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Pacific oyster farming

A practical manual





Cover photographs:

Net bag containing old shells as "cultch" for oyster spat collection (top left – ©Intermas Nets S.A.); Nursey upwelling tank containing spat of the Pacific oyster, *Crassostrea gigas* (top centre – ©L. Gennari); Large Pacific oysters contained in a rigid lantern tray used in long-line farming (top right – ©E. Turolla); Oyster bags on trestles farmed in the intertidal zone (bottom left – ©M. Mercer); Oysters harvested from bottom culture beds by dredge (bottom right – ©Wright Brothers Ltd).

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Mark Mercer
Aquaculture consultant

Lorenzo Gennari
Aquaculture consultant and producer

Alessandro Lovatelli
Food and Agriculture Organization of the United Nations
Rome, Italy

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Preparation of this document

This manual focuses on the practical techniques and cultivation strategies needed to successfully farm the Pacific or cupped oyster, *Crassostrea gigas*. Oysters are a highly nutritious food source and, requiring no manmade feed or fertilizer to grow, are an example of sustainable, low carbon aquaculture production that can make an important contribution towards the goal of feeding an expanding global population in a responsible and environmentally friendly fashion.

The manual provides a detailed and exhaustive list of the components necessary to construct each of the cultivation systems that are described within its pages, and a step-by-step guide on the assembly and installation process. The manual also guides the user as to how to create and execute a management and monitoring plan, ensuring that all the necessary cultivation procedures are implemented in accordance with the production schedule.

This guide is not intended to be a scientific paper and if the reader requires a more in depth understanding of the organism itself, there are many other publications available that can provide this, some of which are listed in the further reading section at the end of the manual.

This publication includes many technical illustrations, instructional drawings, tables and photographs to ensure that all the subjects examined within its pages are elucidated. Where necessary, a clear visual representation of each topic, technique or piece of equipment is included to assist the reader in understanding what is being explained in the text. Supplementary details of the subject matter can be found in the appendixes at the end of the manual that elaborate further on some of the more technical matters described in each chapter.

Hatchery seed production is not included in this manual but a list of reference publications that describe this process are listed in the further reading at the end of the manual if the reader wishes to research this phase of the production cycle further.

Clear definitions of all the technical terms used in the text are included in the glossary and should be consulted when clarification is required.

This document is one of three technical guides on shellfish culture produced as part of a project funded and implemented by the Food and Agriculture Organization of the United Nations (TCP/DRK/3803) in enhancing coastal livelihoods and food security in the Democratic People's Republic of Korea.

Abstract

The purpose of this manual is to give the reader a foundation of practical knowledge regarding all aspects of Pacific oyster cultivation. It is targeted at new entrants to the market wishing to establish a farm, and existing operators who wish to develop their farms and explore new cultivation techniques. The methodologies described can be applied to both low-tech, low budget, small-scale farming operations and to high-tech, big budget, industrial-scale aquaculture production enterprises. This guide focuses on the functional expertise and technical equipment required to construct and manage an operational farm in the diverse environmental and physical locations in which they can be situated, from the initial stages of finding and selecting a suitable site, to the conclusion of the first production cycle and harvesting the crop.

The manual contains a brief introduction which describes the relevance of the species with regards to global aquaculture production figures and how it can form an important part of future food production strategies. Chapter 2 describes the anatomy and biology of *Crassostrea gigas* and gives an indication as to the environmental conditions in which the species thrives as well as the pathologies and predators that can result in poor health leading to potential mortalities. Quality assessment parameters are also discussed with regards to desirable attributes when selling final product into the market and what is necessary to be aware of when considering consumer safety.

Chapter 3 deals with all aspects of undertaking a survey of potential oyster farming sites and what data should be collected and examined in order to both assess a site's suitability, but also which areas are best suited to different cultivation techniques. After this, Chapter 4 introduces the main farming techniques that will be described in detail in the following chapters, which includes off-bottom cultivation, on-bottom cultivation, and suspended cultivation, and also gives details of some of the most common cultivation equipment necessary to undertake these operations. The techniques and strategies necessary to procure seed oysters and how to develop them through the nursery stage are also introduced. This includes the basic principles of upwelling, which then leads into Chapter 5, which provides a detailed description of how to build and operate one particular example of a Floating Upwelling System (Flupsy) which is suitable for use in remote but sheltered conditions. A section on the best practices to be adopted when handling and transporting oysters is also included in this chapter.

Chapters 6, 7 and 8, constitute the main body of the manual and provide an in depth look into the three major cultivation techniques that this guide concentrates on: "Farming with trestles and bags in the intertidal zone", "On-bottom cultivation in the intertidal or subtidal zone" and "Offshore long-line cultivation". These represent three of the most common farming techniques adopted in a multitude of locations and, although other techniques are utilised, are responsible for the majority of oyster production around the globe. In each chapter, all aspects of the farming process are explored including site selection, farm design, farming practices and main constraints.

Finally, the manual finishes with some suggestions for further reading, a glossary and appendixes which includes information on food safety in regard to bivalve molluscs and some further details about cupped oyster production figures.

Keywords: Pacific oyster, cupped oyster, seed recruitment, nursery, Flupsy, on-trestle cultivation, on-bottom cultivation, suspended cultivation, offshore cultivation, long-line.

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Tables

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Practical manuals, of which this is one, require practical, "hands-on" experience and as authors of this guide we have been lucky enough to work with some of the leading lights in the oyster cultivation industry, whose experience and knowledge we have drawn upon, not only in our own farming enterprises, but also in creating this document. We would like to thank all of them and the many diligent and enterprising oyster farmers around the world who have helped to innovate and push the industry onwards and upwards.

A special thanks should be given to Mark Dravers of Guernsey Sea Farms, whose Flupsy design is detailed in Chapter 5 and who's work in oyster hatchery and nursery design and management have helped not only in the writing of this manual but also many others throughout the industry. We would also like to thank Kelsey Thompson of Morecambe Bay Oysters, Tim Marshall of Porthilly Shellfish and James Green of The Whitstable Oyster Company for their assistance in providing crucial information when researching different cultivation strategies for this manual.

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Abbreviations

AAC	Aquaculture Advisory Council (European Union)
AISI	American Iron and Steel Institute
ASFIS	Aquatic Sciences and Fisheries Information System (FAO)
CAC	Codex Alimentarius Commission
COP	Code of Practice
CV	coefficient of variation
DWG	daily weight gain
FAO	Food and Agriculture Organization of the United Nations
FLUPSY	Floating upwelling system
GAA	Growing Area Assessment
GAM	Growing Area Monitoring
GARP	Growing Area Risk Profile
GPS	Global Positioning System
HDPE	high density polyethylene
HP	horsepower
ISO	International Organization for Standardization
OsHV-1	Ostreid herpesvirus type 1
PP	primary productivity
PVC	polyvinyl choride
RMP	revolutions per minute
USD	United States Dollars
UV	ultraviolet
VHF	very high frequency
WHO	World Health Organization of the United Nations
WoRMS	World Register of Marine Species

<	less than
>	greater than
µm	micron
mm	millimetre
cm	centimetre
m	metre
ha	hectare
mg	milligram
µg	microgram
g	gram
kg	kilogram
ml	millilitre
L	litre
‰	parts per thousand
°C	degree Celsius
°F	degree Fahrenheit
Ø	diameter

1. Introduction

Oyster farming is an ancient form of aquaculture that started in China and Europe more than 2 000 years ago. More recently, modern oyster aquaculture developed in Japan at the beginning of the 17th century and in Europe from 1850 onwards. Nowadays, the Pacific or Japanese cupped oyster (*Crassostrea gigas*), which originates from the North Pacific region and the Sea of Japan, is widely distributed all over the world because of its use in aquaculture cultivation and due to its highly adaptable nature. Cultivation is undertaken using many diverse techniques depending on local tradition and environmental conditions.

TABLE 1.1
Global FAO aquaculture statistics (2020)

	Production (live weight equivalent)	
Fisheries & aquaculture	177.8 m tonnes	Seaweeds excluded
Aquaculture	87.5 m tonnes	Seaweeds excluded
Marine aquaculture	33.1 m tonnes	Seaweeds excluded
Shellfish aquaculture	17 740 526 tonnes	Inland & marine aquaculture
Oysters aquaculture	6 060 566 tonnes	All cupped oysters (1)(2)

1) Due to the fact that World Register of Marine Species (WoRMS) registered Pacific cupped oysters, formerly members of the genus *Crassostrea*, in the new genus *Magallana*, FAO Fisheries and Aquaculture data for cupped oysters are registered under two names:
– ASFIS species name "Pacific cupped oyster", ASFIS species scientific name "*Magallana gigas*";
– ASFIS species name "Cupped oyster nei", ASFIS species scientific name "*Crassostrea* spp.".

2) Data of the main producing countries (production and value), referred to 2019 and 2020, are summarised in Table 2.2 and data from 2010 are detailed in Appendix II.

Source: Elaborated by the authors.

Cupped oyster production, expressed in live weight equivalent, represents 7.1 percent of world aquaculture production, 18.3 percent world marine aquaculture production and 34.1 percent of world mollusc aquaculture production. In 2020, with a global production of approximately 6 million tonnes, the cupped oyster was the most produced species followed by Japanese carpet shell clams (4 266 200 tonnes) and scallops (1 746 400 tonnes). The farm-gate value of the production in 2020 amounted to USD 7.079 billion. The market price varied considerably from country to country depending upon their traditions in the way they consume the oysters (crude or cooked/transformed) ranging from USD 0.67 to USD 8.64 for one kilogram of live weight (Appendix II).

China is by far the largest producer in the world with an annual output of 5 424 632 tonnes in 2020 (89.5 percent of the total cupped oyster production). Over the course of the previous decade, Chinese production grew by 69.3 percent, from an annual production of 3 580 474 tonnes in 2011. In the other countries, production did not grow significantly or slightly decreased.

Oysters are bivalve molluscs and, as filter feeders that extract their required nutrition from phytoplankton and zooplankton that occur naturally in the seawater and therefore require no artificial feed, have all the required characteristics to contribute to sustainable aquaculture and food security. Together with macro-algae and many other species of shellfish, oysters can be a critical component when developing "Integrated Multi-Trophic Aquaculture" strategies. Other marine businesses, such as finfish farms and offshore wind farms, are considering developing oyster farming as part of integrated systems to balance the effects of less sustainable activities, thereby helping to mitigate some of the negative effects on the environment.

Oyster farming can also play an important role in strategies for the development of economically deprived coastal regions, contributing to nutritional security and long-term sustainable employment. This is particularly relevant in areas where local fishing communities have seen their livelihoods negatively impacted by the depletion of the wild caught fish stocks that they had historically relied upon.

When contemplating the establishment of an oyster farming operation, it is important to consider how the introduction of farmed stock will affect the already present wild population of the species in the area. Activities of restocking, or wild stock restoration, are not specifically dealt with in this manual, but such strategies can be a convenient and cost-effective mechanism to support the harvesting of natural seed of the species in the zone surrounding the farm. In some areas, wild oyster populations are able to provide a self-sufficient seed supply for oyster farms while in other areas, it will be necessary to rely on artificial reproduction from hatcheries. It is important to bear in mind that oyster farming can benefit from wild stock management and also contribute to the restoration process. Oyster farming must not be considered as a stand-alone activity and a preliminary assessment of the situation will have to be carried out before initiating cultivation activities.

The production systems used to grow oysters can be grouped into three different categories: on-bottom, off-bottom or suspended cultivation. Within these subsets, there are many variations that have been developed by farmers to suit their unique circumstances.

The objective of this manual is not to describe all of the possible methodologies, but to provide technical and practical information relating to three of the most widely used intensive production techniques and guidance on which one to choose in relation to the potential aquaculture sites that are available.

Some of these techniques could be partially used for cultivating other varieties of oyster and, similarly, techniques utilised to farm these alternate species could be extended to the pacific oyster. Other cultivated species of oysters that are considered important to the global oyster market are the flat oyster (*Ostrea edulis*), the eastern or American oyster (*Crassostrea virginica*), the Portuguese oyster (*Crassostrea angulata*) and the Sydney oyster (*Saccostrea glomerata*). Less important cultivated species are *Ostrea angasi*, *Ostrea chilensis, Crassostrea corteziensis*, *Crassostrea sikamea* and *Crassostrea rhizophorae*. It is imperative that the reader takes into account any specific requirements of their own native oyster species.

It will be important for the farmer to consult with the local legislative authorities who are responsible for the operation of aquaculture production businesses in the region where the business is situated, to ensure that all necessary rules and regulations are complied with before commencing cultivation activities.

As with the legislative requirements, the economic situation in each region will vary substantially so it is not possible for the manual to give an accurate forecast of the profitability of an oyster farming operation to reflect all of the diverse situations experienced across the globe. For example, the cost of labour, raw materials with which to construct the farm and oyster seed will vary dramatically from country to country.

2. Pacific oyster biology

This chapter will provide an overview of the major aspects relating to the biology of the Pacific oyster. It will also provide guidance on how to assess the quality of the end product and what important aspects of consumer safety should be considered when producing this seafood product for public consumption.

2.1 DESCRIPTION OF THE SPECIES (*CRASSOSTREA GIGAS*)

The genus *Crassostrea* includes about 20 species of oysters and some of them can be difficult to recognize without doing a molecular analysis. For instance, *C. gigas* and *C. angulata* can easily be confused and are also able to crossbreed with each other. Many studies have been undertaken to assess whether *C. gigas* and *C. angulata* are two different species or not and, even though most authors consider that they are two separate species, the debate is still on-going. Recently, *C. gigas* has been registered as *Magallana gigas* by the World Register of Marine Species (WoRMS).

2.1.1 Anatomy

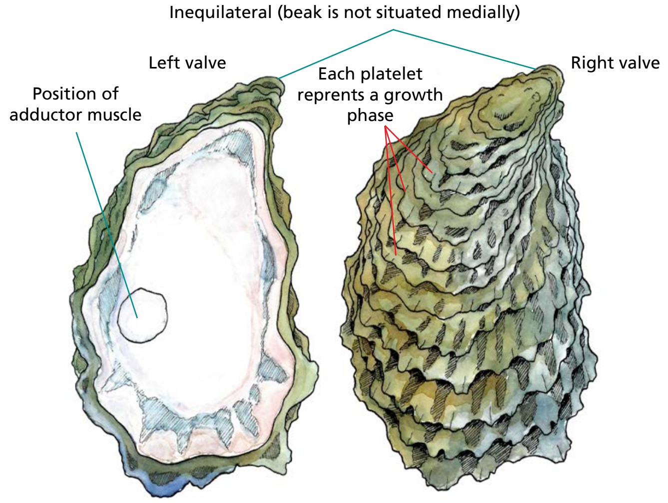
Crassostrea gigas is a marine bivalve mollusc. Bivalve refers to the two-hinged shells that enclose the main body of the organism and provide it with protection from predation and environmental factors. The ability to seal its shells together allows the oysters to settle and populate intertidal as well as subtidal areas. It can maintain a habitable environment within the confine of its own shells whilst out of the water and survive until the tide returns to cover it once more.

Crassostrea gigas is inequivalve (two valves different in shape and size) and inequilateral (beak is not situated medially). It has an oblong outline, longer than it is wide, with the upper valve (right) being flat or slightly convex and the inferior valve (left) being cupped and containing the main body of the organism. At the umbo, the hinge doesn't have a tooth and the ligament is internal.

The shells exhibit a diversity of shape and coloration, both in the wild and in farmed animals. Both of these factors are highly influenced by the environment in which they are grown and the cultivation technique that is used to produce them. Polymorphism is typical of this species. External coloration ranges from beige to black with some strains that have a brown or pink background colour. Many oysters have darker stripes radiating from the umbo. The external shell is lamellar in structure, with each underlying platelet representing a growth phase as the oyster has increased its size to allow its body to grow into the expanded volume of the shell (Figure 2.1).

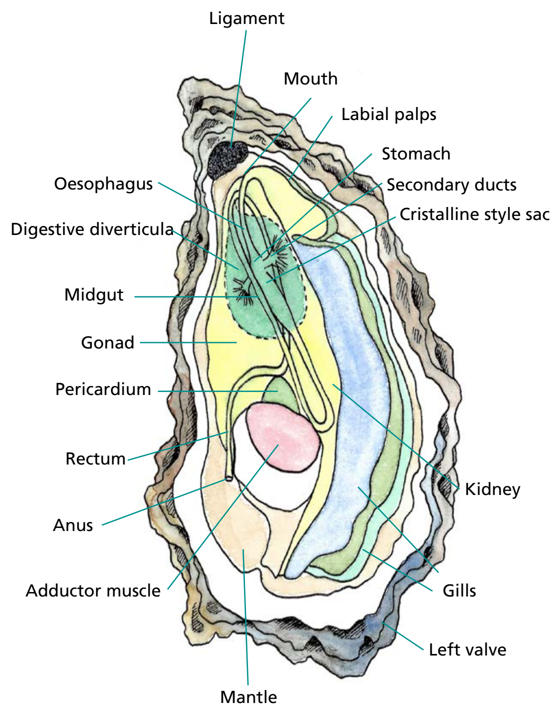
Internally, the shell is white although, in some cases, a brown or purple spot is present at the attachment point of the adductor muscle. The texture of the interior of the shell is smooth and reminiscent of porcelain. This polished surface is the nacreous layer and consists of what is commonly known as “mother of pearl”. The purpose of this layer is to provide the organism with a comfortable environment in which to live (Figure 2.2). The rest of the shell is made almost entirely of calcium carbonate ($CaCO_3$) apart from a very thin outer layer that is un-calcified and known as the periostracum. Cupped oysters have a single adductor muscle, which appears larger and stronger in oysters that grow in the intertidal zone.

FIGURE 2.1
***Crassostrea gigas* outer shells**



Source: Elaborated by the authors.

FIGURE 2.2
***Crassostrea gigas* internal anatomy**

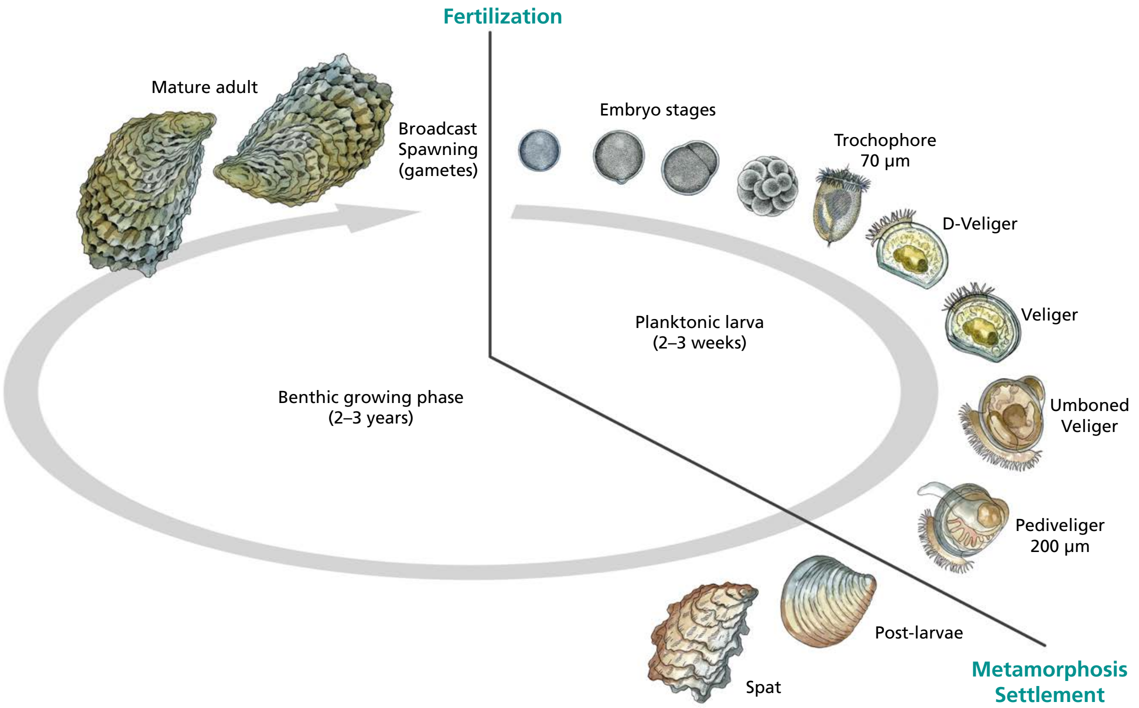


Source: Elaborated by the authors.

2.1.2 Life cycle

Oysters go through several stages of development during their life cycle and these can be categorised as follows: fertilisation, free swimming larval stages, settlement and metamorphosis into spat, maturation into juveniles and then growth into fully developed adults (Figure 2.3).

FIGURE 2.3
Pacific oyster life cycle



Source: Elaborated by the authors.

Reproduction

Oysters are protandrous hermaphrodites, meaning that they can change sex during their life. They often mature first as males and sexual maturation usually occurs after one year of life. Later some of them undergo a sex change into females that is triggered by favourable water temperatures and an abundance of phytoplankton. Maturation and spawning timing are mainly temperature driven: males release sperm over 14 °C and females release eggs over 18 °C.

The gametogenesis, that is the development and maturation of reproductive organs (gonads), occurs in different periods depending on the geographical location.

Along the North Atlantic coast, the development and maturation (gametogenesis) of reproductive organs (gonads) starts between 10 and 12 °C and occurs within a wide range of salinities, even in environments where permanent low salinity (under 10 ‰) or high salinity (over 35 ‰) persists. Spawning will occur when the water temperature reaches 18–22 °C. There will be regional variations regarding the temperature, depending on the environment in which the oyster has developed. At higher latitudes, where the water temperature doesn't reach the necessary trigger temperature for the required amount of degree days, spawning may not occur at all. The oysters will still go through the process of gametogenesis but the gametes themselves will not be released into the water.

In both the North Atlantic region and the central Adriatic Sea, gametogenesis occurs during late winter and spring and spawning during the summer period.

In all cases, males release sperm and females release eggs into the water column where fertilisation takes place when a single sperm combines with a single egg. This produces what is known as a zygote, which is initially a single celled fertilised egg, and contains the necessary genetic building blocks to enable the development of the oyster. The release of gametes (sperm and eggs) by the oysters to float freely in the water is known as broadcast spawning. Fecundity is very high and a single female may produce between 20 and 100 million eggs during each spawning.

The next stages in their evolution are the trochophore larva a few hours after fertilisation, the first veliger larva (D-veliger) after another day, followed by the final stage of pediveliger larvae after 2–3 weeks (Figure 2.3).

In these phases, the larvae swim freely in the water column using microscopic hair-like structures on their exterior called "cilia" and are widely dispersed by currents and tidal movements. Thus, larvae are planktonic for a 2–3 week period depending on environmental conditions and grow from 70 microns to 200–300 µm during this stage of their development before settlement occurs.

Settlement

At the point of settlement, the larvae cement themselves onto suitable substrate with the left valve (cupped valve) in contact with the chosen surface. In their natural environment, Pacific oysters attach themselves onto other living mollusc shells (oysters, mussels, clams, etc.), old shells from deceased molluscs and rocks or concrete blocks to form colonies. Following initial settlement, metamorphosis occurs and the larvae transform themselves into spat. Spat are essentially miniature oysters and this is the first time that they will take on the physical form of their much larger adult counterparts. During their larval stage, they can absorb oxygen from the water through their cell membranes. As spat, they develop gills for the first time and they can now use these, in combination with the exchange of gases through blood vessels in their mantle, to breath and trap phytoplankton.

Feeding

Oysters are filter feeders and obtain nutrients by extracting mainly phytoplankton and, to a lesser extent, small zooplankton and suspended organic matter from the seawater. Due to the microscopic nature of their food source (suitable plankton size ranges from 20 to 200 microns), oysters need to filter vast quantities of water to ensure that they can elicit enough nutrition to sustain their survival and enable them to grow and reproduce. An adult oyster is capable of filtering up to 5 litres/hour depending on the environmental factors in which it is situated. It is also by this filtration process that they extract oxygen from the water, which is essential for their survival.

Picoplankton that are smaller than 20 microns cannot be trapped and are therefore below the suitable size for feeding. When filtering, oysters also accumulate some inorganic suspended solids that are present in the water. These are immediately eliminated as "pseudofaeces" as they cannot be assimilated. If there are large volumes of these suspended solids in the water it can result in the oysters experiencing a lower growth rate. This is because the molluscs are expending energy to filter these particles out of the water but are not gaining any nutritional benefit from this activity.

Growth

Cupped oysters, as with many other shellfish species, are characterised by a non-homogeneous growth rate between subjects of the same population/batch. Under farming conditions, it will be necessary to undertake periodic grading to ensure that the slower growing oysters aren't outcompeted for food by the faster growing stock. If grading is not undertaken, the competitive advantage of larger animals will lead to a reduced growth and lower survival rate of the smaller animals.

Growth rates are mainly driven by temperature and nutrient abundance in the water and will vary depending on site geographical location and seasonal fluctuations. From one year to the next, over the same period, significant variation in product size can be observed.

In the wild, oysters can live up to 30 years and reach more than 30 cm in length, with the largest specimens weighing more than 1 kg.

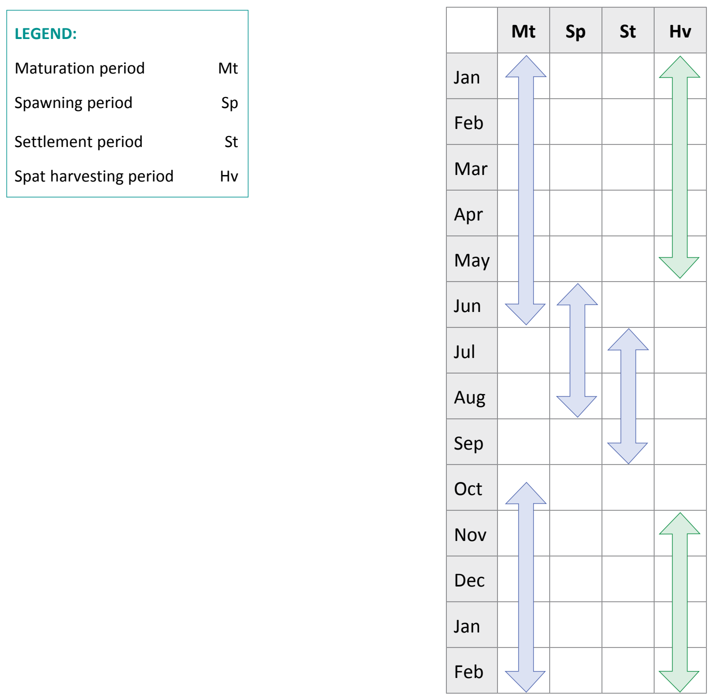
Under farming conditions, the product will be sold at a market size that ranges from 30 to 150 g in weight. Along the European coasts, the related timespan from fertilisation to market size will vary from 18 to more than 36 months.

Life cycle depending on geographic location

As stated above, the production cycle of the oysters will be affected by its geographic location.

For the purpose of this manual, Chapter 6 (Trestle cultivation) and Chapter 7 (Bottom cultivation) refer to the cultivation of the Pacific oyster under the climatic conditions of the North Atlantic coast (see Figure 2.4) where these two techniques are commonly used.

FIGURE 2.4
Pacific oyster life cycle timing in the North Atlantic region



Source: Elaborated by the authors.

For diploid oysters, the life cycle and growth data are summarised below:

Culture phases	Period
Maturation/gametogenesis	mid-October to end-June
Spawning	June to August
Settlement	July to September
Wild spat harvesting	November to February
Best sales period	mid-November to May
Market size: 30–150 g in weight	

Source: Elaborated by the authors.

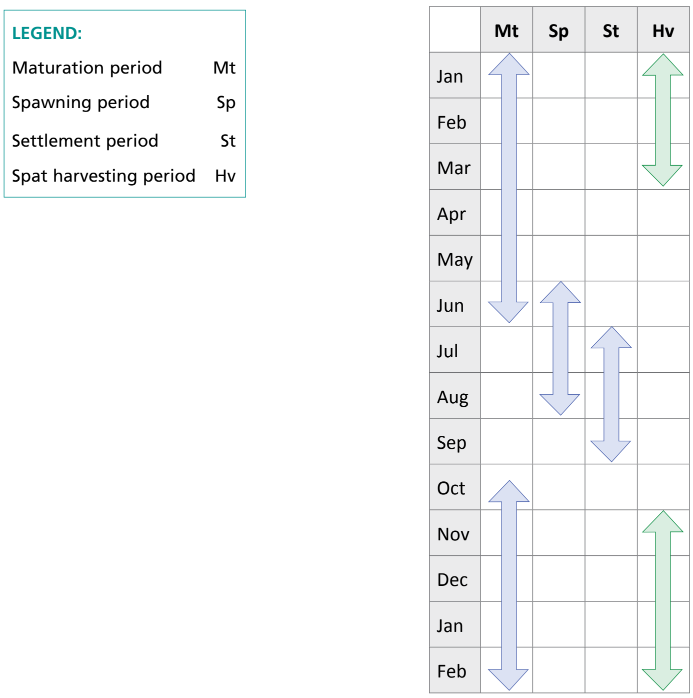
From T6 spat (see Table 4.3), the fastest growing oysters can reach 80 g in weight in about 18 months. Depending on the location and growing conditions, all the oysters under 150 g in weight will be sold within 36 months from T6 spat introduction.

Oysters spawn over a 3-month period (progressive spawning and unsynchronized animals). Consequently, settlement that occurs about 1 month after spawning, starts before spawning ends. For the same reason, all periods will partially overlap one after the other. Considering a physiological "gonads resting period" after spawning, the maturation period is estimated to start 2.5 months after the end of spawning. The market period starts about 1 month after gametogenesis starts and finishes when spawning starts, with sales being suspended during spawning (milky oysters) and in the following 2–3 months where meat content is too low (gonad resting).

For triploid oysters, the market period will extend over the entire year.

For the purpose of this manual, Chapter 8 (long-line technique) refers to the cultivation of the pacific oysters under the climatic conditions of the central Adriatic Sea (see Figure 2.5).

FIGURE 2.5
Pacific oyster life cycle timing in the central Adriatic Sea



Source: Elaborated by the authors.

For diploid oysters, the life cycle and growth data are summarised below:

Culture phases	Period
Maturation/gametogenesis	mid-October to end of June
Spawning	June to August
Settlement	July to September
Wild spat harvesting	November to February
Best sales period	mid-November to May
Market size: 30–150 g in weight	

Source: Elaborated by the authors.

From T6 spat, faster growing oysters will reach 45 g in weight in about 12 months. All the oysters under 150 g in weight will be sold within 32–36 months from T6 spat introduction.

The logical sequence and overlapping periods of the maturation, spawning, settlement and marketability as described for the North Atlantic region remain the same in the Adriatic Sea, while the timing is slightly different.

As above, triploid oysters will be marketable throughout the year.

2.1.3 Required environmental conditions

The Pacific oyster is a highly adaptable organism being both eurythermal (able to tolerate a wide range of temperatures) and euryhaline (able to tolerate a wide range of salinity).

TABLE 2.1
Water reference parameters for Pacific oyster

Parameter	Range
Water temperature	3–28 °C (1) Optimum between 10–22 °C
Air temperature (intertidal areas)	-1–40 °C
Salinity	10–35 ‰ (2) Optimum between 20–35 ‰
pH	7–9
Dissolved oxygen	> 2 mg O_2/litre
Chlorophyll-α concentration	Optimum 2 µg/litre Minimum 0.5 µg/litre

(1) Lower (-1 °C) or higher temperature (30 °C) can be tolerated for short periods.

(2) Lower (0 ‰) or higher salinity (38 ‰) can be tolerated for short periods.

Source: Elaborated by the authors.

The above-mentioned parameters in Table 2.1 are discussed in greater depth in Section 3.1, together with all parameters to be considered when choosing a site for farming.

The origin of the species, also known as the cupped oyster or Japanese oyster, is from the North Pacific area (Japan, Korea Peninsula, China). Nowadays, due to its introduction for aquaculture in many countries, and its ability to acclimate to a variety of environments, the species can be found in many locations across the globe (Appendix II).

TABLE 2 2
Main production countries – Global FAO aquaculture statistics (2020)

Country	Tonnes/year		%	Value/year (USD 1 000)		%
	2019	2020		2019	2020	
China	5 225 595	5 424 632	88 98	5 627 966	5 842 329	81 95
Republic of Korea	326 190	300 084	5 23	196 326	223 244	3 00
Japan	161 646	158 900	2 68	285 206	286 229	4 08
France	84 760	79 500	1 37	437 806	398 986	5 98
United States of America	26 529	22 134	0 41	53 878	42 783	0 69
Taiwan Province of China	19 392	19 165	0 32	117 091	125 518	1 73
Thailand	17 904	15 747	0 28	24 139	13 387	0 27
Ireland	10 460	9 242	0 16	50 586	43 491	0 67
Canada	7 786	5 149	0 11	11 496	7 682	0 14
Portugal	4 034	3 588	0 06	19 766	14 421	0 24
Mexico	3 489	3 873	0 06	5 615	5 717	0 08
Russian Federation	3 297	4 102	0 06	4 946	6 645	0 08
Australia	3 004	2 883	0 05	18 274	21 167	0 28
United Kingdom of Great Britain and Northern Ireland	2 680	2 200	0 04	10 534	8 686	0 14

TABLE 2.2 (CONTINUED)

Country	Tonnes/year		%	Value/year (USD 1 000)		%
	2019	2020		2019	2020	
Netherlands (Kingdom of the)	2 300	2 200	0 04	5 665	8 845	0 10
Brazil	1 900	1 700	0 03	2 023	1 801	0 03
New Zealand	1 871	1 364	0 03	16 172	11 791	0 20
Malaysia	1 568	135	0 01	7 227	233	0 05
Channel Islands	1 281	1 010	0 02	4 087	3 238	0 05
Spain	894	831	0 01	3 183	2 903	0 04
China, Hong Kong SAR	620	631	0 01	1 788	1 935	0 03
Morocco	423	345	0 01	1 760	1 453	0 02
Others	1 589	1 152	0 02	11 592	7 021	0 13
	5 909 212	**6 060 566**	–	**6 917 126**	**7 079 505**	–

Notes:

(1) Due to the fact that World Register of Marine Species (WoRMS) registered pacific cupped oysters, formerly members of the genus *Crassostrea*, in the new genus *Magallana*, FAO Fisheries and Aquaculture data for cupped oysters are registered under two names:
– ASFIS species name "Pacific cupped oyster", ASFIS species scientific name "*Magallana gigas*";
– ASFIS species name "Cupped oyster nei", ASFIS species scientific name "*Crassostrea* spp."

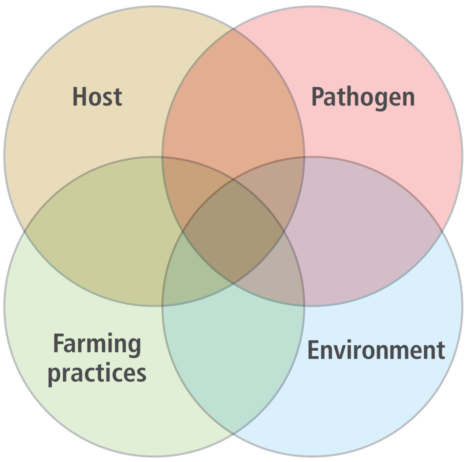
(2) Data from 2010 onward are detailed in Appendix II

Source: Elaborated by the authors.

2.1.4 Pathologies and predators

A variety of factors can lead to mortality and ill health in oysters. Figure 2.6 below summarises the factors to take into account when mortalities occur: a multifactorial approach should always be adopted, with particular attention to environmental conditions and farming practices which represent the majority of outbreak causes.

FIGURE 2.6
Host, pathogens, practices and environment relationship with regards to ill health in oysters



Source: Elaborated by the authors.

In the above-mentioned multifactorial approach, the farming practices represent the main factor on which the farmer can really act to prevent outbreaks or to mitigate their impact. In most cases, when mortality events occur, it must be noted that changes in farming practices can significantly reduce losses.

The other factors are out of the control of the farmer, who can only accumulate as much information as possible on all potential risks while doing the site selection process, and collaborate with the sanitary authorities to set and apply the outlined strategies to control the effects of pathogens and minimise the risks.

Pathogens and parasites

Pathogens can cause harm or impede the oyster's normal bodily functions. In severe cases this can cause mortality events, not just in the individual, but also on a mass scale and can lead to significant losses in the overall population.

Measures to mitigate mortalities are limited:

- Farming is conducted in an open environment so treatments that are based upon adding therapeutics into the water are not feasible;
- Bivalves feed on naturally occurring phytoplankton and therefore treatments based upon the addition of therapeutics to manmade feed, such as is the practice in other areas of marine livestock production, is not feasible.

Treatments can only be made in hatchery or nursery facilities where water flow is controlled and the volumes are relatively small.

When possible, the harvesting of deceased animals and their disposal should be done according to the local sanitary protocols. In many cases, limiting transfers of stocks to avoid the spread of the pathogens is advisable or can also be enforced.

Table 2.3 reports the most common pathogens farmers are likely to encounter. For more information, experts and scientific publications can be consulted.

TABLE 2.3
Main pathogens and parasites of the Pacific oyster

Pathogen species	Type	Susceptible species
Herpes virus – OsHV-1 µvar	Viral disease	*C. gigas* (juveniles mass mortalities)
Vibrio spp.	Bacterial disease	*C. gigas* (mass mortalities)
Nocardia crassostreae	Bacterial disease	*C. gigas* and *O. edulis*
Marteilia refringens	Protistan parasite	*O. edulis* and other oyster species (mortalities) *C. gigas* (without mortalities)
Bonamia ostreae	Protistan parasite	
Bonamia exitiosa	Protistan parasite	
Haplosporidium nelsoni	Protistan parasite	
Perkinsus spp.	Protistan parasite	*C. gigas* and other oyster species
Mikrocytos mackini	Protistan parasite	*C. gigas* (mortalities)
Polydora sp.	Polychaete worm parasite	All oyster species

Source: Elaborated by the authors.

Herpes virus – OsHV-1 µvar

Since 2008, *Herpes* virus has caused significant outbreaks in cupped oyster spat and juveniles and the resulting mass mortalities have been known to reach up to 100 percent. In Europe, the average mortality is considered to be in the range of 50–70 percent when compared to the number of spat that were introduced. Except for a few "Free zones", the virus is widely spread along all Atlantic and Mediterranean coasts.

Along the Atlantic coast, mortalities occur mainly in spring and early summer, as soon as the seawater temperature exceeds 16 °C. The spring outbreak is usually more harmful than the autumn one. A very high variability in mortality can be observed, depending on batches and from one year to the other, which makes it difficult to assess the best practices to mitigate the effect of the virus. During outbreaks, the detection of OsHV-1 is frequently associated with the presence of opportunistic or pathogenic bacterial strains. Mortalities appear to be observed in the same proportions in diploid and triploid oysters and there appears to be no discernible difference with regards to naturally occurring or hatchery produced spat.

Mortalities are lower in oysters stocked in the upper area of the intertidal zone, probably due to the reduced metabolism of oysters that grow less because of the reduced feeding time over the high tide period.

As a result of mass selection breeding programs and genomic selection, “Resistant spats” are currently produced in many hatcheries and the impact of mortality is progressively expected to decrease.

Vibrio spp.

Vibrio aestuarianus, *Vibrio splendidus* and other *Vibrio* species are frequently detected in cupped oysters. Nevertheless, it is often difficult to assess whether *Vibrio* acts as a primary pathogen or not. In many cases, they are thought to be only partially involved in multifactorial mortality outbreaks, for instance with *Herpes* virus as mentioned above. In other cases, as shellfish are filter feeders that can accumulate bacteria from the surrounding water, the detection of high bacterial concentrations may be difficult to interpret.

In France heavy hatchery mortalities have been reported caused by *Vibrio tubuashii*.

Even if they are not a pathogen for their host, three *Vibrio* species, *Vibrio parahaemolyticus*, *Vibrio vulnificus* and *Vibrio cholerae* should be mentioned as present in seafood and responsible for most cases of human illness caused by *Vibrio* strains (see Section 2.3).

Nocardia spp.

Nocardia crassostreae is reported to cause bacterial infection in cupped oysters and in flat oysters when cultivated together. Outbreaks have been reported in the United States of America, Canada, Japan and the Kingdom of the Netherlands. Mortality levels up to 30 percent have been observed.

Bonamia spp., *Marteilia* spp. and *Haplosporidium* spp.

Bonamia ostreae is a parasite belonging to the Cercozoa phylum and the Haplosporidia order. It causes the infestation of oysters’ hemocytes. It is widely spread across Europe, United States of America and Canada. Under laboratory conditions, direct transmission has been observed and the possible involvement of an intermediate host has still to be assessed. It causes heavy mortalities in *Ostrea edulis*, *Ostrea chilensis* and other oyster species. Even if its presence is observed in *Crassostrea gigas*, it does not cause mortalities.

Bonamia exitiosa is reported to infest *Ostrea angasi* (Australian flat oyster) and *Ostrea chilensis*. It is reported mainly in Autralia, New Zealand and Europe.

Marteilia refringens (or *Marteilia maurini)* is a parasite belonging to the Cercozoa phylum and the Paramyxida order. It causes heavy mortalities in flat oyster populations during the second year of infestation, during which the digestive tract is mainly affected. Direct transmission has never been demonstrated. Copepods are reported to be one of the intermediate hosts and the involvement of other hosts has yet to be assessed. Even when reported in cupped oysters, it does not cause mortalities.

Marteilia sidney infests *Saccostrea commercialis*, *Saccostrea echinata* and *Saccostrea glomerata* (Sydney rock oyster).

Haplosporidium nelsoni and *Haplosporidium costale* are known to cause heavy mortalities in *Crassostrea virginica* (MSX disease). Their presence has also been reported in *C. gigas* that does not appear to be affected.

Bonamia ostreae, *B. exitiosa* and *M. refringens* are reported by OIE (World Organisation for Animal Health, formerly the Office International des Epizooties) in the list of species to be notified.

All these parasites are not reported to cause mortalities in Pacific cupped oysters, but the fact that the disease has to be notified can lead to restrictions in available sites and in product transfers.

Perkinsus spp.

Perkinsus spp. belong to the dinoflagellates. Infections of *Perkinsus marinus* are reported in more than 50 shellfish species all over the world. Outbreaks are often reported with high temperatures in tropical and subtropical areas. The main species are *P. marinus* in North and South America, *Perkinsus olseni* in Australia and *Perkinsus atlanticus*, *Perkinsus mediterraneus* and *P. olseni* in Europe. In particular, *P. marinus* is reported to cause heavy mortalities in *Crassostrea virginica* in the United States of America.

Mikrocytos spp.

Mikrocytos mackini is known as the agent of the “Denmam island disease” in cupped oysters along the West coast of Canada. Pacific oyster (*C. gigas*), eastern oyster (*C. virginica*) and European flat oyster (*O. edulis*) are reported to be susceptible host species. On the Canadian West coast, spring outbreaks with mortalities reaching 30–40 percent have been reported in 2-year old oysters. Transmission is direct from host to host.

Outbreaks of *Mikrocytos mimicus* with high mortalities have also been reported in *C. gigas* farms in the United Kingdom of Great Britain and Northern Ireland.

Winter mortalities of the rock oyster, *S. commercialis* due to *Mikrocytos roughleyi* have been observed in Australia. Some authors suggested that *M. roughleyi* belongs in the phylum Haplosporidia and that it is closely related to *Bonamia* spp.

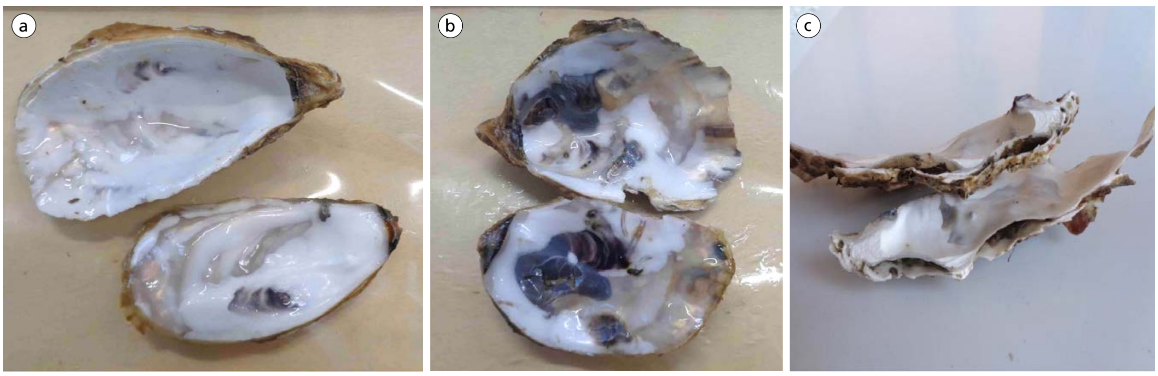
Polydora

The appellation of “*Polydora*” includes different species of Spionida polychaete worms that penetrate the shell affecting its appearance and integrity. The worms excavate tunnels until complete perforation of the shell occurs. After perforation, in reaction to the presence of the parasite, the oyster forms “blisters” with black foul-smelling content in the interior of the shell. As a consequence, there is the risk of breaking the shell or piercing the blisters when opening the oysters.

Depending on geographical areas, different species can cause damage to the shells. They do not induce mortalities, but decrease the commercial value of the product when sold alive for consumption in its shell (Figure 2.7).

Heavy infestations are frequently observed in coastal areas with calcareous rocks. Heat or hyper saline treatments can be applied to eliminate the worms, but empty cavities in the shell will be quickly colonised by a new generation of worms (planktonic larvae).

FIGURE 2.7
The impact of *Polydora* on oyster shells
(a) Grade 0 no blister. (b) Grade 4 blisters. (c) Blister section



The grade of infestation can be measured using the Handley and Berquist scale (1997):
- Grade 0: no blisters.
- Grade 1: less than 25 percent of the surface occupied by blisters.
- Grade 2: between 25–50 percent of the surface occupied by blisters.
- Grade 3: between 50–75 percent of the surface occupied by blisters.
- Grade 4: more than 75 percent of the surface occupied by blisters.

Predators

Oysters have many natural predators, of which humans are only one. Due to the abundance of nutrients that are contained within their flesh, they provide a wholesome and attractive meal for many other animals and, depending on the density of the predatory fauna that occupy the same environment, these organisms can consume a substantial amount of the native or farmed oysters.

TABLE 2.4
Main predators of the Pacific oyster

Predators	Example
Fish	Sea breams (Sparidae), flounders (Pleuronectiformes) and sandpipers (Scolopacidae).
Sponges	*Cliona* sp. – Penetrates the periostracum forming holes in the outer surface and a tunnel network throughout the shell.
Gastropods	Some species belonging to the Muricidae familly like *Hexaplex trunculus*, *Bolinus brandaris* and *Rapana venosa*.
Flatworms	*Stylochus* sp. – Enter the oysters when open for feeding and eat the adductor muscle as well as other internal organs.
Crabs	*Pinnotheres pisum* – Reduces market value. *Carcinus maenas* (shore crab) and *Cancer pagurus* (brown crab). *Carcinus aestuarii* and *Calinectes sapidus* (Mediterranean Sea).
Starfish	*Asterias rubens*
Urchins	*Strongylocentrotus droebachiensis*
Birds	Sea gulls, crows, eider ducks, etc. During low tide.

Source: Elaborated by the authors.

The impact of predation will also depend on the cultivation system that is used:
- Oysters that are grown on the bottom will be directly exposed to benthic predators;
- Oysters farmed in the intertidal zone will be exposed to predation by birds during the period around low tide;
- On-rope farmed oysters can suffer possible predation from turtles (*Caretta caretta*) and seabream (*Sparus aurata*), mainly affecting small- to medium-size animals.

In all the above-mentioned cases, it can be possible to install protective nets, but the related costs in terms of material and added handling will often make farming non competitive compared to areas where predation pressure is lower.

Some predators can cause problems no matter what farming system is used. An example of this is *Stylochus* spp., which is a polyclad flatworm, and is a common predator that feeds on both oysters and mussels from August to October (Figure 2.8). This worm can be partially eliminated during grading operations or by reducing density.

Competitors

Oysters are in direct competition for food with numerous other filter feeders that can settle in and around the cultivation devices. In many cases, the presence of these competitors can also have the deleterious effect of obstructing the water flow through the containers in which the oysters are grown.

FIGURE 2.8
***Stylochus* spp.**

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The oysters' main competitors are other bivalve species present in the same environment:

- Blue mussels (*Mytilus edulis*) along the European Atlantic coast where both mussels and oysters are commonly farmed in the intertidal areas;
- Mediterranean mussels (*Mytilus galloprovincialis*) in the Mediterranean Sea;
- Asian date mussel or Bag mussel (*Arcuatula senhousia*) in Asia, a small mussel species from the Pacific region that was accidentally introduced into other areas where it is becoming invasive;
- *Scapharca inaequivalvis* can be found in high densities in oyster lanterns in the Adriatic Sea.

Gastropods like the slipper limpets (*Crepidula fornicata*), a medium-sized sea snail belonging to the Calyptraeidae family that colonise huge areas where farming is performed, take away phytoplankton from the seawater and must be removed when preparing the seabed for on-bottom cultivation.

Most of these competitors have planktonic larvae which are introduced into the cultivation zone by water currents. The larvae then settle on the oysters' shells, in the containers they are grown in and upon the seabed. As these larvae are very small (less than 1 mm), there is no way to prevent their presence.

2.2 QUALITY ASSESSMENT PARAMETERS

This section provides guidance on the various factors that will need to be considered when looking at the quality of oyster that will be produced at the end of the cultivation process. The factors described below will be taken into account by the purchasers of the product and will have a bearing on the price paid for the product when placed on the market. It is important to note that some of these elements will vary in importance depending on the end use of the oyster and how it is going to be sold and consumed. For example, if the end product is going to be sold as shucked meat only, then the aesthetic appearance of the shell will not be of relevance to the customer. However, if the product will be sold whole and un-shucked, then the shell quality and appearance will be of greater importance, as this will be seen by the end user and potentially form part of the final dish.

2.2.1 Size standards

The size and grade of the oysters can be expressed in many different ways: average live weight, average length, number in a kilogram and so on. Table 2.5, referring to the French classification scale commonly used in all Europe, summarises the above-mentioned standards for commercial size cupped oysters.

TABLE 2.5
Pacific oyster size classification

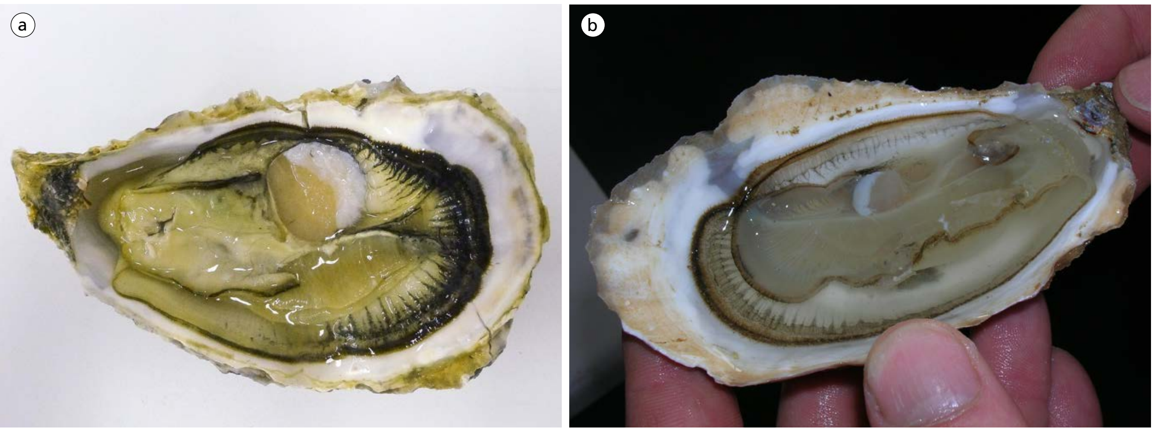
Size	Live weight range (g)	Average live weight (g)	Number/kg range
No.0	>150	>150	<7
No.1	110–150	130	7–9
No.2	86–110	98	9–12
No.3	66–85	75	12–15
No.4	46–65	55	15–22
No.5	30–45	37	22–33

Source: Elaborated by the authors.

2.2.2 Meat content

The oyster meat is ultimately where the value of the product lies and, therefore, the higher the meat to shell ratio is, the higher the potential price of the product that can be demanded from the market. However, there are other factors, such as supply versus consumer demand and the taste of the product, that will affect the market price. For the consumption of raw oysters, the taste will be particularly important. Figure 2.9 gives examples of the meat content of oysters from different provenance.

FIGURE 2.9
Examples of oyster meat content
(a) Oyster with high meat to shell ratio, grown using the bottom cultivation technique in suitable trophic conditions along the North Atlantic coast. (b) Oyster with low meat to shell ratio, grown using the long-line cultivation technique after a drought period with reduced phytoplankton availability in the central Adriatic Sea



Meat content is probably the most important quality criteria. It is commonly expressed as a percentage and reflects the weight of the meat (after draining) in relation to the total weight of the oyster before opening.

In France, the “Afnor index” is calculated using 20 animals with the calculation being the “total meat weight/total weight × 100”. It is used to identify the “*Fines*”, that have an index between 6.5 and 10.5, and the “*Spéciales*” that have an index of 10.5 or more.

The procedure for conducting a meat to shell ratio analysis and calculating the resulting value is as follows:

- Take 20 whole oysters and clean the shells to ensure that there is no bio-fouling or other detritus attached to their exterior;
- Dry and weigh the 20 whole oysters and record the overall figure;
- Shuck the oysters' meat from the shells and place the meats onto an absorbent cloth or pad to remove any excess liquid;
- Weigh the 20 meats and record the total figure;
- Divide the weight of the meat by the weight of the whole oysters and multiply this figure by 100;
- The resulting figure is the percentage of meat contained within the whole organism.

Meat content depends on many factors such as phytoplankton concentration and composition, tide and coastal currents in the farming area, position in the intertidal zone, flow of seawater through the cultivation devices depending on the available volume and the used mesh (bags an lanterns), rearing densities and ploidy.

Regarding this last point, meat content and quality of diploid oysters that undergo gonad maturation, will be different when compared to triploid oysters. Diploid oysters will generally present better meat content as well as better organoleptic features during the maturation period, while quality will be negatively affected during the breeding season and after they have released their gametes. When releasing their gametes, diploid oysters can be described as "milky" and have a creamy texture that can reduce the enjoyment of consuming them during this phase. If the water temperature does not reach the trigger temperature required for the oysters to fully release their gametes, they can remain in this condition for an extended period. If the farm is situated in a location where this scenario is likely to occur on a regular basis, then the use of triploid oysters is recommended for harvesting over the summer season.

The shell thickness and density will also affect the meat-to-shell ratios. For a constant weight of meat, the meat to shell ratios will appear lower in oysters with thicker shells and vice versa. Consequently, where the oysters are grown will have a bearing on their meat-to-shell ratios. Oysters cultivated in the intertidal zone that are slower growing and therefore produce thicker shells will have a relatively lower meat-to-shell ratio. In contrast, oysters cultivated in the subtidal zone or on long-lines that grow faster and present thinner shells will yield better meat-to-shell ratios than their intertidal equivalents.

The shell's internal volume will also affect the meat-to-shell ratios. Oysters that have a deeper cup will generally have a better ratio.

Meat quality and organoleptic features

The organoleptic traits of the oysters are affected by the site characteristics (phytoplankton and salinity), the season and the farming practices. Consequently, their taste (sweet, sour, salty, bitter, umami), their texture (tender, tough, fatty, etc.) and the overall final sensation left after eating (mineral, vegetal, fruit-like, etc.) are influenced by these factors. "Flavour wheels", where all these factors are represented in a graphical form, can be used to describe the oysters and to compare what the French call "*Merroir*" (the local conditions that influence the taste of the product).

In Europe, during local or international events, tasting panels are assembled to compare products and "*Merroir*" and to elect what they believe to be the best "product of the year".

In some particular cases, the environment in which the oysters are grown can be influenced by human management practices. For instance, phytoplankton composition and concentration in coastal ponds can be controlled and boosted through regulation of water intake, drying and preparation of the bottom to control the algal bloom.

A well-known example of such human intervention are the "*Claires*" used by oyster farmers in certain parts of France. These shallow water ponds are used during the final 2–3 weeks of the cultivation cycle to finish the product and the oysters produced in this manner are sold as "*Fines de claires*".

Finally, the conditions and duration of storage post-harvest will also have to be considered, as oxidation processes will quickly take place, modifying both the taste and organoleptic traits.

2.2.3 Shelf life

Shelf life is the period of time that the oysters can remain alive and suitable for human consumption once they have been removed from the water. It is expressed in days after harvesting and depends primarily on previous growing conditions, gonad maturation and storage conditions.

If the oyster meat is processed at the same site from which shellfish have been harvested, or in a short time after harvesting in another processing plant, shelf life is not a relevant consideration. Conversely, if oysters have to be transported to markets in locations some distance from the cultivation site and will not be consumed shortly after their harvest or dispatch from the production facility, it will be important that they have a shelf life that is long enough to ensure their suitability for human consumption.

When the oysters are conveyed as whole live animals, their ability to withstand exposure to the air and handling will have an effect on the quality of the product that is received by the customer. Where the oysters have been cultivated will have a bearing on their shelf life.

Influence of cultivation environment

Oysters grown in subtidal zones or on long-lines spend the majority of their lives with their shells open whilst they filter nutrients out of the water. Because they don't need to open and close their shells on a regular basis, their adductor muscles are relatively weak and therefore, when they are removed from the safety of their underwater environment, they are less able to keep their shells closed for extended periods of time. In this situation, when the oyster gapes open, they lose any of the seawater that they hold within their closed shells and, without this, the organism will desiccate and die unless re-submersion occurs rapidly. This affects their ability to withstand prolonged periods of exposure to the air and therefore reduces their shelf life.

Oysters grown on intertidal sites need to close their shells each time the tide ebbs and exposes them to the elements above the waterline. Due to this repeated exposure, their adductor muscles are stronger and this allows them to remain tightly closed for longer when removed from the water, retaining the moisture within their shells and prolonging their ability to survive. This increases their shelf life.

In suitable and stable storage conditions, the shelf life of oysters grown in intertidal areas can be more than 20 days, while oysters grown in subtidal zones or on long-lines where they are constantly submerged will have a shelf life of about 7–10 days.

Influence of gonad maturation

At the end of maturation and during the period that the oysters release their gametes, the shelf life is usually reduced.

Influence of storage conditions

When packaging oysters, it is important to do so in a manner which limits the loss of water that they hold within their shell. Oysters should always be packed in a horizontal position, with the cupped valve underneath and with the box tightly closed to prevent oysters from gaping.

2.2.4 Shell quality and appearance

The consumption of raw oysters, presented in their half shell, is increasing all over the world. Due to this, the shell shape and quality, other organisms present on the shell (bio-fouling) and the internal aspect become important quality criteria to be taken into account.

Shape of the shell

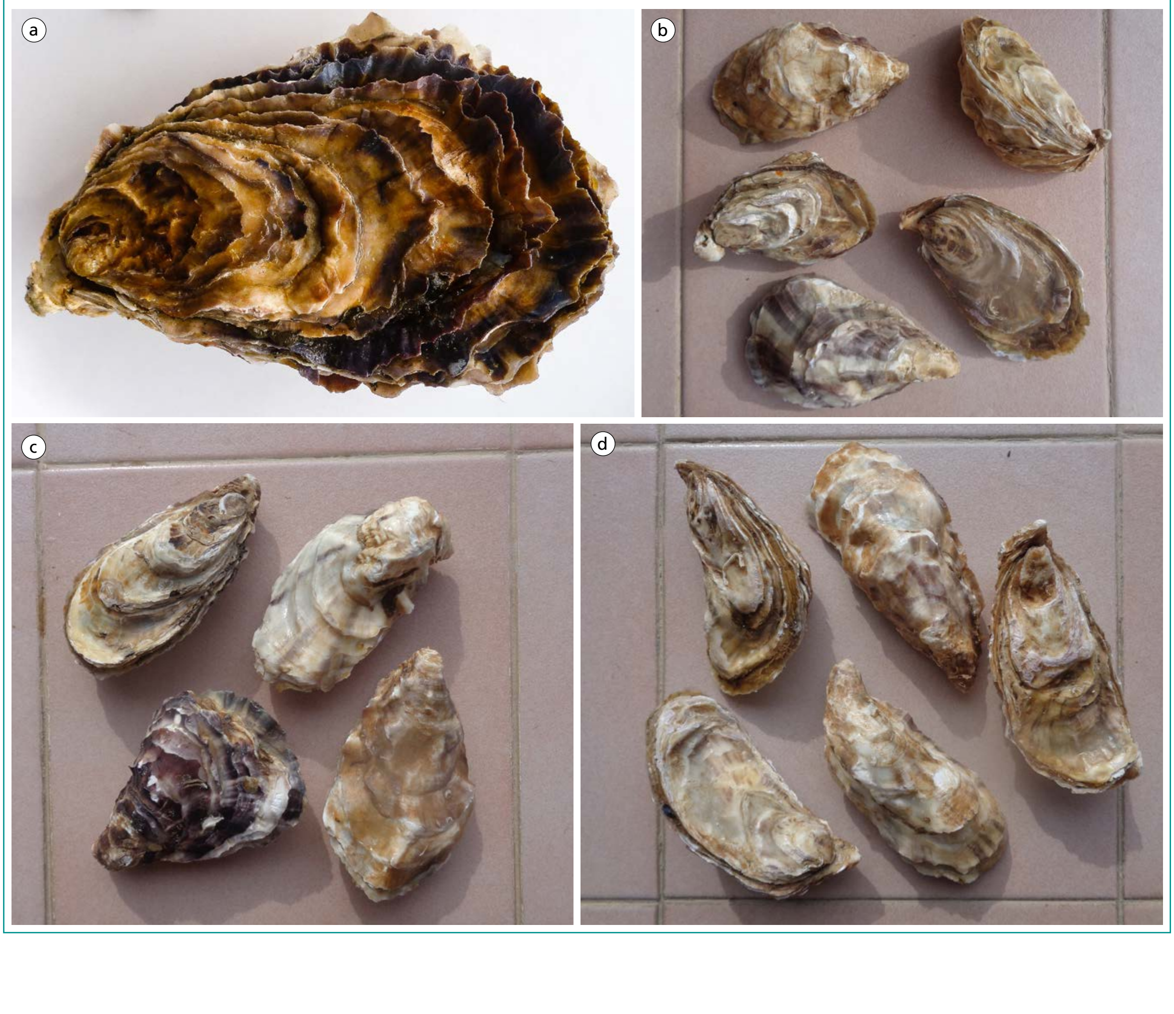
Depending on the cultivation technique, the shape of the shell and its external appearance can be modified as the animals adapt themselves to their available space. If the space inside their cultivation container is not big enough, or the stock is not well managed, the mesh of the nets or baskets in which they are grown will be imprinted on the shell. In other cases, the oysters can appear too long and thin.

The relationship between length, width and thickness can be used as an indicator of quality. In France, a shape index to indicate the desired proportions of an oyster is often calculated using the formula (length + thickness) / width. A result of under 3 is recommended. If oysters are not free to move in a suitable way or periodically moved according to farming practices, the shell shape can be negatively affected with either a shallow cup or deformities occurring. Obtaining a suitable shell shape and volume will depend on the applied practices from the hatchery stage onwards, with particular attention being paid to densities and handling frequency. Figure 2.10 below illustrates some different outcomes regarding external shell shape.

FIGURE 2.10

Examples of Pacific oyster shell shape

Oyster produced on trestle in the Atlantic (a). Oysters produced in long-lines with standard shape (b), malformed (c), and "long" (d) in the central Adriatic Sea



Shell strength

The density and strength of the shell that the oyster produces is another important factor to be considered when assessing quality. The speed at which the oysters grow will influence this factor. Oysters that grow in a high nutrient, subtidal environment tend to grow very fast in relative terms. The same is observed for oysters grown on long-lines. In the Mediterranean Sea, where the temperature is higher compared to the ocean, shell fragility becomes a real problem in the faster growing product.

Because of this accelerated growth, they need to rapidly enlarge their shell size to allow them to increase their body mass. They therefore do not have the time to thicken the shell with the extra layers of calcium carbonate normally present and this can result in a shell that is thinner and weaker. This can lead to more losses during grading and other general farming operations as well as from predation. It is also a particular problem for customers who wish to serve their oysters in the half shell because, if the shell breaks during the "shucking" operation, the oyster is not then presentable for serving and fragments can remain on the flesh making it unpleasant to eat.

Biofouling

Biofouling is the presence of organic growth on the outer surface of the oyster shell that will vary depending on the organisms present in the production area and handling practices. This can take the form of algal growth, sponges, tube worms, encrusting bryozoans and barnacles amongst others. Some will be direct competitors for food as described previously. Some will only affect the aesthetic appearance whilst others can actually affect the physical integrity of the shell and leave the oyster more prone to predation. Also, as these other organisms die and decompose, they can produce an unpleasant odour that affects the quality of the product.

Table 2.6 below outlines the main biofouling elements that are likely to be encountered.

TABLE 2.6
Main biofouling organisms on Pacific oysters

Biofouling organism	Description
Algal biofilm	Aggregation of microalgae that forms mats on aquatic surfaces.
Macroalgae	Multicellular species of algae.
Bryozoa	Filter feeding, small aquatic organisms that live in colonies. They produce organic skeletons that can take many different forms.
Barnacles	Small crustaceans that are sessile suspension feeders. They encrust a marine surface and grow their shell directly onto the substrate.
Serpula worms	Calcareous tube worms that attach themselves to a substrate and live within their protective casing.
Tunicate	Commonly known as sea squirts. Oval shaped ascidians that attach themselves to marine surfaces using a sucker.

Source: Elaborated by the authors.

2.2.5 Managing quality

The meat content, shelf life and shell characteristics of the oysters are interdependent and cannot be dealt with separately. As mentioned previously, final product quality will depend on the applied farming practices from the hatchery stage onward, with particular attention paid to densities and handling frequency. When producing, harvesting or buying spat to be introduced to the farm, the quality of the seed will significantly influence the quality of the final product. The seed should demonstrate good external shape, have very few individuals that are welded together (also known as "doubles") and be able to maintain a strong seal between their left and right valves when out of the water.

An important strategy to improve the quality of the oysters consists of "hardening" them at different stages of the farming cycle. This involves exposing the oysters to the air for a period of time. The techniques for "hardening", during both the growing and pre-sale stages, are introduced in Section 4.6. The specific strategies for "hardening" will be discussed in the chapters describing the "farming practices" for each individual cultivation technique.

2.3 CONSUMER SAFETY

Bivalve molluscs are filter-feeding organisms, and as a result can concentrate microorganisms, chemical contaminants and biotoxins present in their growing environment. Because of this, there is a requirement for stringent food safety protocols for their production and sale, thereby ensuring consumer protection and facilitating trade. Food safety considerations for production and processing of bivalve molluscs, and particularly for live and raw animals, are reported in Appendix I.

The main risks for consumer safety are related to:
- Microbiological contaminations;
- Illness caused by algal toxins;
- Illness caused by some *Vibrio* strains;
- Norovirus contaminations.

Microbiological contaminations

Microbiological contaminations are usually related to anthropic activities on the seashore and freshwater discharges into the sea. Each individual country where shellfish farming is performed adopts their own regulatory framework to prevent and/or monitor the risk for consumers.

In the European Union and the United Kingdom of Great Britain and Northern Ireland, waters are classified depending on contamination levels through sampling made every 15 to 30 days. The criteria and thresholds are reported in Table 2.7.

TABLE 2.7
Bivalve production areas classification in the United Kingdom of Great Britain and Northern Ireland

Class	Yearly limits
A	80 % of samples must be ≤230 *E. coli*/100 g of shellfish flesh; All samples must be less than 700 *E. coli*/100 g
B	90 % of samples must be ≤4 600 *E. coli*/100 g of shellfish flesh; All samples must be less than 46 000 *E. coli*/100 g
C	All samples must be ≤46 000 *E. coli*/100 g of shellfish flesh
Prohibited areas	Any samples containing >46 000 *E. coli*/100 g of shellfish flesh

Source: Elaborated by the authors.

Other systems are based more on prediction models, avoiding harvesting shellfish when conditions are expected to lead to higher contamination levels (for example, during certain seasons or after heavy rain).

Algal toxins

Algal toxins are produced by some phytoplankton species, which in turn are filtered and accumulated by bivalve molluscs. Depending on their chemical structure, algae toxins are classified in 8 classes (FAO/WHO/IOC workshop, 2004):
- Azaspiracids and AZAs
- Brevitoxins and PbTXs
- Cyclic imine toxins
- Domoic acids (DAs)
- Okadaic acid and derivative (OAs)
- Pectenotoxins (PTXs)
- Saxitoxins (STXs)
- Yessotoxins (YTXs)

These toxins are also classified, based on the effect they have on consumers' health:
- Paralytic Shellfish Poisoning (PSP) – Caused by saxitoxins (STXs), neosaxotoxins, gonyautoxins and cyclic imine toxins from algae like *Alexandrium catenella*,

Alexandrium minutum, *Alexandrium tamarense*, *Pyrodinium bahamense*, *Gymnodinium catenatum*, etc.;
- Amnesic Shellfish Poisoning (ASP) – Caused by domoic acid (DAs) from algae like *Pseudonitzschia seriata*, *Nitzschia pungens*, etc.;
- Diarrhetic Shellfish Poisoning (DSP) – Caused by the lipophilic toxins (okadaic acid, azaspiracids, pectenotoxins, yessotoxins and dinophysistoxins) from algae like *Dinophysis* spp., *Gonyaulax grindleyi, Lingulodinium polyedrum*, etc.;
- Neurotoxic Shellfish Poisoning (NSP) – Caused by brevitoxins from algae like *Gymnodinium breve*, *Karenia brevis*, etc.

Vibrio strains

In response to a request from the Codex Committee for Scientific Advice in 2001, the Food and Agriculture Organization (FAO) and the World Health Organization (WHO) of the United Nations established a risk assessment drafting group and convened an expert consultation to take the first steps in developing a risk assessment for *Vibrio* spp. in seafood products that would have the most impact on public health and/or international trade. The expert consultation concluded that three species, *Vibrio parahaemolyticus*, *Vibrio vulnificus*, and *Vibrio cholerae* were the species responsible for most cases of human illness caused by *Vibrio* strains, and several seafood vehicles associated with these illnesses were identified.

