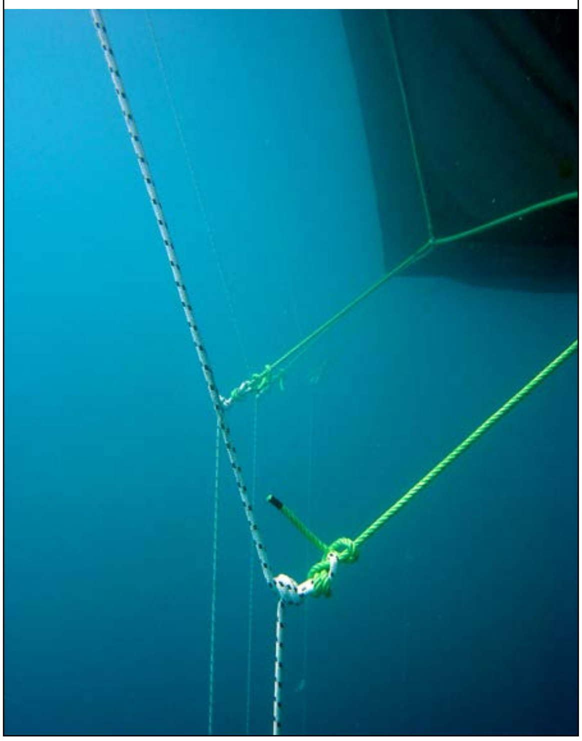
PLATE 33
Mesh bags filled with sand, gravel or small pebbles for use as sinker ballasts

COURTESY OF: F. CARDIA

PLATE 34
Stud link chains used as sinkers. Chains are preferable for use as net tensioning ballasts because of the greater weight in water of steel, compared with concrete, stones or other materials

COURTESY OF: F. CARDIA

PLATE 35
Net fixed on the sinker ropes



COURTESY OF: F. CARDIA

chain, so that the uppermost chain link protrudes sufficiently to be tied onto the sinker rope or net. (*Note:* the weight of concrete drops more than 50% when submerged in water).

Very cheap sinker can be prepared by using mesh bags filled with pebbles and sand (Plate 33). While inexpensive, these bags may tear and lose their ballast.

Pieces of large anchor chain (40 kg per metre) can also be used as sinkers (Plate 34).

It is very important that the sinkers are not hung directly from

PLATE 36
General view of the sinker system with multiple sinkers

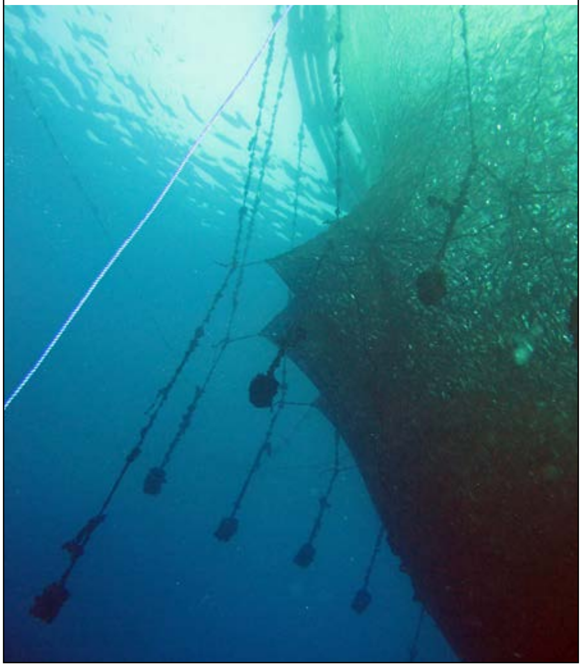

COURTESY OF: F. CARDIA

PLATE 37
HDPE connection element for sinker tube. This model shows how the sinker tube (represented by the portion of pipe) is fixed to the sinker rope (in yellow with plastic thimble), and how additional sinkers can be added (such the chain, as shown). The remaining free hole can be used as an attachment point for the net

COURTESY OF: AD.AQ. SRL

the nets or from the down-lines (vertical ropes) that are woven into the net. The weight of the sinker must be directly carried by the cage collar.

The length of the sinker rope must be long enough to avoid the sinker coming into contact with the net. Attention must be paid to the "down-current" side of the net, where the net base could be pushed onto the sinkers and become damaged through abrasion. This can be prevented by: (i) lengthening the sinker ropes; or (ii) covering the sinkers with spare netting.

The other method of weighting the net is to use a "sinker tube". A sinker tube is a circular sinking system made by butt-welding HDPE pipes together with a chain, steel cable or gravel inserted inside. This chain or cable is usually long as the tube, and is best if secured to prevent it from slipping. Usually, the weight material used in any given situation is what can be bought and transported more inexpensively, which is usually used material from the closest source.

The weight of the sinker tube varies with the cage size and it is calculated mainly according to the expected water current. For example from 40 to 70 kg/m in cages of 90–160 m circumference (e.g. used in salmon farms) and from 15 to 40 kg/m in smaller cages (60–90 m circumference) used in the Mediterranean for farming the European seabass or the gilthead seabream.

The sinker tube is at least the same length as the cage collar (sometimes a few metres longer is the preferred choice), and is usually made with a pipe with an internal diameter variable according to the cage design (e.g. from about 120 mm up to 400 mm) (see Plate 39). As with the sinkers, it is hung from the cage collar with ropes fixed onto the outermost pipe on the collar (Plate 37), or at the base of the bracket (Plate 38). The net can be tied with lines from the net baseline either directly onto the tube itself, or onto the sinker down-ropes.

Although more expensive than sinkers, the sinker tube will better maintain the shape of the net base, and the cage volume, as the structure is somewhat rigid and behaves better when subjected to currents (Plate 39).

The use of a sinker tube to tighten the net base can be very useful in cases where the cages have been moored in a site that is too shallow (although this is strongly discouraged), so that the net base can be kept taut, to ensure the maximum distance between the net base and the sea bed. (*Note:* it is not recommended to use sites this shallow.)

PLATE 38
Example of sinker rope connected to the base of the bracket

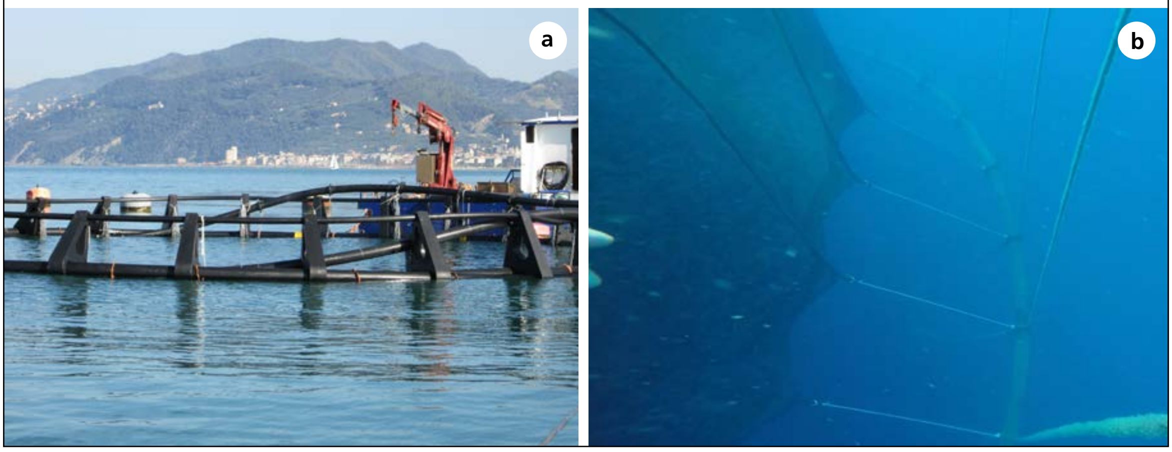
COURTESY OF: AD.AQ. SRL

COLLAR CONSTRUCTION

Cage collar construction procedures vary depending on the cage model to be assembled.

Constructing a cage collar requires an open space, close enough to the sea to permit the easy launch of the cage once completed, and sufficiently large to accommodate all the various components for the task (pipes, brackets, polystyrene cylinders, etc.) and to allow the connected collar pipe to be joined together. A forklift truck or similar vehicle can greatly facilitate the construction. A power supply is also necessary for operating the welding machine, so a generator will be needed if mains electricity is not available.

PLATE 39
Sinker tube. a) the sinker tube is temporarily fastened onto the cage handrail, to facilitate transportation from the harbour to the site; b) an installed sinker tube



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Collar assembly

The HDPE pipes are assembled with a butt-welding machine. Butt-welding involves the heating of the two pipe ends to their melting point and then subsequently joining the two ends together by force. The assembly procedure is as follows:

- Each HDPE single pipe is first filled with polystyrene cylinders (Plates 40 and 43). These cylinders have a slightly smaller diameter than the internal diameter of the pipes. The presence of polystyrene will ensure that the cage floats, even if the pipes become damaged and flooded. Some cage models only have the inner pipe filled with polystyrene due to high reserve buoyancy.
- The HDPE pipes are joined together sequentially with a butt-welding machine to produce two pipes as long as the final cage circumference.
- The brackets are then strung onto both pipes (Plate 41).
- The handrail is then assembled and strung through the upper hole of the stanchions (see Plate 43).
- The brackets are then distributed at predetermined distances along half of the pipes' lengths.

PLATE 40
Polystyrene cylinders are inserted into the pipes


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- The pipes are then bent, with the help of a forklift and appropriate pulleys, to connect the opposite ends, to allow the last butt welds of the main pipes and the handrail to be made (Plates 42–44).
- The remaining brackets are then distributed along all the pipes' lengths, and the distances between the brackets are corrected to ensure that they are equidistant from one another (Plate 45).
- The brackets are then blocked in position by welding HDPE stoppers onto the pipes' surface (Plate 46). Alternatively, a chain running around the cage collar and fixed onto each bracket may be used.
- The sinker tube (if used) is then assembled, and then temporarily tied up onto the cage collar walkway, for ease of transportation of the collar to the site (see Plate 39).

The primary weak point of HDPE cages is poor-quality butt-welds. The most common cause of poor-quality butt-welds is the operator's inattention to the timing, temperature and pressure needed for the welds to adequately fuse, or welding during adverse conditions. Before butt-welding, the operator must ensure that the machine is

PLATE 41
The two main pipes after their construction. The pipes have already been inserted through the brackets, which are distributed along half of the pipe length. The handrail has been inserted as well


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PLATE 42
Pipes are bent into a complete circle


COURTESY OF: AD.AQ. SRL

PLATE 43
Detail of the pipe end: the polystyrene cylinder is visible. Also the handrail is strung through the upper hole of the stanchions


COURTESY OF: AD.AQ. SRL

PLATE 44
Final butt-welding of two pipe ends; after this welding, the first pipe of the cage collar is closed

COURTESY OF: AD.AQ. SRL

PLATE 45
Brackets are distributed evenly along the pipe

COURTESY OF: AD.AQ. SRL

positioned for use in a dry area. The equipment must not be exposed to rain or dust, and welding operations must be suspended in dusty, windy or rainy conditions.

Collar installation

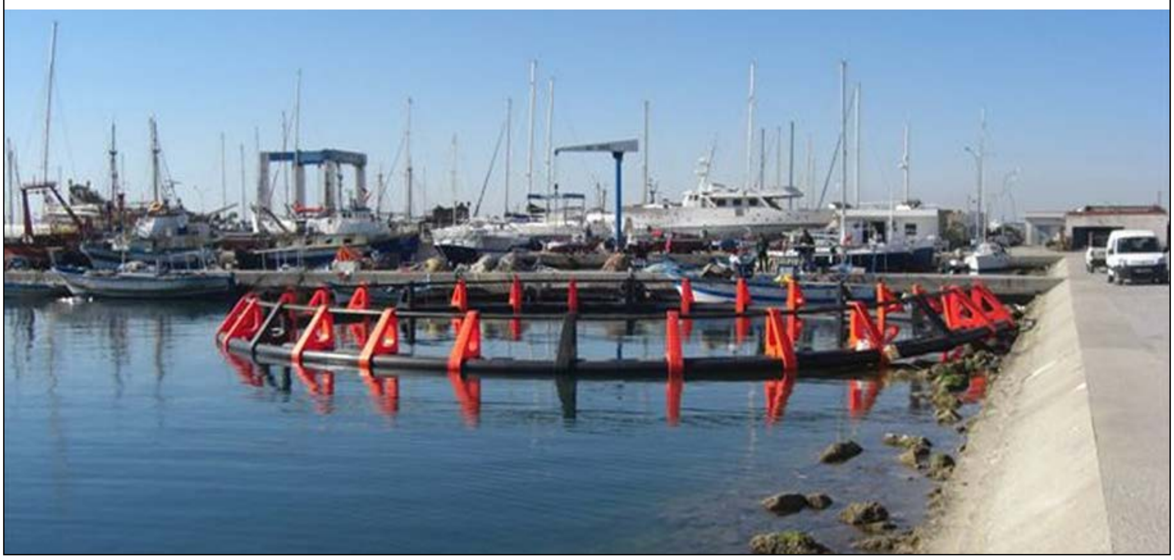
Once the cage collar is completed, it can be launched by being slid into the water (Plate 47). This operation needs to be performed carefully because pipes may kink or buckle if bent beyond their critical limit. Cage components can also be damaged when sliding across the dock.

To minimize the risk of damage, cage collars can be reinforced with some diametrically positioned bracing lines that will maintain the collar's circular shape and avoid excessive bending of the pipes.

PLATE 46
A bracket's position is fixed with HDPE stoppers on the internal pipe (red arrow); the external pipe is without stopper. The stoppers are welded onto the cage pipe with a hand-held HDPE welding machine

COURTESY OF: TECHNOSEA SRL

PLATE 47
Cage collar completed; note the different colour brackets: the black brackets indicate where to attach the mooring bridles



COURTESY OF: AD.AQ. SRL

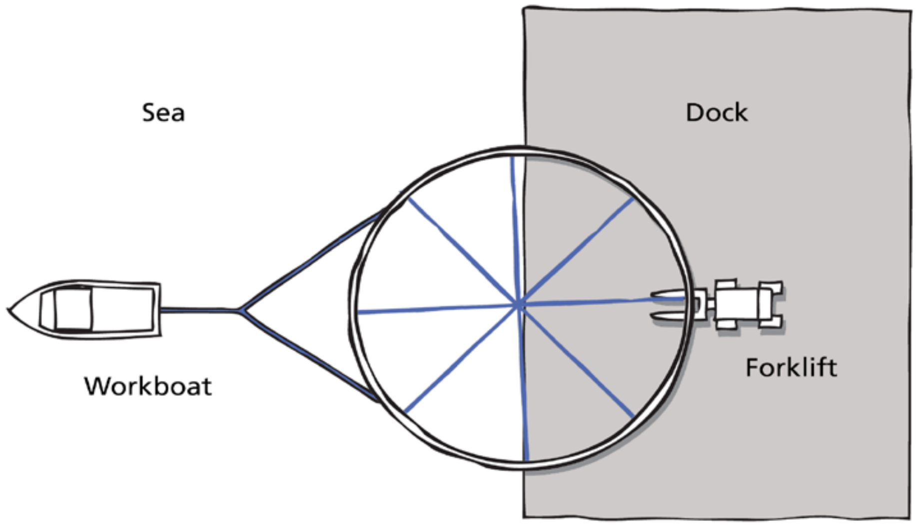
The cage collar can be launched using either a forklift truck or a workboat, or by a combination of the two. Figure 31 provides a schematic view of a cage collar launch – the towing rope and diametrically positioned ropes are represented by blue lines.

Note: Launch sites always differ, the important thing to remember is to not damage the cage in any serious way. For example, if having to drag it over a rocky area (rip-rap) before entering the water, it is advisable to have material (pipes, beams) under the cage that it can slide easily.

The cage can be easily towed with a suitably sized boat with outboard engine.

It is important that two "V-shaped" towing ropes, or bridles, are installed to distribute the pulling force on at least two points on the cage (Figure 31).

FIGURE 31
Cage-collar launch from a dock

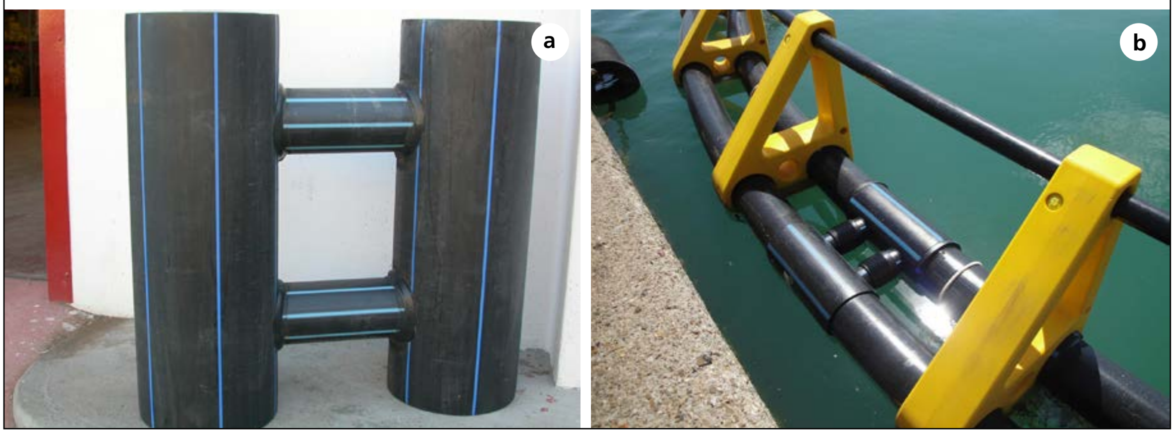


Note: Top view: a workboat pulls the cage into the water on the left, while the forklift truck pushes on the right. Ropes are coloured blue (brackets are not indicated here).

The rope attachment points on the cage must connect to the inner pipe. The distance between the two ropes should be at least 4 m for a cage up to 70–80 m in circumference.

Some cage models may have a mooring bracket specially designed to withstand high tensioning forces. If a mooring bracket is present, the rope can be attached here (Plate 48). These are generally installed if towing over long distances (such as in tuna tow cages).

PLATE 48
The mooring bracket is installed on the cage pipes when the cage is assembled on land. It is designed to withstand strong forces on the mooring points. a) mooring point element before installation; b) mooring point installed on a cage



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The mooring bracket can double the thickness of the tube, and it also prevents the bridle or tow rope from sliding around the HDPE pipe, thereby avoiding abrasion of the ropes on the plastic components of the cage.

It is better to install the internal diametric bracing lines before starting the cage tow.

If the tow is undertaken with the net installed, a minimum distance of 50 m must be maintained between the boat and the cage to prevent the propeller thrusting against the net. This distance should be increased to a minimum of 100 m if there are fish inside the net cage.

A fast towing speed will create a downward force on the leading edge of the collar pipes, on the side opposite to the boat (i.e. the inner edge of the trailing section of the collar). It is therefore advisable to attach floats (fenders, buoys, or other floating material) on these sections of pipe.

On the farm site, each cage collar is moored onto the grid system through bridle lines connected to the grid plates (Plate 49). Usually, two lines from each plate are available for each collar mooring, and as the cage is to be moored onto four plates, a total of eight lines are used for each cage. It may be necessary to have 3 lines for each plate (a total of 12 lines per cage), for larger cages (> 25 m diameter), or in more exposed sites.

The layout of bridle line attachments to a collar is depicted in Figure 32. Four pairs of bridle lines (green) connect each corner plate (blue) with the collar. Attachment points on the cage must be symmetrical. The bridle line attachment points can be easily identified by using different-coloured brackets (see Plate 47). The regular positioning of the bridles on the collar is very important to ensure equal weight distribution. Note that each bridle line is tied onto the farther side of the bracket and, for each pair of bridle lines one is on the left side of the bracket while the other one is on the right side.

The bridles are critical components that may affect the integrity of the cages if not properly installed. It is important that the bridle system is pre-designed, pre-measured and marked to avoid any mistake in the installation phase.

Several different methods can be used for tying the bridle line onto the cage collar (see Plates 50–52 and Figure 33). The most commonly used knot is shown in Plate 50 and Figure 33. The bridle line is passed over the

PLATE 49
Mooring plate (in the blue circle) with two pairs of bridle lines (red arrows) shown in each corner. The orange lines correspond to the grid lines. Note: the two pairs of bridle lines are connected to two different cages

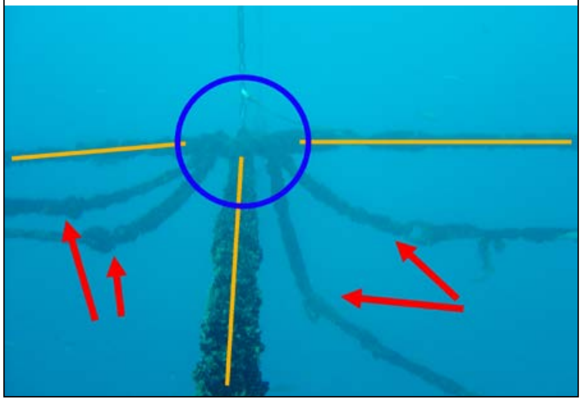

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FIGURE 32
Bracket and bridle line layout on a 24-bracket cage

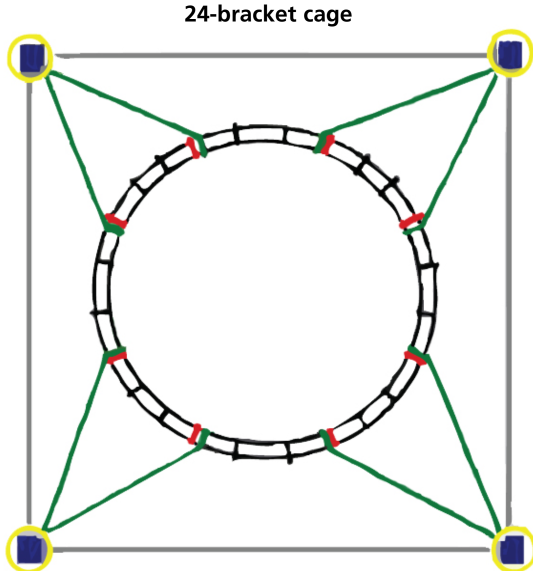


PLATE 50
Bridle line tied to the cage collar pipes. This knot is shown in Figure 33

COURTESY OF: F. CARDIA

PLATE 51
An alternative knot to secure a bridle line onto a collar – a clove hitch on the outermost pipe, with the remaining free end fixed onto a walkway pipe. The preferred knot to secure a bridle line is shown in Figure 33

FIGURE 33
The preferred bridle line attachment knot (schematic) on a double pipe cage collar

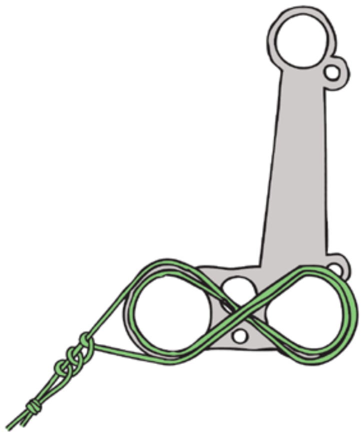


PLATE 52
An alternative bridle method of securing a bridle line. The blue rope is a loop with two spliced eyes (covered with plastic hose, to prevent abrasion). The loop is tied onto the bracket, and then the bridle line is tied onto the spliced eyes. The preferred knot to secure a bridle line is shown in Figure 33

PLATE 53
Sinkers mounted on bridles

COURTESY OF: F. CARDIA

external pipe first and then spooled around the pipes alternately several times before being hitched onto the bridle line running from the grid plate.

If bridle lines are buoyant (e.g. polypropylene), they can hinder boat movements, and may become entangled in the boat's propellers or around the rudder. To prevent this, a small sinker (small concrete block or a small section of chain) can be added to each bridle line (Plate 53).

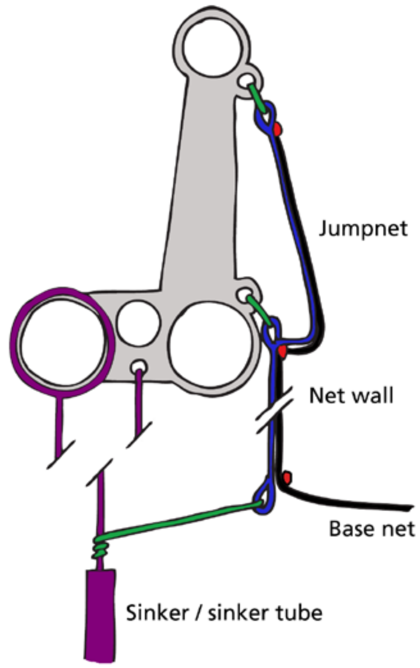
Net installation

The following procedures describe the general process for net installation (net characteristics are described in Chapter 5). Installation procedures for a new net may differ from farm to farm; they are also constantly being refined "in the field" year after year by each team of workers.

- The net is unpacked on land and carefully checked to verify that there are no manufacturing defects.
- If the attachment points of the net are spliced eyes, an adequate number of connecting lines (the green lines in Figure 34) should be prepared and assembled alongside the net. The number of lines for connecting the net to the brackets will be double the number of the net's vertical lines, and each will be about 1.5–2 m long (the actual length will depend on the brackets' design). The number of lines for connecting the net to the sinker system will be equal to the number of vertical lines, and these will be several metres long. The length of these ropes is variable depending on the length of the net and the model of sinker system.
- The net is lifted inside the cage collar with a boat crane. Its top rope is fixed onto the brackets at the handrail level, and the waterline rope is fixed onto the base of each bracket.
- Divers connect the base rope to the sinker system through the connecting lines.

Note: The "jump net" (the portion of net between the top rope and the waterline rope) must be left loose. All of the net's weight must be distributed along each of the waterline ropes' connections.

FIGURE 34
Net installation scheme (side elevation)



Black:	netting
Blue:	vertical line with spliced eye ends
Violet:	sinker system, which can be installed onto either the external pipe or an attachment point on the stanchion
Green:	the lines connecting the net to the brackets and to the sinker system
Red dots:	Horizontal ropes (end elevation of top-line, waterline and baseline)

5. Fibres, netting and ropes

FIBRES

The recent expansion in fish cage culture has been largely driven by the industrial development of new materials and polymers. Ongoing research on new polymeric fibres is continuously providing innovative materials for new nets and ropes.

Synthetic fibres play a key role in the fish cage aquaculture industry subsector, as they are used to manufacture both netting and ropes. The same polymers can be used for both net cages and moorings, resulting in similar issues in terms of robustness, maintenance and reliability.

The most common synthetic polymers for nets and ropes are nylon or polyamide (PA); polyester (PES); polypropylene (PP); and high-performance polyethylene (Dyneema™ or Spectra™). Polyester and polypropylene fibres can be braided together to create netting with the combined characteristics of the two polymers. All these polymers are non-water-soluble; they have good chemical resistance and are therefore well suited for use in the marine environment, providing excellent and long-lasting durability and reliability.

Density

Table 18 shows the different densities, indicating their floating or sinking behaviour, of the main fibres used in fish farming.

TABLE 18
Textile fibres, density and multiplication factor for estimating weight in the water

Tread material	Density (g/cc)	Multiplication factor	
		Freshwater	Seawater
Polyvinylidene	1.70	0.41 (+)	0.40 (+)
Cotton	1.54	0.35 (+)	0.33 (+)
Ramie	1.51	0.34 (+)	0.32 (+)
Linen	1.50	0.33 (+)	0.32 (+)
Sisal	1.49	0.33 (+)	0.31 (+)
Hemp	1.48	0.32 (+)	0.31 (+)
Manila	1.48	0.32 (+)	0.31 (+)
Polyester (PES)	1.38	0.28 (+)	0.26 (+)
Polyvinyl chloride (PVC)	1.37	0.27 (+)	0.25 (+)
Polyvinyl alcohol (PVA)	1.30	0.23 (+)	0.21 (+)
Aramide (Kevlar)	1.20	0.17 (+)	0.15 (+)
Nylon, polyamide (PA)	1.14	0.12 (+)	0.10 (+)
Polyethylene	0.95	0.05 (–)	0.08 (–)
Polypropylene	0.90	0.11 (–)	0.14 (–)
Polystyrene (expanded)	0.10	9.00 (–)	9.26 (–)

The weight of an object varies depending on the substance it is immersed in. Based on Archimedes' principle, an object can either sink or float depending on the relative density of the object itself and the surrounding substance. The multiplication factors in Table 18 are used to find the actual weight of textiles in water.

For example:

- 25 kg of nylon netting in air has the following multiplication factors: freshwater: 0.12 (+); seawater: 0.10 (+), so the final weight:
  - in freshwater is: 25 kg × 0.12 (+) = 3.0 kg;
  - in seawater is: 25 kg × 0.10 (+) = 2.5 kg.

Textiles with a density < 1 will float; therefore, multiplying the weight by the multiplication factor will indicate the buoyancy.

As a further example: polystyrene has a multiplication factor of 9.26 (–) in saltwater; therefore 1 kg of polystyrene submerged in water will have a relative weight of –9.26 kg, or a buoyancy of 9.26 kg.

Polyamide (PA), or nylon

- Sinks (density = 1.14)
- Very resistant to breaking
- Very resistant to abrasion
- High elongation (stretch)
- Excellent flexibility
- High capacity for absorbing different resins

Nylon is the most commonly used fibre in cage aquaculture. Netting for cages, mooring lines and lines used for attaching the net to the collar are mostly made with nylon.

Nylon has poor resistance to UV light and will deteriorate, thus all the equipment made with this fibre must be properly stored away from direct sunlight. The longer nylon nets or ropes are exposed to UV light, the greater the decrease in breaking load and overall strength, resulting in a higher risk of structural breakages.

Nylon is highly elastic (23 percent at breaking load), which can increase the length of each component after a working period of few months by about 10 percent. Therefore, a nylon mooring system will need to be tensioned again a few months after it has been deployed. Nylon net cages will increase in depth by 5–10 percent owing to the elongation of ropes and netting subjected to loads from biofouling or the sinkers on the net.

Nylon fibres can also shrink, causing problems in netting. After several net-washing operations, it is possible that the horizontal dimensions of the cage can be reduced by 3–5 percent. In the net assembly, consideration must always be made for this factor and extra netting built into the design to allow for this phenomenon.

Polyethylene (PE)

- Floats (density = 0.94–0.96)
- Good resistant to abrasion
- Good elasticity.

Polyethylene and high density polyethylene nets are often used as anti-bird/anti-predator nets due to their light weight and resistance to abrasion. Braided or twisted knotted nets are being used in salmon growout in locations where nets treated with antifouling are banned and frequent on site net cleaning is required.

Polyester (PES)

- Sinks (density = 1.38)
- Highly resistant to breaking
- Good flexibility
- Low elongation
- Highly resistant to UV exposure

Polyester has very good resistance to UV light, so it is commonly used for nets that have to be exposed to the sunlight, such as bird nets mounted above the cages, and anti-abrasion net panels around the waterline of the cage.

Compared with nylon, PES is about 20–25 percent heavier (to achieve the same breaking load), but PES has the advantage of not absorbing water, whereas nylon can absorb up to 10 percent of water.

The heavier characteristics of PES can be of value in nets exposed to strong currents because the low elongation of the material ensures that the net will maintain its shape relatively well.

Polypropylene (PP)

- Floats (density = 0.92)
- Resistant to breaking
- Highly resistant to abrasion

Polypropylene netting is not commonly used in cage net manufacturing, but is instead often used for predator nets (commonly for bird protection nets). Polypropylene nets with a large mesh size and large twine thickness are also used as spat collectors in mussel culture, because the buoyancy of the fibre contrasts the weight of the mussels that attach to the net.

High-performance polyethylene (HPPE)

- Floats (density = 0.91)
- Excellent resistance to breaking
- Resistant to abrasion

High-performance polyethylene fibre, such as Dyneema™ or Spectra™ produced by DSM (a division of Royal DSM NV in the Netherlands) or by Honeywell (United States of America), was invented in the 1990s. This fibre has increasingly been used in aquaculture, mainly for net production. The main characteristics of this fibre are the reduced elongation (3.5 percent at breaking load) and the exceptional breaking load compared with other fibres of the same thickness.

Net pens manufactured using netting with HPPE have several advantages:

- The strength of HPPE results in a smaller twine diameter and, therefore, lighter, stronger and more-efficient nets.
- HPPE netting is more resistant than other fibres to fish bites, breaches and other damage (especially with biting species such as the gilthead seabream, *Sparus aurata*).
- HPPE net has twice the longevity of nylon nets.

However, HPPE nets cost two to three times more than traditional nylon nets, while HPPE ropes can cost up to ten times as much as conventional ropes.

Fibres may seem very similar at first sight, but some empirical criteria for a quick field-check can be considered for correct identification (Table 19). Table 20 provides chemical and physical characteristics of those synthetic fibres most commonly used in aquaculture that can help for an empirical identification.