Vibrio parahaemolyticus is a marine microorganism native in estuarine waters throughout the world. The organism was first identified as a foodborne pathogen in Japan in the 1950s (Fujino *et al*., 1953). By the late 1960s and early 1970s, *V. parahaemolyticus* was recognized as a cause of diarrhoeal disease worldwide, although most common in Asia and the United States of America. In 2011, FAO published the volume “Microbiological Risk Assessment series 16 – Risk assessment of *Vibrio parahaemolyticus* in seafood – FAO 2011” (see Further reading).

Vibrio vulnificus naturally inhabits warm estuarine environments and can infect humans via wound exposure or seafood consumption. These infections are rare and generally limited to individuals with pre-existing chronic illnesses or the immune-compromised. However, *V. vulnificus* can invade through the intestinal barrier into the bloodstream, causing primary septicaemia. As a result, it has the highest case/fatality rate (approx. 50 %) among foodborne pathogens. In 2011, FAO published the volume “Microbiological Risk Assessment series 8 – Risk assessment of *Vibrio vulnificus* in raw oysters – FAO 2005 (see Further reading).

Norovirus

Recently, attention has been paid to *Novorirus* foodborne toxi-infections. In November 2019 the European Food Safety Authority (EFSA) published its report on noroviral prevalence in areas of production and shipping of oysters in the European Union (see Further reading). In June 2020 the European Aquaculture Advisory Council (AAC) published its recommendation “*Norovirus* 2” (see Further reading) on the proposal for a delegated act to amend Annex III to Regulation 853/2004 (AAC 2020-04) where AAC agreed that the viral risk assessment should be based on a sound scientific basis and is relevant when:
- It is based on the detection of infectious particles and not on the detection of RNA genomes (the genetic material of *Norovirus*), using the current ISO 15216 standard;
- It demonstrates the link between the prevalence and amount of viral infectious particles in the foodstuff and the prevalence of gastroenteritis among consumers.

3. Site survey

Section 3.1 gives an overview of the possible typologies of sites that can be used for the cultivation of oysters. It also gives definitions and indications on the parameters to look for to assess if a site is suitable for farming or not. Once the reader has familiarised themselves with these factors, Section 3.2 lists the possible constraints to be taken into account before launching a farming activity.

The selection of a good site for bivalve aquaculture is a crucial process and is one of the most important elements that will contribute to the success of any intended farming activities. There are many contributing factors that need to be present in a successful site, some which are mandatory, such as good water quality and an abundance of suitable phytoplankton, and some that can be compromised upon, such as the proximity of the cultivation site to any land-based processing facilities. In an ideal world, all of the desired parameters that are discussed in the following chapter would be present in one site making it a perfect location for the cultivation of oysters. However, in reality, most sites will represent a compromise as there are very few locations that will fulfil every criterion. The site selection process should therefore highlight the strengths and weaknesses of the potential farming location, and the decision made about the suitability for cultivation should be based upon the most important factors that will lead to a successful outcome. An example of an acceptable compromise would be an offshore farm, where the water quality is good and there is an ample supply of the required planktonic nutrients, but the location is a long way from the land-based facilities (the port where the workboat is moored) and the site is exposed to wind and wave action. So long as the travel time to the site is not too long and the climatic conditions not too severe, then the inconvenience of the geographic location is outweighed by the ability to produce a quality product. An example of an unacceptable situation would be an estuarine site with easy access and protection from the elements, but with such poor water quality that the cultivated shellfish would be unsafe for human consumption. Undertaking a thorough site selection process should enable the farmer to pick a location based upon the required criteria and prevent them from attempting to undertake cultivation activities in an unsuitable environment.

3.1 SITE DESCRIPTION

3.1.1 Site typologies

The farm site can be defined as the limited area of operation, where the farm will be installed. More potential farm sites can be available in the extended area of the coastline. According to the seashore configuration, local rules for licensing and traditions, the farmer will have to choose both the farm site and the farming technique that is appropriate for the site.

The main aspects to be taken into account will be the presence of tides, the depth, the level of exposure, the supply of freshwater, the currents and the water parameters like temperature, salinity, dissolved oxygen, suspended solids and dissolved chemical elements.

The presence of tides and the mean tidal range will inform the operator whether it will be possible to farm shellfish in the area of the foreshore that is exposed over low tide, the so-called "intertidal zone". Many farming technologies have been developed in these areas, where access is clearly easier than in the open sea. As it will be pointed out later, farming in the intertidal zone will also impact on production costs and product quality. Farming can also take place in the "subtidal zone", that is in the shallow waters just after the "intertidal zone" before moving towards the open sea. In this last case, farming is carried out continuously under water. Where tides do not exist, or have a limited tidal range, all of the farming activities will be based around techniques that are suited to permanently submerged conditions such as exists on offshore sites. Figure 3.1 shows examples of different oyster farming zones and the most suitable cultivation technique based upon their position in relation to the water depth and tidal range.

The tidal range is the vertical distance through which the tide rises and falls, the difference in water height between low tide and high tide. The "mean tidal range" is calculated as the difference between mean high water (i.e., the average high tide level) and mean low water (the average low tide level).

The extension of the intertidal zone will also depend on the depth and the inclination of the foreshore in the area of coastline under consideration. If detailed cartography is not available, it will be necessary to do a preliminary survey to set up a bathymetric map of the possible areas.

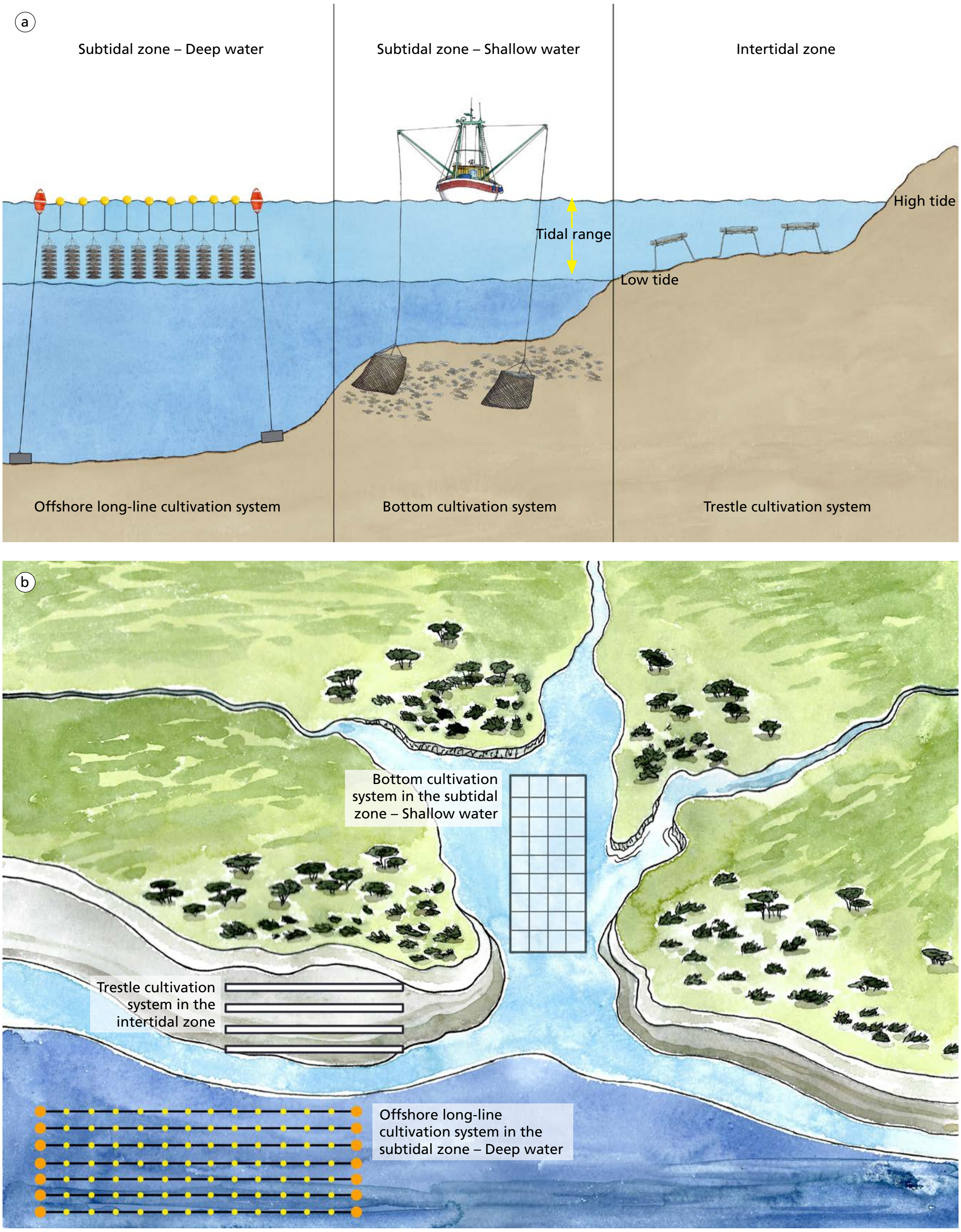
"Exposure" is defined as the way the site can be affected by the potential effect of dominant winds and waves all-round the year. The severity of the effect will depend on the "fetch", which is the distance over the water that the wind has blown without hindrance in the direction of the farm site before impact with the cultivation equipment. The longer the fetch, the higher the risk will be that the farm will sustain some damage, particularly when maximum fetch corresponds to dominant winds or to tempest winds. For a given wind direction, fetch is calculated as the distance between the farm and the opposite coastline (miles or km). In "sheltered sites", for instance in lagoons, rivers, estuarine zones or bays protected by physical barriers, this distance will be reduced and the risks will be limited. In the "exposed sites", the fetch will be typically greater. Exposed sites can be near to the shoreline or completely offshore. Independently from the fetch, the waves' maximum and average height, depends also on the depth of the water: wave height is inversely proportional to depth. In shallow water the waves period will be shorter and waves breaking more frequent.

When considering the exposure, two potential effects have to be considered: the risk of damages in case of exceptional events (storms, tempest or typhoon) and the deterioration of the farm components under the continuous effect of waves. In exposed sites, the "return time" of extreme events, that is the average time between two occurrences, will have to be evaluated (in some countries, historical data is available). In subtidal and offshore farms, the economic impact of the average number of days where the farm cannot be reached because of rough conditions will have to be estimated.

Many sites are affected by freshwater run-off that causes a high degree of variation in salinity and nutrients availability. Farming is currently carried out in these sites because of the resulting benefits in terms of feeding capacity and product quality.

Another physical parameter that needs to be accurately evaluated is the presence and strength of currents in the location of the farm. Currents can be the result of tidal flows, freshwater supply (rivers), dominant wind and marine water circulation. The assessment of currents will influence the choice of cultivation equipment and its positioning within the area as some systems will not be suitable for locations with particularly strong currents. However, the water exchange and the resulting refreshment of nutrients and dissolved oxygen caused by currents is vital for the successful cultivation of oysters. For example, in sheltered areas with limited wind and wave action, currents play a key role in refreshing the water around the stock and thereby reduce the risk of the conditions becoming anoxic which can cause mortalities in the oysters.

FIGURE 3.1
Overview of suitable site typologies
(a) Cross-section view of different oyster farming zones and the most suitable cultivation technique based upon their position in relation to the water depth and tidal range. (b) Aerial view of different cultivation **zones**



Source: Elaborated by the authors.

TABLE 3.1
Sheltered and exposed site characteristics

	Sheltered site	Exposed site
Presence of physical barriers & fetch	Barriers protect the site from the effects of dominant wind and waves. Fetch is typically low.	Barriers that can protect the site from the effects of dominant wind and waves do not exist. Fetch is high and has to be accurately assessed.
Example	Lagoon, bay, river, estuarine area, channel.	Open sea, unprotected shoreline.

Source: Elaborated by the authors.

3.1.2 Environmental parameters to be collected for site description

Environmental conditions can be highly variable from one year to the next and therefore these fluctuations, and their effect on the oysters will have to be taken into account. If available, then the assessment of historical data can help to give a picture of the average conditions that are likely to be experienced on the site. When studying this information, it is important to look at as many previous years as possible. If data is not available, data collecting and in situ surveys should be undertaken for a period of at least 1–2 years. If other farms are already operating in the local area, then it is recommended to consult them to gain insight into the general conditions. Local fishers will also have an in-depth knowledge of the environment and can be an invaluable source of information regarding this. Tables 3.2–3.5 provide key physical, meteorological, chemical and biological parameters that would require to be assessed during a site survey.

TABLE 3.2
Physical parameters to be assessed during site survey

	To be assessed
Coastline configuration Depth	• Cartography • Bathymetric cartography or preliminary survey **Map scale:** - Map scale of at least 1:5 000 for land-based or intertidal facilities - Map scale of at least 1:100 000 for marine maps
Access to the potential farm sites	Access to the facilities is a key factor that has to be considered from the beginning as it can have a significant effect on profitability. • Road access to land-based facilities • Tractor and boat access to intertidal facilities • Boat access to offshore facilities (nearest harbour) **Expression:** Mile or kilometre, but also in time (hour/minute) to reach the farm
Tides	• Presence of tides and related tidal range • Tide flows and related currents • Extension of the intertidal zone (depending on bottom inclination) **Expression:** - Mean tidal range in meters/feet - Mean tidal flow (knot or cm or m)/unit of time (second or minute)
Freshwater supply	• Presence, magnitude and seasonal variations • Related currents and seasonal variations **Expression:** - For rivers in cubic m/time unit (second, minute, hour) - Flow (cm or m)/time unit (second, minute)
Bottom	• Sandy, muddy, rocky • Presence of seaweed or seagrass
Temperature	• For each potential site in a given area: temperature range and related seasonal variations with particular attention to minimum and maximum values that can be a limiting factor for the cultivated species. • In subtidal and open sea conditions, possible water stratification (thermocline) and related seasonal variations. **Expression:** °C (Celsius) or °F (Fahrenheit)

Source: Elaborated by the authors.

TABLE 3.3
Meteorological parameters to be assessed during site survey

	To be assessed
Wind orientation & related fetch	• Dominant wind orientation and related fetch • Tempest wind orientation and related fetch • Winter tempest average duration (number of days) • Risk of typhoon **Expression of wind speed:** knots, kilometres/h, miles/h Wind can also be expressed in "strength" with reference to the Beaufort scale or other similar scales
Waves height	Wave height of a surface wave is the difference between the crest and a neighbouring trough and is twice the amplitude. • Maximum wave height in the case of extreme events • Significant Wave Weight (SWH) defined as the average height of one-third of waves having the greatest heights • Number of days where waves are expected to be too high to allow to work on the farm (this estimation will have to be referred to the workboat design and its dimensions) **Expression of wave height:** metres or feet Table of the World Meteorological Organization (WMO) Sea state code (Table 3.4)
Return time of extreme events	• Winter tempests • Typhoons • Drought periods • Harmful algal blooms (HABs) and anoxia events Take into consideration the fact that, due to climate change, the frequency of extreme events may increase significantly.

Source: Elaborated by the authors.

TABLE 3.4
World Meteorological Organization sea state code (Douglas Sea Scale)

State	Wave height (m)	Description
0	0 m – (0 feet)	Calm (glassy)
1	0–0.1 m – (0.00–0.33 feet)	Calm (rippled)
2	0.1–0.5 m – (3.90 inches to 1 foot 7.7 inch)	Smooth (wavelets)
3	0.5–1.25 m – (1 foot 8 inches to 4 feet 1 inch)	Slight
4	1.25 to 2.5 m – (4 feet 1 inch to 8 feet 2 inch)	Moderate
5	2.5 to 4 m – (8 feet 2 inches to 13 feet 1 inch)	Rough
6	4–6 m – (13 to 20 feet)	Very rough
7	6–9 m – (20 to 30 feet)	High
8	9–14 m – (30 to 46 feet)	Very high
9	>14 m – (46 feet)	Phenomenal

Source: Elaborated by the authors.

TABLE 3.5
Chemical environmental parameters of the seawater to be assessed during site survey

	To be assessed
Salinity	• Presence of fresh water supply and seasonal variations • Salinity range and seasonal variations **Expression:** In g/L or g/kg or ‰ (equivalent per thousand – ‰)
Dissolved oxygen	• Verify if anoxic events have occurred in the past and where. **Expression:** mg/L
Turbidity or light penetration	Turbidity can be defined as an obstacle to the vertical penetration of the light into the water column. It depends mainly on suspended solids and phytoplankton concentrations. • Light penetration in the water can be roughly measured with a Secchi disk (Appendix III). **Expression:** Depth in metres at which the disk disappears for an observer looking down from the water's surface

TABLE 3.5 (CONTINUED)

	To be assessed
Suspended solids	It refers to small solid particles that remain in suspension in water. Some of the suspended solids will be filtered by the shellfish and immediately eliminated as "pseudofaeces" that cannot be assimilated. An excess of water turbidity will cause the shellfish to waste energy and result in slower growth rates. • Suspended solids can be assessed through sampling and laboratory analysis or by electronic measurement devices. **Expression:** - In case of sampling and analysis, it is usually expressed as "Total suspended solids" (TSS in mg/L) that is the dry weight of suspended particles that can be trapped using a filtration apparatus.
Chemical pollutants	Potential pollutants are numerous and, in many cases, difficult and expensive to detect. It is not technically and economically sustainable to carry out periodical samplings and analysis to get a thorough overview of the situation. Alternatively, the best approach is to refer to reports from local authorities or to conduct a survey of pollution sources to focus on a few analyses. Main pollution sources to be consider are: • Presence of industry and related discharge • Presence of polluted river effluents • High population density • Maritime traffic Main pollutants to take in account are: • Cadmium, mercury, lead, nickel and copper • Heavy metals • Aromatic hydrocarbons (benzene, toluene, xylene, etc.) • Chemical compounds that can enter the nitrogen cycle and phosphorus cycle, causing eutrophication and algal blooms

Source: Elaborated by the authors.

TABLE 3.6
Biological environmental parameters of the seawater to be assessed during site survey

	To be assessed
Nutrient availability: Chlorophyll-α concentration	Shellfish are filter feeders that need phytoplankton for growth and the chlorophyll-α concentration in the seawater is the easiest measuring system to get an indication of phytoplankton availability. • Chlorophyll-α concentration and seasonal variations. **Expression:** in microgram/litre or µg/litre - The data indicates the total concentration of chlorophyll-α of all of the various sizes, including picoplankton (<10 µm) that is too small to be filtered and assimilated by shellfish, so this should be discounted from the total amount available and taken into account when undertaking the assessment. - Nowadays, satellite data is fully available and represents a reliable source of data, but in situ sampling should be periodically undertaken and analysed to ensure that there is an accurate correlation between satellite data and in-situ data (laboratory analysis). - Satellite data is limited to chlorophyll-α determination, while laboratory analysis can be performed for chlorophyll-α and other pigments. - Satellite data refers to surface water while in situ sampling can be made at different water depths.
Nutrient availability: Phytoplankton characterization	The parameter assessed above does not give a qualitative indication. Shellfish need a suitable phytoplankton composition for growth and therefore it is important to conduct further investigation into the following factors: • Phytoplankton concentration and related seasonal variations • Phytoplankton composition and related seasonal variations, including concentration of the most representative species/species groups • Phytoplankton size and related seasonal variations
Biological pollutants	Like for chemical pollutants the approach is to refer to reports from local authorities or to conduct a census on pollution sources to focus on few analyses. Main pollution sources to consider are: • Presence of sewage related to high population density or terrestrial animal production • Inefficient water treatment As well as chemical compounds, some biological pollutants such as organic matter in suspension or sediments, can enter the nitrogen cycle and phosphorus cycle causing eutrophication. Other main biological pollutants to take in account are: • Bacterial contaminations • Viral contamination • *Norovirus* See previous Section 2.3 and Appendix I about food safety concerns.

TABLE 3.6 (CONTINUED)

	To be assessed
Algae toxins	During feeding, shellfish can ingest phytoplankton species containing biotoxins that can be harmful for human health. If other wild stocks of shellfish are harvested, or if farms are already operating in the same area, get information from local authorities on the regularity and severity of these events. Toxins effect to ask about will be Diarrheic Shellfish Poisoning (DSP), Paralytic Shellfish Poisoning (PSP), Amnesic Shellfish Poisoning (ASP) and Neurotoxic Shellfish Poisoning (NSP). See previous Section 2.3 and Appendix I about food safety concerns.

Source: Elaborated by the authors.

The availability of both real-time and historical data from satellites is a technological revolution that can be of great value when assessing the suitability of a potential aquaculture production site. With the increasing number of satellites, and the progress in sensor technology, both data frequency (temporal resolution) and data accuracy (spatial coverage and resolution) are continuously increasing. The main data available from satellite networks like Copernicus in Europe are the following:

- Seawater temperature at the surface (SST – Sea Surface Temperature) and at a given depth;
- Salinity and Mixed Layer Depth (MLD);
- Winds, waves, tides and currents through (SSH – Sea Surface Height);
- Chlorophyll-α concentration with extrapolation on phytoplankton composition and size or on Primary Productivity (PP);
- Suspended solids and turbidity, with the possibility to distinguish between mass of water from different origins (for instance a freshwater front with suspended solids penetrating offshore clean seawater);
- Dissolved oxygen;
- Euphotic Zone Depth (ZEU).

The spatial resolution, which is the area on earth represented by a single point, is still limited in coastal areas or intertidal zones where the images are the result of the combination between on-earth measurements and off-shore measurements which are performed differently. Nowadays, in fully offshore sites, where the above-mentioned aspect is not relevant, a single point corresponds to a square with sides measuring roughly 300–600 m in length.

The comparison of satellite data with in situ collected data is still necessary to set up the interpretative models and to make the data reliable. But the installation and the maintenance of a permanent on site sampling station at the farm should become unnecessary.

3.2 CONSTRAINTS TO BE TAKEN INTO ACCOUNT FOR SITE SELECTION

Constraints are classified as any contributing factor that can prevent or limit the successful operation of bivalve cultivation at the selected location. Due to the open nature of the farming operations, there are many elements that can have an influence on the suitability of a site. The section below outlines these factors and each one should be considered carefully before deciding to progress with the establishment of a farm.

An initial step is to look for any available cartography and technical documentation relating to the site. When possible, contact existing farmers or producer associations to gain insight into the factors that can affect the site based on their past experience of operating under similar circumstances.

Take into account that the potential area of operation for the farm is likely to be of relevance to other users as well. Areas of coastal foreshore and nearshore marine zones can be of use to many diverse stakeholders besides aquaculture production businesses. These can take many forms but include such things as fishermen, moorings for pleasure craft, tourism, local residents, property developers, marine protected zones, sewage treatment discharge outlets and boatyards. Many of these interested parties have completely different priorities when it comes to the use of the available space and, as such, conflicts of interest can occur. As competition for space is fierce in these highly desirable areas, it can be difficult to secure licences to operate a bivalve cultivation operation, especially if it interferes with an already established activity in the relevant location. It is important to engage with not only the pertinent licensing authorities, but also the other local stakeholders, to see if a compromise can be negotiated to allow these diverse activities to exist in harmony. When possible, a "Marine Spatial Planning" exercise should be undertaken. This is a process of assessing the various potential uses for the marine area to maximise economic, social and environmental goals and is usually undertaken by the local authority whilst consulting with the various interested parties. If aquaculture businesses have been highlighted as a positive use of the marine space, then gaining the appropriate operating licences can be easier.

3.2.1 Administrative and logistic constraints

Verify:

- The licensing possibilities of the intended site;
- That regulatory compliance for food safety and sustainability do not represent an obstacle;
- If an environmental impact study is required before farming operations can be initiated;
- Seed availability: wild caught seed or hatchery produced seed;
- The authorizations for the access to the farm;
- The proximity to the market;
- The proximity to the laboratory for periodical controls and analysis.

3.2.2 Environmental constraints

Verify according to the parameters listed previously:

- The possible impact of geographical and meteorological conditions on the farm and equipment;
- The possible impact of the current environmental situation on product growth, survival and quality;
- The actual possibility to fit with the regulation for consumer safety.

4. Overview of the main farming techniques and equipment

INTRODUCTION

This chapter will provide the reader with a basic understanding of the main farming techniques and equipment that will be needed to operate an oyster production site.

Section 4.1 provides an overview of the possible ways to obtain the seed that is necessary for any farming activity. If oysters breed naturally in the vicinity of the farm, then spat can be collected from the site using the recruitment techniques described in this section of the manual. If there is no locally occurring spat, or the numbers are so low as to render commercial activity unviable, then seed oyster will need to be bought in from other sites or from a hatchery. A hatchery is an establishment where oysters are conditioned and induced to spawn under controlled conditions and the resulting spat are collected, developed and sold on to farms, who then cultivate them until they reach a size that is suitable for sale and consumption. Hatchery production techniques are not developed in this manual, but some information is provided in the Further reading at the end of the manual.

The nursery stage is described in Section 4.2, as farms with suitable facilities can benefit from buying small spat and carrying out a pre-growing stage in controlled conditions. This part introduces to the concept of a "Flupsy" (Floating Upwelling System) that is fully developed in Chapter 5.

Around the world, oysters are produced in many different ways, adapting the farming technologies to the conditions and local aquaculture traditions experienced at each site, and it would be impossible to describe all of these techniques. Nevertheless, the farming systems to grow the oysters can be classified into the main typologies that are briefly described in Sections 4.3, 4.4 and 4.5. Three of the most commonly used techniques are then described in detail in Chapters 6, 7 and 8.

The different long-line concepts are introduced in Section 4.6, while offshore long-lines to be installed in exposed condition are described in detail in Chapter 8. Some equipment used for grading and other basic operations common to all farming systems are described in Section 4.6. Finally, the basic rules of handling are discussed and elaborated upon in Section 4.7.

The production systems used to grow oysters can be grouped into the three following types:

- Off-bottom cultivation
- On-bottom cultivation
- Suspended cultivation

These techniques can be carried out in either intertidal or subtidal zones. This clarification introduces another important distinction between the growing conditions experienced by the oysters:

- Oysters that are grown whilst experiencing the effect of tides, being out of the water twice a day for a variable length of time depending on tidal range and the position in the intertidal zone;
- Oysters that are grown continuously in submerged conditions as occurs in bottom cultivation in the subtidal zone or in long-line cultivation.

As pointed out in the introduction, within these subsets, there are many variations that have been developed by farmers to suit their unique circumstances. In some cases, farmers will use a combination of techniques to maximise the advantages of each system for different stages of grow-out and to allow them to use more of the area within their lease than would otherwise be possible.

The production cycle can be defined as the sequence of processes that are required to rear the oysters from seed to market size and can be divided into the five steps detailed in the chart below. In the following chapters, this logical scheme will be detailed and illustrated for the 3 most common cultivation techniques.

FIGURE 4.1
Production cycle chart

Source: Elaborated by the authors.

4.1 PROCURING SEED

Seed availability, as a basic condition for any commercial size farm, is assessed during site selection.

The three main approaches currently used to obtain seed are:

- Seed recruitment by harvesting spat from the natural environment;
- Seed recruitment under controlled conditions, for instance in indoor tanks (extensive hatchery);
- Artificial seed reproduction in fully controlled conditions (intensive and high technology hatchery).

The two approaches based on seed recruitment still remain the most important source of seed for farming, especially in Asian countries that account for the majority of world oyster production (see Table 2.2). They often depend upon traditional techniques that require minimal financial investment, but often entail extensive manual handling. Consequently, these techniques are usually undertaken in countries where manpower is cheap. In countries where labour is expensive and more advanced technology is available, the third approach has been developed and adopted following the end of the second world war in 1945 and accounts for an ever-increasing proportion of seed supply. This approach, where all stages of seed production are fully controlled, also offers the possibility of producing triploid oysters or to develop genomic selection. These are the new frontiers of shellfish aquaculture.

The advantages and disadvantages of using wild caught seed or intensively hatchery-produced seed are summarised in the tables below.

TABLE 4.1
Advantages and disadvantages of hatchery-produced seed

Advantages	Disadvantages
Due to the hatchery's ability to manipulate their environment and induce spawning events when required, they are able to produce seed throughout the year and can therefore deliver product to the farms as and when required. Triploid seed available to allow end product to be sold during the season when diploid oysters are spawning. Selective breeding allows strains to be developed with certain desirable traits including the resistance to OsHV-1. It is possible to select seed of a certain colour and appearance that has a desirable aesthetic and increase the marketability when selling the produce to the end customer. Homogeneity of size throughout the seed batch.	Even though hatcheries have strict sanitary monitoring in place, there is a risk of introducing an unwanted pathogen to the production site. Potentially higher cost depending on local availability and hatchery production costs. Competition for buying seed can limit the numbers that are available, especially of the most desirable sizes during the period when demand is at its peak. Reliance on a third-party source for the most vital element required to operate the farm. If there are problems with the delivery logistics, a delay can lead to mortality in the purchased stock whilst in transit.

Source: Elaborated by the authors.

TABLE 4.2
Advantages and disadvantages of wild seed

Advantages	Disadvantages
Increased bio-security as there is no introduction of exterior organisms that could be a vector for unwanted pathogens or invasive species. (Recruitment and farming are performed on the same site). Potentially lower cost of operation as the only cost to the farmer is the purchase of the relatively cheap, reusable recruitment equipment needed and the time taken to deploy it and process the spat settlement that occurs. Sustainable farming system based upon the resources supplied by nature. Advantages in terms of certification for such credentials as organic and sustainable farming.	Number of available seed can vary dramatically from one year to the next depending on the fluctuating conditions experienced at the site. This makes it more difficult to plan for the future infrastructure and equipment requirements of the farm. Long term financial forecasting and business expansion planning is difficult because it is impossible to predict the number of oysters that will be available year on year. The production cycle is determined by natural seasons that do not necessarily tie in with optimal market demand. No triploid stock, so oysters can only be sold outside of the spawning season. Naturally occurring oysters cannot be selectively bred to be resistant to issues such as OsHV-1. Variability in size throughout the seed and therefore it is necessary to grade all of the batches at an early stage.

Source: Elaborated by the authors.

In Europe, during the last few decades, the production of triploid Pacific oysters has increased (the use of triploids is not always allowed by local authorities). Triploid oysters are almost sterile and produce few gametes using their energy mainly for growth. During summer, when diploid oysters undergo reproduction, becoming milky so that they cannot be sold, triploid oysters present higher meat content and a better organoleptic quality.

Even if hatcheries are able to produce seed throughout the year, it is worth noting that the quality of the seed produced outside of the natural season is often lower. Moreover, introducing seed out of season, when environmental conditions as well as plankton availability are not at their optimum level, entails the risk of lower growth and survival rates. Consequently, both the lower quality of the seed and sub-optimum environmental conditions when introducing the spat can compromise the final results. It is therefore recommended to limit the introduction of seed outside of the natural season.

In terms of seed costs, recruited wild spat is usually less expensive, especially in countries where salaries are low. Differently, in industrialised and rich countries the final costs of recruited seed and hatchery seed are often similar.

As a production cycle can last from 2 to 3 years, planning spat introduction and collection correctly is a key factor in ensuring that the desired production levels are attained in the following years. In the case of sites where natural spat fall is abundant, and where the supply of seed is attained by recruiting this resource, the time, effort and equipment dedicated by the farmer to spat collection in previous years will influence the potential production levels of market-size stock achievable going forward. Seasonal fluctuations in naturally occurring spat will also influence availability. In situations where natural spat is not available and the farmer has to buy in seed from hatcheries, the financial performance and profits generated by the farm in previous years will influence how much money is available to invest in seed, thereby dictating the future potential production level of the farm in future years.

In both cases, the farmer will have to ensure that the maximum number possible survive, as each one that perishes represents a financial loss in the future. Table 4.3 gives approximate mean weights for the oysters' spat size classes used in Europe.

TABLE 4.3
Size classification for Pacific oyster spat

Size category	Average number/kg	Mean weight
T2	125 000–83 500	8–12 mg
T3	66 500–40 000	15–25 mg
T4	33 500–22 000	30–45 mg
T5	16 500–10 000	60–100 mg
T6	6 500–4 000	150–250 mg
T8	3 000–1 500	350–650 mg
T10	1 250–700	0.8–1.4 g
T12	700–350	1.5–3.0 g
T15	350–180	3.0–5.5 g
T18	180–120	5.5–8.5 g
T20	120–80	8.5–12.5 g

Source: Elaborated by the authors.

4.1.1 Recruitment supports for wild caught seed

At the end of their planktonic stage in the wild, the oyster larvae settle on substrates that are available to them in the natural environment. To assist this process, and maximise the number of spat that are able to successfully settle, recruitment devices, made from materials that provide a suitable substrate onto which the larvae are able to attach themselves, are deployed in the waters around the farms. Some examples of recruitment supports are shown in Figure 4.2 through to Figure 4.7.

The most common supports used for oyster recruitment are:

- Empty shells (cultch) laid on the bottom or placed in suspended devices;
- *Coupelles* (perforated or not), tubes or tiles (half round roof tiles).
- Ropes, coco ropes, hemp ropes;
- Strapping ribbons placed in suspended net lanterns;

FIGURE 4.2
Lantern containing both plastic ribbon and old oyster shells (cultch) for oyster seed recruitment

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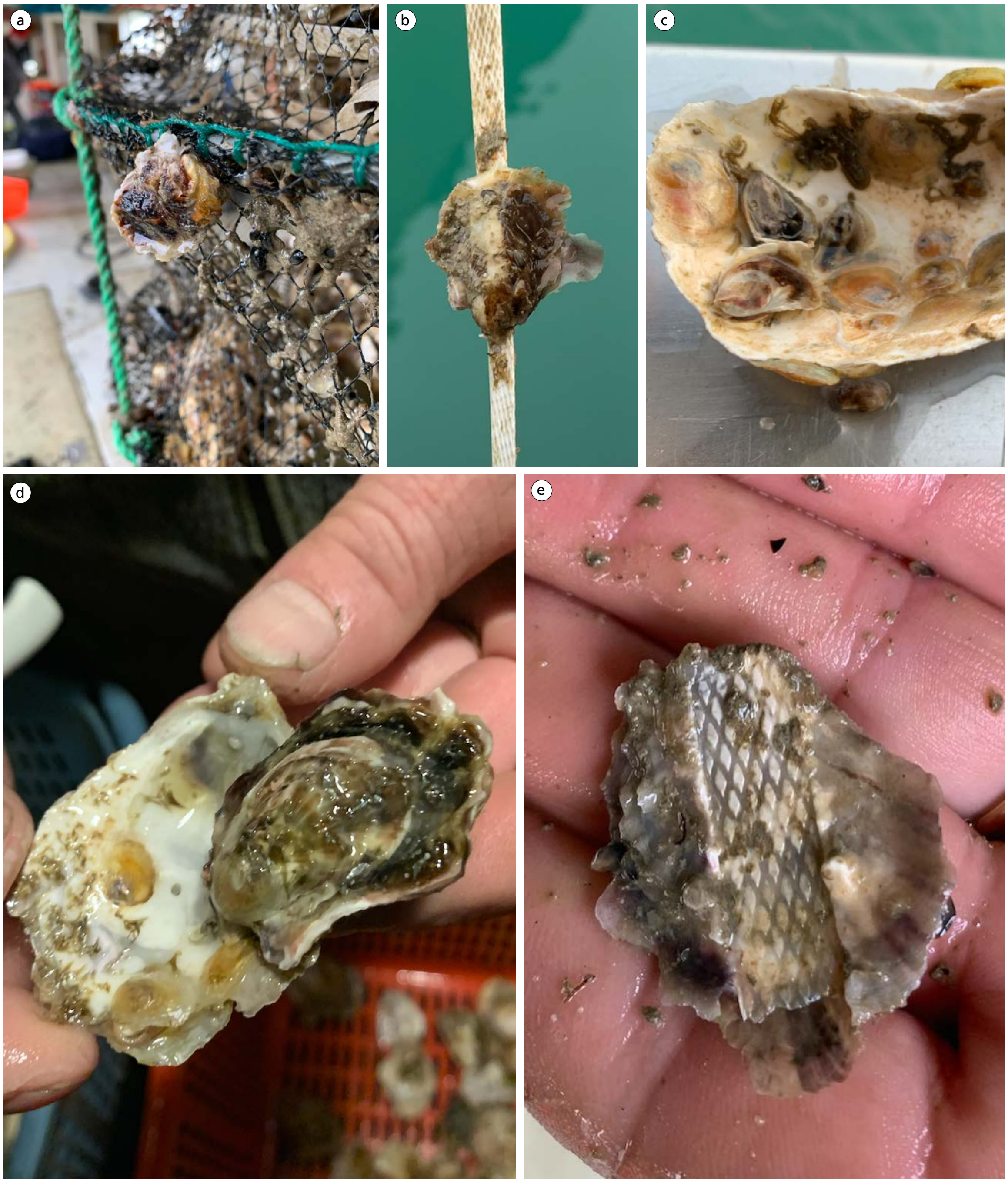
The choice of the substrate will depend on:

- The strength of attraction, which is how easily and firmly the oyster is able to attach itself;
- The ease of stripping without damaging the spat;
- The time efficiency of stripping;
- The possibility of using automation to strip the spat from the settling or recruitment devices;
- The possibility of re-immersion without stripping;
- Limited signs of aesthetic impact left on the shell by the recruitment support.

The strength of attraction will depend on the chosen supports, on their preparation and on the timing of their deployment. Supports that have already been submerged previously, for instance the previous year, will be more attractive. Supports that have

FIGURE 4.3
Examples of oyster seed recruitment
(a) On lantern net. (b) On 8 mm ribbon. (c)(d) On old oyster shell (cultch). (e) Ribbon imprint



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been placed in the water one or two weeks before settlement occurs will be more attractive because of the formation of a thin biological film on them. Supports that have been introduced too early, many weeks before effective settlement starts, will be covered with fouling and less receptive.

Monitoring the state of maturation in the breeding oysters can also help to predict spawning and settlement time. Once the settlement period is assessed, the introduction of the supports can be done progressively so as to have at least one section of the supports that will be in the optimum condition to attract larvae.

FIGURE 4.4
Coupelles for oyster seed recruitment
(a) Perforated *coupelles*. (b) Non perforated *coupelles*. c) *Coupelles* supported by trestles on the foreshore. (d) *Coupelles* with oyster seed attached

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FIGURE 4.5
Plastic tubes used for oyster seed recruitment
(a) Tubes are stacked on top of each other whereby each layer is positioned in an opposing direction.
(b) Detail view of the texture of the tubes

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In the case of *coupelles*, pipes and tiles, supports can be covered with quicklime to increase their suitability for settlement and to facilitate stripping (Figure 4.6). In the Arcachon basin in France, cupped oyster farmers traditionally use piled-up half-round roof tiles covered with a mixture of sand and quicklime. The collectors are then placed in the water at the beginning of summer and lifted for spat stripping in spring of the following year. In south Brittany in France, flat oyster farmers use *coupelles* treated in the same way, immersing the supports on the *fundus* in June and harvesting the following spring in March–April. The use of *coupelles* and ribbons raises the possibility of undertaking automated spat harvesting.

Most of the previously described techniques are also commonly used for recruitment in indoor tanks where sexually mature breeding oysters are introduced together with substrates for seed settlement (Figure 4.7). In this scenario, as opposed to recruitment in the natural environment, it is also possible to add phytoplankton to increase the efficiency of the whole process.

FIGURE 4.6
Quicklime used for seed recruitment
(a) Harvested *coupelles*. (b) Quicklime treatment tank. (c) Seed recovery machine

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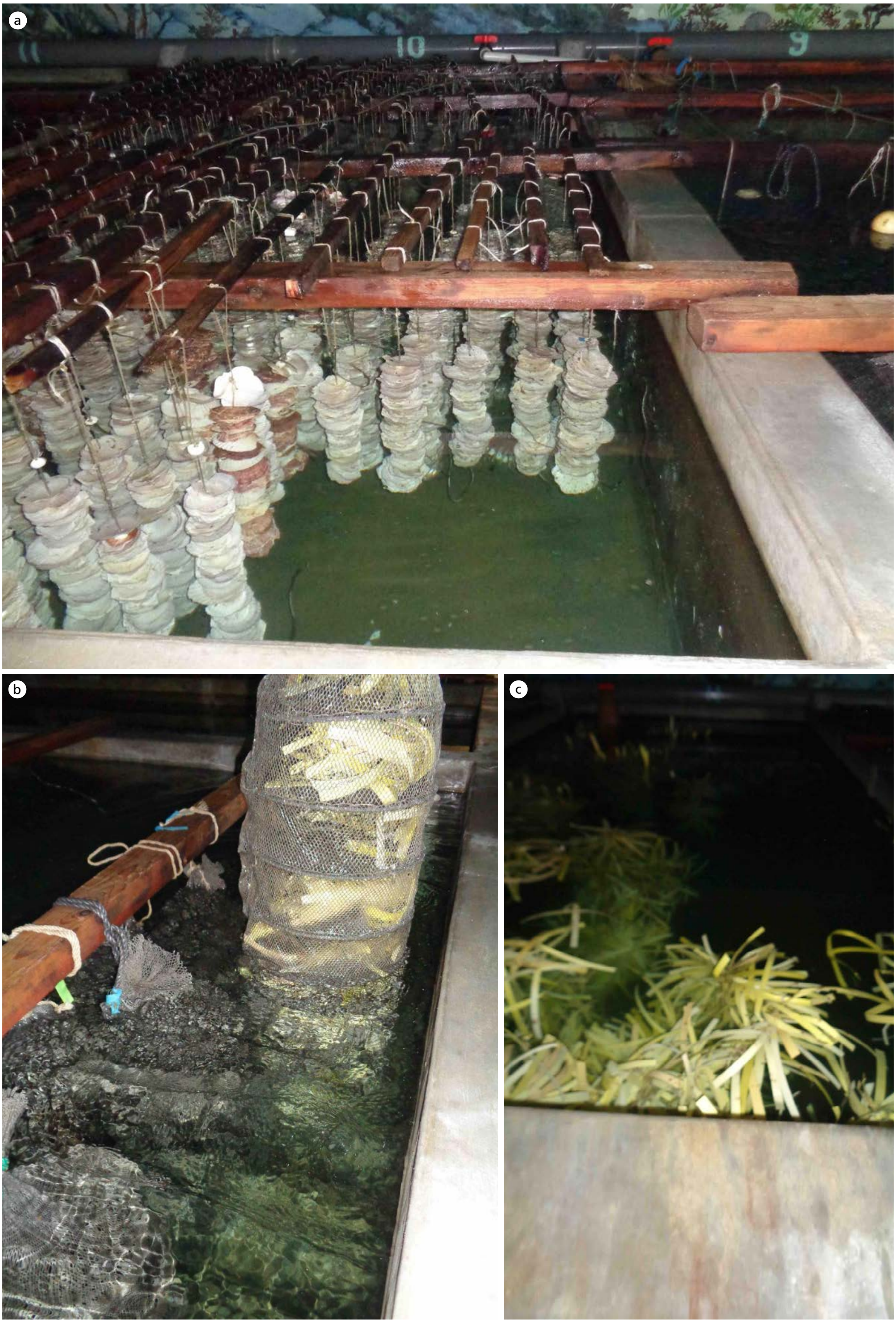
FIGURE 4.7
Seed recruitment in indoor tanks
(a) Tank with collectors. (b) Tank with shells collectors. (c) Tank with ribbons collectors



4.1.2 Re-immersion of recruited seed

In some cases, when harvesting the seed from the settlement substrate, it may be better to let the spat grow to a larger size before detachment is undertaken. This technique can reduce handling time and minimise losses. This approach can be undertaken with cultch, allowing the spat to grow and develop a stronger shell before being detached from their hosts without causing any damage to the new oyster.

In Brittany on the French coast, flat oysters are collected on "*coupelles*" that are covered with quicklime and fixed to rebar supports that are submerged on the seabed at the beginning of the summer. In spring of the following year, oysters, together with the residue of quicklime, are then automatically detached from the *coupelles* (Figure 4.6c) and then laid onto oyster beds to complete the nursery stage.

4.2 NURSERY STAGE

After collecting natural seed locally, a nursery stage will have to be carried out for the product to reach a suitable size to start the growing phase. When using hatchery spat, as the price of small size seed (T2 or T3) is significantly lower, it may be economically convenient to conduct the nursery stage locally when suitable facilities are available.

Pre-growing of small seed (<T6) using the technique used for the growing phase is not easy as devices with very small mesh/openings have to be used with consequent problems of fouling and a high frequency of cleaning/grading. To avoid such problems, seed is often pre-grown in controlled conditions in nursery facilities.

Different solutions can be considered:

- Upwelling systems;
- Suspended baskets with small mesh sizes.
- Suspended lanterns with small mesh sizes.
- Seed in small mesh bags placed in suspended devices with large apertures.
- Perforated nursery trays.

4.2.1 Nursery stage using upwelling systems

Upwelling nursery systems are an efficient way of developing small seed oysters (>T2) into robust juveniles (7–13 mm) more quickly and at higher density than is possible in fine mesh bags or lanterns that would otherwise be used during this phase of growth. They provide a protective, high nutrient environment, thereby reducing mortalities and increasing growth rates and serve as an important transitory phase between purchasing the seed from a hatchery and transferring it to the main grow-out bags, nets or trays. As the name suggests, the systems are designed to force water vertically, in an upwards motion, through a mass of seed oysters that are held in a container whose bottom surface is made of a fine mesh on which they rest (Figure 4.8). This upwelling effect drives nutrient rich water through the population of oysters, constantly refreshing their food source, allowing them to filter feed continuously on the phytoplankton that they need to grow.

There are four main design options of upwelling systems:

1. Outdoor/indoor tanks either situated within a building or on a quayside where the oysters are fed on microalgae that is produced at the facility. Algae can be cultivated by using either fluorescent lights or natural daylight. Various containment equipment can be used depending on the phase of production and the desired volume. Algal batches are initially cultured in test tubes, then moved into flasks or carboys as the volume increases before being transferred to tanks, cylinders or large plastic bags for the final phase of production (Figure 4.9).

FIGURE 4.8
Outdoor upwelling tank at Guernsey Sea

©Guernsey Sea Farms

FIGURE 4.9
Algal cultures being produced at hatchery and nursery facility
(a) Algal cultures produced using artificial UV light in flasks. (b–c) Algal cultures produced using artificial UV light in carboys and large plastic bags; and (d) Algal cultures produced outside using natural daylight (Morecambe Bay Oysters)

©M. Mercer

2. Outdoor tanks where the oysters are fed on phytoplankton that has been developed by fertilising an enclosed water body to create an artificial algal bloom that is then circulated through the upwelling system. Figure 4.10 illustrates how this sort of facility could be set up and Figure 4.11 (a, b) shows a real-world example of this system in operation.

FIGURE 4.10
Diagram illustrating the flow of water containing fertilised algal blooms through a pond fed upwelling system

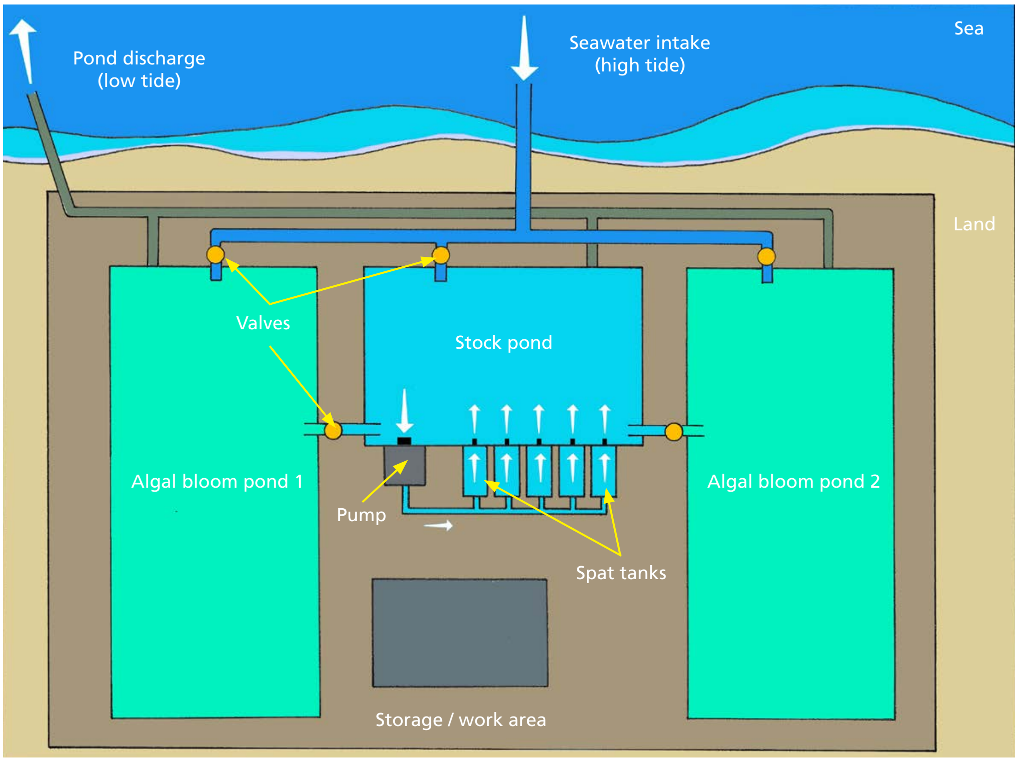


FIGURE 4.11 (a)
Morecambe Bay Oysters hatchery and nursery facilities
(a) Ponds surrounding hatchery/nursery facility in which phytoplanktonic blooms are developed

FIGURE 4.11 (b)
Morecambe Bay Oysters hatchery and nursery facilities
(b) Outdoor upwelling system fed by phytoplankton from the surrounding ponds

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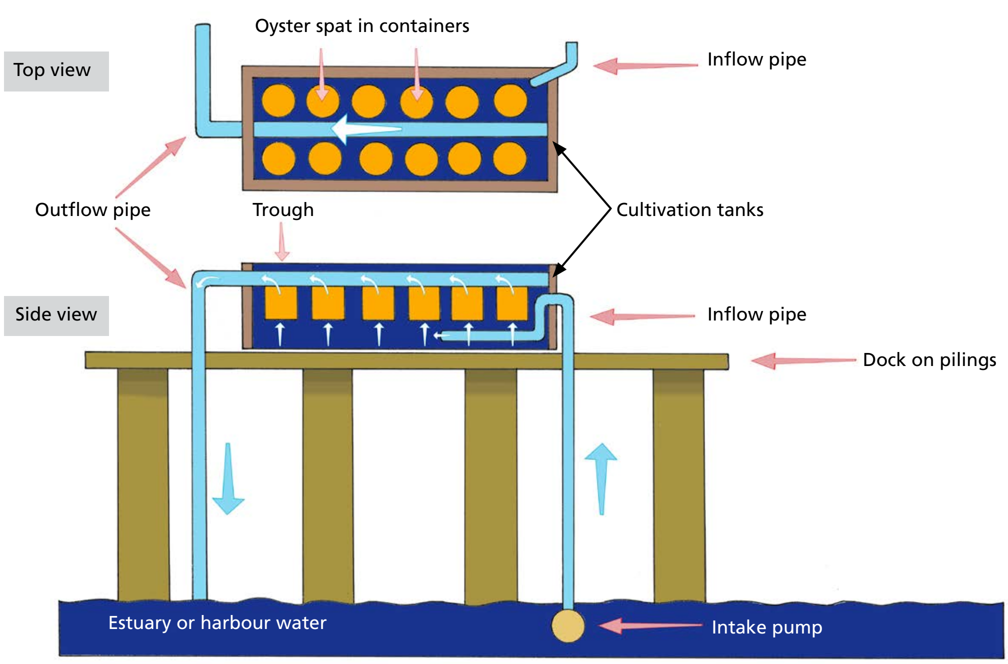
3. Outdoor/indoor tanks that use pumps to move nutrient rich seawater, from an estuary or similar body of water, up to the cultivation tanks and through the oysters contained within them. Figure 4.12 is an illustration of this sort of set-up and Figure 4.13 is a real-world example of a land-based upwelling system.

FIGURE 4.12
Diagram illustrating an example of a land-based upwelling system



Source: Elaborated by the authors.

FIGURE 4.13
Nursery upwelling tanks at Marinove in France
(a) Upwelling tanks; and (b) Example of the seed boxes holding the oysters that are contained within the tanks

4. Floating Upwelling System, known as Flupsy (Figure 4.14). These are situated on the water itself and consist of a raft that supports the seed containers (also referred to as silos) and enables water to be moved through the system by a variety of means including airlift pumps, paddle wheels, suction pumps or propeller. Where no power generation is available, it is possible to use a Flupsy that creates upwelling by harnessing and directing the flow of the tide.

FIGURE 4.14
Floating upwelling raft at Guernsey Sea Farms

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The construction and operation of a Floating Upwelling System is described in detail in Chapter 5 of this manual. The basic principles and a diagram showing movement of water through a Flupsy are also included in Section 5.1.

4.2.2 Nursery stage using lanterns or baskets

When land-based facilities are not available and upwelling systems cannot be installed, it can be convenient to buy cheaper small spat and to carry out a nursery stage in suspended devices. Such a strategy can only be implemented if some basic conditions exist in the farming area used for the nursery stage:

- During the period when the nursery stage is performed, there must be a suitable quantity and quality of phytoplankton available in the seawater to support the seed during this high growth phase.
- The water currents have to be strong enough to ensure that the water within the suspended devices is suitably refreshed on a regular basis. This condition will also depend on the mesh size of the suspended devices and their orientation and ballasting.
- Suspended devices must be installed in such a way that the waves and current experienced on the site ensure that the seed is minimally tumbled within the containers. The dimensions and positions of the floats will determine the extent of this motion and should be specifically suited to the nursery stage.
- Risk of fouling should be minimised. In particular, the nursery stage should not be performed during mussels or other such organisms' settlement period to avoid the mesh of the containers becoming blocked.

As with upwelling systems, it will be imperative to grade and clean the seed on a regular basis to maximise growth and minimise mortalities. Between each grading operation, it is advisable to take the devices out of the water for cleaning. If suspended devices are designed to allow spat to move within them, the handling frequency can be reduced.

As illustrated in Figure 4.15, seed can be placed inside mesh bags or plastic cylinders with an aperture small enough to contain the oysters. These bags are then placed inside a lantern that has a bigger aperture. This solution with small batches may be more efficient in terms of the water flow available to the oysters than higher spat densities in bigger devices with similar small mesh, but handling becomes time consuming.

FIGURE 4.15

Small nursery bags/cylinders inside suspended lanterns

(a) Seed net bags inside lantern with larger aperture. (b) Detail of the seed net bag. (c) Hard plastic cylinders inside a lantern with larger aperture. (d) Detail of hard plastic cylinder

To reduce handling time, the nursery stage can also be performed in perforated trays where the seed can move freely according to currents and the effect of the waves (Figure 4.16). It is possible to use units comprised of 2 to 10 trays stacked one above the other (one tray is ballasted and used as cover). Water flow to the oysters will be maximised by using fewer trays. Both these systems need weekly grading and handling.

FIGURE 4.16
Nursery perforated trays
(a) A five trays nursery unit (perforation 4 × 4 mm) and (b) oyster seed to be pre-grown

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Finally, automated nursery systems can be installed in fertilised ponds. An example is illustrated at the end of Section 4.3 (Figure 4.24). Such a system allows the farmer to schedule tumbling and emersion times.

4.3 OFF-BOTTOM CULTIVATION

"Off-bottom cultivation" can be defined as the cultivation of the shellfish using equipment to raise them off the seabed. Usually, the oysters are supported less than a metre above the bottom, allowing water to flow both below and above the shellfish.

4.3.1 Off-bottom cultivation on trestles

The most common off-bottom technique is growing the oysters in bags laid on trestles installed in the intertidal zone. This technique is described in detail in Chapter 6 of this manual. It is the traditional production technique that is widely used all along the European Atlantic coast of France, Ireland and the United Kingdom of Great Britain and Northern Ireland. This technique has also been introduced along the African Atlantic coast from south Morocco to Senegal. In most of the above-mentioned countries, where exposure to the air due to the tidal movement helps to create a product with a strong shell and long shelf life, the oysters are traditionally sold and consumed as raw product and not processed in any way. With globalisation, these high-quality oysters are now exported all over the world in their natural state.

4.3.2 Off-bottom cultivation in baskets

Another technique, that has been developed more recently, consists of growing the oysters in baskets suspended off the bottom by various supports (Figures 4.17, 4.18, 4.19 and 4.20). Suspended basket cultivation is mainly performed in Australia and New Zealand and is progressively spreading to many other countries.

Basket cultivation is also considered to be an "off-bottom" system rather than a "Suspended" system because in most cases the baskets are separated from the bottom by less than 1–1.5 m.

During the last few decades, many suppliers have designed plastic baskets for oyster aquaculture, studying the complex relationship between the design of the units themselves, the environment, the required handling and the resulting quality of the product. As with the traditional oyster bags used for farming on trestles, these baskets are usually made from extruded plastic mesh nets and plastic frames that can be cleaned and reused many times.

Since their inception, "baskets systems" have been designed with a double purpose in mind: to let the oysters move more freely, thereby preventing them from fusing together or developing an irregular shape, and to minimise handling. These systems have been designed for use in the intertidal zone or shallow waters where the supports can be easily fixed into the seabed. The most commonly used system consists of long-lines tensioned between poles that are inserted into the seabed with baskets clipped onto the lines. In this case, wooden poles should be preferred to metallic ones to avoid problems caused by corrosion to the metal in the marine environment. Some suppliers provide systems that enable the farmer to adjust the height of the basket from the seabed, by raising or lowering the line to predetermined levels on the poles.

FIGURE 4.17
Example of a long-line oyster farm in the intertidal zone
(a) Long-line farm; (b) 10 mm mesh basket

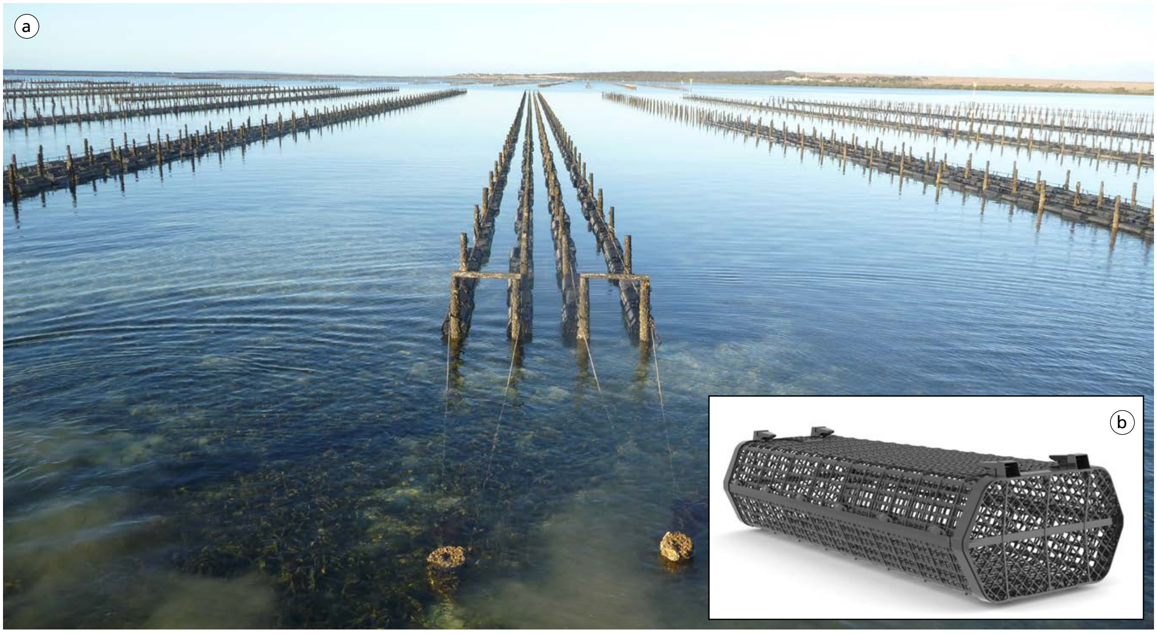

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FIGURE 4.18
Adjustable long-line system in the intertidal zone

©HEXCYL Systems

Baskets can be suspended longitudinally on a single line (Figures 4.18 and 4.19) or between two parallel lines. In the second case, when baskets are clipped on at both ends, their swinging motion is significantly reduced when compared to the single line arrangement. Some models have also been designed to be suspended one over the other. Baskets can also be used suspended on traditional trestles (Figure 4.20).

Most of the models of basket available on the market have an elongated shape with different profiles (elliptical, hexagonal, triangular, etc.) and can contain from 10–20 kg of

FIGURE 4.19
Long-line farm in the intertidal zone (a) using SEAPA® baskets (b)

oysters. They are usually available in different mesh sizes according to the size of the product to be grown within them. The opening mechanisms of many models consist of two removable reinforced covers at the extremities that are also designed to strengthen the whole structure. In a few cases, the elongated part is also reinforced to avoid the baskets becoming squashed or deformed. Other models are composed of two articulated parts with longitudinal opening. Some of these models are designed to directly rotate around a rebar structure fixed into the seabed without an intermediate clipping device. Unlike traditional baskets, these models can be stacked when open and are easier to store and transport.

FIGURE 4.20
SEAPA® oyster baskets on trestles in the intertidal zone

While baskets started to be widely used in Australia and in many other parts of the world, some farmers along the Atlantic coast of France also started to use pre-folded oyster bags with an increased volume compared to traditional flat oyster bags (Figure 4.21). These pre-folded oyster bags were suspended from traditional trestles instead of being fixed on top of them. Further trials were also undertaken with pre-folded bags installed on mobile trestles, with floats that could rotate the bags over the course of the tidal transition.

FIGURE 4.21
Pre-folded oyster bag with increased volume

When choosing to use baskets or pre-folded bags, multiple considerations will have to be taken into account:

- The shape of the baskets will influence the way that the oysters sit on the bottom surface and how they move under the effect of tides, water currents and surface waves.
- The suspension systems should be designed to facilitate easy recovery of the baskets when harvesting, but should also prevent them from detaching and being damaged. Systems with clippers can be very efficient, but can also present a weak point in the farming structure.
- The system should be designed so that raising or lowering the baskets can be easily undertaken thereby adjusting their height from the seabed and their consequent exposure time to the air (Figures 4.18 and 4.19).
- The baskets' opening systems have to be resilient and must allow quick and easy filling and harvesting of the oysters. The design must allow for automation of these processes where necessary. In articulated baskets, the hinge must be strong enough.
- Mesh sizes must be optimised to prevent the oysters from escaping and to allow the water to flow through efficiently.
- The plastic components must be of sufficient quality in terms of durability, with anti-UV treatment where necessary.

Overall, the approach of cultivating oysters in baskets is very similar to those of cultivation on trestles in the intertidal zone, where oysters grow and feed over high tide and are exposed to the air during low tide (hardening and fouling control). Nevertheless, two main differences must be pointed out:

- The oysters are "tumbled" more efficiently than in fixed oyster bags because the suspended baskets can swing under the effect of waves and during the tidal transitions.
- The line on which the baskets are suspended can be raised or lowered on the poles to regulate the time of exposure to the air, without having to move the product from one part of the intertidal zone to another.

As mentioned above, the complex relationship between all the diverse factors relating to the cultivation system and the farm environment has to be taken into account. Each system will have to be carefully tested on the chosen site before making investments on a large scale. These initial trials should be carried out over a period of at least one year to assess the systems with regards to the different seasonal conditions. The meat content and the shelf life will have to be monitored throughout the year to better understand the impact of the cultivation technique on the final product quality. The standardisation of the production protocol may require many years.

Use of floats to improve oyster tumbling

Originally, baskets were simply suspended and moved according to tides and currents with the upper side always exposed to the sun during low tide. Baskets could swing laterally with limited amplitude (40–50° each side) and oysters, even if moving more than in traditional fixed oyster bags, tended progressively to stay more or less in the same position. Consequently, many suppliers started to add floats to promote a partial or total rotation of the baskets or of the pre-folded bags according to tides.

These floats can be tied or fixed externally or inserted internally. They can be filled with air or if possible with polyurethane foam. They can be made by hand from polyvinyl chloride (PVC) pipes or bought moulded and ready to use.

Some examples are described below to give an idea of some of the basic principles that can be implemented.

This increasing use of floats, which is quite a recent strategy, can have further implications for the quality and handling requirements of the oysters:

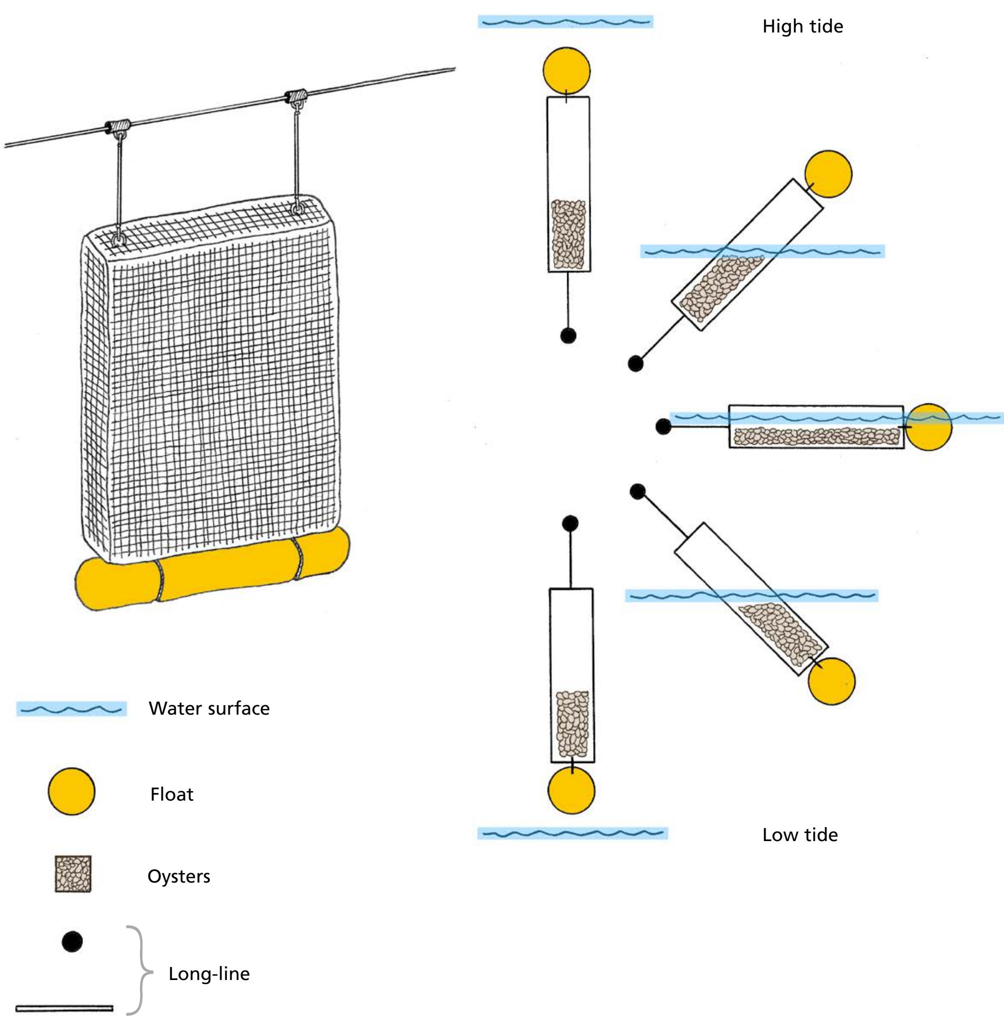
- The increased "tumbling" motion within the baskets or bags has a significant effect on the shell shape and strength, as well on the meat content. Shells develop deeper cups and a more rounded shape with an increased space for meat. The effect can be compared to the result of incessant hitting and turning of the oyster bags on traditional trestles. In some cases, the "tumbling" motion can be excessive, with the edges of the shell suffering serious damage, negatively impacting both growth and shelf life after harvesting.
- The rotation of the whole basket, with all sides potentially exposed to the sun, assists in limiting fouling on both the oysters and the baskets, as macroalgae and epibionts are periodically "burned", assisting to maximise water flow within the baskets.
- The risk of breakages occurring and the need for maintenance increases when compared with more static methods. Particular attention should be paid to the suspension clips, especially their resistance to extreme marine conditions (tempests) and their wear under the continuous effect of tides and currents.

Innovative systems with floats using baskets

Some examples of innovative solutions using baskets and floats are described below. The first example is typical off-bottom farming, while the other two have been designed for deeper waters and can be defined as floating systems.

EXAMPLE 1 – For farming in the intertidal zone, pre-folded oyster bags or baskets with a similar shape can be used that fully rotate around a tension line or around rebar fixed on the bottom (Figure 4.22). Such a solution significantly reduces the handling time as the rotation and tumbling of the oysters occurs naturally twice a day as the tide rises and falls. With the use of hard plastic baskets, container emptying, cleaning and filling can be automated.

FIGURE 4.22
Example of the use of baskets with floats in the intertidal zone

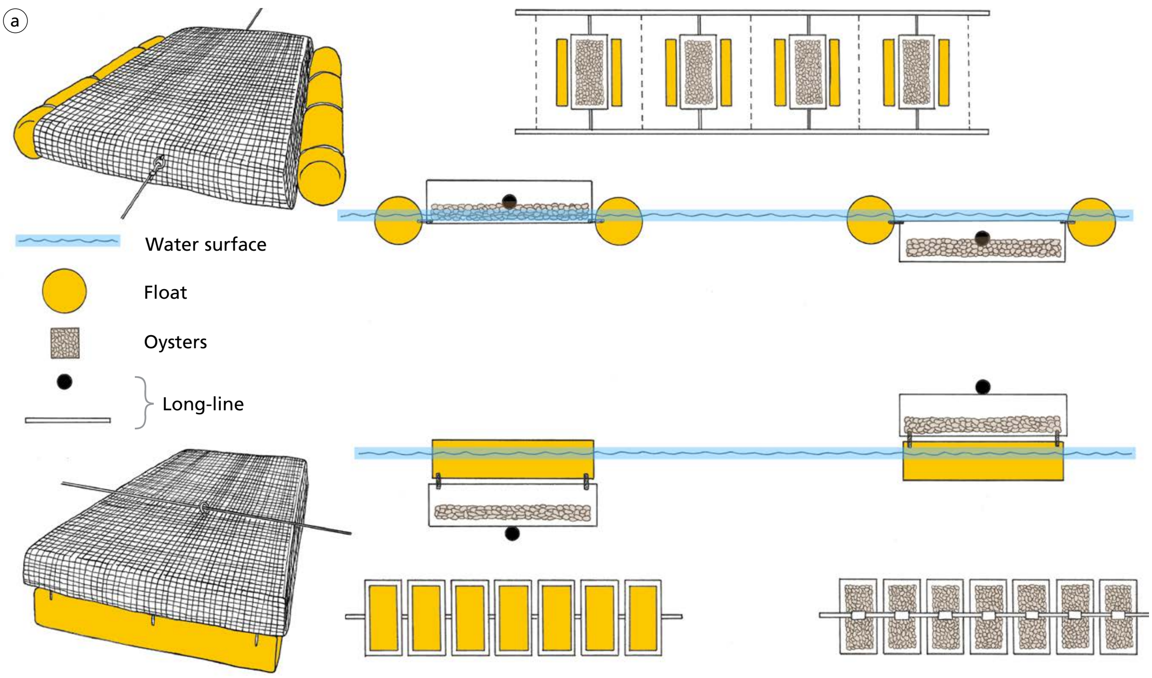


Source: Elaborated by the authors.