TABLE 19
Empirical criteria for identification of synthetic fibres

Identification elements	Fibre type				
	PA	PE	PES	PP	HPPE
Floats	No	Yes	No	Yes	Yes
Combustion	Fusion followed by a brief flame with ejection of fused droplets	Melts and burns slowly with pale blue flame	Fusion followed by slow combustion with bright yellow flame	Fusion followed by slow combustion with a dim blue flame	Melts and burns slowly with pale blue flame
Smoke	White	White	Black with soot	White	White
Smell	Celery-like fishy odour	Snuffed out candle	Hot oil	Hot wax	Snuffed-out candle
Residuals	Solid, yellowish, round droplets	Solid droplets	Solid blackish droplets	Solid brown droplets	Solid droplets

TABLE 20
Chemical and physical characteristics of synthetic fibres

Chemical/physical characteristics	Fibre type				
	PA	PE	PES	PP	HPPE
Tenacity (g/den*)	9	4.7–5.0	9	7	40
Elongation at break (%)	20	25	14	18	3.5
UV light resistance	weak	fair	medium	medium	good
Density (g/cm^3)	1.14	0.95	1.38	0.91	0.97
Melting point (°C)	255–260	115–135	250–260	160–175	144–152
Resistance to alkali	good	good	weak	good	good
Resistance to acids	weak	good	good	good	good
Moisture absorption (%) (65% humidity at 20 °C)	3.4–4.5	0.1	0.2–0.5	0	0

* den = Denier.

ROPES

Ropes are an important component of cage aquaculture. They are used for the mooring lines, the grid system and for the netting frame (such as the rib-lines and down-lines, which distribute the forces on the cage net).

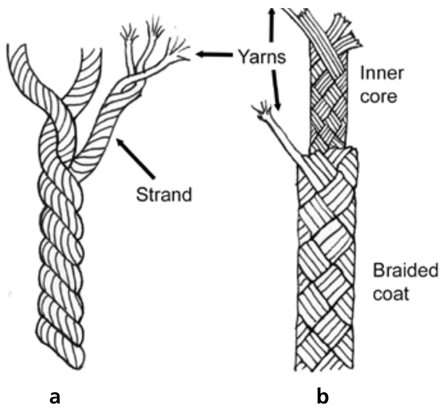
Ropes are generally divided into two types (Figure 35):

- Twisted rope – with an S or Z torsion (either clockwise or anticlockwise twist), and usually composed of 3, 4 or 8 strands. Each strand consists of several twisted yarns. The tighter the twisting, the better the abrasion resistance, and the longer-lasting the rope. A softer twist is generally preferred if splicing is needed. Soft-medium twisting is mostly used in cage net production, owing to their being readily sewn by machine.
- Braided rope – composed of a braided coat with 12, 16, 24 or 32 yarns, and an inner core made with twisted rope or braided yarns. Some braided rope can have a double coating in order to improve the abrasion resistance. Braided rope without any core is generally used when it is necessary having a good elasticity and resistance to torsion.

Indicative breaking loads and weights of main rope types

Tables 21–24 show the weight (in kilograms per metre) and breaking load (in kilograms) of main rope types for ropes of different diameters.

FIGURE 35
Twisted rope (a) and braided rope (b)



NETTING

The cage net is the most valuable component in any fish cage system. Cage nets are ingeniously constructed and include many different features for safe and practical deployment. All nets should be manufactured to the highest possible quality and should be thoroughly inspected after each process and right up to the complete finish of the process.

Net characteristics and cage design can make the difference between a successful fish farm and a failure. Net design, details, specifications and characteristics must be tailored to each farm.

Having highly reliable net cages is essential. This requires attention to several factors, such

TABLE 21
Weight and breaking load for a three-strand polysteel rope

Rope diameter (Ø) (mm)	Weight (kg/m)	Minimum breaking load (BL) (kg)
4	0.008	311
5	0.011	436
6	0.017	680
7	0.023	917
8	0.030	1 190
9	0.038	1 495
10	0.045	1 780
12	0.065	2 590
14	0.089	3 540
16	0.116	4 490
18	0.148	5 720
20	0.181	6 830
22	0.221	8 340
24	0.263	9 780
26	0.303	11 300
28	0.356	12 800
30	0.411	14 600
32	0.453	15 300
34	0.517	17 333
36	0.573	19 270
38	0.638	21 411
40	0.719	24 200
42	0.798	26 060
44	0.876	29 000
46	0.957	31 247
48	1.040	33 700
50	1.130	36 903
52	1.220	43 000
56	1.420	49 000
60	1.630	56 000

as net cage design, manufacturing, strength of netting and net components, strength loss in use, handling and storing.

Net characteristics – material, size, shape and thickness

Netting can be produced as either knotted or knotless. Nylon knotted netting was widely used in the early stages of cage aquaculture because knotted nets were traditionally used in the fishing industry. Knotted nets have good resistance to wear and are relatively easy to repair. However, the protruding knots can damage the fish by causing abrasion on the fish skin, especially when fish density increases (e.g. during the net changing). In addition, the

TABLE 22
Weight and breaking load for a polyester high-tenacity twisted rope

Rope diameter (Ø) (mm)	Weight (kg/m)	Minimum breaking load (BL) (kg)
4	0.012	377
5	0.018	575
6	0.027	809
8	0.048	1 407
9	0.093	1 774
10	0.076	2 162
12	0.110	3 069
14	0.148	4 120
16	0.195	5 292
18	0.245	6 557
20	0.303	8 076
22	0.367	9 585
24	0.437	11 421
26	0.512	13 154
28	0.594	15 194
30	0.682	17 233
32	0.778	19 579
36	0.982	24 473
40	1.210	29 980

TABLE 23
Weight and breaking load for a polyamide (PA) or nylon rope

Rope diameter (Ø) (mm)	Weight (kg/m)	Minimum breaking load (BL) (kg)
4	0.010	320
5	0.016	450
6	0.022	750
8	0.040	1 345
10	0.062	2 080
12	0.089	2 995
14	0.122	4 095
16	0.158	5 300
18	0.200	6 700
20	0.245	8 300
22	0.300	9 990
24	0.355	12 030
26	0.420	13 965
28	0.485	15 800
30	0.555	17 750
32	0.630	19 980
36	0.800	24 890
40	0.990	29 990
44	1.200	35 800
48	1.420	42 020
52	1.660	48 860
56	1.930	56 000
60	2.210	63 850

TABLE 24
Weight and breaking load for a high performance polyethylene (Dyneema™ or Spectra™) rope

Rope diameter (Ø) (mm)	Weight (kg/m)	Minimum breaking load (BL) (kg)
14	0.096	18 500
16	0.128	24 600
18	0.160	30 800
20	0.193	37 000
22	0.225	43 100
24	0.267	49 800
26	0.331	60 800
28	0.364	65 400
30	0.418	79 500
32	0.476	90 000
36	0.602	105 000
40	0.743	124 000

weight of knotted nets is greater than that of knotless nets.

Knotless netting has now almost completely replaced knotted net use in cage aquaculture. Knotless nets can be up to 50 percent lighter, their production costs are lower, they have a higher resistance to abrasion, are easier to handle and are stronger.

The main characteristics to consider regarding netting are the fibre material and characteristics, mesh size and shape, net braiding and colour.

Fibre polymer

As discussed above, a range of synthetic fibres can be used for netting. Different materials vary in terms of durability, cost, maintenance and others characteristics.

The most commonly used material is nylon (PA) with a braiding yarn of 210 denier. Denier is a technical textile term for nets, and it refers to the weight, in grams, of 9 000 metres of a single yarn.

Ultraviolet radiation causes polymer degradation (depolymerization) and a consequent long-term loss of strength. Nylon and the most common plastic fibres should always include UV stabilization by the addition of appropriate materials during the fibre production process.

Twine number and breaking load

Twine number is used to indicate the size of the net twine. It is composed of the "denier" number and the "ply", i.e. the number of strands braided together in each yarn.

A common standard is widely accepted for the knotted net identification, but in knotless netting, each producer usually has its own twine code. To make it more comprehensible, netting producers adopted a common terminology as is used in knotted net (for example, 210/96), but this does not mean that the weight (kilograms per square metre) or the breaking load is similar.

Nylon 210/72 represents a net made with 72 nylon yarns, each of 210 denier. This net will be stronger that a 210/60 net that is made with 60 yarns of the same denier.

The most accurate method to evaluate the strength of a knotless net is the breaking load of the twine. This parameter, requested along with the net order and certified by the net supplier, can be easily verified with a net strength gauge, which is comprised of a hoist with a dynamometer (*Note:* breaking load measurement procedures are outlined in the ISO 1806 standards).

The weight of a unit of netting of standard surface area (usually 1 m^2) is another parameter that can indicate the quality of the net – a lighter net, with the same mesh size and the same breaking point, will be of better nylon quality. The weight per surface area unit can be easily measured in the field.

Therefore, by combining weight per square metre and breaking load (BL), one has a ratio of these two values, which can be used as an objective metric for comparison of nets (with the same mesh size and twine number) provided by different suppliers.

The tables in Appendix 2 show the different weights and breaking loads of different nets.

Weight is listed as weight per 1 000 meshes width × 1 m long. In order to find the weight per square metre:

$$\text{Weight in kg/m}^2 = \frac{(\text{weight per 1 000 meshes width} \times 1 \text{ m long})}{(\text{half mesh size})}$$

Ultraviolet degradation

Fibres are subject to UV degradation, which results in a decrease in the breaking load of twine over time.

Table 25 shows residual breaking loads for nylon exposed to UV light.

TABLE 25
Residual strength in percentage of different nylon fibres exposed to UV – outdoor exposure

Fibre name/ exposure	Treatment	Colour	Exposure time (years)							
			0.25	0.5	1	2	3	4	5	6
Open air										
Polyamide 6										
Enkalon 540T	UV-stabilized	Ecru	--	80	70	55	25	20	--	--
Non-Akzo Nobel	--	Ecru	--	40	35	25	10	--	--	--
Enkalon 149HR	--	Spun-dyed black	95	85	80	70	65	50	40	--
Polyester										
Diolen 855T	--	Ecru	90	80	75	65	55	45	30	--
Diolen 178T	--	Spun-dyed black	100	95	85	80	65	60	55	50
Exposure behind glass (4 mm)										
Polyamide										
Enkalon 540T	UV-stabilized	Ecru	--	--	60	45	35	25	--	--
Enkalon 149HR	--	Spun-dyed black	95	--	85	75	70	65	60	55
Polyester										
Diolen 855T	--	Ecru	95	95	90	85	75	75	65	60
Diolen 178T	--	Spun-dyed black	100	--	95	95	90	90	90	85

Source: Akzo Nobel Business Unit, 1995.

After net changing, regular checks with a net strength gauge should be conducted on each cleaned and repaired net before re-installation. Results should be recorded in a net register, and nets should be disposed of if yarns have a breaking load that does not meet acceptable standards. The acceptable residual strength of a net will depend on the site exposure. For example, used netting yarn with less than 60 percent of the original strength for the jump net, and less than 65 percent of the side net and base net, should be replaced.

Net coatings can affect the breaking load. Some antifouling coatings can increase the breaking load of the netting by up to 5–8 percent while most coatings can decrease the breaking load by up to 30 percent.

Mesh shape

Netting used for cage culture is available in two different mesh shapes, either square-shaped or hexagon-shaped. There are no apparent advantages in using one instead of the other; it is mainly a matter of traditional preferences. In Italy, for example, square mesh is preferred, while in Greece, hexagonal mesh is more widely used.

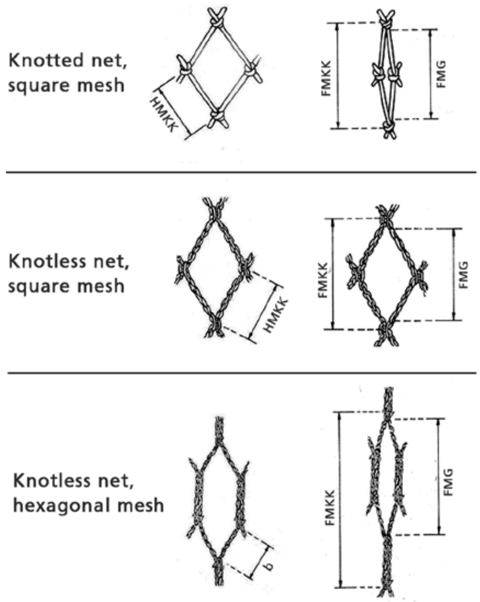
The following considerations are based on general experience, and should not be considered as facts or recommendations:

- Square mesh – advantages:
  - mesh shape remains always open in strong currents, allowing the water to readily pass across the mesh;
  - better durability in the water because the vertical loads are distributed throughout the aligned net twines;
  - easier to repair.

- Square mesh – disadvantages:
  – more waste in the manufacturing process of the cage net because netting needs to be cut to make square panels;
  – less elasticity to the vertical movement from wave action.
- Hexagonal mesh – advantages:
  – more elasticity in vertical movement as cages are subject to wave action (this is a very useful characteristic for netting with low elastic power, such as HPPE);
  – less waste during the manufacturing process.
- Hexagonal mesh – disadvantages:
  – more difficult to repair.
  – not easy to measure the mesh size.

There is no overall preference, and the advantages and disadvantages of these meshes and their characteristics are continuously debated among farmers.

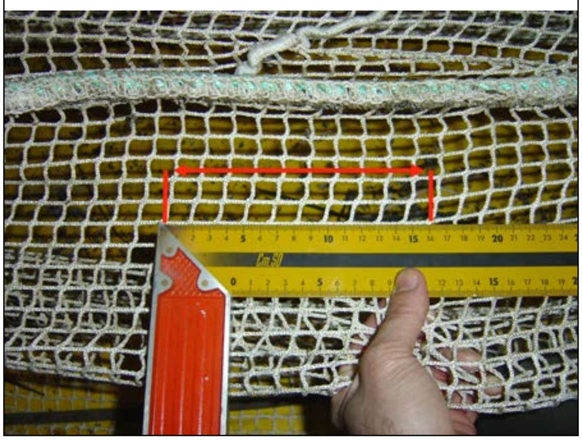
FIGURE 36
Mesh measurement



Note: Half mesh knot to knot (HMKK), full mesh knot to knot (FMKK), full mesh gauge (FMG), bar length (b).

Source: After Prado, 1990.

PLATE 54
Mesh size measurement. The red arrow indicates the width of ten meshes, which is about 16 cm. The mesh size (HMKK) of this net is then 16 mm



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Mesh size

In the fishing industry, mesh size is the distance between two opposite knots of a stretched mesh, commonly expressed in millimetres. This can be measured as full mesh knot to knot (FMKK), which includes the twine of the netting, while full mesh gauge (FMG) represents the internal length of a stretched mesh, without including the knots.

In Mediterranean cage aquaculture, the mesh size (for square mesh netting) refers to the half distance between the knots when the mesh is stretched tight (or HMKK – Figure 36). For hexagonal mesh, either the length of the bar or, better, the FMG is used to indicate the mesh size.

A quick mesh measurement can be obtained by measuring ten square meshes in a row, and dividing their total length by ten, essentially taking an average. This method would include the thickness of twine and therefore be an FMKK-type measurement (Plate 54).

The size of hexagonal mesh netting refers to FMG; thus, to avoid confusion, the type of mesh (i.e. square or hexagonal) must always be specified, along with the mesh size.

When choosing mesh size, it is essential to consider the size and shape of the fish. Cage nets will need to have a smaller mesh size for fingerlings and juveniles, while the mesh size can then increase with subsequent net changes as the fish grow. The larger the fish, the larger the mesh size should be. Although large fish can be accommodated in small mesh nets, this is not a good practice as the mesh size should be as large as possible so to allow the best water flow inside the cage net. For each farmed species, a relationship is determined between the mean weight of fish and the minimum mesh size needed. Net mesh sizes suitable for farming the European seabass (*Dicentrarchus labrax*) and gilthead seabream (*Sparus aurata*) are shown in Table 26.

TABLE 26
Fish size/mesh size (square-shaped mesh) relationship for the European seabass and gilthead seabream

Mesh size (HMKK) (mm)	Twine gauge	Minimum fish size (g)		Half mesh gauge size (mm)
		Seabream	Seabass	
8	210/36	2	6	6.4
10	210/36	4	12	8.8
12	210/48	8	20	9.8
15	210/72	12	40	11.4
18	210/72	25	65	15.2
22	210/72	30	90	20.0
24	210/96	40	120	22.1

Size distribution in any fish cohort must also be considered. If there is a wide variation in size, the smaller fish may escape from the new net.

When choosing a mesh size, the shape and the morphological characteristics of the cultured fish species must also be taken into account. In some species, the mouth shape and mandible features (especially for fish with mouth invagination) may cause the fish to become trapped and, therefore, a conservative size of the mesh should be chosen.

Net braiding

The braiding property is a netting characteristic defined by the number of braidings performed by a netting machine on the yarn. It is usually referred to as soft, medium or hard, as the braiding level has an effect on the "softness" of a net. Given the same twine number, a harder braiding will be stronger and have a higher breaking load. However, a net made with very hard braiding may be damaged if cleaned in a washing machine because the twine may become curly and the mesh shape may shrink. Softer braided nets can also suffer shrinkage problems, but will not be subject to curling.

Colour

Nylon nets are usually white. However, different colours can be useful if the cultured species shows biting behaviours. For example, gilthead seabream held in white cages will bite and abrade the net. These abraded points serve as a further attraction to the fish, which will persistently bite the same white spots, and quickly turn them into holes. In this case, a black coloured net is recommended. With a black-coloured net, the attractiveness of these abraded spots is reduced, and therefore the occurrence of holes is less common.

When ordering a net, all of the characteristics of netting listed above must be specified and verified on delivery. Table 27 provides an example of netting specifications.

TABLE 27
Example of netting specifications

	Polymer and twine gauge	Breaking load	Mesh size (HMKK)	Shape	Colour	Braiding
Specifications	Nylon 210/72	86 kg	15 mm	Square	Black	Medium

NET CAGE DESIGN

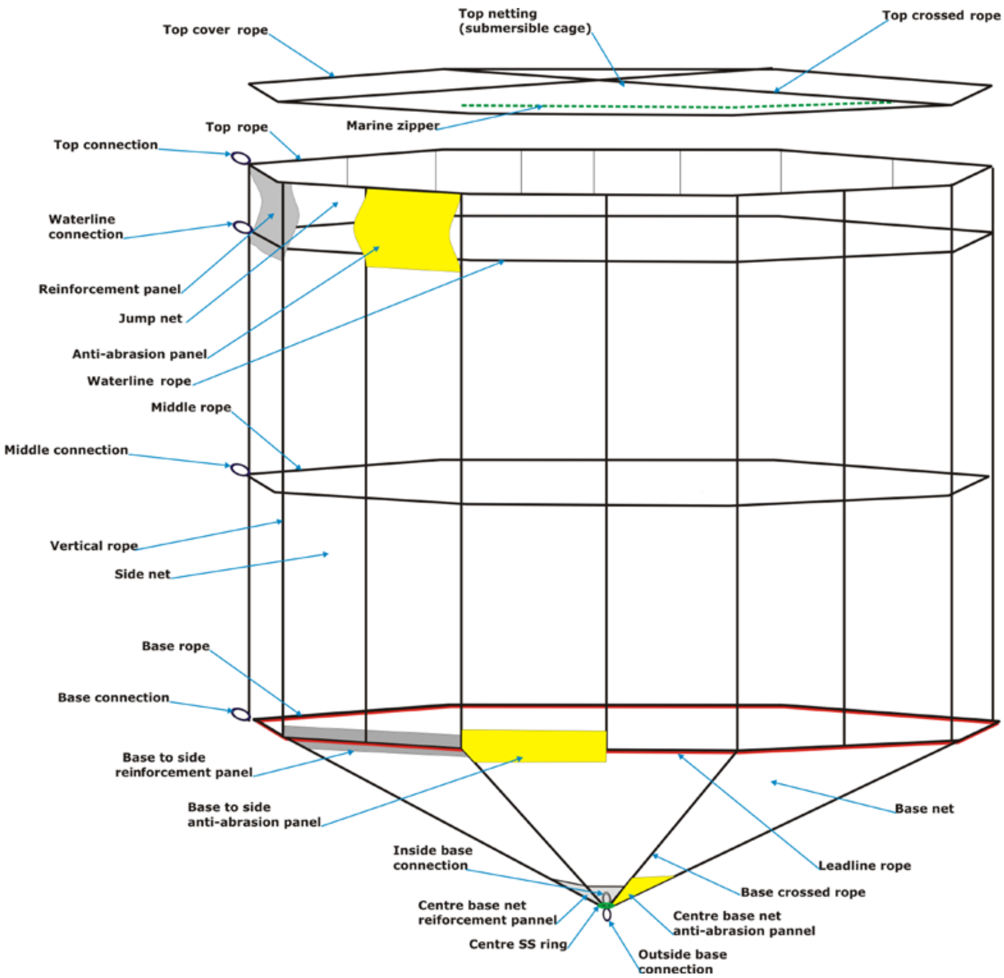
Individual farms may develop net designs that are almost unique. These specific designs are based on overall cage design, site characteristics, production plans and the operator experience at that location.

Net details must be designed according to the common structure of the main cage components (floating collar, stanchion/brackets, sinkers, sinker tube, etc.) to which the net will be fixed. Nets for circular floating cages generally consist of a vertical wall, mounted on a base net (the cage floor). The vertical wall is further divided into a submerged part (more or less corresponding to the net depth) and a jump net, which is the portion of the wall out of the water, from the waterline to the handrail (Figure 37).

A net cage is mainly made by assembling the netting with ropes and should be conceived as a rope frame structure containing the netting (Figure 37). All the weight of the cage should be borne by the ropes; while the netting only has to keep the fish confined inside it, and should have no structural functions. The robustness of the whole structure should be appropriate to the site exposure. The ropes must be of an appropriate length, size, material and type to meet the demands of the specific site.

As with the ropes, the netting attributes (as described above) must be chosen according to the site's characteristics, and the size and species of fish. In more exposed sites, a greater twine number (or breaking load) of the netting is required.

FIGURE 37
Cage layout and main technical details



Source: Courtesy of Badinotti Group SpA.

Norwegian Standards NS-9415 provides advice on the minimum technical specifications of cage nets according to cage dimensions. As per these standards, Table 28 designates cage classification on the basis of depth and circumference ranging from Class I (shallow and narrow) to Class VII (deep and broad). This classification is used to recommend additional technical specifications. Dimension Class 0 is used for exceptionally deep or broad cages, which have critical aspects and should be calculated separately. It is important to note from this table that the depth from the water surface to the bottom rope must not exceed 40 percent of the circumference for circular cages, although 50 percent is acceptable for cone-shaped cages.

TABLE 28
Dimension classes of cages (NS-9415)

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

Classification of cages through dimension classes permits standardization of some key structural parameters of the cage net, such as minimum breaking load (BL) of the netting, the number of vertical and cross ropes, and the minimum breaking load of the ropes (Table 29).

TABLE 29
Technical specifications of key elements of the cage with reference to dimension cage classes

	Dimension classes							
Mesh size (HMKK)	I	II	III	IV	V	VI	VII	0
	Minimum breaking load (kg)							
≤ 6.0	21	21	25	25	25	25	25	25
6.1–8.0	25	31	31	39	39	39	39	39
8.1–12.0	31	39	47	55	55	55	55	55
12.1–16.5	39	47	55	63	71	71	79	79
16.6–22.0	47	63	79	79	79	95	95	95
22.1–29.0	63	71	95	95	117	136	136	136
29.1–35.0	95	95	117	117	136	136	151	151
Max. distance between vertical ropes (m)	7.5	7.5	6.5	6.5	5.0	5.0	5.0	n/a
Min. vertical ropes (no.)	4	8	8	16	16	24	32	n/a
Min. base cross ropes (no.)	0	0	2	4	6	10	14	n/a
Minimum BL for ropes (kg)	1 900	1 900	2 800	3 400	4 100	4 100	5 000	n/a

Net ropes

The main structural component of the net is the system of ropes. These ropes ensure the strength and robustness of the net cage. Different types of rope are used, and there are no specific recommendations. The greatest experience has been with polysteel three-strand-laid ropes. This type of rope is an extruded blend of polypropylene (PP) and polyethylene (PE) that has been UV treated. This rope has from 20 to 25 percent higher breaking load and abrasion resistance compared with other PP or PE ropes. Good results have also been achieved with PES braided ropes. These are very soft ropes that are assembled with netting – like a flat binding. The breaking load of the net's structural ropes must be in proportion to the site exposure. For example, a 14 mm polysteel rope (3.4 tonnes breaking load) is commonly used for the structural ropes in cages in medium-exposure sites.

A standard cage net layout has the following main ropes (see Figure 37):

Top-cover rope
This rope is generally used to fit the top net, or top-cover netting in submersible cages, preventing the fish from escaping while the net pen is underwater.

Top rope
This is the uppermost horizontal rope at the top of the jump net, connected to the handrail.

Waterline rope
This is the horizontal rope running around at the waterline and collar level. This rope contains rope loops or metal rings that are used to fix the net onto the cage collar. Rope loops should be protected with rubber hose or spliced with thimbles to prevent abrasion.

Extra horizontal rope or ropes
These are one or more horizontal ropes located between the waterline rope and base rope, used to support the framework especially for deep net cages and in net cages employed in high-energy sites.

Vertical ropes
The vertical ropes attach the net to the collar and hold all of the net's weight. It is common practice to have as many vertical ropes as there are brackets on the collar. Each vertical rope crosses the top rope, the waterline rope and the base rope. Each crossing is reinforced with hand-stitching. Each vertical rope has at least three spliced rope loops with thimbles (or rings) to attach the net to the stanchion (at the top rope level), to the cage collar (at the waterline level) and to the sinker system (base rope level). The waterline loops are the most important connections of the net, as these points will take the majority of the net's load. Some of these can continue as base crossed ropes – these are also called lifting up ropes. It is good practice to use these ropes to lift the net when installing or dismantling the net cages.

Note: Ensure that all the waterline spliced rope loops with thimbles are well fastened on the bracket base, and that these attachment points are supporting the net load. The upper part of the net – the jump net – must be loose and the handrail must not be supporting any loads (see Figure 34).

Base rope
This is a horizontal rope placed where the side-net and base net are joined.

Base cross ropes
These are ropes that cross the base, in a grid system (Figure 38), through the centre of the base. (At the centre, either a rope ring or steel ring is occasionally installed.) The ends of the base cross ropes are fixed onto the base rope, and usually consist of 6–12 radial ropes originating at the centre of the base net. The overall design can be tailored differently for each farm. Very exposed sites may require as many base ropes as vertical ropes (Figure 39); in this case, each base rope will be spliced directly onto the corresponding vertical rope, which will offer increased strength.

Pulling lines (optional)
Slack lines that run on the outside of the net cage, from the top loop at handrail, to the base rope loop (along with the vertical lift-up lines). These are used for supporting lift-up of the net cage and/or installation of the sinking system (ballasts).

Mortality collector line (optional)
This line connects to the optional dead-fish collector net, i.e. a small net device that can be operated from the surface without the help of divers, which is used to retrieve this net to collect any dead fish lying on the bottom of the net cage.

Lead-line ropes (optional)
Lead-lines are used as additional weights and are sewn on the base rope and/or base crossed ropes. The lead-line ropes also enable the base part of the net to sink more quickly, making installation of the net cage easier.

> ***Note:*** At the corresponding point of each vertical/horizontal rope crossing, reinforcement is recommended by hand-made stitching using nylon-braided twine. A portion of netting can be left unrigged at the rope's crossing (see Plate 76).

FIGURE 38
Different cross-base rope designs

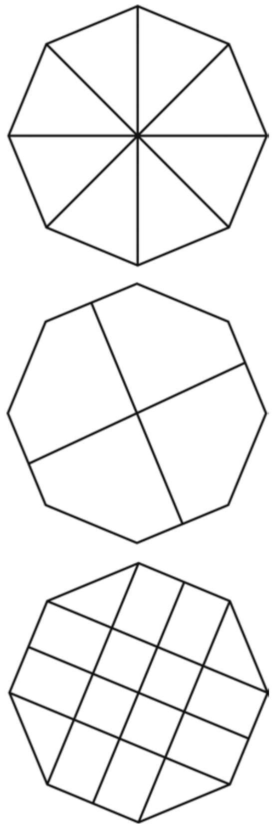
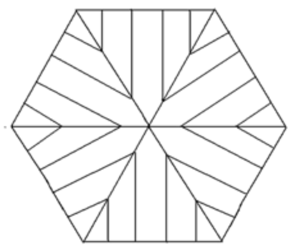


FIGURE 39
Base ropes, designed for exposed offshore cages in high-energy sites



Note: This cage model consists of 30 vertical ropes on the wall of the net, and each external base rope end is connected to each corresponding vertical rope.

Source: Stuart Nets Ltd.

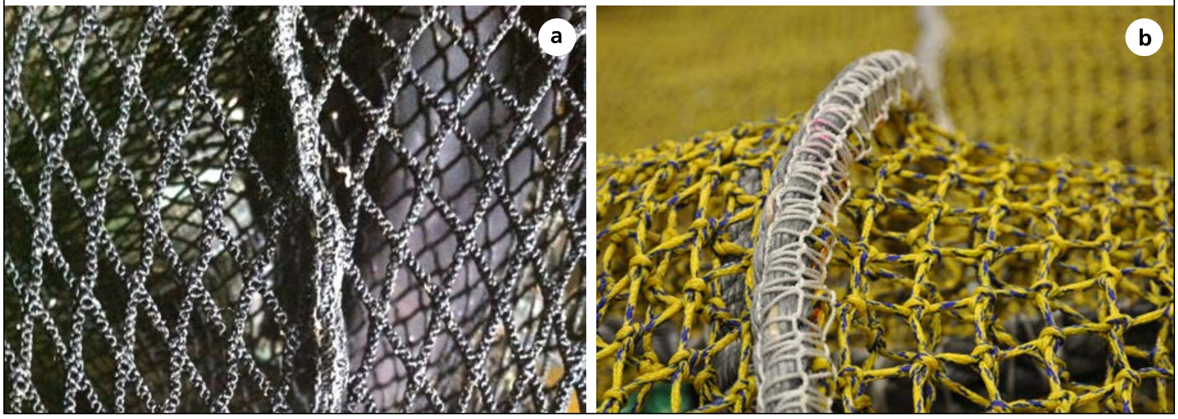
Seams
Netting and ropes are assembled together through seams that can be handmade or done using special sewing machines. There are two different types of seams in a net cage:

1. Net to net seam (Plate 55a): These seams are generally made by machine, using nylon thread or nylon/PES twine (210/36). They can be produced by passing the twine over the same place one to three times.
2. Net to rope seam (Plate 55b): This can be done both by hand (Plate 56) and by machine (Plate 57). In hand sewing, there is no limit to the net twine or rope dimensions (Plate 58). Machine sewing, however, is generally limited to a maximum of 24 mm twisted rope on 210/96 net, or 18 mm rope on 210/400 net.

The seams joining net to rope by machine can be done as a:

- Single seam, where the sewing machine builds a seam around the rope like a sock (Plate 59).
- Double seam inside rope, where the seam is made by passing the sewing yarn inside the rope. This seam fixes the net to the rope, avoiding any possible decoupling of the rope from the seam (Plate 60).
- Double seam, with a single seam outside the rope and another seam inside the rope (Plate 61).

PLATE 55
Seams in cage nets. a) net to net; b) net to rope



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COURTESY OF: A. CIATTAGLIA

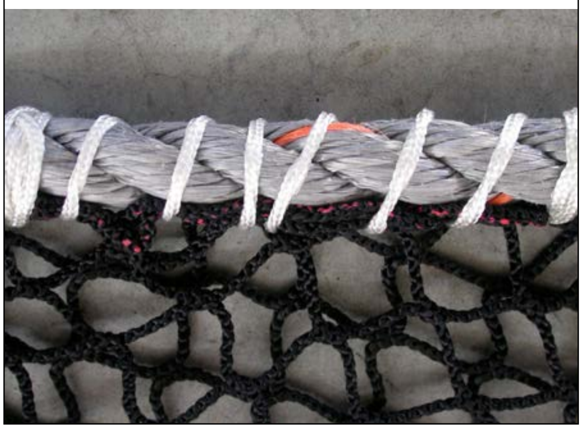
PLATE 56
Manual net to rope sewing

COURTESY OF: A. CIATTAGLIA

PLATE 57
Machine net to rope sewing

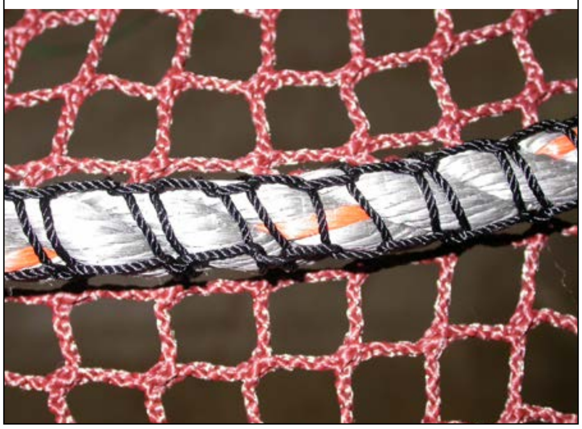
COURTESY OF: A. CIATTAGLIA

PLATE 58
Net to rope hand-sewn seam



COURTESY OF: A. CIATTAGLIA

PLATE 59
Single seam outside the rope



COURTESY OF: A. CIATTAGLIA

Net connecters – loops, rings and zippers

Any knots or splices in a rope will reduce the breaking load (BL) (Figure 40). Splicing is the most reliable way of connecting two ropes and retains the highest percentage of the breaking load. Splicing is therefore recommended for all attachment points on the net.