EXAMPLE 2 – At sites without tides, floating long-line systems based on two alternate equilibrium positions of the oyster containers have been developed. By positioning the floats in an asymmetrical way, oysters can be submerged or exposed to the air according to the position scheduled by the farmer (Figure 4.23a).

Over the last few years, based on the above-mentioned principle, a fully automated system using baskets with floats has been designed and patented by a company in New Zealand (Figure 4.23). Turning the baskets is made without handling by moving along the long-line with a small workboat with low energy requirement. When emptying and filling operations are needed, a bigger workboat with dedicated automation can make handling less laborious and time consuming. This system, designed for sheltered sites, is a synthesis of many of the above-mentioned requirements of automation and control that overcomes most of the problems regarding the farming of oysters on long-lines as described in Chapter 8.

FIGURE 4.23
Example of the use of floats for basket positioning and turning
(a) Basic design of the baskets. (b) Baskets positioned in the field positions. (c–d) Basket turning. (e) Filling the baskets with oysters



Source: Elaborated by the authors.

EXAMPLE 3 - Some fully automated floating systems that can be installed in ponds where phytoplankton blooms can be boosted and controlled, are also available on the market. By filling/emptying high density polyethylene (HDPE) pipes with air (increasing floatation) or alternatively with water (increasing ballast), the baskets containing the oysters can be raised and lowered in and out of the water (Figure 4.24). In an intermediate position, baskets can move freely according to the tide. The blower unit is controlled by specific software allowing the oyster baskets to be exposed to the air according to the scheduled protocol. Such systems, that can be equipped with solar panels, could be a viable option in developed countries where manpower costs are high. For products with high added value, like pre-grown spat or high-quality oysters for human consumption, the investment in fully automated systems can be cost-effective.

FIGURE 4.24
Example automated floating units with blower system

4.4 ON-BOTTOM CULTIVATION

"On-bottom cultivation" or "bottom cultivation" can be defined as the cultivation of the shellfish directly in contact with the bottom, on what are known as oyster "beds" or "lays". The oysters are not held in any form of containment device and are harvested either by dredge, by rake or by hand. This traditional technique is commonly used in the United Kingdom of Great Britain and Northern Ireland, the Kingdom of the Netherlands, Asia and the United States of America. In contrast to off-bottom cultivation, which is mainly performed in the intertidal areas, on-bottom cultivation can be performed in both the intertidal and subtidal zones. In the United

States of America and the European countries of the Atlantic coast, oysters produced in subtidal areas and not exposed to the air for the majority of their production cycle, are often subjected to a hardening process in the intertidal zone before being sold and consumed as live produce (see Section 4.7). Conversely, in Asia or other regions where the oyster meat is separated from the shell immediately after harvesting and frequently transformed before consumption, hardening will not be performed as the shelf life and appearance of the shell is not relevant.

Depending on the conditions and local traditions of the country in which the farming activity takes place, "on-bottom" cultivation techniques can range from intensive aquaculture as described in Chapter 7, to a less intrusive approach, where natural resources are managed, but with limited human intervention to increase productivity.

It can be considered as cultivation when all the following practices are performed together:

- Oyster seed introduction is controlled by the farmer;
- Cultivation areas are clearly defined;
- Cultivation is made on substrates which are specifically prepared for this purpose;
- Stock levels are known and accurately managed.

The strategy of increasing the productivity of natural resources with limited human intervention can be defined as when the follow takes place:

- Seed is harvested from naturally available spat fall from within the local environment. Introduction of seed is only used to restore depleted natural stocks during the initial phase of stock management; this strategy assumes that seed self-sufficiency can be achieved successfully;
- Introduction of additional seed occurs only in years where recruitment is poor;
- Recruitment devices are used to increase the volume of spat settlement from the natural environment.

In both scenarios, the available stock and the maximum sustainable harvesting capacity should be assessed by means of periodical sampling.

The success of each strategy of seed introduction requires an acceptable seed survival rate and this will depend on a multitude of factors. The following recommendations can be made to achieve a positive outcome:

- Use broodstock that has local provenance and will be adapted to local environmental conditions;
- Where possible, use wild recruited seed as the process of natural selection will mean that this spat that will have a higher probability of survival when compared to seed produced in a hatchery;
- If using hatchery-produced seed, implement a control protocol to assess survival rates;
- When introducing seed to the farming area, bear in mind that many can be lost or displaced from the cultivation zone by currents and storms and therefore these losses should be factored into the calculations regarding how much seed should be introduced.
- When sampling, consider age classes as a key parameter for result interpretation;
- When possible, mainly for hatchery-produced seed, use genetic markers to identify batches.

"On-bottom" cultivation requires less intensive manual handling when compared to other forms of oyster aquaculture and therefore can be a more cost-effective solution. Unfortunately, because of the impact of human activities on the marine environment and climate change, "on-bottom" cultivation is becoming exposed to ever increasing constraints such as elevated predation events and higher pollution levels.

See Figure 4.25 for an aerial view of an on-bottom oyster farming operation on the Kingdom of the Netherlands.

FIGURE 4.25
On-bottom cultivation: oyster plots in front of Yerseke, Kingdom of the Netherlands

©M. Mercer

4.5 SUSPENDED CULTIVATION

"Suspended cultivation" can be defined as the cultivation of the shellfish suspended in the water column. Oysters can be grown in containers (lanterns or baskets) or "on-ropes" that are suspended on supports fixed to the bottom (racks or similar) or on floating structures (long-lines). Conversely to off-bottom cultivation, the oysters are grown at a distance from the seabed that is usually greater than 1-1.5 m.

The cultivation of oysters on-ropes or in lanterns are traditional techniques used in many parts of the world, both in sheltered and exposed sites. These techniques, where the entire production cycle takes place in submerged conditions, make it difficult to produce oysters with a hard shell and a long shelf life that are suitable to be sold as raw product. Due to these limiting factors, the markets where these techniques are widely used are oriented more towards meat consumption (fresh or processed) without considering the appearance of the shell or their ability to remain alive out of the water. These systems are widely utilised across the entire Asiatic region.

Originally, supports, lanterns and ropes were made on the farm using local materials. Over the last few decades, the global availability of industrially produced plastic materials (ropes, floats, mesh nets, etc.) and cultivation containers (lanterns and baskets), as well as the progresses made in long-line design, allowed the production systems to be standardised and opened up the possibility of moving cultivation further offshore.

Nowadays, suspended cultivation can be divided into three main categories:

- On-rope cultivation in sheltered sites.
- Lantern or basket cultivation in sheltered and shallow waters.
- Lantern or basket cultivation in offshore conditions.

4.5.1 On-rope suspended cultivation

"On-rope" cultivation, where oysters are cemented onto ropes of different materials, is a traditional way of growing oysters that is used in some sheltered areas throughout the world. It normally takes place in sites where ropes cannot come into contact with one another under the effect of currents and waves. In the Thau Lagoon, in the south of France, cupped oysters are traditionally grown on ropes fixed on wooden racks. In the Mali Ston area in Croatia, the flat oysters produced on ropes are suspended on long-lines. Recently, in many production sites, the on-rope cultivation faces growing problems due to predation by fish, mainly from the Gilthead seabream (*Sparus aurata*) that escape from fish cages. Tubular plastic nets can be installed around each individual rope to provide protection, but this increases handling requirements and reduces economic margins. In some cases, if water is not too deep, a protective enclosure can be deployed over the entire production area.

"On-rope" cultivation consists of cementing the oysters individually or in small groups of 2–3 animals at regular intervals on suspended ropes whereby one end of the rope remains able to move freely. Consequently, the ropes must have a minimum weight of oysters attached to them to provide them with stability. This negates the risk of the individual ropes coming into contact with one another and becoming entangled. For the same reason, production on ropes usually commences using oysters of at least 15–20 g that must be previously pre-grown elsewhere. Normally, it is the left valve that is cemented onto the rope. The cement that is used must be resilient enough to ensure that the oyster remains secured to the rope until the end of the production cycle. The distance between the oysters along the rope should be of at least 10–12 cm (centre to centre) to avoid the individuals to come in contact while growing. The distance between the suspended ropes should be at least 0.25 m. Compared with the farming techniques in containment devices (bags, lanterns or baskets), "on-rope" cultivation has the advantages that the oysters can benefit from the maximum water and nutrient availability as there are not any barriers limiting the water flow around the oysters. At the same time, because the oysters are free of any spatial constraint during their growth, they form regular, cupped shells.

As mentioned in the introductory part of this Chapter, the oysters are submerged during the whole production cycle, which can lead to shell fragility and low shelf life. This makes it necessary to undertake a hardening process to enable the oysters to be sold as raw products. To overcome this constraint, an interesting solution has been developed in the Thau Lagoon where the frames to which the ropes are attached can be raised and lowered in and out of the water by motors powered by solar panels (Figure 4.26). This automatized system effectively creates artificial tides and assists in improving the quality and shelf life of the product.

In offshore conditions, there have been some trials attaching ropes at both extremities to frames suspended on long-lines, allowing cultivation to be undertaken despite handling costs initially appearing to be excessive.

4.5.2 Suspended cultivation in lanterns

A lantern can be defined as a container with a variable number of levels where oysters, or other shellfish, can be grown. Most common lanterns consist of metallic frames (independent rings) covered with a flexible mesh net. Other models consist of hard plastic trays inserted on a central axis/rope and stacked one over another. Lanterns are generally used in sites where tides are limited in amplitude. They can be used in both sheltered and exposed sites. The farming technique using suspended lanterns on offshore long-lines is described in detail in Chapter 8 of this manual.

This technique differs from on-rope cultivation because the lanterns protect the product from losses by detachments or predation, but they do limit the available water flow. As previously mentioned in Section 4.2 for the nursery stage, suspended

FIGURE 4.26
Oysters on-rope farms in the Thau Lagoon (France) equipped with Tarbouriech solar system for artificial tides

©Medithau / Groupe Tarbouriech

cultivation in lanterns can be implemented only if some basic conditions are provided in the farming area:

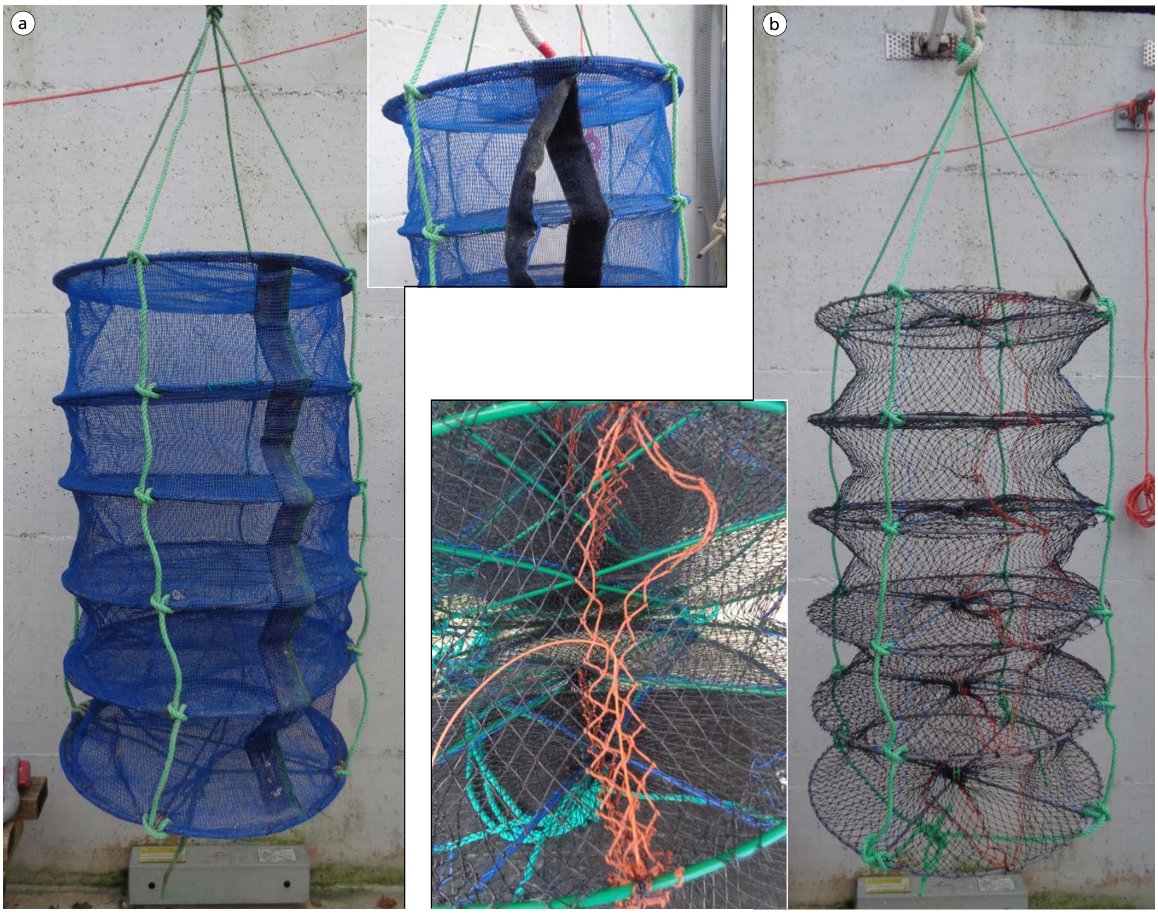
- Phytoplankton quality and density in the seawater must be suitable considering that water flow in the lantern will be partly reduced depending on mesh size.
- The water currents have to be strong enough to ensure that the water within the suspended devices is suitably refreshed on a regular basis. This condition will also depend on the mesh size of the suspended devices and their orientation and ballasting.
- Suspended devices must be installed in such a way that the waves and current experienced on the site ensure that the seed is minimally tumbled within the containers. The dimensions and positions of the floats will determine the extent of this motion.
- Risk of fouling should be limited to avoid further limitation of the water flow.

Compared with other containment devices, lanterns are bulky and can weigh more than 40–50 kg when lifted from the water (oysters, fouling and water). It means that the workboat used to undertake this farming technique will have to be equipped with suitable lifting systems able to manage heavy weights held within the tall stack of lanterns and at least 1 m out from the side of the vessel.

Lanterns with flexible mesh nets or "Net lanterns"

"Net lanterns" for oyster farming have been adapted from fishing devices, and later from aquaculture equipment that is commonly used for the cultivation of other shellfish species like scallops. Nowadays, many kinds of net lanterns are available on the market. They are made with different net typologies (Raschel nets, knotted nets, etc.), with mesh sizes ranging from 1 to 30 mm. Traditional 5–15 levels lanterns (Figure 4.27) can be used in deeper waters and in open sea, while small single level lanterns can be used for pre-growing in shallow waters (Figure 4.28).

FIGURE 4.27
Lanterns with net
(a) Pre-growing lanterns with "Velcro" closing system. (b) Growing lanterns with thin plastic cord **closing** system



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The materials the nets and rings are made of have a significant impact on the quality and prices of the lanterns. The following list outlines some of the important quality criteria to be considered:

- Because oysters have abrasive shells, low quality nets should be avoided to ensure maximum longevity and multiple usages. Good quality nets will also be easier to repair. Moulded nets must be avoided. Nets with anti-UV treatment should be preferred.
- Metallic rings should be made from good quality galvanised steel and covered with plastic to limit the oxidation processes and to prevent rust from forming. Each ring must be reinforced with a suitable crossbar protected in the same way.

FIGURE 4.28
Pre-growing using "pearl nets"

©E. Rambaldi

- Lanterns should be reinforced with 4 lateral 5–6 mm ropes to avoid the net carrying the entire weight of the product. With the correct adjustment of the lateral ropes, the nets must not be under tension when the lantern is filled with the oysters.
- For small size spat, lanterns with "Velcro" closing systems should be preferred.
- For bigger oysters, lanterns are usually closed using a plastic filament.

Usually, net lanterns are sold "ready-to-use". Alternatively, some manufacturers supply models that can be assembled directly on the farm using pre-built trays and tubular single use nets. Assembling the lanterns on site can be less time consuming than cleaning and repairing the traditional lanterns, but it causes much more plastic wastes which can be harmful for the environment and difficult/costly to dispose of.

When choosing the net lanterns, the main aspects to be taken into account are:

- The perforation dimensions of the net in relation to the size of product to be housed within the lanterns. The choice of the mesh size will be a compromise between ensuring good water refreshment and the necessity to avoid oysters getting stuck in the mesh while growing.
- The potential water flow through the walls of the lantern or between the different levels. This will depend on the size of the mesh/perforation opening, water currents on the site and density/size of the grown oysters. When comparing different lanterns, it can be useful to calculate the open external surface compared to the total external surface. Similar calculations can be extended to the separation between the levels, where water circulation is also important.
- The overall resilience in case of rough marine conditions in exposed sites.
- The closing system that can be time consuming and can require specific equipment.
- The overall height that must be adapted to the lifting equipment on the workboat and to the adopted emptying/filling techniques.

As net lanterns are not free-standing, additional supports are usually needed to make emptying, filling and closing operations easier. Such supports will take up a lot of space and can be a constraint in the case of on-board operations or reduced operating spaces. On the other hand, net lanterns can be "folded" after use and consequently easily stored which is advantageous for operators who have limited space. If of good quality and correctly maintained, they can be used for more than 10 cycles of about 3 months each.

When using net lanterns to grow spat or small size oysters, it can be necessary to add ballast to limit the movement of the stock under the effect of currents and waves. When ballasting the lanterns, it must also be noted that the net presents a significant resistance to the current. Therefore, the lantern tends to adopt an inclined position, with all the oysters grouped in a small part of the available internal space. Such a situation will have a deleterious effect on both growth and meat content. It is advisable to ballast the lanterns on their top to reduce this off-balance effect.

Lanterns with stacked circular hard plastic trays

The trays consist in a flat circular perforated bottom, a lateral perforated edge and internal perforated walls creating four independent compartments. Each tray is provided with a central reinforced hole where the supporting rope is inserted and allows a variable number of trays to be stacked on top of each other. Usually, the lanterns are delivered in separate elements to be assembled on the farm. When an element is damaged, it can be substituted without changing the whole lantern.

Depending on models, the diameter of the trays ranges between 30 and 50 cm with a height of 10–15 cm, the central hole is designed for ropes of 14–18 mm in diameter and the perforations of different shapes range from 4 to 10 mm in width. Figure 4.29 shows examples of the lanterns and a suitable workboat to operate this system.

FIGURE 4.29
Hard plastic Ostriga® lanterns
(a) Workboat with lanterns stacked on the roof of the vessel. (b) Suspended lanterns on long-line. (c) Internal compartments of the lantern tray

The main quality criteria to consider is the characteristics of the plastic from which the lanterns are made:

- The plastic must have elasticity and resilience as to not break when hit, even at the low temperatures experienced during the winter season.
- The bottom internal surface must be smooth to allow the oysters to move easily.
- All surfaces must be as smooth as possible to limit fouling.
- Plastic treated against UV should be preferred.

Apart from the lantern itself, the central rope is usually a weak point as it is constantly subject to wear due to the effect of waves and current. The use of high tenacity, double braid nylon ropes is advisable.

The aspects to be taken into account when choosing the lanterns (perforation and volume) and the way they will be used (number of trays and overall height) are similar to the concepts previously expressed for the choice of the net lanterns. Emptying and filling operations remain time consuming. Table 4.4 summarises the advantages and disadvantages of using hard plastic lanterns.

TABLE 4.4
Advantages and disadvantages of hard plastic lanterns

Hard plastic lanterns versus net lanterns	
Advantages	Disadvantages
Smooth surface of the tray allows the oysters to move easily and tumble within the lantern.	Lower open external surface when compared to the total external surface and consequently, lower water and nutrient flow through the lantern and available for the oysters.
Compartments that prevent the oysters within the same level from gathering on one side.	Lower distance between the oysters and the upper level for water circulation (about 10 cm instead of 15 cm in net lanterns).
In exposed sites, the compartments reduce the distance the oysters move, minimising damage to the extremities of the shell.	Minimum lateral apertures too big for nursery stage that therefore necessitates the use of small mesh bags to be placed within the compartments.
Lanterns are mono-material (no rust), more resistant than net lanterns, easier to repair (replacement of single elements) and resilient for a longer time.	More expensive for a similar available volume.
The number of trays in a stack can be altered to best suit the number of oysters that need to be accommodated whereas the net lanterns have a fixed number of levels.	Storage requires much more space.
Emptying and filling is less time and space consuming. Hard plastic lanterns are more adapted to automation processes.	

Source: Elaborated by the authors.

4.5.3 Moving offshore

Shellfish farming is a highly sustainable activity and can therefore contribute to global food security more efficiently than many other zoo-technical sectors. At the same time, the sector is undergoing significant changes in terms of technology, automation and economies of scale. In this context, the ability to move offshore, where competition for available marine space is reduced, can be a viable solution once certain challenges are overcome.

Lantern and basket technology has progressed rapidly in the last few years and will probably assist the industry in moving away from artisanal techniques involving a lot of manual handling towards new, more industrial models featuring a higher degree of automation. This will hopefully encourage more young people into the industry who would otherwise have been put off by the amount of hard manual labour.

However, moving offshore will introduce a new set of challenges:

- The cost of installation and maintenance of the cultivation systems increase significantly compared to sheltered sites. The time to reach the farming area will require a new approach with equipped workboats where it is possible to work while moving from and to the farm.

- The natural diminution in phytoplankton concentration and its different composition when moving away from the shore could be limiting factor.
- The "tumbling" of the oysters can become excessive, thereby damaging their shells. Systems that involve the use of heavier structures combining multiple baskets should be considered as they will be less impacted by waves and currents and therefore avoid any excessive "tumbling" of the oysters.
- Systems similar to submersible fish cages should be implemented, so that the whole structure can be submerged beneath the water's surface to avoid damage during periods of rough sea conditions.
- The increasing use of plastic materials at all stages of the production process must be addressed to avoid dispersion in the marine environment. Sustainable practices should be adopted to reuse or dispose of the equipment.

4.6 OVERVIEW ON COMMONLY USED EQUIPMENT

This section introduces the different long-line configurations that can be used for farming oysters and some equipment that is common to all systems of cultivation.

4.6.1 Long-line typologies and components

Typologies

Long-lines consist of all the necessary components to allow a rope, or headline, to be supported in the seawater column at the chosen depth. The headline runs parallel to the water's surface and is used to support all kinds of cultivation devices whilst being maintained at a suitable depth using buoys. The three main systems can be defined according to the depth that the headline and the buoys sit at (Figure 4.30):

- "Floating" when both headline and buoys remain on the surface;
- "Sub-floating" when only the buoys stay on the surface, whilst the headline is suspended a few metres beneath (Figure 4.31);
- "Submerged" when both headline and buoys remain under the surface, so that nothing is visible from the boat.

From the sea bottom to the surface, a long-line consists of:

- The anchorage devices to which are linked the mooring lines;
- The mooring lines that are maintained under tension by buoys installed at different levels;
- The headlines that support the cultivation devices, which are fastened to the mooring lines at the upper end towards the surface;
- The buoys of different shapes and sizes that keep the whole system under tension in a single plain.

From this basic composition, some variations must be mentioned:

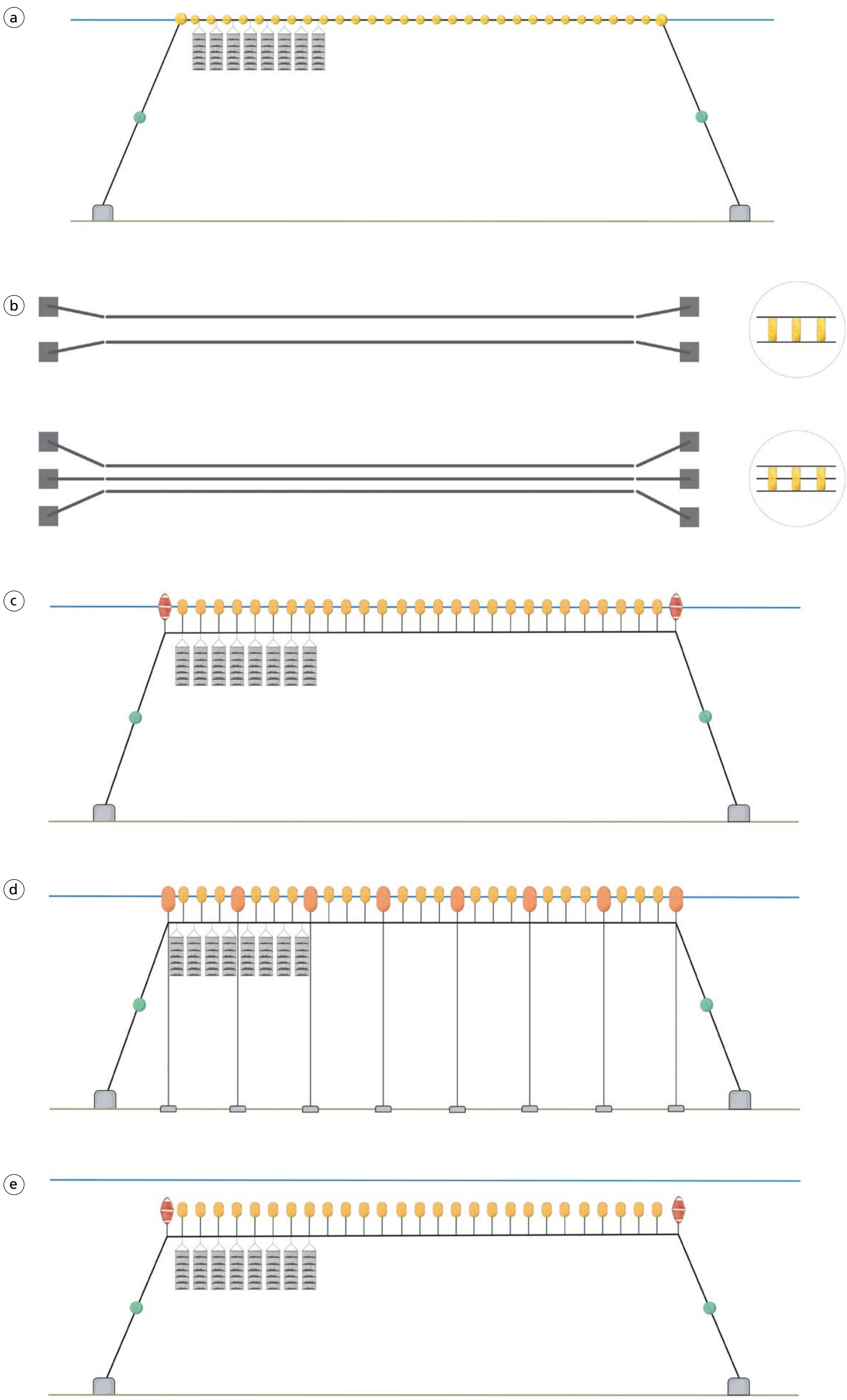
- The presence or not of intermediate mooring lines, also called intermediate legs;
- The possible use of parallel headlines with reduced distance between them.

Components

The commonly used components to build long-lines are listed below:

- Anchoring devices (concrete blocks, anchors, screw anchors, etc.);
- Ground chain or submerged buoys to allow the structure to be correctly tensioned;
- Headline ropes and mooring line ropes;
- Surface buoys of different shapes and sizes;
- Shackles with bolt, nut and safety pin, thimble and bulldog grip.

FIGURE 4.30
Different type of long-line structurers
(a) Floating long-line. (b) Multi-headlines floating long-line. (c) Sub-floating long-line.
(d) Sub-floating long-line with intermediate legs. (e) submerged long-line



Source: Elaborated by the authors.

FIGURE 4.31
Example of sub-floating long-lines in Mali Ston, Croatia

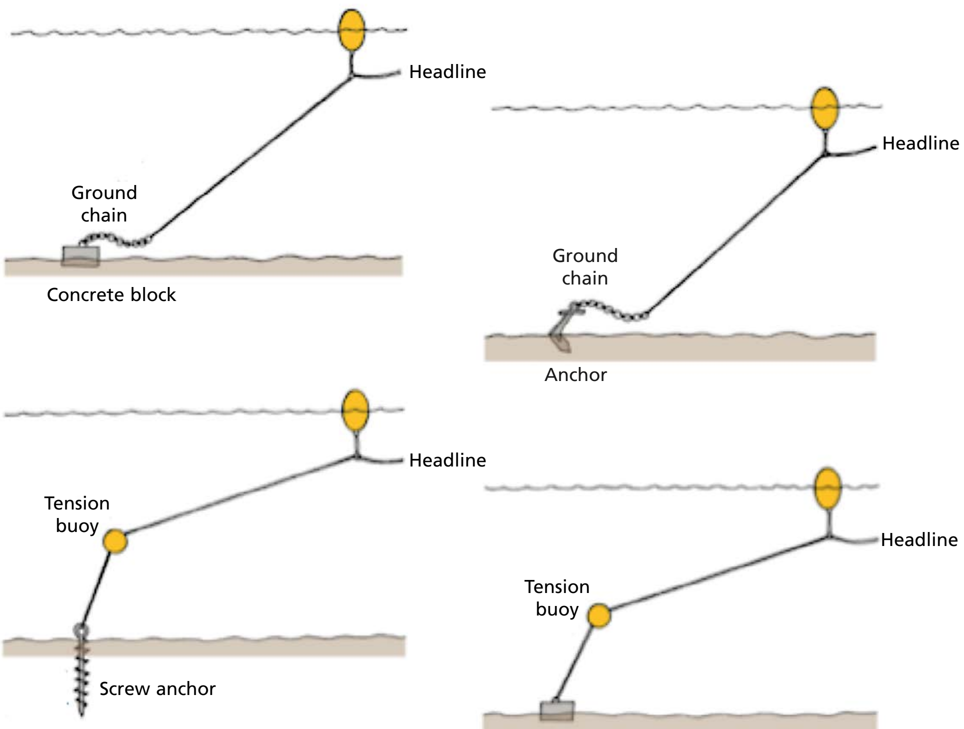
©L. Gennari

Different anchoring systems can be implemented to allow the long-line to adapt to the forces applied to it by currents and waves (Figure 4.32). These systems will allow the elongation of the mooring line when applied forces increase.

Mooring lines can be designed with a ground chain or with an intermediate submerged buoy. In the first case, the mooring line will be kept under tension between the surface buoys that push up and the heavy stainless steel ground chain that pulls down. When the forces applied on the system increase, the chain is lifted from the bottom with consequent elongation of the mooring line. In the second case, by using an intermediate submerged buoy, the lower part of the mooring line will be kept under tension by the vertical force applied by the buoy. When the forces applied on the system increase, the angle of the mooring line at the level of the submerged buoy increases with consequent elongation of the mooring line.

The estimation and calculation of the applied forces, the choice of the most suitable system and the sizing and design of the mooring line will have to be done by specialised engineers. In some cases, in typical marine conditions, it will be possible to replicate existing standardised mooring systems.

FIGURE 4.32
Long-lines mooring systems



Source: Elaborated by the authors.

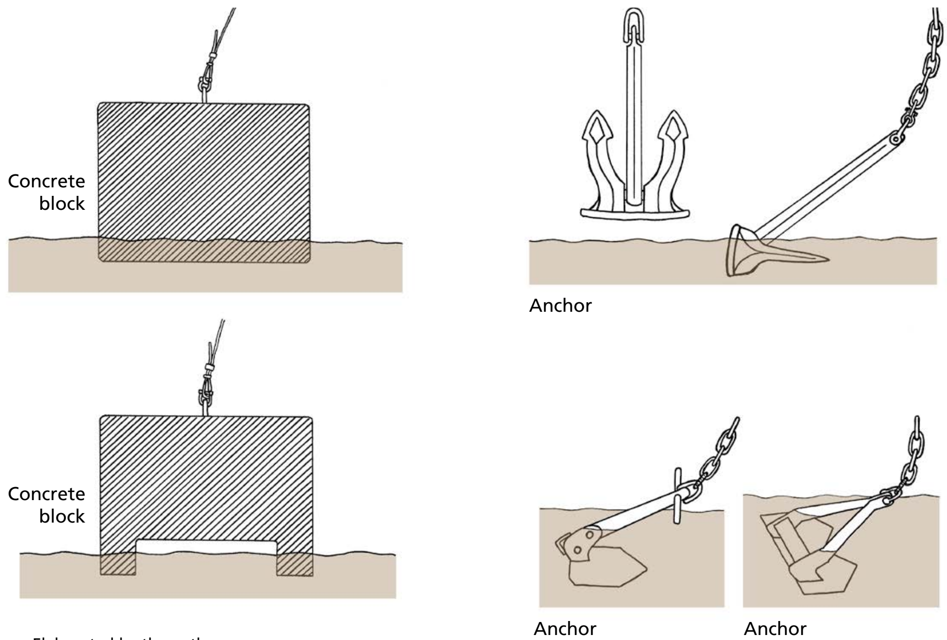
Concrete blocks and anchors

The weight and the characteristics of concrete blocks or anchors is part of the calculation and design above (Figure 4.33). It is recommended to always consult expert companies to undertake these calculations. Under sizing can be deleterious and make all the equipment unusable.

Reinforced concrete blocks for anchoring can be built on site and then deployed in the chosen positions on the seabed. There are two main typologies: a simple cubic block or a concave cavity block where the lower surface is partially empty (Figure 4.33). In all cases, the total weight will have to be sufficient to counteract the traction forces applied to the long-line and to ensure that the block cannot slip on the seabed. Concrete blocks are recommended for sandy or muddy seabeds.

Many anchors, designed for fish cages and long-lines, are available on the market (Figure 4.33). As stated above, an expert should do the size calculation, with regard to the total weight and to the inclination of the anchor/mooring line.

FIGURE 4.33
Long-lines anchoring devices



Source: Elaborated by the authors.

Buoys

Buoys of many shapes and variable volume are available on the market. As they occupy a lot of space and are consequently expensive to transport, farmers or farm designers often prioritise products that are available locally, but this may not always result in the optimal buoy configuration being utilised. The relationship between the shape, volume and position of the buoys and the grow-out equipment that they support will have a significant impact on the meat content, shape and shell resistance of the product. In many cases, it will be possible to adapt farming practices to the buoys available locally, but for high quality final product such a compromise is not always suitable.

The buoys that keep the headline in position can be used underwater or on the surface. In the first case, they should be filled with polyurethane foam to avoid the walls collapsing under the pressure they are subjected to depending on the depth they will be situated. In the second case, except for buoys of primary importance to the stability of the whole system, filling with pressurised air is sufficient.

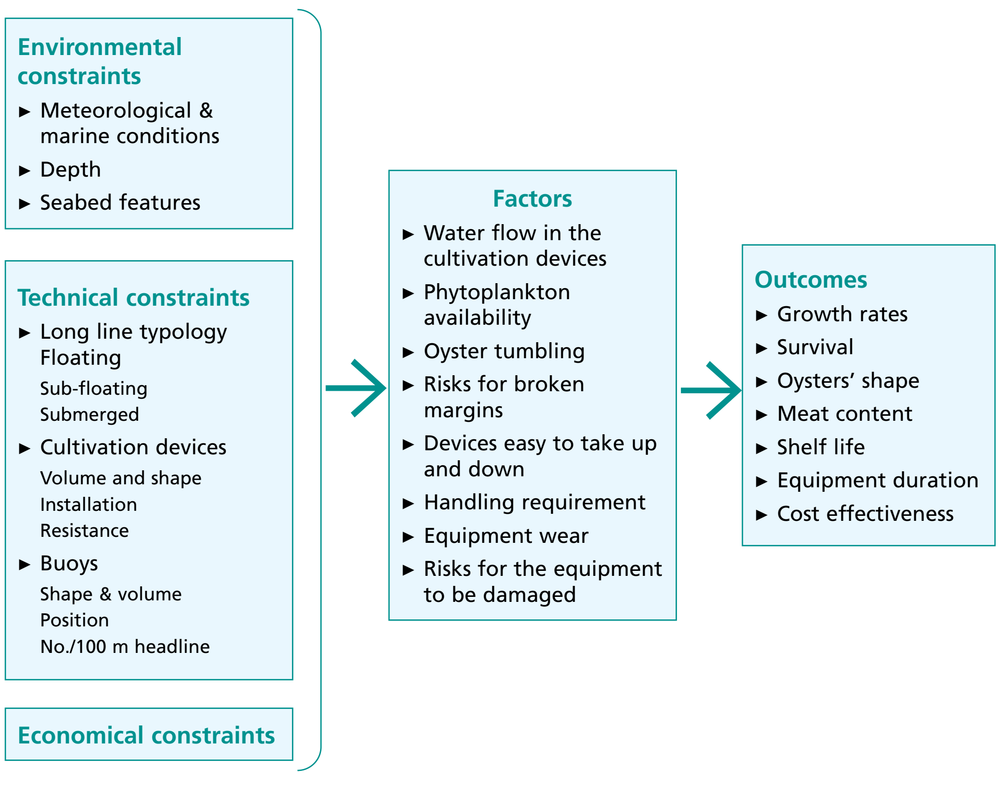
The surface buoys are usually made from moulded plastic and can be spherical, bi-conical, or cylindrical. The shape, the position and the level of immersion will determine the way the buoys move vertically in the water as well as the range of these movements. Consequently, the buoys' movements will have an effect on the suspended cultivation devices and on the oysters they contain. For instance, a bi-conical buoy that is half submerged will have more sudden movements compared to the same buoy that is almost fully submerged. In the same way, the stress on the whole long-line will be reduced in the case of submerged long-lines.

In some cases, floats can be homemade from HDPE pipes. These buoys are particularly suitable for exposed sites. Furthermore, their shape avoids abrupt movements under the effect of waves, reducing the risk of breakage of the long-lines and lanterns/baskets.

Beyond the characteristic of a single buoy, the number of buoys along the headline is another important factor in managing the whole system. When using large volume buoys with a greater distance between them, the lanterns near the buoy will be submitted to completely different conditions when compared to another lantern that is more distant. Under these circumstances, lanterns situated near to the buoys are frequently damaged and oysters can be excessively "tumbled". This in turn can lead to the outer edge of the oysters' shells being broken meaning that they are unable to retain their inter-valvular water and therefore can't be removed from the water and sold. By using numerous smaller buoys, this scenario can be avoided, but the installation and maintenance is much more time consuming.

The choice of the cultivation devices and the related design of the long-line system is a complex matter with many factors that must be considered: constraints, key factors and expected outcomes are summarised in Figure 4.34.

FIGURE 4.34
Constraints to take into account for long-lines design



Source: Elaborated by the authors.

Oysters containment devices

The chosen technique, the farm carrying capacity and the related containment devices will be the starting point of the overall design. Main available devices have been described previously:

- Ropes with cemented oysters (see Section 4.5.1)
- Net lanterns or hard plastic lanterns (see Section 4.5.2).
- Baskets or modified oyster bags (see Section 4.3.2).
- Floating baskets (see Section 4.3.2).

As mentioned previously, a multitude of approaches or strategies are being undertaken all over the world along with the offshore long-lines development and the increasing use of baskets. When compared to lanterns, the baskets have a higher available volume in relation to their external surface area. In lanterns, the oysters in the intermediate levels always grow less than in upper or lower levels, whilst in baskets, the oyster growth is more homogeneous.

4.6.2 Grading equipment

Vertical graduated vibrating oyster grader

The vibrating grader operates by shaking the oysters that are delivered onto it over wire mesh grills or perforated metal sheets with square apertures of varying sizes (Figure 4.35). The oysters drop onto the top grill which has the largest apertures, so that the biggest oysters remain on top, and the smaller ones fall through. This process is repeated with diminishing sizes of grill placed one below the other. The number of layers of grills will depend upon the model of grader purchased but in this example, there are 3 layers delivering 4 grades of oysters. The grader grills are angled downwards so that the end that the oysters are fed onto is higher than the end with the exit chutes. The height, and therefore the angle of inclination, can be controlled by adjusting the length of the rear wheel support bar, which can be extended or retracted inside the main frame of the grader. This angle, combined with the vibrations supplied by the electric motors, moves the oysters across the grills. The grills can be interchanged to allow for the grading of different sizes of oyster. The standard sizes of grill available are shown in Table 4.5.

TABLE 4.5
Grader grills wire mesh sizes

Grader grills wire mesh sizes (mm)	6	8	10	12	15	20	25	30	35	40

Source: Elaborated by the authors.

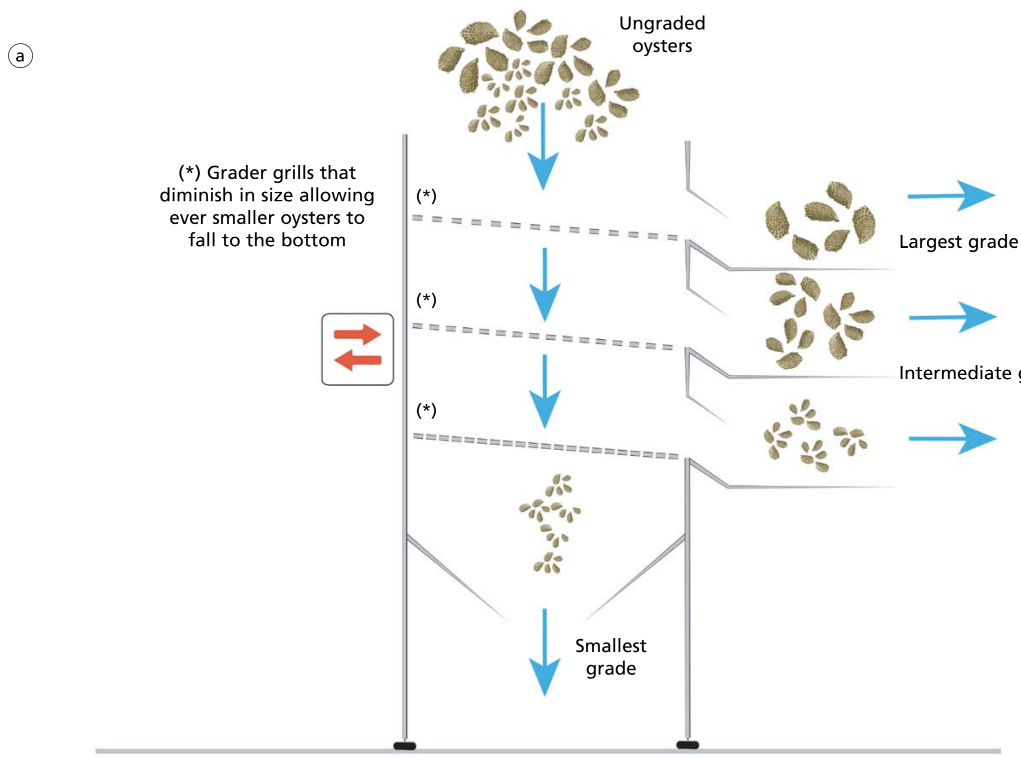
Horizontal graduated vibrating oyster grader

The principle of operation of this grader is very similar to "Vertical graduated vibrating oyster grader". However, rather than the grills or perforated sheets being situated in a graduated stack, one under the other, they are laid out horizontally in sequence, starting with the smallest apertures and finishing with the largest. Refer to the diagram in Figure 4.36 for further elaboration of this motion.

FIGURE 4.35

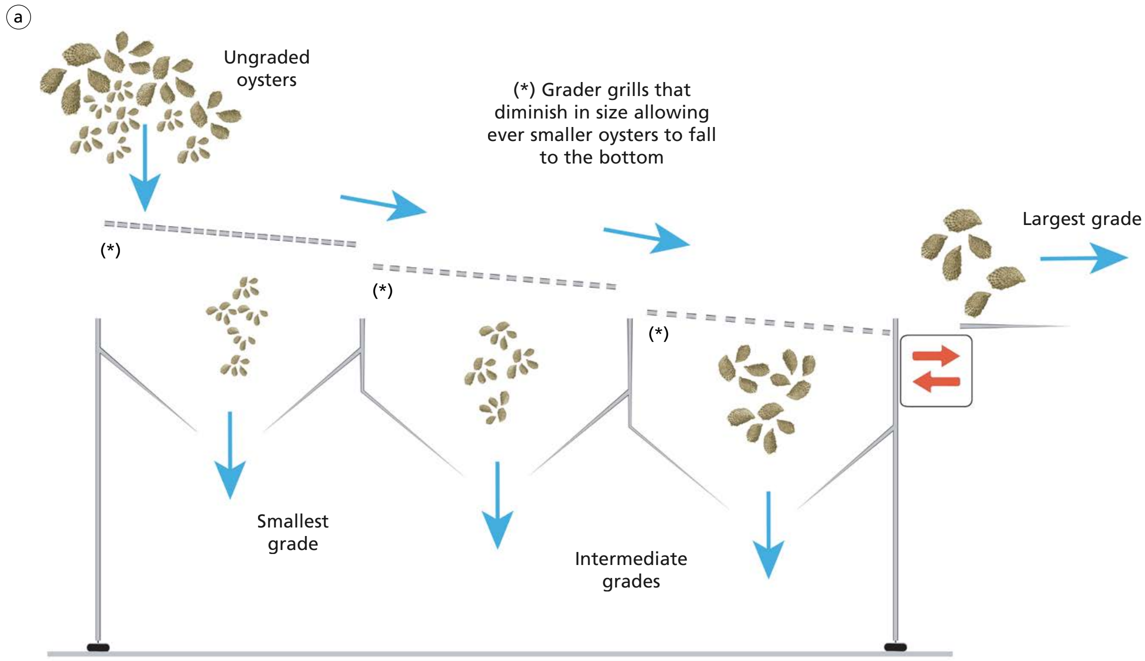
Vertical vibrating oyster grader

(a) Diagram showing the movement of oysters through the grader. (b) Example of vertical vibrating oyster grader. (c) Oysters moving across a grading grill



Source: Elaborated by the authors.

FIGURE 4.36
Horizontal vibrating oyster grader
(a) Diagram showing the movement of oysters through a grader.
(b) Example of a horizontal vibrating oyster grader. (c) Different sizes of grading grills



Source: Elaborated by the authors.

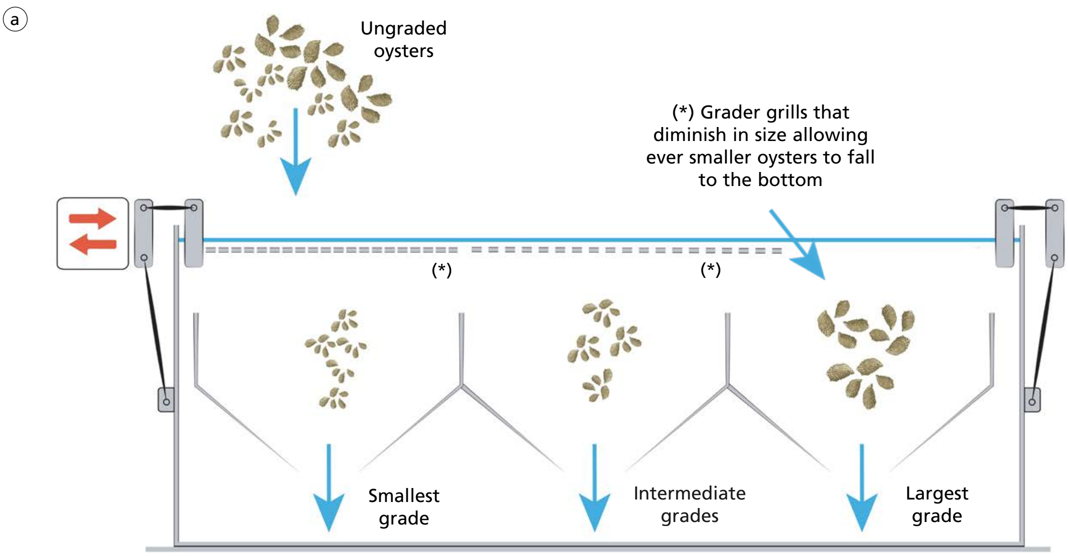
In-water elliptical motion grader

This grader is designed for use with seed oysters (Figure 4.37). The water ensures that the grading process is much gentler and protects the fragile shells of the small oysters. The grader consists of a main tank that is divided into 3 separate compartments. Above the first two compartments is a grill with a different size aperture, starting with the smallest size and increasing as the oysters move along the length of the grader from the end onto which they are fed. The resulting oysters are therefore separated into 3 grades,

FIGURE 4.37

In-water elliptical motion oyster grader

(a) Diagram showing the movement of oysters through a grader. (b) Example of in-water elliptical motion grader. (c) Oysters moving along the grading grills



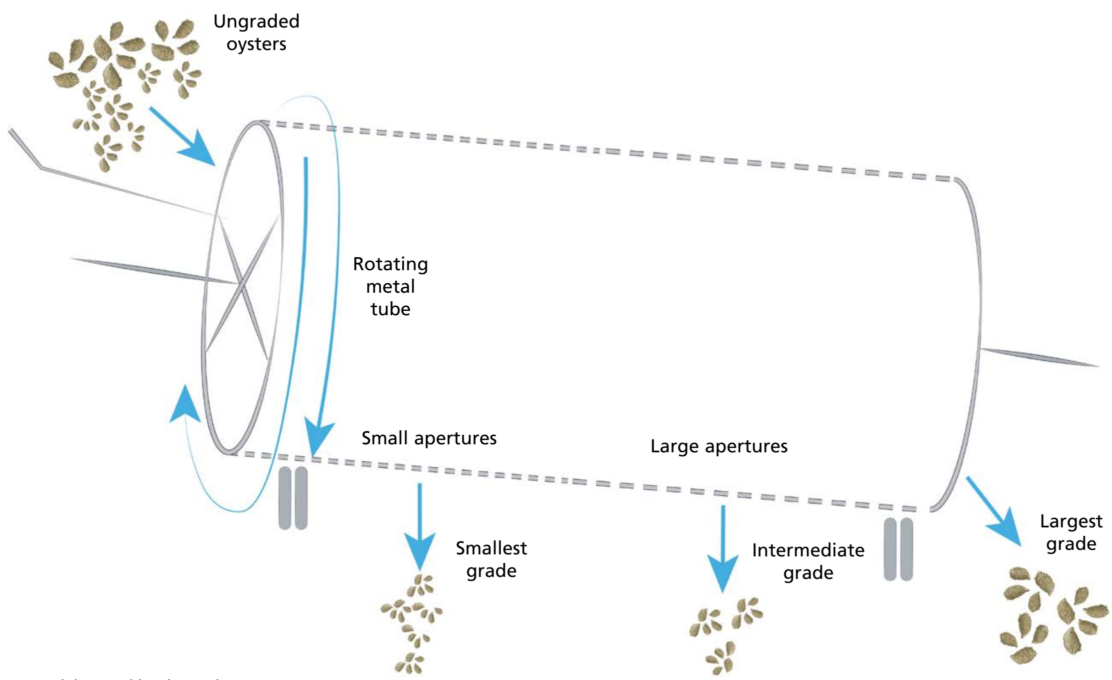
Source: Elaborated by the authors.

with the smallest falling into the compartment nearest to the feed end, a medium grade falling into the middle compartment and the largest oysters being delivered into the end compartment. The shellfish are moved along the grills by an electric motor that is attached to a spring-loaded frame which holds the grills in place. The resulting motion is an ellipse which gently shuffles the oysters down the length of the grader. Below each compartment is a watertight chute. Once the grading has been completed, the chutes can be released, and the oysters will drain out into the containers placed below them.

Rotating grader

The rotating grader (Figure 4.38) is suitable for use with juvenile and market size oysters but not seed. It is a simple but effective system that consists of a rotating metal tube mounted onto a frame which holds the tube at a gentle downward angle. The tube sits on small wheels and is rotated by an electric motor. The tube is constructed in two halves, one with small apertures closer to the top and one with larger ones towards the bottom. The oysters are delivered into the tube and the smaller oysters fall out of the upper apertures and into the boxes positioned below. The next grade falls out of the larger apertures further down the tube and the largest fall out of the end. This results in three separate grades. On some models the tubes of some graders can be interchangeable on some models to allow them to sort multiple sizes of oyster. Inside the tube is a water spray bar that allows the oysters to be cleaned as they tumble down the length of the grader.

FIGURE 4.38
Rotating oyster grader – Diagram showing the movement of oysters through grader



Source: Elaborated by the authors.

Circular calibrator

The circular grader/calibrator (Figure 4.39) is used to grade market size oysters based upon their individual weight. It has 6 exit chutes and can therefore be used to separate the oysters into 6 different grades. The required grades can be programmed into the main control panel and can be set to the exact weights required by the operator. For example, one grade could be 60–80 g. Above the exit chutes is a rotating mechanism onto which are mounted multiple trays. Individual oysters are fed onto these trays by a feeding belt that ensures that only one unit is delivered at a time. The trays are fitted with a load sensor that assesses the weight of each oyster. As the tray rotates, it is released when it passes the correct exit chute, depositing the oyster into the bag or tray below.

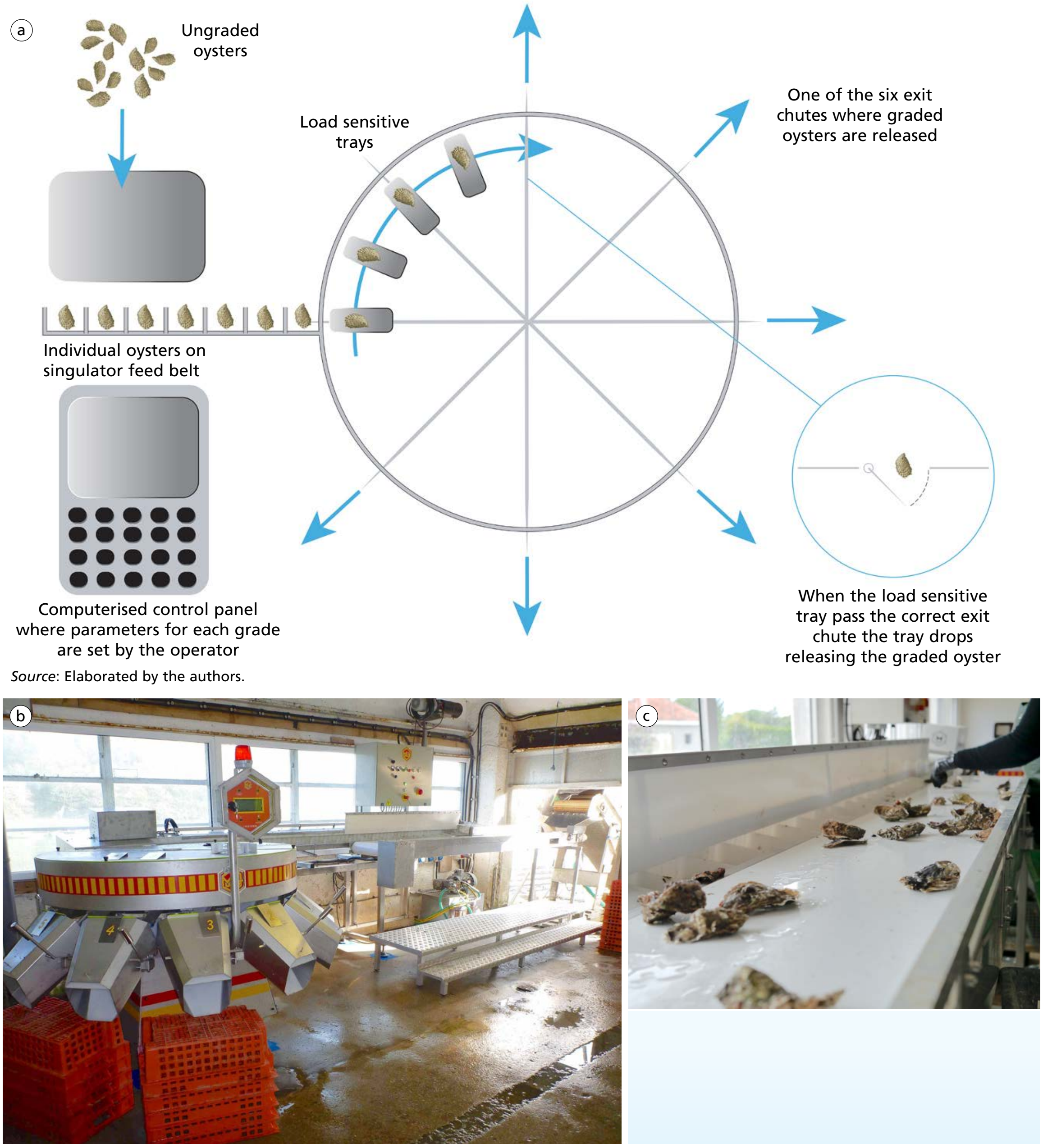
Oyster singulator

The singulator is a piece of equipment used to separate out multiple oysters that are fed in from the elevator belt into single units. One example of these is shown in Figure 4.39c. It can be used before the circular weighing grader or the vision grader where it is important that single oysters are delivered for final calibration.

FIGURE 4.39

Circular oyster calibrator

(a) Diagram showing the movement of oysters through the grader. (b) Example of a circular calibrator. (c) Oysters on a sorting belt being placed into the singulator feeding belt that deposits them onto the load sensitive trays of the calibrator



Source: Elaborated by the authors.

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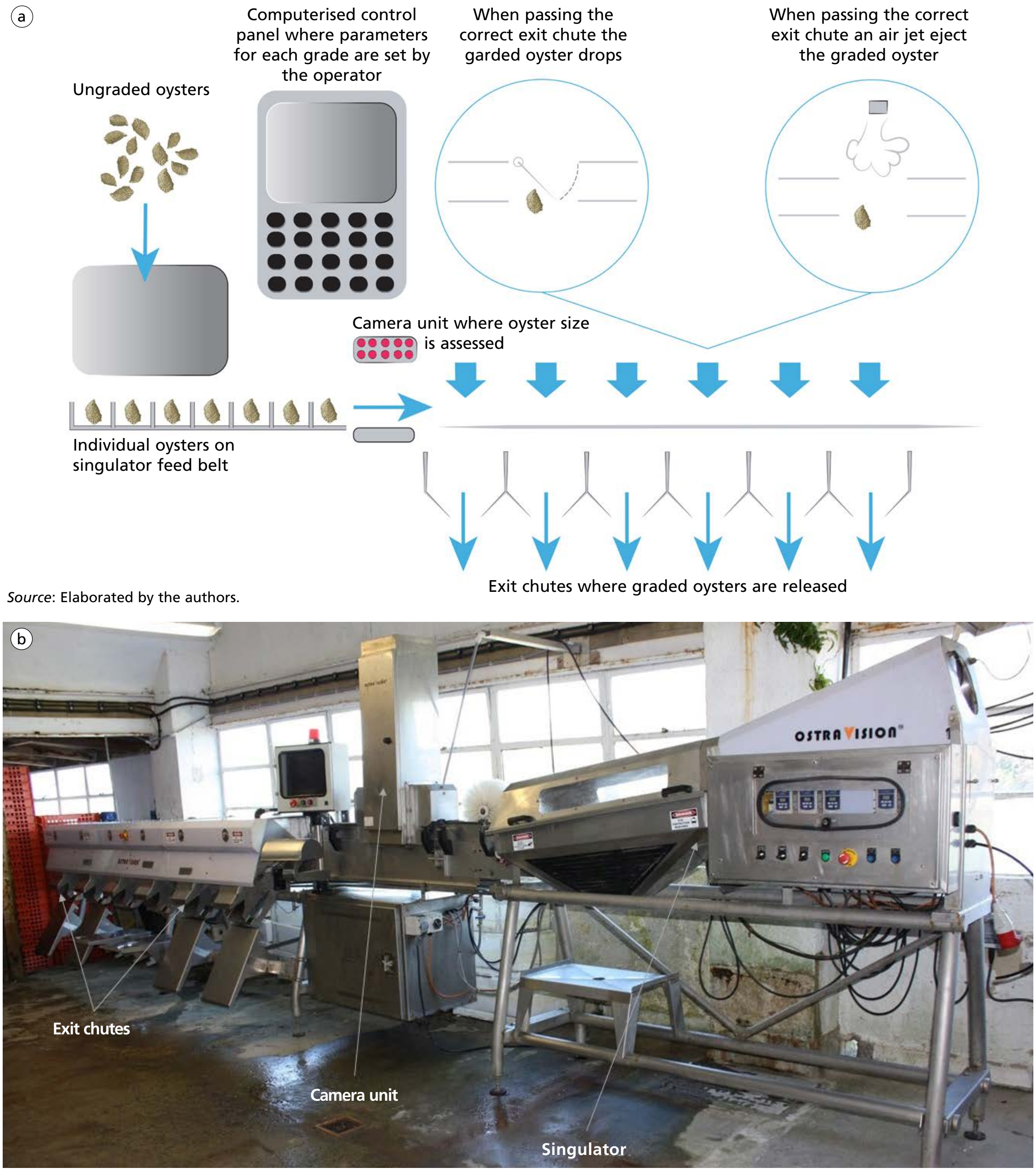
Linear vision calibrator

Vision graders use high-tech cameras to assess the size of the oysters passing below their camera unit (Figure 4.40). They grade according to pre-programmed size rather than weight. Each individual oyster is fed onto the grader belt by a singulator so that only a single oyster passes under the camera at one time. In the model shown in the photo, there are 6 exit chutes programmed to deliver 6 separate grades. Opposite the chutes, on the opposite side of the conveyor belt, are high-pressure air jets. Once the grader has determined the size of the oyster, they continue along the belt until they reach the designated chute. At this point, the air jet is activated, blowing the oyster out on the chute and into a bag or basket. Other such calibrators use mechanical pushing systems instead of air jets.

FIGURE 4.40
Linear view of an oyster calibrator
(a) Diagram showing the movement of oysters through the grader. (b) Example of a vision calibrator



Source: Elaborated by the authors.

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4.6.3 Other equipment

Weighing elevator

This machine has a conveyor belt that delivers shellfish into a weighing unit that can be pre-programmed to the exact weight of oysters that is required (Figure 4.41). When the intended weight is reached the conveyor stops and the mechanical jaws that are containing the oysters can be opened to release them into whatever reciprocal is being used. This can be used in any form of cultivation technique where it is important to record and dose exact quantities of oysters.

FIGURE 4.41
Weighing elevator

4.7 BASIC RULES OF HANDLING

4.7.1 Grading

Individual oysters demonstrate different growth rates and need to be graded periodically to avoid size discrepancy within a batch. This phenomenon is true both for oysters produced in a hatchery and for those that are fertilised and settle in the natural environment. For example, if grading is not performed, the weights of individual oysters from the same batch, with an average commercial weight of 80 g, can range from 10–150 g. In all batches, 5–15 percent will demonstrate a slow growth rate and should be rejected after the first couple of grading cycles. A similar percentage of faster growing stock is usually also observed.

The primary purpose of grading is to reduce the competitiveness between individuals. Many studies have demonstrated that maintaining oysters of diverse sizes next to each other penalises the growth of the smaller ones as result of being outcompeted by larger individuals for water and nutrition.

Grading is a useful stock management process for the farmer to undertake. It reduces overall handling and gives an accurate picture of how the stock is developing throughout the production cycle. From T6 spat to commercial size (80 g average weight) grading should be performed at least 3–4 times. However, the timespan between two grading operations will depend on the duration of the whole production cycle experienced at the individual farm location, and the season in which the operation is being undertaken.

Grading can be performed manually or mechanically. Grading on wire mesh grills or perforated grids is usually more efficient than with parallel bars where the oysters get stuck more easily.

Mechanical grading is usually more stressful than manual grading and can lead to the outer margins of the oyster's shell becoming damaged. However, when grading small or medium size stock to be reintroduced into the water for further growing, this can be an advantage, as the animals will produce a thicker and stronger shell as they repair their outer margins. When grading market size oysters that are ready to be sold, it is advisable to re-immerse them for a period of 3–4 weeks, allowing them the time to repair their shells and maximising their shelf life. Together with the presale hardening, which is described later in this chapter, this practice is essential when the oysters are destined to be sold as live product in their shells.

The way in which grading is undertaken, the relationship between wire mesh/parallel bar sizes and the average weight of the resulting batches of graded oysters, as well as the timing of grading operations is detailed in Chapters 5, 6, 7 and 8 depending on the chosen production technique.

4.7.2 Hardening

Hardening is a process that is used to improve the resilience of oysters, particularly those grown for most of their lives in subtidal zones or on long-lines. It involves exposing the oysters to the air and can be achieved in a few different ways. Together with farming practices and grading, hardening is a key factor in controlling and improving the quality traits of the oysters as described in Section 2.2 (meat content, shelf life and the shell characteristics). In this section, the ways in which this can be accomplished and the various stages of the growing cycle that it can be applied to is introduced.

Hardening by placing oysters in the intertidal zone

On sites that have access to intertidal foreshore, placing the oysters in the intertidal zone is the most common practice for hardening (Figure 4.42). Placing stock in this zone regularly exposes the shellfish to the air when the tide recedes. This has two main effects that contribute to the hardening process. The first is that the oysters must regularly open and close their shells, strengthening their adductor muscle. This allows them to prevent their shells from gaping and thereby losing the water that they need to maintain themselves in a healthy state without desiccating until the tide floods to cover them. A strong adductor muscle also helps them to resist predators that attempt to prise open their shell. The second result of intertidal exposure is to slow the rate of growth. This allows the oyster to build a thicker, stronger shell. This is not only useful to protect the organism from predation, but it can also help to prevent damage to the shell during any processing that the oyster has to withstand, such as grading.

FIGURE 4.42
Hardening cages on intertidal foreshore seen at low tide

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This technique of hardening can be used at three different stages of production depending on the cultivation technique used.

1. Hardening seed
   Seed can be placed in the intertidal zone before being moved into subtidal grow-out equipment or into lanterns supported on long-lines. This will increase the resilience of the oysters as they develop and allow the weaker, slower growing individuals to be graded out and removed before taking up space in the grow out equipment. This improves survival rate in the stock that remains. The period that the seed is kept in this zone varies depending on the region in which they are grown and cultural traditions. In some areas, they will be kept in the intertidal zone for 8 weeks and in others this period can be up to 6 months. Compared to oysters that are directly grown in subtidal or offshore conditions, the small size oysters that undergo hardening at the beginning of the production cycle will keep a stronger adductor muscle until commercial size.

2. Hardening half-ware
   This is particularly relevant for oysters that have been grown using an enclosed, subtidal technique for their juvenile stage but are then going to be grown on to market size on oyster beds. Once the oysters have reached the ideal weight to be placed onto the beds (10–20 g) they should be moved to an intertidal site for a minimum of 1 month before relaying onto the bottom commences.

3. Pre-sale hardening
   Once the oysters have reached market size and are ready to be shipped to the customer, it is recommended to hold them in the intertidal zone before transportation. This allows them to recover from any shock caused during the harvesting process or final grading and will build up adductor muscle strength which will in turn increase their shelf life. A period of 1 month is recommended for this process, but if market demands are high and this length of time cannot be achieved, then 2 weeks will still improve shelf life.

Hardening without access to the intertidal zone

On sites that do not have access to intertidal foreshore, and where it is not possible to install fixed supports onto the seabed, other strategies must be adopted, like placing the oysters in floating devices or removing them from the water during a certain period of the production cycle. This requires time-consuming handling, installing floating systems that must be resilient enough to endure wave action and strong currents or having dedicated land-based facilities, where the same process can be replicated using ponds that can be drained and flooded to emulate the movement of the tides.

In these circumstances, different strategies can be undertaken:

- Produce oysters only for meat extraction and further transformation, whereby their resilience and shell strength are not key issues.
- When introducing oysters to the farm, use spat or half-ware that has already been hardened elsewhere.
- Increase the frequency and stress of grading that can have a partly similar effect with regards to their resilience to being out of the water and promotes thicker shell growth.
- Design farming systems that make use of floating devices that expose the oysters to the air for designated periods of the production cycle. An example of this is described previously in Section 4.3.2 (Figures 4.21 and 4.22).

- Adopt systems to lift the growing devices which make it quick and easy to raise the oysters out of water for significant periods.
- Have land-based facilities in close proximity to reduce transfer times.

On sites that have very limited tides or only have the use of offshore cultivation zones, serious consideration needs to be given as to the cost and equipment necessary to undertake a hardening process of the oysters. This issue is also discussed in the conclusions.

4.7.3 Moving and transporting oysters

Some basic precautions should be undertaken when moving oysters from hatchery or recruitment sites to the farm, within the farm or between different sites during the growing cycle and then on to the market when commercial size has been reached.

When transporting oysters that have to be grown-on at a farm in a different location from their original site, temperature fluctuations between the different farms should be reduced to a minimum as much as possible. This also applies to the period that they are in transit. If the temperature at the new site is significantly different from the temperature where the oysters originated from, an adaptation period is recommended. During this period, refrigerated or low temperature storage should be avoided to prevent the oysters from suffering temperature induced shock which can potentially lead to mortalities. Conversely, once the product is harvested, temperature should be constantly maintained between 4 and 6 °C without any interruption of the "cold chain" during storage, processing and transportation.

Hatchery seed can be safely transported in closed polystyrene boxes for periods of 24–48 hours. In this state, the oysters can be shipped by air freight over long distances. The box can be almost completely filled and closed with adhesive tape. Half-ware product can be harvested and transported in bulk bags or heavy-duty plastic pallet boxes.

When moving oysters from their farm of origin to a new site for on-growing, factors such as shell fragility and the difference in growing conditions between the two sites must be taken into consideration to minimise the risk of mortalities. For instance, moving thin shelled oysters that have been grown in lanterns in offshore conditions, to an intertidal zone where the oysters will be exposed to the effects of waves and experience long periods out of water can be deleterious.

It should also be noted that the risk of mortalities occurring during transportation increases with product size and with a change in the farming conditions between the sites, whereby a change in both the environmental conditions and the cultivation technique can have an effect on the number of mortalities experienced.

If a batch of oysters that is destined for another farming site presents an abnormal percentage of dead or weak oysters, sanitary controls must be carried out and any transportation must be avoided so as to not spread possible pathogens.

5. Nursery floating upwelling system (Flupsy)

In this Chapter, the manual will concentrate on the design and construction of one particular solar powered Floating Upwelling System (Flupsy) as featured in Figure 5.1, although the operator will have to decide which of the many different upwelling options, both floating or land-based, are best suited to their particular circumstances. This design is particularly useful for farms in remote locations without a suitable site to allow the Flupsy to be powered by electricity from the land. It is also only suitable for use in relatively sheltered environments like protected bays and estuaries.

FIGURE 5.1
Upwelling raft powered by solar panels

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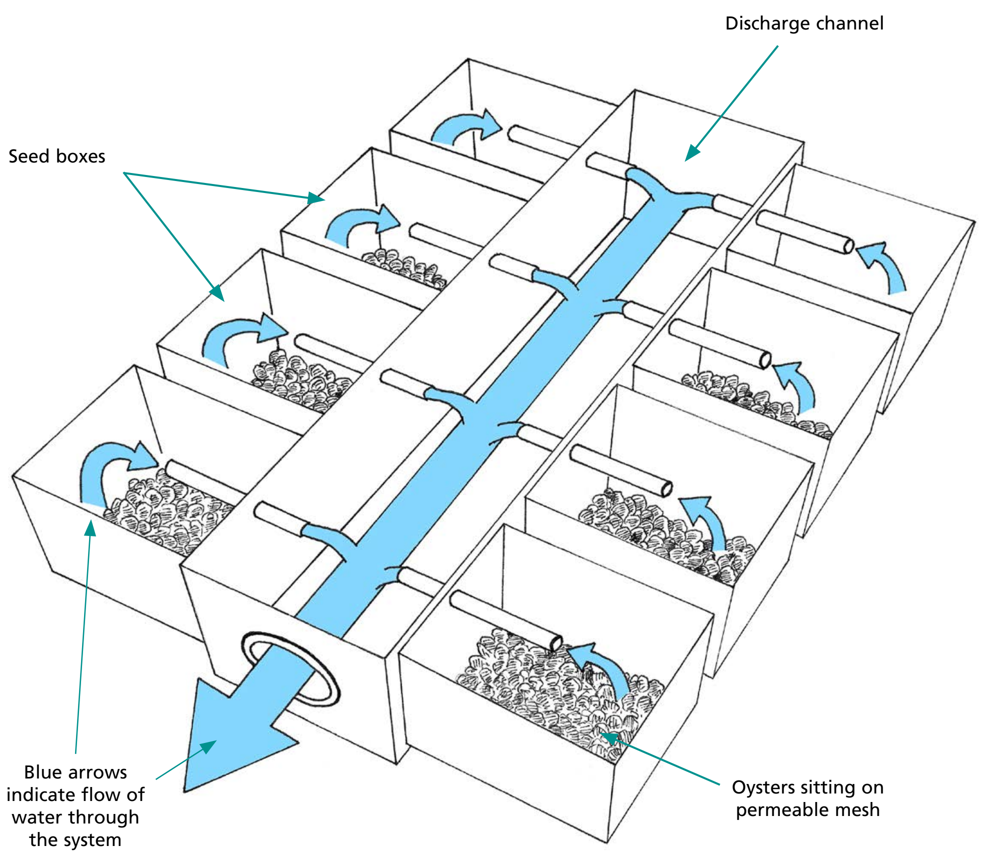
5.1 BASIC PRINCIPLES OF A FLUPSY

The diagram in Figure 5.2 illustrates the basic principles of how floating upwelling systems operate.

The boxes, in which the seed oysters are held, are connected to the main discharge channel. As water is drawn out of the discharge channel, by whichever extraction equipment is incorporated in the design (pump, paddlewheel, propeller, etc.), it causes the water level within the channel to drop. The head differential between the higher level of the seawater surrounding the Flupsy and the lower level in the discharge channel causes water to be drawn from the silos into the channel. The mesh screen at the bottom of the silos, on which the oysters rest, is the only permeable access point through which water can re-enter the system. The seawater is therefore pulled up vertically through the mesh, driving fresh nutrients past the oysters, and back into the discharge channel which is then deposited back into the body of water surrounding the Flupsy.

FIGURE 5.2
Diagram showing movement of water through the Flupsy system



Source: Elaborated by the authors.

5.2 LOCATION AND DESIGN

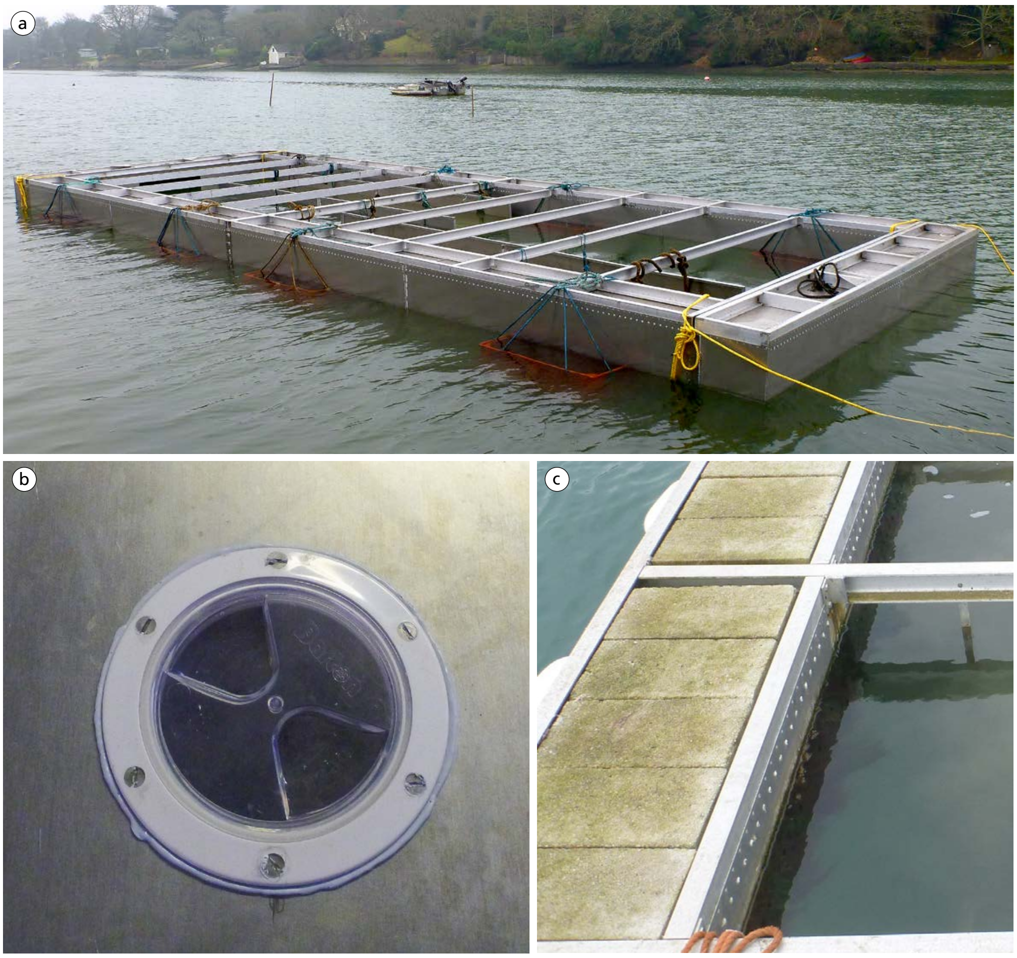
5.2.1 Location

A Flupsy can be situated next to the shore or moored remotely depending on the availability of suitable marine space. They are often positioned next to a dock or pontoon system that is linked to the land. This allows the seed and equipment to be monitored easily and they can be supplied with electricity from the mains power grid. However, suitable conditions in terms of water quality and tidal depth are not always available next to the shore so it is also possible to position them remotely and power the chosen water exchange equipment using solar panels. This allows the operator to choose a location that will provide optimal growing conditions without the restriction of being tied to a shore-based power source. If this option is decided upon, then the chosen location should be protected from wave action to prevent damage to the equipment and disturbance of the seed oysters. It should also be as close to the land-based facilities as possible to enable efficient management and monitoring of the stock. At this stage of their development, the oysters are growing very rapidly and require frequent attention. Also, millions of individuals can be held on the Flupsy at one time which represents the future output of the farm. It is therefore imperative that the device is moored in a secure location where the operator can undertake all of the crucial processes, including moving stock to and from the grading facilities on land, without unnecessary time delays or interruptions.

5.2.2 Main elements of the design

There are several major elements of the Flupsy that are brought together to house the oyster seed and enable the desired flow of water and nutrients through the enclosed stock. Each one, and their function, is listed below. Please note that all of the individual components and their specification are listed in the "Component Chart".

FIGURE 5.3
Flupsy frame and ballasts
(a) Flupsy frame with flotation attached. (b) Porthole closing system in the top plates of the floatation end units to allow for water to be added as extra ballast if required. (c) Concrete block ballast to stabilise raft



Frame and flotation

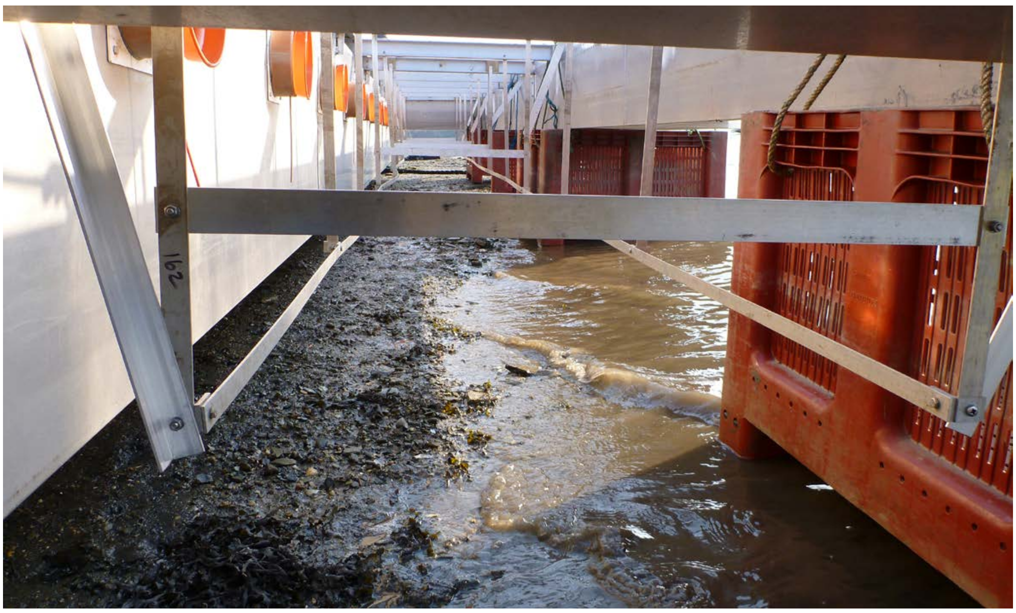
The frame and attached flotation provide the necessary structure on which the rest of the elements are supported (Figure 5.3). The frame provides the skeletal form of the raft and must be strong and rigid enough to provide a stable working platform from which the boxes of seed and discharge channel are suspended. The layout of the frame should be designed around the desired size and shape of the seed containers, thereby maximising the available space and potential production capacity of the Flupsy. In this case, the material used is marine grade aluminium beam, but a similar structure could also be made from wood if other materials aren't available. If timber is the chosen construction material, then a hardwood such as eucalyptus is recommended to ensure the maximum longevity of the structure due to the harsh saltwater environment in which the raft is situated.

Flotation is provided by sealed boxes made from aluminium plate that are attached to the frame along both sides and the ends of the raft. These boxes are filled with polystyrene foam to ensure that, in the event of damage to the exterior plate and the ensuing ingress of water, the raft will remain afloat. In the featured example, sealable openings are cut into certain sections of the floats to allow water to be added as ballast if the draft of the raft requires altering as seen in Figure 5.3b (i.e. the seed boxes are sitting too high in the water and optimum flow is not being achieved). Concrete blocks (Figure 5.3c) are added to the raft above the flotation, which are also used to control the level at which the raft sits in the water. Their other function is to weigh the raft down and thus provide a more stable platform for the seed boxes to be contained within. This is to dampen down the effects of wave action on the Flupsy and to therefore limit disturbance to the seed oysters. This is because lightweight, buoyant objects react more frenetically when interacting with wave action than objects with greater weight and ballast.

Box support rails

The rails on which the seed boxes sit (Figure 5.4 and 5.29) are designed to ensure that the openings in the boxes are located exactly in line with the portholes in the discharge channel. They are made of aluminium flat bar and are suspended from the main frame of the raft.

FIGURE 5.4
Seed box support rails



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Discharge channel

The discharge channel runs down the centre of the raft (Figure 5.5). The water displacement equipment is housed at one end (although in some designs this is central) and the other end is sealed. Cut into the side walls of the channel are portholes onto which the seed boxes are connected. In this example, the channel is made from two L-shaped aluminium plate sections that have been bent into shape and then riveted together. Alternative designs have fibreglass channels or use PVC pipe onto which the boxes are connected. The flow of water through the channel is explained in the section above (Basic principles of a Flupsy) and is central to the effectiveness of the design.

FIGURE 5.5
Central water discharge channel during cleaning process

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Water displacement equipment

Due to the Flupsy being situated away from any mains power source, the water displacement equipment was designed to move the most amount of seawater possible whilst keeping the electrical power consumption to a minimum. In this example, the seawater is moved through the Flupsy by twin model aeroplane propellers that have a large diameter and fine pitch. This allows them to move 10 m^3 water/minute on 50–100 watts of power which is a relatively large volume of water when compared to the minimal amount of power usage. They are mounted on aluminium shafts that are driven by 24-volt electric motors. They are situated in nozzles at one end of the channel. The function of the nozzles is to increase the efficiency with which the propellers can move water through and out of the channel. Positioning the propellers within close fitting ducts reduces the loss of pressure experienced around the tips of the blades and thus a relative increase in flow is generated. The equipment can be seen in Figure 5.6.

FIGURE 5.6
Flupsy propellers
(a) Propellers and nozzles with motors running. (b) Propeller and nozzle out of water

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Solar raft

The solar raft (Figure 5.7) houses the solar panels, batteries, charge controller units and speed controllers that provide power for the electric motors on the Flupsy. The specification for these items is directly linked to the power requirement of the electric motors. When calculating the power element of the Flupsy it is important to design plenty of extra capacity into the system to ensure that the flow of water through the oysters is not interrupted at any stage of the 24-hour cycle. The decision process should therefore be:

1. What is the electrical current draw of the motors when operating at a speed that generates the optimal water flow rate through the Flupsy?
2. Based on this, what electrical storage capacity (battery Amp Hours) is required to ensure that the motors operate consistently without a drop in power either reducing their revolution rate or stopping them completely?
3. How much solar generating capacity is required to keep the batteries charged so that they can provide enough electricity for the motors to operate 24 hours a day?

Once the current draw of the motors is established, the next important element to be calculated is how many daylight hours are available in which the solar panels can generate the required power. Generally speaking, the Flupsy will be in use over the summer months as this is when optimal growing conditions are available for the oyster seed that will be held in the raft. This is also when there are more daylight hours, so the calculation regarding how many solar panels will be required should consider the season in which it is being operated. To ensure efficient solar generation capability, the raft should be oriented in a direction, and positioned in a location that maximises the panel's exposure to the sun. So, in the Northern Hemisphere the panels should be orientated in a southerly direction and in the Southern hemisphere, they should be orientated towards the North. The raft should be located away from tall trees or other such items that may shield the panels from the sun's rays.

FIGURE 5.7
Solar raft being towed out to Flupsy

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Seed boxes

The boxes in which the seed oysters are held are sealed units apart from the mesh bottom face and the exit hole at the top of one side (Figure 5.8). In this example, the box walls are made of riveted aluminium plate and angle sections. The bottom is made

FIGURE 5.8
Flupsy seed boxes
(a) Seed boxes on place on the Flupsy raft. (b) Internal view of box showing seed resting on 1.5 mm mesh and sock to prevent loss of oysters through discharge hole. (c) Locking bars secure box in place

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from 1.5 mm mesh stretched and glued over an aluminium frame. The box lids are made from marine ply and feature an inspection hatch for easy access to the oyster seed. The boxes are held in place by a locking bar made from aluminium angle. Not only does this ensure that the box remains lined up with the porthole in the discharge channel, but it also provides some security by limiting access to the seed.

Moorings

Due to the importance of keeping the solar panels correctly orientated towards the sun, the rafts should be moored fore and aft. The moorings should be of suitable size and weight to securely maintain the Flupsy in the most extreme weather and sea conditions that are likely to be experienced at the chosen site. Either use four smaller moorings positioned at a suitable distance from each corner of the raft, or one larger mooring at each end of the Flupsy with riser chains going into a chain bridle which is then attached to each corner.

Box lifting equipment

In this example, the boxes are lifted out of the raft using a winch and derrick fitted to the workboat (Figure 5.9a). However, it is also possible to use a winch fitted onto a gantry that is incorporated into the design of the raft (Figure 5.9b).

FIGURE 5.9
Lifting Flupsy seed boxes
(a) Seed box being lifted out of Flupsy using small derrick and winch. (b) Gantry for lifting seed boxes at Morecambe Bay Oysters, United Kingdom of Great Britain and Northern Ireland

5.2.3 Construction of the Flupsy

This section will describe the various stages of construction and the order in which they should be completed. Please note that the cutting and welding of parts such as the floatation sections and the beams for the frame were undertaken by specialist outside contractors and supplied as units to be assembled with the rest of the components. A complete list of the components, tools and fittings necessary for the construction process is provided in the chart “Flupsy component table” below (Table 5.1). This table also gives details of the dimensions that the raw materials, such as the aluminium bar, need to be cut to. Please note that all the aluminium components of the Flupsy are made from marine grade aluminium. It is essential to use this grade to ensure the longevity of the apparatus in the marine environment.

Delivery of components:

- Use a checklist to ensure that all the necessary parts have been received.
- Assemble all the parts needed for the construction of the raft and label each one so that they can be easily identified and connected to the correct corresponding component (Figure 5.10)

TABLE 5.1
Materials required for the construction of an aluminium Flupsy

A	FRAME AND FLOATATION			
	Component	Dimensions/specification		Quantity
A1	Side floatation units	Length Width Height Plate thickness	= 6 000 mm = 560 mm = 530 mm = 3 mm	4
A2	End floatation units	Length Width Height Plate thickness	= 5 100 mm = 560 mm = 530 mm = 3 mm	2
A3	Side floatation unit top plates	Length Width Folded lip Plate thickness	= 3 000 mm = 560 mm = 30 mm = 3 mm	8
A4	End floatation top plates	Length Width Folded lip Plate thickness	= 2 550 mm = 560 mm = 30 mm = 3 mm	4
A6	Welded frame for end floatation units	Length Width Beam height Beam width Beam thickness	= 5 100 mm = 560 mm = 100 mm = 50 mm = 6 mm	2
A7	Outer side beams	Beam length Beam height Beam width Beam thickness	= 5 900 mm = 100 mm = 50 mm = 6 mm	4
A8	End crossbeams	Beam length Beam height Beam width Beam thickness	= 5 100 mm = 100 mm = 50 mm = 6 mm	4
A9	Interior crossbeams	Beam length Beam height Beam width Beam thickness	= 5 000 mm = 100 mm = 50 mm = 6 mm	8
A10	Inner bracing beams	Beam length Beam height Beam width Beam thickness	= 1 135 mm = 100 mm = 50 mm = 6 mm	20
A11	Beam connector angle brackets	Bracket height Angle dimensions Angle thickness	= 100 mm = 50 × 50 mm = 6 mm	64
A12	XPS foam for side floatation units (top)	Length Width Height	= 3 000 mm = 540 mm = 330 mm	8
A13	XPS foam for side floatation units (bottom)	Length Width Height	= 3 000 mm = 165 mm = 100 mm	16

TABLE 5.1 (CONTINUED)

A	FRAME AND FLOATATION			
	Component	**Dimensions/specification**		**Quantity**
A14	XPS foam for end floatation units (top)	Length	= 1 800 mm	4
		Width	= 540 mm	
		Height	= 330 mm	
A15	XPS foam for end floatation units (bottom)	Length	= 1 800 mm	8
		Width	= 165 mm	
		Height	= 100 mm	
A16	Side floatation unit joining plates (side)	Length	= 430 mm	4
		Width	= 90 mm	
		Plate thickness	= 5 mm	
A17	Side floatation unit joining plates (bottom)	Length	= 500 mm	2
		Width	= 90 mm	
		Plate thickness	= 5 mm	
B	**DISCHARGE CHANNEL**			
	Component	**Dimensions/specification**		**Quantity**
B1	L-shaped aluminum channel units	Length	= 6 000 mm	4
		Width	= 600 mm	
		Height	= 900 mm	
		Plate thickness	= 3 mm	
B2	Lengthways channel angle brackets	Length	= 6 000 mm	8
		Angle dimensions	= 32 × 32 mm	
		Angle thickness	= 6 mm	
B3	Vertical channel angle brackets	Length	= 865 mm	8
		Angle dimensions	= 32 × 32 mm	
		Angle thickness	= 6 mm	
B4	Horizontal channel angle brackets	Length	= 535 mm	8
		Angle dimensions	= 32 × 32 mm	
		Angle thickness	= 6 mm	
B5	Prefabricated aluminium diagonal discharge channel supports	Angle dimensions	= 32 × 32 mm	18
		Angle thickness	= 6 mm	
B6	Aluminium plate seal for end of channel	Width	= 1 200 mm	1
		Height	= 900 mm	
		Plate thickness	= 3 mm	
B7	Marine plywood nozzle mounting plate	Width	= 1 200 mm	1
		Height	= 900 mm	
		Plate thickness	= 18 mm	
B8	Propeller nozzles made from HDPE drum	Height	= 250 mm	2
		Diameter	= 590 mm	
C	**U-BOLT MOORING EYES**			
	Component	**Dimensions/specification**		**Quantity**
C1	Stainless steel U-bolt mooring eyes	Size	= M12	4
		Inside diameter	= 80 mm	
D	**WATER DISPLACEMENT APPARATUS**			
	Component	**Dimensions/specification**		**Quantity**
D1	Electric motor	Voltage	= 24 volt DC	2
		Current	= 9 Amp	
		RPM	= 1 800	
D2	Gearbox	Ratio	= 7.5 : 1	2
D3	Prefabricated motor & upper bearing mount	--		2
D4	Upper bearing	Suitable for 10 mm Ø propeller shaft		2
D5	Lower bearing	Suitable for 10 mm Ø propeller shaft		2

TABLE 5.1 (CONTINUED)

D	WATER DISPLACEMENT APPARATUS			
	Component	**Dimensions/specification**		**Quantity**
D6	Prefabricated lower bearing frame mount	--		2
D7	Stainless steel propeller shaft	Length	= 1 375 mm	2
		Diameter	= 10 mm	
D8	Model aeroplane propeller	Pitch	= Low	2
		Diameter	= 580 mm	
D9	Timber frame for motor mount	Length	= 1 140 mm	4
		Width	= 100 mm	
		Height	= 50 mm	
E	**BOX SUPPORT RAILS**			
	Component	**Dimensions/specification**		**Quantity**
E1	Aluminium flat bar	Length	= 975 mm	48
		Width	= 25 mm	
		Thickness	= 3 mm	
E2	Aluminium flat bar	Length	= 4 000 mm	12
		Width	= 25 mm	
		Thickness	= 3 mm	
E3	Aluminium flat bar	Length	= 900 mm	10
		Width	= 38 mm	
		Thickness	= 3 mm	
E4	Aluminium flat bar	Length	= 745 mm	12
		Width	= 38 mm	
		Thickness	= 3 mm	
E5	Aluminium angle brackets	Length	= 25 mm	60
		Angle dimensions	= 32 × 32 mm	
		Angle thickness	= 3 mm	
F	**WALKWAY OVER DISCHARGE CHANNEL**			
	Component	**Dimensions/specification**		**Quantity**
F1	Marine plywood decking boards	Length	= 2 440 mm	5
		Width	= 1 220 mm	
		Thickness	= 18 mm	
F2	Aluminium angle	Length	= 4 000 mm	6
		Angle dimensions	= 25 × 25 mm	
		Angle thickness	= 3 mm	
G	**CONCRETE BLOCKS OVER SIDE FLOATATION UNITS**			
	Component	**Dimensions/ specification**		**Quantity**
G1	High density concrete block	Length	= 440 mm	100
		Width	= 100 mm	
		Height	= 215 mm	
		Weight	= 17.1 kg	
H	**SOLAR RAFT**			
	Component	**Dimensions/ specification**		**Quantity**
H1	Pontoon	Length	= 5 500 mm	2
		Width	= 2 000 mm	
H2	Marine plywood decking boards	Length	= 2 440 mm	6
		Width	= 1 220 mm	
		Thickness	= 18 mm	
H3	Solar panels	Peak power	= 300 Watts	4
		Height	= 1 640 mm	
		Width	= 990 mm	
H4	Solar panel mounting frame	Height	= 1 700 mm	1
		Width	= 4 000 mm	
		Adjustment angle	= 25° to 90°	

TABLE 5.1 (CONTINUED)

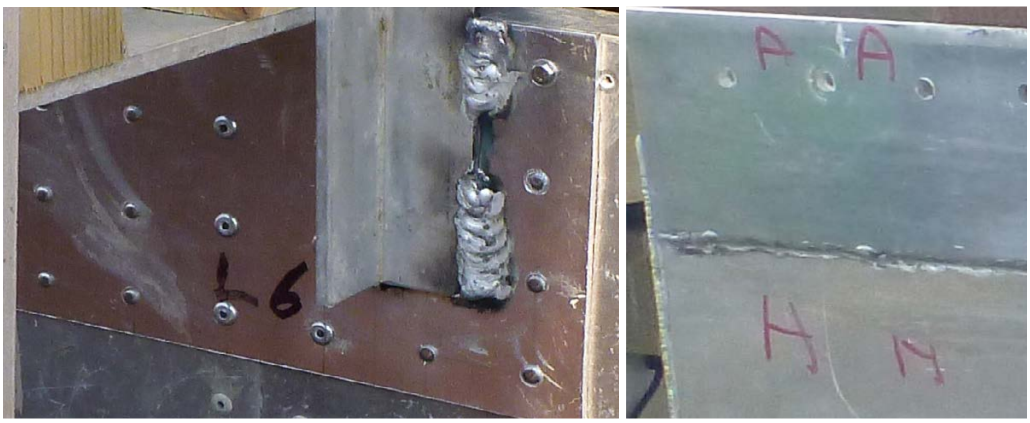
H	**SOLAR RAFT**		
	Component	**Dimensions/specification**	**Quantity**
H5	Batteries	Amp hours = 130 Length = 330 mm Width = 172 mm Height = 220 mm Weight = 29 kg	8
H6	Electric motor speed controller	Voltage rating = 12v DC/ 24v DC Current rating = 20 Amps Supply voltage = 10 to 35v DC	2
H7	Solar charge controller	Rated charge current = 60 Amps Max PV input power = 1 500 Watts	1
H8	Disconnect switch	Contact current rating = 80 Amps	2
I	**SEED BOX** (COMPONENTS LISTED ARE FOR ONE BOX)		
	Component	**Dimensions/ specification**	**Quantity**
I1	Aluminium upper box-frame	Length = 1 140 mm Width = 940 mm Angle dimensions = 25 × 25 mm Angle thickness = 3 mm	1
I2	Front and back aluminium panels	Height = 700 mm Width = 940 mm Thickness = 1 mm	2
I3	Aluminium side panels	Height = 700 mm Length = 940 mm Lip = 40 mm Thickness = 1 mm	2
I4	Aluminium lower box-frame	Length = 1 140 mm Width = 940 mm Angle dimensions = 25 × 25 mm Angle thickness = 3 mm	1
I5	Aluminium bottom mesh-support frame	Length = 1 140 mm Width = 940 mm Angle dimensions = 25 × 25 mm Angle thickness = 3 mm Central 3 mm flat bar length = 1 140 mm 4 × cross 3 mm flat bars width = 470 mm	1
I6	1.5 mm woven polyester mesh	Length = 1 190 mm Width = 990 mm	1

Note: All aluminium components should be "marine grade" aluminium.

Source: Elaborated by the authors.

FIGURE 5.10

Components clearly labelled to assist ease of construction



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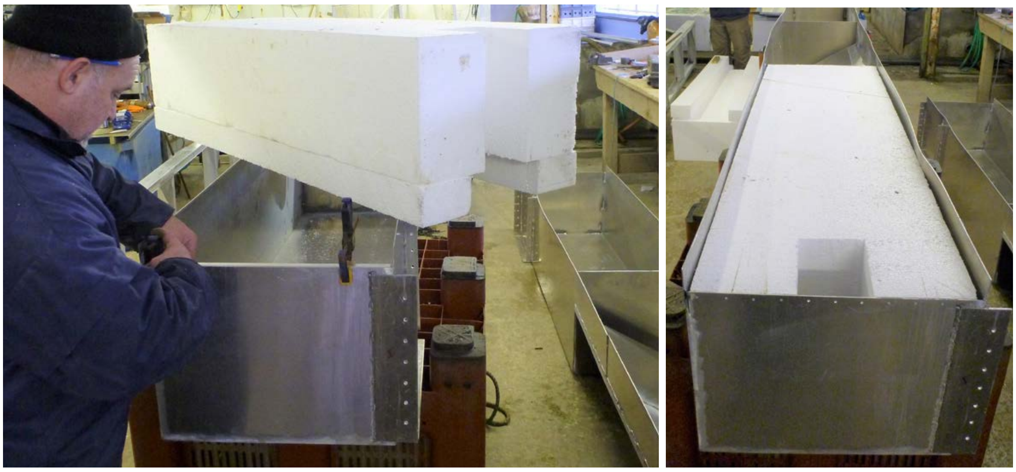
Filling floatation units with foam

The prefabricated floatation sections need to be partially filled with extruded polystyrene foam (XPS) (Figure 5.11). This foam is recommended because it is vastly more water resistant than expanded polystyrene (EPS). This is advantageous in the event of damage to the hull resulting in water ingress. Also, as stated in the previous section, the floatation sections have been designed to allow water to be added on purpose as ballast and therefore a non-absorbent foam is essential to be able to correctly utilise this function. The foam should be cut to match the internal dimensions of the floatation compartment. However, space should be left at the bottom of the foam and under the porthole that is cut into the top of the compartment to allow water to be inserted if necessary. Refer to Figure 5.13.

FIGURE 5.11
Filling the floatation units with extruded polystyrene foam (XPS)



Attaching the top plates to the flotation units

The flotation sections are manufactured with the top left open to allow for the insertion of the foam. Now that this has been completed, the separate top sections (Figure 5.12a) can be secured in place resulting in a sealed unit (Figure 5.13). This is done using rivets and marine sealant and the process is completed in the following order:

1. Insert the pre-cut top plates into the flotation section so that they are resting on top of the foam blocks. The top plates have a folded 30 mm lip which now sits inside the outer walls of the main flotation section.
2. Draw a line on the outside of the float 20 mm down from the top plates. Along this line, make marks using a metal punch at 50 mm increments.
3. Drill 4 mm holes at these marked points through both the outer wall of the float and the folded lip of the top plate.
4. Put a bead of marine sealant on the tip of each rivet and insert it into the hole. Repeat this for each of the drilled holes.
5. Use a rivet gun to secure the top plate onto the floatation section.
6. Put a bead of sealant along the total length of the flotation section where the top plate meets the rest of the unit.
7. The circular openings on the top surface of the floatation units can now be sealed by inserting the hatches shown in Figure 5.3b. The hatches are 150 mm Ø and there are 12 in total, 8 of which are installed on the side floatation units and 4 on the end units. These are mounted using marine sealant and 20 × 4 mm stainless steel screws.

Please note that marine sealant is only necessary for this part of the assembly because a sealed unit is being created and the ingress of water needs to be prevented (Figure 5.12b). During the other stages of construction, rivets will be used without marine sealant.

FIGURE 5.12
Top plates and sealant
(a) Top plates with folded lip and portholes cut into them. (b) Marine sealant used on lower rivets shown in photo to prevent water ingress to sealed units

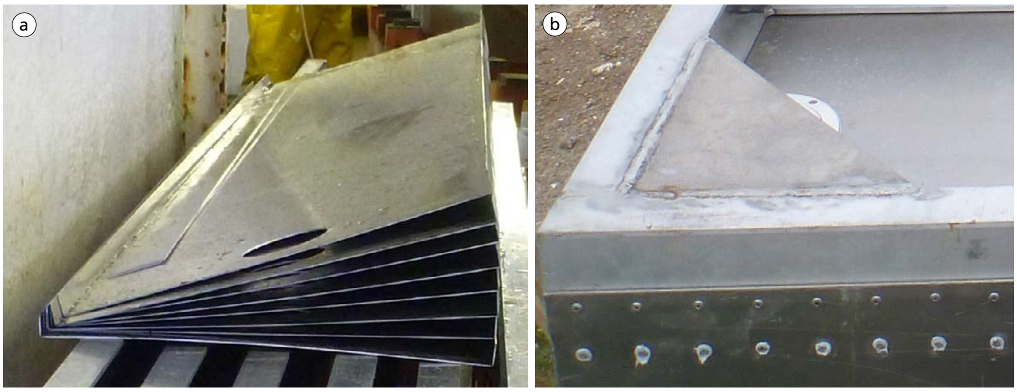
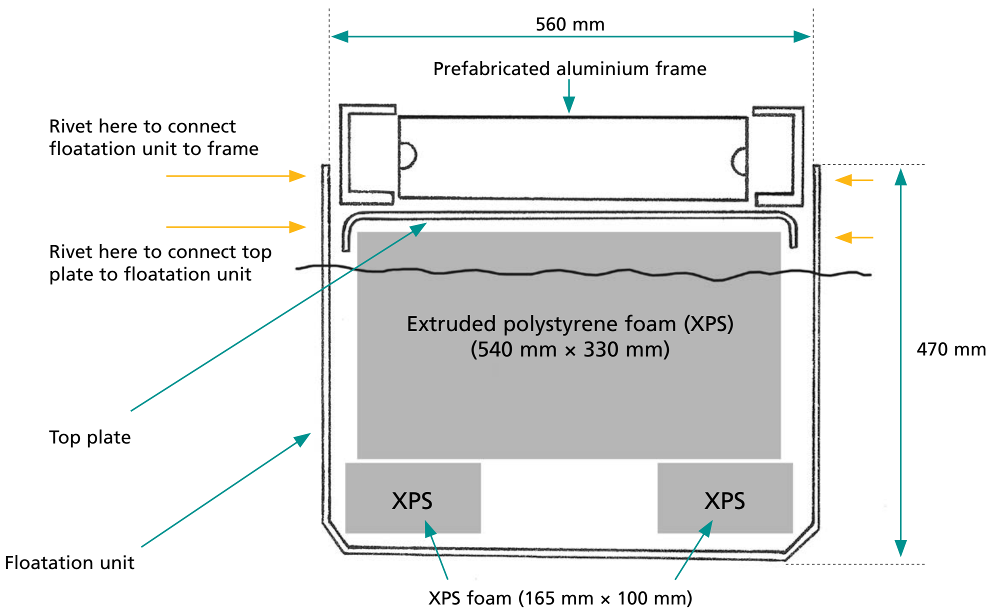


FIGURE 5.13
Cross section of sealed floatation unit with top plate and foam inserted



Source: Elaborated by the authors.

Riveting the frame onto the end floatation units

The two end flotation units (Figure 5.14) have corresponding prefabricated frames made out of welded aluminium beams which provide strength and rigidity to the structure (Figure 5.15a). The joining of the two components should be completed using the following steps:

1. Place the frame on top of the floatation unit so that the ends are perfectly aligned and so that it is sitting inside the 40 mm lips that project from the top of the unit.
2. Draw a horizontal line on the outside of the float 15 mm down from the top of the lip. Along this line, make marks using a metal punch at 50 mm increments.

3. Drill 4 mm holes at these marked points through both the projecting lip of the float and the frame inside it (Figure 5.15b and 5.15c)
4. Insert a rivet into each of the holes and secure using a rivet gun.

FIGURE 5.14
Diagram of end floatation units measurements

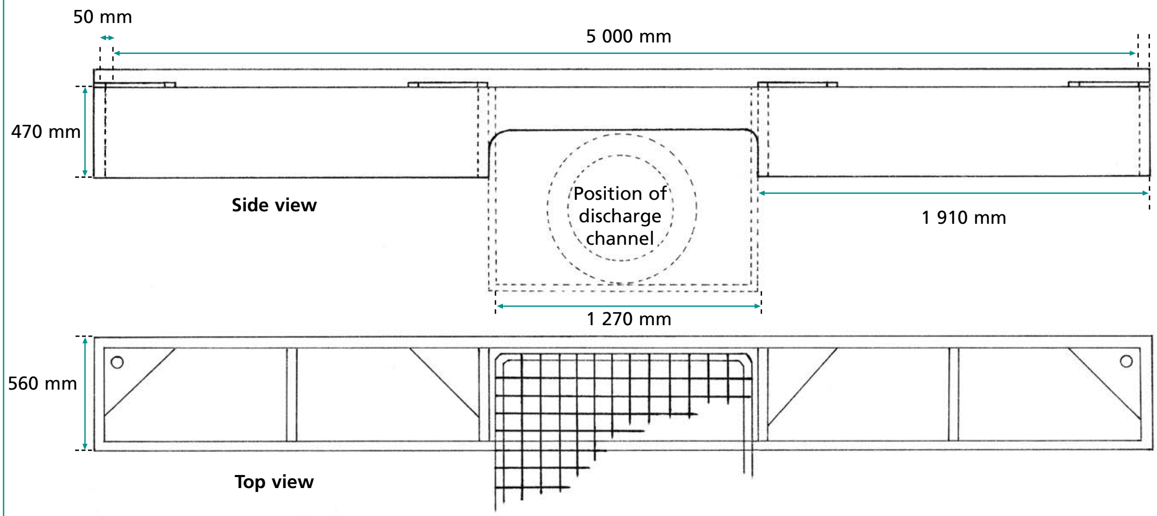


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FIGURE 5.15
End floatation unit assembly
(a) End floatation units and frame components. (b–c) Drilling holes for rivets to attach frame to floatation unit

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Laying out the flotation units and loosely bolting together

Before any further assembly can be achieved, the floatation units need to be laid out and loosely bolted together (Figure 5.16). Because the backside of the connecting flanges will not be accessible to tighten a nut onto the bolt, rivet nuts will be required to be fitted to each of the pre-drilled holes. In this case, 6 mm rivet nuts are used with 6 × 20 mm bolts and washers. This will be the same for connecting both the side floats to each other and for connecting the side floats to the end floatation units. This should be done on flat, even ground to ensure that the joints between the different sections meet correctly and that there are no distortions to the shape of the overall structure. It is imperative that this layout is achieved precisely as this will form the template on top of which the framework will be assembled. The floats can be raised off the ground on trestles or boxes to achieve a more comfortable working height if desired (Figure 5.16). Please note that it is important not to tighten the connecting bolts so that a small amount of movement is possible to make it easier to assemble the frame on top of the floatation section.

FIGURE 5.16
Laying out the flotation units and loosely bolting together

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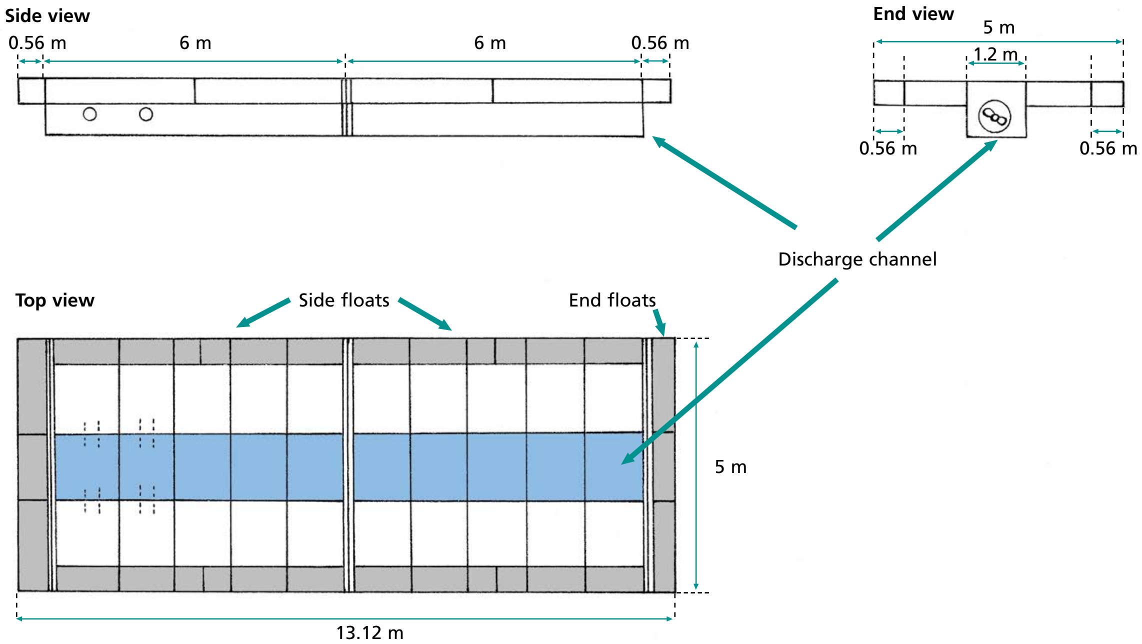
Bolting the framework together

The main structural frame of the Flupsy is made up of a series of interconnecting aluminium beams (Figure 5.17 and 5.18) that have been cut to the desired lengths and attached to the floatation units. Brackets have been welded onto them to allow the corresponding beams to be bolted to one another. Each beam has been labelled, indicating its position in relation to the overall layout of the raft and which corresponding beam it attaches to. The nuts, bolts and washers used to construct the frame are A4 marine grade stainless steel (AISI 316). The size of bolt used is 10 × 25 mm. Locking nuts are used to prevent them from coming undone. The process should be completed in the following order:

1. Position all the beams on top of the floats in their correct location according to the pre-applied labelling. When manipulating the beams into position, it may be necessary to use a rubber mallet to tap them into their final position without damaging the aluminium.
2. Align all the bolt holes and insert the 10 mm bolts with a washer on each side of the beams that are being linked together before loosely tightening the nuts.

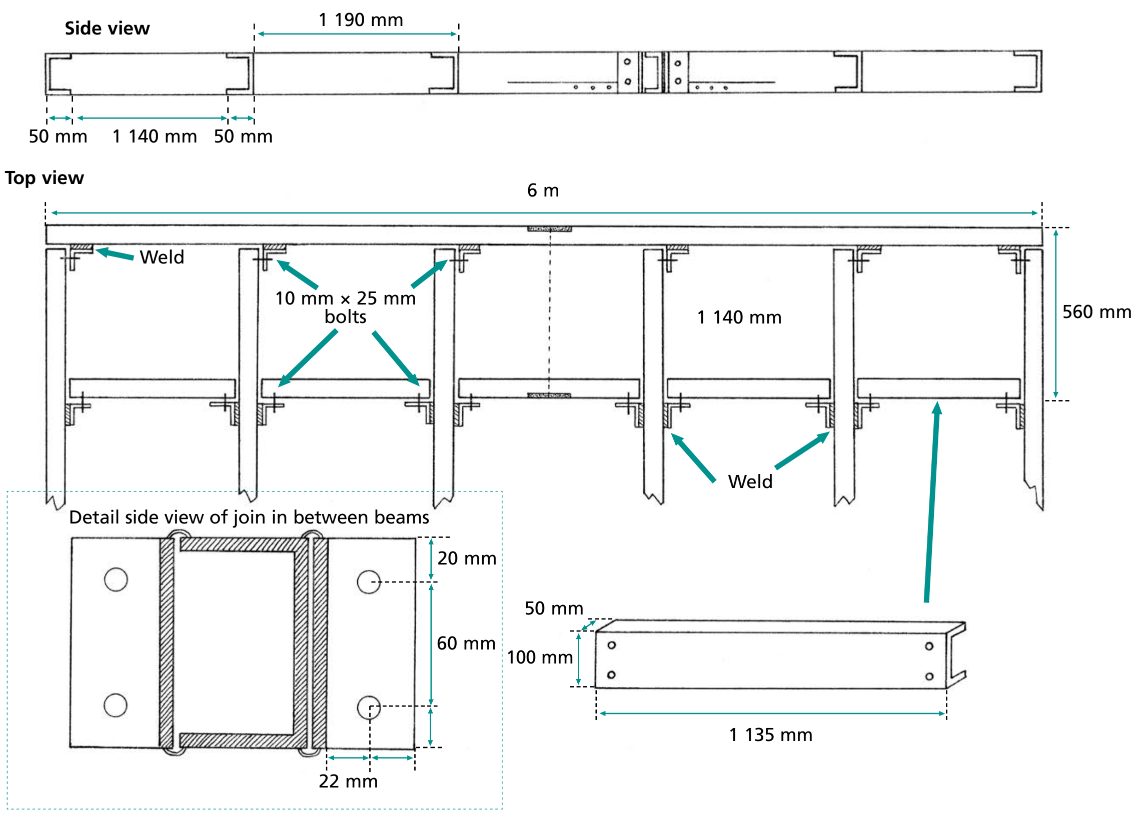
3. When all the bolts have been successfully located, the nuts can then be tightened to make the frame rigid (Figure 5.19).

FIGURE 5.17
Diagram of frame measurements



Source: Elaborated by the authors.

FIGURE 5.18
Diagram of beam measurements



Source: Elaborated by the authors.

FIGURE 5.19
Frame assembly
(a) Aluminium beam components. (b) Interconnecting beams bolted together. (c) Complete Flupsy frame

Tightening of end float bolts

Once the frame has been made rigid, the bolts that were loosely connecting the end floatation unit to the side sections can now be tightened to secure the parts together:

1. Tighten all the 6 × 20 mm bolts into the pre-installed rivet nuts that secure the side floats to the end floats.
2. Tighten the 10 × 25 mm bolts that secure the crossbeams of the side and end floats together.

Riveting the beams onto the side floatation units

The side floatation units are connected to the frame by riveting them to the beams that run down the length of the raft (Figure 5.20). The procedure for completing this action is described in the paragraph above entitled "Riveting the frame onto the end floatation units".

Lifting sections into the water and moor on foreshore

The Flupsy raft is constructed in two halves. Each completed half should be craned into the water separately to avoid putting unnecessary strain on the joint that holds the two halves together (Figure 5.21). The lifting operation should be undertaken at high tide so that the sections can be floated into position on the foreshore before the tide ebbs. Suitable moorings to hold the raft in position should be placed on the foreshore prior to lifting the raft into the water. The process is completed in the following order:

FIGURE 5.20
Riveting the beams onto the side floatation units

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1. Attach supports onto the bottom of the flotation sections so that, when the Flupsy rests on the foreshore as the tide recedes, it has enough clearance to enable the discharge channel to be fitted to the raft. Supports with a height of 800 mm will allow a reasonable clearance and working height to be achieved.
2. Strops should be attached to the four corners, to allow each half to be lifted evenly and with a stable weight distribution. Ensure that no personnel are located underneath the raft when lifting operations are taking place.
3. Tie mooring ropes to the two end corners of the raft.
4. Lift the two halves separately into the water using the crane.
5. Use a boat to manoeuvre the two separate halves onto the foreshore and tie each end onto the pre-deployed moorings.

FIGURE 5.21
Lifting the two halves of the Flupsy into the water using a crane

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Bolting the two halves of the raft together (floatation units and central beams)

The two halves of the raft are joined by bolting the connecting cross beams together (Figure 5.22) and by 3 aluminium plates that connect each side flotation unit. For connecting each pair of side floats, the following plates will be required: Two 430 × 90 × 5 mm plates for each side join / One 500 × 90 × 5 mm plate for the bottom join. The plates should be pre-drilled with 7 mm holes to match the holes on the floatation unit flanges. Making the holes slightly bigger than the bolts will allow for a bit of manoeuvrability when attaching the plates because getting the correct alignment can be challenging.

This should be achieved using the following steps:

1. Align the bolt holes of the two central cross beams of each half of the raft and clamp in place.
2. Use a 10 × 25 mm bolt, two washers on each side of the beams and a locking nut in each of the pre-drilled holes to join the beams together. Locate all the bolts and loosely engage the nuts.
3. Position the connecting plate on the outer face of the side floats and loosely insert the M6 bolts and washers into the rivet nuts. A small drop of thread locker adhesive should be applied to the head of each bolt before insertion.
4. Repeat this process for the inner face and bottom face of the side float connecting flanges.
5. Once all the bolts have been correctly located, tighten them onto the plates to produce a rigid joint.

FIGURE 5.22
The two halves of the Flupsy bolted together and resting on the foreshore

Install U-bolt mooring eyes on each corner

To enable the raft to be securely moored, stainless steel U-bolts should be attached to each end corner of the raft. The dimensions of the four U-bolts are 12 × 80 mm inside diameter. These should be drilled and bolted onto the outer beam of the end floatation units.

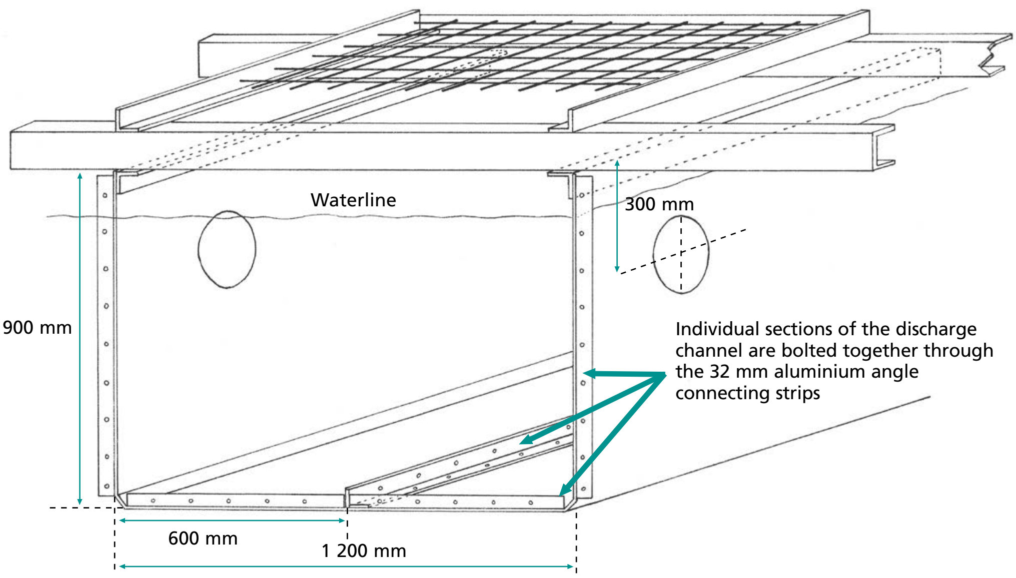
Drilling and riveting angle onto plate for discharge channel

The discharge channel (Figure 5.24 and 5.25) is made up of 4 separate L-shaped sections of 3 mm aluminium plate (6 000 × 600 × 900 mm) that when connected form a U-shaped channel (12 000 × 1 200 × 900 mm) (Figure 5.23a). The panels have holes (200 mm diameter) pre-cut into the upright sides which is where the connections for the seed boxes will be fitted (see section on "Box construction" later in this chapter). The different sections of the channel will eventually be fastened together using M6 × 25 mm bolts and bolted to the frame of the raft. To allow this to happen, aluminium angle (32 × 32 × 6 mm) needs to be riveted to the internal edges of the L-shaped sections (Figure 5.23b). This process should be undertaken in the following order:

1. Cut the angle into the required lengths (8 × 6 000 mm, 8 × 865 mm, 8 × 535 mm)
2. Drill 7 mm holes for 6 mm bolts into one face of the angle every 100 mm. This should be done to all the lengths of angle except for 4 of the 6 000 mm lengths because these ones will be used to suspend the channel from the frame. These should have 11 mm holes for 10 mm bolts drilled every 1 190 mm to coincide with the beams of the raft framework.
3. On the other face of the angle, 4 mm holes should be drilled every 50 mm to allow them to be riveted to the channel sections.
4. Clamp the angle onto the edge of the appropriate channel sections.
5. Drill holes through the aluminium plate of the channel using the holes that have just been drilled through the angle as a guide.
6. Rivet the angle to the channel sections.

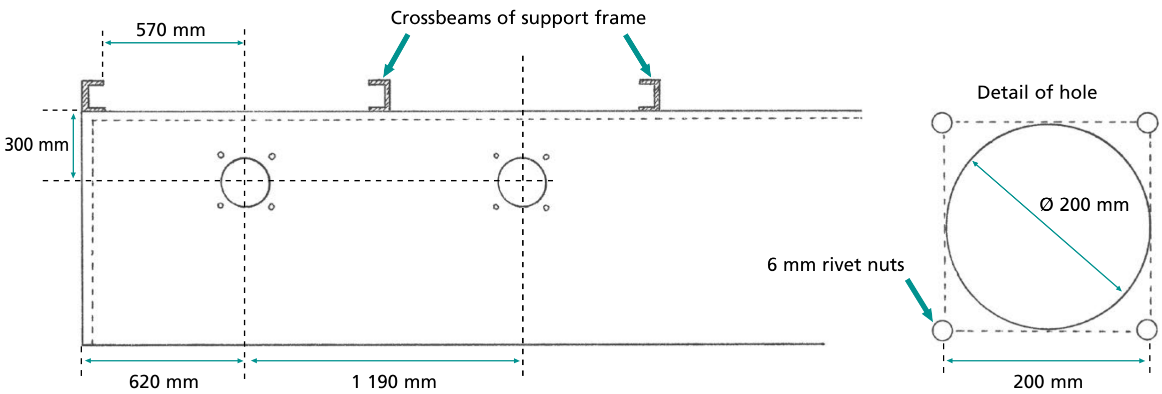
FIGURE 5.23
Discharge channel components
(a) Discharge channel components including aluminium angle joining plates and L-shaped channel units.
(b) Aluminium angle bolted to top edge of discharge channel

FIGURE 5.24
Diagram of the discharge channel



Source: Elaborated by the authors.

FIGURE 5.25
Side view of the discharge channel



Source: Elaborated by the authors.

The flanges that are used to connect the seed boxes to the discharge channel are identical to the porthole sock supports that are mounted inside the seed boxes. Please reference page 111 and Figures 5.36c and 5.36d for further details. These should be attached using 20 × 6 mm stainless steel bolts to the exterior of the discharge channel around the pre-cut 200 mm holes shown in Figure 5.25. There are 10 units in total.

Suspend and bolt discharge channel to frame and connect both halves

At this point, the separate L-shaped channel sections should be bolted together to form 2 × 6 000 mm U-shaped sections which can be positioned under each half of the Flupsy. To connect them to the framework of the raft, use the following steps:

1. Lift one 6 000 mm channel section into position and clamp in place (ratchet straps can be used to hold the channel under the frame).
2. Drill 11 mm holes into the bottom of the beams where the frame meets the top angle of the channel using the holes that were drilled in the previous stage as a guide.
3. Bolt the channel to the frame using 10 × 30 mm stainless steel bolts and washers using locking nuts.
4. Repeat steps 1–3 for the other half of the channel.
5. Place supports under the channel where the two halves meet so that the internal angle flanges are aligned correctly.
6. Bolt the two halves together using 6 stainless steel bolts, washers and locking nuts.

Install diagonal discharge channel supports

Eighteen prefabricated diagonal braces (9 pairs) are used to reinforce the rigidity of the channel (Figure 5.26). These are installed as follows:

1. Support the channel under the section that is being worked on.
2. Position the 2 opposing diagonal braces squarely onto the central flange of the channel. Ensure that the top end of the brace is flat against the beam of the framework above it, onto which it will be bolted.
3. Using the pre-drilled holes for alignment, drill 6mm holes through the central flange at the bottom of the channel.
4. Bolt the two opposing braces to the flange using 6 × 40 mm stainless steel bolts, washers and locking nuts.
5. Drill two 7 mm holes through the crossbeam above using the pre-drilled holes in the top of the braces as a guide.
6. Bolt the braces to the frame using 6 × 40 mm stainless steel bolts, washers and locking nuts.
7. Repeat steps 1–6 for the installation of the remaining braces.

FIGURE 5.26
Diagonal discharge channel supports

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Seal one end of channel and attach propeller nozzles to the opposing end

The discharge channel is now secured but is open at both ends. The next step is to mount the nozzles inside which the propellers will sit (Figure 5.27). The nozzles themselves are made by cutting the central section out of a 220 litres HDPE drum with a diameter of 590 mm. These are mounted inside a sheet of 18 mm marine ply and secured onto it with brackets. They are offset to match the angle of the propeller shaft. The ply sheet is then screwed onto the end flange of the channel using 4 mm × 20 mm stainless steel screws and washers.

FIGURE 5.27
Propeller nozzles

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At the opposing end, the channel is sealed by bolting on a 3 mm aluminium plate to the end flange. Marine sealant is applied to the plate where it meets the flange before bolting down.

Mount water displacement apparatus (Figure 5.28)

The electric motor is bolted onto a prefabricated mounting bracket that also holds the upper bearing unit. The angle of the bracket allows the motor to sit clear of the water in the discharge channel whilst powering the propeller that is situated in the nozzles below the water line. The assembly should be carried out in the following order:

1. Attach the lower bearing frame by screwing its brackets onto the propeller nozzle.
2. Construct a mounting frame out of 100 × 50 mm timber. The frame is 1 140 mm long so that it can be attached in between the two crossbeams where the motor is situated. The motor mounting bracket should fit snugly inside the internal width of the frame.
3. Clamp the frame in place and drill 9 mm holes through the opposite side of the beams to allow the frame to be secured in place by 8 × 100 mm coach screws. The alignment of the propeller shaft needs to be perfect so ensure that the frame is exactly in line with the centre of the nozzles. This can be done by running the propeller shaft up through the lower bearing to provide a positioning guide.
4. Screw the mounting bracket containing the motor/gearbox and upper bearing unit onto the timber frame using 3 × 25 mm screws. Packers can be used between the bracket and the frame to adjust the angle if the alignment of the propeller shaft is not quite correct.
5. Run the propeller shaft up through the lower and upper bearing units and affix it to the gearbox shaft using a rubber coupling secured on both sides using stainless steel worm drive hose clips.
6. Check that the propeller is rotating smoothly within the nozzle and that the alignment of the various elements of the propulsion unit are correct.

It is important to note that any discrepancies in the alignment will cause unnecessary resistance in the operation of the propulsion unit. This in turn leads to premature wear on the equipment and the use of excess electrical power which will drain the batteries more quickly.

Install box support rails

The box support rails are suspended from the cross beams of the raft between the discharge channel and the outer floatation units (Figure 5.29). They are made from lengths of 25 × 3 mm and 38 × 3 mm aluminium flat bar. The 25 mm flat bar is used for the vertical struts and for the long, horizontal rails at the bottom on which the boxes sit. The 38 mm flat bar is used for the stabilising cross struts and for the diagonal stabilisers. The brackets used to secure the vertical and horizontal bar together are made from 32 mm × 32 mm aluminium angle cut into 25 mm lengths. Installation should be carried out as follows:

1. Cut the aluminium components to the length required (25 mm flat bar: 48 × 975 mm; 12 × 4 000 mm) and (38 mm flat bar: 10 × 900 mm; 12 × 745 mm; 32 mm angle: 60 × 25 mm).
2. Drill 5.5 mm holes in all the vertical struts, 12.5 mm from each end.
3. In 24 of the vertical struts, another 5.5 mm hole should be drilled 200 mm from the bottom end.
4. In 12 of the vertical struts, a further 5.5 mm hole should be drilled 400 mm from the bottom end.

5. Drill 5.5 mm holes into crossbeams of the raft frame where vertical struts will be bolted.
6. Bolt all vertical struts in place using 5 × 30 mm stainless steel bolts, washers and locking nuts. At the central point of the raft and on the end beams, timber blocks should be hammered into the concave side of the beam and stainless-steel screws used to secure the vertical struts in these positions (see Figure 5.29).
7. Bolt on stabilising cross struts and diagonal stabilisers.
8. Bolt on horizontal aluminium rails.

FIGURE 5.28
Water displacement apparatus mounting
(a) Electric motor and gearbox mounting bracket (side view). (b) Electric motor and gearbox mounting bracket (top view). (c) Propeller shaft lower bearing and mounting bracket. (d) Water displacement apparatus installed on Flupsy

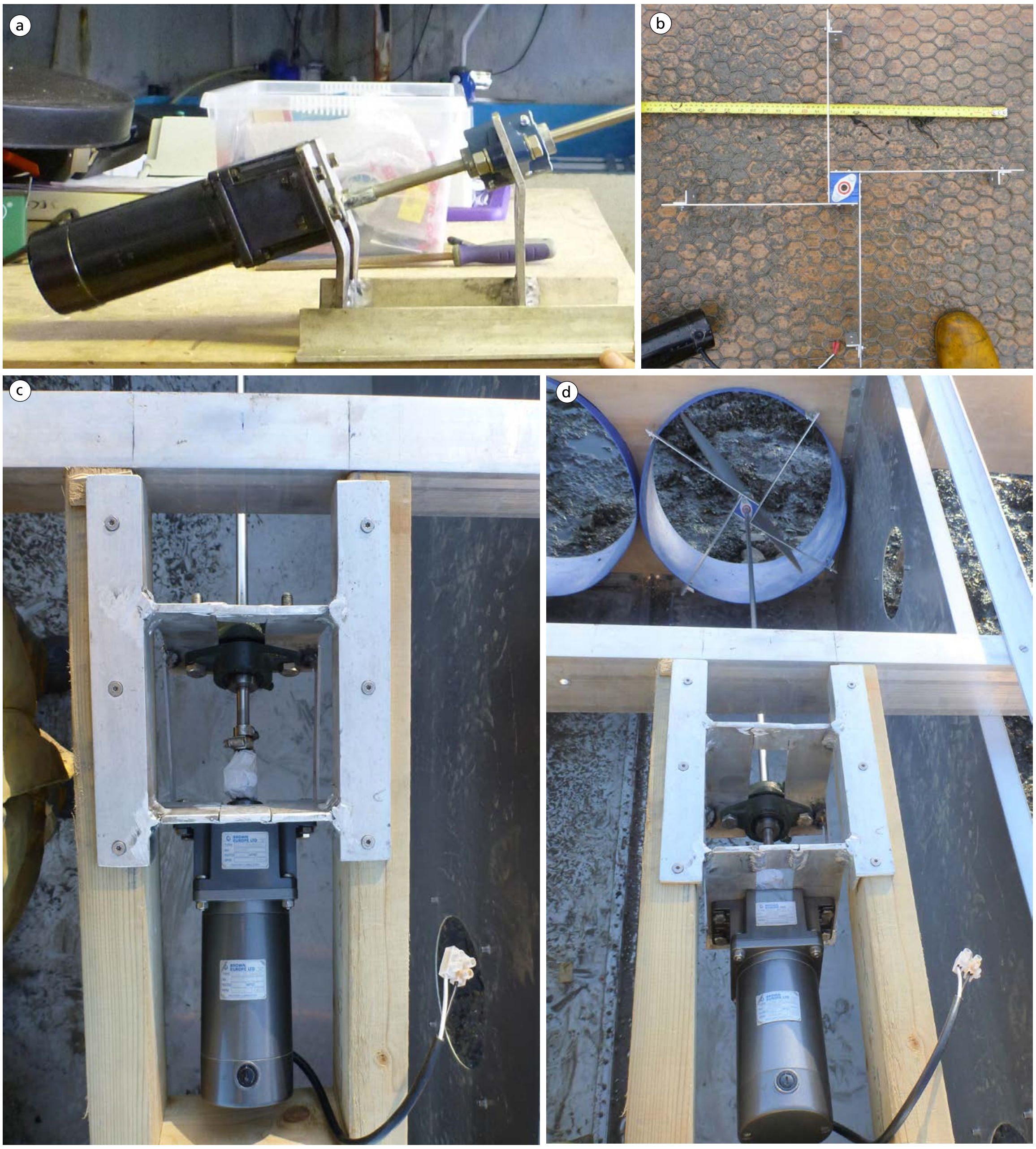
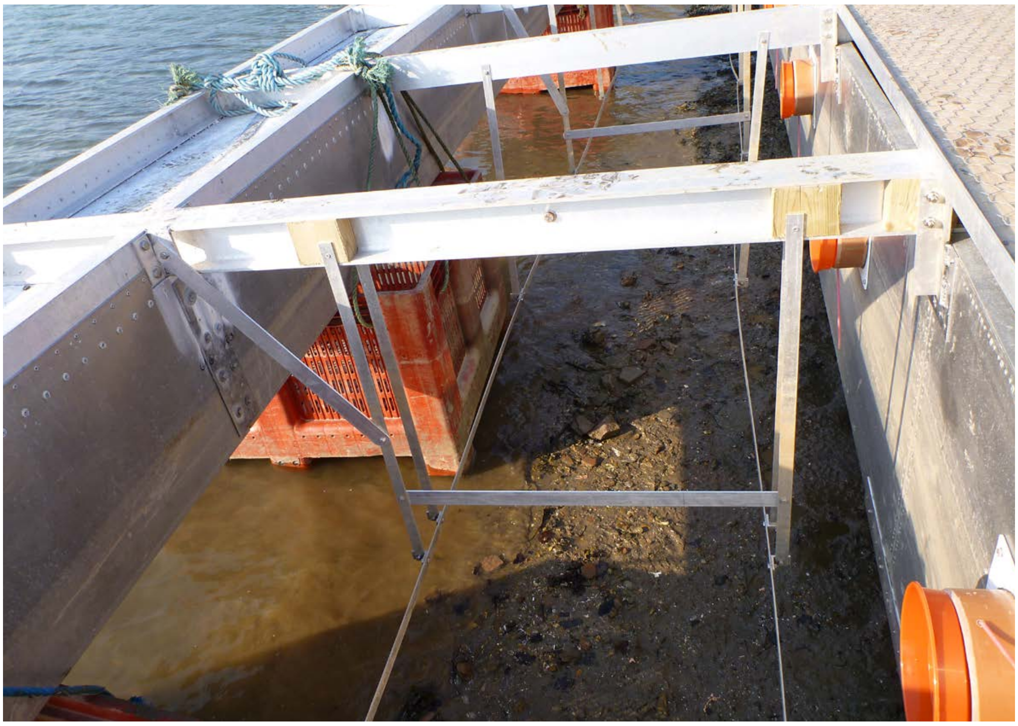


FIGURE 5.29
Seed box support rails including the timber blocks onto which the rails are screwed



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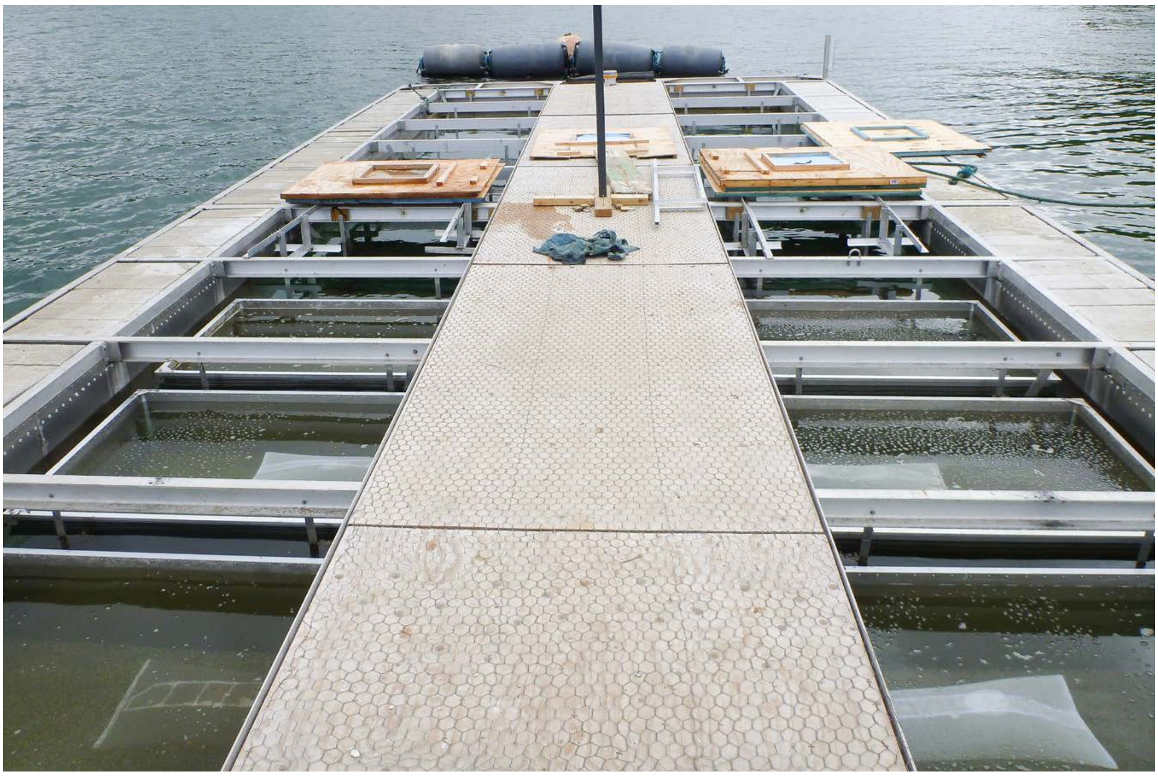
Install the walkway over the discharge channel

18 mm marine plywood is used to create a walkway over the discharge channel (Figure 5.30) using the following steps:

FIGURE 5.30
Walkway over the discharge channel covered with galvanized steel mesh



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1. Bolt 25 × 25 mm aluminium angle to the top of the Flupsy frame directly above and parallel with the top of the discharge channel. They should run the entire 12 000 mm length of the channel.
2. 100 × 50 mm timber beams should be bolted between the cross beams above the channel to help support the walkway.
3. Apply non-slip treatment to the 18 mm marine plywood boards (either galvanised steel mesh or non-slip paint).
4. Lay the boards on top of the channel and locate them between the aluminium angle.

Place concrete blocks on top of side floats as ballast and to form outer walkway

1. Lay 5 mm rubber strips on top of side floats in between cross beams. This is to prevent the concrete blocks from being in direct contact with the aluminium tops of the flotation units, thereby reducing wear and corrosion.
2. Place 5 × concrete blocks (440 × 215 × 100 mm) on top of rubber strips in between cross beams (Figure 5.31).

FIGURE 5.31
Concrete blocks on top of side floats

Solar raft

The raft on which the solar panels are installed (Figure 5.32a) is moored onto the end of the Flupsy where the electric motors and propellers are situated. The raft in this example was created by bolting together two old pontoons and decking them with 18 mm marine plywood painted with non-slip paint. The size of the raft will depend on the number of solar panels required in the location of the farm. This in turn is dependent on the amount of sunlight available in the location and should be calculated specifically for each farm site.