The ropes of the net cage are provided with a number of connection points that will allow the proper installation of the net onto the collar, the handrail, the sinker system and any other cage component that needs to be connected with the cage net. Each of

PLATE 60
Double seam passing through the rope

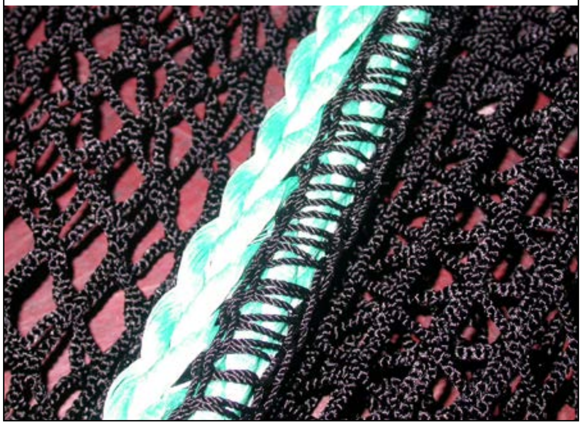


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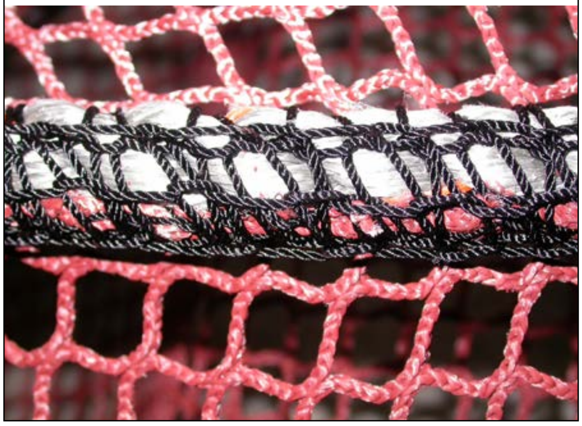
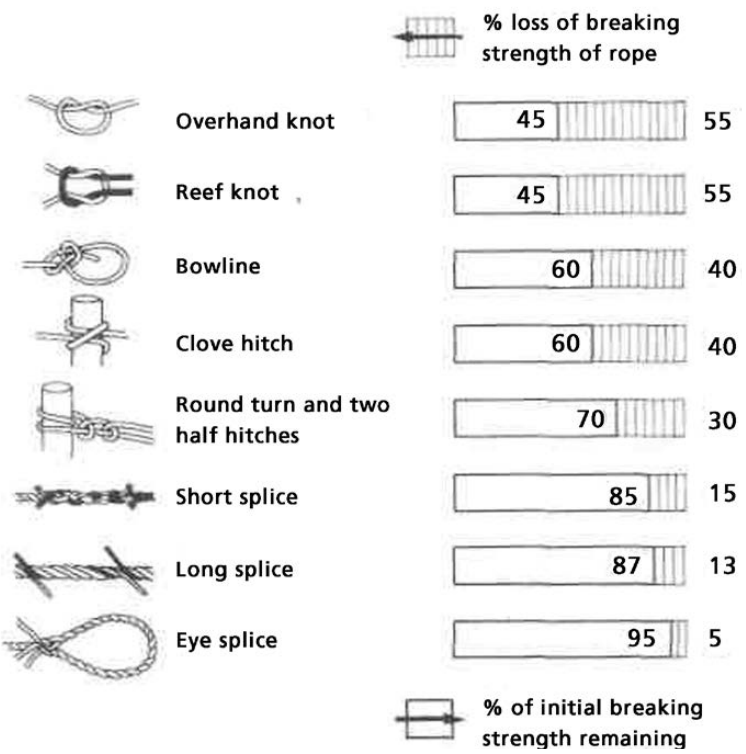
PLATE 61
A combination of internal and external seams



COURTESY OF: A. CIATTAGLIA

FIGURE 40
Loss of strength in knotted ropes



Source: Prado (1990).

these connections will have different requirements regarding strength and abrasion resistance.

Lifting points are always placed on the ropes, and never on the netting panel. The netting itself should not bear any weight nor be subjected to loads; any load on the net cage should be borne on the ropes.

The different kinds of connections can be seen in Plates 62–68, and include:

1. Rope looped with flexible pipe protection
2. Plastic thimble
3. Plastic or steel ring
4. Rope looped without protection
5. Free rope

Some of the different locations on the cage net that need to be connected are included in the following section. Each of these connection locations will use one of the connections types listed above.

Top loops

Top loops are used for connecting the jump net to the handrail (Plate 62). These loops are spliced into the top rope, or onto the vertical rope at the top rope level. These loops should be protected from abrasion with pipe or plastic thimbles. An additional tie rope may be spliced or tied into the loop in order to secure the top rope to the handrail pipe or stanchions (Plate 63).

Waterline loops

Waterline loops are used to connect the net to the collar (Plates 64–65). These loops are spliced into the waterline rope, or onto the vertical rope at the waterline level. Normally, the loop will be protected by plastic pipe. A tie rope may be spliced or tied into the loop in order to tie the waterline rope to the floating collar, attaching on the inner pipe or stanchion base.

Base rope loops

Base rope loops serve to connect the bottom of the net to the sinker system (Plate 66). Base rope loops are spliced into the base rope or on the vertical rope at the base rope

PLATE 62
Top rope loop, spliced with pipe protection

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PLATE 63
Top loop with spliced tie rope

COURTESY OF: A. CIATTAGLIA

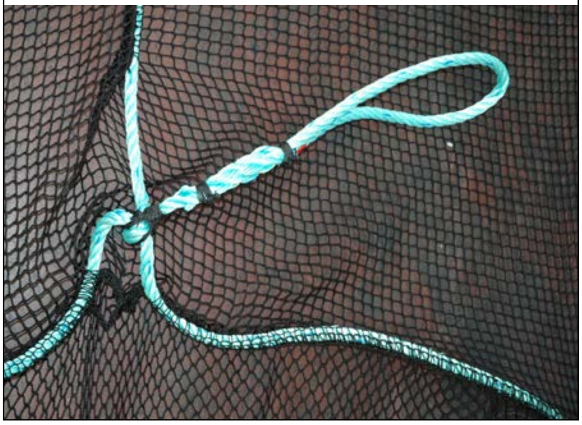
PLATE 64
Waterline rope loop with flexible pipe protection

COURTESY OF: A. CIATTAGLIA

PLATE 65
Waterline rope loop with plastic thimble

COURTESY OF: A. CIATTAGLIA

PLATE 66
Base rope loop



COURTESY OF: A. CIATTAGLIA

PLATE 67
Cross base ropes spliced on the central ring (with additional external loop)

COURTESY OF: A. CIATTAGLIA

level. From these loops, a secondary tie rope is spliced or tied into the loop, in order to complete the connection to the sinkers or sinker tube.

Base crossed rope loops

Base crossed rope loops are located at the centre of the base, where base crossed ropes are joined together (Plate 67). These are connected by lashing or splicing the cross ropes onto a rope ring. An additional rope loop or steel ring might be installed as an inside loop or an outside loop. The outside loop is used for ballast attachment to create a conical base shape, while the inside loop can be used for a dead fish collector rope (Figure 37). Both the internal and the external central loops are useful to lift the net while harvesting or for net installation or changing.

Rings

Rings can be used as additional attachment points from the net ropes, either external or internal. For example, on the vertical rope (on the external side of the cage), rings can secure the net to the sinker lines. Rings are made of plastic, stainless steel or hot-dipped galvanized steel, and can be placed in various locations on the cage according to the farmer's preference (Plate 68).

Marine zippers

In recent years, the use of large marine zippers has increased in cage culture for different reasons (Plate 69). Zippers are useful to fasten cage parts, fishing nets and cage access doors quickly and securely. They are usually plastic-moulded zippers, with plastic teeth that are considerably larger than the zippers commonly used for clothing (Plate 70).

PLATE 68
Plastic ring on a vertical rope

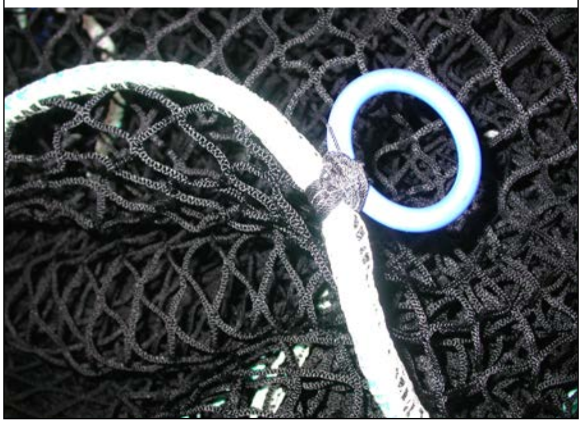


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PLATE 69
Zipper on the base net of a cage (secure cable ties not yet installed)

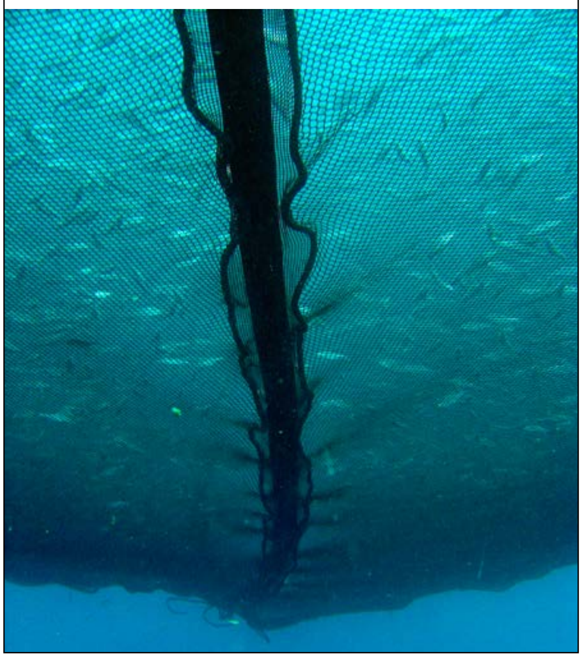

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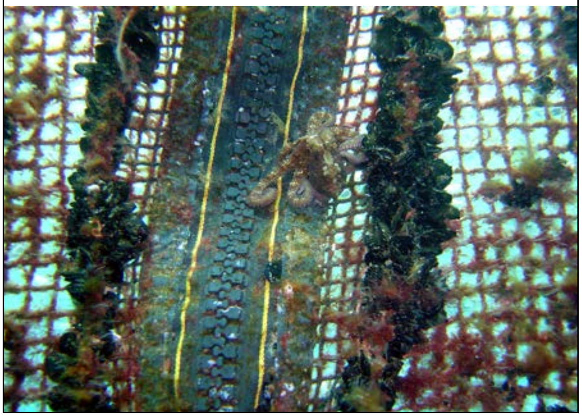
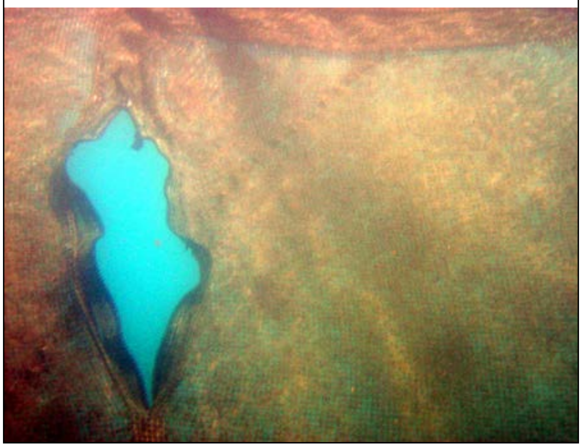
PLATE 70
Detail of a zipper (the half mesh size of the netting is 18 mm)



COURTESY OF: F. CARDIA

PLATE 71
Zip used for submerged door for divers



COURTESY OF: F. CARDIA

PLATE 72
Cage top-net fixed with a zipper in a submersible cage

COURTESY OF: F. CARDIA

In some large cages, the nets may be divided into two identical halves by a marine zipper to facilitate the handling of the net cage (the weight to be handled is halved) during installation and removal. When the new cage is installed, the two halves are positioned outside the older net and then a diver runs the slider along the zipper fastener, thereby closing the new net.

Marine zippers have a breaking load (BL) of up to 5.9 tonnes/m.

To separate a fouled net, the slider is separated from one side of the zipper and, without having to unzip the zipper, the net can be easily and quickly opened by just pulling the two sides apart (similar to when there is a zip malfunction in a garment).

In the case of longer zip fastenings that attach two cage halves, it is good practice to secure the zipper with additional cable ties fastened across the zip every metre.

Zippers are also used to provide divers with access to submerged cages for inspection (Plate 71). The opening is aligned vertically along the wall of netting, and it is usually a couple of metres long to allow access to the diver. Again, it is sound practice to always secure the slider with a cable tie after each cage inspection.

In submersible cages, zippers are also used to connect the cage top-net to the cage wall, at the top rope level (Plate 72).

The two major constraints on zipper use are: (i) the high cost of the equipment (about USD70/m); and (ii) the need to take great care when handling the nets to ensure that the plastic teeth of the zipper are not damaged, as broken teeth increase the risk of zipper malfunction. A repair kit to replace broken zipper teeth is available commercially.

Alternative connection method

Instead of spliced rope loops with thimbles (as described above), vertical ropes may have 1.5–2 m of free working ends at the top rope level (for fastening the net on the handrail) and at the base net (to fix the net onto the sinker system). This retains the maximum breaking load of the rope because there are no knots or splices, and will save some installation labour. It may not be feasible during initial construction but it is worth considering.

Net dimensioning

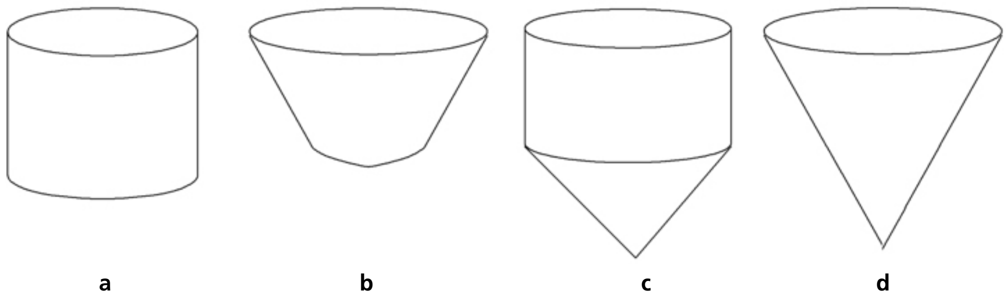
Shape

Nets may have a cylindrical or a reverse truncated cone shape, depending on the size of the base net. If the base net has the same circumference as at the waterline, then the cage will be roughly cylindrical (Figure 41a); if it is smaller, then the shape will be a reverse truncated cone (Figure 41b). A cylinder with a conical base has vertical walls that then come to a point at the centre of the bottom crossings (Figure 41c). A reverse cone base makes mortality collection easier (dead fish will sink to the tip of the cone). A cylindrical shape maximizes the volume of the net cage, while nets with a reverse truncated cone shape may be more suitable in sites with stronger currents.

In cylindrical nets, net depth is equivalent to the wall's depth from waterline to base rope, plus the net cone base height, where present. It is recommended that this depth is equal to or less than one-third of the water depth at the farm site.

The jump net, from the waterline to the handrail, should be at least 50 percent higher than the stanchion. Stanchions are commonly one metre high, so the jump net should be 1.5 m high.

FIGURE 41
Cage net shapes



Notes: cylindrical (a), truncated cone (b), cylindrical with a reverse cone base (c), and tapered conical shape (d).

Volume

It is important to calculate the volume in order to understand the stocking density and water exchange rates. The volume depends on the shape of the object. Some general formulae and an example are provided below.

Formulae to calculate volumes

Cylindrical shape:	$V = \pi r^2 h$
Truncated cone shape:	$V = \frac{1}{3}\pi h (r^2 + Rr + R^2)$
Tapered conical shape:	$V = \frac{1}{3} (\pi r^2 h)$

where,

V = volume
π = 3.14
h = height of the wall of the net (without considering the jump net)
r = radius of the net (half of the net circumference divided by 3.14)
R = radius of the base net

The base net may be a conical shape (Figure 41c), which increases the overall volume of the cage. In this case, the volume of the reverse cone must also be added to the cylinder volume to provide the total cage volume.

Formula to calculate the volume of the reverse cone formed by the base net

$V = ⅓ (\pi R^2 h)$

where,

V = volume
π = 3.14
h = depth of the cone
R = radius of the base net

Formula to calculate radius (R) and diameter (D)

D = C / π
R = D / 2

where,

D = diameter
C = circumference
π = 3.14

The circumference of the net should be slightly less than the circumference of the cage collar so that the net, once installed, will not be in contact with the cage collar, and any damage caused by abrasion will be reduced. The cage circumference should be at least one metre less than the cage collar circumference. This will keep the net about 15 cm away from the cage collar.

Example

Cage collar circumference = 60 m
Cage collar diameter = 60 m / 3.14 = 19.1 m
Net cage circumference = 59 m
Net cage diameter = 59 m / 3.14 = 18.7 m
Difference in diameters = 19.1 m – 18.7 m = 0.31 m = 31 cm
Distance of cage net from cage collar = 31 cm/2 = 15.5 cm

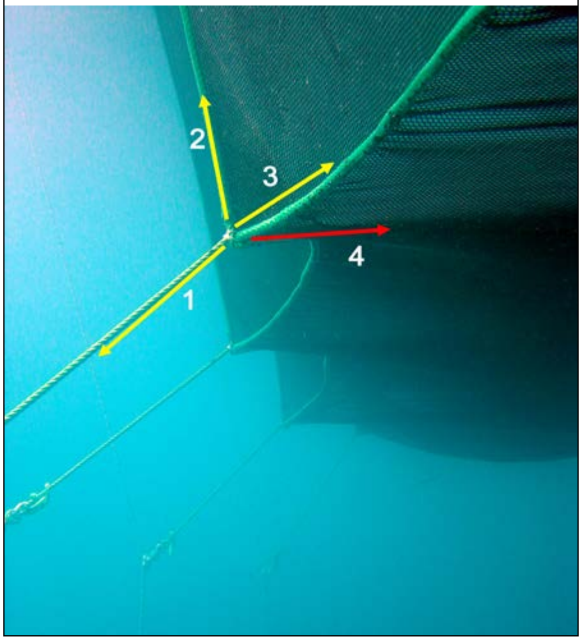
Structural details

For exposed sites, additional elements can be added during the net manufacturing process to increase net cage safety and minimize the risk of netting failure.

An anti-abrasion panel added at the waterline level will prevent the abrasion of the net by the plastic collar and by any possible hard fouling on the net (see Figure 37). This panel is mounted onto the external-facing side of the net; it is usually made with netting that has a mesh size and a twine number larger than the internal netting. The anti-abrasion panel will cover the cage net completely from the top line up to at least 0.5 m above the waterline rope. In addition, anti-abrasion netting can be used around the centre of the base, especially when using dead-fish collectors. In this case, it will be made of the same or similar netting as the main net.

A critical point for a net cage is the base rope, where the base net and the side net are joined together. This is where the attachment points for the sinker system are joined onto the base rope. There are four load components in this zone (see Plate 73): (1) the vertical load component, running along the vertical rope on the side net; (2) the horizontal load tangential along the base rope; (3) the downward-external load running along the line attached to the sinker system; and (4) the horizontal-internal load along the netting of the base net. The force of these four components is distributed along the ropes (the vertical rope, the base rope and the rope to the sinker system) and along the netting (the base net). If some exceptional force is applied to this point (e.g. during a storm or a stronger-than-normal current), the netting of the base net will be the weak point where damage may occur.

PLATE 73
The four components of load at the base rope. Yellow components are carried by ropes; the red component is applied to the netting, which may fail at this point. See text for further explanation

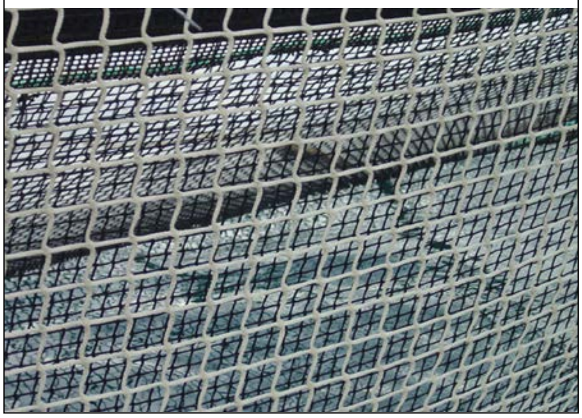


COURTESY OF: F. CARDIA

PLATE 74
Net panel inside the cage, at the base rope level

COURTESY OF: F. CARDIA

PLATE 75
Anti-abrasion panel (white netting) installed outside the jump-net



COURTESY OF: F. CARDIA

PLATE 76
Risk of netting failure is higher at the crossing ropes owing to existing loads as shown in Plate 73. Netting is sometimes not sewn into ropes at the attachment point, to distribute the loads on multiple points and minimize the potential for failure

COURTESY OF: F. CARDIA

To prevent fish from escaping if the netting fails, an additional internal net panel (identified as a reinforcing panel) can be added to the cage near the base rope (Plate 74). This reinforcing panel is sewn onto the base net and the net wall, at points about 50 cm from the base rope. This panel is usually made of the same netting as the net cage (Plate 75).

To further reduce the risk of damage to netting, a special sewing method can be used. A small section of the net, about 20 cm in the bottom corner of the net panel is not sewn onto the ropes all the way to the corner where the ropes meet (Plate 76). This will distribute onto a larger area of the netting the load forces that are carried by these attachment points.

Net treatments – antifouling and UV protection

Biofouling is one of the major management issues in aquaculture, and it represents a serious threat for a net cage if not properly addressed. The fouling includes diverse macroalgae, bivalves (such as mussels and oysters), corals, sea urchins, sponges and others sessile organisms. All of these settle out of the plankton onto the nets and farm structures.

Biofouling directly or indirectly inflicts damage on the net. Direct damage is caused by shells or other hard parts of invertebrates rubbing against the netting and ropes and, thereby, causing damage, such as holes in the netting or severed ropes. This structural failure is often associated with the abrasive action of the fouling itself, and mainly occurs in the netting panels. The indirect damage can be caused by the structural failure of netting or ropes owing to the increased loads on the cage.

Furthermore, abundant biofouling reduces the water exchange in the cage, resulting in poor water quality for the fish (see Plate 71). The immediate and more dangerous effect of excessive biofouling is the depletion of DO in the cage. This may have different effects on the fish, ranging from a sudden reduction in feed consumption, to increased incidences of pathogens and disease outbreaks, up to the loss of the entire cohort of fish owing to anoxia. Fingerlings in cages with a small net-mesh size are the most vulnerable to catastrophic losses, especially if periods with low or no current occur at the site.

To prevent biofouling settlement, nets can be treated with antifouling coatings to inhibit the build-up of marine organisms and thereby reduce the likelihood of damage. Treated nets can be changed less often than untreated nets, which reduces labour costs.

Antifouling can also extend the working life of the net by reducing the degradation of the polymers caused by UV light, and by reducing the wear and tear experienced during cleaning. However, it is also important to stress that antifouling coatings can also reduce the breaking load of the netting.

Usually, an antifouling treatment should last from 9 to 12 months, depending on sea conditions.

Most antifouling paints used as net treatments in the fish farming industry today contain cuprous oxide as the active ingredient. The antifouling activity of copper-based treatments is achieved by the cuprous oxide (Cu_2O), which dissociates to release the cuprous ion (Cu^+). This ion further oxidizes to the cupric ion (Cu^{++}), which is mainly responsible for the toxicity that prevents the growth of biofouling organisms. However, zinc-based biocides are also used.

The presence of copper and zinc is a major concern for the environmental sustainability of these products because these chemicals are released into the marine environment as significant and persistent pollutants. Some biting fish (e.g. breams) can also ingest these heavy metal ions by biting the nets, thereby creating a risk of heavy metal contamination in the fish. For these reasons, various production protocols or regulations (e.g. the organic aquaculture production regulations in Italy) ban the use of antifouling on nets.

Antifouling coatings used in aquaculture are mainly water-soluble. A few commercial antifouling paints used in aquaculture include the following.

- Netrex AF: Produced by NetKem, this is a wax-based paint containing 3 percent cuprous oxide. This treatment can be applied to wet nets. Nets must be dried about eight hours before being used in the sea. After treatment and net drying, the nylon net's weight increases by 10–20 percent. This added weight is commonly called "net pickup".
- Flexgard: Produced by Flexbar, this is a lattice-like treatment that may be diluted in up to 100 percent water in the concentrate formula. Nets must be clean before treatment, and are soaked for 20 minutes before being left to dry for three days. Fish can be introduced after a further 72 hours. After treatment, the net's pickup is 30–35 percent for nylon, and 40–45 percent for HPPE.
- Aquasafe: Produced by Steen-Hansen, this is a water-based antifoulant made in Norway. It is an unscented product, with its basic ingredient of cuprous oxide. The pickup of nets treated with this product is about 35 percent.

Nets are coated with antifouling paint by dipping and drying (Plate 77). The whole net is dipped into a tank full of antifouling paint (*Note:* a sufficient amount of paint is required to properly coat a net), left in the tank for a few minutes and then hung up to dry for several hours. This treatment is performed by net producers in dedicated buildings, where the nets are treated and hung up indoors for drying.

In addition to the UV light stabilizers added to fibres during production, there are also specific products that can further protect the net from UV light. Similarly to the antifouling treatments, these coatings have to be applied by net dipping and drying. One example is Flexdip™, a black net coating that preserves the nylon from UV degradation and makes the net easier to clean, as the fouling organisms are unable to penetrate the netting fibres, and so are unable to gain a firm anchor on the netting. This coating has also proved effective in preventing damage caused by grazing fish, such as gilthead seabream and cod. Not only does it bind any loose threads, which may attract the fish, but it also prevents any loose ends from fraying. In untreated netting, fraying attracts more fish, leading to larger holes developing quickly.

Other coatings generally used in certified organic farming are also available on the market. These products are designed to facilitate net cleaning, where antifoulant coatings are not allowed. These coatings (e.g. Flexdip or Ecopolish) can be applied by dipping (Plate 78). After drying, the net feels slippery, making the biofouling attachments weaker, so that the net can be cleaned more easily. These coatings do not contain any heavy metal in their formulation.

Other products can be applied as "primer-like" coatings, in order to reduce the absorption of the synthetic fibres, and consequently reduce the antifoulant coating pickup.

PLATE 77
A net treatment plant

COURTESY OF: A. CIATTAGLIA

PLATE 78
Net dipping in an antifoulant tank

COURTESY OF: A. CIATTAGLIA

Predator nets

Net pens containing live or dead fish attract a wide range of predators, including birds, sea lions and sharks. Predation represents one of the uncontrolled factors in the stock balance (see Chapter 7), representing a non-quantifiable amount of biomass lost from the batch. To gain access to their prey, the predators may also damage the net, thereby causing additional fish losses (escapees). The cage must be protected against these kinds of attacks, which if they cause damage to the net, can become more costly than the predation itself.

PLATE 79
Cage protected by an bird net

COURTESY OF: F. CARDIA

Bird nets

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

The most efficient way to prevent bird predation is to cover the open top of the cage with a bird net (Plate 79). This net should have a large mesh size (e.g. 100 mm) and be mounted with a rope running along the perimeter of the cage. Additional diagonal cross ropes may be added for strength.

PLATE 80
Bird net floater ready to be installed. Numerous ropes are used to fix it in the centre of the cage

COURTESY OF: F. CARDIA

PLATE 81
Bird net held clear of the water with stakes

COURTESY OF: FIRDA SEAFOOD AS

The bird net must be kept out of the water. To achieve this, the net must be mounted securely on the handrail. If the cage is very large, the bird net may not be sufficiently taut, and it may lie in the water at its centre. This must be avoided because fish can be damaged by the bird net's twine when feeding. Furthermore, the net could become fouled, making it difficult to handle. The bird net has to be removed and reinstalled whenever the fish are harvested.

Special floating supports have been developed to lift the bird net out of the water. There are different models of supports made from HDPE pipes, but the most commonly used structure is comprised of a floating collar with vertical supports, connected to a smaller collar supporting the bird net (Plate 80).

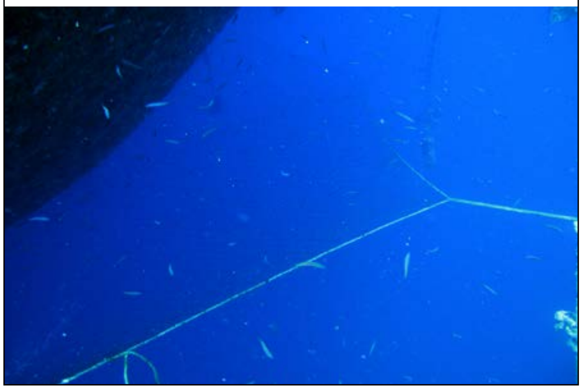
Bird nets can also be held clear of the water by stakes fixed on the stanchions. Several stakes around the cage are fixed on the stanchions, and the bird net is hung from the top of these stakes by a system of ropes and pulleys (Plate 81).

Shark nets

Damage from fish (large predators such as sharks) or seals can be very serious. Underwater predators are usually attracted by the dead fish lying on the bottom of the base net. They try to eat these fish through the net, causing damage by tearing the netting. This can then result in fish escaping through the breach in the net.

Underwater-predator nets are used in sites where this problem can occur (Plate 82 and Figure 42). Dyneema™ netting is a good material to use for this kind of anti-predator nets, being light in weight and very robust. It is strong enough to resist large predators such as seals and sharks. The design of underwater-predator nets depends on the cage design, and is usually discussed with the net manufacturer beforehand. The base net is the most important part of the net to be protected, and an additional external net is therefore often mounted outside the base net (Plate 82).

PLATE 82
Shark net installed below the base net of the cage. In this case, it is a simple Dyneema net panel, which is installed for protecting the net base

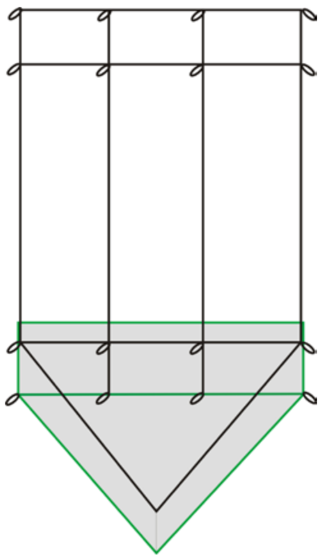


COURTESY OF: F. CARDIA

Marine mammals

A predator net that covers the whole underwater part of the cage net (not just the bottom part) could be a solution against marine mammal predation (seals and sea lions). Sea lions have the ability to push down and climb over the hand rails onto the aerial protection net to try and access the fish from above. In areas where sea lions are present, perimeter protection is also used so that the animal cannot haul out on to the piping.

FIGURE 42
Advanced design of a shark net

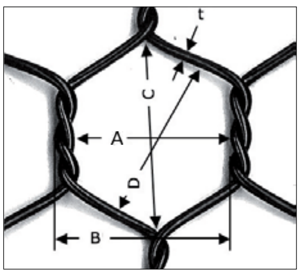


Note: Advanced design of a shark net (in grey). The predator net is installed below the base net, overlapping the lower part of the net wall.

PET monofilament nets

More recently, the use of PET (polyethylene terephthalate) monofilament nets against predators is increasing; PET nets have good strength and at the same time are relatively low in weight. The tread itself is uniform and the hard surface gives a more resistant net material than standard nylon. Since the net is rather stiff, the mesh size and opening keep generally retains its original shape allowing a good water flow through the net cage. Compared with standard net produced from nylon where the life span is normally 4-6 years, the PET monofilament nets have around 14 years life span provided that normal maintenance is done.