Install frame and panels onto pontoon

A solar panel mounting frame should be purchased of the correct size to allow for the number of panels required. The frame should be made of high-grade aluminium to resist corrosion in the marine environment. The frame should allow for the angle of inclination to be adjusted to maximise the panels' solar energy generation ability. This angle will depend on the latitude at which the farm is situated. Guidance should be sought from local solar energy installers. The frame should be securely fastened onto the decking boards of the raft using stainless steel fixings. The specific fixings will depend on the model of frame that has been purchased. Once the frame is secured, the panels can then be mounted onto it. In this example, 4 × 300-Watt panels are used to harness the required solar energy to keep the electric motors operating continuously (Figure 5.32b).

FIGURE 5.32
(a) Solar raft. (b) Solar raft with panels installed

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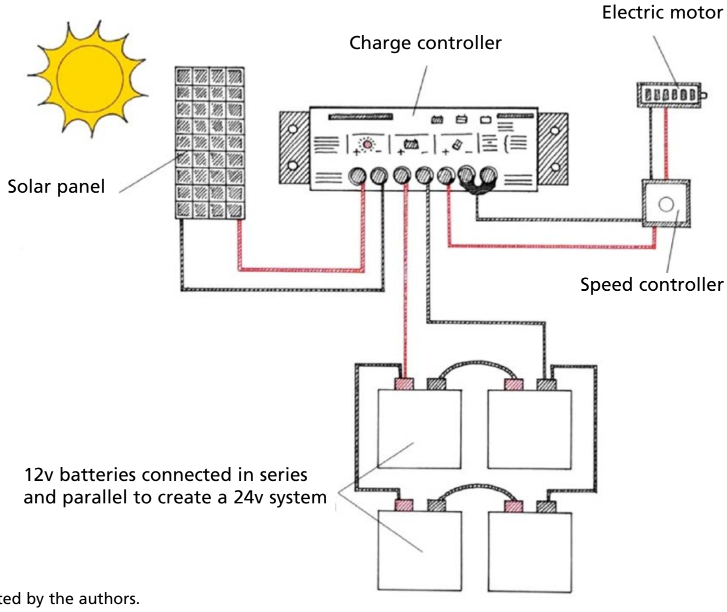
Install batteries, charge controller, speed controller in waterproof box on raft

The electricity generated by the panels is directed through the charge controllers to the electric motor speed controllers and into the batteries for storage (Figure 5.33). Each electric motor is independently connected to its own battery bank and speed controller (Figure 5.34a) to allow them to be operated as autonomous units. All these elements should be mounted inside a box on the raft to protect them from the elements. The box should be vented to allow any moisture to be released and to avoid the build-up of condensation on any of the electrical components. The installation should be undertaken in the following order:

1. Install the batteries. The electric motors used in this example are 24V units so two 12V batteries need to be connected in series to create a 24V battery bank. The two 24V battery banks (four 12V batteries in total) are then connected in parallel to maximise the storage potential. In this example, 4 × 12V 130Ah batteries are connected in series and parallel to create a 24V bank with 260Ah of storage capacity (Figure 5.34b).
2. Connect the battery banks to the charge controller.
3. Connect the solar panels to the charge controller.
4. Connect the electric motor to the speed controller.
5. Connect the charge controller to the speed controller.

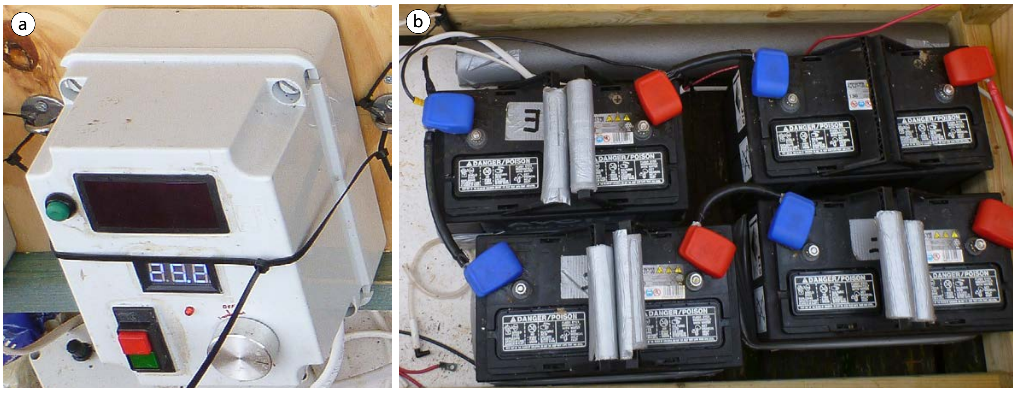
Please note that it is advised to use disconnect switches between the various elements of the electrical system to allow for safe operation and maintenance.

FIGURE 5.33
Flupsy electrical component diagram



Source: Elaborated by the authors.

FIGURE 5.34
Electrical components of the Flupsy
(a) Electric motor speed controller. (b) 12V batteries connected in series and parallel to create a 24V system



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Clean panels regularly

The solar panels should be cleaned on a regular basis to ensure that there is no build-up of any fouling elements that could reduce their energy generation potential.

Box construction

The seed boxes (Figures 5.36a and 5.36b) are made up of several components that have been prefabricated, details of which are included on the "Flupsy component table" (Table 5.1). Please refer to Figure 5.35 for details of how the components fit together. The order in which the construction should take place is as follows:

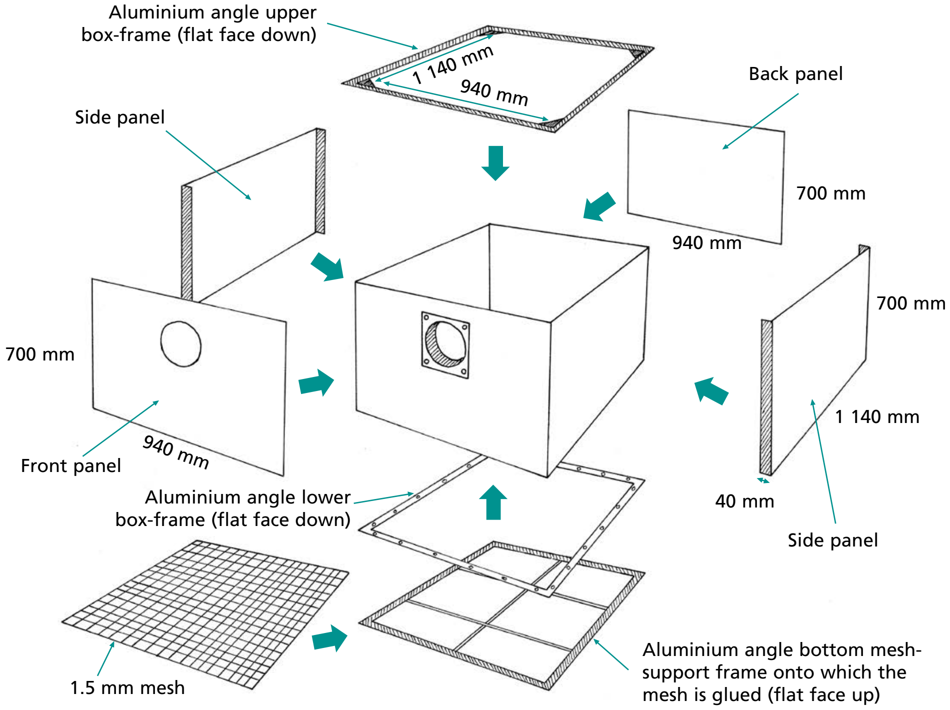
1. Place the lower, aluminium angle box-frame on the ground, ready for the panels to be inserted internally.
2. The front and back panels of the box are made from 1 mm aluminium sheet cut to a size of 940 × 700 mm. The two side panels are also 1 mm aluminium sheet, but these have been folded on either end to form a lip, inside which the front and rear panels sit. Run a bead of marine sealant inside the lips and position the side and end panels inside the aluminium frame so that they form a box.

3. Position the upper, aluminium angle box-frame around the top edge of the box with its flat face upwards.
4. Clamp both frames to the aluminium sheets to hold everything in place.
5. Measure out the positions of the holes required to install the rivets that will hold all the components together and mark using a punch. All holes should be 3 mm in diameter and have 50 mm spacing between them.
6. Drill the required holes through the aluminium angle frames and panels positioned within them.
7. Rivet the frames to the side panels.
8. Rivet the front and back panels to the sides.

The next process involves sticking the 1.5 mm mesh onto the aluminium angle frame used as bottom mesh-support frame on which the oysters will sit. To enable this procedure, it is necessary to cut out a separate frame made from 18 mm plywood which is used to stretch the mesh over before being glued onto the bottom mesh-support frame.

9. Roll out the mesh so that it covers the plywood frame and cut to size.
10. Attach the mesh to the plywood frame using a staple gun. It is important to make sure that the mesh is under as much tension as possible and that no creases are present so that a taught flat surface is achieved.
11. Run a bead of polyester or epoxy resin or a high modulus polyurethane sealant around the flat face of the bottom mesh-support frame.
12. Place the plywood frame with the mesh attached over the bottom mesh-support frame ensuring that good contact is made between the mesh and the bead of adhesive.
13. Allow to dry overnight.
14. Once the adhesive has fully cured, using a sharp knife, cut the mesh away from the plywood frame, leaving it securely glued to the bottom mesh-support frame.
15. Clamp this frame to the lower frame of the box so that it sits squarely underneath it.
16. Drill 5 × 6 mm holes on each side of the box through the aluminium angle running down each bottom edge of the box (lower box frame) and bottom mesh-support frame.

FIGURE 5.35
Diagram of box showing measurements and components



Source: Elaborated by the authors.

17. Secure the mesh-support frame to the box using 5 × 20 mm bolts and locking nuts.
18. Run a bead of marine sealant along each internal corner of the box to ensure that no seed oysters can become wedge in the angle.

The porthole sock supports for inside the box now need to be constructed (Figures 5.36c and 5.36d). This is done by using PVC solvent cement to attach the 200 mm diameter pipe to the square PVC flanges (240 × 240 mm) that attach around the portholes.

19. Once the cement has cured, attach the 4 aluminium brackets that help to reinforce the unit.
20. Drill 4 × 5 mm holes through the corners of the sock support in line with the pre-drilled holes around the opening in the front face of the box.
21. Cut out a square (240 × 240 mm) of 30 mm high density foam.
22. Cut a 200 mm diameter hole in the centre of the foam.
23. Drill 5 mm holes though the corners of the foam to match the holes in the box.
24. Countersink these holes with a 10 mm drill bit to a depth of 15 mm to allow a washer to be inserted.
25. Bolt the components together using 5 × 30 mm stainless steel Phillips head bolts, washers and lock nuts.

Next, the socks that fit over the units that have just been fitted need to be made (Figures 5.36e and 5.36f). These socks are to prevent any lightweight seed from being sucked out of the boxes and there are 2 different types. One is made from the same mesh (1 mm) that is used for the bottom of the boxes and the other is made from 4 mm oyster bag mesh for use with larger seed which also increases the potential flow rate through the boxes. The technique for making them is basically the same.

26. Cut the mesh into the desired size: 680 × 550 mm.
27. Wrap the longer side of the mesh around a spare 200 mm porthole pipe and secure it in place with a reusable cable tie so that the mesh forms a 50 mm overlap.
28. Using a hot glue gun, run two beads down the length of the overlap and press together.
29. Run a bead of glue along the bottom edge of the sock and clamp in place.
30. Once the glue has set (5–10 minutes), remove the sock from the pipe and glue the section that was underneath the cable tie to complete the fabrication.

The box lids provide protection for the seed and also form part of the mechanism that holds the boxes in their correct position (Figures 5.36g and 5.36h).

31. Cut a sheet of 18 mm plywood to the required dimensions: 1 220 × 1 040 mm.
32. Cut 20 × 15 mm timber into: 2 × 1 220 mm lengths and 2 × 1 000 mm. Secure them to one side of the plywood using wood glue and nails to form a lip. This lip will grip the top frame of the box.
33. Cut some more 20 × 15 mm timber into: 2 × 400 mm and 2 × 360 mm. Secure these to the top of the plywood to form a square around the centre of the lid. This is where the locking bar will be located.

The locking bars ensure that the boxes stay aligned with the portholes in the discharge channel. They are constructed using 32 × 32 × 3 mm aluminium angle.

34. Cut angle into required lengths: 1 × 2 430 mm, 2 × 360 mm, 1 × 354 mm, 2 × 180 mm.
35. Drill and bolt together using 5 × 15 mm stainless steel Phillips head bolts and lock nuts.
36. Drill and bolt U-bolt with internal diameter of 34 mm onto main crossbeam of raft to secure one end of the locking bar.
37. At the other end, drill a hole through the locking bar and crossbeam and secure in place using a padlock.

FIGURE 5.36
Seed box components
(a) Seed boxes sitting in the water next to the discharge channel. (b) Seed boxes. (c) Seed box porthole outside box. (d) Seed box porthole inside box. (e) Seed box sock with large mesh. (f) Seed box sock with small mesh. (g) Seed box locking bar and box lid. (h) Locking bars secured with padlocks

5.3 FLUPSY STOCK MANAGEMENT

5.3.1 Access to the Flupsy and box handling by workboat

The workboat is used to transport equipment and oysters between the Flupsy and the land-based processing facilities (Figure 5.37). The vessel is fitted with a winch and derrick to lift the boxes of seed out of the Flupsy. At the end of the winch wire is a gripping device that locates under the top lip of the boxes, securing them whilst the lift takes place (Figure 5.9a). They are then either stacked on the deck and brought back to the farm building whenever they require grading or placed on the deck of the Flupsy so that the seed can be inspected and washed. Great care should be taken when moving the boxes to ensure that no damage is done to the mesh bottom which would result in a loss of oysters.

FIGURE 5.37
Transporting seed boxes out to Flupsy

5.3.2 Introduction of seed – Season and staggering batches

The strategy for the introduction of seed should be based around 3 main factors:

1. Optimal growing conditions

These conditions occur from Springtime onwards and throughout the summer months. Seed introduced during this period will grow quickly and will reach a suitable size to be transferred from the Flupsy and into the chosen on-growing equipment in the shortest possible time frame. It should be noted that seed introduced towards the end of the summer may not have enough time to grow to the desired transfer size as phytoplankton blooms will diminish during this period as daylight hours reduce. It is therefore important to make sure that the last seed batch is introduced early enough to avoid small seed remaining on the Flupsy at the end of the growing season. The exact timing of this will vary depending on the region in which the farm is situated.

2. Availability of seed from the hatcheries

Hatcheries will tend to time the start of their production cycle so that they can deliver seed to their clients at the beginning of the growth season. However, one of the major advantages of having a nursery Flupsy is the ability to take seed from the hatcheries at a much smaller size. The competition for purchasing seed of a suitable size (T6/7) to go directly into on-growing apparatus, such as standard 4 mm mesh oyster bags, can be fierce. Being able to take seed of a smaller size (T2/T3/T4/T5) allows the farmer to ensure that required seed numbers are attained before the competition has a chance to buy them. The purchase price per 1 000 units is also cheaper so there are economic savings to be gained as well. It is possible for farms to take small seed without a Flupsy by using specially adapted small mesh bags to hold the oysters in (Figure 5.38) but the mortality rates tend to be higher in these than in an upwelling raft.

FIGURE 5.38
Small mesh seed bag contained within a standard oyster bag

©Nets S.A.

3. Holding capacity of the Flupsy

Seed should be bought in staggered batches from the hatchery over the course of the season so that there is enough holding capacity on the Flupsy. Each batch will contain faster and slower growing individuals so it is important to make sure that enough empty boxes are available to handle the volume as the oysters expand. For example, in the Flupsy detailed in this section of the manual, 1 million T2 oysters, with an average individual weight of 12 mg (see Table 4.3), can initially be held in 1 seed box. However, after just 1 month in optimal growing conditions, it requires 8 seed boxes to hold the same number of oysters. It is therefore important to stagger the delivery of seed to allow the faster growing oysters to be removed from the Flupsy to make space for the next batch. The Flupsy described in this chapter of the manual is designed to handle 10 million oysters over the season. The ideal delivery schedule for this production capacity is to have 2 million oysters delivered every month from the start of the season until this figure is attained.

Densities dependent on the size of seed

Table 5.2 lists the density of seed oysters that should be stocked in each box. All figures listed are based around the operation of the particular Flupsy used as an example in this section of the manual. For alternate designs, the numbers will vary considerably depending on the volume of the seed containers used and on the flow rate generated by the water displacement equipment. For example, a dockside situated Flupsy that is connected to mains electricity powering a water displacement unit with high flow rates of 30 m^3/minute and above can have seed stocked in the boxes with a depth of 600 mm. This contrasts with the remotely situated Flupsy featured in this example that has a flow rate of 10 m^3/minute and a stocking depth for the seed in the boxes of 200 mm.

TABLE 5.2
Seed numbers and weight per box depending on size

Seed grade by sieve size	Shell size lLength (mm)	Average weight (mg)*	Initial weight of oysters in box (kg)	Approximate number of seed/box
T2	3–4	8–12	10	1 000 000
T3	4–5	15–25	10	500 000
T4	5–6	30–45	12.5	335 000
T5	6–8	60–100	15	185 000
T6	8–10	150–250	15	75 000
T7	10–12	250–350	15	50 000

(*) Weights can vary depending on how fast the stock is growing but these figures provide a guide to the average weights expected from each grade (see also Table 4.3).

Source: Elaborated by the authors.

5.3.3 Grading, washing and inspection schedule

Seed that is developed in the Flupsy needs to be graded much more regularly than the other oyster stock on the farm due to the speed at which it is growing and to prevent the boxes from becoming too full and therefore reducing the flow rate. As with all the other oysters, it is important to separate out the faster growing stock so that it does not out compete the slower developing oysters for food. However, it is even more crucial at this early stage of development as they are expending all of their energy to enable them to grow so quickly and therefore, without the required nutrition to support this rapid expansion, they will starve and perish. Grading out the faster growing stock regularly will limit the number of mortalities experienced in the slower maturing oysters. Generally, the seed will be graded every 2–4 weeks depending on the growing conditions at the time. Careful monitoring of the stock is needed to be able to judge the timing of this correctly. It is important not to grade the seed too often because each time the oysters are removed from the Flupsy and put through the grading apparatus it slows their growth rate. Not only is this caused by them being removed from the water, but also because the disturbance of the grading process slows their development for the first couple of days after they are returned to the Flupsy. However, grading too late will cause the volume of seed in the boxes to become too great which reduces the flow of phytoplankton and oxygenated water through the oysters and can ultimately lead to mortalities. Table 5.3 provides a guide to the required schedule of activities.

When inspecting the stock, a good sign that the oysters are feeding well is the development of a layer of faecal deposits on the top layer of the molluscs (Figure 5.39). This should be observed within the first few days of the oysters being introduced

TABLE 5.3
Seed management schedule

	Grading	Washing	Inspection
Summer	Every 2 weeks	Every week	Every day
Winter	Every 4 weeks	Every 2 weeks	Every other day

Source: Elaborated by the authors.

FIGURE 5.39
Washing the seed. Note the faecal layer which is darker in colour on the section of seed in the bottom left of the photo that has not yet been cleaned

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FIGURE 5.40
Size differential between new seed (on the left of the photo) and ones that have been in the Flupsy for 2 weeks (on the right of the photo) during the peak growing season

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to the Flupsy. If there is no sign of this after one week, then it would indicate a mortality event within that seed batch. Under normal circumstances, the faecal layer will build up over the course of a few days. At this point, the boxes should be raised up out of the water and the oysters washed off to prevent the deposits from becoming excessive. The faeces slow the flow of water through the oysters and can clog up the mesh at the bottom of the box. It can also cause turbidity in the water within the box which will inhibit the oysters' ability to feed efficiently. Regular washing alleviates these issues. When washing the seed, it is also important to hose down the mesh socks that prevent the oysters from being drawn out of the box and into the discharge channel.

When grading the stock, it is important to keep the different seed batches separate from one another. This will enable the operator to spot any issues with a particular batch and this information can be fed back to the hatchery from which they were sourced.

Monitoring daily weight gain

Daily weight gain (DWG) can be used as an indicator of the progress of the seed oysters in the Flupsy. The most accurate way to measure this is to compare the overall weight of each seed batch at the start of each growth cycle and at each grading event. For example, a box containing 10 kg of seed that weighs 20 kg after 14 days will have a DWG of 5.48 percent. At growth rates of this speed, the oysters will increase in size rapidly as seen in Figure 5.40. The results from the Flupsy used as an example in this section of the manual are summarized in Table 5.4

TABLE 5.4
Daily weight gain percentage of seed in Flupsy

Low	Average	High	Record high
2.7%	4.2%	5.1%	6.7%

Source: Elaborated by the authors.

Grading equipment

The equipment used to grade seed is quite different from the apparatus used to grade larger oysters. At this early stage of their development, the oysters are much less robust and unable to withstand the shock and disturbance that would be caused to them by using traditional grading machines. To avoid distressing and damaging them, the seed oysters should be graded in water which dampens any impact. Before grading begins, the seed should be thoroughly washed by hosing them down in the boxes using a relatively low-pressure hose to avoid causing any damage to their shells. The boxes should then be tipped onto one edge at an angle of approximately 80° and the seed hosed gently into the bottom corner so that they can be easily accessed (Figure 5.41). There are then two ways of undertaking the grading process and these are as follows:

FIGURE 5.41
Box on edge with seed collected at the bottom

©Guernsey Sea Farms

1. Manual grading

This technique involves grading the oysters using handheld sieves (Figure 5.42), each with a different mesh size that allows the smaller oysters to fall through whilst retaining the larger ones. The process is as follows:

- The sieve is held in a tub of clean water.
- The seed oysters are scooped carefully out of the Flupsy boxes and tipped onto the mesh of the sieve.
- The sieve is then shaken gently backwards and forwards and up and down in the water so that the smaller oysters are pulled through the grading mesh.
- The oysters left on top of the mesh are then tipped into a container and will be either put back into a box on the Flupsy with the same grade of oysters or moved into on-growing equipment if they are of suitable size.

FIGURE 5.42
Hand grading the seed using a sieve

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- The downgrade that has fallen through the mesh collects at the bottom of the tub. When the tub is full, it is drained of water and the smaller oysters are then tipped back into a seed box to be placed back on the Flupsy to allow them to develop further.

2. Automated grading

There are different variations in design of in-water seed graders. What they all have in common is that the mesh grading grills that the oysters pass over are submerged in water (Figure 5.43). In this section, the manual will use one specific design to demonstrate the process. This design can use an automated feeding belt to move the oysters onto the grader or it can be fed manually. This grader has 3 compartments that are separated by internal bulkheads, each with its own outlet chute. Above the first two compartments, grading grills are secured in place with different mesh sizes utilised depending on the size of stock to be sorted. The mesh size increases as the oysters move across the grader so the smallest fall through the grill into the first compartment, the medium grade fall into the second compartment and the largest collect in the third compartment. The grader moves the grills in an elliptical motion which encourages the oysters to move along the length of the machine. The process is as follows:

- The outlet chutes of the grader are closed using metal clasps and the compartments are filled with clean water.
- Oysters are fed onto the grading grills either by hand or via the automated belt.
- When the compartments are full, seed boxes from the Flupsy are placed under the outlet chutes and the retaining clasps are undone, releasing the water and oysters into the boxes.
- The process is then repeated until the grading process for each separate seed batch is complete.

FIGURE 5.43
Automated oyster grading
(a) In-water automated grading of the seed. (b) Boxes lined up next to grader, ready to receive seed of different sizes from the three outlet chutes

Cleaning and removal of biofouling

Cleaning and the removal of biofouling from the Flupsy equipment and structure is just as important as washing the seed itself. The peak growing season for oysters is also the time of year when the optimum conditions for the growth of many other organisms exist. They can settle on the equipment and inhibit the performance of the Flupsy so regular cleaning and maintenance is essential to ensure the on-going efficiency of the system. There are 4 main areas that should be concentrated on:

1. Seed boxes

Particular attention should be paid to the mesh on the bottom of the boxes and the mesh socks that prevent oysters escaping through the outlet hole. A clean flow of water through the system is essential for encouraging a healthy growth rate and optimal survival rates. When washing the seed, the faecal deposits from the oysters are removed but it will not get rid of the growth of macroalgae and other biofouling that can collect on the bottom of the boxes. Therefore, whenever the boxes and socks are brought into the farm for grading, they should be cleaned using a pressure washer to ensure that the mesh is free of blockages and flow rate is maintained (Figure 5.44).

FIGURE 5.44
Pressure washing the boxes and mesh to remove biofouling

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2. Discharge channel

Over the course of the season, silty deposits can build up inside the channel. These should be removed as and when required. The best way to achieve this is by using a hose to disturb the sediment while the electric motors are running. The flow of water through the system will clear the sediment from the channel, allowing the tide to take it away from the Flupsy. Any boxes containing seed should be lifted out of the water before this procedure takes place to avoid contamination of the stock.

3. Raft structure

Biofouling of the structure can alter the relative buoyancy of the raft. This is particularly noticeable in areas where natural spatfall of bivalves occurs. Before the weight of the organisms that settle on the raft become too great, causing excess stress and increased resistance on the equipment, efforts should be made to remove these elements throughout the season. This can be done by divers using rigid plastic scrapers without the need to dry the raft out on a foreshore.

4. Removal of mussel spat from oyster seed

In areas where large volumes of mussel settlement occur, it may be necessary to ensure that mussel spat does not contaminate the seed oysters. If left untreated, mussel spat will collect oyster seed with their byssal thread, forming balls of seed with a mussel at the centre. This makes handling and grading the oysters very difficult and has a negative effect on the flow of water through the boxes. The removal of mussel spat is achieved by dipping the seed oysters into a solution of freshwater and bleach. The time of the season to undertake this task is when the mussels have just finished their pediveliger stage of development and have recently settled as microscopic spat. At this point, the oyster seed can be safely submerged in the solution without causing them any harm, whilst the bleach will kill off any mussel spat that has settled on them. The procedure for undertaking this task is as follows:

- Fill a pallet tank with the freshwater and bleach solution (6 ml of bleach/1 000 ml of freshwater).
- Remove the boxes from the Flupsy and wash the seed to remove any faecal deposits.
- Using the hose, wash all the oysters into the bottom angle of the box.
- Dip the box into the bleach solution for 60 seconds, ensuring all the seed is submerged, before raising it back up and letting the solution drain back into the pallet tank.
- Repeat this process for a second time.
- Thoroughly rinse the oysters using the hose to ensure that no bleach remains on their shells.
- Replace the seed boxes back onto the Flupsy.

Please note: Great care should be taken to ensure that no bleach enters the watercourse in which the farm is situated.

6. Farming with trestles and bags in the intertidal zone

INTRODUCTION

The farming of oysters in bags on trestles in the intertidal zone is a widely practised cultivation technique.

It was originally conceived in France and has disseminated from there, with the design and layout being altered and adapted to suit the individual locations in which it is practised. In this chapter, the manual will describe the traditional method of growing oysters in mesh bags that are attached to the trestles situated in intertidal regions of the foreshore, as seen in Figure 6.1. The mesh bags provide the oysters

FIGURE 6.1
Oyster bag and trestle cultivation site in Northern France

with a protective environment in which to grow, limiting the ability of predators to prey on them and allowing the operator to handle the stock in a controlled manner. By raising the bags off the ground and onto trestles, it allows water to circulate both above and below, providing a good flow of nutrients to be ingested by the oysters no matter their position in the bag. This encourages even growth throughout the stock and assists in producing a quality product. This system has the advantage of being easy to set up and the equipment involved is simple in design. The trestles are relatively cheap and uncomplicated to manufacture, using material that is widely available. The main disadvantages are the large amount of manual handling required to produce a quality product and that it can only be undertaken in the relatively limited intertidal zones that have a suitable fundus and tidal range.

6.1 SITE SELECTION

6.1.1 Water depth and tidal range

This system of trestle cultivation can only be undertaken on the foreshore in an intertidal zone. Ideally, the gradient of the foreshore should be relatively flat, allowing the trestles to be laid out easily and in a systematic design that makes the most of the geographical area available. Separate zones of the foreshore, that are covered by water at varying states of the tide, are advantageous for the management of the stock so that exposure time to the air can be increased or decreased as desired by the farm operator. Areas that are lower down on the foreshore and are therefore submerged for a larger proportion of the day, are better utilised to encourage faster growth. This is particularly suitable for smaller oysters, as the quicker that they can gain mass and size, the more resilient they become and less likely they are to succumb to mortality. Areas that are higher up on the foreshore spend a larger proportion of the day exposed to the air which assists in slowing the growth and hardening the oysters. These areas can be used to encourage oysters to produce thicker shells and stronger adductor muscles. Slower growth rates can also assist the oysters in fattening their meat content. Oysters that grow too fast can end up having undesirable qualities such as thin brittle shells and limp, watery meats, so placing them in a tidal zone that decelerates their growth rates can help combat these issues. When OsHV-1 outbreaks are expected and before critical environmental conditions occur, moving the juveniles or pre-grown oysters to the upper part of the intertidal zone can reduce their metabolism and consequently lessen the impact of the disease.

The mean tidal range (see definition in Section 3.1.1) will determine which areas of the intertidal foreshore will be suitable for trestle cultivation. This system is best suited to areas that have a mean tidal range greater than 2 m. There are two main considerations regarding tidal range when installing a trestle cultivation site. Firstly, the oysters must spend enough time immersed in the water to allow them to feed and grow successfully. Trestles placed too high will not spend enough time under the water and will therefore stunt the growth of the oysters. Secondly, the trestles must be exposed to the air for enough time to allow the farmer to undertake the necessary handling and turning of the oyster bags. Trestles placed too low down on the foreshore will not enable these procedures to be achieved. A location and tidal range that allows both priorities to be addressed in a balanced fashion will be the most suitable for this cultivation system.

6.1.2 Structure of the seabed

A bag and trestle site can only be installed onto ground that is firm enough to not only support the cultivation structures themselves, but also the vehicles and staff that will need to access the location.

If trestles are placed onto ground that is excessively soft, the legs will sink into the fundus and this will eventually lead to the bags being engulfed with mud and silt, diminishing the water flow across the oysters and potentially leading to mortalities. It is also important to note that the areas of ground under the trestles will eventually become softer over time due to excretion of faeces and pseudofaeces from the oysters themselves. Finally, the ground should be free of large rocks or other such impediments so that the trestles can be laid out in rows of relatively even height.

Soft ground is also very difficult and, in some cases, dangerous for farm workers to operate in. When lifting and moving heavy oyster bags whilst standing on soft ground, it is very easy for the individual undertaking these tasks to get their feet stuck in the mud. In extreme cases, this can turn into a perilous situation, especially when working in locations with fast rising incoming tides. But even if there is no threat to life, working in these conditions is extremely slow and inefficient and should therefore be avoided. If the site is accessed by tractor and trailer, then overly soft ground can also cause vehicles to become stuck. This can cause operational inefficiencies and, in a worst-case scenario, result in valuable equipment being submerged in salt water and irreparably damaged. Not only will this result in a large bill to replace the damaged vehicle, it can also prevent the farm from operating competently, potentially leading to loss of earnings and reduction in quality of the stock.

6.1.3 Tidal flow and fluvial currents

It is important that the site is situated in an area that has enough tidal flow to encourage a healthy water exchange which will bring a fresh input of nutrition to the oysters contained in the bags. A tidal flow of somewhere between 0.2 and 2 knots (10–100 cm per second) will provide the oysters with a suitable environment in which to feed and grow. Due to the intertidal nature of trestle sites, there will always be an interaction with outflows from the land. This can have both a positive and negative effect on the suitability of a site. When nutrients are washed off the land and into the water column it can cause increased levels of phytoplankton on which the oysters feed. In small quantities, this creates a nutrient rich environment in which the oysters can thrive. However, when the run-off becomes excessive, it can cause eutrophication of the aquatic ecosystem and an increased turbidity which can negatively impact the suitability of a site to successfully cultivate oysters. It can also lead to an increase of pollutants entering the cultivation area which can affect the water quality and therefore the viability of producing a consumable product. These scenarios are dealt with in detail in Chapter 3 of the manual.

6.1.4 Exposure to wave action

Wave action is at its most destructive in the breaking zone where the sea meets the shore. If trestles and oyster bags are placed in an area that is exposed to dynamic wave action, equipment damage and a resulting loss of stock is likely to occur. Therefore, it is important to install the site in an area that is relatively protected from direct exposure to these forces.

6.2 FARM DESIGN

6.2.1 Trestles and oyster bags

Trestles

Trestles provide the support and framework upon which the oyster bags are attached and can be constructed from either metal or wood (Figure 6.2). They are usually constructed from "rebar" which is short for "reinforcing bar". This is a carbon steel rod that is used in the construction industry to reinforce concrete structures and is therefore widely available and can be sourced from many locations around the world. Due to its mass production, it is a cheap material and can therefore be used to

FIGURE 6.2
Oyster bags on trestles in the intertidal zone at Porthilly Shellfish in Cornwall, United Kingdom of Great Britain and Northern Ireland

construct the trestles for a relatively low price. It is easily manipulated, cut and welded, making the construction of them a simple task. The following section will describe the technique to construct a trestle out of steel. However, if this material is not available, then similar structures can be made using locally available resources such as timber and bamboo. The measurements detailed below can be used as a guide for the construction of a trestle, even if it is made using these alternate materials.

Construction and installation – Steel

There are two main options when considering the manufacture of the trestles. One option is to buy the trestles in from an outside company who will undertake the construction of the trestles themselves and deliver them as whole units. This is the most expensive option, not only because of the labour cost charged to weld the objects together, but also because, once constructed, they are bulky items and will cost considerably more to deliver to the location of the farm. The other option is to have the steel bar cut into the required lengths and bent into the necessary shapes before being delivered flat packed in kit form, ready to be welded on site. This service can usually be provided by the company supplying the rebar. The welding required to construct the trestles is straightforward and can be undertaken by someone with basic welding skills at the farm site. This will save money on both construction and transportation. In this section, the manual will provide details of one method to construct a trestle from pre-bent and cut steel.

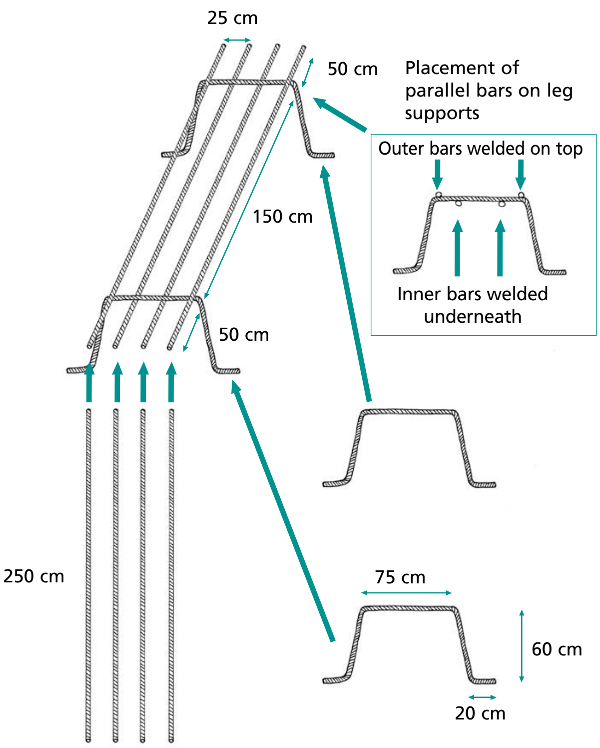
Assembly of trestle

These instructions are for the assembly of a trestle designed to support 5 standard oyster bags as illustrated in Figure 6.3. There are different variations on this theme, but the example highlighted is one of the most common designs.

Steel components: 4 × 2.5 m lengths of straight bar, 2 × pre-bent leg support units. For this example, 16 mm diameter rebar is used but, if required, it is also possible to use 20 mm rebar.

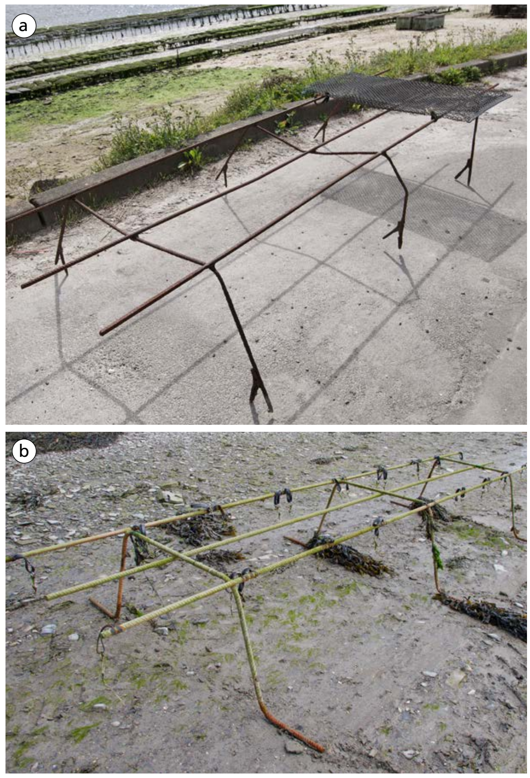
Please note that it is possible to construct a trestle using only 3 lengths of straight bar, with 1 positioned centrally between the 2 perimeter supports (Figure 6.4). This design is widely used and perfectly capable of supporting the bags. It is also cheaper to produce as less rebar is required.

FIGURE 6.3
Trestle components and construction layout. The separate components should be welded together in the positions indicated in the diagram



Source: Elaborated by the authors.

FIGURE 6.4
Oyster trestle with three length-ways supporting bars
(a) Oyster trestle for 5 oyster bags at Beg Ar Vill Oyster Farm, France. (b) Longer trestle designed to support 8 bags



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As the farm will require multiple identical units to be assembled, the first thing to do is to construct a jig to enable fast and accurate reproductions to be made. A jig is a simple framework that will hold the various components in place whilst they are welded together and can be made of metal or wood.

The trestle will initially be assembled upside down with the feet facing upwards. Place the two outer 2.5 m straight lengths of bar into the jig so that they are parallel with the ground, then lower the support sections on top of them so that they are at 90° to the straight bars with their feet vertically in the air. Lastly, place the two remaining 2.5 m straight lengths on top of the support sections, parallel with the outer bars, in the positions dictated by the jig. All the components are now in position and weld can be applied to all of the areas where the bars intersect. Once this has been completed, the trestle will be strong enough to be lifted out of the jig and flipped onto its feet so that it is now standing in the upright position. Weld can now be applied to the intersections of the bars that were inaccessible whilst the trestle was in the jig. All the welds should now be checked to ensure that a strong bond has been achieved at each of the intersections. Once this has been established, the trestle is now ready for deployment.

Oyster bags

There are many different variations when it comes to oyster bag design, but most are made out of HDPE which is a strong material that does not break down in the marine environment. This material is moulded into semi-rigid mesh bags that allow water to flow through them whilst preventing the oysters from escaping and protecting them from predation. When available anti-UV treated HDPE bags should be preferred. This section of the manual will look at two standard designs (Figure 6.5).

FIGURE 6.5
Oyster bags
(a) Diamond mesh bag pre-sealed at one end. (b) Square mesh oyster box bag

Diamond mesh bag
Diamond mesh bags come in two types, conformed and non-conformed, and are pre-sealed at one end. They measure 100 × 50 cm and require no assembly process. Conformed bags are more voluminous, forming a shape like a pillowcase, that encourages an increased flow of water through the bag. Non-conformed bags are usually cheaper but are more restrictive for the oysters and have a lower flow of water.

Square mesh box
Square mesh box bags come flat packed and need to be formed into a rectangular box shape. One end is then closed using hog rings or cable ties which allows the bag to then hold its shape. When assembled, it measures 80 × 40 cm. Due to the increased volume within the bag that this design enables, it provides the oysters with a less restricted environment in which to grow with a good flow of water and encourages tumbling under the effect of waves and tide which helps to shape the oyster shell.

Mesh sizes
Mesh sizes start at 2 mm and increase up to 23 mm (Figure 6.6). These measurements describe the aperture of the openings in the mesh through which water can flow. Standard mesh sizes are shown in Table 6.1. The decision as to what mesh size to use

FIGURE 6.6
Three oyster bags with different mesh sizes: 4, 6 and 9 mm

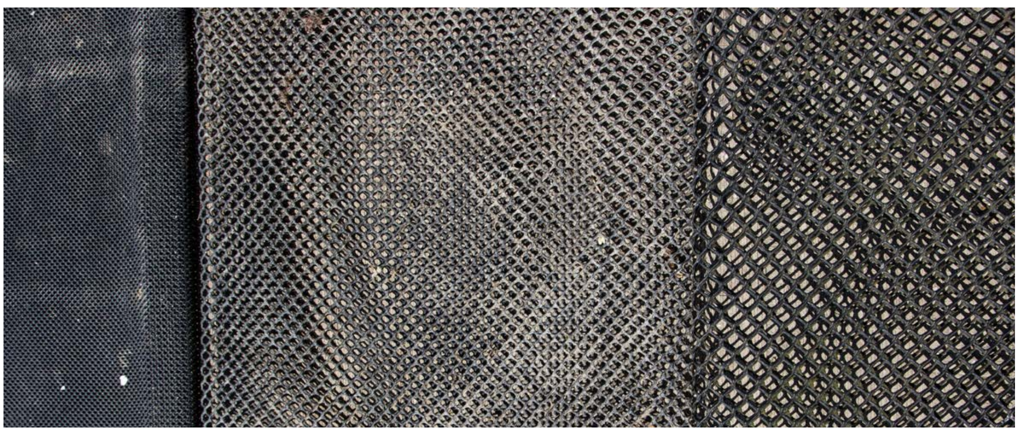


TABLE 6.1
Standard oyster bag mesh sizes

Standard mesh size of oyster bags							
2 mm	4 mm	6 mm	9 mm	12 mm	14 mm	18 mm	23 mm

Source: Elaborated by the authors.

will be discussed in Section 6.3. The bags also come in a variety of weights with the standard ones being 550 g, 700 g and 900 g. The different weights denote the thickness and therefore the strength of the structure of the bags. It is recommended to avoid the lighter, weaker bags where possible, as their lifespan is shorter leading to increased plastic waste. They also damage more easily with the potential loss of oyster stock.

Bag closing mechanisms

The end of the bags into which the oysters are loaded can be held shut by a number of different closing mechanisms. These are to ensure that when the bags are placed back into the water no oysters can fall out and to limit the ability of predators to get in. However, they also can be used for another important function which is to give an indication of what grade of oysters are in the bag. This is done by using a colour coding system. Each of these closing mechanisms can be purchased in a variety of colours and so the operator can choose which colour will represent a different grade of oyster. For example, they may choose to use red hooks to represent 10 g oysters, green hooks to indicate 20 g oysters and white hooks to represent 40 g oysters. These then serve as a quick visual reference point for the farmer so that when surveying a line of trestles, they can immediately see which bags contain the size of oyster that they are looking for. The number of bags, their coloured closing mechanism and their location should then be recorded in the stock management records. Stock management and record keeping will be discussed in greater detail in Section 6.3. Figures 6.7, 6.8, 6.9 and 6.10 show some of the different closing mechanisms available. Please note the different colours that can be used for stock management:

Hooks and rubber bands

Both plastic coated metal hook and plastic hooks are available on the market.

FIGURE 6.7
Plastic coated metal hooks and rubber bands
(a) Oyster bag closed with plastic coated metal hooks and rubber bands. (b) Closing hook with alternate design of rubber band for connecting onto the oyster bag

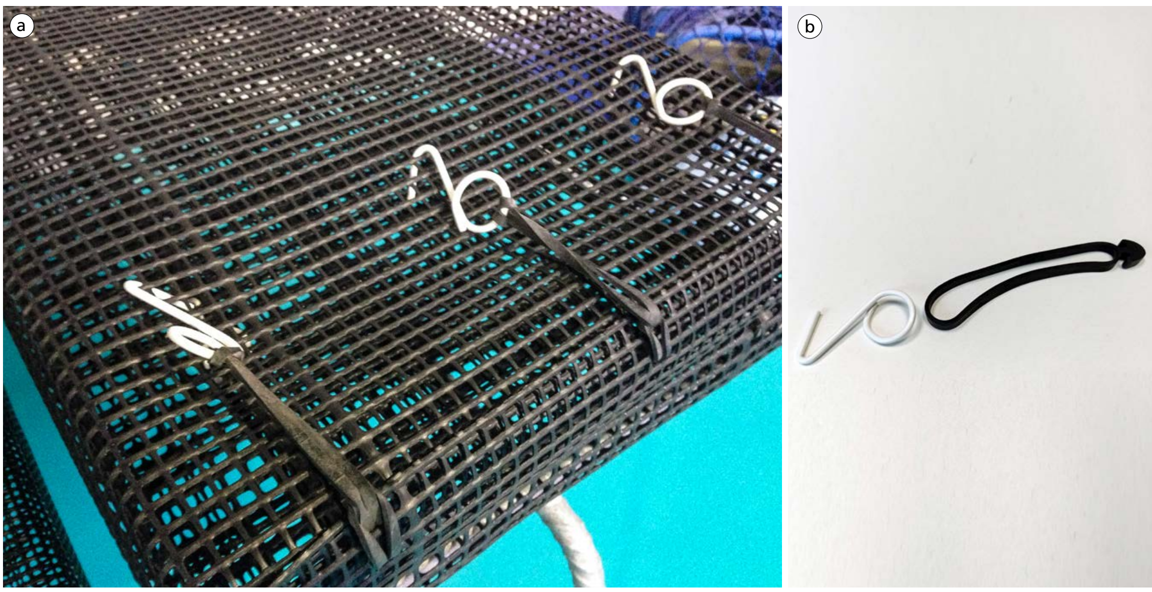
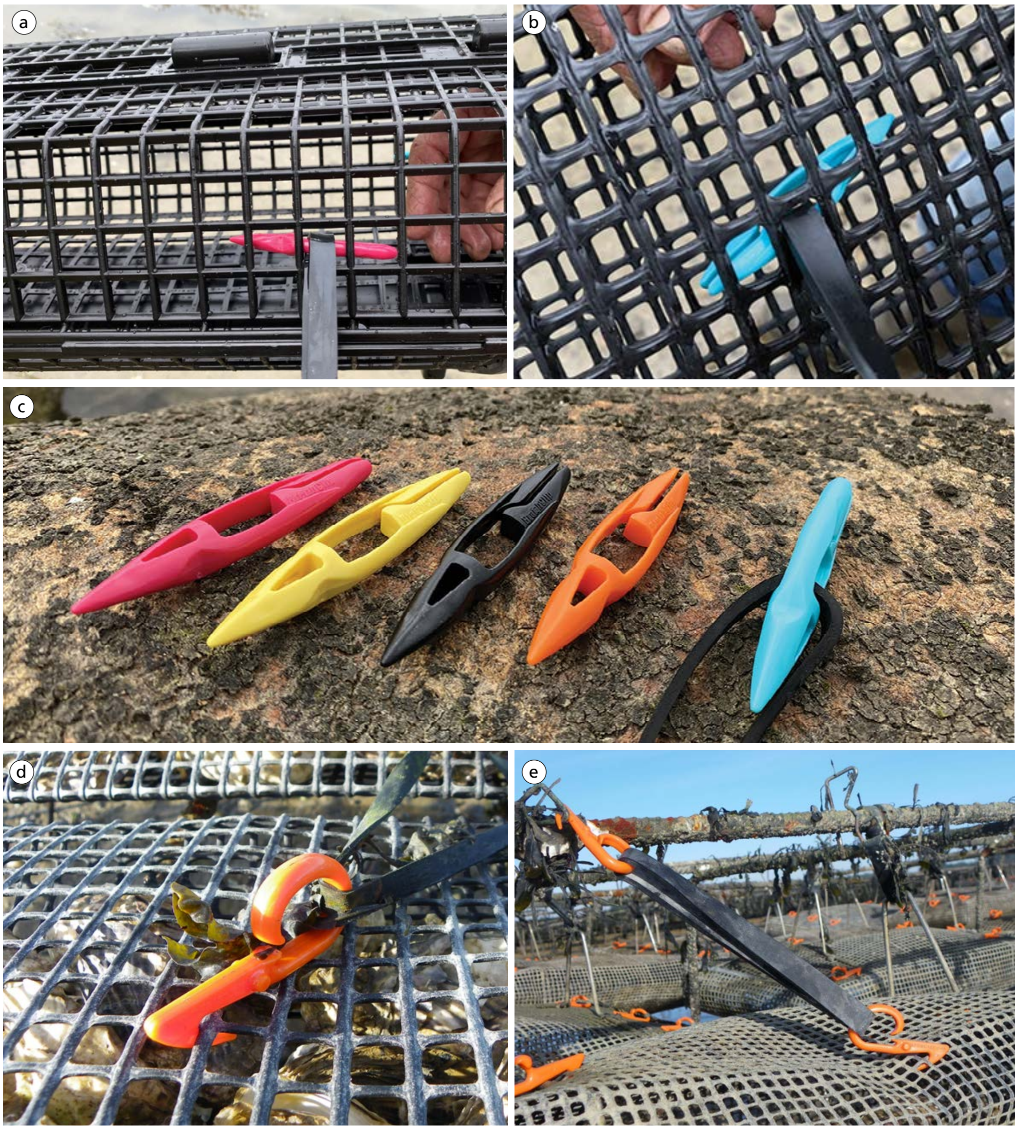


FIGURE 6.8
Plastic clips and hooks used to close and keep oyster bags in place
(a–b) Multi-purpose clips. (c) Clips of different colours to assist in stock identification and management. (d–e) Hooks of different design are available to secure all types of ouster mesh bags



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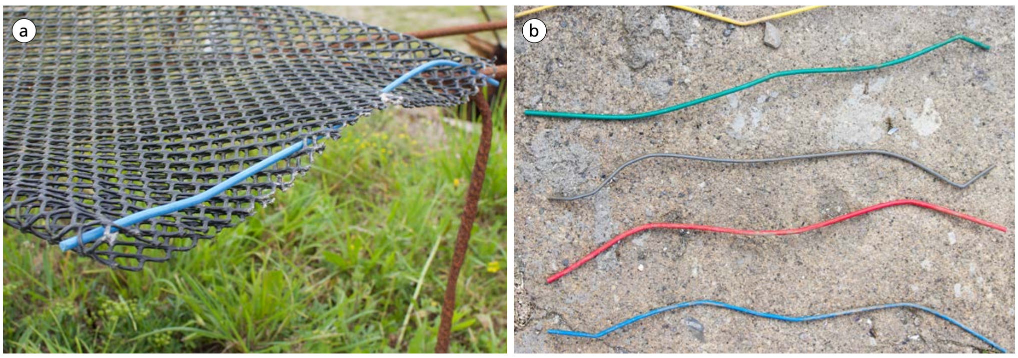
"Joncs" (closing sticks)

FIGURE 6.9
Oyster bags closing sticks
(a) Oyster bag sealed with closing stick. (b) Closing sticks (Joncs) in a variety of colours



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PVC tube sliders

FIGURE 6.10
PVC tube sliders for closing oyster bags

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Attaching the bags to the trestles

The bags are laid on the trestles and secured to the upper parallel bars using rubber bands and hooks. This is to ensure that the bags will remain in place and will be unaffected by tide and wave action. Depending on the exposure of the site, it is possible that even heavy bags may be displaced and end up on the ground around the trestles if not firmly secured, with light weight bags of seed or smaller oysters being even more vulnerable. When bags fall off the trestles and are left on the foreshore, the mesh can become clogged with silt and mud, disrupting the flow of water through the bags. This will result in a reduction in growth rates and can lead to mortalities if the problem is not remediated.

There are several different ways that the rubber bands and hooks can be used to complete this process and they are outlined in the images below:

1. The bands are looped directly onto the outside parallel bars of the trestle and the attached hook is stretched on to the top of the bag and placed through the mesh to secure the bag in place as seen in Figure 6.11. The spacing of the bands corresponds to the width of the oyster bags as seen in Figure 6.4(b).

FIGURE 6.11
Rubber bands attached directly to trestles and then hooks inserted into the mesh of the bags to secure them in place

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2. The rubber bands are tied together to form a loop that is the same width as the bag. The bag is then slipped under the loop and secured in place without the use of any hooks. The loops are secured to all three parallel bars of the trestle (Figure 6.12).
3. The rubber bands are cable tied to the oyster bags and looped under the bars of the trestle and then back onto the bag using a hook through the mesh to secure it (Figure 6.13).

FIGURE 6.12
Oyster bags secured in place by rubber bands without the use of hooks

©Intermas Nets S.A.

FIGURE 6.13
Rubber band attached directly to the bag and looped under the trestle to secure in place using a hook

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Production capacity depending on expected survival and expected growth rate

The production capacity of a site will depend on many factors, but the three main ones are the size of the site, the growth rate of the oysters and the average mortality rates experienced at the site. In this section, two examples are given to demonstrate the potential output of a site with a 2-year growth cycle, showing the area in square metres and the number of trestles/bags required depending on two different mortality rates (Table 6.2). In both examples, the end weight of the oysters is assumed to be 80 g, with a stocking density of 150 oysters per bag, yielding a total weight of 12 kg per bag. One standard 5 bags trestle covers a surface area of 2.5 m^2 and, as it is not possible to have a fraction of a trestle, only whole units are used for the purposes of these calculations. The surface area taken up by a trestle is the same whether it only has 1 bag on it or is full and supporting 5 bags.

The examples demonstrate how 1 bag of T6 seed oysters can expand over the course of a production cycle and therefore how many bags and trestles will be needed to accommodate the oysters by the time they reach market size. These figures can be used to estimate the production capacity of a site based upon the area that is available and therefore the number of trestles that can be installed.

In example 1, a mortality rate of 30 percent is assumed from T6 to market size. This represents a fairly average scenario without any excessive mortality events.

In example 2, a higher mortality rate of 50 percent from T6 to market size is assumed as may be experienced at sites that have issues such as OsHV-1.

TABLE 6.2
Table showing production capacity depending on expected survival and expected growth

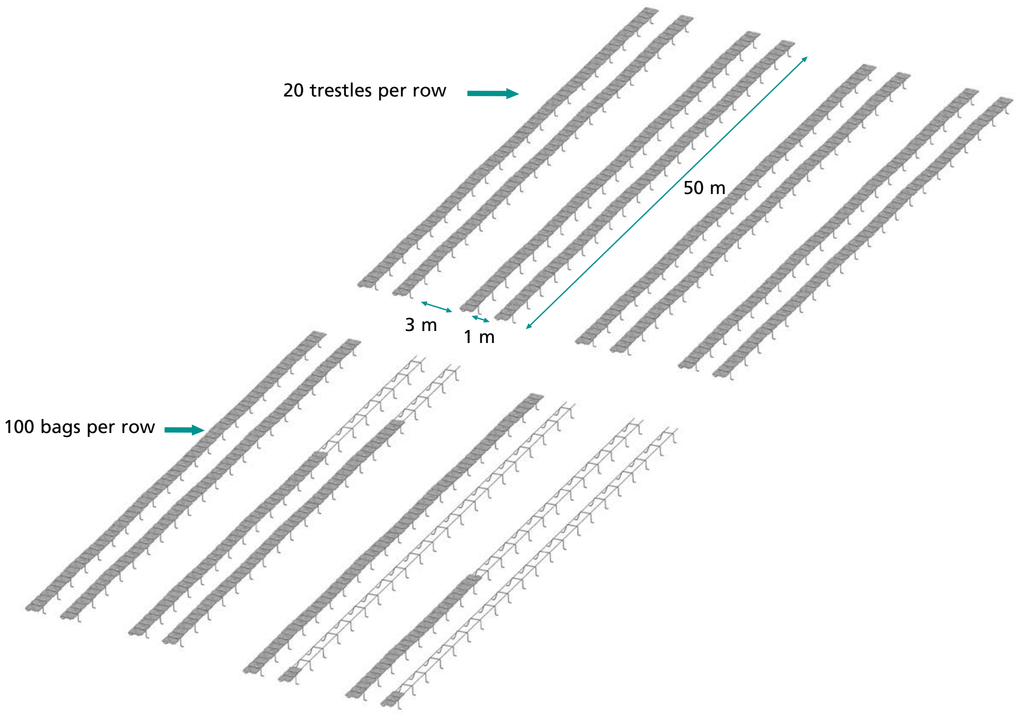
Example 1								
	Initial number of oysters	**Number of oysters/bag**	**Average weight of each oyster**	**Total weight of oysters**	**Number of bags**	**Number of trestles**	**Surface area required**	**Mortality rate by end of year**
Start of the production cycle	4 000	4 000	0.2 g	0.8 kg	1	1	2.5 m^2	20%
After 1 year	3 200	640	15 g	48 kg	5	1	2.5 m^2	10%
After 2 years End of the production cycle	2 880	150	80 g	230 kg	19	4	10 m^2	–
Example 2								
	Initial number of oysters	**Number of oysters/bag**	**Average weight of each oyster**	**Total weight of oysters**	**Number of bags**	**Number of trestles**	**Surface area required**	**Mortality rate by end of year**
Start of the production cycle	4 000	4 000	0.2 g	0.8 kg	1	1	2.5 m^2	40%
After 1 year	2 400	640	15 g	36 kg	3,75	1	2.5 m^2	10%
After 2 years End of the production cycle	2 160	150	80 g	173 kg	15	3	7.5 m^2	–

Source: Elaborated by the authors.

6.2.2 Farm layout

The layout of the farm will be dictated by the topography of the foreshore that is available and how the tidal range affects the site. In this section, the manual will describe the layout of a theoretical farm illustrated in the diagram below. In the example illustrated in Figure 6.14, there is a large, open section of beach and the trestles are divided into rows, spaced out to allow access to the bags by both people on foot and by the vehicles used to transport the oysters to and from the site. The rows of trestles are grouped together in pairs, 1 m apart, to enable workers to walk between them so that when the bags need to be turned or collected for grading, they can be accessed with ease. These pairs of rows are then separated by a 3 m gap to allow a tractor and trailer to gain access to the site to collect bags when they are ready for grading or harvesting. In this example, the rows also have breaks in them every 50 m to allow workers to cross between them. This is just one example of an ideal layout when space is relatively unrestricted. However, each site will be different and will have its own restrictions so layouts will vary considerably to maximise cultivation space within the physical limitations of the farmed area.

FIGURE 6.14
Example of trestle farm layout with each row of 20 trestles supporting 100 oyster bags



Source: Elaborated by the authors.

In the image below (Figure 6.15), another layout can be seen, where the narrow nature of the foreshore dictates that the rows must be grouped closer together and there are less gaps in the rows. In this scenario, it may be slightly more difficult for the workers to access the bags. The operator has maximised the space available, and therefore the output of the site, at the expense of a certain amount of convenience. These are the sort of decisions that will have to be made when accessing each individual site.

6.2.3 Access to the farm

Access to the site can be achieved by either tractor and trailer or boat, depending on the location of the farm and the availability of suitable entry points. Some sites will allow access by both options whilst others will be limited to one means of transport. In this chapter section, the manual will look at each alternative.

Tractor

Access to the site by tractor and trailer (Figure 6.16) will be limited to states of tide that are low enough to expose the ground around the trestles. As discussed in Section 6.1.2 of this chapter, the ground must be of a suitable firmness to allow the tractor to operate on the site without getting stuck. The vehicle must be of a suitable size and power to allow

FIGURE 6.15
Longer rows of trestles with narrow gaps in between due to the restricted area of the foreshore at Porthilly Oyster Farm, United Kingdom of Great Britain and Northern Ireland

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FIGURE 6.16
Tractor moving oyster bags on intertidal foreshore at Porthilly Oyster Farm, United Kingdom of Great Britain and Northern Ireland

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it to transport several tonnes of oysters in bags on its attached trailer to successfully move stock from the cultivation site to the land-based grading and processing facilities. The more stock that can be moved in one trip to and from the site the better, as this will maximise efficiency and cut down on wasted travel time. The size of the tractor will also dictate the spacing between the rows of trestles, as discussed in the previous section. There will therefore have to be a compromise between maximising carrying capacity and maximising spatial efficiency of the layout of the site. The larger the tractor is, the more carrying capacity it has, but the more space it requires, the larger the gap needs to be between the rows. For example, on a site that has limited space, the loss of 0.5 m per pair of trestle rows to allow for a larger tractor, when multiplied down the width of the foreshore, could result in a significant reduction in the potential production capacity of the farm. In this scenario, a smaller tractor would probably be a better option to enable the operator to maximise the yield of the site.

Workboat

A workboat allows admission to sites where suitable land access is unavailable. For example, many farms that operate in estuarine environments may have their farming area separated in two by the tidal river that feeds the bay. Often in this situation, one side of the bay may be accessible by land and the other can only be approached by boat across the river. A suitable workboat, as seen in Figure 6.17, is therefore essential in this situation to allow the operator to maximise the use of all available foreshore. A workboat can also operate when the tide is partially in, with only the bags situated on top of the trestles protruding from the water. This allows access to the site for a longer period which can potentially allow more work to be achieved on a single tide. To assist in this ability to make the most of the available working time, the ideal design for the workboat should incorporate a flat-bottomed hull and shallow draft, enabling it to operate in very shallow water. Some vessels have their outboard motors mounted on a frame that can be winched vertically out of the water to assist in their shallow water usability. In terms of the size and carrying capacity, the same compromises apply to the workboat as they do to the tractor and the operator will have to make the decision as to what to prioritise depending on the physical attributes of the site. The other major design factor to consider when looking for a suitable boat is stability. The vessel will need to transport relatively heavy loads stacked upon its deck and will therefore need to be stable enough to allow this to be done safely in the weather and wave conditions that occur on the site. Generally, trestle sites are located in areas that do not regularly experience significant swell and therefore a flat-bottomed vessel will be most suitable as they are more stable in calm conditions.

Figure 6.18 shows an example of an amphibian workboat that was designed to optimize access to the production site and available working time.

FIGURE 6.17

Oyster workboat next to trestles at Beg Ar Vill oyster farm, France. Note the shallow draft to allow access to the site in the minimum depth of water

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FIGURE 6.18
Amphibian workboat

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6.3 FARMING PRACTICES

This chapter section will give guidance on the cultivation management practices that will need to be undertaken in order to successfully grow the oysters from the "T6" spat size to market size product. It should be noted that the information regarding grading and bag turning schedules, and the number of oysters inserted into the bags is for guidance only. Each cultivation site will have its own unique set of environmental parameters that will determine how the oysters grow and develop, so each farmer will have to design his own management strategy around these factors.

For new sites where farming activities have never been undertaken before, it is highly recommended that the operator carries out a trial on the farm site for a minimum of 12 months to monitor these factors and the development of the oysters over the course of a year before scaling up the operation to a commercial size. This should be done by placing sample bags of oysters on trestles in various places around the production area and recording monthly growth rates, mortalities, biofouling and biological condition of the molluscs. Temperature and salinity data should also be recorded over this period to start building a picture of seasonal environmental influences on the oysters. The results from this monitoring process will help educate the farmer as to the unique parameters of the farm and can form the foundation of knowledge upon which a cultivation strategy can be built. Due to annual variations in environmental conditions, this strategy will no doubt change and evolve over time, but this trial data will provide a starting point for the commercialisation of the farm.

6.3.1 Strategy for seed introduction

In this section, the manual will outline the different approaches to the management of seed oysters when starting the production cycle from a "T6" spat size. This choice comes from the minimum mesh size of the oyster bags normally available on the market.

Seed will either need to be bought in from a hatchery or collected from natural spat settlement as discussed in Section 4.1 where different spat collection techniques are outlined. A farm that is in an area of abundant natural spat fall can use these techniques to provide a potentially lower cost means of seed collection. If this option is viable, then it will affect the strategy and general approach to seed. Furthermore, depending on the possibility or not to install pre-growing facilities on the chosen site, the farmer will have to decide if a nursery stage can be carried out directly on the farm as discussed in Section 4.2 and in Chapter 5 of the manual.

Period and quantities

The timing of the introduction of seed onto the site will largely depend on the source of the oysters. If they are being collected from the wild on settlement apparatus, then the timing will be dictated by the season in which spat naturally occurs on the site which will generally be over the summer months. If the seed is being bought in from a hatchery, then the timing will be dictated by the production strategy of the supplier. Most hatcheries will work in line with the natural breeding season because this ensures that the oysters will be introduced to the site when the prevalent conditions are most suitable for seed oysters to thrive, with suitable levels of phytoplankton available and warming water temperatures. However, because hatcheries can induce spawning events, it allows increased flexibility as to when the seed will be available and therefore it will generally be possible to purchase oysters from early in the Spring right through until Autumn.

Size and density

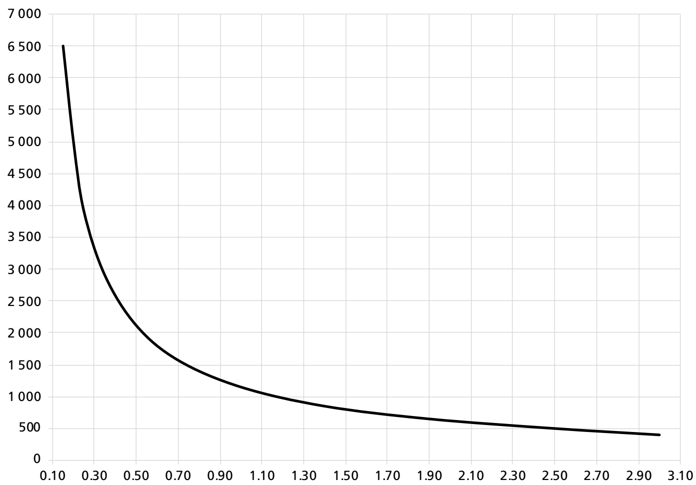
Table 6.3 provides guidance on the densities of seed oysters that can be placed within the oyster bags. These figures are for guidance only and adjustments should be made to match the individual conditions experienced at each farm site.

TABLE 6.3
Seed sizes and densities in bags

Grader grill oyster size	> 6 mm ≥ T 6	> 8 mm ≥ T 8	> 10 mm ≥ T 10	> 12 mm ≥ T 12
Bag mesh size	2 to 4 mm	4 to 6 mm	6 mm	9 mm
Average number of spat/kg	6 500 4 000	3 000 1 500	1 250 700	700 350
Average spat weight (g)	0.15 0.25	0.35 0.65	0.8 1.4	1.5 3.0
Recommended weight of spat/bag (kg)	1.0	1.0	1.25	1.25
Approximate number of spat/bag	6 500 4 000	3 000 1 500	1 500 900	900 400

Source: Elaborated by the authors.

FIGURE 6.19
Abacus of seed number/bag depending on average seed weight (g)



Source: Elaborated by the authors.

Seed handling practices

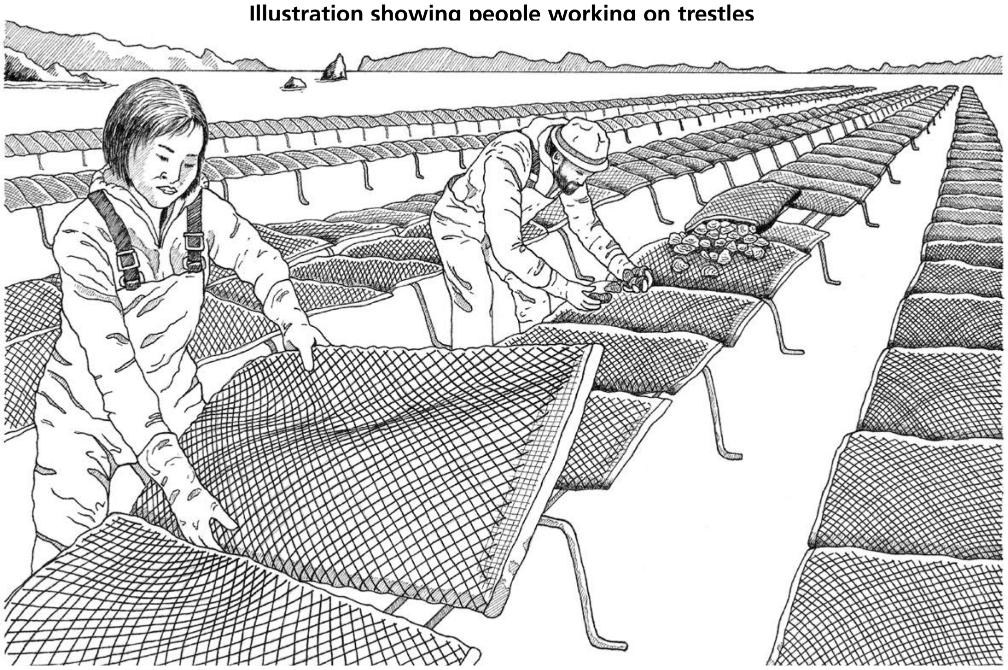
Seed oysters need to be placed into oyster bags that have an even smaller mesh size to contain them without any falling out. (Recommended mesh size in relation to the size of oyster is detailed in Table 6.3). These smaller mesh sizes (2, 4 and 6 mm) are particularly prone to biofouling and clogging due to a build-up of sediment and excrement from the oysters themselves. When the oysters are in this juvenile phase, they are particularly sensitive to reduced flow through the bags and require a good water exchange to deliver the dissolved oxygen and nutrients that they require to grow and remain healthy. It is therefore imperative to inspect these bags on a regular basis, at least once every two weeks, to ensure that the mesh is remaining free of any impediments so that the water exchange is maintained at an optimal level. It is also important to check that the oysters are not bunched up in the corner but remain evenly distributed across the length of the bag. If the oysters become clumped together, the ones on the inside will be outcompeted for food and dissolved oxygen by the ones on the outside of the cluster and this can result in uneven growth rates and even mortality in extreme cases.

Another area of concern in this scenario is that, due to the speed of growth that the oysters are experiencing at this stage of their development, they can become conjoined or start to grow through the mesh of the bags. This can lead to misshapen shells and potential losses when trying to separate the oysters either from themselves or the bag. It is recommended that small seed (T8 and below) should be graded every 3-4 weeks during the growing season and all seed should be turned in their bags at least once every 2 weeks when controlling mesh clumping. It is worth noting that any issues with the seed oysters can have extremely serious consequences when considering the impact that it can have on the number of market size oysters produced. For example, a single 1 kg bag containing 4 000 T6 seed could produce up to 300 kg of market size oysters. Therefore, the loss of stock from one bag of seed oysters represents the loss of a much larger mass of end product. The way in which the seed oysters are managed in the first 3–6 months of their life cycle will have a huge impact on their growth rates and the quality of the end product. It is therefore recommended that the operator pays particular attention to this phase of production.

6.3.2 On-growing strategy and technique

This section of the manual outlines the major stock management practices that must be adhered to complete the grow-out phase of the oysters successfully. The two most important activities that must be carried out during this phase are grading the oysters and turning the bags, as shown in Figure 6.20. The schedule for undertaking these activities will depend upon the conditions experienced at the farming site as growth rates can vary enormously depending on the location of the farm. For example, a farm located in the higher latitudes with colder water and a lower concentration of phytoplankton will experience a much slower growth rate when compared to an operation located in the lower latitudes with higher year-round temperatures and available food. An oyster

FIGURE 6.20
Illustration showing people working on trestles



Source: Elaborated by the authors.

grown in the cold-water environment may take 3 years + (for instance in Galway Bay along the Irish Atlantic coast) to reach market size whereas an oyster grown in warm water conditions could reach the same size in under 12 months (for instance in Dakhla Bay on the southern Atlantic coast of Morroco). Due to this discrepancy in growth rates, the schedule for attending to the stock will have to be tailored to the individual growth characteristics of the site. In extremely fast-growing conditions, bags may have to be attended to every 2 weeks as opposed to the slower growing environment where bags could be left for several months without harm coming to the crop. In the section below entitled "Recommended frequency for grading batches or turning bags", examples are given of different tactics regarding this subject.

Grading

The grading process enables several different outcomes:

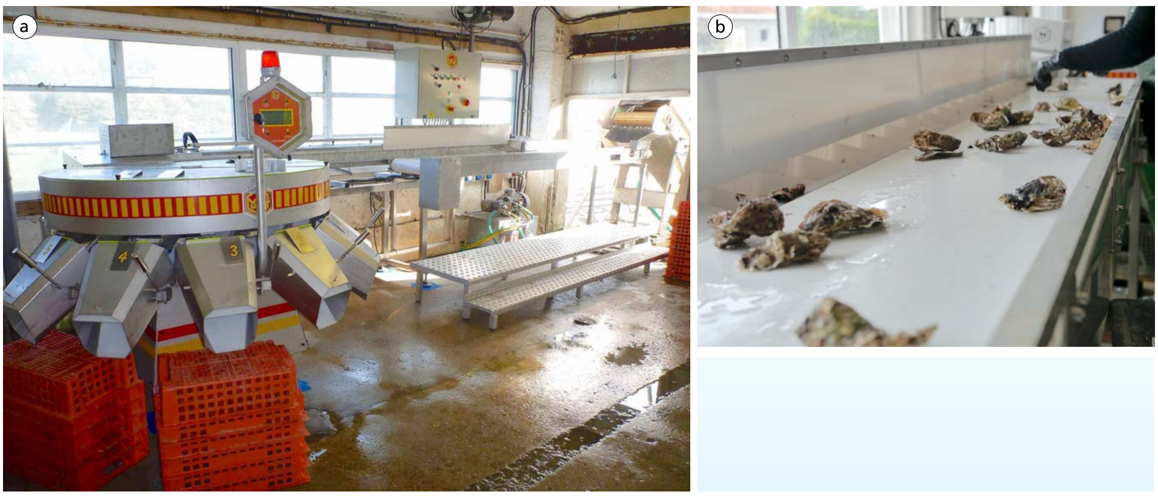
- Most obviously, grading allows the oysters to be separated and grouped together with other oysters of a similar size. This is vitally important to ensure that all the oysters from a batch have the opportunity to feed and grow without being outcompeted for nutrition. If a large, faster growing oyster is left near a smaller, slower growing oyster, the larger mollusc will continually dominate its smaller rival in terms of filtering phytoplankton from the water column. If this situation is allowed to continue for too long, then eventually the smaller oyster becomes so used to being starved of sustenance that it will become what is known as a "runt". When these "runts" are eventually graded out, and placed in a bag with similar size oysters, they are permanently stunted, and many will never reach a marketable size. However, if these slower growing oysters are separated before this scenario occurs, they can comfortably reach market size but will just take a bit longer than their faster developing counterparts.
- When the oysters are emptied out of their bags to be sent through the grading line, they must pass over an inspection conveyor belt, where the stock can be easily scrutinised, and any predators removed. Although the oysters are partially protected from predation by larger organisms whilst inside the bag, creatures such as crabs and starfish can enter through the mesh when they are very small, before

maturing and enlarging inside the container. When they enter the bag in their juvenile form, they are unable to cause any damage to the oysters. However, when they reach a size and strength where they can prise open the oysters or damage their shells, they can then cause extremely high mortality levels within the bag. In this instance, the farmer will be left with a bag full of dead shell and a very large crab or starfish who has fed off their valuable crop. It is therefore imperative to remove such predators from the bags before this eventuality occurs.

- As the oysters are tumbled over the grader, small amounts of new shell growth around the frill are knocked off. This does no harm to the oyster, but it does serve to encourage the mollusc to develop an even shape which is desirable if they are being sold in their shells.
- During this process, it is possible to accurately measure the development of the stock. Periodic quality assessment, including meat to shell ratio and average weight calculations, can be done at this time and all data recorded. This will allow the operator to carefully monitor how well the oysters are progressing and take any action necessary to enhance their advancement. The process for calculating the meat to shell ratios is explained in Section 2.2 of this manual. Average weight calculations should be done by taking 20–30 oysters out of each grade, washing and drying them, and then dividing their total weight by the number of oysters sampled.
- After grading, the oysters can then be put back into clean oyster bags. Refreshing the bags is an important part of the management of the stock as it is imperative that the oysters receive a constant flow of nutrients and dissolved oxygen to allow them to grow at a desirable rate. The mesh of the oyster bags can easily become clogged up due to oyster faeces, sediment and biofouling organisms and all of these can combine to restrict the water flow through the bags. Farming in the intertidal zone will naturally reduce some of the biofouling, as certain organisms will not be able to survive exposure to the air when the tide recedes to uncover the bags. However, it will not eradicate the problem so the use of clean bags should be a mandatory procedure on each grading cycle. Particular attention should be paid to the condition of the bags over the summer months when biofouling will be at its most extreme due to increased growth rates during this period.

Figure 6.21 shows a semi-automated grading line in operation, where oysters are placed onto the feeding belt by hand, but the grading is completed by a pre-programmed machine to separate the sizes into the desired grades.

FIGURE 6.21
Grading oysters
(a) Semi-automated oyster grading line with circular grader that separates the oysters by weight.
(b) Oysters on sorting and feeding belt that delivers the oysters to the circular grader



Turning

Turning the oyster bags (Figure 6.22) should be done on a regular basis in between each grading cycle as detailed in Table 6.4. The purpose of bag turning is as follows:

- It prevents the oysters from growing into the mesh of the bags.
- It prevents the oysters from fusing together.
- As with the grading process, it helps to shape the shell resulting in an aesthetically pleasing product.
- It reduces fouling from seaweed on the bags (Figure 6.23). Macroalgae need sunlight to photosynthesise so any new growth that has accumulated on top of the bag will be limited when the bag is turned over so that the seaweed is now hidden from the daylight. This will not completely eliminate the issue, but it will help to reduce algal growth.
- It allows the oysters to be evenly distributed within the bag which will encourage an even growth rate.
- Any damage to the bags can be spotted and repaired or the bag replaced before too much stock is lost.

FIGURE 6.22
Oyster bags being turned on their trestles at Beg Ar Vill Oyster Farm, France

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Due to tidal flow and wave action, the oysters can become bunched up in the extremities of the bag which can lead them to grow into the mesh itself. Whilst turning the oysters, the bags should be tapped with a stick to free up any molluscs that have attached themselves to the bag (Figure 6.24a). This should be done with the minimum force required to dislodge them to ensure that no damage is done to the oysters themselves. Special attention should be paid to the corners and edges of the bags as this is where the oysters will tend to get wedged and therefore grow into the meshes of the bags.

If there are still oysters that are attached to the mesh then it will be necessary to open the bag and dislodge them by hand (Figure 6.24b) or, for ones at the bottom

FIGURE 6.23
Algal growth on oyster bags at Beg Ar Vill Oyster Farm, France

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FIGURE 6.24
Dislodging oysters that have grown onto the bag or attached to the mesh
(a) Dislodging by tapping gently with a stick. (b) Dislodging by hand

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FIGURE 6.25
Ensuring that the oysters are evenly distributed in the middle of the bag when placed back onto the trestle

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of the bag that cannot be reached, by gently poking them with a stick.

Once the bags have been turned and any attached oysters have been dislodged, the bags should be placed back on the trestles and given a light shake to make sure that most of the stock is positioned in the middle of the bag and evenly distributed (Figure 6.25). This will ensure that the oysters are in the optimal position to continue feeding and growing without being unnecessarily restricted by the bag.

Recommended frequency for grading batches or turning bags

Table 6.4 gives three different examples of grading/turning strategies depending on the growing conditions experienced at the farm site. Please note that these are only examples, and that the operator will need to adjust these schedules to suit their individual conditions and circumstances.

To an extent, grading and turning are interchangeable depending on the stocking density of oysters placed into the bag. Each grading operation is simultaneously an efficient turning operation. If the bags are stocked at a low density, then the grading period can be extended, and the oysters can be turned more often instead. Conversely, high density bags will need to be graded more often and, if this is the case, then turning will be done less frequently. Some farms with exceptionally high growth rates will forego turning entirely and just ensure that they grade the oysters on a frequent basis. On other farms, where they have an exposed site and low densities within the bags, it may be possible to turn less often or not at all if the oysters are being moved in the bags by tide and wave action. What is consistent throughout most of the different strategies is that the stock is attended to on a regular basis, being monitored and handled in a way that ensures that the quality and quantity of the product is maximised and any potential issues, including biofouling, predation or other mortality events, are spotted and dealt with quickly and efficiently.

In Table 6.4 the indicated timespan must be considered as the time past from the last grading/turning operation that has been performed.

TABLE 6.4
Grading and oyster bag turning frequency depending on season and growth rates

		Grading	Turning
Fast growing environment (Seed to market size in 12 months)	Summer	Every 4 weeks	Every 2 weeks
	Winter	Every 6 weeks	Every 3 weeks
Average growing environment (Seed to market size in 24 months)	Summer	Every 8–12 weeks	Every 4 weeks
	Winter	Every 12–16 weeks	Every 4–6 weeks
Slow growing environment (Seed to market size in 36 months)	Summer	Every 12 weeks	Every 6–8 weeks
	Winter	Every 16-20 weeks	Every 8–10 weeks

Source: Elaborated by the authors.

Recommended bag mesh size depending on product size

Placing oysters in the bags of the correct mesh size is critical to ensure that no stock is lost whilst maximising the flow of water through the bags. Ideally, oysters should be contained within a bag with the maximum aperture possible to encourage the ingress of nutrient rich water. However, the mesh size must be small enough to prevent oysters from either falling out of the bag or becoming wedged into the mesh and then growing into the bag itself. A balance must therefore be struck between these two factors. It must be the physical size of the oyster that is used to make this judgement and not its weight because the relationship between the two can vary greatly depending on factors such as meat content, shell density and shell shape. For example, a slower growing oyster with a thicker, deeply cupped shell and high meat content will weigh substantially more than the same size of oyster that has grown quickly and has a thin, shallow cupped shell and low meat content. By this logic, some oysters of a similar weight could either be perfectly suited to a particular mesh size whilst others would fall through the gaps. It is therefore the size of the shell that is the crucial factor when deciding on which bag mesh size to use. As the size of the oysters depends on the mesh size of the grill used for grading, the bag mesh size to use will have to be decided according to the mesh size of the grader grill. Thus, it is recommended that the mesh size of the grader grill should be roughly 1.5 times greater than the size of the mesh of the bag that is used to contain it. For very small oysters, the mesh size of the grader grill should be roughly 2–3 times greater than the size of the mesh of the bag.

Table 6.5 shows the relationship between the standard grill sizes of a grader and the corresponding recommended bag mesh size that the oysters should be placed into. It provides a good illustration of how this relationship works. As mentioned above, the average weight of the oysters per grill size can vary so the figures shown in the table are a rough guide.

TABLE 6.5
Correspondences between oyster bag mesh sizes and the grader grill sizes

Bag mesh size (mm)	2	4	6	9	12	14	18	23	23	23
Grader grill size (mm)	6	8	10	12	15	20	25	30	35	40

Source: Elaborated by the authors.

The above-mentioned relationship between grading grill size and bag mesh size is only relevant to grading machines using grills with square openings. For rectangular apertures or other typologies of grills, the relationship must be newly assessed. Section 4.6.2 of this manual gives an overview of commonly used graders.

Recommended densities depending on product size

The density of oysters placed into a bag should always be calculated by working backwards from the anticipated size and weight that they will reach when they are next graded. Oysters loaded into a bag at the start of the fast-growing season will increase in size and weight dramatically in a relatively short amount of time. Exact growth rates will be dependent on the circumstances of the individual site, but the increase in volume of oysters inside the bag will be significant. For example, if the average weight of an individual oyster when it is first placed into the bag is 10 g, and it is anticipated to reach an individual weight of 40 g by the end of the summer, then this represents a fourfold increase in weight. If this is applied across the entire weight of stock in the bag, it means that an initial dosage of 3 kg would result in 12 kg of oysters being contained within the bag at the end of the summer, which is an acceptable result. However, if the operator loaded the bag with 6 kg at the beginning of the growing season, this would potentially produce a bag weighing 24 kg at the end of the summer. This would lead to overcrowding, inducing vastly reduced flow through the bag, and potentially resulting in a reduction in quality and oysters that have grown into the mesh of the bag. It is therefore imperative to understand the growth rates experienced at the farming site and dose the bags with suitable densities to allow for the uplift in size and weight.

There are different approaches to the density of oysters placed in each bag after being graded. Operators can either pursue a strategy of high densities with a more frequent grading schedule or lower densities with a less frequent grading schedule. There are advantages and disadvantages to both approaches and farmers will have to decide which is most suitable to their specific circumstances.

Low density with less frequent grading strategy

This program would be recommended for most farms as it will deliver positive results in the majority of environmental situations and is the easiest to manage. It is also recommended for pre-growing seed from T6 to T12 as previously illustrated in Table 6.3.

Table 6.6 gives details regarding the recommended dosage per bag.

TABLE 6.6
Low density/less frequent grading strategy

	Doses for the summer growing season (*)									
Average weight of oyster (g)	0.15 0.45	0.45 0.80	0.80 2.0	2.0 4.0	4.0 7.0	7.0 15.0	15 25	25 35	35 45	45 55
Weight of oyster/bag (kg)	1.00	1.10	1.20	1.35	1.5	2.0	3.5	5.0	6.0	7.0
Approximate number of oysters/bag	3 350	1 750	850	450	275	210	180	165	150	140

(*) *Note:* These doses are for the summer growing season. Over the winter, when the growth rates have slowed or stopped, the bag dosage can be increased because the rate of expansion is negligible.

Source: Elaborated by the authors.

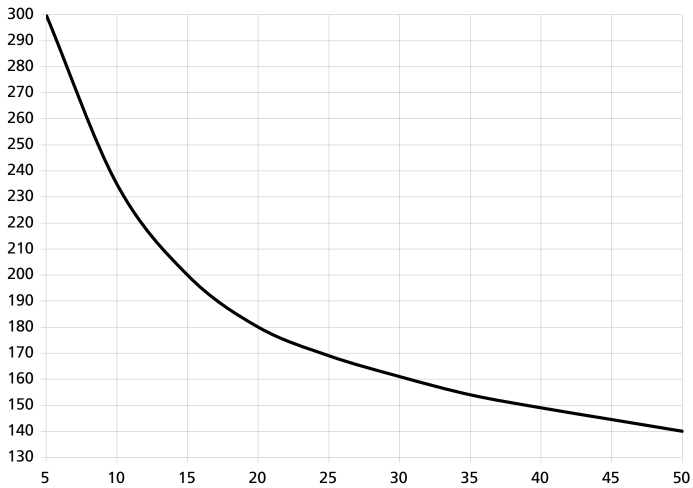
The main advantages are:

- Less movement of the oysters between the growout site and the land-based grading facilities.
- Less handling time as turning the bags is much quicker than grading them.
- Lighter bags are easier to handle.
- Less strain on bags and trestles.
- Less cramped conditions for the oysters to grow in resulting in better water flow through the bags, potentially increasing growth rates.
- Extra space within the bags allows for slippages in the grading schedule.

The main disadvantages are:

- More frequent turning is required between grading.
- More physical area required to reach the desired production output.
- More trestles and bags required per kilogram of oysters therefore increasing capital outlay.
- Increased handling per kilogram of oyster.
- Less frequent removal of predators in the bags.
- Increased build-up of biofouling on the bags.

FIGURE 6.26
Abacus oysters number/bag depending on average oysters weight (g) with low density/less frequent grading strategy



Source: Elaborated by the authors.

High density with frequent grading strategy

This program should only be attempted in areas with high levels of phytoplankton and good water exchange and is not suitable for lower nutrient environments. This is because the increased volume of oysters in each bag will require substantial amounts of food to survive and grow, and in areas with low levels of nutrition and poor water exchange the oysters will either grow very slowly with poor meat content, potentially becoming "runts" or, in the worst-case scenario, mortalities can occur. If used for pre-growing seed from T6 to T12 particular attention should be paid with very frequent grading and turning.

Table 6.7 gives details regarding the recommended dosage per bag. However, in areas with suitable environmental conditions, there can be advantages to this approach:

- By increasing the number of oysters in each bag, it allows the operator to increase the potential production volume of the farm without needing to physically expand the site and increase the number of trestles.
- It also means that the desired production volume can be achieved with less capital outlay on bags and trestles.
- Less bags need to be handled per kg of oysters leading to efficiency gains.
- More frequent grading allows the operator to inspect the stock more regularly and remove any predators from the bags.
- Any "doubles", oysters that have become conjoined, can be separated before the bond becomes too strong.
- Fouled oyster bags can be replaced with clean ones on a more regular basis.

TABLE 6.7
High density/frequent grading strategy

	Doses for the summer growing season [1]									
Average weight of oyster (g)	0.15 0.45	0.45 0.80	0.80 2.0	2.0 4.0	4.0 7.0	7.0 15.0	15 25	25 35	35 45	45 55
Weight of oyster/bag (kg)	2.50	3.00	3.50	4.25	5.50	7.5	10	10	10	10
Approximate number of oysters/bag	8 300	4 800	2 500	1 400	1 000	700	500	330	250	200

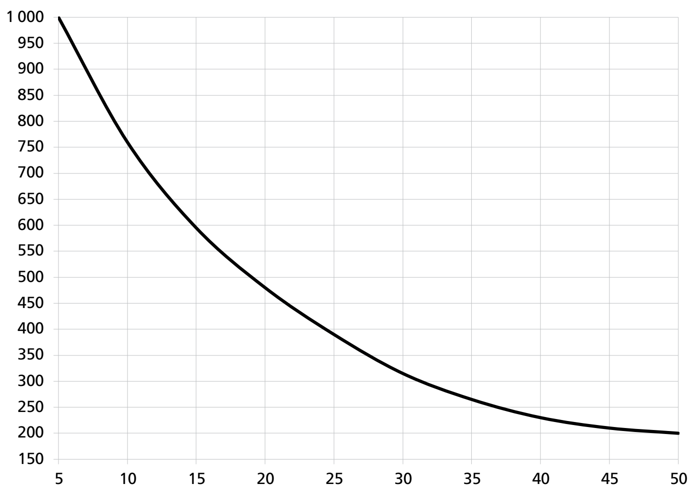
[1] *Note:* These doses are for the summer growing season. Over the winter, when the growth rates have slowed or stopped, the bag dosage can be increased because the rate of expansion is negligible.

Source: Elaborated by the authors.

The main disadvantages apart from the nutritional limitations mentioned above are:

- Grading is a more time-consuming procedure than turning the oysters, especially if the bags are located far away from the land-based processing facilities which increases transportation time.
- Heavier bags are more strenuous to manhandle.
- Increased load can cause the bags and trestles to wear out more quickly leading to quicker depreciation.
- Grading becomes time critical during fast growing periods. If there is some event that prevents the operator from grading the

FIGURE 6.27
Abacus oysters number/bag depending on average oyster weight (g) with high density/frequent grading strategy



Source: Elaborated by the authors.

stock at the necessary time, the bags will become overcrowded very quickly, causing the oysters to grow into the bag mesh and into each other and can cause misshapen shells and potential mortalities. The disruption to the schedule could be caused by issues such as staff shortages, mechanical breakdown of either transport or grading equipment, power supply interruptions or adverse climatic conditions preventing access to the grow-out site.

Recommended position (high or low in the intertidal zone) depending on product size and season

Within the intertidal zone of the production site, there will be areas that are both higher up and lower down in relation to the tidal range. This allows the farmer to utilise these areas for different stock management objectives. For example, oysters held lower down on the foreshore will spend longer time submerged in the water and will therefore be able to feed for extended periods each day thereby increasing their growth rate. This is especially advantageous for seed oysters to assist them to gain size and weight quickly. However, this must be balanced against the restriction to handling time that holding the stock at these deeper positions results in. If these bags are situated at the lower extremity of the tidal range, they will only be exposed for a very limited amount of time and therefore any work that is required to be carried out must be achieved within this restricted timescale. Seed oysters need to be attended to on a regular basis to ensure uniform growth and sustained quality. It is imperative that the operator is meticulous in their husbandry at this early stage, as this will set the precedent for how they will develop for the rest of their growth cycle. Seed that is not turned or graded often enough, when held in fast growing locations low down on the foreshore, can result in conjoined or misshapen oysters with thin, brittle shells. Therefore, if the farmers are going to use these lower positions to increase growth rate, they must also have enough manpower to regularly handle the bags and a strict stock management timetable that must be adhered to.

Positioning larger oysters higher up the foreshore can assist in "hardening" the stock, by acclimatising the organisms to spending time out of the water. This is particularly useful for oysters that are about to be transported to market as the hardening process will allow them to lengthen the time that they are able to remain alive out of the water and therefore extend their shelf life. This is discussed in further detail in Section 2.2.3 for shelf life and Section 4.7.2 for hardening. Prolonging their time out of the water also slows the growth rate; this can be a useful strategy to prevent market size oysters from becoming too big and consequently reducing their commercial value. If the oysters spend more than 35 percent of their time exposed to the air, they will stop growing completely.

Another aspect to be considered when positioning of stock within the intertidal range is exposure to climatic conditions. The environmental circumstances will almost certainly vary from site to site and so, oyster positioning will have to be planned depending on the geographic location of the farm. However, the following will provide a couple of examples of the sort of decisions about bag placement that will have to be made having analysed these factors:

- In locations that experience extreme cold, where freezing conditions may occur, the placement of the bags high up on the foreshore can expose the oysters to the risk of being frozen that may lead to unwanted mortalities. It is therefore advisable that, over the winter months in these locations, the stock should be held as low down as possible so that it is submerged under the water for the maximum period of time available, reducing the exposure to unfavourable freezing conditions.
- On the other extreme, oysters cultivated in areas that experience particularly high temperatures can suffer heat stress if left exposed to the air for extended periods over the hottest part of the day. It is therefore recommended that, in these circumstances, the stock is held low enough down on the foreshore so as not to extend their period of exposure to these high air temperatures.

Bag cleaning

The importance of holding the oysters in clean bags to allow maximum water flow has been discussed in previous chapters. There are various machines that are manufactured specifically to enable this cleaning process. These vary in design with some using high pressure jets of water as seen in Figure 6.28, some using mechanised brushes and others using a hot water bath to ensure that all contaminants are killed off. The operator is advised to research what machines are available in their territory and take advice on which devices would be most suitable to remove the biofouling experienced in their area. However, the simplest solution, if no bag washing machines are available, is to use a standard pressure washer to clean the bags. There will be more manual handling involved in this process than some of the automated machines, but the results will be perfectly acceptable. If possible and depending on the biofouling present in the farm, it is advised to allow the bags to dry out completely over the period of 2–4 weeks before pressure washing. This will ensure that any biofouling has desiccated completely, and it will then be much easier to remove.

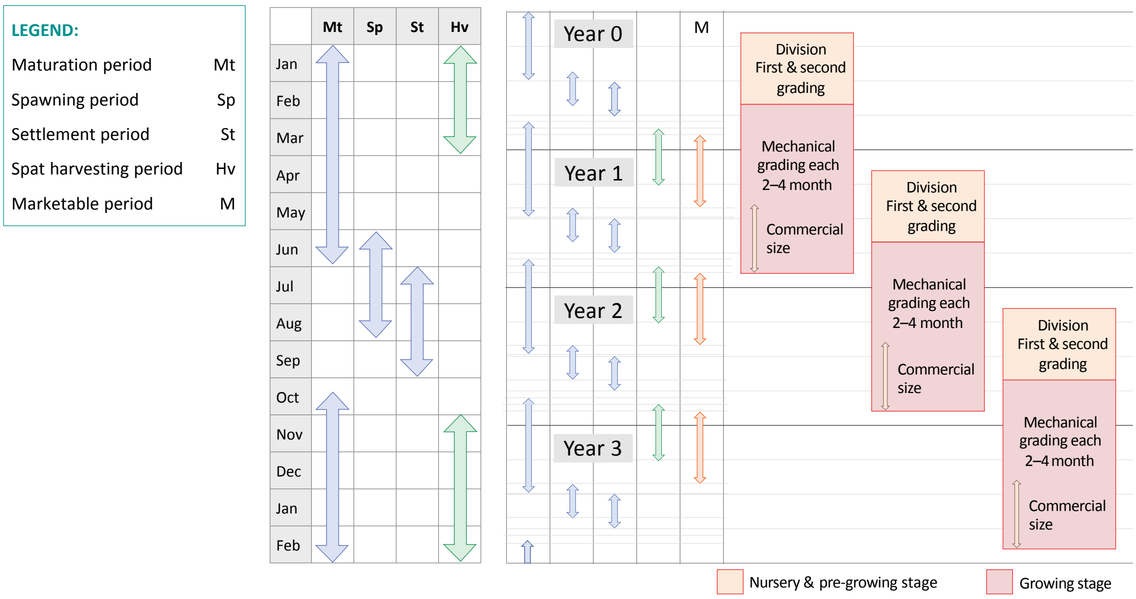
FIGURE 6.28
An example of an oyster bag cleaning machine using high pressure water delivered through a rotating nozzle

©M. Mercer

6.3.3 Farming calendar

The farming calendar refers to the reproduction and settlement timing of cupped oysters in the North Atlantic region as described at Section 2.1 of the present manual.

FIGURE 6.29
On trestle Pacific oyster production cycle and farming schedule in the North Atlantic region



Source: Elaborated by the authors.

6.3.4 Maintenance

There are a number of tasks that the operator should undertake on a regular basis to ensure that all of the equipment used to produce the oysters is maintained to a correct standard. The marine environment is particularly harsh on equipment and so to gain the maximum longevity and safe operation of the cultivation apparatus, regular checks and servicing should be mandatory. Some of the items that should be checked on are listed in Table 6.8 below.

TABLE 6.8
Farming equipment chart featuring daily, weekly, monthly and annual maintenance tasks

Task	Frequency
Workboat/tractor engine checks	Daily – Before use
Freshwater wash-down of equipment	Daily – After use where possible
Greasing	Weekly or monthly – Particular attention should be paid to equipment that is used on a daily basis
Anodes inspection and replacement	Quarterly inspection – Replace anodes as necessary
Servicing the workboat/tractor engine	In line with the manufacturer's guidelines regarding engine hours and usage
Workboat hull inspection and upkeep	Annually – Check hull integrity, apply antifoul, replace anodes as necessary
Bag repair	When required
Recovery of any bags, rubber bands, hooks, closing sticks etc.	When required
Welding of loose bars on trestles	When required

Source: Elaborated by the authors.

Workboat

Daily checks should be undertaken before starting the engines to ensure that the correct coolant and oil levels are present. The engine should be serviced in line with the manufacturer's recommendations.

All the anodes that protect all metallic parts, (propellers, shafts and hull if steel built) should be inspected every trimester and replaced before they have deteriorated to the point of being ineffectual. The hull should be inspected and cleaned, including reapplication of antifoul, when necessary. It is recommended that this should be undertaken on an annual basis. All safety, navigation and lifting equipment should be in good condition and certified by a qualified inspector if the local regulations require this.

Tractor and trailer

Daily checks should be undertaken before starting the engines to ensure that the correct coolant and oil levels are present and that the tyres are at the correct pressure. Tyres should also be checked for excessive wear and replaced when necessary.

The engine should be serviced in line with the manufacturer's recommendations. At the end of each day, the tractor and trailer should be washed down with freshwater to prevent corrosion.

Grading and processing equipment

Any equipment that is exposed to salt water should be washed down with freshwater after use when possible. Even items built of stainless steel can rust in certain conditions although not as swiftly or seriously as regular steel. Equipment with moving parts can get clogged up with debris and salt deposits from activities such as grading so it is recommended that they are cleaned on a regular basis.

Greasing

Regular greasing of any components that require lubrication (tractor/workboat and equipment) should be carried out in line with the manufacturer's recommendations.

Bag repair

Over time, oyster bags can become damaged, with rips appearing in the mesh (Figure 6.30a). If the majority of the bag still maintains its structural integrity, then they can easily be repaired with the use of heavy-duty cable ties (Figure 6.30b). This will extend the life of the bag, ensuring better value for money and reducing the amount of plastic waste created by the farm.

Any bags that are damaged beyond repair should be recycled where possible to lessen the farm's impact on the environment. Some manufacturers are now producing new oyster bags made from recycled plastic from the old ones. Operators should check on the recycling facilities in their local area.

FIGURE 6.30
Repairing the oyster bags with cable ties

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Recovery of any bags, rubber bands, hooks, closing sticks, etc.

Any bag or associated equipment that is displaced from the trestles should be recovered before it can cause a negative impact on the habitat of the production site and neighbouring areas. By design, all the equipment used for oyster cultivation is resistant to breaking down in the marine environment, so if it is not recovered it can cause harm to the other organisms in the ecosystem surrounding the farm. From a stock management perspective, it is also important not to leave any bags on the ground as they can become engulfed by silt which can result in the loss of oysters.

Welding of loose bars on trestles

Any damage to the structure of the trestles could result in bags being displaced so it is important to repair any breakage as soon as possible. The weld that holds the bars together is usually the weak point and can corrode more quickly in the marine environment than the rebar itself. However, due to the simple nature of the construction, the repairs can also be carried out in a straightforward fashion by simply re-welding the components back together. Before welding, thoroughly clean all the metallic parts so that all organic material is removed. As indicated previously, use suitable electrodes.

6.3.5 Monitoring and traceability

Data collection and elaboration

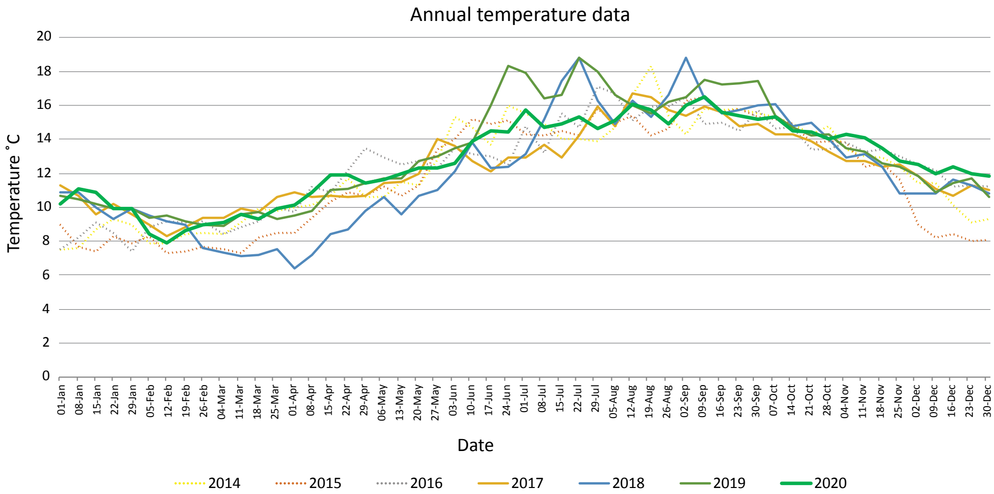
The collection of data on key parameters affecting the growth and development of the shellfish is important. It will help the farmer on how to maximise the production of the farm and work in the most efficient manner. Over several years, having collected data about each growing season, a pattern of stock development can be built up and used to inform the operator about such things as when to purchase seed and how much will be required, when to undertake crucial stock management practices like grading and when different batches of shellfish will be ready for harvesting.

Parameters that can be monitored are:

- Water temperature
- Salinity
- Chlorophyll-α
- Monthly oyster growth rates
- Monthly meat to shell ratio
- Monthly mortality figures

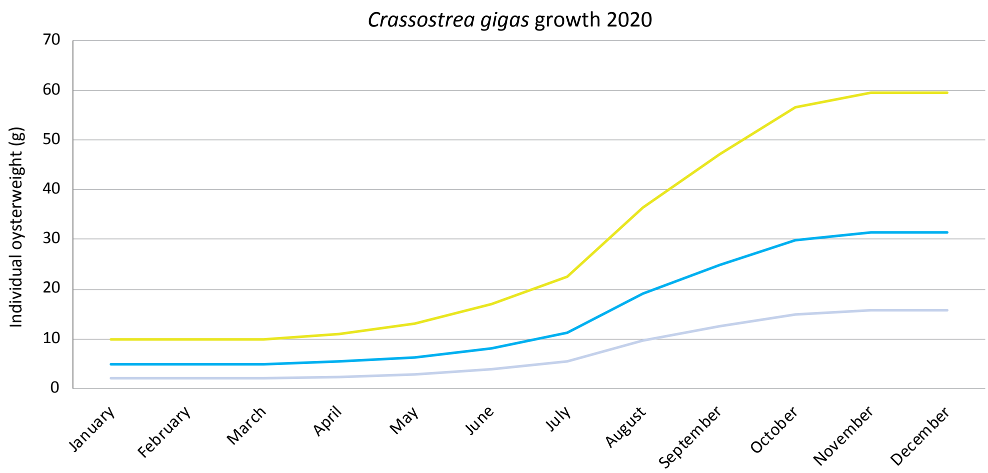
Examples of the sort of data that should be collected are given in Figures 6.31, 6.32 and 6.33.

FIGURE 6.31
Example of annual water temperature data graph



Source: Elaborated by the authors.

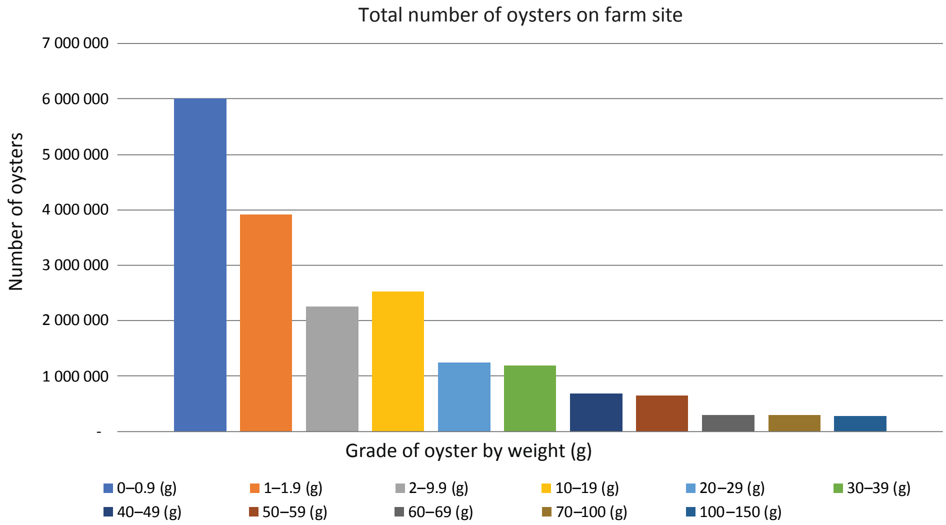
FIGURE 6.32
Example of annual oyster growth rate graph



Source: Elaborated by the authors.

FIGURE 6.33

Example of graph showing the total number of oysters on the farm, divided by weight



Source: Elaborated by the authors.

All of the data that is collected should be recorded in a stock management document so that it can be easily accessed. Stock management charts, as demonstrated in Figure 6.34, are a crucial tool that allows the operator to keep track of the location, numbers and weight of all of the shellfish that are in production and what action needs to be undertaken at each stage of the season. The example shown was created using Microsoft Excel, but there are now specific software packages commercially available designed to be used by shellfish production businesses.

FIGURE 6.34

Example of Pacific oyster stock management chart illustrating some of the important data to be recorded

Trestle site zone	Row No.	Seed batch	Seed type	Date bag filled	Colour jonc	Bag mesh size (mm)	No. of bags	Activity Record	Initial average weight of oyster (g)	No. of oyster per bag	No. of oysters per row	Initial weight of bag (Kg)	Initial total stock weight (Kg)
A	1	Aug-14	Dip	03.04.16	Green	18	50	Turned 24.05.16	85.3	129	6 448	11	550
A	2	Aug-14	Dip	14.04.16	Pink	18	46	Turned 18.05.16	101.6	108	4 980	11	506
A	3	Apr-16	Trip	05.07.16	White	6	45	Graded 05.07.16	0.7	2 857	128 571	2	90
A	4	Apr-16	Trip	05.07.16	Blue	9	38	Graded 05.07.16	0.9	2 444	92 889	2.2	83
A	5	Jun-15	Trip	19.02.16	Blue	9	50	Turned 18.04.16	3.6	611	30 556	2.2	110

Source: Elaborated by the authors.

Sample bags

Sample bags are a useful reference for the farmer, to give an indication of how the oysters are progressing during their growth cycle. The bags contain a predetermined number of oysters and are monitored monthly. Their main purpose is to be an indicator of growth rate and mortality rate for the rest of the stock. There will evidently be variation throughout the many bags across the farm, but these sample bags will provide a snapshot of the general condition of the oysters. The data collected from them each season allows the farmer to build up a picture of the growth and mortality rates at different areas of the farm. This is a useful management tool when making decisions about issues such as:

- When is the best time to introduce seed?
- When will most of the oysters be ready to harvest?
- How often should the oysters be graded and at what point in the season?
- Are there areas that have faster/slower growth rates that can be used to engender different outcomes for specific groups of stock? For example, faster growth to develop the seed more quickly into juveniles or slower growth to encourage thicker shell growth.
- Are there areas to be avoided due to higher mortality rates?

As growing conditions can vary quite considerably throughout an oyster production site, it is important to have enough of these sample bags placed in strategic positions around the farm to ensure that they are as representative as possible of the rest of the oysters. The quantity of oysters in each sample bag should also be similar to the bags that they are representing as the density will have an effect on growth rates. For example, if the sample bag has considerably more oysters inside it than the stock it was purporting to depict, the growth rates recorded would likely be slower due to higher competition for food and potentially lesser flow rate through the bag.

During the trial period of the site, and for the first few years of production, it is recommended to collect as much data as possible as this will form the foundation of the knowledge required to formulate an efficient and productive management strategy. It is advisable to continue to use sample bags as an on-going monitoring tool each production season, although it may be possible to reduce the number of these bags once a more comprehensive understanding of the farm site has been established.

6.4 MAIN CONSTRAINTS

6.4.1 Environmental constraints

Intertidal and nearshore sites, such as the locations necessary for trestle cultivation, are by their nature highly impacted by environmental influences issuing from the land next to which they are situated. There are a number of different factors that must be considered when discussing these issues:

Salinity

Due to the proximity of freshwater sources such as rivers, the salinity of these sites can vary substantially depending on seasonal rainfall patterns and its influence on fluvial discharge and run-off from the land. If the flow of freshwater into an estuarine or nearshore environment increases, the salinity levels will decrease. Salinity is one of the main factors that influence the filtration rate of oysters and, in usual circumstances, the lower the salinity, the slower the oysters' filtration rate. This can in turn lead to a potential reduction in growth rate if this scenario continues over an extended period. As freshwater enters the watercourse, it does not immediately mix with the saltwater which can cause stratification. Freshwater is less dense than saltwater and therefore naturally floats on top of the denser seawater. The mixing between the two different water types is influenced by tidal range and flow, wind speed and direction, bathymetry and fluvial flow rate. In extreme circumstances, a wedge can form with the freshwater held at the top of the water column whilst very little mixing between the two water bodies occurs. If these conditions persist for long enough, whereby the oysters are situated in this freshwater wedge for an extended period, it can result in mortalities due to the dramatic drop in salinity to below their tolerable range.

Water quality

Water quality is impacted by the number of contaminants that enter the marine environment. These contaminants can come from many sources such as sewage overflows, run-off from agriculture, outflows from industrial plants, mining activities in the coastal region and pollutants dumped into the water by other marine users. Depending on the nature of the contaminant, it can affect the water quality in different ways. For example, sewage overflow and run-off from farming activities that involve the use of animal faeces will raise the level of *Escherichia coli* bacteria in the water. This can cause health issues in humans that consume bivalves that have been filtering this contaminated water. It can also cause the production areas to be either temporarily or permanently shut down for the harvest of bivalves if the local authority that monitors these factors deems product harvested from the area unfit for human consumption (Section 2.3 and Appendix I). As bivalves are filter feeders, they are particularly affected by any form of contamination in the water so an awareness of any possible pollution sources around the farm and a management plan to deal with such incidences is imperative.

Eutrophication

Eutrophication describes the process when a body of water becomes enriched with an excessive amount of nutrients, resulting in an unnatural abundance of algae and marine plants. As these organisms die and decompose, the bacteria that feed on them consume oxygen and release carbon dioxide, causing the water to become hypoxic. Marine creatures, including bivalve molluscs, need the dissolved oxygen in water to survive so when it is depleted to critical levels it can cause mass mortality in organisms that are situated in the affected zone. The carbon dioxide also lowers the pH leading to acidification of the water. Amongst other consequences for the wider marine environment, this can have a negative impact on the growth rate, but also on the reproduction, larval development, settlement and shell formation of the oysters.

6.4.2 Conflicts for site availability and licensing

Areas of coastal foreshore and nearshore marine zones can be of use to many diverse stakeholders besides aquaculture production businesses. These can take many forms but include such things as moorings for pleasure craft, tourism, residents, property developers, marine protected zones, sewage treatment discharge outlets and boatyards. Many of these interested parties have completely different priorities when it comes to the use of the available space and, as such, conflicts of interest can occur. As competition for space is fierce in these highly desirable areas, it can be difficult to secure bivalve cultivation licences, especially if it interferes with an already established activity in the relevant location. It is important to engage with not only the pertinent licensing authorities, but also the other local stakeholders, to see if a compromise can be negotiated to allow these diverse activities to exist in harmony.

7. Bottom cultivation in the intertidal or subtidal zone

INTRODUCTION

Bottom cultivation means that the oysters are grown loose on the seabed or fundus. They are sown directly onto the ground and are not enclosed by any form of bag, basket or cage as can be seen in Figure 7.1. It is the simplest form of oyster farming, requiring

FIGURE 7.1
Oysters at low tide on an intertidal bed in the Helford River, Cornwall, United Kingdom of Great Britain and Northern Ireland

the least amount of equipment and husbandry techniques. It also most closely replicates the conditions in which oysters naturally grow and has been practised by humans for thousands of years. By sowing oysters onto predefined areas, known as oyster "beds", the farmer is essentially creating a manmade oyster reef, imitating the natural structures that oysters create when they settle and cluster together on the seabed. The low-tech nature of this cultivation system means that it is the simplest to set up and manage. However, the relative lack of control over the stock and its exposure to predation and environmental factors means that the mortality rate is higher than in other techniques and therefore a higher input of seed oysters is required to yield the desired amount of market size product. It is possible to lay and harvest oysters by hand, but this chapter of the manual focuses mainly on the equipment and practices required to undertake bottom cultivation using a boat in both the subtidal and intertidal zones.

7.1 SITE SELECTION

7.1.1 Water depth and tidal range

Oyster beds should be situated in either intertidal or relatively shallow subtidal locations (<15 m). Below the depth of 15 m, the process of dredging becomes more challenging and inefficient. Also, below this depth, the availability of phytoplankton can decrease as there is less sunlight penetration which is an essential element that these organisms need to live, grow and reproduce. A reduction in this vital food source results in slower growth rates and a reduction in the quality of meat that the oyster produces. There will be areas where turbidity is very minimal and therefore light penetration will allow suitable levels of phytoplankton to exist at greater depths. However, under average conditions the 15 m depth guide is a suitable reference point. There are merits and constraints associated with subtidal or intertidal sites, but both can produce favourable results.

The main benefit of subtidal beds is that the stock is permanently submerged and can therefore filter feed continuously, encouraging faster growth that will allow the oysters to reach a marketable size in a shorter period of time. This is obviously advantageous in terms of cash flow, as a financial return can be gained more rapidly, but it is also beneficial in terms of exposure to risk from potential mortality events. It stands to reason that the longer the oysters are left in this exposed environment, the more likely it is that some negative event may occur that will diminish the final numbers that are harvested. When you consider that, depending on conditions, it takes between 18–36 months to produce a market size oyster, a lot of time and effort is necessary to replenish any stock that is lost through mortality. Therefore, a location that encourages a faster production time reduces vulnerability to these inherent risk factors. However, because the oysters are never exposed to the air, they do not have the need to close their shells on a regular basis, resulting in weaker adductor muscles. This will affect their ability to withstand prolonged periods out of the water which, in turn, leads to a shorter shelf life, an important consideration for oysters that are sold in the shell. They also have a reduced capacity to survive attacks by predators that wish to prise open their shells. Due to the faster growth rate, their shells are generally thinner and weaker which can also affect their resistance to predation and their ability to withstand processes such as dredging and grading. Oysters grown on intertidal beds, that are regularly exposed to the elements, develop extremely strong adductor muscles and thicker shells and can therefore maintain themselves out of the water for a greater length of time, ensuring a superior quality product for longer. The process of exposing the oysters to the air is known as "hardening" and is discussed further in Chapter 4. Having a site where both subtidal and intertidal cultivation can be performed in close proximity can be advantageous.

7.1.2 Structure of seabed

Because the oysters are lying directly on the seabed or fundus, ensuring that they are deposited onto the correct substrate is a crucial factor in determining the success of an oyster bed. Suitable substrate is important for oysters that are being brought in from hatcheries and sown onto the seabed. It is also important for encouraging natural spat settlement from native stocks that already exist in the environment.

There are many different types of substrates that exist in the marine environment but only some are suitable for oyster cultivation. Oysters need a relatively firm surface on which to exist so that they can rest on top of the seabed, allowing them to remain in a suitable position to filter feed nutrients from the water column. If the seabed is too soft, the oysters will sink into the fundus over a period of time, which will prevent them from feeding successfully and eventually will result in suffocation as they are fully covered by sediment. Also, the oysters will syphon in particles of silt that will eventually block their gills which will lead to mortality. Consequently, seabed that primarily consists of deep mud and silt is not suitable.

The risk of siltation of suitable oyster beds caused by runoff from land-based development and intensive agriculture is a major problem in the estuarine environment and must be considered when choosing the site. When siltation occurs, if the substrate below the layer of silt is suitable for oyster farming, then it is possible to restore these beds by dredging and raking. Usually, these interventions are subject to the correct permissions being granted by the local relevant authority. If siltation events are expected to be frequent the site should be rejected.

The best ground for oyster beds consists of a mix of gravel, pebbles, sand and old shells as can be seen in Figure 7.2. Not only does this provide a firm, supportive surface for the bivalves to sit on, it also presents the oyster spat with a suitable surface on which to settle. Cultch (old shell) is widely used as a successful settlement medium and its application for this purpose is discussed further in Section 7.3.

Oysters also naturally recruit onto rocky ground and will happily thrive in this environment (Figure 7.3). However, if the harvesting of the stock

FIGURE 7.2
Examples of some suitable substrates for oyster beds
(a) Small pebbles and gravel on sand. (b) Firm sandy bottom. (c) Old shells

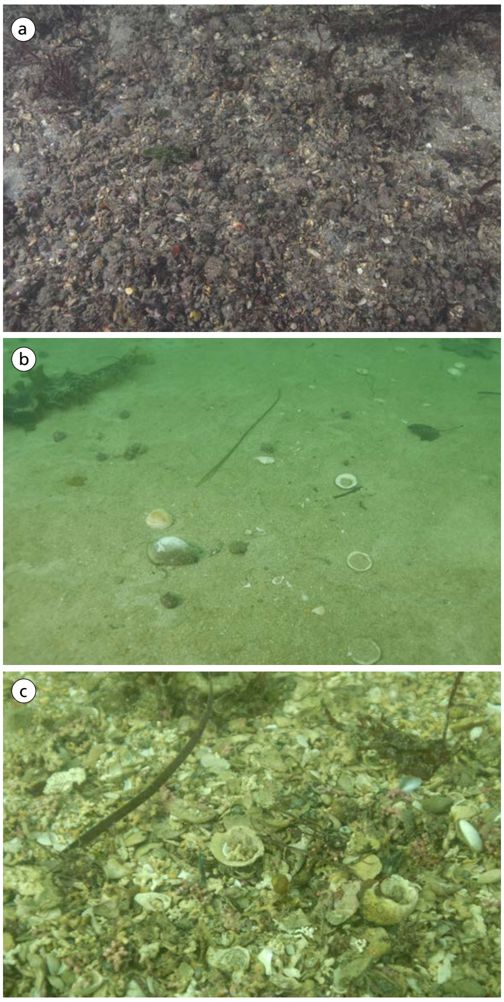


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FIGURE 7.3
***Crassostrea gigas* oyster settled on rocky ground**

©A. Ford

is going to be undertaken by dredge, then this type of seabed will not be appropriate because the dredges will either become entangled or merely bounce over the oyster stock in the area being harvested.

7.1.3 Tidal flow and fluvial currents

Where the oyster beds are situated in relation to the tidal flow and fluvial currents of the area, will determine not only the amount of nutrients that is available to the oysters, but also the salinity levels present in the water as fresh and saltwater mix. They will also influence the water temperature and dissolved oxygen levels. All these factors combined have an effect on the growth rate and quality of the traded product.

There is no exact equation that can be applied to the perfect site for a cultivation bed in relation to these factors. However, a good flow of water passing the oysters provides them with a constant replenishment of their food source and reduces some of the impacts of eutrophication, including hypoxia. It also assists in the removal of faecal matter and pseudofaeces from the oysters themselves which can otherwise build up on the oyster beds. The effects of Harmful Algal Blooms (HAB's) caused by eutrophication and hypoxia are discussed in more detail in Section 3.2 of this manual.

On the other extreme, excessive tidal flows can limit the ability of the oysters to successfully filter nutrients from the water column. The oysters find it difficult to feed as the phytoplankton speeds past them in the fast moving current. This in turn leads to a reduction in growth rate. A tidal flow of somewhere between 0.2 and 2 knots (10–100 cm per second) will provide the oysters with a suitable environment in which to feed and grow.

7.1.4 Exposure to wave action

Subtidal beds are largely unaffected by wave action as they are below the main dynamic energy of the waves. Intertidal beds, by their nature, are more prone to the effect of wave action especially in exposed coastal sites. This is especially true of sites where the prevailing wind direction blows onto the shoreline. As the tide rises and falls over the bed, the waves can break directly onto the exposed oysters. This can cause damage to their shells which can leave them exposed to predation and unable to maintain seawater within their shells when out of the water. Both issues can lead to mortality.

The repeated impact of the waves and the resulting high energy movement of water in the breaking zone can also lead to the oysters being displaced from the beds. They may then end up in areas of the foreshore that are not accessible for the dredging vessel and will therefore require recovery by hand which is less efficient. Sites that are exposed to this sort of dynamic sea state can also be very difficult for dredging vessels to operate on. Not only can there be a risk to the safety of the crew of the workboat, but there is also the possibility of damage to the vessel itself. Operation of the deck equipment, dredging and the recovery of the dredges on-board can become very difficult if the wave height is too great. The ideal location for an oyster bed is therefore in protected bays and estuaries that are not exposed to the forces of breaking waves.

7.2 FARM DESIGN

7.2.1 Farming beds

Once a suitable area of ground has been identified for the oyster beds, there are three main actions to be undertaken before any stock can be sown onto the seabed: mapping and marking the beds, preparation of the ground and the removal of predators.

Mapping and demarcation of the oyster beds

The beds can be mapped and marked using both electronic and physical navigational aids. This not only allows the farmer to know exactly where the oysters have been laid, but also serves to inform other water users to be careful when navigating the area and where to avoid anchoring. The issue of other vessels anchoring on oyster beds can be a significant problem. When a boat lay anchor it will generally do so using a chain, which measures 4 times the maximum water depth. For example, a vessel anchoring in 10 m of water will deploy 40 m of anchor chain. As the tide ebbs and floods, the boat will swing around the point where the anchor was dropped, sweeping the chain across the seabed in a circular motion. Oysters can therefore suffer damage, not only directly where the anchor was dropped, but also on the ground where the chain is dragged over. Having clearly marked oyster beds, both physically and on electronic charts, can help warn other water users about the crop that lies beneath them and will discourage them from anchoring in these areas.

Physical oyster bed markers

Markers can come in different forms, but the two main ones used are navigational buoys and wooden or metal poles. Navigational buoys are deployed around the perimeter of the oyster beds and will usually have signage warning of the product on the seabed. The signs will contain text such as: "Oyster Beds - No anchoring" or something similar (Figure 7.4a). Another method of marking the beds is the use of wooden or metal poles that are driven into the ground on the outer extremities of the beds. They need to be long enough that they are still exposed at the top of the highest astronomical tide and can also often have signage attached to them. If there is other oyster aquaculture equipment such as submerged cages in the same zone as the beds that could be a hazard to navigation, then buoys known as "Special Marks" are deployed (Figure 7.4 b). These are an internationally recognised marker and are always coloured yellow, often having either a yellow flashing light or a yellow "X" on a pole above the buoy. Figure 7.5 shows a workboat dredging an oyster bed within the area indicated by navigational markers.

FIGURE 7.4
Navigational markers
(a) Navigational markers indicating that there are oyster beds on the seabed. (b) "Special Mark" navigational buoy

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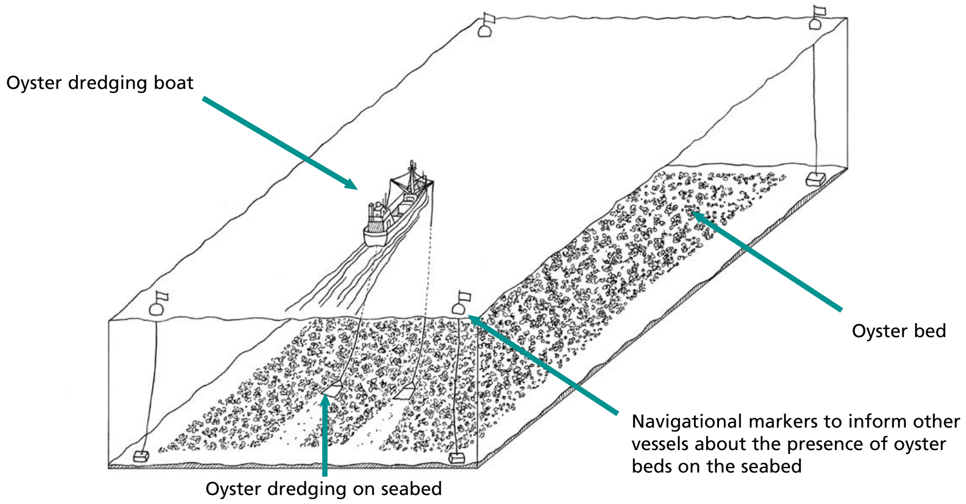
FIGURE 7.5
Illustration of workboat dredging for oysters. The bed is marked by navigational buoys situated at the four corners of the production zone



Source: Elaborated by the authors.

Electronic navigational aids

Electronic navigational aids use Global Positioning System (GPS) coordinates to pinpoint a position on the earth's surface. It is possible to use navigational instruments such as Chart Plotters to precisely mark out the areas on which oysters are sown (Figures 7.6 and 7.7). Oyster farm operators should inform the local navigational authority about the position of their oyster beds. These can be included on the electronic charts that are used by other vessels and can therefore warn other water users that there are oysters on the seabed in a given area. Usually, the communication of the geographical coordinates of the farm and of the markers used is part of the licensing procedure.

When re-laying or harvesting the stock, it also allows the boat skipper to know precisely where they need to be and to ensure that no oysters are missed. Some

FIGURE 7.6
Electronic chart plotter showing position of oyster beds (black, shaded areas) within an estuary

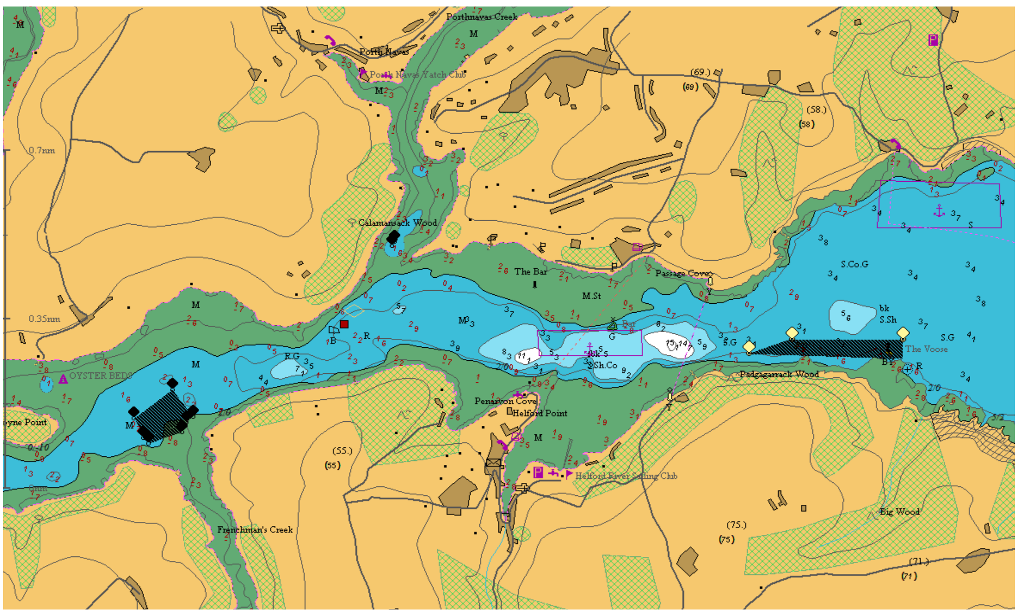


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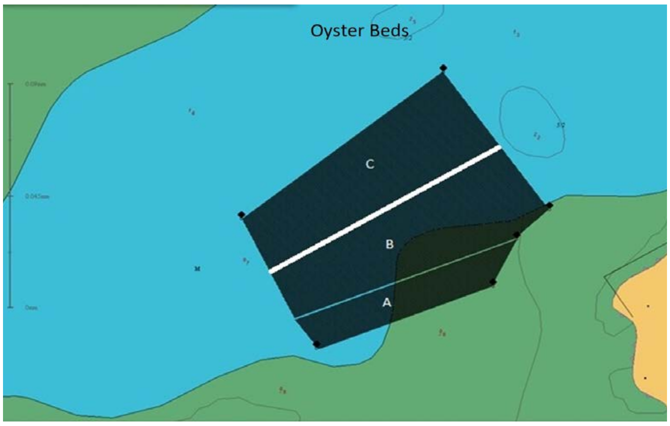
FIGURE 7.7
Electronic chart showing detail of oyster beds separated into 3 different zones



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systems will show a "Track", which is an electronically generated line on the chart plotter indicating exactly which course the boat has taken when moving over the oyster beds. The skipper can refer to these "Tracks" to ensure that no ground has been missed and therefore minimise the oysters left behind after dredging.

Preparation of the fundus

Before laying any oysters onto the beds, it is important to ensure that the ground is in the best possible condition to allow the oysters to thrive. If the ground has not been used for oyster beds previously, then it is likely that there will be a build-up of general marine debris, seaweed and possibly excessive sediment. It is recommended to survey the intertidal beds at low tide to assess the necessary action required to be undertaken in order to clear the beds prior to sowing. Any debris, such as old tyres, tree branches, plastic bags or other such items, should be removed by hand as they will interfere with the dredges and impede efficient use of the beds. It is also worth noting any areas of particularly soft ground where sedimentation has occurred. When undertaking this survey, it is a good idea to take a handheld GPS unit so that any areas of concern can be logged. Subtidal beds will need to be surveyed by diving on them and any bulky debris removed using lift bags that can be collected at the surface by a boat.

Once any larger impediments have been removed from the beds, it is now possible to deploy the dredges to remove any excess sediment from the fundus by repeatedly crisscrossing the bed. It is important to make sure that the dredges are open when undertaking this job so that the dredges are able to disturb the sediment without getting clogged and full of mud. This technique is only possible with dredges equipped with nets that can be unlocked and left in an open position. It is best to complete this process on an outgoing tide, so that the suspended matter is dispersed by the tidal flow. The technique of dredging is discussed in much greater detail in Section 7.3.3 of this chapter. Excess sediment is a particular issue in areas where there is agricultural activity bordering the area of the beds. The soil that has been disturbed by land-based farming processes can be washed into the water course by heavy rainfall and build up on the fundus of the oyster beds.

Removal of predators

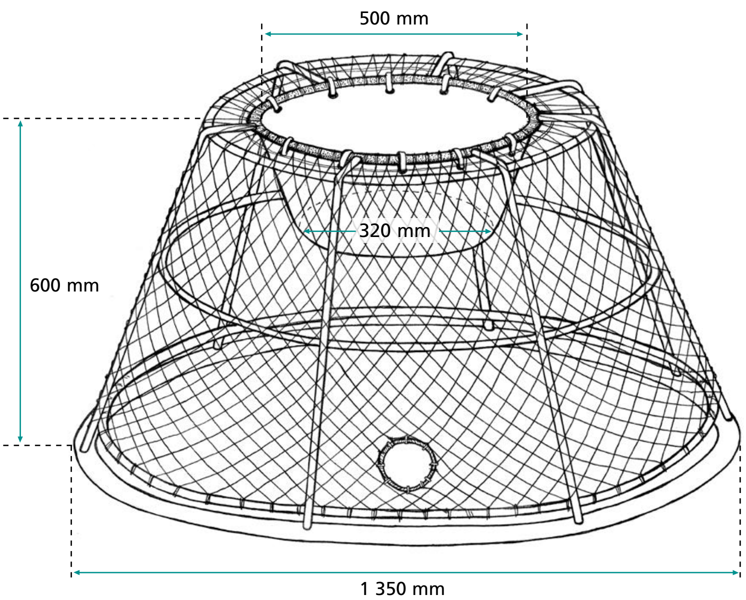
It is impossible to eliminate all causes of predation from an oyster bed due to their exposed nature. However, it is wise to limit the number of potential predators in the area and thus limit the number of mortalities that they can cause. Bear in mind that, by laying large amounts of oysters onto a relatively compact area, it will undoubtedly attract unwanted attention from animals that feed on them, so the operation of removal should be an ongoing process throughout the cultivation cycle. The aim of this process of removal is not to completely decimate the number of predators, as it is important to maintain a thriving and balanced ecosystem around the oyster beds. The goal is just to limit the numbers so that mortalities do not cause the bed to become unviable. There is a comprehensive list of oyster predators in Table 2.4 of Section 2.1.4, while in this section the manual will describe the techniques required to remove two of the most voracious: crabs and starfish.

Crabs

The best way to remove crabs from the area of the oyster beds is by deploying crab pots around the periphery. Pots should be baited with crushed oysters or waste products from fish processing and distributed along a continuous line around the beds. They should then be recovered by boat on a regular basis, every few days (Figure 7.8). The reduction in crab numbers will decrease mortalities and, depending on the type of crab that is caught, could provide another income stream if they are of commercial value. If there are many crabs present initially, then this process can be done every few hours to reduce the population. Figure 7.9 shows an example of a widely used design for a crab pot used commercially and for this purpose.

FIGURE 7.8
Crab pot being hauled from area around the oyster beds

FIGURE 7.9
Typical crab pot design



Source: Elaborated by the authors.

Starfish

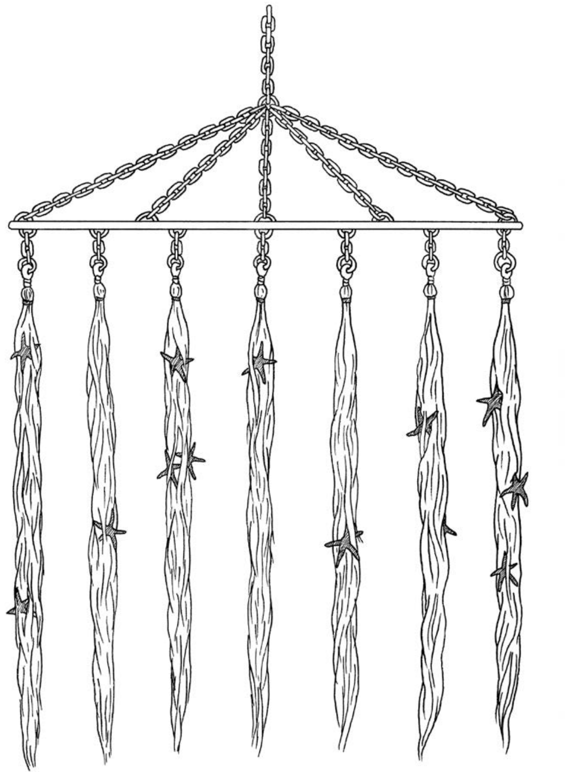
Starfish can also be removed using pots or traps in a similar fashion to crabs. However, the most efficient means of removal is by using a piece of equipment known as a starfish mop (sometimes referred to as a Faubert mop). Usually, the apparatus is made up of a triangular metal frame, like the front end of a dredge, with several mops attached to it (Figure 7.10). These mops, that are usually made up of frayed rope material, are trailed across the seabed in a similar fashion to dredging. As they traverse the oyster beds, the starfish become entangled in the fabric of the mops and can then be raised to the surface and deposited into containers on-board the workboat.

7.2.2 Farm layout

Each farming area will have its own unique set of factors that will determine how the beds will be laid out to maximise the production potential. There will be areas that will be better for encouraging fast growth but not necessarily good for fattening the oysters to obtain a product with a superior meat to shell ratio. Some beds will be intertidal and some subtidal which will have an effect on growth rates and on their shelf life when removed from the water. Oysters should be placed onto the beds that are most suitable for attaining the desired result, whether that be encouraging seed oysters to grow quickly or fattening larger oysters to prepare them for market. When designing the layout of the farm these different farming strategies should be considered.

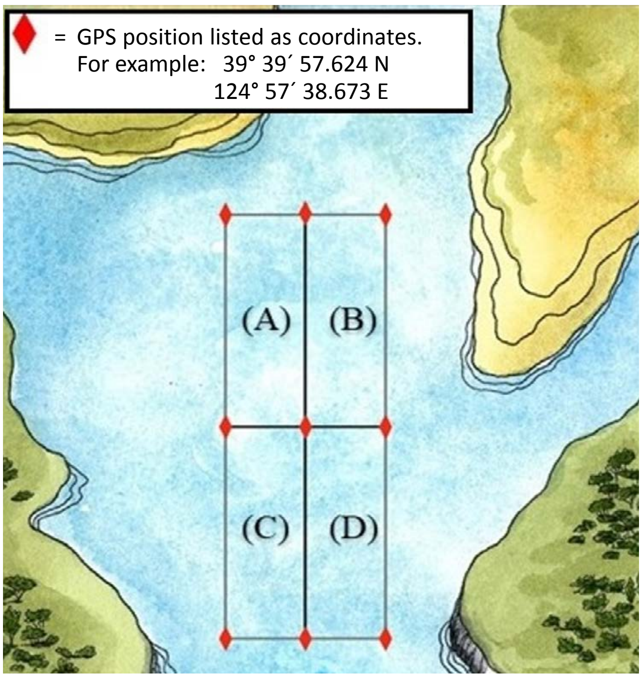
Another important aspect to consider when designing the layout is dividing the beds into different areas so that oysters of different sizes can be laid onto them at different times of the year. If the farmer wishes to harvest oysters throughout much of the year, then this strategy will allow the operator to harvest stock that has attained market size from one area without disturbing smaller stocks that were laid later in the year and that can be left to grow further. It is a more efficient way of harvesting because it prevents dredging up a proportion of oysters that will then have to be re-laid back onto the beds. For example, a farmer has four beds A, B, C and D as seen in Figure 7.11. He lays 20 g oysters onto each bed at different times of the year: bed A – January, bed B – April, bed C – July, bed D – October. Under standard growing conditions, beds A and B would be ready to be harvested during the late summer and early Autumn, while beds C and D would be harvested during the following season. Having the stock separated in this way prevents double handling and targeted harvesting ensuring the most efficient use of bed space.

FIGURE 7.10
Starfish mop



Source: Elaborated by the authors.

FIGURE 7.11
Oyster bed subdivided into different areas with GPS coordinates
Small oysters are laid onto the beds (A), (B), (C) and (D) at different times of the year, thereby allowing the stock to reach marketable size at staggered points throughout the growing season



Source: Elaborated by the authors.

7.2.3 Access to the farm

Tractor or alternate 4-wheel drive vehicle

It is possible to use a tractor and trailer to access and work on oyster beds that are intertidal, arriving as the tide ebbs and working over the low tide until the water floods back in and covers the oysters. The trailer should be of a suitable size and sturdy construction to be able to safely carry the weight of oysters that are deposited onto it. If the beds are located in an area where access requires crossing a foreshore that has a soft substrate, then it is recommended to fit wider tyres to prevent the trailer from becoming stuck. Some trailers will also be fitted with a crane to assist in the handling of containers, into which the oysters have been deposited.