The PET monofilament nets are made with an hexagonal mesh, with a thread thickness of approximately 3 mm and different mesh widths (mesh size) starting from 40 mm and above. The weigh is approximately 500–600 grams/m^2. Example of mesh sizes available for PET monofilament nets are provided in Table 30.



COURTESY OF: AKVA GROUP ASA

TABLE 30
PET monofilament net sizes

Mesh size	t (mm)	A (mm)	B (mm)	C (mm)	D (mm)	Weight
Small	2.5	35	40	43	37	570g/m^2
Large	3.0	45	50	71	59	590g/m^2
Super large	3.5	73	80	100	85	450g/m^2

6. Maintenance and controls

This chapter illustrates the main types of damage that can occur on a surface net-pen farm site, the source of the problems, and the maintenance steps necessary for good farm management. Structural damage can cause major economic losses, through material costs, time for qualified workers to rectify any problems, and above all, loss of inventory owing to escaped fish.

The first rule to be followed by those who want to undertake net cage culture is to pay scrupulous attention to the installation and maintenance of all the farm site's components. Moreover, small imperfections or irregularities in components must not be ignored, and instead must be quickly remedied. The failure of a single component can have repercussions on the entire structure.

The marine environment has a high number of physical, chemical and biological forces at work, a high number of variables involved, and it is constantly in motion. This motion affects everything submerged or on the water surface.

The physical forces that affect a net cage are grouped into two general types:

- Static forces include gravity (which pushes downwards according to the mass) and buoyancy (which pushes upwards, according to the density) of the site's components.
- Dynamic forces are mainly horizontal, and depend on the wind, the waves and the current.

In both cases, these forces, acting together, affect the whole farm structure, which is thereby constantly stressed in accordance with the action–reaction principle. These processes can cause abrasion and breakage of the various components.

Net cages are also exposed to chemical and biological processes, including:

- Oxidation (rust) of metallic parts (chains, shackles, rings or plates), which corrodes the materials, making them thin and weak.
- Chemical degradation from the saline environment, which attacks the plastic polymers of ropes and nets, reducing their breaking load.
- Biological activity, especially marine organisms and biofouling (mussels, barnacles, worms, etc.). Biofouling adds considerably to the structures' weight and, in the case of the netting, by increasing resistance to the movement of the currents.

RECORD-KEEPING AND SITE PLAN

For optimal management of a floating cage farm, there must be reliable record-keeping protocols. An archive should be created where the "site plan" is securely stored. This should have the records of the origin of the various components, the date when they were installed, any possible non-conformities that have been identified, and the maintenance or restoration of these components.

These records will allow the farmer to keep track of the activities for maintenance and replacement of all parts over time. These records will also benefit the farm site management plan, adapting it to the particular site's characteristics. Even if there are standardized maintenance procedures, every site has its specific characteristics, and such procedures should be adapted to each site.

Logbook

Tables 31 and 32 provide an example of an inspection logbook that could be used for cage inspection and mooring-line inspection. The number of cages and mooring lines, as well as items to be inspected should be adapted to each farm design and model of net cage. Each of these aspects is discussed below.

TABLE 31
Example of daily cage inspection logbook

Date	Operator/s					Weather conditions ....
	Checked (x)	Conform (x)	Non-conform (x)	Fixed (x)	To be fixed (1–2–3 priority)	Notes/Non-conformity
CAGE 1						
Handrails						
Bird net						
Brackets						
Cage collar						
Bridles						
Vertical ropes						
Net						
Sinker tube						
Mortality						
Disease						
Uneaten feed						
CAGE 2						
Handrails						
Bird net						
Brackets						
Cage collar						
Bridles						
Vertical ropes						
Net						
Sinker tube						
Mortality						
Disease						
Uneaten feed						
CAGE 3						
Handrails						
Bird net						
Brackets						
Cage collar						
Bridles						
Vertical ropes						
Net						
Sinker tube						
Mortality						
Disease						
Uneaten feed						

TABLE 32
Example of a mooring-line and anchor inspection logbook

Date	Operator/s					
	Checked (x)	Conform (x)	Non–conform (x)	Fixed (x)	To be fixed (1–2–3 priority)	Notes
ANCHOR 1						
Ballast chain						
Anchor shackles						
Trip line						
Submerged buoys						
Mooring line						
Mooring line – plate shackles						
ANCHOR 2						
Ballast chain						
Anchor shackles						
Trip line						
Submerged buoys						
Mooring line						
Mooring line – plate shackles						
ANCHOR 3						
Ballast chain						
Anchor shackles						
Trip line						
Submerged buoys						
Mooring line						
Mooring line – plate shackles						

PERIODIC INSPECTIONS

The different components of a farm are exposed to different degrees of the forces described above. Several parameters impose how often the components need to be inspected. The location and function of the components within the structure, as well as the relative sturdiness (material and thickness), determine how much the forces affect the particular component. For this reason, some of the farm's components have to be checked daily, and others have to be subjected to weekly, monthly or six-monthly inspection. The type, frequency and outcome of all monitoring should be recorded on special technical management forms. These can then be reviewed, analysed and stored for future reference.

Inspections of the underwater structures will be made by scuba divers. Underwater work is dangerous. All safety precautions should be strictly followed. External sources are provided in the References and Further Reading section of this publication because it is outside the scope of this manual to discuss underwater safety. In general, excessively dangerous activities should be avoided completely, and some deep-diving operations may require specialized marine engineering contractors.

SIX-MONTH INSPECTION

Mooring lines

The anchors and the bottom ballast chains are unlikely to become damaged once they are installed correctly. Their size and thickness make them very robust, and they are located at a depth that is usually more than 20–30 m. At these depths, the wave motion does not act directly on the components the way it does on components in more shallow waters. In fact, the forces are distributed throughout the grid of mooring lines, chains and buoys, which can act as shock absorbers. Inspections can be difficult because of the depth, and deep diving can expose the divers to additional dangers, and the bottom time will be restricted. For these reasons, visual inspections can be conducted every six months, and also after intense weather and wave events.

With these inspections, it is important to verify that:

- The anchor is upright and properly embedded in the sea bed. An anchor that has been dragged along the sea bed because it is undersized or upturned leaves a furrow behind that is easily recognizable for a diver.
- The shackle is not worn out or loose and the split pin is present.
- The bottom anchor chain is laid out straight and the links are not worn out.
- The shackle connecting the bottom anchor chain to the thimble is not worn out or loose, and the split pin is present.
- The rope connecting the chain to the plate (or ring) does not show any abrasion and is not excessively colonized by biofouling organisms.

Marker buoys

Inspection of the marker buoys should verify that:

- The concrete block has not been dragged.
- The pad eye of the concrete block and the connected shackle function properly and are not worn out.
- The chain is not worn out and/or excessively colonized by biofouling organisms.
- The shackle and the iron plate in the lower submerged part of the buoy are not worn out and work properly.
- The submerged part of the buoy is not excessively colonized by biofouling organisms.

ONE-MONTH INSPECTION

Marker buoy lights

Every month, it is important to inspect that the lights on top of the marker buoys. These lights are usually powered by a small solar panel that is charged with batteries during the daytime, and they activate at dusk and in low-light conditions.

The marker-buoy lights should be visible from land. An alternative inspection method is to cover the upper part of the buoy with a dark cloth (simulating dusk) and observe whether the light is activated. If the light device does not work, it is necessary to unscrew it from the top of the buoy and examine it on land.

During inspection, the emergent part of the buoy should be checked for scratches or damage to the anti-rust protection paint. Any bird droppings (guano) or other obstructions should be cleared from the light and solar panels.

WEEKLY INSPECTION

Grid system

It is recommended that all of the components of the grid system be inspected on a weekly basis. These components are in the depth range determined by the length of the chains under the grid buoys.

Usually, the connections between ropes, chains, rings or plates and surface buoys are made with shackles, which represent the primary weak point in the whole structure.

In weekly inspections, divers must verify that:

- All the shackles are properly locked and their split-pins are present.
- The buoy chains have not been worn or corroded, and are not excessively colonized by biofouling organisms.
- The rings or the plates have all their elements in order.

- The ropes do not show any fraying or other abrasion, and are not excessively colonized by biofouling organisms.
- The buoys do not have any cracks in their PVC external covering, and are not excessively colonized by biofouling organisms.

Collar and mooring lines

The above-water components, including the cage collar, should also be inspected. Inspectors should verify that:

- The plastic frame of the cage is not damaged (in the submerged parts, as well as in the emergent parts) and all of its components, such as the main cage rings, brackets and handrail, work properly.
- The bridle ropes of the cage are tied tightly and the knots are secure. These bridle ropes may suffer damage from the service boats (approaching and mooring).

DAILY INSPECTION

Nets

Every cage on the farm must be checked every day, most importantly to inspect the nets. Nets are made of materials less strong than other components and they can be damaged by a number of factors.

As with other components, nets are exposed to both static and dynamic forces. They may also suffer more than other components from biofouling. Nets can be damaged both by the fish that they contain and by the surrounding marine fauna. Also nets can suffer from incidents of theft or vandalism where the nets may be cut to allow thieves' access to the fish inside, resulting in subsequent fish escapes.

During the nets' inspection the diver must check all the structural parts of the cage, the sinker-tube or sinkers and their respective lines.

These inspections must verify that:

- No abrasion or damage is visible on the nets or ropes.
- Nets are not excessively clogged by biofouling organisms.
- The nets are well installed and the attachment ropes are not worn or excessively fouled and are functioning properly.
- The sinker system is well trimmed (correct position of ropes), and the lines holding it in place are not worn out or excessively colonized by biofouling organisms.

NON-CONFORMITIES

Table 33 describes some of the most common non-conformities and their respective corrective actions. They are presented in more detail below.

TABLE 33
Periodic mooring check – possible non-conformity and corrective actions

Non-conformity	Consequences	Corrective actions
Anchors or bottom ballast chains are not correctly positioned	The mooring lines are not under tension	Re-positioning of the anchors and tightening of the mooring line
Worn-out mooring line shackle	Mooring line may detach	Replacement of the mooring line shackle
Worn-out buoy shackle	Buoy loss	Replacement of the buoy shackle
Damaged buoy	Buoy may sink, creating imbalance in the grid	Replacement of the buoy
Worn-out bridle line shackle	Bridle line may detach from the plate	Replacement of the bridle line shackle
Abrasions on the mooring line	Line may break	Replacement of the line
Excessive fouling on the mooring components	Structure may be overly burdened and dynamic balances changed	Clean mooring lines and grid
Excessive fouling on the nets	Mesh becomes clogged, changing the load and drag forces, weakening the net and hindering water exchange	Change or clean the net with high-pressure water-jet washer

PROCEDURES FOR COMPONENT REPLACEMENT

Many of these specialized corrective actions require a detailed knowledge of the main principles, rules and safety procedures for marine engineering work, as well as knowledge of some of the techniques used in operating specialist equipment and materials. The main problem that will be faced when a mooring grid component is replaced is that all components are under very strong load, mainly owing to line tension and drag forces.

If any of these elements are detached, the integrity of the mooring grid system will be compromised. The loose ends of the disconnection point will be pulled apart by the opposing forces and may be difficult to reattach.

Furthermore, in order to unscrew a shackle and/or loosen a knot, the tension on the shackle and/or knot has to be initially reduced. This is accomplished by the use of a block and tackle and an auxiliary line that temporarily takes the strain off the components to be changed, and prevents the two detached components from spreading apart.

Note: The techniques described below may be changed and/or integrated according to: (i) the competence and experience of operators; (ii) the availability of tools; and (iii) the hydrodynamic characteristics of the site.

Anchor repositioning and mooring line tightening

If the anchor has been turned upside down or dragged across the sea bed, it is necessary to re-set the anchor correctly. An anchor that is not properly positioned will lose its holding capacity.

To carry out a re-setting operation, the trip line (also known as the crown line or the heel line) must be accessible and securely attached to the back of the anchor. If there is no trip line, it should be re-attached.

First, the service boat recovers the anchor's trip line from the surface floats and connects it to a V-shaped bridle line.

Initially, the anchor must be dragged towards the cage so that it breaks free completely from the sea bed, usually 20–30 m. This is necessary so that there is a larger manoeuvring margin during the tightening phase, which permits better repositioning of the anchor.

Then, after the anchor is free, the boat moves away from the cage with its bow pointing away gradually tighten the mooring. The trip line is released when the grid system is correctly tensioned (surface buoys are correctly aligned and scuba divers verify the correct tensioning) and the anchor should re-set into the sea bed. If not, the action is repeated.

Replacement of a grid-line-to-corner-plate shackle

The service boat, equipped with a hydraulic line-hauler, is moored onto the buoy above the plate where the shackle has to be replaced.

An auxiliary line is threaded through the centre of the plate, passing through a temporarily installed shackle, and is then attached with a "stopper knot" on the line to be disconnected (Figure 43). The other end of the auxiliary line is wound onto the winch on the vessel.

When the winch is engaged, the line will be pulled up, which loosens the tension on the line between the plate and the stopper knot. The diver can then unscrew and replace the worn-out shackle. The auxiliary line is then slowly released, so that the grid line returns to its original tension. The stopper knot is untied, and the auxiliary line is retrieved on board.

Note: If the grid system is not under high tension, the auxiliary rope may also be pulled up by a lift bag operated by a diver; the lift bag applies a direct force upwards.

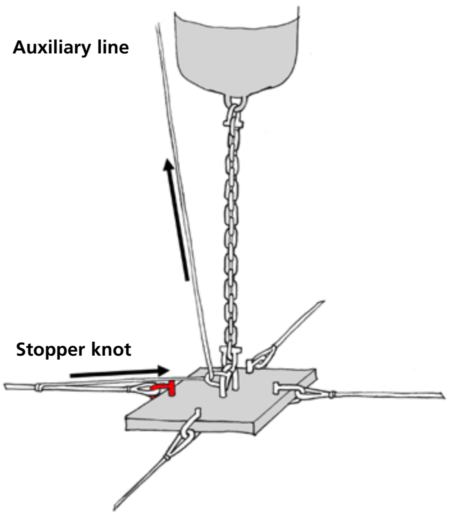
Replacement of buoy-to-corner-plate shackle

The same general principles apply for replacing the buoy-to-corner-plate shackle as described in the above paragraph. In this case, the operation is easier because the tension is less, the shackle is smaller and the applied force is only vertical.

The buoys are connected to the grid plates via a length of chain. This chain is fixed to the buoy and to the plate through two shackles, one between the chain and the buoy, and the other between the chain and the corner-plate.

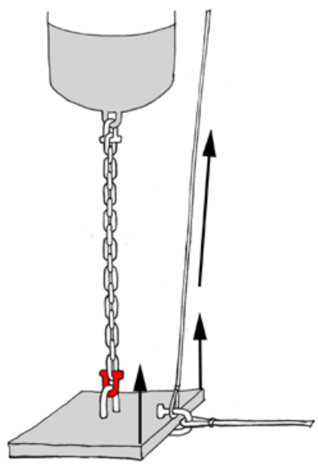
To replace the shackle between the chain and corner-plate (Figure 44), a diver ties one end of an auxiliary line (using a bowline knot) onto a grid-line shackle on the same corner-plate. The other end of the auxiliary rope is wound onto the boat's winch. When the winch is started, an upwards force is applied onto the corner-plate, lifting the corner-plate and relieving the tension on the chain. The diver is then able to unscrew the worn-out shackle and replace it. Once this shackle has been replaced, the auxiliary line is let out, the plate drops back to its original position, and the chain will be tensioned again. The bowline knot onto the shackle is then untied and the line is recovered to the vessel.

FIGURE 43
Replacement of grid-line-to-corner-plate shackle



Note: Grid-line-to-corner-plate shackle (in red). The arrows indicate the direction of force applied to the auxiliary line by haul-up on the boat's winch.

FIGURE 44
Replacement of buoy-to-corner-plate shackle



Note: Buoy-to-corner-plate shackle (in red). The arrows indicate the direction of lifting force applied to the auxiliary line by haul-up on the boat's winch.

Replacement of a shackle between chain and buoy

A diver secures an auxiliary line onto the chain one metre below the buoy. The auxiliary line is then connected to the boat's winch, and the chain is raised as much as necessary to reduce the tension on the shackle to be replaced. The buoy is secured to the boat, and the shackle is replaced. The auxiliary line is then carefully released and recovered.

Buoy replacement

Using a bowline knot, a diver secures an auxiliary line onto a line's shackle, attached to the same chain-plate (see Figure 44). The other end of the auxiliary line is wound onto the boat's winch. The plate is lifted up as the winch is engaged, thereby loosening the chain. At this point, the diver is able to unscrew the old shackle. The damaged buoy is lifted aboard the vessel, and replaced with a new one. The auxiliary rope is released and recovered.

Replacement of a bridle-line shackle

To replace the shackle connecting the bridle line to the corner-plate, it is only necessary to untie the knot on the cage collar, on the opposite end of the bridle line. A diver is able to accomplish this work easily, and can replace a worn-out shackle.

Grid line replacement

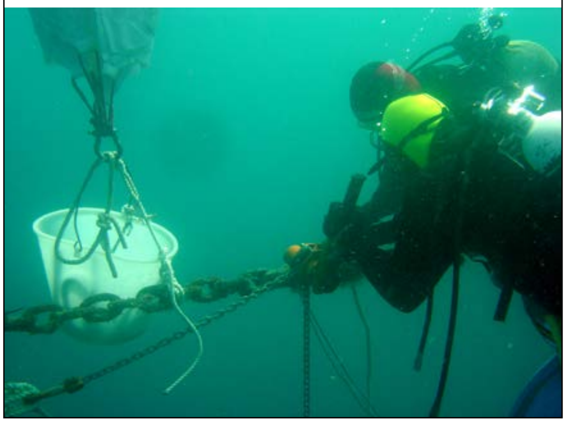
Worn grid lines must be replaced as soon as possible. A grid failure will apply an excessive load on the plastic collar of the pen as a result of the diversion of the load onto the bridle lines.

To replace one of the grid lines between two grid-plates, the boat moors onto the buoy above one of the two plates concerned. A diver passes an end of the auxiliary line through a temporary shackle on the corner-plate and secures the end of the line onto the opposite plate.

When the boat's winch is engaged, the two plates will be pulled closer together. As the two plates approach each other, the tension is released from the grid line to be replaced and it becomes loose. Divers can then unscrew both of the shackles on the plates on either end of the grid line, and retrieve the worn rope.

Note: A hand-lever hoist, also called a come-along winch (Plate 83), can replace the boat winch in reducing tension on the components to be replaced. The hoist can be securely fixed over or around the point where the tension is to be reduced. Hand-lever hoists usually require more manual labour, and make it longer to complete a task, but it can save the use of the boat or can be used when a boat with a hydraulic winch is not available. The hoist should be stored immersed in a bucket of gasoline or light oil to prevent it from rusting when not in use (the lubricant should be washed off before using the hoist).

PLATE 83
Use of a hand lever hoist (or come-along winch) to reduce tension on a mooring line



COURTESY OF: F. CARDIA

BIOFOULING REMOVAL

Cleaning the mooring and grid lines

All the grid system lines need to be regularly cleaned of fouling organisms. Biofouling makes the structure heavier, stresses the lines, and affects the system's balance between weights, loads and buoys.

To carry out this maintenance, a diver places a suitably sized shackle, tied to an auxiliary line, around the rope to be cleaned. The auxiliary line is attached to a small work boat, and as the boat moves along the line, the shackle runs along the line thereby stripping the larger fouling organisms.

This very simple technique can be used on all of the lines in the mooring system, including the lines and the mooring lines, extending down to the anchors.

Cleaning the nets

Fouled netting with clogged mesh reduces water exchange inside the pen, and needs to be cleaned (Plate 84 and 85). The net is cleaned in order to maintain functionality if net replacement is not possible (see below).

A possible way to clean an installed net is to use a high-pressure water-jet washer. The cleaning is conducted by a diver who operates the cleaner gun underwater while the engine and compressor remain on the support vessel.

It is best if the diver cleans the net from the inside, flushing the biofouling outside of the pen with the water jet. Also, it is best practice to clean vertical strips as wide as the distance between two vertical lines. This allows for quicker cleaning of the net around the entire circumference, which ensures a quick recovery of water exchange through the cage.

PLATE 84
Portion of netting cleaned with a high-pressure water-jet washer. The anti-abrasion net panel (in orange) is visible behind the cleaned net

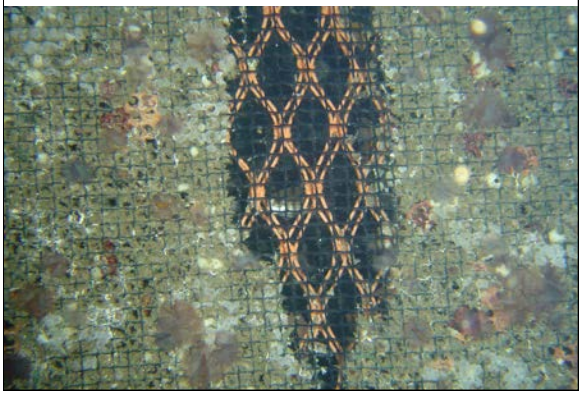


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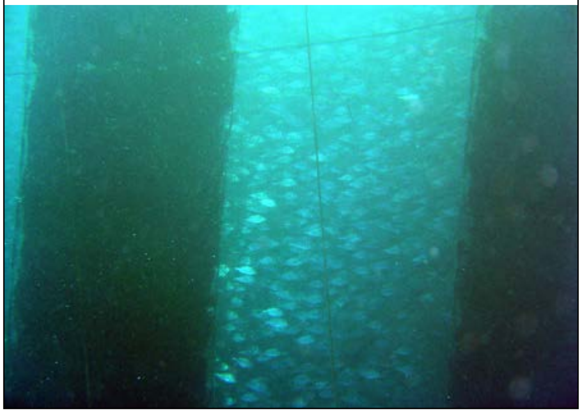
PLATE 85
Underwater cleaning of a cage net wall with a high-pressure water-jet washer. Note the vertical strips



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There are several models of net cleaners with rotating discs, specifically designed for net cleaning, that can be operated from the surface. These types of washers reduce the time and labour of cleaning when compared with other standard models equipped with a gauge and nozzle and operated by divers.

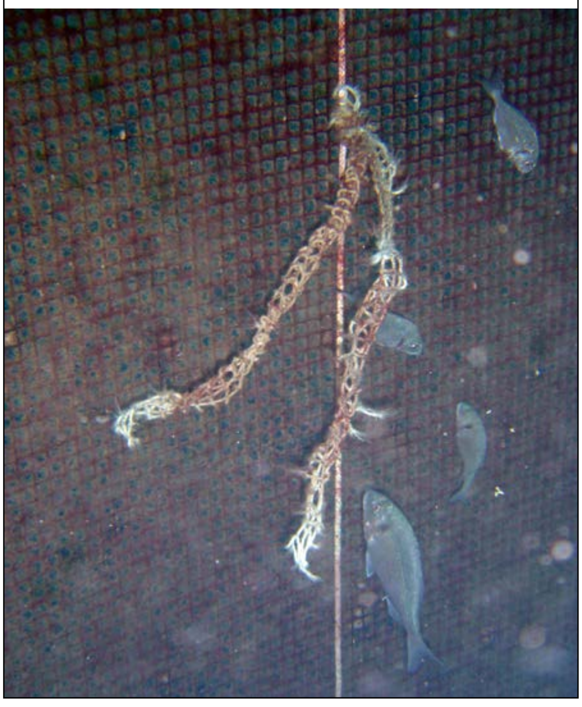
Additional suggestions for net cleaning

Grazing distraction devices

A significant reduction in the occurrence of holes in the net has been noted where objects designed for distracting the grazing activity of the fish are introduced into the cage. Good results have been obtained using ropes (8–12 mm in diameter × net wall length) where several tufts of netting are fixed along the rope length (approximately one tuft each metre) (Plate 86). The ropes are as long as the net wall, with the upper end of each rope tied onto the handrail, and the lower end fixed with a plastic cable tie onto the lower part of the net wall. Alternatively, it can be weighted with a 2 kg dive weight tied onto the lower end of the rope. The number of ropes in each cage is half the number of stanchions (i.e. one rope for every two stanchions).

The tufts of netting act as attractors for grazing fish, and this reduces the fish grazing activity on the cage net and, consequently, the number of holes created by the fish.

PLATE 86
Tuft of netting fixed on the rope. Note the white frayed twine chewed by bream



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Self-cleaning pipes

Cage collars, which are often used as walkways by workers, are also subjected to biofouling. Mussels and other sessile organisms settle on the submerged part of the pipes, while slippery algal biofouling is very common on the emergent portion of the pipes.

This fouling represents a threat both for workers, who can slip on the algae and fall, and for the nets, which can be abraded by the hard shells of invertebrates. Therefore, these pipes also need to be cleaned regularly.

PLATE 87
A rope ring (red arrow) installed on the internal pipe section between two brackets. Note the absence of the rope ring on the external pipe, and the difference in biofouling settlement between the external and internal pipes

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An easy and effective way to clean these pipes is to install rope rings around the pipes (Plate 87). These are rings made from a 20–30 mm diameter rope that is tied loosely around pipes. The rings are then moved along and around the pipe by the wave action. Their movement counters the fouling settlement because the ropes continuously brush the pipes. One ring is needed for each pipe section between each bracket of the cage.

NET CHANGING

Net changing is routine maintenance activity that has to be planned, scheduled and organized efficiently.

A logbook should be kept with the number of working days (number of days in the water) for each net. A limit should be set on the number of days in the sea for each net, defined on the basis of the fouling characteristics of the site, and this should be strictly followed.

Each net must be tagged on arrival at the farm site with a unique code.

The main information to be recorded in the net logbook should include:

- Code number: code for each net.
- Design: shape (e.g. if cage shapes other than circular are used on the farm), number of vertical ropes, any other relevant details.
- Size: volume, circumference, wall depth, base cone depth.
- Supplier: net manufacturer.
- Delivery date.
- Netting characteristics: mesh size, mesh shape, breaking load, material and colour.
- Antifouling: whether the net is treated or not, and date when it was last treated.
- Days in the water: number of working days of the net, if used more than once.
- Repairs and patches: any relevant repairs done on the net.
- Test date and result: when the last strength test was performed and the verified residual breaking load.
- Current location: location of the net, on which cage it is currently installed and its location in the depot.

One or more divers are usually required for changing large nets. Smaller nets may be changed using only surface staff. Depending on the net size and the amount of biofouling, a boat with a suitably sized crane may be used. A square metre of net can weigh up to 10–15 kg (out of the water) if it is not changed in a timely manner. Heavy fouling is possible, especially if nets are not treated with antifoulants.

Preliminary actions in net changing

- The new net must be fully inspected on land to check for manufacturer faults or repair mistakes. There is no point in exchanging a dirty net for a faulty one.
- Attachment lines must be checked and fastened on the attachment loops.
- All the required equipment must be carefully checked (crane lines, scuba gear, rope slings, etc.).
- Anti-predator nets should be removed in advance from the cage where the net will be replaced.

Net detachment

The attachment points on the fouled net are untied from the cage in the following sequence:

- sinkers;
- sinker tube;
- connections along the sinker ropes;
- cage collar attachment points.

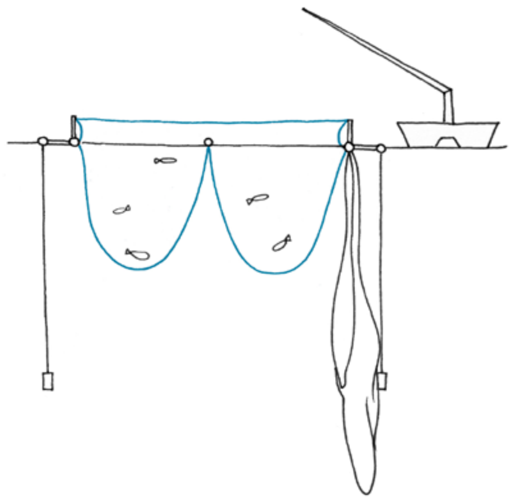
Note: The net is now secured through the top rope onto the handrail only.

Positioning the new net

- The new net is dropped into the water on the up-current side of the cage.
- The bottom of the fouled net is lifted with a lift bag (Figure 45).
- Divers draw the new net underneath the fouled net.
- The new net is gradually raised by the surface workers and by divers underwater. Surface workers can help the divers by hauling on lines to pull the new net underneath the fouled net (Figure 46).
- When the new net is in place underneath the fouled net, surface workers fasten the attachment lines of the new net onto the handrail.

At the end of this phase, both the new net and the fouled net are only attached onto the cage handrail. The fish are completely contained by both nets. It is necessary to ensure that the new net is well attached before removing the old net.

FIGURE 45
Net replacement – step 1

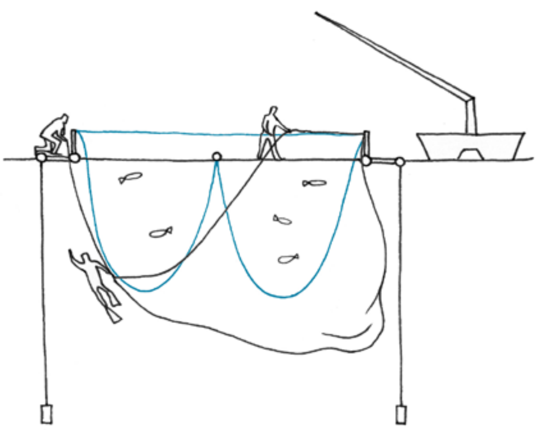


Note: New net (black line) is positioned in the water beside the fouled net (blue line), which is lifted in the centre through a lift bag.

Removal of the fouled net

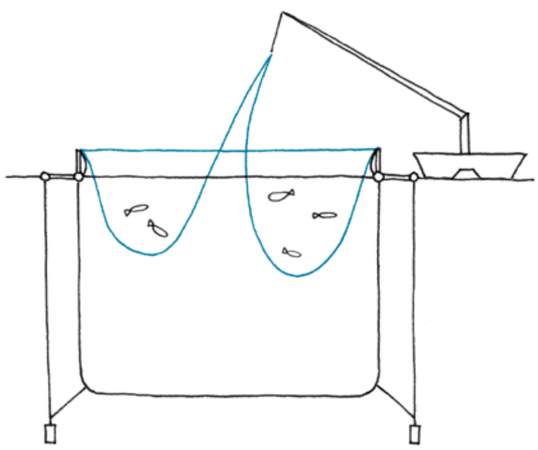
- The fouled net base is lifted out of water and fastened onto the crane hook with a sling (Figure 47).
- Using the winch, further slings are tied onto the net base below the first sling.

FIGURE 46
Net replacement – step 2



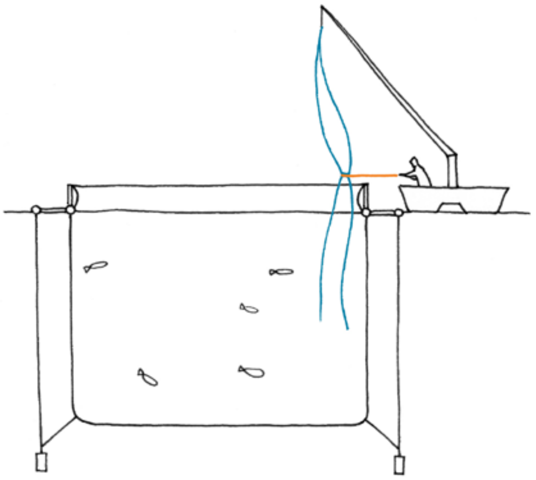
Note: The new net is fitted underneath the fouled net.

FIGURE 47
Net replacement – step 3



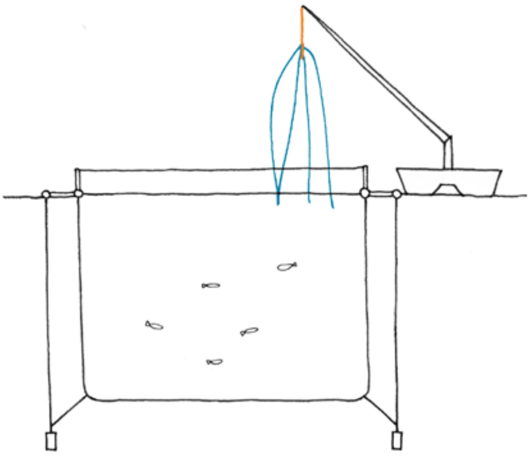
Note: The fouled net centre is lifted out of the water.

FIGURE 48
Net replacement – step 4



Note: The fouled net is detached from the cage and secured with a sling.

FIGURE 49
Net replacement – step 5



Note: The fouled net is lifted out of the water and moved on board the work boat.

Note: Net changing or installation should not be performed during adverse weather or current conditions.

New net attachment

This operation can start before the removal of the fouled net.

The new net needs to be fixed to the following attachment points:

- cage collar;
- sinkers;
- sinker tube.

This operation is usually carried out by divers, who attach the base net to the sinker system. It may be problematic if these attachments are made when a strong current

- Once a large portion of the fouled net is out of the water, the jump net is unfastened from the handrail (Figure 48).
- The fouled net is then pulled out of the water and loaded on board the work boat, paying attention that there are no fish trapped in the fouled net (Figure 49 and Plate 88).

The use of web slings or endless slings is recommended for better net handling and removal (Plates 89 and 90). Endless slings may be made by splicing two ends of the same rope together, or commercially produced endless slings can be purchased.

PLATE 88
A dirty net on board of the work boat. Note the sling used to lift the net is still attached to the crane's hook

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PLATE 89
The use of endless slings for net handling (in this case a harvesting net is shown)

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PLATE 90
A fouled net is removed from the cage using a web sling (arrow)

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PLATE 91
A net depot for storage and repairs of nets

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is flowing at the site, because the net will be under load and the attachments will be difficult to connect.

Net maintenance on land

Once the net is removed from the cage, it is transferred onto land.

If the net is to be cleaned with a high-pressure cleaner, it has to be dried first. The fouled net is left in an open space for drying, preferably spread out over the ground. If the net is to be cleaned using a net washing machine, drying is not necessary but preferable.

Repeated or prolonged use of high-pressure cleaners may damage the nets over time.

Repairs on the cleaned net will be done after cleaning, and will include the removal of all the plastic ties and the net mending, including replacement of ropes as needed.

A residual net strength test should be performed, with the use of a net strength gauge, and the data updated in the net logbook. If the residual net strenght is below 60% of the initial breaking load value, the net should be replaced.

At the end of this process, the net is folded and stored in a warehouse, avoiding direct exposure to sunlight (Plate 91).

Net washing machine

Net washing machines are used to clean dirty cage nets once these are removed from the cages (Plates 92–95). There is a wide variety of models and sizes, but the principle is always the same: the cleaning action is obtained through the friction resulting from

PLATE 92
A large net washing machine (about 4 m wide and 2.5 m high). The engine unit and the wastewater collector are visible, respectively, on the right and on the left of the equipment

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PLATE 93
The opening on the side of the drum is large, thus facilitating the transfer of the net in and out the drum

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PLATE 94
Owing to the weight of nets, lifting equipment (such as a forklift or a crane) is necessary for moving the nets

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PLATE 95
A catamaran boat equipped with a fibreglass net washing machine on board. The washing machine is operated through a hydraulic motor, which is connected to the hydraulic drive system of the vessel (which also powers the crane)

COURTESY OF: F. CARDIA

the movement of the nets. Only water is added inside the drum while it is rotating; no additional soaps or cleaning products are required.

The resulting wastewater, containing the dead fouling organisms removed from the net, needs to be treated, at least through a sedimentation tank, before being discharged back into the sea.

It is preferable to dry the dirty nets before they are washed, as this makes the cleaning action more effective.

Net washing machines are usually made of stainless steel, and consist of the following main elements:

- A main frame that supports the drum axle. An additional stainless steel tank below the drum may be installed on the frame to collect the wastewater that drips from the drum (Plate 92). This tank is usually in the shape of a half cylinder, and envelops the lower half of the drum.
- A rotating drum. This has a large volume (several cubic metres), sufficient to contain the largest nets used on the farm. (Note: biofouling increases the volume and weight of the nets dramatically.) A large, lockable door is located on one side of the drum (Plate 93). The drum is usually rotated at a speed of 5–8 revolutions per minute (rpm). The dinty nets are usually placed in the drum with a forklift or crane (Plate 94).
- An engine unit. This can be either electric or hydraulic powered. The engine is connected to the drum through a gear system, which increases the engine power while reducing the revolutions per minute of the drum. Hydraulic motors are preferred if the net washing machine is installed on a boat, where the hydraulic motor can be connected to the hydraulic drive system of the vessel (Plate 95). A control panel with a safety switch is connected to the engine unit.
- A water supply. This is a pipe connected to a dedicated pump that provides water through a water inlet into the drum. The inlet is usually a hole in the drum axle, opposite the engine axle.

7. Fish stocking: fingerlings and juveniles

The quality of juveniles stocked into the net cage or pen is a key factor in the successful grow-out of fish in cages, as it affects the quality of the final product, the cost of the production process and the overall product image. The use of high-quality fingerlings is therefore often a prerequisite, which demands well-defined quality benchmarks.

BATCH QUALITY

Before each fish delivery, a quality check of fingerlings must be performed at the hatchery. The size of fish must be verified and the size variation quantified. This procedure is indispensable in order to ensure that the net where the fish will be stocked has a mesh size suitable for the size of the fish (see Table 23), so that no fish will become trapped or escape from the cage.

Fish size

Fish size variation can be quantified by sampling the fish and weighing them one by one, and then calculating the "coefficient of variation" (CV). This parameter is a standardized measure of variation. The CV is defined as:

$$CV = \sigma / \mu$$

where,

σ = standard deviation

μ = mean weight

This value can alternatively be expressed as a percentage (CV × 100), which is referred to as the relative standard deviation (RSD).

Low values of RSD (e.g. between 3 and 10 percent in breams) usually indicate homogenous batches. High values of RSD (more than 20 percent) indicate a large size variation, i.e. fish that range in size from small to large, and the presence of specimens that are possibly too small for the mesh size of the net. A high RSD also indicates that the feed pellet size – determined by the mean weight of the fish – may be not suitable for all of the fish that make up the batch. Therefore, the size of the feed pellets provided to the fish needs to be carefully evaluated.

Disease

The quality check of the fish sample must also include:

- Quantification of the percentage of deformed fish is obtained by sampling (Plate 96). A sample of 100–200 fish is collected from the tank, anaesthetized and inspected to determine the percentage of deformed fish. Usually, a deformity level of 3 percent is an acceptable limit. There is a large variety of fish deformities, but the most common usually relate to the fishes' skeletal structure. In the field, a preliminary examination can be performed, but a closer analysis with an X-ray machine is recommended in order to reveal any possible hidden deformities.
- A pathological survey is conducted by sending a sample to a laboratory. A sample of about 30 fish is collected (one sample from each tank, if the batch is divided into more than one tank) and sent to a laboratory for fish pathology diagnosis.

Fish should be inspected for viral, bacterial and parasitological diseases. This is a very important inspection, which should be conducted a few days before the fish are delivered to the farm. This will permit the evaluation of any possible hidden diseases, and will minimize both the risk of disease outbreak in the batch and the introduction of the pathogen into the environment, which could result in the possible transmission of diseases to fish populations in the wild (Colorni, 2002).

PLATE 96

A small batch of fish sampled and examined, in the field, to check for deformities. In this particular case, 136 gilthead sea bream were examined: 88 fish (65%) on the right were identified as "normal", 48 fish (35%) on the left were considered "deformed". This batch of juveniles can therefore be considered "not acceptable", and should not be stocked into a net pen

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FISH NUMBER COUNTS

Production cycles in cages may last for many months, and updating the biomass information of each cage is essential for managing the stock well. This biomass evaluation is essential to be able to calculate accurately the quantity of feed needed, and for planning the harvesting, sale and future stocking schedules.

No instrument is available capable of providing accurate counts of fish in a cage. Therefore, the best approach is to maintain an accurate record of the numbers of fish stocked and removed from the pen, and to minimize any uncontrolled variations in these numbers.

The biomass of a batch is obtained by multiplying the number of fish by the average weight of the fish. The average weight of the fish can be determined by taking a sample of the batch in the cage. However, in order to estimate the entire biomass, the number of fish at the moment of sampling needs to be known. An inaccurate assessment of the number of fish will result in several biomass-related errors, which can be detrimental to the company's accounts as well as to the surrounding environment.

An overestimation of the fish biomass will result in overfeeding, which means an increase in feed wasted on the site, with a consequent negative impact on the environment and a higher FCR (and higher production costs). On the other hand, underestimating will result in a reduced amount of feed provided to the fish. Underfeeding will lead to a reduction in growth rate, which lengthens the overall production cycle. It can also lead to stress-induced immunosuppression, leading to greater potential for disease outbreaks and reduced fish value or survival.

An accurate estimate of the biomass allows the appropriate planning and assessment of the future production of the farm, as well as permitting tracking of the growth of the different batches of fish.

To reduce the risk of biomass errors, it is essential to: (i) record accurately the input of new fish; (ii) record mortalities, sampling and harvesting; and (iii) minimize the effects of uncontrolled output such as escapes, theft, predation and cannibalism. Each of these topics is discussed in more detail below.

Fish inputs

The initial fish count can be quantified or measured in several ways:

- Manual counting. After the fingerlings have been anaesthetized, they can be counted one by one. This method can only be applied to small batches. It is a time-consuming method, but provides an exact count.
- Automatic electronic counting. There are several fish counting machines available, but they are expensive and are usually not available at the hatcheries. An error of about three percent can be expected when using these machines.

- Statistical estimate. This is the commonly used method and is based on calculating the average weight of one fingerling from a sample, as well as the total weight of fish received from the hatchery. To conduct a sample, several fingerlings are netted and placed into buckets or basins filled with a previously measured amount of water. A known number of fish are added, and the net weight is calculated and recorded. The difference between the final weight and initial weight will be the total weight of all of the fish, which is divided by the number of fish to calculate the average. Several average weight estimates should be made during the loading operation. In general, larger samples will produce more accurate and precise results. Depending on the way of conducting this measurement, 1–3 percent should be deducted to account for water weight.

Controlled fish output

The controlled outputs can be quantified by simply counting or estimating the number of fish that are deliberately or actively removed from the cage by the farmer. Controlled outputs are possible when recording fish mortalities and during fish transfers, sampling and harvesting:

- Mortality: Dead fish must be periodically removed from the cage, counted and disposed of as special waste. Any variation in the pattern of mortality could indicate a disease outbreak and should lead to immediate pathological inspection, and to diagnosis and cure or other response. The expected and acceptable percentage mortality depends on the species, the environment and the rearing conditions.
- Transfers, sampling and harvesting: It is essential to record all the inputs and outputs of fish transfers for each batch. It is helpful to compile a periodical stock report, with the updated status of each cage.

Uncontrolled fish output

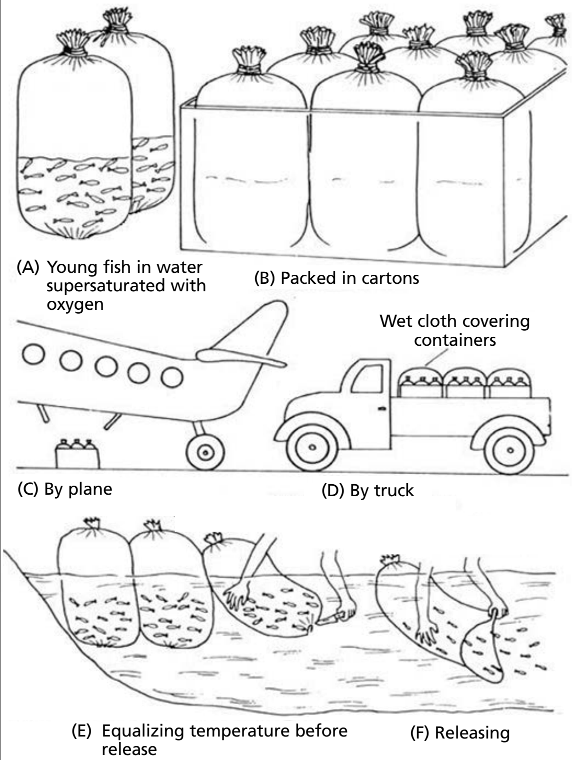
The causes of uncontrolled fish loss must be minimized as much as possible:

- Accidental escapes may be drastically reduced by applying a plan of control and maintenance of nets and cages as discussed in Chapter 6. Nets must be kept clean by regularly changing them or cleaning them with a high-pressure cleaner. This avoids the build-up of biofouling, which makes the nets heavier, and thus represents a potential cause of net failure. Increased controls are necessary when culturing grazing species because the risk of breaches in the netting is higher as a result of net bites.
- Predation must be countered through the use of predator nets. It is possible that large predatory fish (e.g. amberjacks) can be unintentionally introduced into the cages during a batch transfer between cages. In these cases, predators need to be removed from the cage to reduce the risks of fish loss.
- Cannibalism is a naturally occurring behaviour in many species. It can be minimized by reducing the variation in fish size so to ensure size homogeneity as much as possible. It is possible to reduce the size spread by ensuring that fingerlings are inspected before they leave the hatchery, together with correct feed management on the farm site.
- Theft can be reduced through surveillance of the site, by either humans or video equipment. Surveillance of the fish farm is highly recommended.

FISH TRANSPORT AND STOCKING

Transfer of live fish is required in order to transport the juveniles from the hatchery to the farm jetty and then from the jetty to the cage site for final stocking. Depending on the number and size of the fingerlings, fish may be delivered to the farm in transport tanks or in plastic bags filled with water and oxygen. This can be a delicate time for the fish, and great caution should be used to prevent unnecessary stress and mortality.

FIGURE 50
Transport of fish fingerlings in plastic bags



Source: From Berka (1986).

Plastic bags

This transport option is preferable for small numbers and/or small sizes of fish. If the fish are smaller than 1 g each, the final stocking into the cage must be delayed. It is not recommended to stock fish smaller than 1–2 g into the cages because the cage environment is not suitable for very small fish. Feeding cannot be correctly controlled; strong currents may stress the young fish, leading to high mortality. Moreover, predators may kill or injure a larger number of fish, and the counting of mortalities is more difficult with smaller fish.

Therefore, fish of about 1–2 g should first be held for a period of pre-growout, in a proper land-based nursery facility equipped with tanks, water inflow, aeration system, outflow depuration system and a water heater/chiller system. Fingerlings transported in plastic bags (Figure 50) must be carefully acclimatized before they can be released into either cages or tanks. Plastic bags must be left floating in the new water to equalize the temperature. Then, the bags must be opened so that the internal and external water will slowly mix together. As the water exchange increases, the fish will become fully acclimatized, and therefore can be released into the cage or tank.

If the juvenile fish are large enough to be stocked directly into cages, they can also be delivered in transport tanks (usually tanks installed on specialized flat-bed trucks). Different methods may be used for transferring the fingerlings to the cage site, including using a towed transport cage or a boat equipped with tanks.

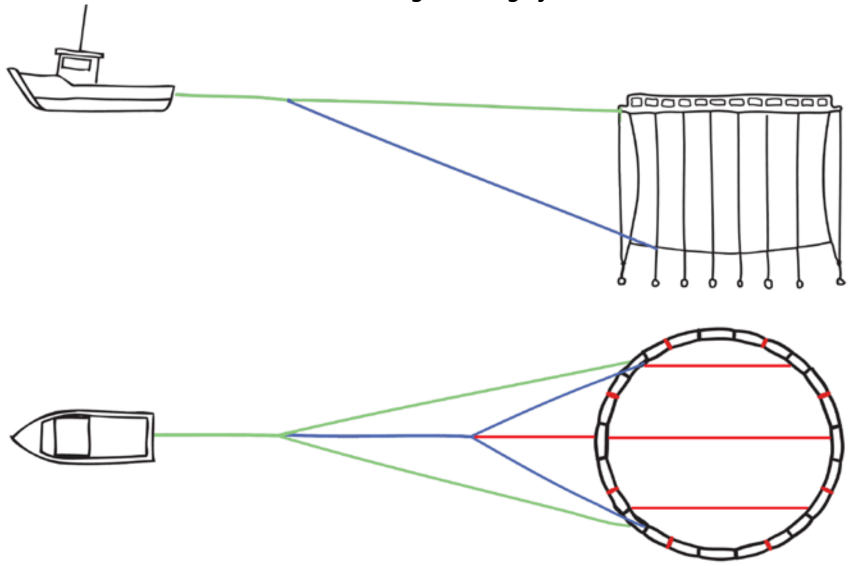
Cage towing

The cage that is to be stocked is detached from the mooring system and then towed to a nearby jetty. At the jetty, the juveniles are transferred from the truck into the cage. The cage is then towed back to the site and moored in its final position.

If a cage is to be towed, the following actions must be considered:

- Check the site where the jetty is located. Carry out an underwater survey to verify its depth and the presence of rocks or obstructions that could damage the net.
- Reduce the net depth ("shallow-up" the net) and the length of the sinkers in accordance with the water depth in front of the jetty.
- Increase the weight of the sinkers on the up-current side (front, or leading edge) of the cage.
- Attach two or three additional tow lines, fixed onto the sinkers on the up-current or front side of the cage, which can help reduce net deformation and help maintain the available volume inside the cage (Figure 51).
- Transport the fingerlings at a slow speed. A speed through the water of 1–2 knots is recommended. Consider currents.
- Regularly check the fingerlings while towing them. At regular intervals, a diver should check that the juveniles are not becoming exhausted or being pressed back against the down-current (back) side of the net by the current. This would indicate that the boat is towing the cage too rapidly.

FIGURE 51
Schematic cage towing system



Note: **Green lines:** surface ropes connected to the cage collar; **blue lines:** submerged ropes connected to the base rope of the net; **red lines:** surface ropes connected to the cage collar to maintain its shape and distribute the dragging forces.

- Take into consideration that, in case of current or in case of large cages, the drag force of the cage net could be very strong and the vessel may have not enough power to tow the cage, therefore the use of large vessels with enough horse power is recommended to execute this kind of operation.

A smaller transport cage (Plate 97) may be used instead of a large grow-out cage. This would avoid having to detach the large cage from the grid. Moreover, a smaller transport cage is lighter and easier to manoeuvre, does not require a fixed mooring point, and can be easily stored away on land when not in use. However, if a transport cage is used, the fingerlings will need to be transferred into the grow-out cage at the farm site. This transfer procedure will depend on the design of the transport cage. Often, the most convenient method is to use a transport cage similar to that shown in Plate 98. This cage has no stanchions and has a lid that is closed with a zip. This allows the cage to be pushed/pulled under the collar of the grow-out cage. Once placed inside the net, fish can be readily released, and the transport cage can then be easily lifted out

PLATE 97
Transport cage ready to be stocked near the jetty. The truck on the jetty is changing the water to acclimatize the fish before releasing them into the transport cage

COURTESY OF: F. CARDIA

PLATE 98
Transport cage with double pipe collar, and without stanchions. As the cage is without stanchions, the cage is covered with a top net fixed on the surface, and removable through a zipper. Two inflatable fender buoys are used here to keep the top net on the surface

COURTESY OF: F. CARDIA

of the grow-out cage by the boat's crane. To enable this, the grow-out cage must be prepared by lowering the top of the net under the water and removing some of the sinkers from the side where the transport cage will be introduced.

If a cage with stanchions is going to be used as the transport cage, then a different procedure should be followed:

- Fasten the two cage collars together with rope.
- Unfasten a few metres of the grow-out cage net from the handrail and from the collar.
- Unfasten a few metres of the transport cage net.
- Join the top rope of the grow-out cage net to the top rope of the transport cage's net underwater (under the cage collars) using plastic cable ties.
- The two nets are therefore joined together underneath the two cage collars, and a passage is available for transferring the fish by swimming them from one pen to the other.
- Slowly lift the transport net by hand, or by using the crane, reducing the volume inside the net and forcing the juveniles to swim across into the grow-out net.

Fish transport tanks

Fish transport tanks should be equipped with an air diffusion system, valves for water inflow and outflow, and a large sluice door near the bottom. The tank should be insulated depending on the environmental conditions. A wide range of models is available on the market, but it is also possible to construct one by using large plastic tanks for potable water (such as those used as domestic water reservoirs for houses).

On the large lower sluice gate, a special slide can be fixed for easy release of the fish. A plastic flexible tube can also be fixed onto this slide.

A boat equipped with fish transport tanks also needs to be equipped with:

- Oxygen: It is possible to use oxygen cylinders from oxyacetylene cutting torches or those used for medical purposes. The number and size of the cylinders should be considered in relation to the number of tanks to be served, air diffuser efficiency, distance to the cage site, the temperature of the water, and specific species requirements.
- Water pump: Water will be needed if the transport tanks are equipped with open water circulation systems, to flush out the last fish of the batch, and to clean and refill the tanks if more than one batch will need to be transported in the same day.
- Oxygen meter: A hand-held oxygen meter will be needed. This should also incorporate a thermometer.
- Oxygen pressure regulator.

The maximum loading capacity of the boat will be a limiting factor because of the weight of the water in the transport tanks. The number and volume of the tanks carried on the boat is a key factor in optimizing transport operations. If a truck has been loaded with fish at a density (biomass per cubic metre) suitable for road transport lasting one or more days, the density of the transported fish on board the vessel may be doubled or even trebled, given that, during this operation, the water in the transport tank is renewed (it is not the same water as in the truck) and transportation to the cage takes a few hours or minutes.

Table 34 provides an example of the calculations that need to be considered when transporting the juveniles to the cages, using a boat with transportation tanks, including number of trips, time required for transporting each batch, and time required for the overall operation. In the example provided (see Table 34), the density of the transported fish in the tanks on board the boat is three times the density of the fish in the tanks on the truck.

TABLE 34
Example of calculations for fish fingerling transport to the farm cages

Ref.	Item description	Example quantity	Calculation
a	Number of tanks on the boat	2	
b	Volume of each tank (m^3)	2	
c	Total tank volume on boat (m^3)	4	a × b
d	Total number of transported juvenile fish (no.)	180 000	
e	Average weight of one fish (g)	10	
f	Total weight of all fish (kg)	1 800	d × e ÷ 1 000
g	Transport density on the truck (kg/m^3)	50	
h	Transport density on board (kg/m^3)	150	g × 3
i	Volume required on board (m^3)	12	h ÷ f
j	Number of transport batches (jetty -> site)	3	i ÷ c
k	Number of full trips (to and from)	6	J × 2
l	Distance between the jetty and the site (nm)	2.5	
m	Boat speed (kn)	7.5	
n	Time per trip (minutes)	20	l ÷ m × 60
o	Time for loading the boat (minutes)	40	
p	Time for stocking fish (minutes)	20	
q	Duration of a return trip (minutes)	100	(n × 2) + o + p
r	Total time for the whole transport operation (minutes)	300	q × j

Extra care is required when increasing the fish density in the boat's transport tanks (see raw "h" of Table 34). It is preferable to make extra trips to prevent stress and mortality. Fish transport density should not be increased if:

- the fish have been stressed during the road transportation;
- the mortality rate exceeds an acceptable amount;
- the truck has been overloaded, and fish density is already very high (because the hatchery is very close to the farm, for example).

Operations for fish transfer from the truck to the boat:

- Verify that the height difference between the jetty and sea level is enough to permit fish transfer by gravity from the truck to the boat. One should also consider whether the fish outlet in the truck is in the lower part of the tanks, or if the openings of the tanks on the boat are on the top. If the boat level is higher than the truck, fish cannot be transferred by gravity but other more stressful system will need to be applied (e.g. scoop net, fish pumps).
- Check the truck on arrival, and verify the health status of the fish.
- Change the water in the truck's tanks using seawater, which will acclimatize the fingerlings to the new water conditions (e.g. temperature, salinity and oxygen), reducing stress (Plate 97). Usually, trucks are provided with a pump to carry out this operation. If not, a pump for transferring seawater from the sea into the tanks of the truck needs to be available at the jetty. The required time for water exchange should be at least one hour per each degree of Celsius difference (e.g. truck tank temperature = 27 °C, and seawater temperature = 24 °C, then the water exchange should take three hours). Ensure that the water near the jetty is free of pollutants.
- Fill the boat's tanks with water, start the aeration system and check the oxygen levels (see Plate 101).
- Transfer the fish onto the boat by gravity through a hose or slide (Plates 99 and 100). Take care to prevent the fish from hitting the walls of the receiving tank. The transfer pipe should run straight into the tank, and its outflow should be angled towards the water rather than the tank wall.

Operations for fish transfer by boat from the jetty to the cage site:

- Secure all the tank openings.
- Regularly check the levels of dissolved oxygen.
- If DO decreases below the safety level (< 2–3 ppm) increase the oxygen pressure in the system (Plate 101).

Operations for fish release into the grow-out pen:

- Securely moor the boat onto the cage collar or handrail.
- Install the tank slide, and place the flexible end of the transfer pipe into the cage.
- Lower the water level in the transfer tank, using the outflow valve.
- When the water level is about one-third of the tank's total volume, open the tank sluice and flush out all the fish. A broom may be used to push the last remaining fish out of the tank (see Plate 102).

At the end of the transport operation, always perform a dive check to verify mortality rates, to remove dead fish and to verify that the net is not damaged.

PLATE 99
Juveniles are transferred from the truck to the boat with a rigid tube

COURTESY OF: F. CARDIA

PLATE 100
A small work boat equipped with two tanks, each with a volume of 2 m^3

COURTESY OF: F. CARDIA

PLATE 101
A large container modified for fish transport. In the foreground, the oxygen meter display can be seen

COURTESY OF: F. CARDIA

PLATE 102
Flushing out the last fingerlings at the farm site. Note the external slide mounted onto the tank's sluice and the red flexible tube mounted on the slide that extends into the cage

COURTESY OF: F. CARDIA

8. Fish feeding

Feeding is the most important management task to optimize, this is necessary in order to increase the efficiency of the production process.

The primary objective for most fish farms is to produce high-quality fish for the lowest cost. Feed typically accounts for 50–75 percent of the operating costs in an efficient farm. If feed costs are less than this percentage, it suggests that the other costs are too high and there are inefficiencies in the operations.

The different cages within the grow-out site will require different feeding procedures. Poor feed management can result in:

- increased production costs (higher FCR, longer grow-out cycle, higher management costs, etc.);
- higher environmental impact from uneaten feed.

If not stored in silos, feed must be stored in a warehouse, where the following characteristics should be ensured:

- Warehouse should be dedicated exclusively to feed storage.
- Low humidity (feed must be kept dry).
- Temperatures should not exceed 40 °C.
- Pest-free.
- All surfaces must be cleanable.
- Entry restricted to authorized staff only.

The feed warehouse must also have some physical features to facilitate feed handling, such as:

- accessible to a forklift;
- large enough to permit the movement of pallets.

The feed storage should be organized in order to give priority to the "older" feed. A mnemonic saying is "first in, first out". This means that when a new order of feed is delivered, the older feed should be moved to where it will be available for ready use and not stored behind the new feed.

Silos are worth considering for bulk storage if loose feed is to be used on the farm. Silos facilitate the feed handling and distribution, but require a larger investment in terms of feeding equipment, because of the higher level of mechanization needed for moving, quantifying and distributing the feed.

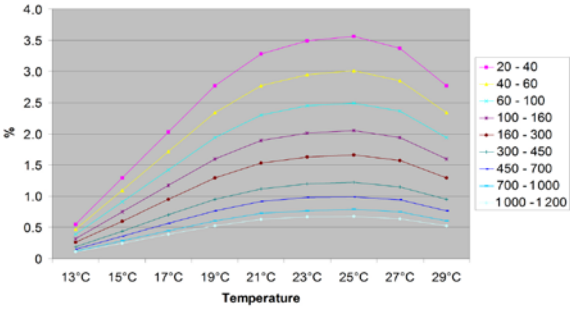
If a centralized feed system is not used, then a dedicated feed boat (or boats) should be considered. The size, number and characteristics of the feed boats depend on the farm size, production and feeding strategies. The loading capacity of the feed boats must be determined according to the peak needs of feed to be distributed.

Logistics (jetty, pier, harbour) must also be considered for feed loading. Easy boat-loading facilities will simplify this operation and reduce the time and costs of the whole feeding activity.

Feed requirements and feed conversion efficiencies vary with changing environmental conditions (oxygen, temperature, water quality, current speed, light intensity, day length). Feed utilization also varies with diet quality and physiological factors of the fish, such as age/size, life stage, stress level and endogenous biorhythms. All of these factors contribute towards uncertainty regarding the precise amount and correct timing of feeding. This might lead to underfeeding or overfeeding of stock, and can result in poor economic performance of the farming operation.

To determinate the daily feed rate (Figure 52), expressed as a percentage of body weight per day, the main parameters to be considered are:

FIGURE 52
Daily feed rate for gilthead seabream (*Sparus aurata*)
(% live weight/day - 35 MJ digestible energy)



Note: The amount of distributed feed (% of live weight) changes according to size classes (expressed in grams on the right-hand side) and water temperature.

Source: Biomar feeding tables (adapted).

- fish size;
- water temperature;
- feed composition (nutritional requirement).

Feeding tables (see Table 35) are usually available from the feed manufacturer for each commercial feed type and species. These tables should be used as a reference to estimate the actual daily feed rate. However, other factors should be considered and the feeding rate adjusted accordingly. These factors include:

- fish appetite;
- dissolved oxygen levels (current, and presence/absence of fouling on the net);
- diseases;
- sea condition;
- stressing events (handling, harvest, etc.).

Each feeding table, applicable to a specific feed and species (example gilthead seabream in the case of Table 35), indicates the suggested amount of feed that should be distributed to the fish stock, along with information on the more appropriate pellet size to use. The values in the table are to be considered as a percentage of the biomass to be fed.

TABLE 35
Example of a daily feeding table as a percentage of live body weight

Fish size (g)		Pellet size (mm)	Temperature (°C)								
			13	15	17	19	21	23	25	27	29
20	40	3.0	0.55	1.29	2.03	2.77	3.28	3.49	3.56	3.37	2.77
40	60	3.0	0.47	1.09	1.72	2.34	2.77	2.95	3.01	2.85	2.34
60	100	4.5	0.39	0.91	1.42	1.94	2.30	2.45	2.49	2.36	1.94
100	160	4.5	0.32	0.75	1.17	1.60	1.89	2.01	2.05	1.94	1.60
160	300	4.5	0.26	0.60	0.95	1.29	1.53	1.63	1.66	1.57	1.29
300	450	6.5	0.19	0.44	0.70	0.95	1.12	1.20	1.22	1.15	0.95
450	700	6.5	0.15	0.36	0.57	0.77	0.92	0.98	0.99	0.94	0.77
700	1 000	9.0	0.12	0.29	0.45	0.61	0.73	0.77	0.79	0.75	0.61
1 000	1 200	9.0	0.11	0.25	0.39	0.53	0.63	0.67	0.68	0.64	0.53

Source: Biomar feeding tables (adapted).

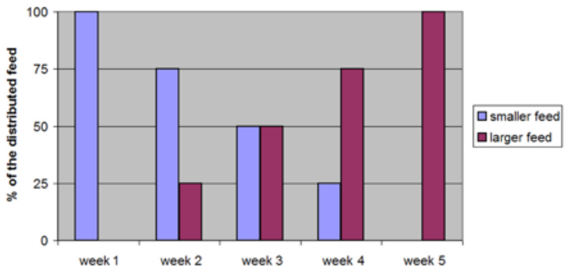
Example:
Parameters: batch of 100 000 fish, ABW = 150 g (15 000 kg of biomass), water temperature 23 °C.
Suggested daily feed quantity = 15 000 × 2.01% = 301.5 kg; pellet size: 4.5 mm.

Larger fish should be fed larger pellets, which will help ensure the best possible FCR. As the fish grow and require larger pellets, the substitution to larger feed should be done smoothly, over a period of about one month. Both the small and the large pellet sizes should be provided during this period, with the amount of smaller feed decreasing, and the amount of the larger pellet size gradually increasing (Figure 53). This will allow the fish to adapt to the new feed size. The smaller fish in the cohort will have some additional time to increase their size so that they can then ingest the larger pellets. When feeding, larger pellets should be distributed first, followed by the smaller pellets.

A datasheet should be used to track the feeding for each cage. This datasheet should include:

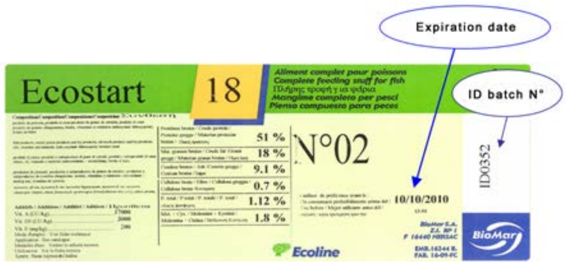
- Feed rate, expressed in kilograms and/or in number of bags.
- Feed type, including brand/name and pellet size.
- Actual distributed feed should be recorded, including the fish appetite and behaviour.
- The feed ID batch number (Figure 54) must also be recorded to ensure traceability of the product throughout the entire cycle.

FIGURE 53
Feed pellet-size change-over



Note: The amount of the larger feed is increased gradually, while the smaller feed is decreased accordingly.

FIGURE 54
Feed bag label



Note: Nutritional information, composition, expiration date and feed ID batch must be reported by the manufacturer and easily understandable.

FEEDING SYSTEMS

The development of efficient equipment and feeding routines and techniques is a priority to enhance technical and financial success, especially because feed accounts for such a large percentage of the operating budget. In larger cage systems, the choice of feeding strategies and feeding systems is one of the main operational issues. Investments in proven and effective feeding systems should, therefore, be quickly recovered.