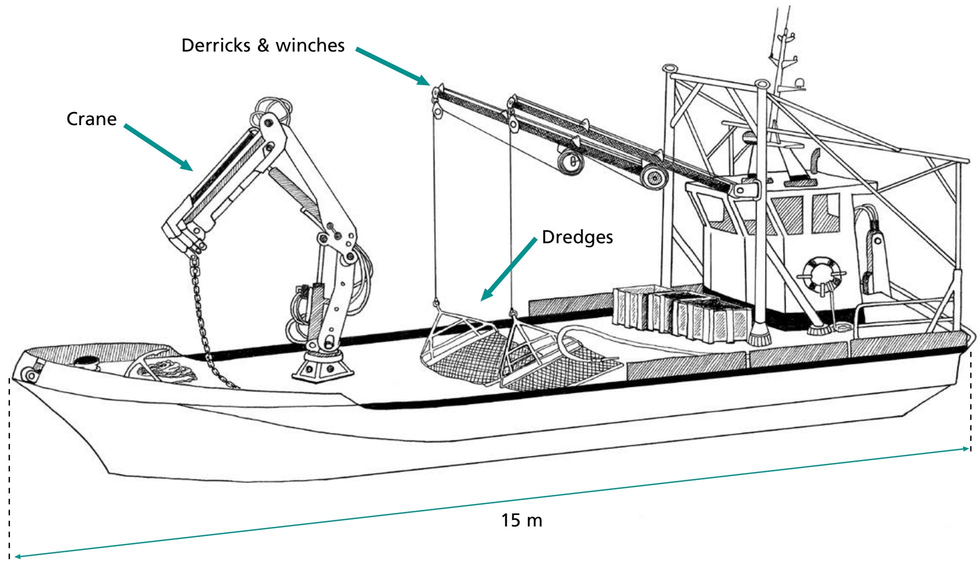
Workboat and basic on-board equipment

The workboat or dredging vessel is at the centre of the farming operation. It is therefore vital that the chosen vessel is of a suitable design and size to match the desired production volume and location of the farm. The workboat is effectively the "tractor of the sea" so, as well as having some very specific functions such as dredging, it will be needed for the accomplishment of a multitude of diverse tasks. When thinking about the design, it is therefore important to incorporate a degree of flexibility into the layout and functionality. The vessel that is used as an example of a representative workboat in this section of the manual, displays the main features that are required to operate efficiently in the environment of oyster beds. It is 15 m long and 5 m wide. However, there are many different variations in design available and the farm operator should ensure that their chosen vessel fulfils the requirement of their site. The example vessel that is described in detail in the following sections (Figures 7.12 and 7.13) demonstrates the desired features necessary for working on a medium- to large-scale of production (> 50 tonnes annually). For small-scale production using hand dredges for harvesting, many of the features listed below will be unnecessary and the size of the boat can be scaled down to match the size of the operation. Dredging using hand dredges can be achieved using a vessel as small as 4 metres in length and powered by a 10 HP outboard motor. Figure 7.14 shows 2 examples of small workboats.

However, the main features of the ideal workboat for medium to large scale production are as follows:

FIGURE 7.12

Drawing of workboat used for farming oyster beds featuring dredges deployed from derricks and a crane for loading and unloading oysters and equipment



Source: Elaborated by the authors.

FIGURE 7.13
Oyster workboat with derricks to deploy dredges, crane and box tipper for laying oysters onto beds

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FIGURE 7.14
Examples of small oyster workboats with shallow draft and open deck space

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Shallow draft
The "draft" or "draught" of a ship's hull is the vertical distance between the waterline and the bottom of the hull (keel). The draught of the vessel is the maximum depth of any part of the vessel. Draft determines the minimum depth of water a ship or boat can safely navigate.

Typically, the workboat will be operating in intertidal or relatively shallow subtidal zones. As the tide ebbs, the depth of water over the beds decreases, disappearing completely in the intertidal zone and becoming shallower in the subtidal zone. Tidal range varies significantly across the globe. In extreme circumstances it can be as much as 16 m or as little as 0.1 m, but in more usual conditions it will be in the 1–6 m range. Due to this variation in depth in locations that are affected by tidal movement, the vessel will only be able to operate over the oyster beds when the tide is sufficiently high. To maximise available working time, it is therefore advantageous to have a vessel with a relatively shallow draft of 1 m or less so that it can access the beds during the largest tidal window (Figure 7.15).

FIGURE 7.15
Vessel with shallow draft

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Hull shape

One way of minimising the draft is to design the hull with a flat bottom (Figure 7.16). Not only does this allow the vessel to operate in shallow depths, but it also allows it to be dried out on the beds or foreshore without the boat tipping over. This allows it to be moored comfortably in locations where the water completely recedes and is also useful when loading and unloading equipment and oysters when the tide is out, as the deck will remain relatively horizontal depending on the ground below it. The same shallow draft and stability can also be achieved using multihull and pontoon style hulls.

Flat hulls are also more stable when operating in calm waters so will provide a better working platform on deck under these conditions. However, in choppy conditions, flat-bottomed vessels become less stable than traditional rounded or V-shaped hulls, so it is important to tailor the vessel's design to the particular environment in which the beds are located.

FIGURE 7.16
Flat bottom hull shape

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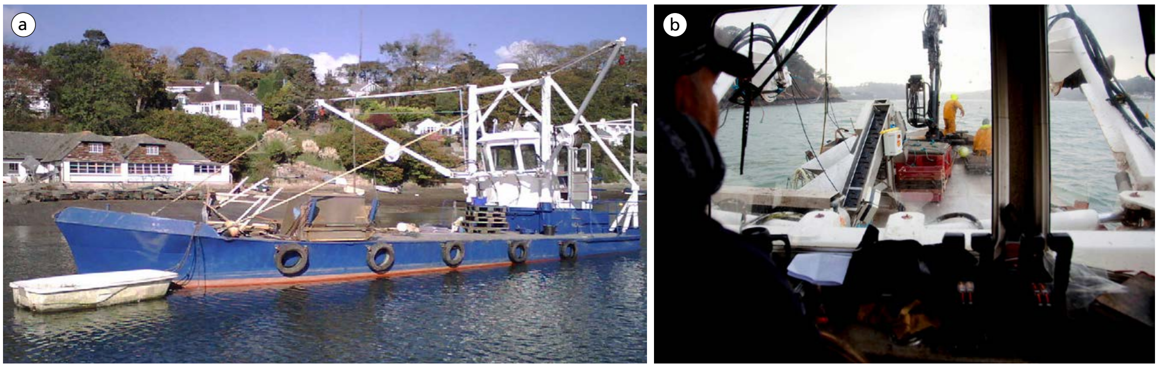
Deck space

Due to the multiple tasks that the workboat must accomplish, an adaptable deck space is imperative. Generally, a flat, open deck is recommended so that it can be configured easily to suit the task that is needed to be achieved, whether that is dredging, grading, moving equipment or transporting oysters (Figure 7.17).

FIGURE 7.17

Deck space examples

(a) Flat, open deck space on workboat. (b) Deck space reconfigured to accommodate grading equipment



Derricks and winches

A derrick is a metal arm that pivots out from the vessel and is equipped with the winch needed to deploy and recover the dredges (Figure 7.18a). The winch cable will need to be of a suitable length to allow the dredges to be deployed in the maximum depth experienced over the beds. Generally, there will be two derricks on board, one on each side of the vessel. It is possible to have four on the larger workboats, two shorter and two longer, allowing the deployment of four dredges at a time. Both the derricks and the winches are operated by hydraulic power with control levers situated in the wheelhouse for the skipper to use (Figure 7.18b). The control levers are situated in pairs, Port and Starboard, so that both winches or both derricks can be controlled simultaneously.

FIGURE 7.18

Oyster workboat lifting equipment

(a) Derrick with hydraulic winch attached. (b) Control levers for the derricks and winches in wheelhouse

Crane

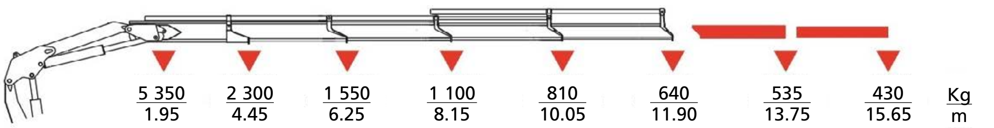
Many of the functions of the workboat will involve moving heavy items on and off the vessel. Therefore, a crane with sufficient reach and lifting capacity is essential to the efficient operation of the farm (Figure 7.19). Examples of typical lifting procedures would be the offloading of harvested oysters or the movement of on-board processing equipment. A crane's lifting capacity is expressed as tonnes per metre. The example given in Figure 7.20 is a 10.4 tonnes/metre crane. This means that the crane will lift 10 tonnes at a 1 m radius from the central rotation point. The diagram indicates how the lifting capacity diminishes as the crane's telescopic booms are extended away from the central base.

The specification and use of the crane should be matched to the stability of the vessel to ensure safe working procedures and to avoid capsizing the workboat. Each vessel will have a maximum angle of roll (sideways movement) beyond which the stability of the vessel will be compromised. Professional advice should be sought from a marine surveyor with regards to vessel stability whilst undertaking lifting operations.

FIGURE 7.19
Crane being used to lift equipment onto raft

©M. Mercer

FIGURE 7.20
Example of lifting capacity of a 10.4 tonnes/metre crane. As the crane is extended, the lifting capacity diminishes



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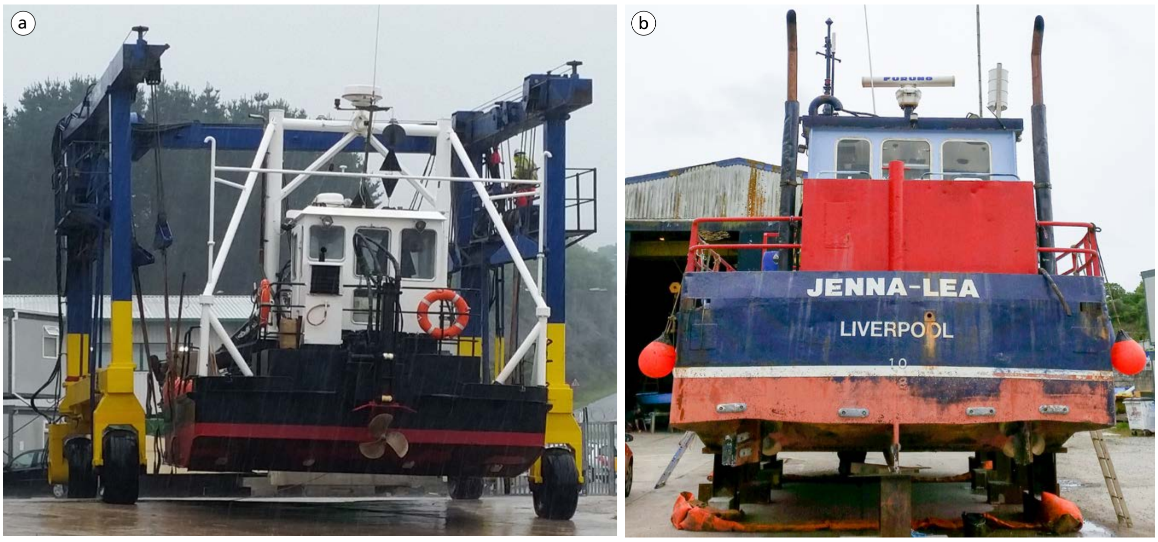
Source: Elaborated by the authors.

Propulsion system

When dredges are being towed across the seabed, they will cause a certain amount of resistance. As the dredges fill with shellfish, they become heavier causing the drag to increase. Due to the nature of this operation, it is important that the vessel is equipped with a propulsion system that has enough power and torque to enable it to continue to tow at a consistent speed even when the dredges are full. The propulsion system should therefore prioritise pulling power over speed. There are many different systems but the main one used at present is the diesel engine. The vessel featured in this section of the manual has a variation on this, whereby a diesel engine is used to power a hydraulic pump that in turn drives the propeller (Figure 7.21a). It has a 6 litre marinized truck engine that delivers 230 HP at 2100 RPM.

Some vessels have twin engines driving two propellers, one to Port and one to Starboard (Figure 7.21b). This setup gives greater torque which is particularly useful when dredging. It also enables better manoeuvrability and, if one engine fails, it allows the vessel to safely return to land whilst running on the remaining unit.

FIGURE 7.21
Examples of propulsion systems
(a) Vessel with hydraulic propulsion system. (b) Vessel with twin propellers



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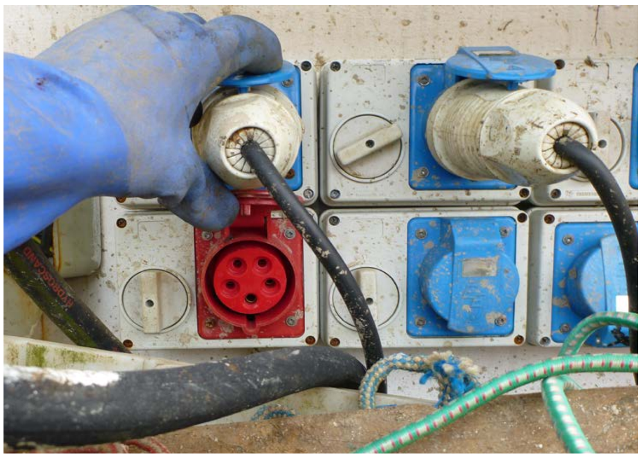
Navigation and communication system
The use of chart plotters has been discussed in the previous section of this chapter entitled "Electronic navigational aids". It is also necessary for the vessel to be equipped with Very High Frequency (VHF) radio so that it is possible to communicate with other water users in the area. This is especially important whilst undertaking dredging activities because, when the dredges are on the seabed, the vessel is limited in ability to manoeuvre and therefore use of the VHF to warn other vessels can help to avoid potential collisions or entanglement. The VHF should be always monitored on Channel 16, which is the international distress frequency and is also used by vessels to initiate communications before switching to another channel.

Electrical power
Some of the items of processing equipment may require either single or three phase electrical power (Figure 7.22). When installing a generator to produce this power it is recommended that the operator purchases one with a higher power specification than the bare minimum that is required. This will allow for the use of equipment that was not initially needed. Also, certain pieces of equipment require a larger amount of power to start them which drops down once they are running, so this must be factored into the installation calculations.

FIGURE 7.22
Waterproof electrical sockets to provide power for equipment on deck



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Hydraulic power
Hydraulic power can be used to power the crane, winches, derricks, water pump and in some cases the propulsion system itself. It can also be used to power other items of processing equipment. It is therefore an integral part of the vessel's operating system and, as with the electrical power system, must be designed with plenty of extra capacity to allow for the expansion of its use.

Specific on-board equipment
There are two options for processing the oysters that are dredged from the beds. Either they are loaded from the dredges directly into containers and transported back to the shore-based facilities for grading or they are graded on-board the workboat itself. This section of the manual will examine what equipment is required to facilitate the grading of oysters whilst on the vessel.

Dredging the oysters from the bed will commence when the majority of them are of a suitable size to be harvested. However, the growth rate of the individual oysters will vary over the season and so, when harvesting takes place, there will be a variety of sizes landed in each dredge. These need to be separated out, and only the oysters that have attained a minimum market size will be landed for further processing. The rest of the slower growing stock that is under the minimum size needs to be re-laid back onto the beds to allow it to grow on. This is achieved using the grading equipment. The advantage of undertaking this process on-board the vessel is twofold. Firstly, it means avoiding the unnecessary transportation of the smaller stock from the beds to the shore-based facilities and back again saving time and double handling. Secondly, the oysters can be returned immediately to the water, which will reduce any potential mortalities from the grading process. The on-board grading line will require the following elements:

FIGURE 7.23
Oyster hand dredge

Dredges
These are used to harvest the oysters from the beds. They can vary in size and design depending on the vessel that they are being deployed from. Here are two examples, one being a small manual dredge that can be recovered by hand (Figure 7.23) and the other being a larger design that would require recovery by mechanical winches (Figure 7.24 and 7.25).

FIGURE 7.24
Examples of dredges
(a) Large oyster dredge – This is the underside of the dredge that comes into contact with the seabed. It features a steel mesh to withstand abrasion whilst being dragged over the fundus. (b) Large oyster dredge – This is the top side of the dredge. The netting on this side is a woven nylon mesh

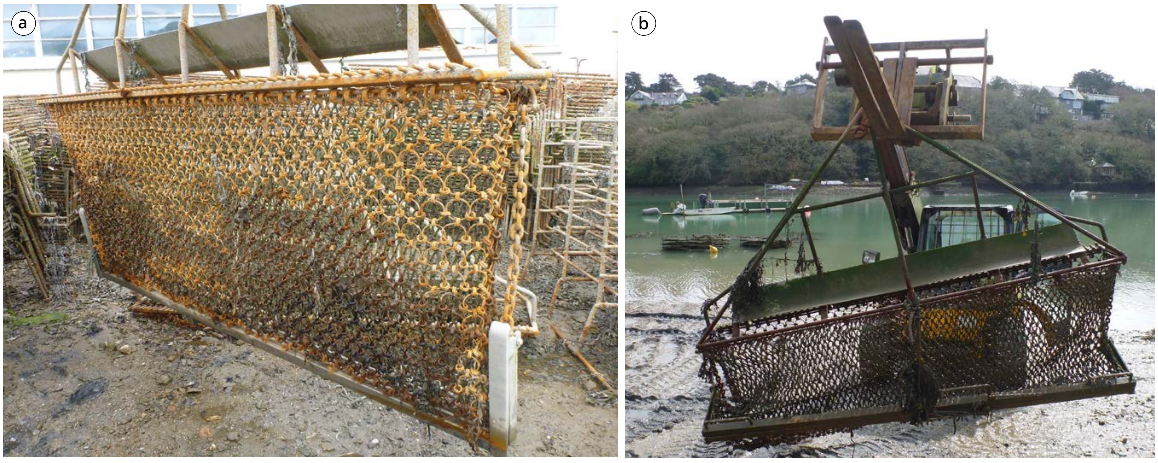

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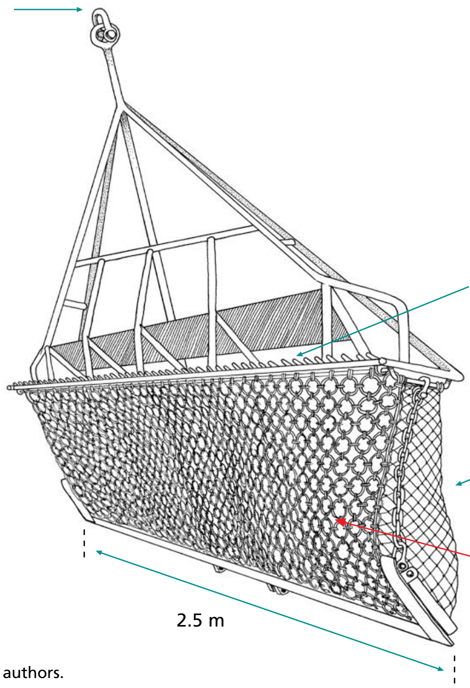
FIGURE 7.25
Large oyster dredge with measurements

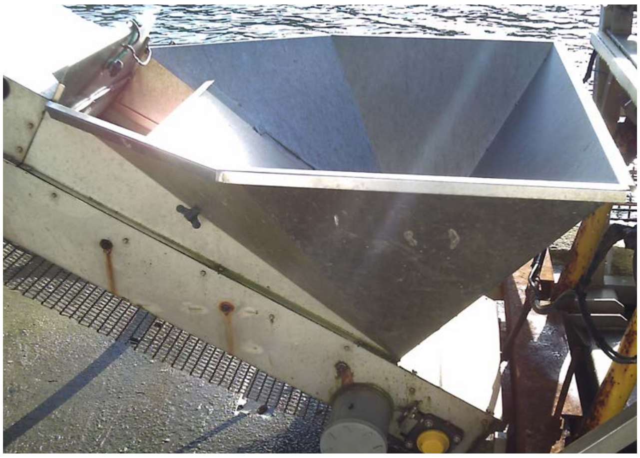


Source: Elaborated by the authors.

Hopper or washer

When the vessel has made a pass of the bed and the dredges are full, they are swung inboard on the derricks. The dredges will then be opened, and the oysters dropped into a hopper (Figure 7.26). The hopper needs to be of sufficient size to ensure that it is at least as wide as the size of dredge and with enough volume to be able to unload the contents of both dredges. This is so that the dredges can be offloaded and redeployed whilst the crew on-board process the oysters that have just been harvested whilst the skipper makes another pass of the beds. This piece of equipment will incorporate a chain belt that moves the oysters through water jets to clean the product and to deposit them onto the next item in the grading line.

FIGURE 7.26
Example of hopper or washer. Once the oysters are dropped into the hopper, a chain belt delivers them through high pressure water jets and deposits them onto the next piece of processing equipment



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Inspection table
The oysters then travel across an inspection table where any predators and debris can be removed by hand.

Grader
From the inspection table, the oysters then drop onto the vibrating grader which separates the market size product from the smaller stock to be relayed (Figure 7.27).

Bagging machine
If the harvested oysters are to be sold as live product in their shells, then they will need to be put into bags and rested before further processing or depuration (Figure 7.28).

FIGURE 7.27
Vibrating oyster grader on deck of workboat

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Heavy-duty plastic pallet boxes or bulk bags
If the oysters do not require depuration and are to be sold as shucked meats, then they can fall directly into heavy-duty plastic pallet boxes or bulk bags. These can then be lifted directly off the boat to be processed ashore.

FIGURE 7.28
Shellfish weighing and bagging machines on deck

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7.3 FARMING PRACTICES

7.3.1 Strategies for the introduction of seed and part-grown oysters

In this section, the manual will outline the different approaches to the management of seed oysters. Seed will either need to be bought in from a hatchery or collected from natural spat settlement as discussed in Section 4.1 of the manual where different spat collection techniques are outlined. Because this section is dealing with techniques that relate specifically to the use of beds and bottom cultivation, spat is collected by laying cultch onto beds to provide a suitable settlement medium. A farm that is located in an area of abundant natural spatfall can use this technique to provide a low-tech, low cost means of seed collection. If this option is viable, then it will affect the strategy and general approach to seed. A farm that has to pay for the supply of seed oysters from a hatchery will have to ensure that the maximum number possible survive, as each one that perishes represents a financial loss. They also only have a finite number of oysters available to them in terms of the number of seed available from the hatchery. This differs dramatically from a farm that can collect ample amounts of spat from the wild. In this last scenario, their only cost is the time to lay the cultch onto the collection bed and the time to harvest it. Under these circumstances, a less rigorous management strategy is required.

Settlement of wild spat on cultch

Cultch is material laid onto the seabed that forms a substrate onto which the oyster spat can settle and attach. Generally, this is made up of old bivalve shells (oyster, mussel, clam and scallop) but can also include suitable aggregate materials such as crushed rock and mixed pebbles. Any material that is to be introduced into the fishery should be checked and, if necessary, treated to ensure that no unwanted bio-contaminants are imported into the production site.

Cultches should be laid onto beds next to breeding populations of oysters and in areas where currents and tidal movements will encourage the larvae to migrate towards; this is to maximise spat collection. Ideally, this process should be initiated shortly before the breeding season commences in Spring. If cultch is laid too early, it can become covered with unwanted biofouling organisms such as seaweeds, sponges and algal biofilm. This organic covering can prevent the oyster larvae from adhering to the underlying surface of the cultch. If the settlement material is laid too late, then spawning will occur without a suitable surface for the larvae to settle on and the opportunity to collect the spat will be missed. It is therefore important to understand the seasonal fluctuations of the production site to ensure that this process is initiated at the correct time.

Depending on the type and size of workboat used by the farm, the sowing of cultch can be achieved in a number of ways. For larger vessels, the material can be piled up on the deck and then sprayed onto the beds by high pressure hose if suitable water pumping systems are available. For smaller vessels, distribution can be achieved manually by using brushes or shovels or being tipped directly from the bags that the cultch has been supplied in. If this is the case, care should be taken to try and accomplish an even spread of the material across the beds to ensure that the maximum area is covered per bag of clutch used, supplying the larvae with the most chance of finding a suitable surface on which to settle.

Depending on the management strategy of the farm and the suitable grow-out beds available, once successful settlement has occurred, the spat covered cultch will either remain on the bed onto which it was initially laid or will be moved to another bed where better growth rates and end product quality can be achieved. In the scenario where the settlement bed is not necessarily a suitable site for on-growing and it is located within the intertidal zone, the cultch can be laid down in mesh sacks during the spat settlement period. Once the spat has been recruited onto the old shells, the bags can then be moved more easily to an on-growing bed than loosely distributed cultch.

Strategy for seed bought in from hatcheries

Timing is everything when it comes to the introduction of seed oysters (Figure 7.29) onto the cultivation beds. Seed strategy is important in all cultivation techniques, but is particularly so when it is applied to bottom cultivation due to the exposed nature of the stock. When the oysters are sown onto the bed, they have no protection apart from their own shells. Smaller oysters, and particularly seed, have thinner, more fragile shells and weaker adductor muscles. This makes them much more vulnerable and open to attacks by predators. Due to their diminutive size, they are also more easily smothered and suffocated by silt or mud. As such, introducing seed should be done at a time of year when there is an abundance of food available and suitable water temperatures to encourage rapid growth. These ideal conditions occur from late Spring through to the middle of Summer. Seed oysters sown onto the beds in late Summer won't have the required

FIGURE 7.29
Seed oysters ready for on-growing

time to attain enough size before growth slows in Autumn, leaving them vulnerable to predation and storm damage over the winter and should therefore be avoided.

Placing oysters of less than 10 g (approximately 20 mm long) in size onto a bed will usually lead to a considerable percentage being lost and should therefore only be done in circumstances when the seed can be purchased for a very cheap price and in large enough quantities to mitigate the effects of these losses.

FIGURE 7.30
Bag containing cultch generally consisting of old shells

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Hatchery-produced seed settled on cultch

Seed oysters can be settled onto cultch in a hatchery environment. Net sacks containing the cultch (Figure 7.30) are immersed into holding tanks. Oyster larvae are then introduced into the tanks and allowed to settle as spat onto the old shells whilst being fed with water containing microalgae that are produced by the hatchery. The cultch is held in the tanks until the settlement phase has been completed and the spat have reached a suitable size (>2 mm) to be transported out of the hatchery environment and into the open water of the estuary or bay. The bags are then held on an intertidal foreshore for one week to allow them to acclimatise to the outdoor environment before they are transported to the on-growing cultivation beds. At this point, the mesh bags containing the spat covered shells are split open and the cultch is distributed onto the beds in an even layer, ensuring that the density of oysters contained in each m^2 is suitable for the nutrient availability of the particular site.

Part-grown oysters

Part-grown oysters, also known as “half-ware”, are defined as having grown beyond the juvenile stage and have attained a weight of between 10–20 g (20–25 mm) (Figure 7.31). This is the perfect size to lay onto the beds as they are resilient enough to resist predators and large enough not to be engulfed by siltation. It is possible to

FIGURE 7.31
Half-ware oysters sampling

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buy this size in from other farms and, although it is a more expensive way to seed the beds, it will result in a lot less mortalities than when using smaller seed. Under normal growing conditions, the majority of these oysters, especially if introduced at 20 g, will be of marketable size after one growing season and can therefore be harvested more quickly providing income for the farm in a more timely manner. This approach is especially useful when first starting a farm as it allows the operator to achieve some sales relatively quickly.

Nursery solution

Depending on the location of the farm and the sites within the lease that are available to use, it may be possible to set up a nursery facility where seed oysters can be grown on to half-ware size before being sown onto the beds. If this option is possible, then this can be the best solution, allowing the farm to purchase seed oysters at a lower price and with greater availability, whilst reducing the losses suffered by laying small seed onto the beds. The nursery stage can be used to grow the oysters from 0.01 g to 20 g and can be achieved using a number of different techniques, each one of which is discussed in other sections of this manual:

- Floating upwelling system – Chapter 5
- Oyster bags on trestles – Chapter 6
- Suspended lanterns – Chapter 8

Size of seed and density

The numbers and densities given in Table 7.1 should only be considered as a guide based on average climatic conditions and average predation. Each site will have its own individual set of factors that will dictate the stock yield from each bed and therefore figures can vary depending on the specifics of the unique location. Factors such as nutrients and dissolved oxygen levels will dictate how densely the beds can be stocked and it is therefore recommended that monitored trials using different stocking densities are carried out to ascertain the optimal levels before committing to commercial production. It is assumed that an average bed can support a density of 100 commercial size oysters per m^2 (1 000 000/ha).

Differences in the level of predation suffered will also vary from site to site but this can be managed to a certain extent by the elimination of some of the predators as described in the sub-section entitled "Removal of predators" of previous Section 7.2.1.

TABLE 7.1
Table showing examples of expected harvest densities per m^2 depending on mortality rates

Size of seed (mm)	Initial density (individual oysters/m^2)	Expected mortality rate (%)	Harvest density (individual oysters/m^2)	Harvest weight (kg/m^2)
5–10	400–750	50–85	80–150	5–15
10–25	120–300	20–50	80–150	5–15

Source: Elaborated by the authors.

Seed handling practices

Laying oysters on the bed

When laying oysters onto the beds, it is important to try and achieve an even spread across the area of the bed. This will allow each individual an equal opportunity to feed and will therefore encourage an even growth rate throughout the stock. If the oysters land in large clumps on the seabed or foreshore, the molluscs on the bottom will be smothered and outcompeted for food by the ones on top and will grow more slowly. When distributing the oysters by hand onto an intertidal bed, care should be taken to achieve the required even distribution by slowly pouring the oysters from the bags in which they have been transported onto the ground. Any clumps should be raked flat before moving onto the next section of foreshore to avoid having to step on any of the oysters that have already been laid on the bed.

When distributing the oysters from a boat, the task should be undertaken at mid to high tide, when there is a good depth of water between the surface and the seabed (at least 3 m). This is so that when the oysters are scattered at the surface, they will diffuse in the water before landing evenly on the beds below. There are three main techniques for distributing oysters onto the beds and these are outlined below.

Hydraulic box tipper

The box tipper is designed to hold heavy duty plastic pallet boxes and is only suitable for larger seed and half-ware (≥5 g). The stock to be sown is tipped into boxes, ensuring that the minimum possible impact is experienced by the oysters as they are placed into the containers. Once the box is full, it is inserted into the box tipper ready to be delivered onto the bed. The tipping mechanism consists of a stainless-steel housing that secures the box, and this pivots on a hinge which is secured to the outer edge of the workboat's deck (Figure 7.32). Hydraulic rams are used to raise and lower the opposing side of the housing, thus controlling the angle of the box within it. As the angle between the box tipper and the deck increases, so does the flow of oysters being dispersed from the box. This allows the operator the ability to control the density of distribution and avoid any large clumps of oysters on the seabed. Depending on how the hydraulic system is set up, this can either be controlled by a crew member on deck or by the skipper in the wheelhouse.

FIGURE 7.32
Hydraulic box tipper
(a) Hydraulic ram. (b) Hinge on which the box tipper pivots. (c) Stainless-steel housing into which the heavy-duty plastic pallet box is inserted

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This operation should be undertaken whilst the workboat is moving slowly down the length of the oyster bed. The movement of the boat is an essential element in controlling the distribution of the oysters onto the fundus. The technique involves steering the boat in straight lines down the length of the bed whilst slowly tipping the oysters from the box. To maximise the dispersal of the stock, the boat should be driven in reverse. This guarantees that as the oysters enter the water, they pass directly into the trail of turbulence left in the propeller's wake which ensures maximum dispersal of the stock. For ultimate efficiency, the movement of the workboat down the beds should be assisted by the tidal flow. Careful attention should be paid by the skipper to map exactly where the vessel has travelled over the bed and what quantity of oysters has been sown into each section. This can be assisted by the use of a chart plotter with track laying capability as detailed in the sub-section "Electronic navigational aids" of previous Section 7.2.1 of this chapter.

Deck hose or brush

As stated above, this technique is only suitable for larger seed and half-ware (≥5 g). The oysters are tipped carefully onto the outer edge of the deck and are then scattered into the water using a deck hose or brush as the vessel moves along the bed. The waterflow from the hose should be of sufficient pressure to be able to move the oysters off the deck but not so excessive as to cause damage to the shells.

By hand

This is the most suitable technique for smaller seed (≤5 g) but can also be used for larger seed and half-ware. With this method, a handheld container such as a jug can be used to scoop out the seed oysters from the bag or box that they are held in and flung over the side of the boat in a controlled fashion, taking care to maximise their dissemination over the bed.

7.3.2 On-growing strategy and technique

In this section, the manual will outline the actions necessary for the correct management of the beds and the stock distributed on them, taking the oysters from seed or half-ware to a saleable size. This will include the physical tasks that need to be undertaken and the best strategy to maximise the most efficient use of the beds themselves.

Recommended frequency for dividing and/or grading batches

Unlike other oyster cultivation techniques, where regular grading and division is the normal practice, bottom cultivation does not require this process to be carried out once the oysters are sown onto the beds. Grading normally only takes place before the oysters are distributed and when they are harvested.

The pre-sowing grading is important to ensure that oysters of a similar size are grouped together on different beds. For example, oysters with an average weight of 20 g would be laid on one bed whilst a batch with an average weight of 5 g would be laid on a separate bed. This is because larger oysters are capable of filtering nutrients from the water at a higher rate than smaller ones and therefore will suffer from stunted growth as a result. By organising the oyster beds in this way, it helps to encourage an even growth rate across the stock. The subject of oyster bed organisation is dealt with in previous Section 7.2.2 entitled "Farm Layout".

When the oysters are harvested, they are graded again. This allows the stock that has reached market size to be separated from the slower growing oysters. These smaller oysters can then be re-laid onto another bed to allow them to grow on to a suitable size and be harvested at a later date.

Recommended frequency of raking/open dredging/removing predators

One of the advantages of bottom cultivation is that it requires less manual handling of the oysters than some other culture techniques. However, there are some vital tasks that need to be accomplished on a regular basis to ensure that the maximum yield is obtained from each bed and that the oysters produced are of the best quality possible. These techniques will be described in this section of the manual:

Raking

An oyster rake is a piece of apparatus that is used to rotate the stock on the bed, remove weed and disperse silt. The rakes are usually made of steel as it needs to be of sufficient weight to ensure the necessary contact with the fundus. They consist of a frame, onto which are welded 32 mm diameter rebar spikes laid out in an offset pattern (Figures 7.33 and 7.34). They are used in pairs (port and starboard) and deployed from the workboat using the same technique described in the previous Section 7.2.4 entitled "Dredging technique". As the rakes pass over the beds, they make contact with the oysters, rolling them over and evening out the distribution of the stock. This action results in several outcomes being achieved:

- It prevents oysters from sinking into any silt that is present on the top layer of the bed.
- It helps shape the oyster by gently knocking off some of the uneven frill that the mollusc produces whilst expanding its shell, resulting in a more regular shell shape.

- It allows oysters that were covered by other individuals to be brought to the top, ensuring that they have an equal opportunity to feed. This in turn leads to a more even growth rate across the entire population on the bed and therefore a better consistency of size.

FIGURE 7.33
Oyster rake with rebar spikes configured in an offset pattern

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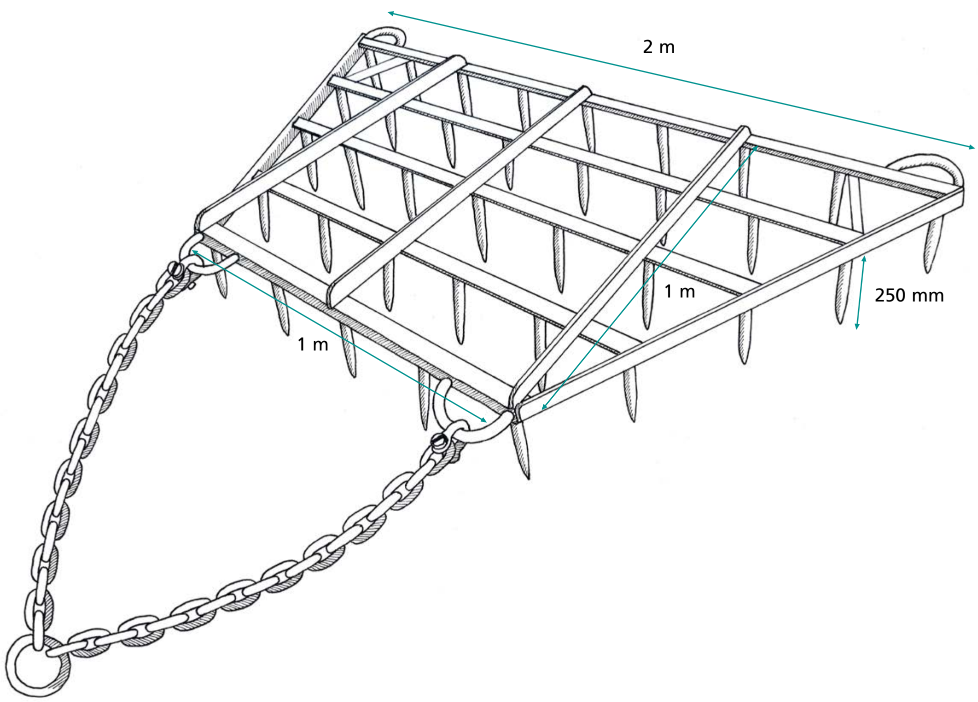
FIGURE 7.34
Oyster rake with most common measurements



Source: Elaborated by the authors.

Another important role of the rake is to remove any excessive amounts of macroalgae. Small amounts of seaweed on the oyster beds will not cause any harm but, if significant quantities build up over the oysters, it can inhibit their ability to filter, slowing growth and, in extreme cases, cause mortality. When undertaking this task, the rakes must be hauled back on deck on a regular basis in order to clear the weed from the metal spikes.

During periods of fast growth, from Spring through to Autumn, it is recommended to rake the beds once every two weeks. Over the winter period, when growth slows, only one raking session per month should suffice. However, if the beds are in an area that is affected by excessive siltation, then the bi-weekly schedule should be maintained throughout the winter. An example of such an area would be where oyster beds are located in an estuary surrounded by land used for agriculture. During periods of heavy rainfall, large amounts of sediment can be washed off the land and deposited onto the beds. In situations such as this, regular raking is advised.

Open dredging

Open dredging, as the title suggests, is the practice of dragging the dredges over the beds with the jaws unlocked. This technique can be used to achieve two goals:

- If a rake is unavailable, it is possible to use the dredges in this fashion to tumble the oysters on the bed to achieve the goals stated in the previous section. However, by using the dredges for this purpose, it can result in deposits of oysters collecting at the edge of the beds where the dredges are lifted. It is therefore recommended that a rake is used where possible.
- Open dredging is also used to prepare an oyster bed and remove excess siltation.

The schedule for using open dredging as a substitute for raking is outlined in the section above. The preparation of oyster beds using open dredges will be undertaken when an area of seabed is required and will therefore be scheduled as and when it is called for. Depending on the size of the bed and the depth of silt and mud to be removed, it is wise to undertake this process well in advance of the date that the bed will be needed. This will allow ample opportunity to engage in this activity on suitable outgoing tides and the chance to inspect the results of the dredging in between sessions.

Removal of predators

This process is discussed in the sub-section entitled "Preparation of the beds" of the previous Section 7.2.1 of this manual. However, it is possible to combine the removal of starfish with the process of raking the beds. The starfish mops can be attached to the trailing edge of the rake, allowing both processes to be undertaken at the same time. Table 7.2 describes the recommended schedule for removing predators from the oyster beds.

TABLE 7.2
Recommended frequency of removal of predators from oyster beds

Species	Frequency of removal
Crabs	Throughout the year, especially during times of population growth brought about by locally favourable conditions. Pots (Figure 7.9) can be lifted and emptied every few hours during peak periods or every few days during low population density months.
Starfish	Throughout the year, especially during times of population growth brought about by locally favourable conditions. It is important to monitor the population densities and adjust the removal schedule accordingly. During peak periods, it is good practice to drag the starfish mops (Figure 7.10) over the beds once a week as mass invasions can occur quickly. Starfish can move at an average speed of 1 m/minute

Source: Elaborated by the authors.

7.3.3 Dredging techniques

Dredging is arguably the most important technique to master when operating a bottom cultivation site. In this section, the manual will describe the approaches required to achieve this successfully.

Preparation whilst approaching the bed

Before lowering the dredges onto the bed, it is important to position the workboat correctly and ensure that dredges are properly set up. The boat should begin its approach at least 50 m before the start of the bed. This allows the skipper enough time to select the correct course and get the boat up to the desired speed. Establishing a good forward momentum is critical to ensure that, when the dredges make contact with the seabed, they don't cause the vessel to stop. A good approach speed would be in the region of 2–3 knots, allowing the workboat to maintain a dredging speed of roughly 1–2 knots over the course of the bed. During the approach, the dredges must also be positioned correctly and prepared, ensuring that the leading edge and mouth is orientated towards the bed and that the jaws at the trailing edge of the dredge are correctly locked together. When checking the locking mechanism, it is important to ensure that there is no debris preventing the jaws from closing properly. There is nothing more frustrating than lifting the dredges at the end of a run, only to discover that the jaws were not locked correctly and all of the oysters have just passed through the belly of the dredge and back onto the beds. Once the dredges are locked, they are then extended over the sides over the vessel using the derricks and lowered into the water so that they are situated just below the surface and behind the stern of the boat. As the bow of the boat nears the bed, the dredges are then lowered on their winches, ensuring that they make contact with the seabed before reaching the outer limit of the bed. This way, no oysters are missed from the perimeter.

During the tow

The two most important elements to consider whilst dredging are speed and the angle of the dredge cable.

Speed

As mentioned above, it is important to maintain forward momentum when moving across the beds. As the dredges fill with oysters, the vessel will begin to slow down as the increased weight will cause extra resistance on the seabed. The skipper will therefore have to increase engine revs as the boat moves down the bed in order to maintain speed and prevent the boat from coming to a standstill. However, if the vessel goes too fast, it will cause the dredges to skip across the fundus thereby missing a lot of the oysters on the bed.

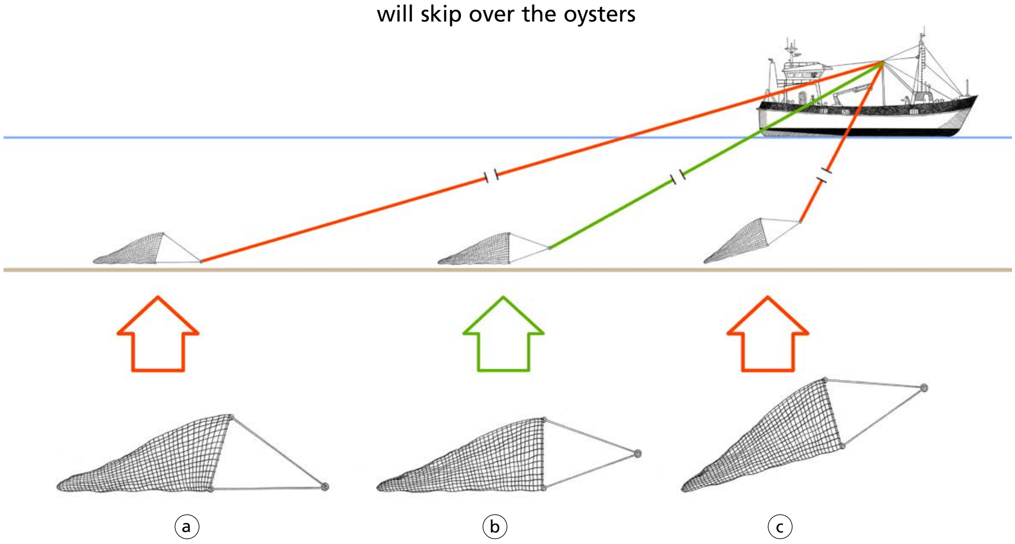
Angle of dredge wire

The angle of the dredge wire dictates the angle with which the dredge makes contact with the bed. The correct angle will dictate how the dredge will engage with the seabed and therefore the efficiency with which it will harvest the oysters. If operating correctly, the leading edge of the dredge should travel under the oysters and cut through the layer of pseudo-faeces and mud that they are sitting on. If the wire is too short, the dredge will not engage firmly with the ground and it will skip over the oysters. If the wire is too long, then the dredge will dig into the ground with too much force and become bogged down, potentially causing the vessel to stop (Figure 7.35). A good guide for wire length, considering only the part of the wire under water, is to use between 3 to 4 times the depth of water. For example, if the water depth was 4 m, then the length of wire should be between 12–16 m. That will result in a wire angle of between 70° to 75° (Table 7.3). As the skipper becomes accustomed to dredging, the operator will be able to feel if the dredge is skipping or getting bogged down and adjust the wire length accordingly. A useful tip when starting out is to stick a length of masking tape along the window of the wheelhouse at the desired angle. As the cable runs from the end of the derrick to the water past the wheelhouse, the skipper will be able to use the tape as a visual reference with which to check the angle.

FIGURE 7.35

Drawing illustrating the effect of different lengths of dredge wire on the interaction between the dredge and the seabed

(a) Wire too long: dredge will dig into the ground and become bogged down, potentially causing the vessel to stop. (b) Submerged section of the wire set at good length (3 to 4 times the depth of water): Dredge will make good contact with the bed and harvest oysters efficiently. (c) Wire too short: Dredge will not engage firmly with the ground and it will skip over the oysters



Source: Elaborated by the authors.

TABLE 7.3

Table showing the relationship between water depth, wire length and angle of the dredge wire when undertaking dredging operations on the oyster beds

Depth of water (m)	Length of dredge wire (m) should be 3 to 4 times water depth	Angle of dredge wire (°)
2	6–8	70° to 75°
4	12–16	70° to 75°
6	18–24	70° to 75°
8	24–32	70° to 75°
10	30–40	70° to 75°

Source: Elaborated by the authors.

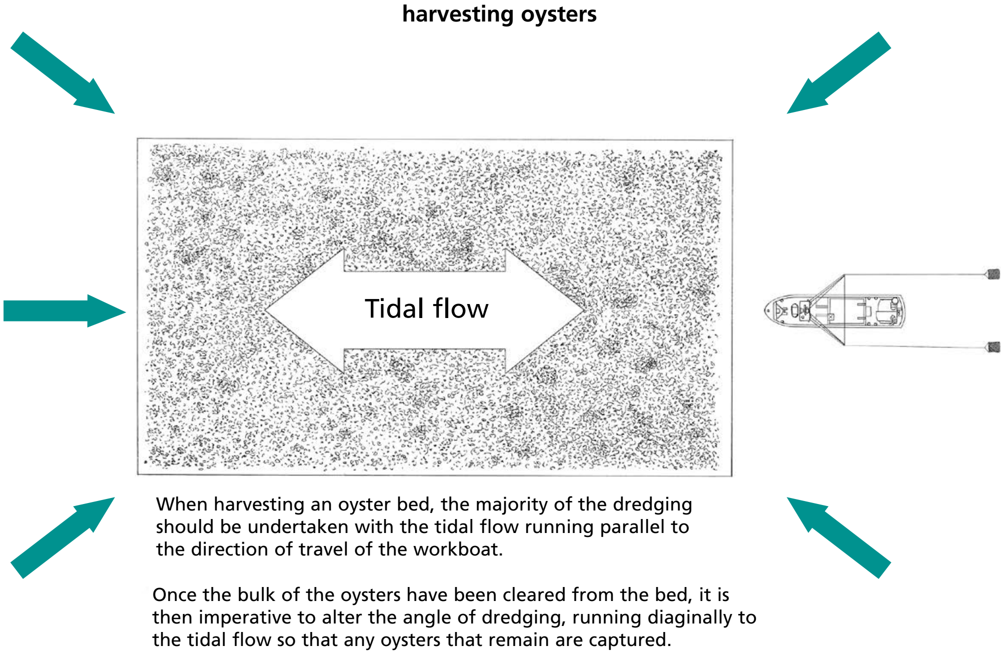
At the end of the tow

It is imperative that the skipper continues to tow the dredges right through the end of the bed so as not to miss any oysters that are right on the edge of the culture area. It is important to note that the dredges are a considerable distance behind the vessel. This distance will vary depending on the depth of water that is over the bed at the time. For example, when operating in a depth of water of 4 m the leading edge of the dredge will be roughly 16 m behind the stern of the boat, so the skipper will have to allow for this distance before beginning to haul in the dredges. It is important to winch in both the Port and Starboard dredges simultaneously so that the workboat continues in a straight line until both dredges reach the surface of the water. If one is raised without the other, it will cause the boat to veer towards one side and this can potentially cause a cable to become entangled in the propeller. When both dredges are at the surface the skipper can then safely change course. Before hauling the catch on board, the winches can be used to repeatedly lower and raise the dredges in and out of the water to dispel as much excess mud and silt as possible. Once the stock is relatively clean, then the derricks can be swung inboard and the dredges emptied either into the grading line or directly into containers to be offloaded and processed ashore. Using the dredges that are detailed in this example, it is possible to harvest up to 500 kg of oysters in a single dredge.

Vessel course over the beds

When beginning to harvest a bed, the workboat should be steered on a course that is parallel to the longest side of the bed, working in straight lines, running with and against the tide (Figure 7.36). Once the main bulk of the oysters have been cleared in this fashion, the skipper should then approach the bed from different angles, criss-crossing the bed in a diagonal pattern. During the process of harvesting, ridges are formed next to the furrow made in the fundus by the dredge. Therefore, after the initial dredging of the bed, a multitude of these ridges remain on the seabed. Contained within these ridges can be large quantities of oysters and the most efficient way of recovering them is by steering the workboat on a diagonal course over the bed (Figure 7.36).

FIGURE 7.36
Diagram showing dredging from different angles of approach to bed when harvesting oysters



Source: Elaborated by the authors.

7.3.4 Harvesting strategy

Harvesting will take place from oyster beds when the average individual weight of the oysters has exceeded the minimum required size to be placed on the market. Harvesting can take place throughout the year depending on the condition of the oysters.

The use of diploid or triploid oysters will affect the condition of the oysters, and therefore their suitability for harvesting, especially during the summer months. The differences between diploid and triploid are discussed in the Section 4.1 entitled "Procuring seed". When the water temperature rises in the late Spring and into Summer, diploid oysters will produce gametes. During this period before the release of gametes into the water, the oyster becomes "milky", affecting the taste, appearance and texture of the meat. Immediately after the gametes have been released into the water, the meat can become deflated and thin thereby also negatively affecting its quality.

Harvesting diploid oysters during this period should therefore be avoided. Triploid oysters are essentially sterile and therefore do not lose their condition through the summer months. If it is important for the farm to be able to harvest at all times of year, then the use of some triploid oysters will enable this. Triploid and diploid oysters should be kept on separate beds so that they can be harvested when required.

Harvesting can be undertaken by dredging on the subtidal beds (Figures 7.5 and 7.37), as described in the previous Section 7.3.3. On the intertidal beds, harvesting should be done using a combination of dredge and hand picking. Once the number of oysters being recovered by each tow of the dredge has fallen dramatically, it becomes inefficient to continue gathering the oysters in this way. At this point, it is better to wait until the tide drops to reveal the bed and then harvesting can continue by hand. When done correctly, dredging is a very effective way of harvesting but there will always be oysters left behind, so picking by hand is the only way to ensure that the remaining stock is recovered.

FIGURE 7.37
Oysters harvested from the beds by dredge

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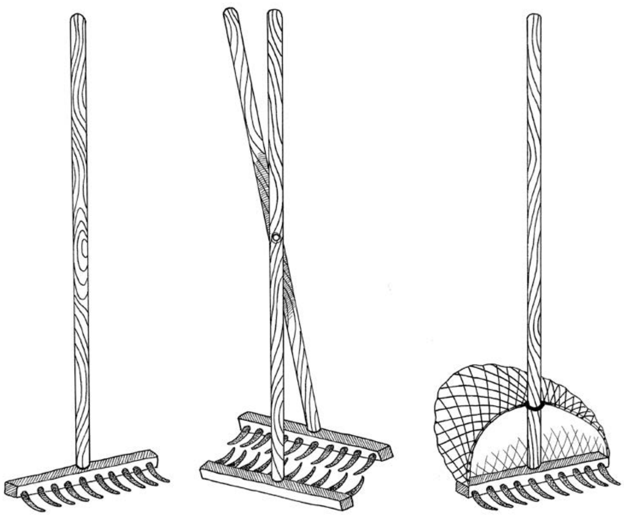
FIGURE 7.38
Different types of rakes used for harvesting oysters from beds by hand



Source: Elaborated by the authors.

Harvesting by hand can also be achieved by using oyster rakes (Figure 7.38). These devices can either be used by people on foot at low tide on the foreshore or from a boat in areas with shallow, submerged beds.

Fit with the market demand

There will be certain times of year when the demand for oysters will peak. This can be due to certain public holidays, feasts and festivals or merely tradition. When considering harvesting and production strategy, it is important to take these times of intense demand into consideration to ensure that the farm is holding enough market size stock to fulfil this requirement.

Quality assessment

When undertaking the final grade of the oysters before they are sold, the quality of the product must be thoroughly assessed. This will involve analysing the key factors that the customer will be concerned with: size, meat quality and taste, meat to shell ratio and shell shape and appearance if they are being sold into markets that will serve them in their shell. All of these aspects are discussed in detail in Section 2.2. Depending on which market they are being sold into, they can all play a part in determining the price that the oysters will demand. It is worth noting that, under normal circumstances, the price per oyster will increase as the size increases. However, once they exceed a weight of 140–150 g the price can drop quite dramatically, especially in markets that sell oysters in the shell. Above this size, they are considered too big for serving at the table and can therefore only be used in a processed form such as for oyster sauce.

Handling and storage practices

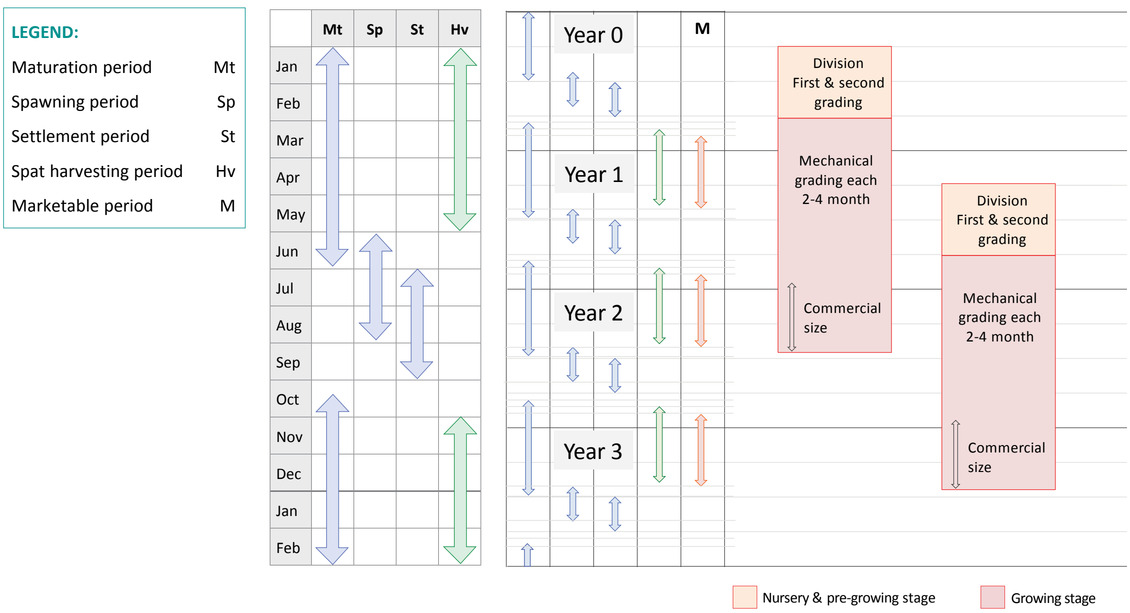
Due to the nature of the dredging process, the oysters are exposed to a certain amount of disturbance, especially when they are discharged from the dredges into boxes on deck and then when they are tipped from the boxes onto a grading or sorting line. Although these impacts are unlikely to cause mortality directly, it is recommended to rest the oysters after these processes and before they are dispatched. This can be done by either placing them in the water in mesh oyster bags on trestles or by depositing them into baskets which are then placed into storage ponds.

7.3.5 Farming calendar

The farming calendar refers to the reproduction and settlement timing of cupped oysters in the North Atlantic region as described in Section 2.1 of the present manual.

FIGURE 7.39

On-bottom pacific oyster production cycle and farming schedule in the North Atlantic region



Source: Elaborated by the authors.

7.3.6 Maintenance

There are a number of tasks that the operator should undertake on a regular basis to ensure that all of the equipment used to produce the oysters is maintained to a correct standard. The marine environment is particularly harsh on equipment and so to gain the maximum longevity and safe operation of the cultivation apparatus, regular checks and servicing should be mandatory. Some of the items that should be checked on are listed in Table 7.4.

TABLE 7.4
Maintenance chart featuring daily, weekly, monthly and annual maintenance tasks

Task	Frequency
Workboat engine checks	Daily – Before use
Check dredge for holes in metal and nylon mesh	Daily – Before use
Check dredge cable for signs of fraying	Daily – Before use
Fresh water wash-down of equipment	Daily – After use where possible
Greasing	Weekly or monthly – Particular attention should be paid to equipment that is used on a daily basis
Hydraulic hose replacement	Weekly – Check for signs of wear and abrasion
Hydraulic valves and fittings	Monthly – Check for signs of corrosion and to ensure that the protective coverings are still valid
Shackles and strops	Monthly – Check for signs of wear and abrasion
Anodes inspection and replacement	Quarterly inspection – Replace anodes as necessary
Servicing the workboat engine	In line with the manufacturer's guidelines regarding engine hours and usage
Workboat hull inspection and upkeep	Annually – Check hull integrity, apply antifoul, replace anodes as necessary

Source: Elaborated by the authors.

Workboat engine checks

Each day, before starting the engine of the workboat, all of the oil levels (engine, gear box, hydraulic), coolant level and fuel level should be checked to ensure that the vessel is fit to go to sea. Once the engine is running, the saltwater cooling system should be inspected to ensure that the correct flow is occurring.

Check dredge for holes in metal and nylon mesh

Dredges are usually constructed with steel mesh on one side and polypropylene mesh on the other side of the belly. The steel mesh is the one that is in contact with the seabed whilst dredging operations are underway. As such, it experiences wear and will need replacing when the mesh becomes thin or damaged. Oyster shells can be sharp and abrasive so tears can appear in the polypropylene mesh as well. These can normally be repaired using rope until the material becomes too damaged and then it will also need replacing. Running repairs on both types of mesh are essential and inspection of these items should be carried out every day before dredging commences. Any large holes in the mesh will result in oysters passing through and lead to lower catches and missed stock.

Check dredge cable for signs of fraying

The steel cables that are attached to the dredges and are used to haul them in by the winches can become worn and frayed. The main area of wear is usually along the length of cable that runs through the pulley blocks that it passes through towards the end of the derricks. As soon as fraying is visible, it is recommended to cut this section off so as to minimise the risk of losing the dredge whilst it is underwater being towed along the seabed. The cable should also be greased on a regular basis to minimise the effects of corrosion. Even with careful maintenance, it is possible that a cable will break during dredging due to the forces applied to it during operations. A separate rope and small pick-up buoy can be attached to the dredge before deployment so that, in this eventuality, it can easily be located and recovered.

Freshwater wash-down of equipment
Any equipment that is exposed to salt water should be washed down with freshwater after use when possible. Even items built of stainless steel can rust in certain conditions although not as swiftly or seriously as regular steel. Equipment with moving parts can get clogged up with debris and salt deposits from activities such as grading so it is recommended that they are cleaned on a regular basis.

Greasing
Regular greasing of any components that require lubrication should be carried out in line with the manufacturer's recommendations.

Hydraulic hose replacement
If the operator is using any pieces of equipment that are powered by hydraulics, such as the crane and derricks, then all hydraulic hoses should be checked for wear and abrasion on a regular basis. Hoses that are exposed to the elements, particularly UV light and salt water, will perish over time. If a hose bursts whilst under pressure it can create a dangerous situation for anybody working in the vicinity of the stricken piece of equipment. Also, the consequent loss of hydraulic oil into the water around the boat will have a negative effect on the environment and must therefore be avoided at all costs.

Hydraulic valve and fittings protection
Many of the metallic fittings, such as the hose connectors and the hydraulic valves themselves, are prone to corrosion and should be protected from the elements as much as possible. Where possible, they should be wrapped in corrosion prevention sealing tape or spray to maintain their integrity.

Shackles and strops
All lifting gear must be checked for signs of wear and replaced when necessary. Particular attention should be given to any shackles that are used on a daily basis for dredging and lifting as they will incur the most attrition. As well as checking for wear, the operator should also ensure that all shackle pins are tightened and secured. Any shackles that are used for these operations should be tested and certified to ensure that they are suitable for this purpose and for the forces that will be applied to them.

Servicing the workboat engine
Mechanical breakdowns of any propulsion unit at sea can have serious consequences for the crew of the vessel, so it is imperative that regular servicing of the main engine is carried out in line with the manufacturer's guidelines.

Workboat hull inspection and upkeep
The hull of the vessel spends the majority of its existence submerged in salt water. As such, depending on the construction material used, corrosion and deterioration can take place and so it is vital to regularly check that the integrity of the hull is maintained to ensure that there is no danger of water ingress. The vessel should be lifted out of the water to allow a full inspection of the hull to occur. An annual application of antifoul is recommended to protect the hull. This also reduces biofouling which will maximise the hydrodynamics of the vessel and thereby reduce fuel costs. If the hull is of metal construction, then anodes must be checked and replaced when their effectiveness has been reduced through galvanic corrosion.

7.3.7 Monitoring and traceability

Data collection and elaboration

It is important to collect as much data as possible about the aquaculture production area so as to build up a detailed picture of the conditions that affect the growth of the oysters. As each season passes, and data is collected and analysed, it is possible to use this information to predict expected growth rates and as a tool to guide the operator in their decisions regarding stock management and harvesting. Parameters that can be monitored are:

- Water temperature
- Salinity
- Chlorophyll-α
- Monthly oyster growth rates
- Monthly meat to shell ratio
- Monthly mortality figures

Examples of data collection graphs can be seen in Section 6.3.5 (Figures 6.31, 6.32 and 6.33).

Sample squares

The purpose of setting up these sample squares is to give the farmer a snapshot of the progression of the oysters on the different beds. The 1× 1 m squares should be marked out using small stakes in each corner, inserted into the fundus and with rope running around the perimeter of the square denoting the enclosure. Similar size oysters to those on the bed should be laid in the square at the same density as the main stock, thereby giving a realistic representation of the growing conditions. For example, if the density of the stock on the beds is 100 oysters/m^2, then 100 oysters should be placed in the sample square. The combined initial weight of these 100 oysters should be recorded and divided by 100 to give an average weight of the individual units. This process should be repeated at monthly intervals and the weights and number of mortalities recorded. The positioning of the sample squares should be as close to the main bed as possible, but not so close that they will be interfered with by any dredging or raking activity.

Stock charts

Stock management charts are an essential tool for keeping track of the oysters that are in the production cycle and determining what actions need to be taken and when to maximise the production capacity and quality of the product. An example of a stock management chart can be seen in Chapter 6 (Section 6.3.5 and Figure 6.34).

7.4 MAIN CONSTRAINTS

As mentioned previously, one of the main constraints of this particular technique is the general exposure of the oysters to both physical and environmental threats. As they are not enclosed by any cultivation equipment, they have no protection from predation or from boats anchoring or going aground on the beds and causing damage to the shells. In the case of a negative environmental event, they are unable to be moved quickly out of harm's way because of the dispersed nature of the stock. Because the beds are situated in the intertidal or shallow subtidal zone, they are exposed to any contaminants or excessive freshwater run-off from the land and, as such, can suffer from highly variable water quality issues. They are thus more likely to be closed for harvesting operations due to these factors when compared to cultivation systems that are situated further from the shore. They are also more easily accessible and therefore more prone to human intervention with issues such as theft and tampering with the stock being a possibility.

7.4.1 Environmental constraints

Intertidal and nearshore sites, such as the locations necessary for bottom cultivation, are by their nature highly impacted by environmental influences issuing from the land next to which they are situated. There are a number of different factors that must be considered when discussing these issues:

Salinity

Due to the proximity of freshwater sources such as rivers, the salinity of these sites can vary substantially depending on seasonal rainfall patterns and its influence on fluvial discharge and run-off from the land. If the flow of freshwater into an estuarine or nearshore environment increases, the salinity levels will decrease. Salinity is one of the main factors that influence the filtration rate of oysters and, in usual circumstances, the lower the salinity, the slower the oysters' filtration rate. This can in turn lead to a potential reduction in growth rate if this scenario continues over an extended period. As freshwater enters the watercourse, it does not immediately mix with the saltwater which can cause stratification. Freshwater is less dense than saltwater and therefore naturally floats on top of the denser seawater. The mixing between the two different water types is influenced by tidal range and flow, wind speed and direction, bathymetry and fluvial flow rate. In extreme circumstances, a wedge can form with the freshwater held at the top of the water column whilst very little mixing between the two water bodies occurs. If these conditions persist for long enough, whereby the oysters are situated in this freshwater wedge for an extended period, it can result in mortalities due to the dramatic drop in salinity to below their tolerable range.

Water quality

Water quality is impacted by the amount of contaminants that enter the marine environment. These contaminants can come from many sources such as sewage overflows, run-off from agriculture, outflows from industrial plants, mining activities in the coastal region and pollutants dumped into the water by other marine users. Depending on the nature of the contaminant, it can affect the water quality in different ways. For example, sewage overflow and run-off from farming activities that involve the use of animal faeces will raise the level of *Escherichia coli* bacteria in the water. This can cause health issues in humans that consume fresh and untreated bivalves that have been filtering this contaminated water. It can also cause the production areas to be either temporarily or permanently shut down for the harvest of bivalves if the local authority that monitors these factors deems product harvested from the area unfit for human consumption (see Section 2.3; Appendix I). As bivalves are filter feeders, they are particularly affected by any form of contamination in the water so an awareness of any possible pollution sources in the area of the farm and a management plan to deal with such incidences is imperative.

Eutrophication

Eutrophication describes the process when a body of water becomes enriched with an excessive amount of nutrients, resulting in an unnatural abundance of algae and marine plants. As these organisms die and decompose, the bacteria that feed on them consume oxygen and release carbon dioxide, causing the water to become hypoxic. Marine creatures, including bivalve molluscs, need the dissolved oxygen in water to survive so when it is depleted to critical levels it can cause mass mortality in organisms that are situated in the affected zone. The carbon dioxide also lowers the pH leading to acidification of the water course. Amongst other consequences for the wider marine environment, this can have a negative impact on the growth rate, reproduction, larval development, settlement and shell formation of the oysters.

7.4.2 Conflicts for site availability and licensing

Areas of coastal foreshore and nearshore marine zones can be of use to many diverse stakeholders besides aquaculture production businesses. These can take many forms but include such things as moorings for pleasure craft, tourism, local residents, property developers, marine protected zones, sewage treatment discharge outlets and boatyards. Many of these interested parties have completely different priorities when it comes to the use of the available space and, as such, conflicts of interest can occur. As competition for space is fierce in these highly desirable areas, it can be difficult to secure licences to operate a bivalve cultivation operation, especially if it interferes with an already established activity in the relevant location. It is important to engage with not only the pertinent licensing authorities, but also the other local stakeholders, to see if a compromise can be negotiated to allow these diverse activities to exist in harmony.

8. Offshore long-line cultivation

INTRODUCTION

This chapter focuses on long-line farming conducted in offshore conditions. This cultivation technique is relatively recent and has developed as a result of two main factors: the increasing competition for space on the foreshore, and the availability of new farming equipment and techniques better suited to growing oysters in exposed conditions. Compared to on-trestle (see Chapter 6) and on-bottom farming

FIGURE 8.1
Long-line farm in the Adriatic Sea, Italy

©L. Gennari

(see Chapter 7), investment is higher, farm design more complex and farming operations more time-consuming even through the automation of certain production processes. These challenges require a different approach with regards to the organisation and economy-of-scale of the entire farming operation. Furthermore, the environmental farming conditions are different, with limited tidal currents, no air exposure of the oysters at low tide, higher salinities and generally lower plankton concentrations. Consequently, even if grown in suspended containers opened on all sides, the oysters generally experience lower water currents, lower nutrient availability and remain submerged for the entire production cycle, except for farms that have coastal or land-based facilities where different nursery and hardening activities can be contemplated. In addition, as the oysters are always submerged, they do not require to close their shells on a regular basis, resulting in the development of weaker adductor muscles thus affecting their ability to withstand prolonged periods out of the water, an important consideration for oysters sold fresh and in the shell. One key advantage of this culture system is that farmed oyster are generally protected from predation and product losses much reduced as the bivalves are grown within containers such as lanterns, baskets, bags, etc.

The techniques detailed in this chapter are those employed in commercial farms operating in the Adriatic Sea at water depths ranging between 10–20 m and adapted from traditional and well-tested long-line mussel farming systems. In the case of open ocean locations, the culture structures, materials and farming activities described in the subsequent sections of this chapter would need to be redesigned to allow farming to take place in more exposed conditions and tested before undertaking any significant investments. In the case of relatively sheltered sites, the reliability and the resistance of long-lines will be less important, while minimizing operational costs will be the determining factor in the viability of a farm. Chapter 4 provides an overview on suspended cultivation systems (see Section 4.5) and the different long-line systems currently in use (see Section 4.6.1).

8.1 SITE SELECTION

8.1.1 Overall approach

All the conditions and environmental parameters listed and described in Chapter 3 will have to be carefully considered when selecting a site to establish a long-line operation, particularly those listed in Tables 3.1 and 3.3. If no farming activities exist or have been previously carried out in the identified area it is advisable to consult a site expert and analyse available historical data on weather and sea conditions.

Unlike the equipment and culture techniques used in on-bottom and on-trestle that have been standardised and tailored for farming in intertidal and subtidal areas, long-lines need to be adapted to extremely variable offshore conditions. The combination of unpredictable marine conditions and the fact that this recent farming technology has yet to be fully tested in different conditions, requires a precautionary approach, whereby farm site selection, choice of farming techniques and equipment will be fully interdependent. The final choice will depend on the farmer's investment capacities, the existence of on-site logistical support, on local farming traditions and availability of equipment and service suppliers. All these aspects will have to be taken into consideration to determine the technical, logistical and economic feasibility of any given project. An entrepreneurial approach will be required to maximise the chances of success, with a thorough analysis of the financial investments required to set up and run the farm. This approach is strongly recommended, regardless of whether the farmer intends to undertake much of the operation set-up on his own or opts to purchase a ready-to-operate and "all included" farm, noting that long-lines will require regular maintenance and logistical support. “Economies-of-scale” are relevant at all production scales, regardless of whether the farming operations are small or large.

Some key criteria will have to be considered when selecting a site to establish a commercial farm:

- The exposure of the farm site must not be excessive, whereby the relationship between water depth, maximum wave height and average wave period must be suitable;
- According to the envisaged long-lines design and workboat dimensions, the number of days that the farm cannot be accessed due to adverse weather conditions should not exceed 50–60 days/year;
- The seabed slope should not be too steep or uneven as to impede the installation of the long-line mooring system;
- Suitable landing facilities must be available in the vicinity and the time to reach the farm from the nearest harbour must not be excessive.

8.1.2 Water depth, tidal range and exposure

In relatively exposed offshore sites, the depth of the water column stands as the pivotal parameter and primary limiting factor when assessing the suitability of a location for long-line farming. It is important to take into consideration the following observations:

- If the average depth of the site is less than 10 m, the available space for installing farm structures and suspended cultivation devices will be suboptimal. This situation may result in farmed oysters coming into contact with the sea floor, which is undesirable.
- Conversely, when the average depth of the site exceeds 30 m, underwater diving operations become exceedingly demanding. The extended decompression periods required under these circumstances will significantly prolong installation and maintenance efforts, thereby adversely affecting production costs.
- The average water depth is closely linked to the local tidal range, thus exerting a direct influence on the feasibility of the farming endeavour.
- Wave height and wave period exhibit a partial dependency on the average depth of the water column. This factor contributes to the overall assessment of site suitability.
- Sites with depths greater than 10–15 m and high turbidity may encounter reduced light penetration. These environmental conditions can diminish phytoplankton availability, thereby impeding the growth of the farmed oysters.