Efficient feeding can also reduce environmental impacts. When a cage farm is in a relatively exposed site, the safe and reliable operation of feeding systems becomes particularly important.

Critical factors to be considered for the kind of feeding system used on a farm are:

- labour costs, ease of operation;
- species being farmed;
- scale and type of farm operation;
- scale of holding facilities;
- type and quantity of feed;
- farm feeding strategies;
- exposure, reliability;
- effectiveness of food distribution into the holding system;
- amount of feed that can be delivered in a single feeding event.

The most common options for feed distribution are hand feeding, feed cannons, automatic feeders and centralized automatic feeders (see Plates 103–110). Each of these is treated separately in the following sections.

Farm staff should pay attention to several different aspects:

- Currents: feed should be distributed from the up-current side of the cage.
- Wind: can blow the feed out of the cage.
- Fish appetite: should be closely monitored, and feed distribution rate should be adjusted accordingly.
- Induced currents: while feeding, fish can often produce a circular current.

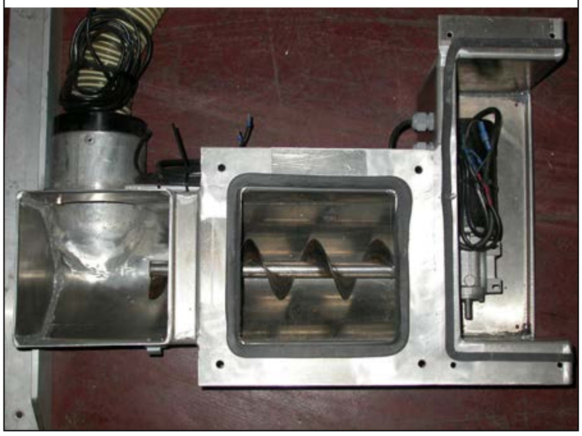
PLATE 103
A barge with a crane is used for handling of feed pallets

COURTESY OF: F. CARDIA

PLATE 104
Feed cannon with integrated air blower, powered by a petrol engine

PLATE 105
Feed cannon with integrated air blower, powered by a petrol engine. In this case, the feed is transported to the blower through an electrically-powered auger (see Plate 106)

PLATE 106
The auger is installed below the hopper, where it moves the feed into the air duct (on the left)



- Type of distributed feed: a large amount of bags in the boat can lead to confusion and mistakes by workers.

Hand feeding

The principal advantage of hand feeding is that farmers can closely monitor the appetite of their fish and, consequently, can adjust the amount of food provided. Hand feeding also increases the farm workers' attention to fish behaviour, which can signal possible disease outbreaks or other problems at an earlier stage.

Hand feeding is labour-intensive and time-consuming. Therefore, it may be very difficult on large farms, or expensive in terms of labour costs.

Hand feeding is to be preferred when juveniles are first introduced into the cage to ensure a better monitoring of feeding behaviour and a better distribution of feed at this critical early stage. Moreover, small size pellets can be easily damaged in automatic feeding equipment.

Results from hand feeding depend upon staff reliability and diligence.

Hand feeding may be difficult in large cages and the advantages of hand feeding are minimized in case of bad visibility.

Feed cannons

Feed cannons reduce the manual work involved with hand feeding. This can be considered a semi-automatic feeding system; the feed is often delivered by hand into the feed cannon, while the distribution is mechanized.

The simplest systems consist of a small feed hopper (50 litres) fitted with an air blower (Plates 104–106) or water pump (Plates 107 and 108) powered by a diesel,

PLATE 107
Feed cannon connected to the water pump of the boat. The water pump is operated by the boat's hydraulic system

COURTESY OF: F. CARDIA

PLATE 108
Feed cannon with integrated water pump, powered by a petrol engine

COURTESY OF: F. CARDIA

PLATE 109
Boat with a semi-automatic cannon feeder. In this case, the cannon is provided with a large hopper for bulk feed storage. The amount of feed to be distributed to each cage is controlled by the boat captain, using electronic controls on the bridge

COURTESY OF: F. CARDIA

gasoline or hydraulic motor that distributes the feed. Depending on the size of the motor, the feed spread can extend up to 30 m.

Feed distribution capacity usually varies between 25 and 150 kg/minute.

Mobile cannon feeders are available in a wide range of sizes. Most of them can be operated by a single person.

Feed cannons have similar issues as hand feeding (currents, wind, fish appetite, etc.). Machine maintenance and fuel supply are additional aspects that must be taken into consideration. Feed cannons can also be installed in purposely-built feeding boats (Plate 109) usually constructed in fibreglass or HDPE. The size of the feed delivery vessel depends on the amount of feed (usually in the form of dry pellets) that has to be delivered.

Automatic feeders

Automatic feeders are fully automated systems that deliver a set dose of feed to a specific cage at designated times. They generally have three main components:

- feed hopper,
- a distributing and dosing device,
- a timing device.

There is a wide range of brands and models available. They come in different sizes and capacities, and have various means of dosing and distribution mechanisms. Plate 111 shows an example of a floating automatic feeder.

Electrical or battery-operated automatic feeders are controlled by timers that regulate the duration of feeding and the time interval between feedings. A single control unit can be used for an individual feeder, or a central control system can operate multiple feeders.

This kind of equipment is usually not suitable for installation in very exposed offshore sites as the usually light equipment items are not designed to withstand rough seas.

Centralized feeding systems

A centralized feeding system serves many cages at once from a single location where food is stored and delivered. These systems have an economy of scale, and as the average sizes of aquaculture units has grown, so the pressure for efficiency has increased and subsequently the feeding systems have developed greater capacity. These systems also afford the farmer greater control and improved monitoring.

An automatic feeding system generally consists of: bulk feed storage modules (silos or floating barge) (see Plate 110), blower unit, rotary valves, feed distribution system and feeder control system (Plates 111–114).

Feed is stored in one or more central silos, and from there it is moved into a dosing unit through an auger (see Plate 106), and then transferred to an injector unit. From there, it is blown through the main feed transport pipe and then through a distribution valve and individual feed pipes to its destination cages (see Plates 112 and 113).

Centralized feeding systems greatly reduce the amount of labour required for feeding (which is traditionally very labour-intensive), but they also have a high capital cost and may not be suitable for sites that are widely spread out or far offshore.

Platform-based systems with large floating silos are increasingly being used for offshore cage sites (Plate 114).

PLATE 110
Logistics on land: silos for bulk feed storage are located on the edge of the dock, to permit easy loading of the feed boat

COURTESY OF: F. CARDIA

PLATE 111
Automatic feeders

COURTESY OF: A. CIATTAGLIA

PLATE 112
Detail of a centralized feed system. Visible are two feed distribution units from which several HDPE pipes convey the feed to the cages

COURTESY OF: AKVA GROUP ASA

PLATE 113
Feed delivery pipes connecting the centralized feed system with the cages

COURTESY OF: AKVA GROUP ASA

Centralized feeding systems consist of the following components:

- Feed silos store the feed and are available in various capacities. They must be corrosion-resistant. Operator safety and ease of feed transfer are key elements to be considered.
- Air blowers move the feed through the lines and may be electric, diesel or hydraulic powered.
- Rotary valves measure the feed from the silo while isolating the hopper from the air stream. Speed of rotation is either fixed or variable. A variable speed control regulates the amount of feed that is delivered into the distribution pipe. Ease of access is important as these valves need regular maintenance.
- Distribution systems (or manifolds) provide several feed outlets from a single inlet. This makes it possible to feed several cages or to use multiple feed outlets in one larger cage.
- Feed delivery pipes: Accurate positioning of the feed delivery pipes minimizes feed pellet damage. Delivery pipes are mostly made of HDPE. High temperatures (> 50 °C) considerably reduce the strength and abrasion resistance of the pipe.
- Feeder control systems are operated by computer and continuously monitor the status of the system.

These systems are all computer-controlled. Their value is greatly enhanced with feedback controller systems or appetite monitoring systems that monitor the actual feed intake of the fish.

There are several type of appetite monitoring systems, including video cameras and pellet counters.

Underwater video cameras can be installed inside each cage. The video signal is transmitted to a monitor control unit (a screen), and personnel in charge of monitoring the feeding operations can check whether feed wastage is occurring, and can reduce the feed rate accordingly. This system relies on operator diligence and on water clarity.

PLATE 114
Centralized feed system on a purposely built barge

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9. Fish stock management

Recommendations on fish management issues such as nutritional needs, disease management, and handling, are similar, regardless of the culture system used (cages, ponds, tanks, etc.). For this reason, information that may not be strictly related to cage aquaculture is provided in this chapter.

BIOMASS MONITORING AND ASSESSMENT

The biological parameters analysed to evaluate the growth of fish are the same, regardless of the technology used. Fish reared in inland ponds or in offshore cages may be assessed using the same methods (for evaluating growth) and parameters (for growing conditions). Some of the most useful indices for analysis are described below, including FCR, SGR and condition index (CI).

Feed conversion ratio (FCR) is the ratio between the weight of feed fed to the fish and the weight gain of the fish. It is a measurement of how efficiently a fish converts feed into body mass (i.e. weight gain). For example, an FCR of 2.8 means that 2.8 kg of feed is required to produce 1 kg of live fish weight.

$$FCR = \frac{\Sigma \mathrm{Feed}}{W_1 - W_0}$$

where:

- Σ Feed is the quantity of feed distributed during a set time interval $t_0 - t_1$;
- W_0 is the fish biomass at t_0 (start period);
- W_1 is the fish biomass at t_1 (end period).

Specific growth rate (SGR) is a measure of how quickly the fish grows over a certain time interval. Fish growth, measured as weight gain, rarely follows a linear pattern and, therefore, the natural log (ln) is used to transform the data.

$$SGR = 100 \; \frac{\ln W_1 - \ln W_0}{t_1 - t_0}$$

where:

- $t_1 - t_0$ is the time period (number of days);
- W_0 is the biomass at t_0;
- W_1 is the biomass at t_1.

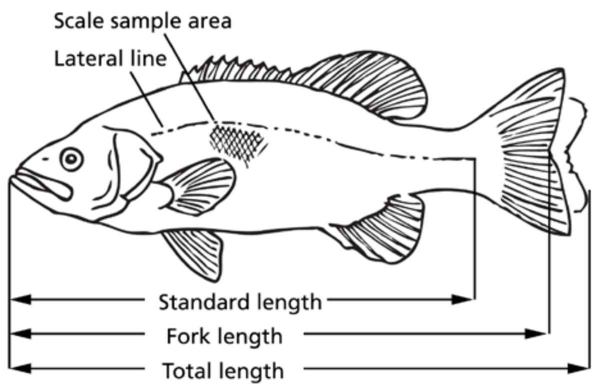
Condition factor (K) or **condition index (CI)** is a metric to determine how heavy a fish is for its length. Fish gain weight faster than they gain length, essentially becoming "fatter" as they get longer. The condition factor provides a way to compare the relative health of groups of fish. Different species will have a different exponent, but most have one of about three.

$$K = \frac{W}{SL^3}$$

where:

- W is the weight of fish;
- SL is the standard length of the fish.

FIGURE 55
Main fish length measurements



Source: FAO Glossary of Aquaculture.

Standard length is measured from the tip of the mouth of the fish to the base of the tail, and does not include the caudal fin, which can be variable in length. Figure 55 provides the most frequently-used fish measurements. Consistency in the method of measurements is important in order to compare the results between cohorts and over time, so all staff should be trained on exact methods of measurement.

Tracking cages and cohorts

Traceability can only be assured on a cage farm if the information recorded is organized according to cohorts and not by cages. Cage numbering should refer to each cage's position in the mooring grid, while cohorts of fish may be moved from one cage to another during the production cycle.

A unique batch ID code must be assigned to each new cohort of fish that is introduced into the cage farm. This code will be used for recording all pertinent information to ensure traceability. Table 36 provides an example of batch coding. A two letter species code is assigned to each reared species and then each batch number will contain the species code (two letters), the year of stocking (two numbers) and a following number for each batch of that species. The example below refers to the batch SB1105, which is the fifth batch of sea bream stocked in the farm on 2011.

TABLE 36
Example of fish cohort numbering

Batch No.	Species code	Year of stocking	Progressive No.
	SB	11	05

Fish stock report

For stock management, a stock report will provide the basic control tool of the different fish batches. The report should include all of the most relevant biological parameters and batch information that could prove useful for a quick evaluation of the status of each batch.

Each report refers to a specific period, either a week (preferred) or a month, and the information refers to each batch.

A comprehensive stock report would include the type of information shown in Table 37.

The report can also include information on any fish samples taken during the report period. Information for each sampling should include: batch number, date, number of sampled fish, expected average weight, actual observed calculated weight, coefficient of variation (if sampled individually).

TABLE 37
List of information to be included in the periodic fish stock report for management control for each fish batch

Ref.	Information	Description
1	Period	Time period of reference of the report: starting (T1) and ending (T2) date
General		
2	Batch number (no.)	As described in Table 35
3	Cage	Position of the batch, i.e., cage number where the batch is stocked
a	Opening number (no.)	Number of fish at T1 (data from previous report)
b	Mortality (no.)	Number of dead fish
c	Sample and transfers (no.)	Number of “sample” fish analysed, or moved from one cage to another
d	Closing number (no.)	Number of fish at T2 (a - b - c - v)
e	Average weight (kg)	Average weight at T2
f	Biomass opening (kg)	Biomass at T1 (data from previous report)
g	Biomass closing (kg)	Biomass at T2 (e × d)
h	Fish growth (%)	(g – f) / f × 100
i	Last sample (date)	Last date of sampling
Feeding		
j	Feed provided (kg)	Feed distributed over the period T1–T2
k	Daily feeding (%)	Average feed rate for the period (j/n) / ([f + g]/2) × 100
m	Total cumulative feed (kg)	Total amount of feed provided from the stocking date (m from previous period + j)
n	Days of feeding (no.)	Number of feeding days over the period
Mortality		
o	Mortality (%)	(b / a) × 100
p	Mortality over previous report period (%)	Data from previous report
q	Mortality rate (trend)	Mortality trend comparing current and previous report periods (higher, lower, stable)
r	Cumulative mortality (no.)	Cumulative number of dead fish recorded from the stocking date (p + b)
s	Cumulative mortality (%)	(r / C) × 100
t	Cumulative mortality as biomass (kg)	Biomass of mortality (b × e), added to the previous t (cumulative mortality as biomass [kg])
Harvesting		
v	Harvest over the report period (no.)	Number of fish harvested during the report period
w	Harvest over the report period (kg)	Harvested biomass during the report period
x	Cumulative harvest (no.)	Total number of harvested fish from stocking date to T2
y	Cumulated harvest (kg)	Total biomass harvested from stocking date to T2
Origin		
z	Stocking date (date)	
A	Number of days in grow-out (no.)	Number of days from stocking date to present (z–T2)
B	Hatchery	Hatchery that provided the fish
C	Starting number (no.)	Number of fish received from the hatchery
D	Starting biomass (kg)	(C × E)
E	Starting average weight (kg)	Average weight at stocking
FCR and SGR		
F	Cumulative SGR	SGR calculated from stocking date (z) to T2 (*ln* [g + y + t] - *ln* [D]) / A × 100
G	SGR over the report period	SGR calculated from T1 to T2 (*ln* (g + w) - *ln* [f]) / (number of days over the period) × 100
H	Cumulative FCR, economic	FCR calculated from stocking to T2 (m / [g + y – D])
I	Cumulative FCR, biological	Similar to economic FCR, but also considering cumulative mortality rate (m / [g + y + t – D])
J	FCR of the period	FCR calculated from T1 to T2 (j / [g – f])
Density		
K	Kilograms per cubic metre	Density expressed in kilograms per cubic metre (g / cage volume)
L	Kilograms per square metre	Density expressed as kilograms per square metre (g / cage surface area)
Other		
M	Handling	Notes on external events affecting the fish (e.g. taking of samples, positioning equipment, harvesting)
N	Pathologies	Notes on possible diseases and treatments during the report period

PLATE 115
Fish are caught with a seine net

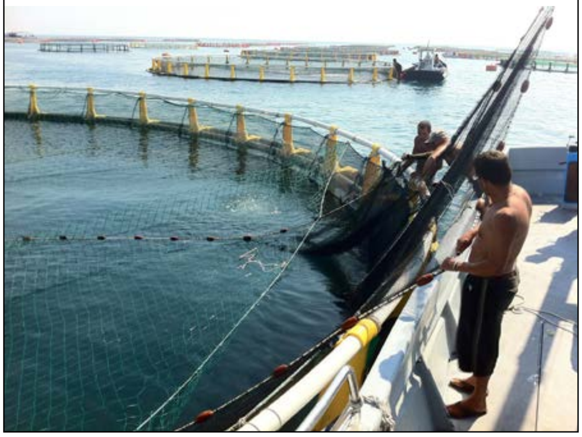


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PLATE 116
Fish are collected with a hand scoop net

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PLATE 117
Small fish holding tank on-board of a service vessel with an inner net lining

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Fish sampling

It is strongly recommended that farmers periodically sample each fish cohort to check the growth rate and make observations on fish health. When taking a sample of fish, several different approaches may be taken, such as:

1. Live sampling at cage-side. Catch the fish, make the observations on board the farm boat, and then release the fish back into the cage (see Plates 115–120). This is the most time-efficient method, but the boat must be equipped with a hanging scale, a tank (possibly including an aeration system), small containers to weigh the fish, a fishing net and a hand-scoop net.

   The procedure is as follows:
   - Boat is moored onto the side of the cage.
   - A larger group of fish (up to one tonne) are caught with the seine net (Plate 115). A diver can help trap the fish, ensuring that the sampled fish are representative of the entire cage population (including the smaller or weaker fish that are often found towards the bottom of the cage).
   - A small number of fish (about 200–300 individuals) are carried to the tank on board with the hand-scoop net (Plates 116 and 117). If the fish are overly sensitive to being handled, a dose of anaesthetic can be added into the tank. The tank can be provided with an internal net that can be lifted to collect fish quickly when a few fish are left in the tank at the end of the operation.
   - Fish are weighed and released back into the cage (Plates 118–120). This operation can be done on single fish or groups of fish. The latter option is quicker, but does not provide information on size variation. This information may become relevant if the batch is soon to be harvested and sold, and information on size variation is required.
2. Live sampling on shore. The general method is to catch the fish, transfer the fish to a land-based facility, conduct the measurements on land, and then return the fish to the cage. This alternative method is advisable if the sea state is rough, which can cause the scales to give inaccurate readings. The procedure is very similar to the methods described above, except that in this case, two tanks will be needed, both of which must be equipped with

an aeration system. On the jetty, the scale should be positioned near the boat. The fish are then moved from one tank to the other after each weighing on land.

3. Terminal sampling. A sample of fish is collected, killed, and then taken to the land-based unit for measurements on land. This option is preferable if a closer inspection of the fish is desirable. In this case, the length and weight of each fish can be measured accurately. Moreover, a pathology inspection can be conducted on-site or at a specialized laboratory.

Fish can be sampled as described above, and then killed by thermoshocking them in a tank filled with seawater and ice slurry (see Chapter 10). If analysis of the fish is to include monitoring parasites, some sample specimens should be killed with a percussive stunning, using an appropriate tool such as a heavy wooden handle or a metallic wand to deliver a concussive blow to the head in the area just above the eyes (the area adjacent to the brain). Percussive stunning is necessary because ectoparasites may detach from the host in the water-ice slurry. Always keep the fish refrigerated after stunning.

PLATE 118
Fish are counted and sampled in small groups

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Note: A number of chemicals are available as fish anaesthetic drugs, such as 2-phenossietyhanol, clove oil, and MS-222. Concentration levels and exposure of the fish to the drug vary depending on the species, the water temperature and the level of sedation required; furthermore, the chemicals may be approved or not by local regulations, therefore only approved drugs should be taken into consideration. Be sure that the tank is drained, washed and refilled with clean seawater after sampling from each cage, to prevent contamination of parasite samples.

PLATE 119
The weight is measured for each group of fish

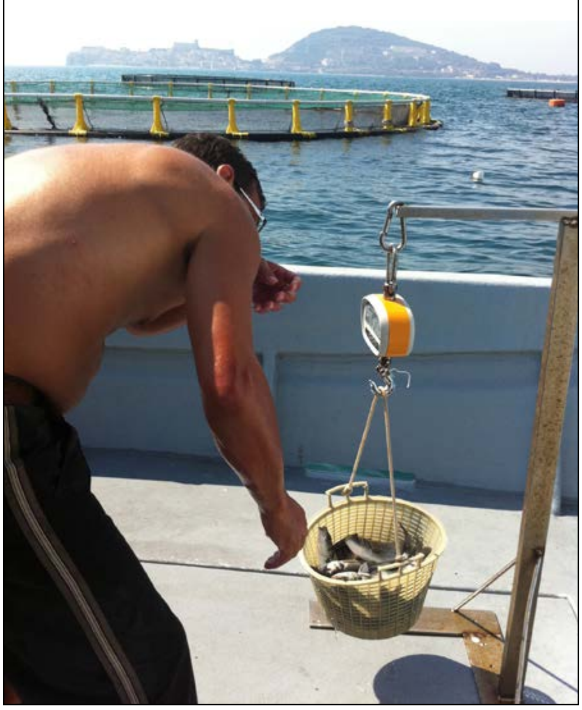

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PLATE 120
Detail of a hanging scale and its portable frame

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10. Harvesting and packaging

The production cycle ends with fish harvesting once the fish have reached the desired market size and can be sold.

The regular availability and steady supply of good-quality fish is one of the main factors that distinguish aquaculture from wild-stock fisheries. This is an advantage from a commercial point of view, but at the same time it also means specific responsibilities for producers. Producers may even lock in contractual commitments with their customers as to the product's supply on prearranged days and in precise quantities.

Some harvesting techniques are described in detail below. The decision on which technique depends on the operator's experience, as well as on other factors such as the type of cages, sea conditions and weather conditions at the time of harvesting, the quantity of fish to be harvested, the target species, and the fish density inside the cage. Harvesting is a key operation that requires the use of trained and skilled surface operators and divers. The quantities of fish to be harvested from each cage must be planned ahead of time. A technical briefing is useful for coordinating the harvesting crew.

The common problems that may be encountered during harvesting operations include harvesting the wrong number of fish, damaging the fish and failing to chill the harvested fish properly. These problems are critical, and every care should be exercised to avoid them:

Harvesting too few fish
If the first attempt does not provide sufficient fish to meet the harvest orders, then further attempts must be made. Repeated harvest net sweeps can be difficult as, in some cases, the fishing net may need to be prepared on land, there may be insufficient scuba bottles, or the divers can be approaching their maximum allowable bottom-times. Moreover, repeated harvest net sweeps can stress the fish inside the cage, with consequent risks of disease or lack of appetite.

Harvesting too many fish
If more than the planned quantity of fish is caught, there may be insufficient bins and ice, and, consequently, the cold chain might not be maintained.

Alternatively, the release of excess fish once they have been caught in the harvest seine net may result in stress, scarring or mortalities.

Damage to harvested fish or to the fish remaining in the cage
This may result in an economic loss owing to the decreased value of the harvested fish or increased mortality in the cage stock.

Cold chain interruption during harvesting or in packing and processing
This can lead to unsellable product because food safety and quality require that the fish be quickly chilled and then remain cold throughout the processing stages.

PRE-HARVEST PREPARATION

Sampling the fish

If a cage is going to be harvested for the first time, it is a good practice to sample the fish a few days before the harvest to check the mean weight and size distribution. Sampling will verify that the sampled weight corresponds to the expected weight. This will avoid harvesting a batch of fish that have not yet reached the required market size.

Starving the fish

It is important to starve the fish before harvesting to keep the process as clean and stress-free as possible. Starving the fish will serve the following purposes:

- Prevent partly digested feed from being regurgitated into the transport bins, or faecal matter being released, which can foul the ice or brine slurry.
- Remove residual feed from the intestine, which increases shelf-life because undigested feed will decompose.
- Reduce the overall stress of the stocked fish: it is a good practice to starve the fish prior to any handling (harvesting, transfers, net changing, etc.) as it has been noted that it increases the resistance of the fish to these stressful events.

If fish have been fed with medicated feed, make sure that the proper withdrawal period has passed before they are harvested.

Preparing the equipment

Organize all the necessary equipment in advance, including nets, bins, divers' gear and scuba air cylinders. Verify quantities of ice to be sure that a proper amount will be transported to the cage site (see section below on processing and packaging).

If a cage is going to be harvested for the first time, it will be densely stocked and harvest operations must be carried out carefully. Farm staff must avoid catching an excessive number of fish (see above considerations). It is recommended that a diver inspect the stock inside the cage a couple of hours after harvesting in order to verify that the remaining fish have not suffered from the harvesting operation.

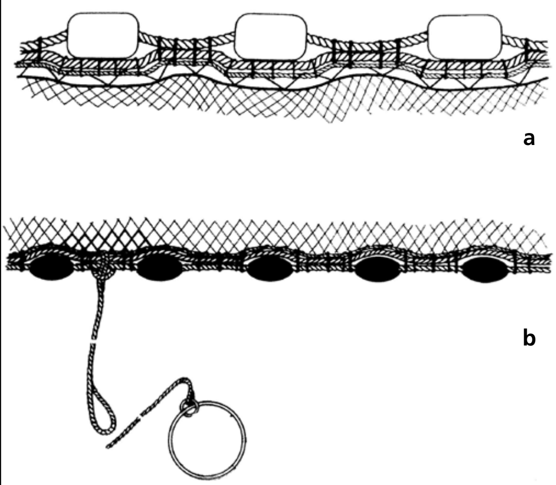
HARVESTING METHODS

Purse seine

The purse seine technique is appropriate for harvesting large quantities of fish or when the cage needs to be completely harvested. It uses a large fishing net, whose length is at least as long as the cage's perimeter, to encircle all the fish present inside the cage.

A standard purse seine net is rectangular in shape, made with light netting (e.g. nylon 210/24) to simplify handling, with a mesh size proportionate to the size of the fish.

FIGURE 56
Construction details of floating line and sinker line of a seine net



Note: Construction details of floating line (head-rope) (a) and sinker line (footrope) (b) of a seine net. Note that the netting is securely sewn onto the floating and sinker lines, so that there are no open spaces.

The seine net has floats on the upper line (head-rope) (Figure 56a), while the lower line (footrope) has a lead line sewn in (Figure 56b) to ensure correct orientation in the water column.

The seine net's dimensions should be:

Height = cage wall height + one-sixth of cage diameter
Length = cage circumference

Floating and sinker dimensioning will depend on cage dimension and biomass to be harvested – the larger the cage and the biomass to be harvested, the greater the buoyancy and sinking of the fishing net will be necessary.

Along the length of the footrope, pursing rings are attached, through which runs a purse line, which extends up to the workers on the surface. When this purse line is pulled taut, the lower part of the net will close ("purse") and the entire fishing net will became a closed bag with a sealed bottom.

In preparation for the harvest, the seine net is gathered up so that the head-rope lies close, and parallel, to the footrope. The head-rope is then secured with short "bundling" lines tied with "quick-release" knots (Figure 57).

The net is bunched in this way so that it can be set inside the cage, around the perimeter, until the two opposite ends of the net are close to each other; usually, the ends should meet near where the boat is moored (Figure 58a). When ready, the "bundling" lines are quickly released so that the net lead-line drops quickly to the bottom (Figure 58b).

Divers check to ensure that the net is properly set and that it is not tangled or twisted. The two vertical opposite ends of the net are then joined together with plastic cable ties ("zip" ties).

The next phase consists of closing the seine net lead-line by pulling on the pursing line so that a closed "purse" is obtained, separate from the farm net (Figure 58c).The divers' task at this time is to ensure that the lead-line does not lift off the cage net floor until the final closing of the purse, so that the fish cannot escape from the bottom.

Once the fish are "pursed" and before hauling the net, it is important that the divers perform a visual estimate of the number of fish in order to avoid excessive harvesting. Excess quantities of fish can be released by the divers back into the net cage through the bottom before the purse is completely closed.

FIGURE 57
Purse seine net prepared for harvesting (a) and once set in the water (b)

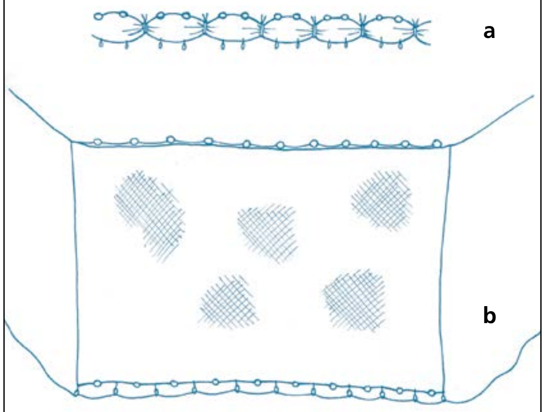
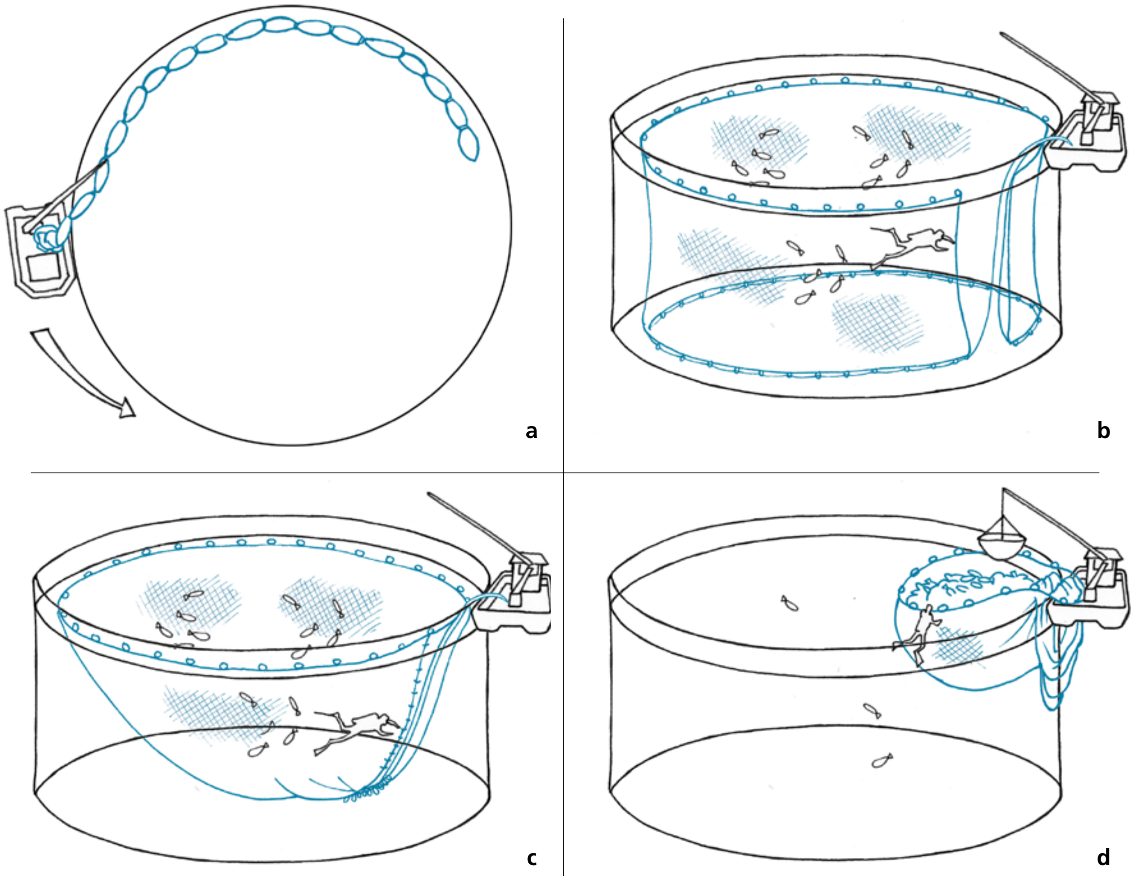


FIGURE 58
Purse seine harvesting system



Once the purse has been completely closed, the net is hauled in by workers with the aid of the crane, if needed (Figure 58d).

As the net is hauled in, and the seam is out of the water, the plastic cable ties which hold the two vertical ends together are cut, and the net is opened and laid along the handrail.

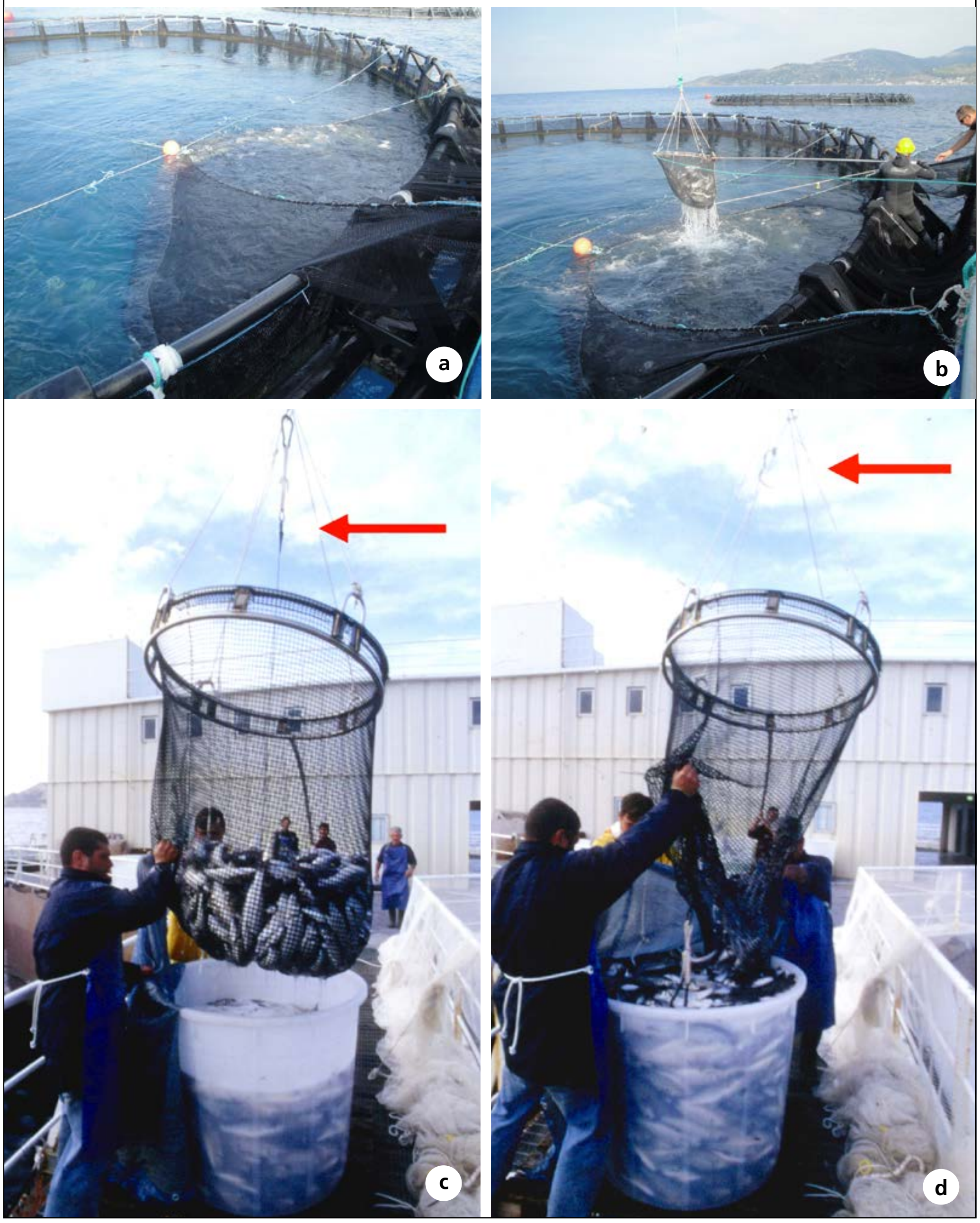
Care must be taken to avoid trapping and damaging fish in any of the netting folds.

As the net is hauled in, the volume inside the seine net decreases, until the fish start to appear on the surface. At this time, it is still possible to release excess fish by simply submerging the float line.

Once the required quantity of fish has been secured, and the net is fastened on the handrail, fish are harvested with a special scoop net (also known as a “brailing net” or “landing net”) (Plate 121). This scoop net is manoeuvred using the boat’s crane, and

PLATE 121

Scooping fish from a floating farm cage. a) commercial-sized fish clustered densely in a seine net, b) scooping the fish with the use of an onboard crane, c) scoop net fitted with a quick-release system, and d) harvested fish released into a collection bin



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its base can be opened by triggering a quick-release system that allows the fish to be released into the bins without inverting the scoop net. The frame of the scoop net is made of steel. The base of the scoop is closed by a wire passing through several rings. The wire is fixed onto the top of the scoop bridles (red arrow in Plate 121b), and thence onto an automatic locking system (i.e. a quick-release snap hook). When the wire is released, the scoop net base is opened to release the fish.

Hand seine net

Technique 1

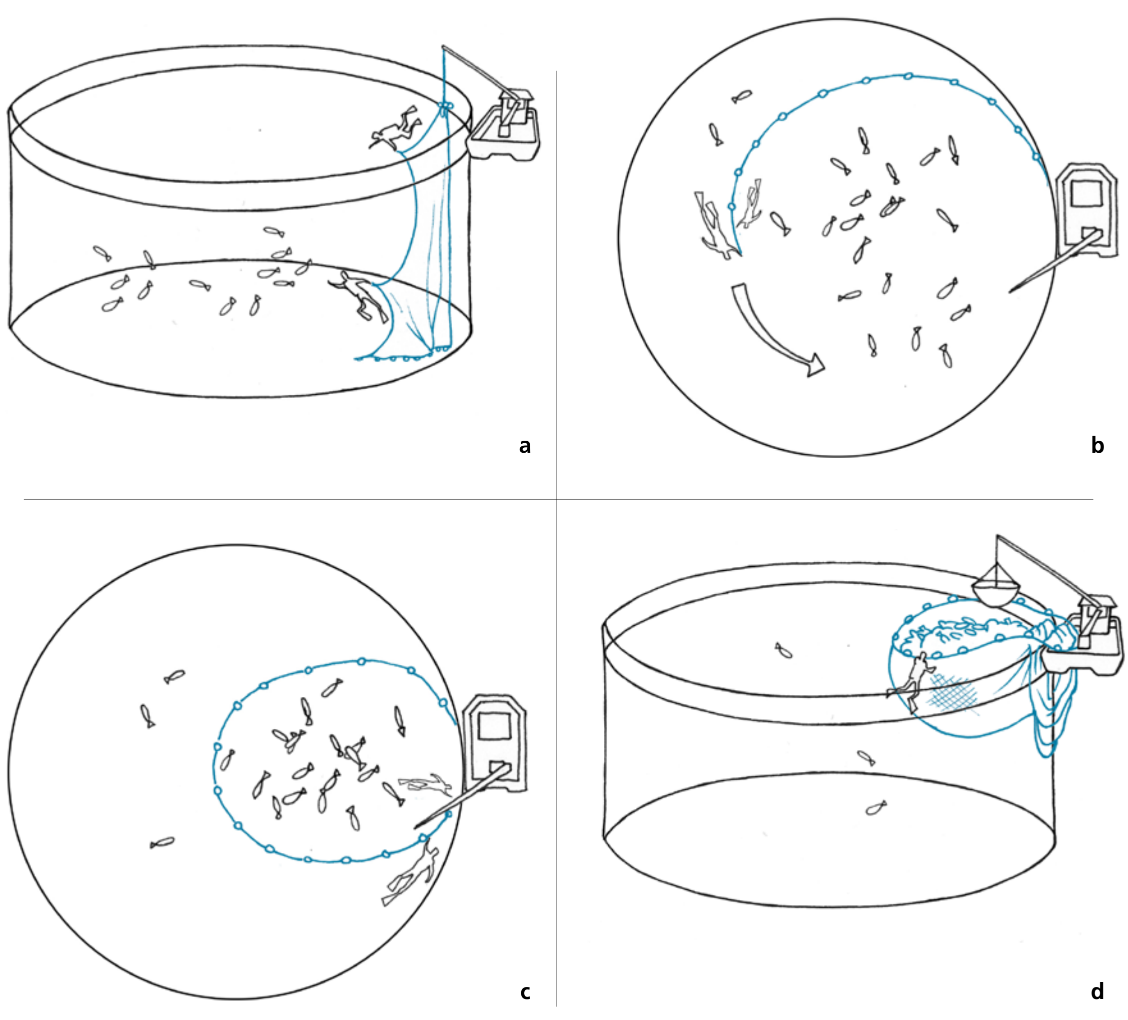
This harvesting technique is similar to that used in the purse seine method just described, but the seine width is smaller (from one-third to one-half of the cage circumference). The smaller net is easier to handle, and it is used in a different way. This system requires fewer workers, and is suitable for use when a limited number of fish are to be harvested or when a cage is densely populated.

The seine net is set vertically inside the cage from the boat, which is moored onto the cage collar (Figure 59a).

The divers fix one end of the net to the cage wall, using plastic cable ties ("zip" ties).

The free end of the seine is pulled by divers along the cage's perimeter (Figure 59b) until the circle is closed with the opposite side of the seine (Figure 59c).

FIGURE 59
Hand seine – fish harvesting technique 1



The two sides of the seine may then be secured with some plastic cable ties, while the ties previously fixed to the wall are cut free, releasing the seine net.

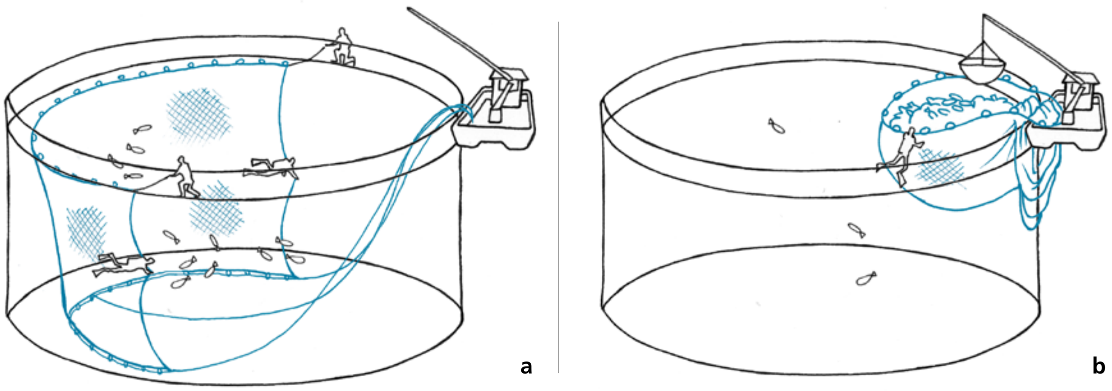
From this position, operations proceed as described above for the purse seine (Figure 59d).

Technique 2

The seine net is lowered into the water on the opposite side of cage from the boat (Figure 60).

The seine net is slowly pulled towards the boat by the operators on the cage and by the divers who drive the seine close to the walls of the cage. Divers also ensure that the lead-line moves forwards together with the rest of the net (Figure 60a). The divers are responsible for estimating the number of fish in the net and for allowing some to escape the harvesting seine, as appropriate.

FIGURE 60
Hand seine – fish harvesting technique 2



The lead-line can be handled from the boat, through ropes connected to the net bottom. The hauling in is completed by the lines handled by the crew on the boat.

The lead-line is lifted, and the purse is closed (Figure 60b). Once the purse is closed, the rest of the harvesting proceeds as described above.

Lift net system

The lift-net harvesting system is simple and effective, and the fishing net used is cheap and of simple construction. The lift net has no floats or sinkers. It is a circular shaped net with a diameter of at least 1.5 times the diameter of the cage. It is reinforced with two perpendicularly crossed ropes and fitted with a series of hooks ("snap hooks" or "carabineers" are best) along its perimeter.

The first part of the operation consists of laying the lift net completely over the base of the cage (Figure 61a).

One or two divers gradually lift the net to the surface (Figure 61b).

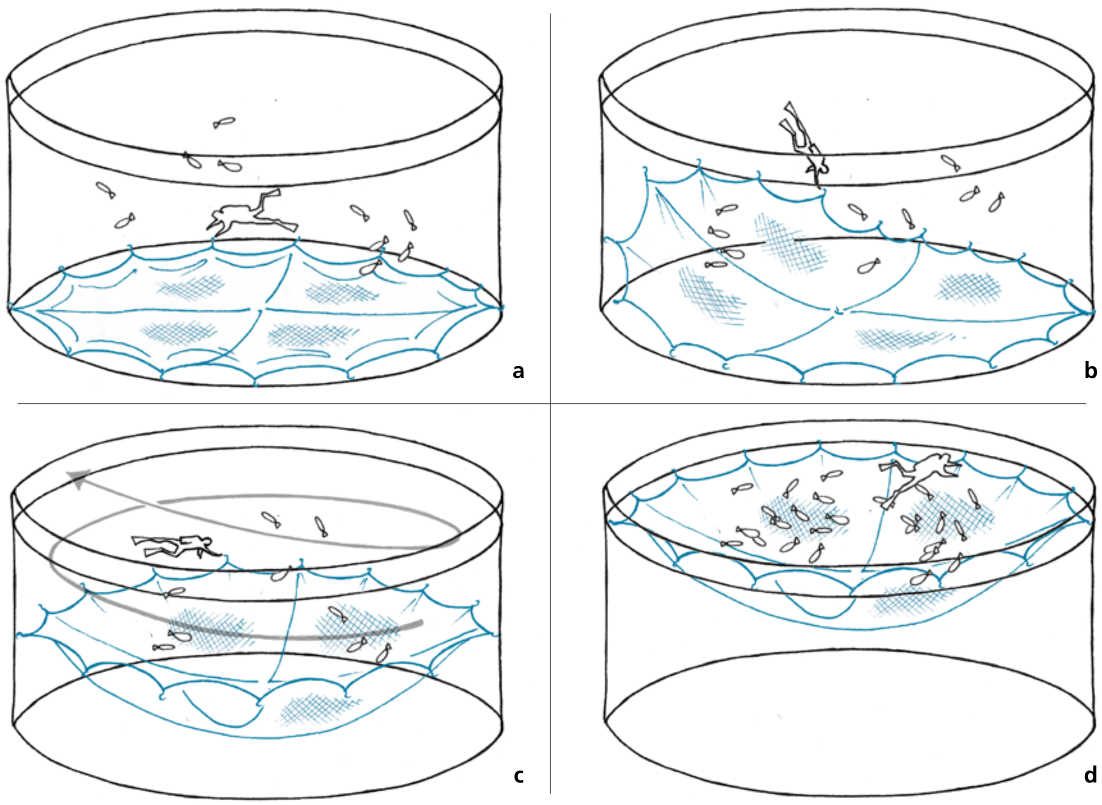
This operation is done gradually, as divers swim from the bottom upwards, following a spiral path (Figure 61c). The hooks are detached and then re-positioned onto the cage wall, progressively higher and higher, so that after a number of rounds, the lift net is close to the surface (Figure 61d).

Once the lift net is completely at the surface, it is hauled by the surface crew so that the lift net is close to the harvest boat. Harvest then proceeds as for the other harvest systems described above.

Small internal harvest cage

This system is a strategy to facilitate later harvesting without affecting the rest of the fish in the cage by containing a subset of the fish in an internal cage. A smaller, rectangular cage is installed inside the larger farm cage (Plate 122 and Figure 62).

FIGURE 61
Lift net system



Note: The lift net, equipped with hooks on its perimeter, is deployed over the floor of the cage pen. Divers then swim from the bottom upwards, following a spiral path (grey arrow), progressively affix the lift net, hook after hook, increasingly higher on the net wall until the entire lift net perimeter has been lifted out of the water.

The advantages of this method are twofold:

- The fish fasting will be confined to the batch inside the small "harvest cage", while the other fish will be fed regularly.
- The reduced volume of the smaller cage will facilitate harvesting operations, which will therefore be quicker and will require the use of fewer personnel and less equipment.

For example, a cage of 19 m diameter, 60 m circumference and 10 m wall height can be equipped with a smaller cage of about 10 × 4 × 10 m height.

The lateral side of the internal harvest cage has a door that can be closed by a zipper. The zipper runs along three edges of the harvest cage so that the whole side can be completely opened (Figure 62a). The method consists of herding the desired quantity of fish into this smaller cage. This quantity should be sufficient for several further harvests to be performed over the following few days.

To fill the harvest cage, the hand seine can be used (Technique 1) as described above. The difference is that the ends of the seine, top and bottom, are attached onto the open side of the harvest cage. The hand seine is manoeuvred so that the end of the harvest cage is open

PLATE 122
Visible in the large farm cage is an internal harvest cage

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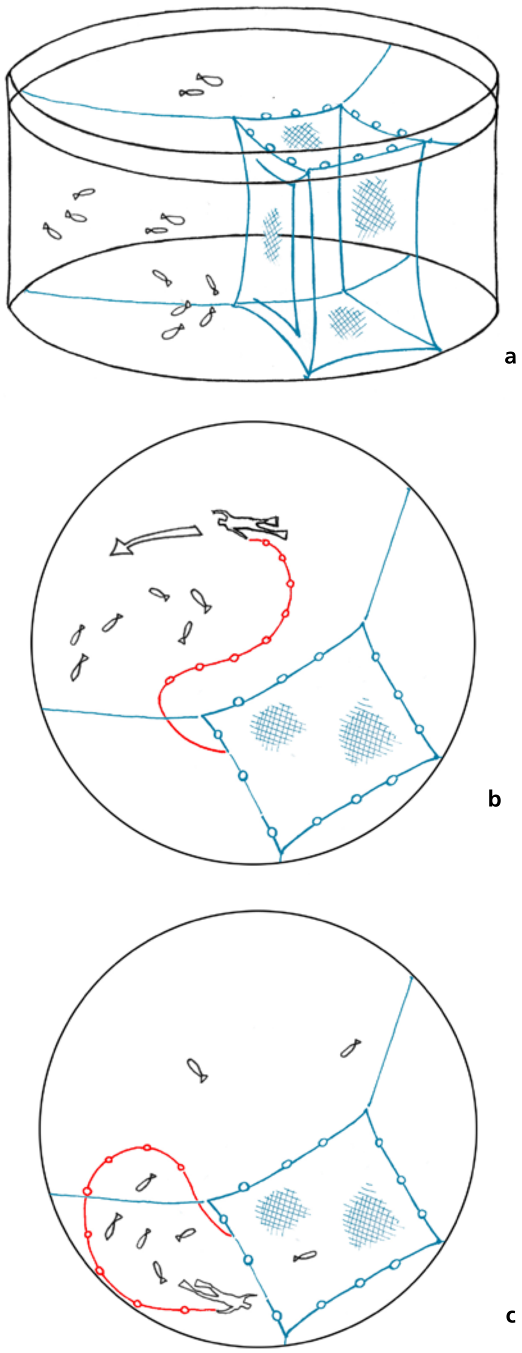
FIGURE 62
Small harvest cage placed inside a larger fish cage



(Figure 62b). The seine wall made by the divers will then push the fish inside the harvest cage. The open wall of the harvest cage can then be closed, concluding the operation (Figure 62c).

Harvesting from the small harvest cage can be performed using either of two methods:

- A rectangular hand seine, similar to that shown above, but of much smaller size.
- The entire harvest cage can be hauled up, if the biomass has been sufficiently reduced by previous harvests.

Whichever technique is applied, when the net is hauled in, a "bag" will be created, with the fish inside ready for harvesting.

Harvest systems can vary widely. Every farm and every harvesting team has its own techniques, based on its experience, the equipment and the facilities available at that site.

For all the above techniques, the divers who handle the seine nets play a critical role. The divers must:

- Understand the movement of the fish inside the cage, and adjust the net accordingly.
- Understand how many fish are enclosed in the harvesting net, and give a signal to the surface operators when the net has to be hauled in.
- During the hauling phase, they have to estimate the fish biomass that is in the harvest net, and determine how many of the excess fish should be set free back into the cage net.

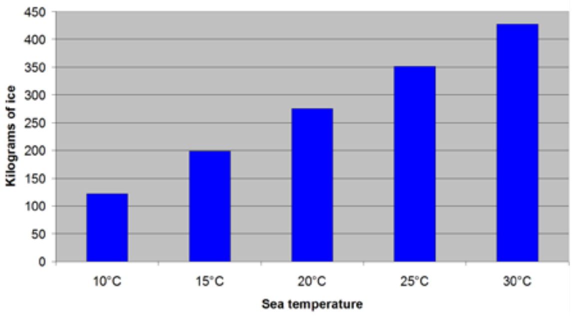
These skills are particularly important to minimize the harvest risks described at the beginning of this section.

PROCESSING AND PACKAGING

Fish harvesting, processing and packaging must be carried out while maintaining the "cold chain" in each phase of the process; ice is essential to this process. "Cold chain" is a temperature-controlled sequence of storage and distribution processes that usually applies to food processing. In the case of fresh seafood, the fish must be maintained at temperatures below 4 °C from the time of harvest until they are shipped.

The cold chain integrity should be validated and managed through a proper Hazard Analysis and Critical Control Points (HACCP) procedure, where all the steps from harvesting to shipment are analysed. This procedure allows the farmer to: (i) assess possible risks to safe storage and/or contaminations; (ii) identify possible critical points of the process and the relative parameters to be controlled; (iii) define acceptable standards for the parameters; and (iv) identify corrective actions to take in case of non-standard parameters posing a threat.

FIGURE 63
Theoretical quantity of ice needed to chill one tonne of harvested fish



Note: Theoretical quantity of ice needed to chill one tonne of harvested fish to 4 °C (ice temperature = –5 °C).

In contrast with other aquaculture systems, cage aquaculture harvesting requires the transport of equipment, ice and fish by vessels. This transport phase can be very lengthy, and it requires the purchase and proper use of the correct equipment, and an awareness of proper fish handling and storage practices.

Ice

An efficient ice machine can provide flaked ice sufficient for harvesting and packaging operations. Ice is used for killing and packaging the fish, as well as to maintain integrity of the cold chain during the process.

Before harvesting the fish, insulated bins should be prepared with a sufficient amount of ice.

Fish can be humanely killed by thermal shock using ice/water slurry. The ice slurry is prepared by adding seawater to the bins with ice. For each tonne of fish, the required amount of ice will be proportional to the seawater's temperature. The higher is the temperature, the greater the amount of ice needed in the bins.

As an example, Figure 63 provides the theoretical amount of ice necessary to cool one tonne of fish to 4 °C, assuming that the temperature of the ice is –5 °C, and that 200 litres of seawater are added to make the ice slurry.

The amount of ice needed for a harvest will depend on the following parameters:

- insulation of the bins;
- the external air and water temperatures;
- exposure of the bins to sunlight;
- the distance of the cage site from the jetty;
- the duration of the whole operation.

Fish must be kept chilled in the bins. The temperature of the fish should be checked regularly, and ice should be added to the bins whenever the temperature exceeds 4 °C. For this reason, spare ice stored in a dedicated bin should be included among the harvesting equipment.

Flake ice machines may be preferable to other ice machines for ice production because flake ice has a larger surface-area-to-volume ratio. This means that the heat exchange will be faster during harvesting and packaging operations. Drinkable freshwater should be used, rather than saltwater, for packaging fish because ice made with the latter has a lower melting temperature that may damage the skin of the fish.

As harvesting operations are carried out on boats (usually equipped with a crane), the risk of chemical contamination of the harvest should be considered and minimized. Possible causes of chemical contamination include oil spillage from the crane or fuel or grease contamination. To avoid these risks:

- The crane must be kept in good working order and all the hydraulic components checked regularly.
- The harvesting team should have dedicated clothes and equipment used only for harvesting.
- Fish that have fallen onto the boat's deck should not be stored in the fish bins, but placed into a separate bin and examined later, upon docking, for any possible contamination.
- Contact between the crane's hook, cage and wire with the fish or bins should be avoided.
- Any kind of vessel maintenance operation while harvesting should be avoided.

11. Safety notes

Aquaculture-related worker safety, especially for sea cages, requires a separate manual. Even so, a few relevant points that should be considered are briefly discussed in this chapter.

"SAFETY FIRST" are the two words, painted in capital letters, on the bridge that dominates many commercial vessel decks. A safe working environment is a **MUST** when people are working on the cages or boats in aquaculture (Plate 123). Risks for employees are increased on workboats at sea because of the use of tools and equipment in uncomfortable conditions, such as waves, wind and rain exposure. These environmental conditions make the work harder and increase stress and fatigue.

Specific regulations usually apply to work on the water. If no specific regulations for safety on cages are applicable, then comparable regulations on safety related to specific tasks (professional diving, working vessels, lifting equipment, etc.) may apply in cage culture operations.

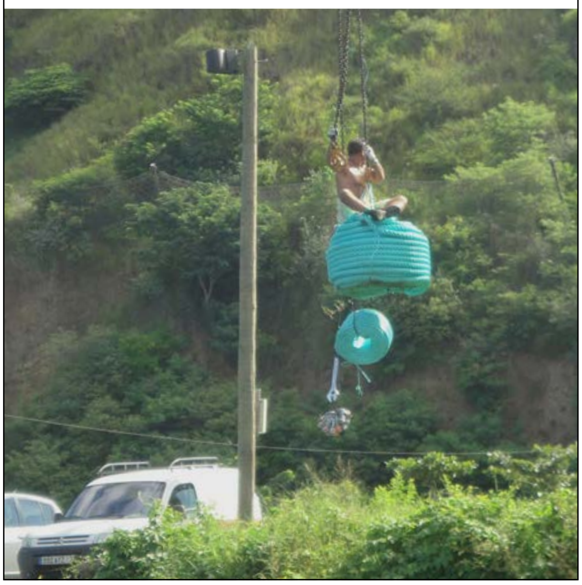
The law does not usually require that every threat be eliminated, but it expects that risks are assessed and minimized and that workers are protected as far possible.

Risk reduction and consequent increases in safety can be achieved through several actions, such as:

- Development of risk assessment plans, adoption of safety management systems, and identification of staff persons in charge of their implementation.
- Development of maintenance plans and maintenance scheduling for vessels, vehicles and lifting devices.
- Correct planning of daily activities. Overloading workers with tasks or underestimation of the correct number of people needed for a task may expose personnel to stress and fatigue, increasing the risks. Daily tasks should be planned according to the sea state forecast, avoiding heavy work (net changes, mooring maintenance, etc.) at times when bad weather is probable.
- Constant updating of staff training. Workers must be aware of possible risks, how these can be minimized, and how accidents are to be managed. The attention level and conscientiousness of workers may be reduced if a task is considered "safe" – i.e. if it has been carried out many times without accident. However, risks can be everywhere. A culture of safety should be instilled.
- Availability of safety equipment that is in good working order. Workers must be protected and must be familiar with the use of protective equipment.
- Have at least one or more workers trained in first aid, cardiopulmonary resuscitation (CPR) and in the use of an automated external defibrillator (AED).

Boats should be equipped with a radio that can be used in the event of severe accidents on the cage site. A radio distress call may be necessary

PLATE 123
Hazardous conduct – loading of ropes and personnel on board a farm vessel



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to activate a first-aid response on land, or for requesting a rescue operation on the cages.

Safety and rescue equipment must be available on board all vessels, including a life ring with lifeline, light buoy, flares, etc. Recommended standards and mandated regulations are usually provided by coastguard or other relevant authorities regarding the minimum type and numbers of safety equipment items to be stored on board any vessel, and their accessibility.

Suitable personal buoyancy equipment, such as lifejackets, should be provided by employers and should be worn by everyone while on workboats, and particularly during operations on cages.

Specific regulations on personal buoyancy equipment are usually available from the coastguard or other relevant authorities.

Helmets should be worn while a crane or other lifting device is in use, by anyone either operating or working in reach of the machine.

It is strongly advised that workers should not wear rings, bracelets and watches while working with nets because these objects can become caught in the netting mesh and may cause serious injury.

SCUBA DIVING

The use of divers should be minimized as much as possible, however when automated monitor systems to check the integrity and functionality of the farm are not available, divers provide a key support to the farm management and to ensure safety of the fish stock.

Professional diving, such as with scuba or hard-hat/hookah surface supplied systems, represents a significant source of risk for farm operators. Specific regulations for professional diving safety are usually established at the national level, but these regulations rarely address the specific challenges for cage farm divers. Therefore, safety rules and recommendations need to be adapted from the national regulations to the cage farm working environment, and then formally adopted by each company or aquaculture association.

Regulations and best practices that may be used as templates, or as references, are provided in detail by organizations and associations such as Health and Safety Executive (HSE), Association of Diving Contractors International (ADCI), International Diving Schools Association (IDSA), International Marine Contractors Association (IMCA) and others.

The appointment of a senior professional diver with specific skills on scuba safety can support the cage farm management in the development of a dedicated risk analysis and prevention plan as well as in the supervision and audit of the diving team.

Only properly trained and licensed divers should be permitted on the farm. The use of professional divers is highly recommended rather than using farm workers to conduct occasional dives.

A safety buddy system should be mandated on the farm. Diving alone should be strictly forbidden. At least two divers must be assigned to complete any single task, with a third diver on the surface vessel, ready to provide assistance in the event of an underwater accident.

The bulk of farm diving work is usually done within the first 15–20 m. The maximum depth of diving operations depends on the specific tasks the divers are undertaking. Generally, depth profiles for each component are:

- 6–8 m for grid system maintenance;
- 0–15 m for cage maintenance and harvest operations;
- 15–20 m for sinkers and sinker tube maintenance.

These depth ranges are not particularly dangerous, and decompression diving should not necessary if the work is properly planned. Nevertheless, divers should always use conservative bottom-time estimates and conservative dive tables, and should always use safety stops. One recommended safety stop is at five metres for three minutes during any ascent.

The above-mentioned depth ranges are referred to 10–12 m deep cages. Specific safety procedures have to be developed and implemented for deeper fish cages (e.g. in tuna farming).

Decompression diving is frequently necessary when mooring lines and anchors need to be inspected or maintained. In this case, the diving must be carefully planned, with pre-dive assessment of the time to complete the tasks, the allowable bottom-time, the actual dive time required, and the number and duration of any decompression stops. This must be completed before starting the work.

All divers should always be equipped with a dive computer. This will inform divers of their present depth, maximum depth achieved, dive time, decompression stops (if needed) and safety stops. This tool could also be very useful to doctors in the event of an accident or a decompression illness that needs to be treated in a hyperbaric chamber. The diving data retrieved from the diving computer can be a great help to doctors if they need to determine the best hyperbaric treatment.

Some of the most common risks to be considered while diving in cage operations are:

- Becoming trapped in nets or ropes, mainly when harvesting or handling the harvest nets underwater or when passing through the diver door in the net wall. Equipment such as the dive mask or regulator may become entangled in the net (Plate 124).
- Ascent rate may be faster than normal or exceed a safe rate especially during harvest operations.
- Repeated "bounce" diving (yo-yoing) can represent a serious risk to divers, especially if the surface intervals are short, or if the dives are deep.

Divers are often required to work on mooring components that are operating under tension and where strong force loads are applied. Maintenance of these components may require the use of lift bags, hand-lever hoists ("come-along") or boat cranes. The failure of a tool or a component under load or tension can cause accidents or exacerbate unsafe conditions.

Service vessel for divers must always be equipped with an oxygen supply unit that can be used for first aid in the field, in case symptoms of a decompression illness become apparent in a diver. All service vessel crew should be trained in the use of oxygen and other first-aid equipment, diagnoses and treatment of decompression illnesses or other barotrauma, and in the procedures for contacting farm management and emergency response services. Emergency contact numbers and communication equipment should be readily accessible to the boat crew.

PLATE 124
Protective cover made of knotless netting is wrapped around the first stage of a scuba diving regulator to reduce the risk of it becoming untangled in the seine net

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SAFE WORKING LOAD

In any lifting operation, the safe working load (SWL; also called "working load limit" or WLL), of each lifting component must be respected and obeyed. The SWL is the load limit that is calculated by dividing the minimum breaking load (MBL) by some safety factor. This factor ranges from 4 to 10 and is usually provided by the component manufacturer.

For example, if a rope has a MBL of 1 500 kg and a safety factor of 6, the SWL will be:

$$1\,500 \div 6 = 250 \text{ kg}$$

The rope or lifting component must never be used for lifting heavier loads.

The SWL of the weakest component must be considered the SWL of the entire rig in any lifting operation.

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Glossary

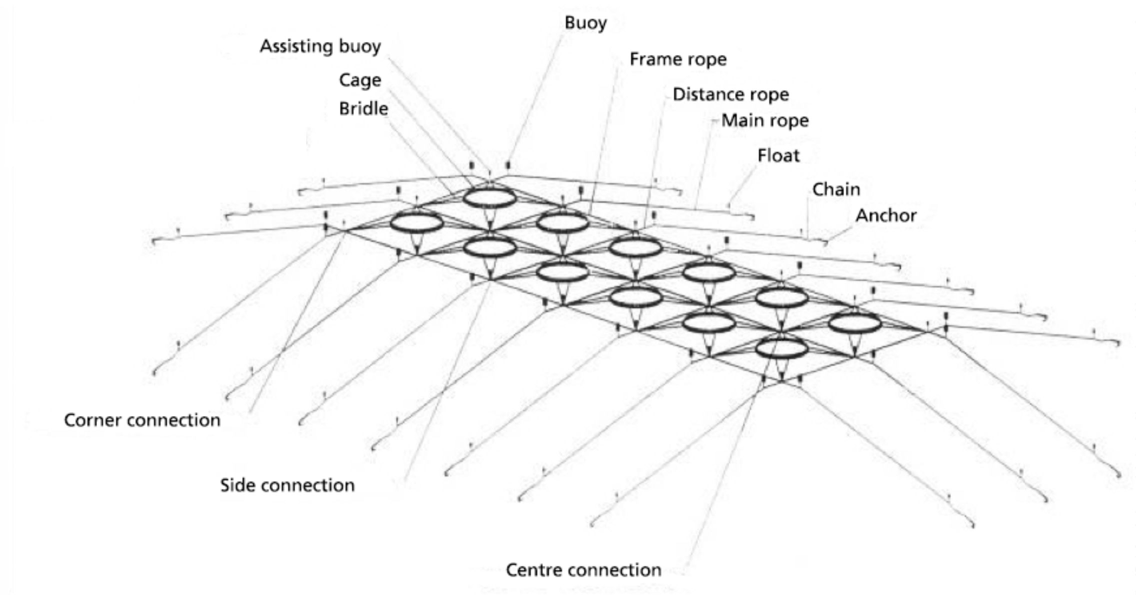
Anoxia	deficiency or absence of oxygen in the blood and tissues.
Ballast chain	the large chain connecting the mooring point on the sea floor (anchor or concrete block) to the mooring line connected to the grid system. This chain has the function of cushioning (absorb) the drag forces on mooring points generated by waves and currents on the cages.
Barotrauma	injury due to pressure variation exposure, such as decompression illness, ears and sinus squeezes, embolism, etc.
Batch	or lot, i.e. a group of specimens homogenous for at least one characteristic (usually age) and cultured together in the same rearing unit (net pen).
Beaufort scale	scale referring to the strength of the wind and the relevant sea status. It is empirical and based on the observed sea status. It ranges from 0 (calm) to 12 (hurricane).
Biomass	the total live weight of a group (or stock) of living organisms (e.g. fish, plankton) or of some defined fraction of it (e.g. fish spawners), in an area, at a particular time.
Bridles	the mooring ropes that connect the cage collar to the grid system. Bridles are usually connected to the corner plates and tied on the collars, either onto the high-density polyethylene (HDPE) pipes or on specific supports built in the collar.
Bracket	a plastic or metallic component of the cage collar. Each cage is equipped with a number of these, equidistant along the collar circumference. These have the function of keeping assembled the HDPE rings of the collar and to provide the collar with stanchions holding a handrail, for facilitating surface operations.
Cohort	a subpopulation; if a population is divided into several groups based on spawning date, the population is divided into age cohorts.
Collar	the floating cage structure made with HDPE pipes on which the cage net is hung.
Denier	unit of measure of linear mass density of textiles; it is referred to the mass in grams of 9 000 m of a single filament fibre.
Fetch	the distance the wind can blow over the sea; usually expressed in kilometres or nautical miles. Fetch distance and wind force determine the size of the waves at a given site.
Fingerlings	related to any fish from advanced fry to the age of one year from the date of hatching regardless of size.
Fluke	the part of the anchor that becomes embedded in the sea bottom, providing resistance to dragging forces.
Footprint (farm)	the total area occupied by a farm, including the submerged components of the mooring system and the mooring lines.
Fouling	the accumulation of aquatic organisms that attach to and grow on underwater objects, such as ship hulls, harbour structures, net cages and rafts.
Galvanized	metal component (usually iron or steel) protected through a coating of zinc.

Jump net	the exposed or visible part of a net cage from the waterline rope to the top rope; it is usually fixed on the upper part of the stanchion or the handrail of the floating collar.
Mesh	one of the open spaces between the cords of a net. The size of netting mesh is measured as the length of one mesh side, e.g. a 25 mm mesh (also known as “bar size”). The mesh size measurement can also be indicated as “stretched size”, which is the size of netting mesh measured as the length of a stretched mesh.
Net cage	the structure holding the fish stock; it is made of netting material and ropes seamed together. It may have loops or rings to fix it to the floating (collar) or sinking (sink tube) components of the fish cage.
Netting	for the purposes of this manual, “netting” refers to an open mesh fabric (whether in bulk or incorporated into a net cage), whereas “net” refers to a ready-to-use product made from netting (e.g. cage net or fishing net).
No fishing zone	an area of the marine environment together with its overlying water and associated flora and fauna where no fishing is allowed and which is protected legally by law or regulations.
Pellet	agglomerated feed formed by compacting and forcing it through die openings by a mechanical extrusion process.
Purse seine	nets characterized by the use of a purse line at the bottom of the net. The purse line enables the net to be closed like a purse and thus retain all the fish caught.
Shackle	a movable metal link, U-shaped, used to connect mooring components, chains, thimbles, etc. It is fixed trough a bolt, which is usually secured with a cotter pin.
Shank	the central, straight part of an anchor to which the fluke is connected on one end and the stock on the other end.
Sinker system	the weights and other structures connected to the net cage to sink the net and maintain its volume and shape.
Siting	the process of site selection, up to the detail of exact mooring location and orientation.
Spliced eye	a splice formed by bending a rope end back and splicing it into the rope so that a loop is formed.
Splicing	a semi-permanent joint between two ropes or two parts of the same rope by partly untwisting and then interweaving their strands.
Stanchion	the vertical part of a bracket holding the handrail pipe in a floating cage unit.
Tenacity	unit of measure of fibre strength. It is calculated dividing the tensile strength of a fibre by the denier.
Tensile strength	the strength of a fibre or yarn measured as the maximum tension the material can withstand without breaking.
Thimble	a loop of metal or plastic having a groove at its outer edge for a rope or cable. Used for protecting ropes from abrasion. It is usually mounted inside a spliced eye.
Tripping line	rope installed on the anchor, opposite the fluke, useful to launch the anchor during installation or to remove the anchor from its embedding.
Wave crest	the highest part of a wave. A wave length is measured from crest to crest.
Zipping line	a rope connected to the anchor crowne used to recover an embedded anchor.

Appendixes

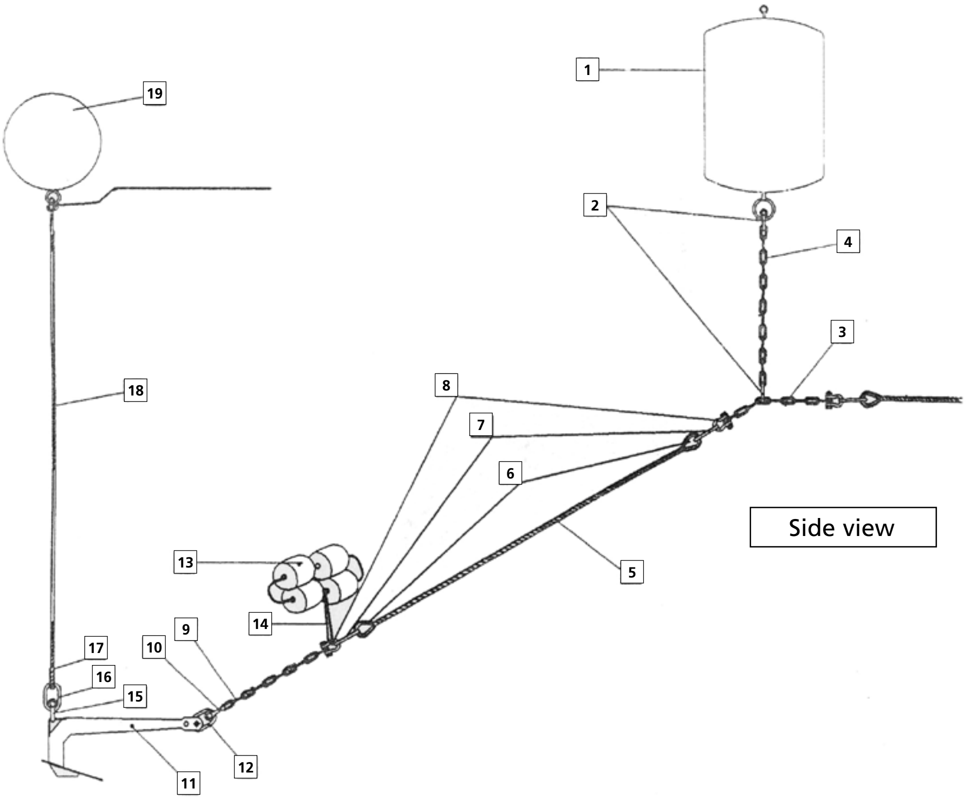
Appendix 1 – Technical drawings and component list of a mooring system for a double-buoy cage system, moderate exposure, 16 m diameter cages

FIGURE A1.1
Complete grid mooring system



Source: Polarcirkel (Norway).

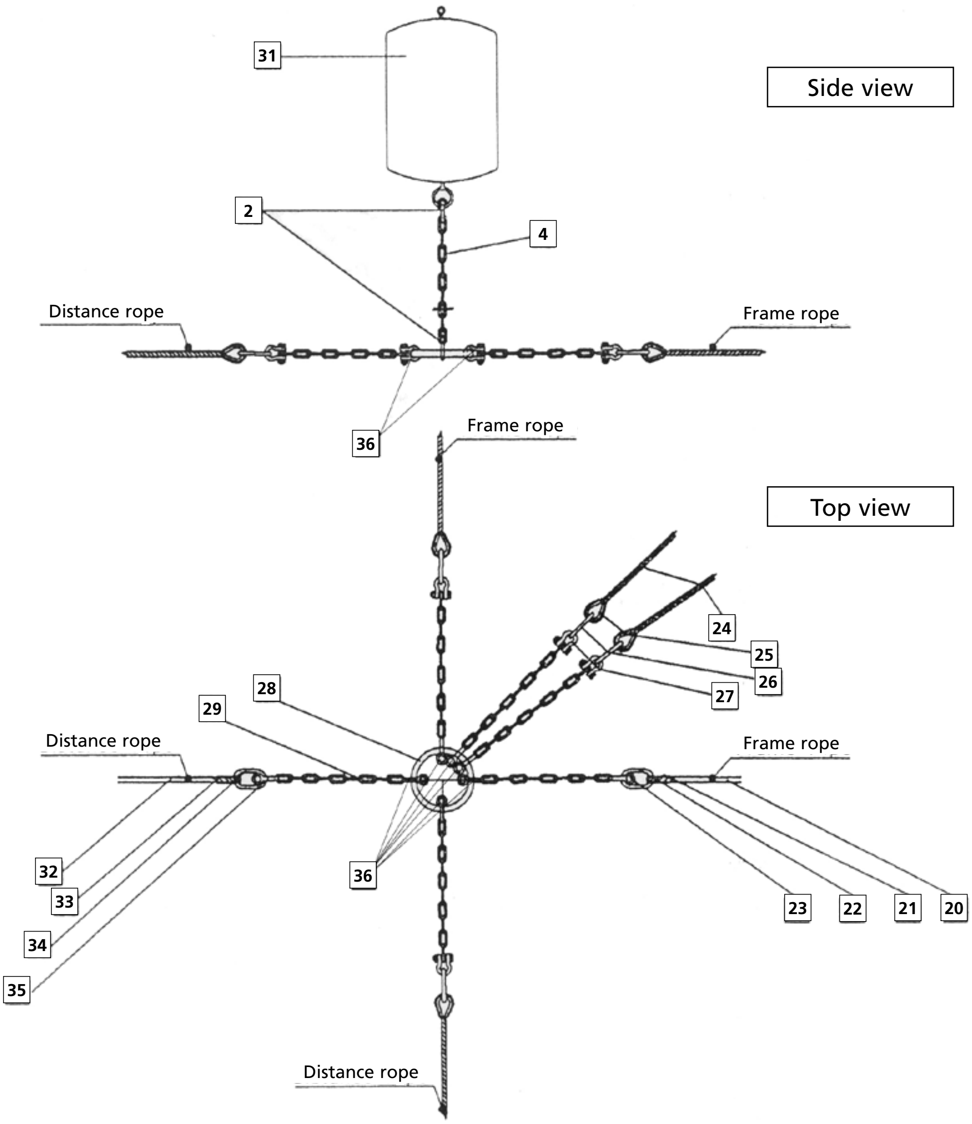
FIGURE A1.2
Mooring line



ID	Description	Note	
1	Main buoy	CB 680 litres buoyancy made with rotomoulded PE and filled with expanded polystyrene	
2	Shackle	SWL 4.75 tonnes	
3	Distance chain	16 × 100 mm, length 2 m	
4	Chain	13 × 88 mm, length 6 m	
5	Main rope	Rope polysteel Ø 48 mm, length 120 m	
6	Thimble	11” – suitable for a rope of Ø 48 mm	
7	Distance ring	25.B.6 – 100 × 190 mm, ≠ 25 mm	
8	Shackle	SWL 8.5 tonnes	
9	Bottom chain	Second-hand tarred chain, Ø 40 mm, length 30 m	
10	Anchor shackle	SWL 8.5 tonnes or SWL 9.5 tonnes	
11	Anchor	SAMSON type 1 200 kg	
12	Connector	Optional	
13	Deep water buoys	PP rigid, Ø 280 mm, buoyancy approx. 10 litres	
14	Rope	Optional	Rope polysteel Ø 12 mm, length 3 m
15	Shackle	Optional	SWL 8.5 tonnes
16	Distance ring	Optional	
17	Thimble	Optional	
18	Rope	Optional	Rope polysteel Ø 24 mm, length 50 m
19	Float	Optional	Various (9–10 litres approx.)

Source: Polarcirkel (Norway).

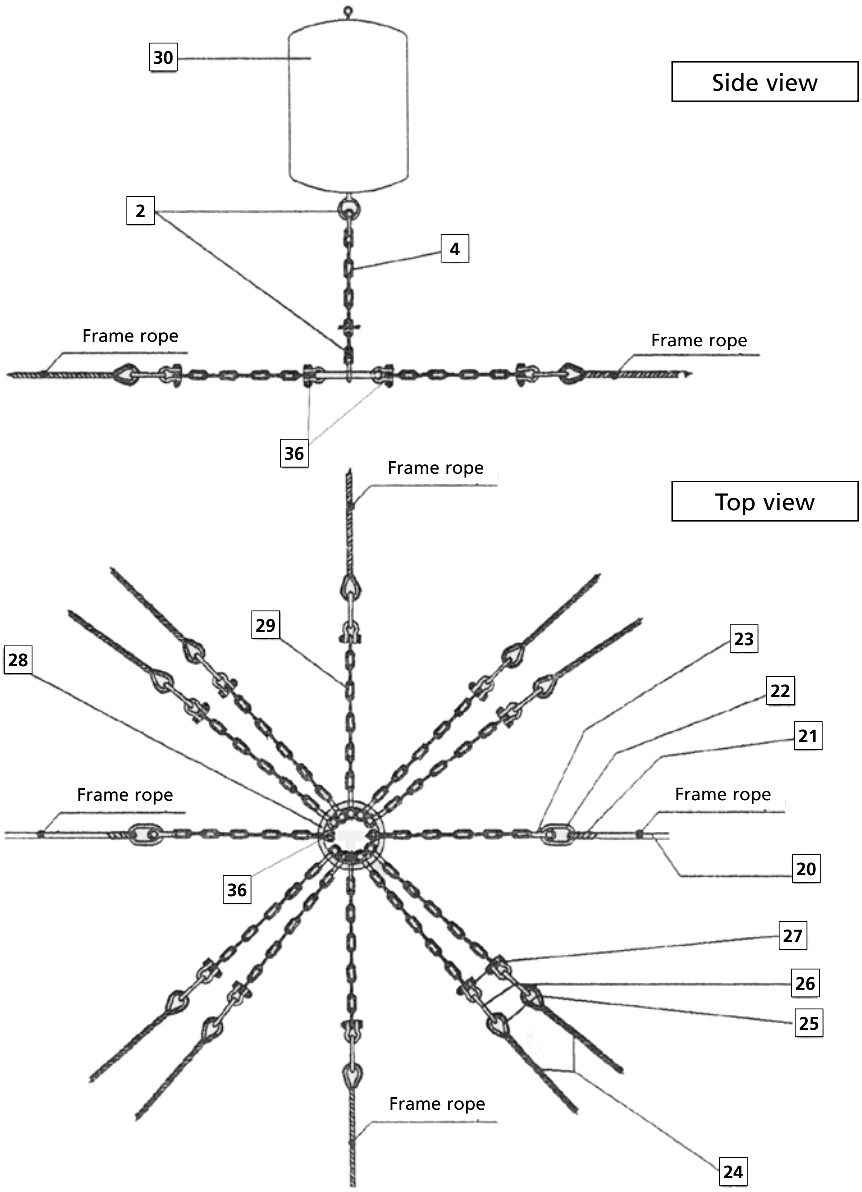
FIGURE A1.3
Corner connection



ID	Qantity	Description	Note
2	8	Shackles	SWL 4.75 tonnes
4	4	Buoy chain	13 × 88 mm, length 6 m
20	see side connection.	Grid line	Rope polysteel, Ø 48 mm, length 27.3 m
21	see side connection.	Thimble	11" – suitable for a rope of Ø 48 mm
22	see side connection.	Spacing ring	22.B.6, 90 × 170 mm, ≠ 22 mm
23	see side connection.	Shackle	SWL 8.5 tonnes
24	see side connection.	Bridle line	Rope polysteel, Ø 36 mm, length 20 m
25	see side connection.	Thimble	8.5" – suitable for a rope of Ø 36 mm
26	see side connection.	Spacing ring	16.B.6, 90 × 120 mm, ≠ 16 mm
27	see side connection.	Shackle	SWL 4.75 tonnes
28	4	Ring	28.O.6, Ø 175 mm, ≠ 28 mm
29	24	Chain	16 × 100 mm, length 1 m
31	4	Buoy	CB 260 litres buoyancy made with rotomoulded PE and filled with expanded polystyrene
32	see side connection.	Distance rope	Rope polysteel, Ø 48 mm, length 2 m
33	see side connection.	Thimble	11" – suitable for a rope of Ø 48 mm
34	see side connection.	Distance ring	22.B.6, 90 × 170 mm, ≠ 22 mm
35	see side connection.	Shackles	SWL 8.5 tonnes
36	24	Shackles	SWL 8.5 tonnes

Source: Polarcirkel (Norway).

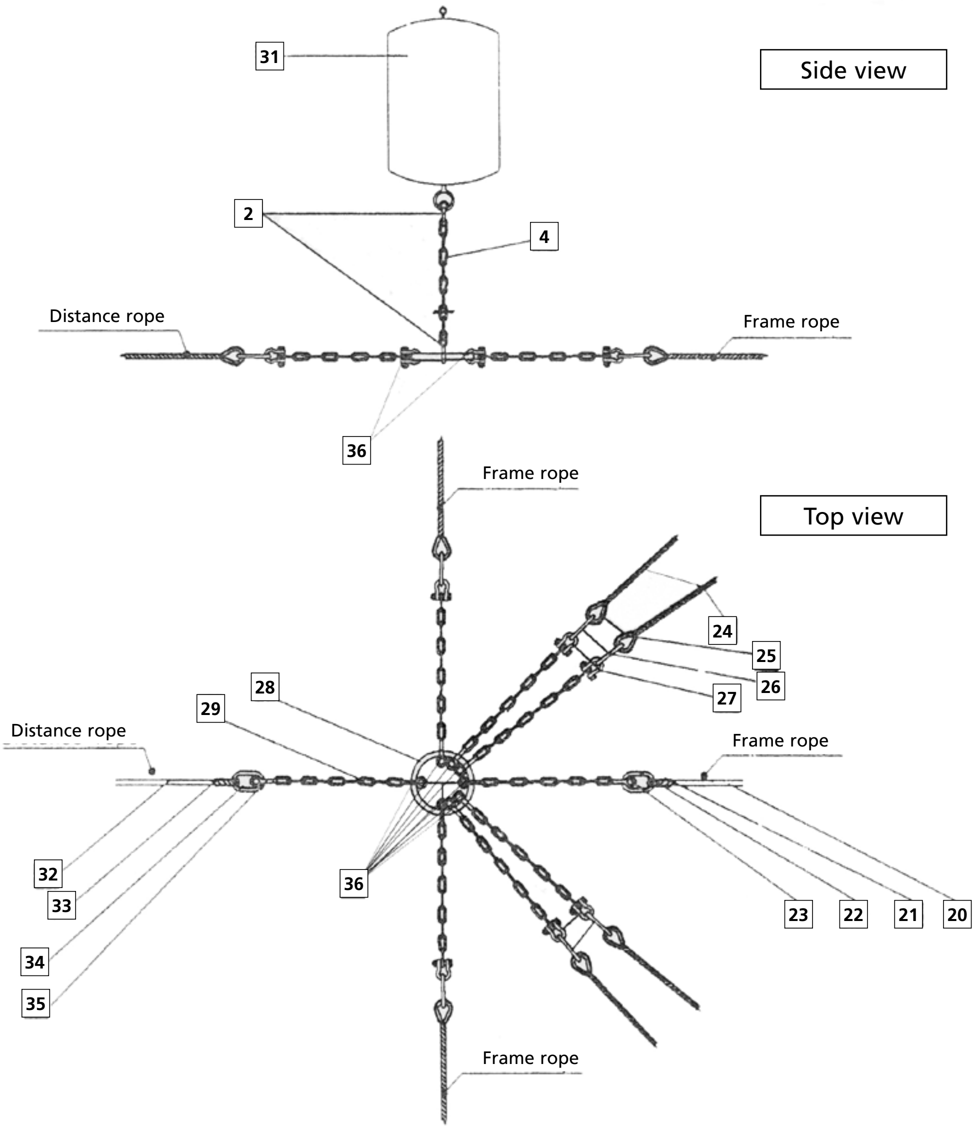
FIGURE A1.4
Central connection



ID	Quantity	Description	Note
2	4	Shackles	SWL 4.75 tonnes
4	2	Buoy chain	13 × 88 mm, length. 6 m
20	see side connection.	Frame rope	Rope polysteel, Ø 48 mm, length 27.3 m
21	see side connection.	Thimble	11” – suitable for a rope of Ø 48 mm
22	see side connection.	Spacing ring	22.B.6, 90 × 170 mm, ≠ 22 mm
23	see side connection.	Shackle	SWL 8.5 tonnes
24	see side connection.	Bridle rope	Rope polysteel, Ø 36 mm, length 20 m
25	see side connection.	Thimble	8.5” – suitable for a rope of Ø 36 mm
26	see side connection.	Spacing ring	16.B.6, 90 × 120 mm, ≠ 16 mm
27	see side connection.	Shackle	SWL 4.75 tonnes
28	2	Ring	28.O.6, Ø 175 mm, ≠ 28 mm
29	12	Chain	16 × 100 mm, length 1 m
30	2	Buoy	CB 680 litres buoyancy – rotomoulded PE and filled with expanded polystyrene
40	28	Shackles	SWL 8.5 tonnes

Source: Polarcirkel (Norway).

FIGURE A1.5
Side connection



ID	Qantity	Description	Note
2	12	Shackles	SWL 4.75 tonnes
4	6	Buoy chain	13 × 88 mm, length 6 m
20	17	Grid line	Rope polysteel, Ø 48 mm, length 27.3 m
21	34	Thimble	11" – suitable for a rope of Ø 48 mm
22	34	Spacing ring	22.B.6, 90 × 170 mm, ≠ 22 mm
23	34	Shackle	SWL 8.5 tonnes
24	48	Bridle rope	Rope polysteel, Ø 36 mm, length 20 m
25	48	Thimble	8.5" – suitable for a rope of Ø 36 mm
26	48	Spacing ring	16.B.6, 90 × 120 mm, ≠ 16 mm
27	48	Shackle	SWL 4.75 tonnes
28	6	Ring	28.O.6, Ø 175 mm, ≠ 28 mm
29	48	Chain	16 × 100 mm, length 1 m
31	6	Buoy	CB 260 litres buoyancy – rotomoulded PE and filled with expanded polystyrene
32	14	Distance rope	Rope polysteel, Ø 48 mm, length 2 m
33	28	Thimble	11" – suitable for a rope of Ø 48 mm
34	28	Spacing ring	22.B.6, 90 × 170 mm, ≠ 22 mm
35	28	Shackles	SWL 8.5 tonnes
36	48	Shackles	SWL 8.5 tonnes

Source: Polarcirkel (Norway).

Appendix 2 – Technical characteristics of netting

TABLE A2.1
Nylon knotless net

Twine 210/…	Type of braiding	Weight (1 000 mesh ×1 m) (kg)	Breaking load (BL) (kg)		
			Min.	Average	Max.
4	soft	0.35	–	7.5	–
	medium	0.38	–	8.0	–
	hard	0.40	–	8.5	–
6	soft	0.51	–	8.8	–
	medium	0.53	8.6	9.1	10.2
	hard	0.55	8.8	9.3	10.3
7	soft	0.73	–	–	–
	medium	0.76	13.5	14.0	14.5
	hard	0.80	–	–	–
9	soft	0.77	–	13.5	–
	medium	0.82	13.0	14.0	15.5
	hard	0.85	14.0	15.0	16.5
12	soft	0.92	16.0	16.5	17.5
	medium	0.95	16.5	16.7	18.0
	hard	1.00	16.0	17.0	19.5
15	soft	1.21	21.0	22.0	23.5
	medium	1.28	21.5	22.5	24.5
	hard	1.32	22.5	24.0	25.5
18	soft	1.61	28.0	30.0	31.5
	medium	1.71	28.0	30.5	34.5
	hard	1.80	30.0	31.5	33.5
24	soft	1.91	32.5	33.5	35.5
	medium	1.99	32.5	34.5	37.5
	hard	2.03	33.0	35.0	38.0
30	soft	2.12	35.5	37.0	38.5
	medium	2.22	–	38.5	–
	hard	2.46	38.0	39.5	41.0
36	soft	2.44	44.0	44.5	45.5
	medium	2.59	42.0	45.5	48.0
	hard	2.70	45.0	46.5	47.5
42	soft	2.65	46.0	47.5	49.0
	medium	2.87	46.0	48.5	52.5
	hard	3.00	46.5	49.5	51.6
48	soft	3.40	57.5	57.0	59.5
	medium	3.55	58.5	59.5	64.5
	hard	3.68	58.5	61.0	63.0

TABLE A2.1 (CONTINUED)

Twine 210/…	Type of braiding	Weight (1 000 mesh ×1 m) (kg)	Breaking load (BL) (kg)		
			Min.	Average	Max.
60	soft	3.82	61.5	64.5	66.5
	medium	4.01	63.0	67.5	73.5
	hard	4.18	67.0	70.0	74.5
66	soft	4.45	72.5	75.5	78.0
	medium	4.70	72.5	76.0	80.0
	hard	5.01	–	77.5	–
72	soft	4.85	80.0	84.5	87.0
	medium	5.28	81.5	86.0	93.0
	hard	5.45	82.5	87.0	92.5
96	soft	5.51	87.5	92.5	100.5
	medium	5.82	90.0	93.5	97.5
	hard	6.45	90.5	95.0	98.0
120	soft	6.70	109.5	112.5	116.0
	medium	7.11	109.0	114.6	125.0
	hard	7.55	110.0	115.8	124.5
150	soft	8.13	125.5	130.5	140.5
	medium	8.41	126.0	132.5	141.0
	hard	9.02	132.5	137.5	143.0
180	soft	10.01	164.0	168.0	180.5
	medium	10.60	160.5	170.0	181.5
	hard	11.20	157.5	174.5	185.0
200	soft	10.38	–	174.0	–
	medium	11.22	–	183.0	–
	hard	12.80	–	190.0	–
240	soft	13.97	200.5	217.0	240.5
	medium	14.59	208.0	218.5	238.5
	hard	15.40	206.0	219.5	230.5
300	soft	19.67	265.0	280.0	332.0
	medium	21.54	269.5	288.0	297.5
	hard	23.00	–	305.0	–
400	soft	26.25	315.5	334.0	355.0
	medium	28.33	318.0	338.0	366.5
	hard	29.76	332.0	349.0	349.5
500	soft	36.60	–	430.0	–
	medium	38.50	–	450.0	–
	hard	40.60	–	460.0	–
600	soft	51.00	–	562.0	–
	medium	53.60	–	605.0	–
	hard	55.00	–	636.0	–

Source: Badinotti Group SpA.

TABLE A2.2
Nylon + polyethylene knotless netting

Twine 210/…	Type of braiding	Weight (1 000 mesh × 1 m) (kg)	Breaking load (BL) (kg)
24	soft	1.44	19.4
48	soft	2.88	39.0
48 DAL	soft	3.30	45.0
260	soft	11.88	118.0
280	soft	17.00	170.0

Source: Badinotti Group SpA.

TABLE A2.3
Nylon knotless netting with superknot

Twine 210/…	Mesh size (mm)	Weight (1 000 mesh × 1 m) (kg)	Average breaking load (BL) (kg)
30	10	2.85	42
	12.5	2.76	42
	14	2.70	42
	15.5	2.60	42
	21	2.50	42
36	10	3.80	56
	13	3.55	56
	14	3.52	56
	15.5	3.47	56
	18	3.42	56
	19.5	3.40	56
	21	3.30	56
42	13	4.10	63
	14	3.95	63
	15.5	3.90	63
	18	3.80	63
48	13	4.70	67
	15.5	4.55	67
	18	4.50	67
	19.5	4.45	67
	22.5	4.30	67
	25	4.15	67
60	15.5	5.75	85
	18	5.60	85
	19.5	5.50	85
	22.5	5.30	85
	25	5.15	85
	28.5	4.95	85
66	22	5.62	89
72	22.5	6.06	93
	25	5.90	93
	27	5.90	93
	28.5	5.60	93
84		6.20	106
96	22.5	6.95	118
	25	6.85	118
	28.5	6.75	118
108	25	8.32	138
120		8.74	140

Source: Badinotti Group SpA.

TABLE A2.4
NEXT with HPPE, 100% genuine, knotless netting

Twine 100% HPPE	Twine nylon	Type of braiding	Weight (1 000 mesh × 1 m) (kg)	Breaking load (BL) (kg)
	Correspondence			
NEXT 100/72	210/66	medium	1.65	72.0
NEXT 100/86	210/96	medium	2.20	86.4
NEXT 100/ 103	210/96+	medium	2.53	103.8
NEXT 100/109	210/120	medium	2.52	109.0
NEXT 100/152	210/180	medium	3.29	152.0
NEXT 100/196	210/200+	medium	4.09	196.0
NEXT 100/245	210/240+	medium	5.84	245.0
NEXT 100/250	210/240+	medium	6.72	250.0
NEXT 100/320	210/400-	medium	11.20	320.0

Source: Badinotti Group SpA.

TABLE A2.5
Polypropylene knotless netting

Twine 210/…	Weight (1 000 mesh × 1 m) (kg)	Breaking load (BL) (kg)
18	1.36	26.0
48	2.68	49.0
72	4.00	73.0
180	6.14	89.5
200	5.70	97.0
220	8.00	136.0

Source: Badinotti Group SpA.

TABLE A2.6
Polyester knotless netting

Twine 210/…	Type of braiding	Weight (1 000 mesh × 1 m) (kg)	Breaking load (BL) (kg)
18	soft	1.39	26
	medium	1.54	27
24	soft	1.61	27
	medium	1.79	28
36	soft	2.17	35
	medium	2.47	38
40	soft	–	–
	medium	2.85	40
48	soft	2.92	44
	medium	3.05	47
60	soft	3.13	46
	medium	3.33	48
72	soft	4.09	58
	medium	4.35	60
96	soft	4.64	67
	medium	4.86	73
120	soft	6.07	96
	medium	6.43	99

TABLE A2.6 (CONTINUED)

Twine 210/…	Type of braiding	Weight (1 000 mesh × 1 m) (kg)	Breaking load (BL) (kg)
150	soft	6.78	110
	medium	7.28	116
180	soft	8.35	144
	medium	9.03	149
192	soft	–	–
	medium	8.84	127
200	soft	9.55	152
	medium	10.15	158
240	soft	11.25	160
	medium	11.96	166
280	soft	–	–
	medium	13.75	183
300	soft	17.50	206
	medium	18.00	214
400	soft	23.00	280
	medium	24.10	300

Source: Badinotti Group SpA.

NOTES

Cage aquaculture has grown rapidly in recent decades, and there has been a move towards the development and use of more intensive cage-farming systems to access and expand into untapped open-water areas, particularly in marine offshore waters. Fish cages vary in design, size and materials used, as they have been designed for employment in diverse environments, ranging from relatively protected to highly exposed and dynamic sites, either as floating or fully submerged structures. This technical manual focuses on high-density polyethylene (HDPE) cages as they are widely used in modern industrial marine aquaculture in many parts of the world. It provides the reader with highly practical and technical information on the design and components of a typical HDPE cage, and on how a cage collar is assembled and the net pen installed. Along with the structure of the cage, comprehensive information on the grid mooring system and installation is provided. Finally, the manual presents and discusses information on farming operations, including maintenance and control of the farming structures, stocking of the farmed fish, feeding, harvesting and packaging as well as other practical aspects and routine management operations.

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