A thorough understanding of these depth-related considerations is essential for making informed decisions regarding the feasibility of long-line oyster farming in exposed offshore sites.

In many instances, the adoption of long-line cultivation for oysters proves to be a viable solution to address the absence of tides in coastal regions where farming is planned. Moreover, as mentioned in the introduction, it can provide a solution to the issue of competing for foreshore space.

Furthermore, exposed open sea sites characterized by high tidal ranges pose significant challenges when it comes to designing mooring systems capable of accommodating the substantial fluctuations in the distance between the sea surface and the sea floor, stemming from the cumulative impact of the maximum tidal range and maximum wave height. Engaging in farming under such extreme conditions appears impractical and economically unviable when considering the utilization of existing, well-established farming equipment and techniques.

Relative wave height and the occurrence of breaking waves tend to increase as water depth decreases, while wave period exhibits a proportional increase with greater depths. Regardless of the water depth, both wave height and wave period also depend on the fetch and wind forces affecting the designated production area. The combination of these parameters leads to a wide range of potential conditions that require site-specific evaluation. Along the Adriatic Sea shoreline, characterized by shallower depths ranging from 10–20 m, limited fetch distances of less than 500 km, and short storm durations not exceeding 72 hours, conditions result in concise breaking waves with significant heights measuring less than 6 meters. In contrast, the vast expanse of the Atlantic coast features deeper waters and longer fetch distances, resulting in waves characterized by extended periods and infrequent breaking, with significant heights exceeding 8 meters. Regarding the resilience of long-line systems in the face of storms, it is important to note that waves with comparable significant heights, yet shorter and more turbulent, can cause more substantial damage than their elongated, non-breaking counterparts.

Ultimately, the exposure level of a selected farming site depends on the coastal configuration and geographic location. Sites situated within relatively sheltered bays or coastal regions where fetch distances and prevailing storm winds are limited should be the preferred choice.

8.1.3 Sea bottom

Installing moorings for farm structures becomes challenging when the sea bottom exhibits irregularities, a steep slope profile, or rocky terrain. In cases where water depths feature vertical variations exceeding 3–5 m on short distances, each mooring line must be of a specific length corresponding to its position on the seabed. The associated installation costs and ongoing maintenance of moorings in such locations are likely to be excessively high. In areas with a sharply inclined seabed, it may be difficult in install the desired number of long-line units within the mooring depth range of 10–30 m. Furthermore, in areas with rocky substrates, there exists a risk of concrete blocks or anchors slipping or shifting from their initial positions.

8.1.4 Currents, water quality and nutrients

In offshore locations, even in areas with larger tidal ranges, tidal currents tend to be lower when compared to intertidal or subtidal zones. Current velocities ranging from 0.2 to 2 knots (10–100 cm/sec), as mentioned for on-trestle or on-bottom cultivation, are unlikely to be encountered. In offshore conditions, the currents, which are influenced by geophysical configurations of the coast, typically remain below 1 knot. These conditions result in reduced water flow for oysters, affecting their feeding and growth. When selecting a site, it is advisable to opt for one where the average current speed is not below, and preferably exceeds, 0.4–0.5 knots (equivalent to 20–25 cm/sec). Moving farther offshore, away from anthropogenic activities and river discharges, generally leads to improved water quality characterized by reduced eutrophication and pollution levels. This improvement can offer a significant advantage in terms of minimizing contamination risks and enhancing meat quality. However, this shift also leads to lower plankton concentrations, which can limit both growth and meat content. In the site selection process, when determining the distance from the shore, striking a balance between these parameters becomes crucial. It is important to note that excessively oligotrophic waters should be avoided to ensure optimal conditions for cultivation.

8.2 FARM DESIGN

To design and construct appropriate long-lines for offshore sites, it is imperative to conduct calculations pertaining to the forces the system is anticipated to endure. The entire system should be designed with sufficient resilience to withstand these forces. As a result, it is highly advisable to seek guidance from a specialist with expertise in these matters to obtain the essential information and cost estimates. In situations where a custom farm design is necessary for the specific site due to the absence of a proven, demonstrated, and standardized solution, it is advisable to embrace a progressive approach. This approach involves conducting initial tests with a prototype, followed by iterative refinements and replication, before proceeding with the installation of a full-scale farm.

The following chapter sections describe the long-line system widely utilized along the western coast of the Adriatic Sea for mussel farming, which has subsequently been adapted for oyster cultivation. Since the shoreline exhibits considerable similarity in numerous coastal areas, featuring extensive sandy regions at depths ranging from 10–20 m, "sub-floating long-line" systems have been standardized and replicated in various locations. Typically, two farm systems are installed and selected based on considerations such as water depth, site exposure, and the personal preferences of individual farmers:

- "Sub-floating long-lines" consisting of numerous short and separated mainlines (refer to Figures 4.30c, 8.3 and 8.4), with each mainline typically measuring between 150–300 m;
- "Sub-floating long-lines" configured with a smaller number of longer mainlines (as shown in Figure 4.30d), where the mainline length typically span from 1 000–2 000 m, with intermediate legs fixed at intervals of 150 to 250 m.

In farm sites that are more exposed to adverse conditions such as short-period waves with a maximum height exceeding 4 m and strong currents, it is advisable to opt for the first type of long-line configuration. Short, independent units are recommended as they offer greater resistance and reliability compared to the second type.

The advantages of using short, independent headlines are as follows:

- The occurrence of an event, such as the breakage or detachment of a mooring line, does not impact the stability of nearby lines.
- Shorter lines result in lower forces exerted on the structure. For example, a 200 m headline with 60 lanterns, each weighing approximately 30 kg, will experience less mechanical stress than a 300 m headline with 90 lanterns of the same weight.
- In the event of a breakage, shorter lines result in a smaller loss of equipment and product.

In the context of extended headlines, should the main or intermediate mooring line experience breakage or detachment, the increased forces exerted on the remaining components of the culture system can potentially trigger a chain reaction leading to further rupture or detachment of the line. This domino effect may culminate in the total loss of significant equipment and product.

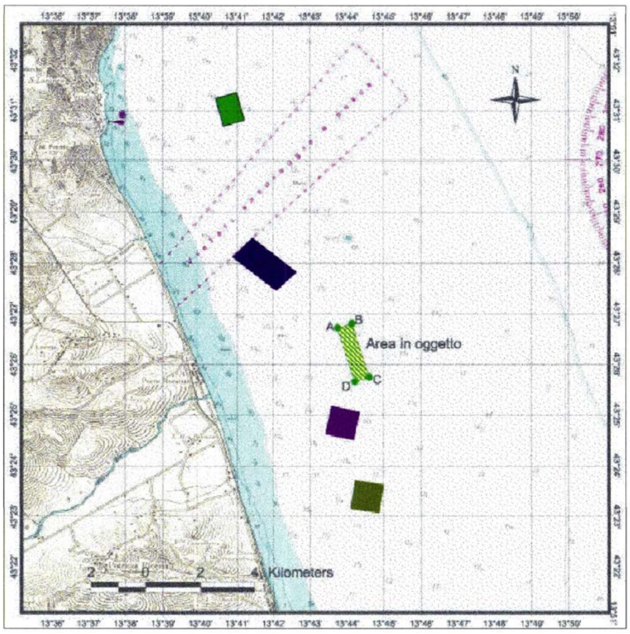
Shorter lines, while offering reduced risk, come with higher associated costs and diminished capacities. This is primarily due to the unutilized spaces between the lines, which cannot be harnessed for production purposes. The resistance and cost factors are also contingent upon the materials employed and the design of the aquaculture farm. Notably, these factors hinge on the type and diameter of the ropes used, the anchoring mechanisms, and the arrangement of the buoys.

From this point onward in this chapter, all the particulars discussed pertain to a long-line farm situated in a semi-exposed location (see Figure 8.2). This farm consists of 12 lines, each spanning 2 km and featuring ten independent headlines, each of approximately 180 m in length. The spacing between these lines is approximately 50 m, as depicted in Figure 8.3.

To provide the reader with a comprehensive understanding of the environmental conditions prevailing at the farm detailed in this chapter, the main site characteristics are outlined below:

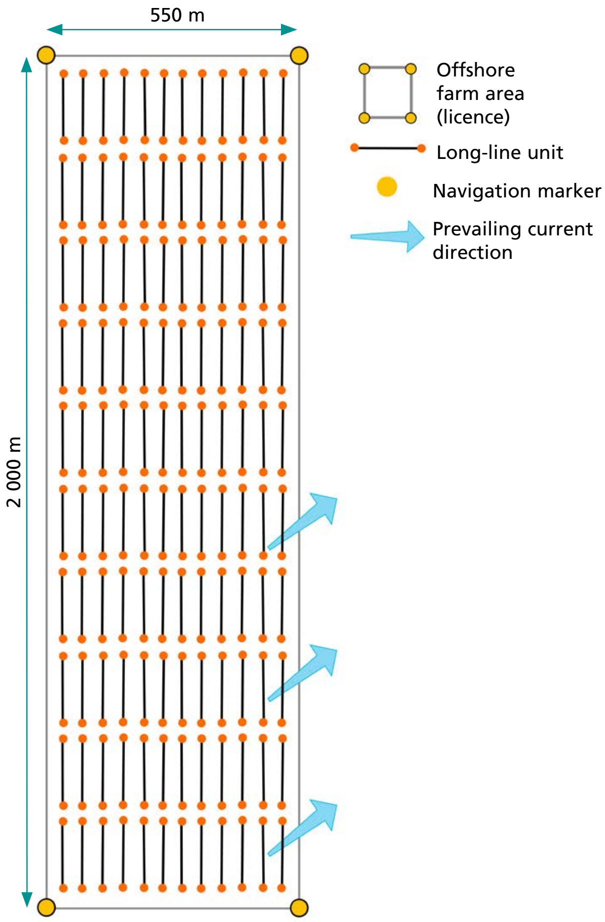
- Water depth ranges from 13–14 m, with a minimal tidal fluctuation not exceeding half a meter.
- The seabed consists of a sandy flat terrain.

FIGURE 8.2
Example of an offshore long-line farm map where points A, B, C and D are the coordinates of the concession area



- The maximum wave height observed in this region reaches 4–5 m.
- Consistent currents flowing north to south are present, with velocities ranging from 0.1 to 1.0 knot, depending on the season.
- Water stratification is limited due to the pervasive influence of currents throughout the entire water column, with greater intensity observed near the seabed. Consequently, the presence of a thermocline is sporadic and predominantly occurs during summer months when there is a decrease in current strength and an increase in surface water temperature.
- The farm is situated 3.5 nautical miles away from the coastline and 6 nautical miles from the nearest harbour.

FIGURE 8.3
Example of a long-line farm layout in Mali Ston, Croatia



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8.2.1 Long-lines and oyster lanterns

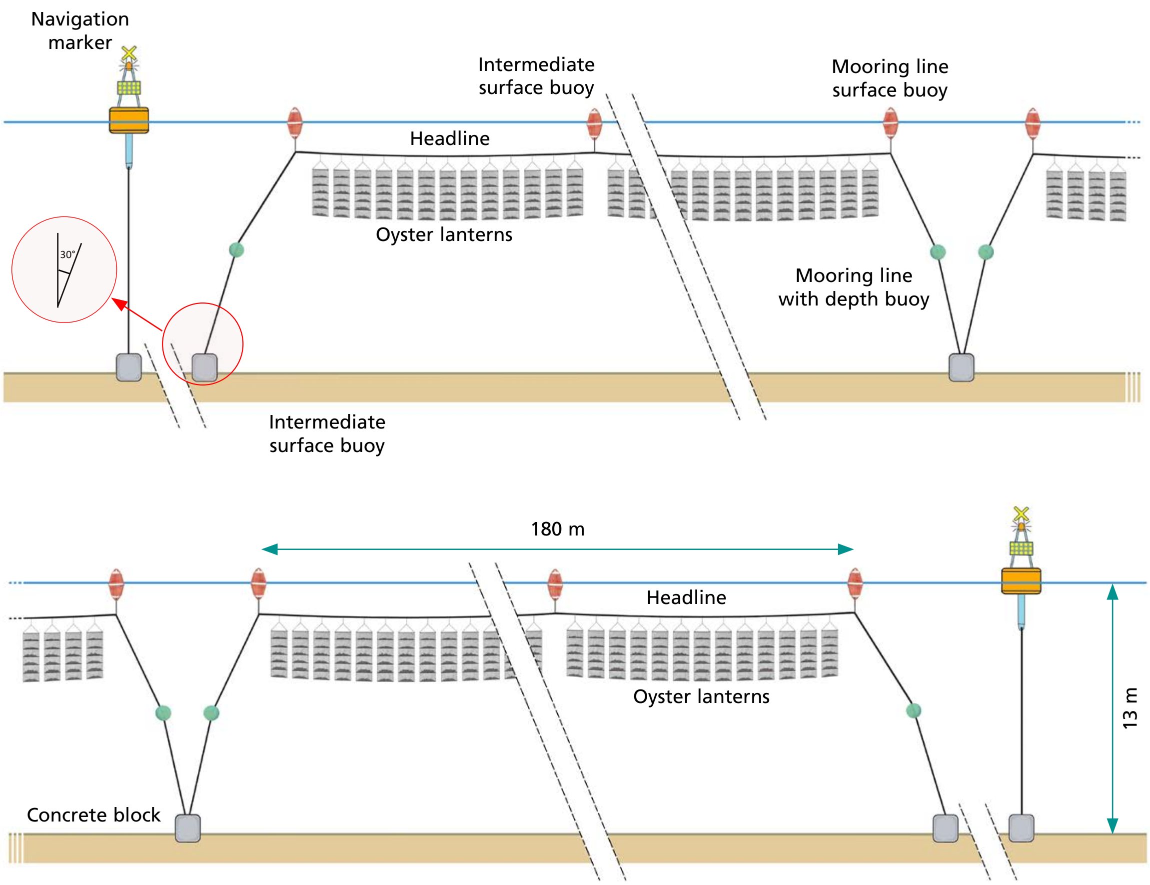
A long-line aquaculture farm comprises navigation markers delineating the boundaries stipulated in the license agreement, as well as the long-lines employed for suspended cultivation. In floating and semi-submerged long-line systems (see Figure 4.30), both navigation markers and buoys are visible from the surface, as depicted in Figure 8.1 and illustrated in Figure 8.4. On the other hand, in the case of fully submerged long-lines, only the navigation markers remain visible (see Figure 4.30e).

Distance between the lines

The spacing between two parallel lines must be sufficient to facilitate the manoeuvrability of the workboat, as detailed in Section 8.2.4. Ideally, this distance should be approximately three times the length of the workboat. In cases where the topography of the seabed necessitates a narrower gap between lines, the workboat should be equipped with propellers and navigation devices designed to facilitate navigation within confined spaces.

In the farm configuration outlined in this chapter (see Figures 8.2, 8.3 and 8.4), the separation between the culture lines is approximately 50 m, while the total length of the workboat is 17 m.

FIGURE 8.4
Illustration of a long-line section typically in use in the Adriatic Sea, Italy



Source: Elaborated by the authors.

Long-line components

As previously introduced in Section 4.6.1, which discusses long-line typologies and their associated components, each long-line, from the seabed to the water's surface, encompasses the following elements:

Anchorage devices: These are fixtures to which the mooring lines are affixed, ensuring stability and secure positioning.

Mooring lines: These lines are integral to maintaining tension within the aquaculture system. Buoys, positioned at various depths, contribute to this tension by keeping the mooring lines taut.

Headlines: These components serve as the primary support for the cultivation devices employed. They are attached to the mooring lines at the upper end, closer to the water's surface. Headlines can either operate independently or be equipped with intermediate mooring lines, also referred to as intermediate legs, depending on the specific aquaculture system design.

Buoys: These buoyant structures, which come in various shapes and sizes, play a pivotal role in maintaining the entire aquaculture system under tension within a single plane.

Anchoring system

The anchoring system must be meticulously engineered to enable the long-lines to withstand and endure extreme events, a critical consideration for all floating aquaculture systems. In the case of a sandy seabed, viable options for anchoring include the utilization of concrete blocks, surface anchors, or screw anchors, as illustrated in Figures 4.32 and 4.33. These anchoring solutions are chosen based on their compatibility with the specific seabed conditions, ensuring the long-lines' stability and resilience even in adverse circumstances.

Construction of the concrete blocks

Considering the conditions mentioned and the specific characteristics of the described aquaculture farm, which features a sandy-muddy flat bottom, the anchoring solution chosen consisted of cubic reinforced concrete blocks. These blocks have approximate dimensions of 1.75 × 1.75 × 1.75 m, resulting in a volume of approximately 5.5 m^3 and a total weight of around 12.5 tonnes, given that concrete typically exhibits an average density of about 2.2–2.4 tonnes/m^3. Given the likely susceptibility to extreme storm events attributed to climate change, it is strongly advisable to contemplate the deployment of heavier mooring blocks.

To optimize the contact area between the block and the seabed, it is recommended that the length and width slightly surpass the height. Moreover, in scenarios with particularly soft seabed conditions, where there is a risk of blocks sinking deeply into the substrate, the height should be at least 1.5 m. This ensures that the hooks on the upper portion of the blocks remain consistently visible for inspection and maintenance purposes. Additionally, longer, lower-profile blocks are less prone to tipping over during storms.

Furthermore, in cases where the seabed exhibits a shallow incline and possesses a highly compacted nature, it is preferable to employ concave cavity blocks (see Figure 4.33). These blocks feature a partially empty lower surface, creating a suction effect, which helps mitigate the risk of slippage and ensures enhanced stability.

When fabricating reinforced blocks for aquaculture applications, it is imperative to adhere to specific precautions:

Proportions of cement and aggregates: Care must be taken to ensure the right proportion of cement to sand and gravel, a critical factor for the long-term durability of the blocks.

Utilization of additives: Additives should be incorporated into the block mix to diminish the penetration of seawater and mitigate corrosion-related processes.

Reinforcing steel rebar: The steel rebar, with a diameter ranging from 16–20 mm, must consistently remain at least 5 cm beneath the surface of the block. For optimal corrosion resistance, it is advisable to utilize 310/316 stainless steel rebar.

Integration of hooks: The hooks, crafted from the same rebar material, should be securely fastened to the internal rebar structure of the block.

Additional hook: It is imperative to include an extra hook in the block's design. This additional hook serves two essential purposes: assisting in sinking the block and facilitating the installation of the mooring lines.

The fabrication of these blocks can be carried out either by the farm operator or by a specialized enterprise. To minimize transportation and loading costs, it is advisable to construct the blocks near the harbour.

FIGURE 8.5
Long-line mooring concrete blocks

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Installation of the concrete blocks

As workboats commonly employed in aquaculture operations may not be suitable, this operation often necessitates the involvement of a specialized enterprise and a dedicated vessel equipped for this specific task. Concrete blocks should be transported to the installation site via a vessel designed with adequate buoyancy and equipped with a hydraulic-powered crane or derrick for handling these substantial blocks. Alternatively, they can be towed to the site while suspended in the water using temporary buoys.

Subsequently, employing a GPS system or an equivalent technology is imperative to achieve precise positioning of the blocks. Accurate placement is paramount, as it ensures that the subsequent installation of the mooring lines can attain the requisite tension for optimal performance. This positioning work should ideally be executed during a period characterized by favourable meteorological conditions and when bottom currents are not excessively strong, safeguarding the safety and efficiency of the installation process.

Ropes for mooring lines, headlines and buoys

Ropes are the key components of a long-line culture systems, and as such, the careful selection of rope type and the materials from which they are constructed is of primary importance in ensuring the successful installation and operational efficacy of the aquaculture farm.

An array of rope configurations exists, including but not limited to braided, double-braided, and twisted strands, each offering distinct advantages. These ropes can be manufactured from a variety of materials, such as polyester, nylon, polyethylene, polypropylene and Polysteel. Consequently, rope characteristics and prices can differ considerably.

In the selection of ropes, several critical factors need careful consideration, as they will significantly impact the operational integrity and efficiency of the farm system:

Tensile strength when wet: Ensuring robust tensile strength, especially when exposed to adverse weather conditions, is imperative to prevent rope breakage.

Resistance to wear: Ropes are subjected to considerable wear during farming operations. Therefore, choosing ropes with high resistance to wear, minimizing fraying, is essential.

Longevity: The longevity of ropes hinges on various factors, including the material composition, diameter, and anti-UV treatment. These aspects collectively affect the durability of the ropes.

Elasticity: Minimizing elasticity of the ropes is desirable to maintain stability within the aquaculture system, as excessive stretching can disrupt operations.

Elongation over time: Many ropes may experience lengthening after installation and necessitate periodic tensioning over several months, making this an important consideration.

Density and flotation characteristics: The density and flotation properties of ropes play a role in their buoyancy and how they interact with the aquatic environment. Buoyant ropes are easier to install as they remain visible on the surface.

Considering the intricacies involved in rope selection, it is highly advisable to engage with specialized rope suppliers and review technical data sheets before making a procurement decision. This ensures that the chosen ropes align with the specific needs and demands of the operation.

In the example outlined in the following section, the ropes used are as follows:

- Units of 20 m in total length of 36–40 mm diameter: double braid nylon ropes for mooring lines.
- Units of 200 m in total length of 32–36 mm diameter: Polysteel twisted 3-strand ropes for headlines (see blue rope in Figure 8.14).
- Units of 4 meters of 16–20 mm Ø: double braid nylon ropes for buoys.

Cutting ropes

When it comes to cutting ropes, it is important to use methods that effectively prevent fraying. For ropes with a diameter ranging from 30–40 mm, the recommended approach involves utilizing an angle grinder. This tool generates heat during the cutting process, effectively welding the filaments and strands together. Alternatively, there are specialized heating tools designed specifically for this purpose.

For smaller diameter ropes ranging from 10–20 mm, there are two viable methods. One option is to employ dedicated heating tools designed for precision cutting. Alternatively, a simpler approach involves using a knife after creating 4–5 loops with robust adhesive tape at the intended cutting point, as shown in Figure 8.6. This technique ensures a clean and fray-resistant rope end.

FIGURE 8.6
Cutting small diameter ropes

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Surface buoys components and assembly process

Surface buoys are integral components of the mooring line or will be affixed to the headline to provide buoyant support to the devices containing the farmed organisms. In preparing the buoys for deployment, the assembly process outlined below must be followed.

Concerning the farm layout described in this chapter, the specifications for each buoy at the upper extremity of the mooring lines are as follows:

- One double braid 20 mm Ø nylon rope unit of 4 m.
- One surface 150–180 L bi-conical buoy filled with polyurethane, to be positioned at the upper segment of the mooring line.

- One unit of transparent, flexible, antifreeze PVC garden hose pipe of 0.3 m with an internal diameter not less than 20 mm, intended for reinforcing the rope at the point of attachment to the buoy.

The nylon rope is inserted into the hose section and secured with a knot, ensuring that 0.5 m of free rope remains for fastening with a thin nylon cord measuring 2–3 mm Ø, as illustrated in Figure 8.7. Once the knot is securely fastened, the hose should remain firmly fixed in place.

FIGURE 8.7
Knot used to secure a surface buoy of a mooring line
(views from various angles)

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FIGURE 8.8
Knot used to secure an intermediate surface buoy
Visible the security knot to prevent the rope from becoming dislodged

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The specifications for each intermediate buoy are as follows:

- One double braid 16 mm Ø nylon rope unit of 4 m.
- One surface 120–130 L bi-conical buoy filled with air (pressure >0.8 bar/atm).

The nylon rope is threaded through the mooring eye and fastened securely with a knot. It is important to leave an additional length of approximately 0.5 m of free rope, which is used for tying a security knot, as depicted in Figure 8.8.

Mooring lines

In order to maintain the system under proper tension and within the same plane, it is imperative to maintain an angle of approximately 30 degrees between the mooring line and the vertical reference. As a result, for a water depth of 13 m, the total length of the mooring line, prepared for installation, should be approximately 15 m. Further calculation must account for the extra length of rope needed to accommodate all the knots, thereby the individual mooring unit should measure approximately 20 m.

In contrast to fish cages, which exhibit considerably higher resistance to marine currents, the utilization of bottom chains affixed to the concrete block or anchor is unnecessary.

The following sections provide a comprehensive explanation of the assembly and installation procedures for the mooring lines necessary for the farm layout outlined in this chapter. These mooring lines correspond to the sub-floating long-lines shown in Figure 4.30c, featuring a tension buoy (see Figure 4.32) and a simple concrete block (see Figure 4.32). The overall layout of the farm is further illustrated in Figures 8.3 and 8.4.

Mooring lines components (excluding surface intermediate buoy)

The specific components required for a single mooring line are itemized below:

Rope: As previously indicated, 20 m of a double braid 36–40 mm Ø nylon rope is recommended. For optimal reliability and durability, it is important that the rope remains in one continuous single piece.

Thimbles: One thimble is needed, constructed from zinc-plated high-quality steel, with an estimated lifespan of approximately 4–5 years.

Shackles: One shackle is necessary, also made from zinc-plated high-quality steel, with a projected lifespan of around 6–7 years. The shackle should have a load capacity of 9–10 tonnes and should be equipped with bolt, nut and pin.

Rope clamp: One rope clamp, composed of zinc-plated high-quality steel, is required.

Submersible buoy: A submersible buoy with a volume of 90–110 L (approx. 0.5–0.6 m Ø if spherical) is essential. This buoy should be filled with polyurethane and equipped with a central hole adapted to the diameter of the utilized rope. It is to be positioned on the mooring line approximately 5–6 m above the sea floor.

PVC garden hose pipe: A single unit of 1.0 m of transparent, flexible and freeze-resistance PVC garden hose, with an internal diameter >40 mm. This unit is employed to reinforce the rope rings where the headline and the main buoy will be securely fastened to the mooring line.

Surface bi-conical buoy: Lastly, one surface bi-conical buoy with a volume of 150–180 L prepared as shown in Figure 8.7.

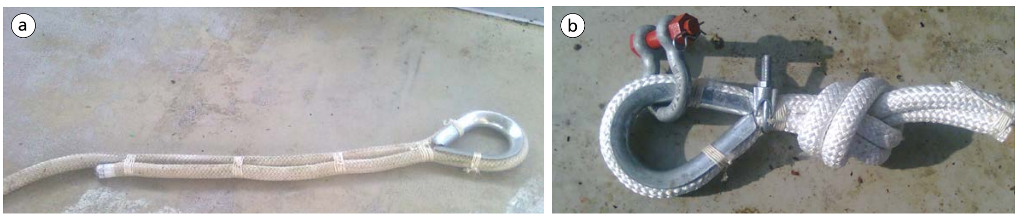
Mooring lines assembly process

1. Wrap the rope around the thimble, leaving approximately 1 meter of rope free. Use a thin nylon cord with a diameter of 2–3 mm to fasten it securely on both sides. Ensure that the fastening occurs on the narrower part of the thimble to prevent wear from contact with the shackle (Figure 8.9a).
2. Attach the free rope to the main line along 3–4 points using the same nylon cord method mentioned above. The first attachment point should be as close as possible to the thimble to prevent the rope from slipping. At the same level, position the rope clamp for added security (Figure 8.9a and 8.9b).
3. After the rope clamp, tie a simple knot to prevent any movement of each element (Figure 8.9b).

FIGURE 8.9

Extremity of the mooring line to be tied on the anchoring device

Step 1: the mooring line is securely attached to the thimble (a); and Steps 2 and 3: the mooring line is further secured using a rope clamp, and a shackle is inserted (b)



4. Thread the rope through the central hole of the submersible buoy and make another single knot on the mooring line approximately 5–6 m from the thimble. To prevent this knot from shifting, secure it with a thin nylon cord (2–3 mm Ø). This knot's purpose is to keep the buoy from rising, maintaining constant tension on the lower part of the mooring line to prevent contact with the concrete block or the seabed. (Figure 8.10).
5. Insert the shackle into the ring formed by the thimble. Do not tighten it yet. Place the bolt and nut in position without fully securing them. Keep the pin in a secure location until the mooring line is ready for installation on the block.
6. Insert the upper end of the rope into the 1.0 m piece of flexible garden hose, leaving 1.2 m of free rope to create the knot as illustrated in Figure 8.11. Secure it with a thin nylon cord (2–3 mm Ø). Once the knot is tied, the hose should remain in place.
7. Place the assembled surface mooring buoy aside for future use.

FIGURE 8.10
The knot employed on the upper side of the submersible buoy serving to secure the position of the buoy along the mooring line

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FIGURE 8.11
Extremity of the mooring line where the headline will be tied

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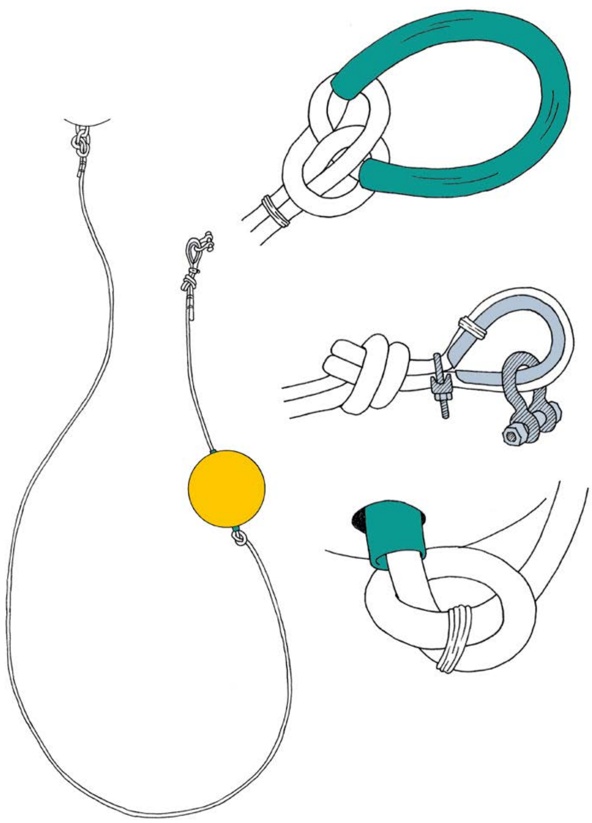
Installation of the mooring lines

Typically, this operation necessitates the involvement of a specialized company, which encompasses the expertise of certified professional divers.

1. Preparation. The following technical components are required:
   - A first temporary double braid 20 mm Ø nylon rope measuring 40 m in length.
   - A second temporary double braid 20 mm Ø nylon rope measuring 2–3 m equipped with a pulley suitable for the first 20 mm rope.
   - A third temporary double braid 16 mm Ø nylon rope measuring 2–3 m.
2. Verify that the mooring line is assembled in accordance with the instructions outlined in the assembly process (Figure 8.12).
3. Securely attach the mooring line surface buoy to the upper ring of the mooring line.
4. Fasten the first temporary rope approximately 1 m above the thimble.
5. Connect the third temporary rope to both the mooring line buoy and the boat. This will prevent the mooring line from drifting too far from the boat until the installation is complete.
6. Gradually lower the mooring line into the water, beginning from the thimble end, while ensuring that the opposite end of the initial 40 m temporary rope remains onboard.

FIGURE 8.12
A full assembled mooring line



Source: Elaborated by the authors.

7. During the initial (1st) dive:
   - Bring to the concrete block the second temporary 2–3 m rope equipped with a pulley and the free end of the second temporary 40 m rope (the other end is secured in proximity to the thimble).
   - Securely fasten the second temporary 2–3 m rope, along with the pulley, to the additional hook located in the middle of the concrete block.
   - Thread the second temporary 40 m rope through the pulley, and then guide the rope's end back to the boat.
   - Commence the retrieval of the second temporary 40 m rope from the boat. Initially, this can be done manually until the submersible buoy no longer descends further. Subsequently, utilize the winch to compensate for the resistance exerted by the submersible buoy, thereby completing the operation. Detection of resistance signifies that the mooring line thimble is near the concrete block hook, where it should be securely fastened.

FIGURE 8.13
Wrenches and pulleys used when installing a mooring line

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8. During the following (2nd) dive:
   - Connect the lower end of the mooring line to the dedicated hook with the designated shackle, ensuring that the bolt and nut are securely fastened and that the pin is inserted correctly.
   - Release the first and second temporary ropes and secure them together for retrieval back to the boat.
9. From the boat, hoist the primary and secondary temporary ropes on board in preparation for the next phase of the operation.

Headlines

The approximate length of the headline is determined by considering several factors, including the distance between the two anchoring devices, the total depth of the water column, the angle of inclination of the mooring lines, and the size of the headline buoys. When ordering and preparing the headlines, it is crucial to ensure that the line is sufficiently long to accommodate knots at both ends. A recommended practice is to add a few extra meters to the length to mitigate potential issues.

Deciding on the orientation of the long-lines involves a compromise between minimizing the impact of external forces, such as waves and currents, on the system and optimizing the availability of nutrients carried by water currents. To reduce the stresses the system may experience, both in terms of storm-related forces and continuous wear from prevailing currents, it is recommended that long-lines be aligned parallel to the dominant force direction. However, opting for a parallel alignment would result in the initial lanterns benefiting from nutrient-rich water, while downstream lanterns would receive water that has been progressively depleted of nutrients due to filtration by the oysters cultivated in preceding units. Moreover, maintaining a parallel configuration raises the risk of lantern collision, potentially causing damage. To mitigate this, lanterns would need to be spaced farther apart along the headline, negatively impacting production capacity. On the other hand, positioning the lines perpendicular to the main applied forces would expose the structure to significant risks but could ensure a more uniform distribution of nutrients among all lanterns. As a viable compromise, positioning the lines at an angle of 30–40 degrees relative to the direction of the dominant applied forces can strike a balance between optimizing nutrient availability and reducing collision and damages.

Both Polysteel ropes and double braid nylon ropes are commonly employed as headlines in long-line systems. Polysteel ropes, when compared for equivalent tenacity, exhibit the advantage of being lightweight (buoyant), non-absorbent to water, are UV-treated, and are less expensive. On the other hand, double braid nylon ropes offer greater flexibility, making them easier to handle for tying purposes. It is important not to confuse Polysteel ropes with polypropylene or polyethylene ropes, which are less robust and less resistant to abrasion. Headline ropes made from either of these materials will inevitably experience abrasion during lifting operations. High-quality nylon ropes can endure for more than a decade, whereas Polysteel ropes are prone to fraying sooner than that.

The subsequent section provides a detailed overview on the headlines installation process for the farm featured in this example.

Installation of the headlines

Once the two mooring lines are ready:

1. Begin by preparing a temporary 2–3 m double braid 16–20 mm Ø nylon rope. Securely fasten the two extremities to form a closed ring.
2. Attach one extremity of the headline to the upper ring of the first mooring line. To proceed with the next step, ensure that the deployment of the headline occurs with a tailwind, allowing the wind and current to be consistently at your back.
3. While steering the boat toward the second mooring line, extend the headline. Note that Polysteel rope will remain buoyant, while nylon rope will sink. In the latter case, for ease of installation, it is recommended to attach some small temporary buoys to help locate the position of the headline in the water. When the headline is properly tensioned, the floating rope or small buoys will be perfectly aligned with the buoys on the two mooring lines.
4. Pass the opposite extremity of the headline through the upper ring of the second mooring line.
5. Using the winch on-board, tighten the headline rope until it appears perfectly aligned.
6. While maintaining tension in the headline as described above, secure the pre-prepared temporary rope ring along the headline. Follow the knotting instructions illustrated in Figure 8.14. Then, wrap the other part of the ring around the boat's bitt to prevent the headline from retracting when removed from the winch.
7. Fasten the second extremity of the headline to the upper ring of the second mooring line. Once this is accomplished, untie the previously used temporary rope ring.

It is important to take into consideration that all headline ropes will experience elongation after their initial installation and will require subsequent tensioning, typically after a few months. This periodic tensioning is crucial for maintaining the desired level of tension in the headline. It is advisable not to trim any excess rope but to retain it as a precautionary measure in the event of damage or breakage.

FIGURE 8.14
Temporary knot used to keep the headline in tension during positioning

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Surface intermediate buoys

As outlined in Section 4.6.1, the interaction between the shape, volume and placement of the buoys and the suspended grow-out devices will impact the ultimate meat content, the shape and shell strength of the farmed oyster. This complex issue will be thoroughly examined in the subsequent Section 8.3.2.

Navigation markers

Once the designated site for farming has been established, it is vital to demarcate it with four navigation marker-buoys strategically placed at the four corners of the cultivation zone. These marker-buoys serve the critical purpose of alerting other water users to the restriction of navigation and anchoring within this area. To effectively deter interactions with the farming equipment, the markers should be positioned at least 50 m from any ropes or buoys constituting the farm's structural elements.

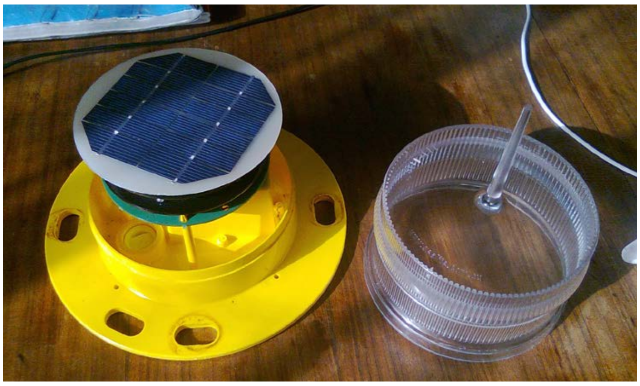
The local navigation authority will stipulate the specific type of internationally recognized markers to be employed in compliance with both national and international laws and regulations. A standard navigation marker typically comprises a floating buoy, distinguished by either a yellow "X" and/or a yellow flashing light mounted on a vertical pole extending above the buoy (Figures 8.15 and 8.16). Additionally, navigation authorities may specify the height of the yellow "X" above the water surface, the distance at which the light should be visible (typically 2–3 nautical miles), and the colour of the emitted light. In all cases, the navigation marker must be large enough to be detected by radar systems.

As an integral aspect of the licensing process, navigation authorities will incorporate the farm area into maps and electronic navigation systems utilizing GPS coordinates to precisely delineate its geographical position. This facilitates the utilization of navigation tools such as Chart Plotters to accurately demarcate the specific zones occupied by the long-line farm.

FIGURE 8.15
Example of a navigation marker
(a) The upper or exposed section with the "X" signal; (b) the lower or submerged section fitted with a shackle

The responsibility of determining the method by which navigation markers are anchored or moored typically falls upon the farm operator. Given their requisite distance of at least 50 m from the long-lines, these markers necessitate an independent anchoring and mooring system. The construction and installation of these anchoring and mooring mechanisms align with the procedures previously outlined in this chapter, albeit with one notable difference: the mooring line will remain in a predominantly vertical orientation.

FIGURE 8.16
Solar-powered LED warning light fitted on a marker-buoy



This aspect introduces durability concerns, as all applied forces act in a single direction. To mitigate and address this issue, various strategies with varying cost implications can be employed:

- Incorporate a bottom chain into the mooring line to enhance the even distribution of forces.
- Employ comparatively smaller buoys to diminish the applied force.
- Implement a dual anchorage and mooring line setup, originating from two distinct seabed points.
- Equip the mooring line with a safety rope affixed to the nearest long-line anchoring device to prevent the navigation marker from drifting away and potentially becoming lost should the primary mooring system fail.

Containment devices for oyster farming

Containment devices utilized in oyster cultivation can be categorized into four primary groups, all of which were introduced in Chapter 4:

- Lanterns with flexible mesh nets, often referred to as "lantern nets" (see Section 4.5.2; Figures 4.27 and 8.17).
- Lanterns featuring stacked circular hard plastic trays (see Section 4.5.2; Figures 4.29 and 8.17).

FIGURE 8.17
Different oyster containment devices
(a) A lantern made of five stacked circular hard plastic trays and a central support rope. (b) Pre-growing lantern nets fitted with a Velcro closure strip. (c) A stacked perforated unit comprising six holding trays. (d) On-growing lantern nets fitted with knotted mesh

- Suspended baskets (see Section 4.3.2).
- Suspended perforated trays (see Section 4.2.2; Figures 4.16 and 8.17).

Lanterns are widely use in offshore long-line farms, while the suitability of baskets in these conditions is still undergoing testing. However, it's important to note that their potential suitability should not be dismissed.

The selection of the containment devices and the configuration of both the long-line farm and the workboat are interrelated, with certain fundamental considerations to be observed:

- The lower section of the lantern, when fixed on the headline, should be no less than 5 m above the sea floor to prevent contact with the seabed during adverse weather conditions.
- Onboard lifting equipment must be appropriately designed to handle the chosen containment devices. Managing lanterns exceeding heights of 1.0–1.2 m will be challenging in the absence of a derrick or a crane.

Lanterns nets

Lantern nets are constructed with metallic frames (one independent ring for each level) and enveloped by a mesh net. These lanterns usually have from 5 to 20 levels depending on the specific models and manufacturer. Quality criteria for procuring lantern nets are described in Section 4.5.2.

The key characteristics of the models utilized in the farm outlined in this example are listed in Table 8.1. Numerous other models with varying dimensions and mesh sizes are readily accessible in the market.

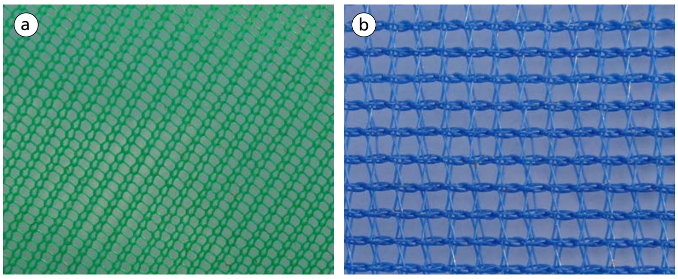
TABLE 8.1
Lanterns nets dimensions and mesh size

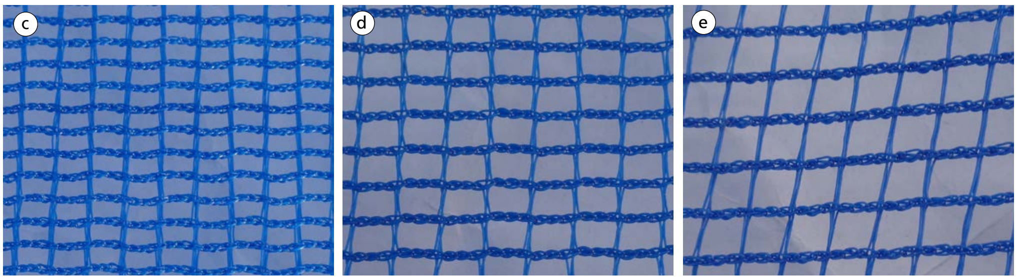
	Mesh size (mm)	Closure mechanism	Diameter (m)
Pearl nets (Rachel net)	1.0 × 0.8	Velcro strip	--
 ©E. Rambaldi	2 × 3		--
	3.5 × 5		--
	4.5 × 6		--
Pre-growing lantern nets (Rachel net)	0.8 × 0.8	Velcro strip	0.40
 ©L. Gennari	1.8 × 2.0		0.45–0.50
	2 × 3		0.45–0.50
	3.5 × 5		0.45–0.50
	4.5 × 6		0.45–0.50
On-growing Lantern nets (knotted net)	9 × 9	Plastic cord	0.50
 ©L. Gennari	12 × 12		0.50
	15 × 15		0.50
	21 × 21		0.50
	30 × 30		0.50

In the nursery and pre-growing phases, the utilization of "pearl nets" is a viable option, particularly when operating in sheltered conditions or during calm sea periods. These nets are compact, single-level lanterns measuring 35 × 35 cm (see Figure 4.28). They are constructed from monofilament "Rachel net" material, featuring a Velcro strip for effortless opening and closing of containment chambers. The total open surface area of the mesh relative to the total net surface varies from 75 to 85 percent as the mesh size increases (Figure 8.18). The square shape of the pearl nets is maintained by a metallic frame constructed from galvanized steel coated with PVC to mitigate oxidation and prevent rust formation. These units can also be fastened on top of one another.

In more exposed conditions for the pre-growing phase, it is recommended to employ multilevel lantern nets constructed from similar materials – namely, "Rachel net" monofilament, Velcro strips, and galvanized steel frames coated with PVC – with similar mesh characteristics. These lanterns typically feature 5 to 20 levels, each with compartments measuring 15–17 cm in height and a diameter ranging between 40–50 cm and are further reinforced with four lateral ropes measuring 5–6 mm Ø.

FIGURE 8.18
Rachel nets with different mesh sizes
(a) 0.8 × 0.8 mm
(b) 1.8 × 2.0 mm
(c) 2 × 3 mm
(d) 3.5 × 5 mm
(e) 4.5 × 6 mm





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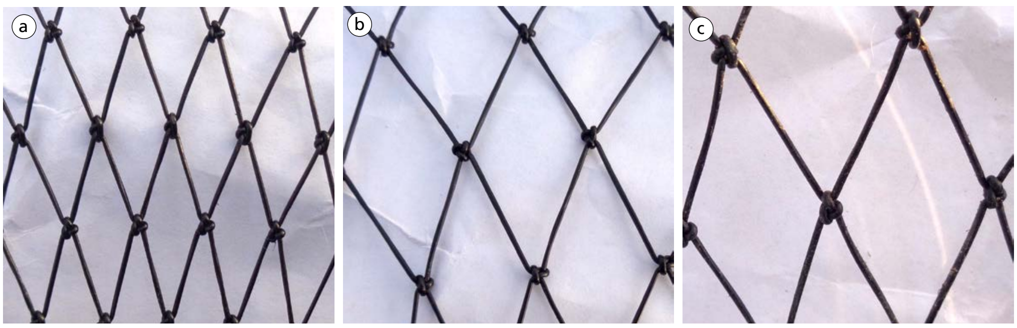
For growth to commercial size, the use of monofilament "knotted net" lanterns is advisable. These lanterns typically have the same number of levels and diameter as described above. However, the compartments have a height of 18–20 cm while closure of the containment chambers is achieved using a plastic cord, as illustrated in Figure 4.27. The total open surface area of the mesh relative to the total net surface varies from 85 to 95 percent as the mesh size increases (Figure 8.19).

FIGURE 8.19
Knotted nets with different mesh sizes
(a) 9 × 9 mm; (b) 15 × 15 mm; and (c) 21 × 21 mm



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Net lanterns assembly process

Net lanterns come equipped with lateral ropes that run along the exterior and extend beyond the top section. These ropes are subsequently secured by knotting them onto the dropper rope, which is suspended from the long-line. The length of the suspension rope will depend on the site characteristics and on the chosen cultivation strategy. It is important to note that the suspension rope can be longer than strictly necessary, and the distance between the top of the lantern and the headline can be determined when fastening the lantern onto the headline, allowing for some free slack in the suspension rope.

1. Prepare a single unit of double braid 16 mm Ø nylon rope measuring 2.0–2.5 m in length (see Figure 8.35).
2. Insert the rope into the upper ring created by the lateral ropes of the lantern, leaving a 0.5 m section of free rope to do the knot as shown in Figure 8.20.
3. Secure the rope in place using a thin 2–3 mm Ø nylon cord (Figure 8.20).

Ballast positioning on the pre-growing lanterns net

When employing net lanterns with spat, they may often be too buoyant, necessitating the addition of ballast to prevent excessive swaying caused by waves and currents. One effective solution is to affix a ballast weight ranging from 3–5 kg on top of the lanterns, as shown in Figure 8.21. It is crucial to securely fasten the ballast to prevent any shifting or loss.

FIGURE 8.20
A lantern net securely attached to a suspension rope

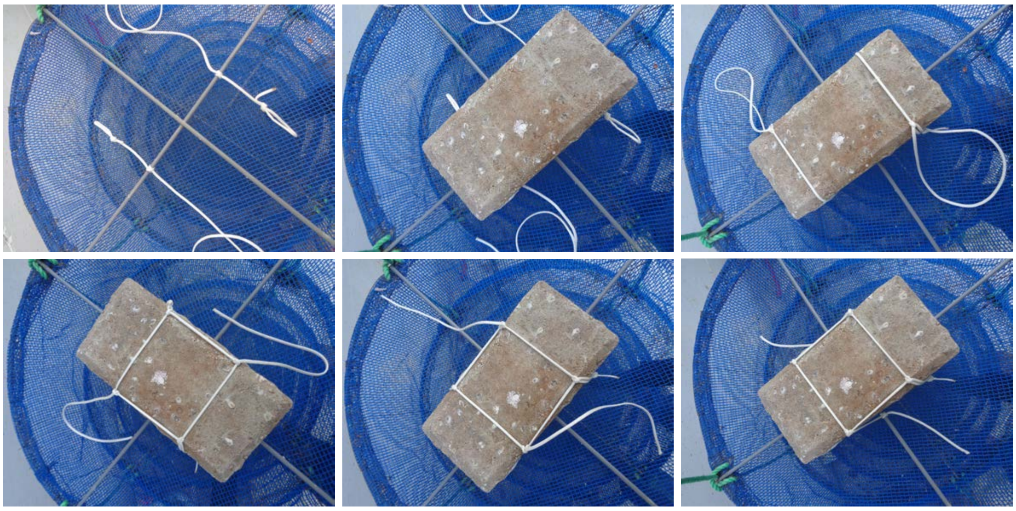
Hard plastic lanterns

Hard plastic lanterns are comprised of sturdy plastic trays arranged along a central axis or rope, stacked one atop the other. Criteria for assessing the quality and purchasing these lanterns can be found in Section 4.5.2. A comparative analysis of the advantages and disadvantages of hard plastic lanterns in contrast to net lanterns is presented in Table 4.4.

The model shown in Figures 4.29, 8.17a and 8.22 has the following specifications: each tray measures 11 cm in height and 60 cm in diameter, featuring square-shaped perforations of 9 × 9 mm on the bottom and elongated perforations of approximately 9 × 70 mm on the lateral sections. These lanterns can be assembled with anywhere from 5 to 12 trays, after which the total weight becomes excessive.

Lantern components are typically delivered separately for on-site assembly. To ensure the durability of these lanterns, it is important to fully insert the lateral elements into all the designated holes on the circular plate of the tray. In offshore conditions, it is advisable to employ a central rope instead of a PVC axis that may break under stress.

FIGURE 8.21
Ballast positioned and secured on top of a lantern net



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Assembly and closing of hard plastic lanterns

The length of the suspension rope will be determined based on site-specific characteristics and on the chosen cultivation strategy. The suspension rope can be longer than strictly necessary, and the distance between the top of the lantern and the headline can be adjusted when securing the lantern onto the headline, allowing for some slack in the suspension rope.

1. Begin by preparing a single unit double braid 16 mm Ø nylon rope, ranging from 3.5–4 m in length (see Figure 8.36).
2. Thread the rope through the PVC perforated plate and tie a knot as illustrated in Figure 8.22a. Ensure the knot is securely tightened and consider reinforcing it with a plastic cable tie for added stability.
3. Insert the desired number of trays and the two closing elements, then tie a knot as depicted in Figure 8.22b. It is crucial to secure the knot tightly to prevent the trays from shifting along the rope. See Figure 8.22c for the assembled lantern.

FIGURE 8.22
Assembling a hard plastic lantern unit
(a) Bottom knot of the supporting rope; (b) upper knot around the closing elements; and (c) an assembled lantern ready for employment

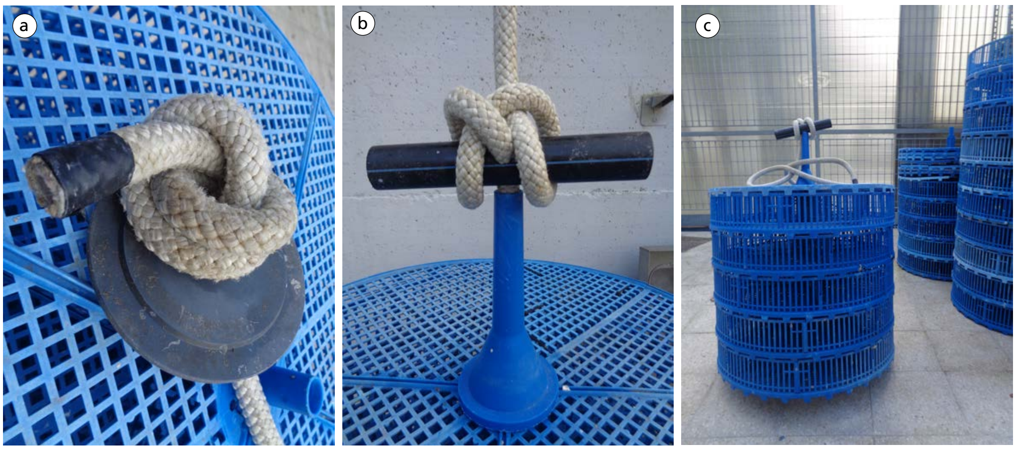

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FIGURE 8.23
Securing the closure of a hard plastic lantern to prevent loss of small oysters

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Once assembled, empty lanterns can be stored separately, although this may lead to a significant utilization of space as they are not easily stackable. Since the lanterns will need to be disassembled for oyster filling (as outlined in Section 8.3.2), the trays can be stored in stacks comprising 15–20 units, each accompanied by its related ropes and closing elements placed in one of the trays.

Due to the influence of waves and currents, lantern trays assembled using a central rope may experience slight movement, resulting in gaps of 1–2 cm appearing between the trays. As a result, small pre-grown oysters may become dislodged and lost. To mitigate this issue, it is recommended to secure the trays in place using a thin rope (2–3 mm Ø) or by employing a metal rod, as shown in Figure 8.23.

8.2.2 Farm layout

The layout of the long-line farm will be determined by the site topography. The farm depicted in Figure 8.3 serves as a typical example of a layout applicable when there is relatively ample sea space. Nevertheless, it is important to note that each site is unique and comes with its own set of constraints. Therefore, farm layouts will vary significantly to maximize cultivation space within the physical constraints of the designated area. Several key considerations must be made:

- The distance between the lines should be a minimum of three times the length of the workboat. This spacing allows for easy access to the headlines and facilitates lifting operations.
- To enhance navigation efficiency within the farm, it is preferable to employ a square farm layout over a rectangular one.
- In cases where lines are designed with lengthy headlines and intermediate legs, it is crucial to ensure that the maximum line length does not exceed 500–1 000 m. This ensures navigation space at both ends of the lines.

As emphasized in the preceding section, the design of a long-line aquaculture farm is a complex engineering endeavour. It is strongly advisable to seek consultation from a specialist to obtain comprehensive information and cost estimates. Additionally, it is important to recognize that the design of long-lines, the choice of the workboat (including propulsion and equipment), and potential onshore facilities are interdependent factors that must be considered collectively rather than in isolation.

8.2.3 Access to the farm

The workboat is at the centre of the farming operation, serving as the sole means of accessing the farm. It is therefore vital that the chosen vessel is appropriately designed and sized to align with the intended production capacity and the farm's location. In addition to specific functions like headline lifting, the workboat must be versatile, as it will be required to undertake a diverse array of tasks.

The workboat design must encompass the following primary functions:

- Appropriate propulsion system and hull design to facilitate navigation between the harbour and the farm, taking into consideration factors such as distance, local meteorological conditions, required harvesting and transport capacity.
- Adequate propulsion system and hull design to facilitate manoeuvres among the long-lines within the farm.
- Properly equipped with machinery to efficiently lift the headlines from the water and carry out harvesting procedures.
- Equipped with the necessary machinery and systems for on-board farming operations.
- Sufficient deck space to accommodate the installation of required equipment and to facilitate the execution of all on-board operations.
- Suitable hull shape for accessing to the landing facilities in accordance with the water depth at the harbour.

The vessel used as an illustrative example in this section embodies the essential characteristics necessary for effective operation in offshore long-line farming. The following sections initially provide descriptions of the onboard equipment essential for farming operations and then delve into the discussion of their potential adaptations to various conditions and purposes.

Workboat and basic on-board equipment

Hull shape, deck space and propulsion system

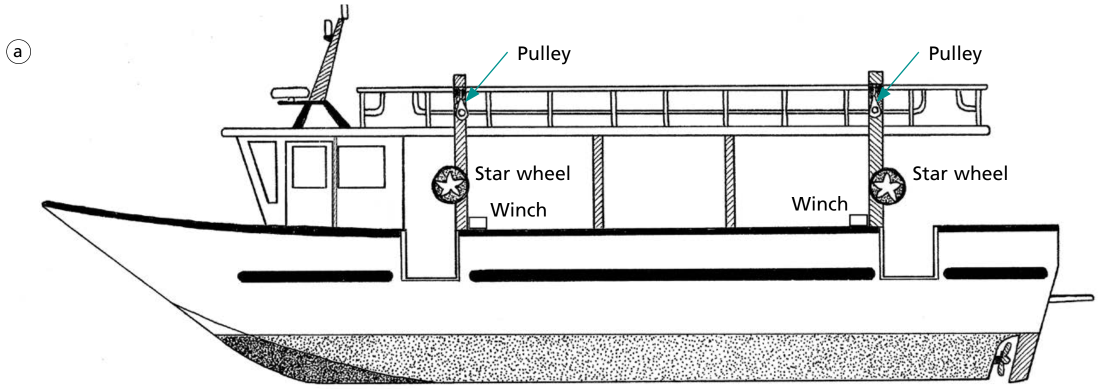
The workboat, described here as an exemplar, has been designed to facilitate navigation between the long-lines, ensure a stable platform for on-board personnel, and ensure swift travel, given that the farm is situated approximately 6 nautical miles from the harbour (Figure 8.24). It boasts dimensions of 17.6 m in length and 5.22 m in width, with a gross tonnage of 8.38 tonnes and a net tonnage of 5.70 tonnes. These specifications are well-suited for managing approximately 12 000–15 000 m of long-lines in an offshore and exposed site.

The propulsion system for navigation consists of twin diesel inboard engines of 185 HP (1 HP = 0.75 Kw) driving two propellers, one to port and one to starboard. These two engines are used only when moving between the harbour and the farm or moving from a line to the next. The availability of two independent engines, each with adjustable power settings, enables precise manoeuvring and significantly aids in the headline lifting procedure, detailed in the next section below. Alongside the primary navigation engines, the vessel is equipped with a small motor located in the submerged section of the hull toward the bow, known as a "Bow thruster" used to increase the manoeuvrability of the vessel. The propeller, positioned within a circular aperture that spans from one side of the hull to the other, occupies the entire diameter of the opening. This system proves particularly valuable when countering the effects of surface currents, winds, and waves during headline retrieval manoeuvres.

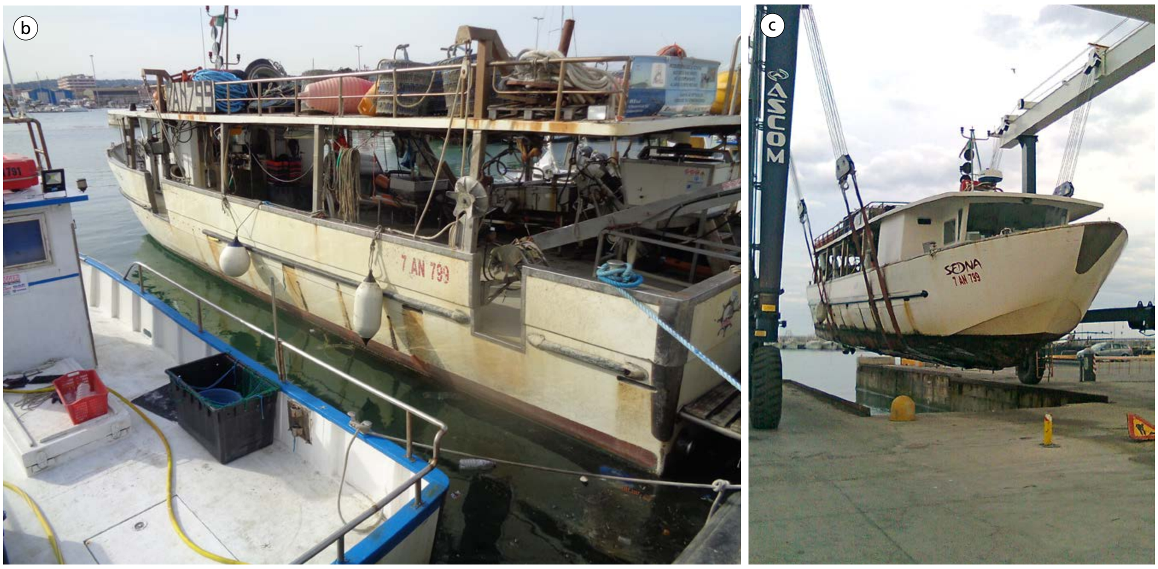
FIGURE 8.24

A typical long-line farm workboat utilized in the Adriatic Sea, Italy

(a) Technical illustration of the vessel: (b) a side view photograph; and (c) a hull view on the gantry



Source: Elaborated by the authors.



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The "V" shaped hull design facilitates rapid navigation, achieving speeds of up to 9 nautical miles per hour, while keeping fuel consumption relatively economical. The vessel's width of 5.2 m ensures stability during onboard operations and provides ample deck space for equipment installation, product handling, temporary storage, and staff mobility (Figure 8.25).

It is worth emphasizing the importance of maintaining a hull draught at a depth that minimizes the potential for propellers coming into contact with the headlines.

The workboat is additionally equipped with an auxiliary diesel engine that operates a hydraulic pump, serving as the power source for all on-board machinery. This includes the two star wheels and two winches employed for elevating the headlines from the water, as well as the conveyor belts, graders, and various other machinery used in oyster handling. The auxiliary engine can be utilized either when a headline is positioned on the star wheels with the navigation engines turned off or during navigation when traveling between the harbour and the farm, and vice versa.

Headline lifting equipment

Elevating the headlines and the oyster containers they support from the water, represents the fundamental operation in long-line farming. The choice of method varies depending on the farm design and the size of the workboat. Options range

FIGURE 8.25
Deck space on a typical long-line farm workboat used in the Adriatic Sea, Italy

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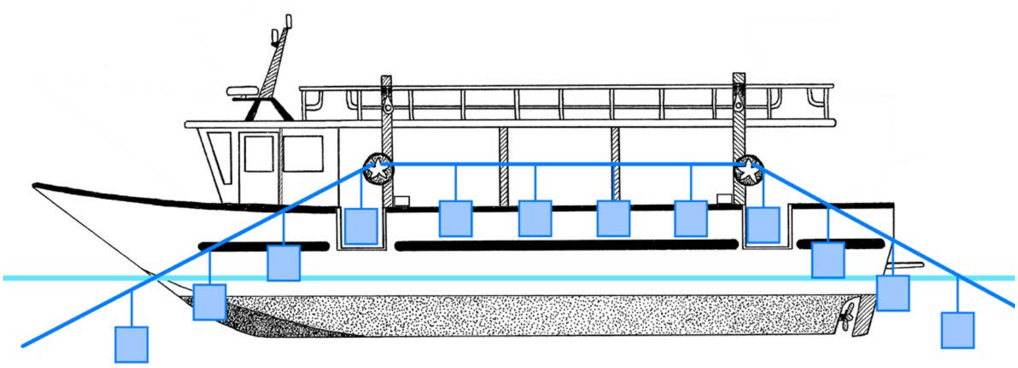
from manual lifting devices on smaller vessels (8–15 m in length) to mechanical lifting solutions involving cranes or winch-based equipment installed on larger workboats.

On larger and medium-sized workboats, the fundamental approach involves hoisting the headlines from the sea to a level where operators can easily inspect, remove or re-suspend the culture devices housing the oysters (Figures 8.26 and 8.27). The initial step involves hoisting the headline from the water when the vessel aligns parallel to the headline. Subsequently, the headline is positioned atop two apparatus known as "star wheels" or "star rollers" which are set in motion by their hydraulic motors. Manipulating the rotation direction of the star wheels enables forward or backward movement along the headline and, as the headline is anchored to the seabed, it is the boat that adjusts its position along the headline (navigation motors are deactivated

FIGURE 8.26
Workboat with headline placed over two star wheels



Source: Elaborated by the authors.

FIGURE 8.27
Headline with a hanging oyster lantern suspended from a star wheel

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during this phase). Each star wheel is equipped with a lever that enables it to change direction and adjust its speed.

The workboat described as an example is equipped with a hydraulically powered winch-based system designed for lifting headlines. The various components that make up this system are detailed below, while the technique for lifting headlines is elaborated in Section 8.2.4.

The system illustrated in Figures 8.28 and 8.29 comprises the following elements and exhibits uniformity at both the stern and the bow:

- An anchor and its rope utilized for grasping the headline when submerged beneath the water surface;
- A winch for retracting the anchored headline after it has been hooked;
- A support structure with a pulley, used to elevate the anchor and headline beyond the height of the star wheels;
- A star wheel serving as a support for the headline when it is lifted out of the water.

The anchor must possess sufficient strength and weight to quickly sink and reach the headline. However, it must not be overly heavy, as the operator needs to throw it 5–6 m away from the side of the boat. The rope should be 20 m in length, with one end attached to the anchor and the other end securely tied to the boat's gunwale to prevent loss overboard. A double-braid nylon rope is recommended for this purpose.

Each winch is equipped with a lever that enables the adjustment of the direction of rotation and regulation of the speed.

The pulley on each hoist arm is vertically aligned with the underlying star wheel. It is important that the distance between the pulley and its corresponding star wheel exceeds the length of the anchor. This configuration is crucial to facilitate smooth operations during the insertion of the headline rope onto the star wheel.

Different designs of star wheels are available, and the selection of a model should be guided by the following criteria:

- The number of arms on the star element should range between 5 and 8.
- The shape and length of the arms must facilitate the free movement of the headline while preventing it from becoming dislodged.
- The distance from the extremity of the arm to the circular support element must be adequate to prevent entanglement or wedging of the ropes.
- The hinged bracket designed for affixing the star wheel to the supporting pole should provide adjustability for both the height and inclination of the roller.
- All components of the roller must exhibit a flawless, smooth surface to prevent chafing and damage to the headline ropes.

The entire system was engineered for mussel socks with a diameter less than or equal to 20 cm. As a result, it is not fully compatible with oyster culture structures which normally have a diameter ranging from 50 to 60 cm. The larger size of these devices increases the likelihood of contact with the boat's hull, thereby posing a potential risk of damage to the apparatus.

FIGURE 8.28
Images of the headline lifting device positioned at the prow of the workboat

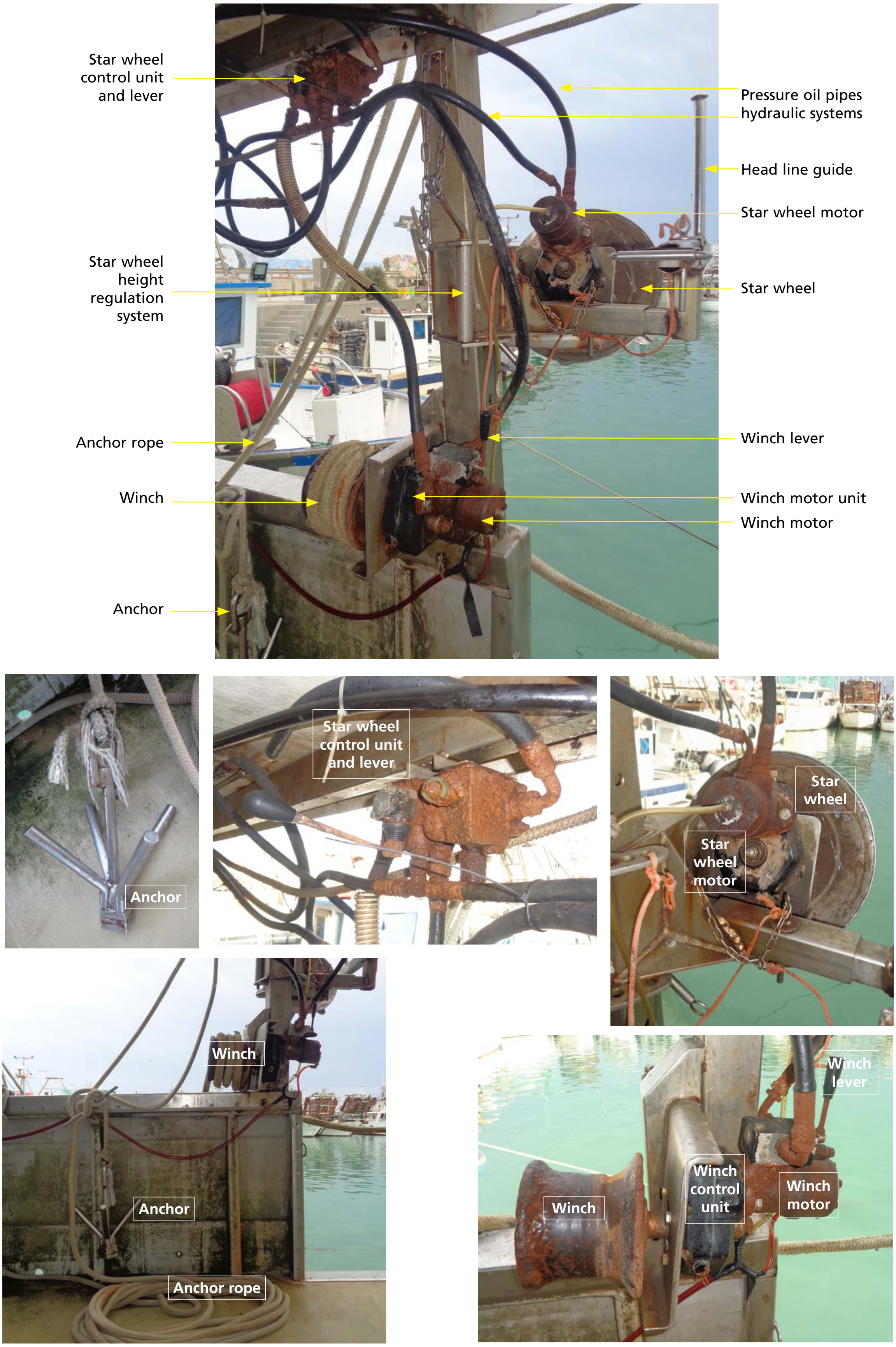


FIGURE 8.29
Images of the headline lifting device positioned at the stern of the workboat

Other on-board basic equipment
The boat should be outfitted with a saltwater pumping system to ensure a continuous water supply during both operational and navigational activities. This system can be powered either by one of the main engines or by the auxiliary engine.

In addition to the essential pumping system, the boat should be equipped with chart plotters for electronic navigational aids. Integration of a VHF radio is also crucial, facilitating communication with other water users operating in the vicinity.

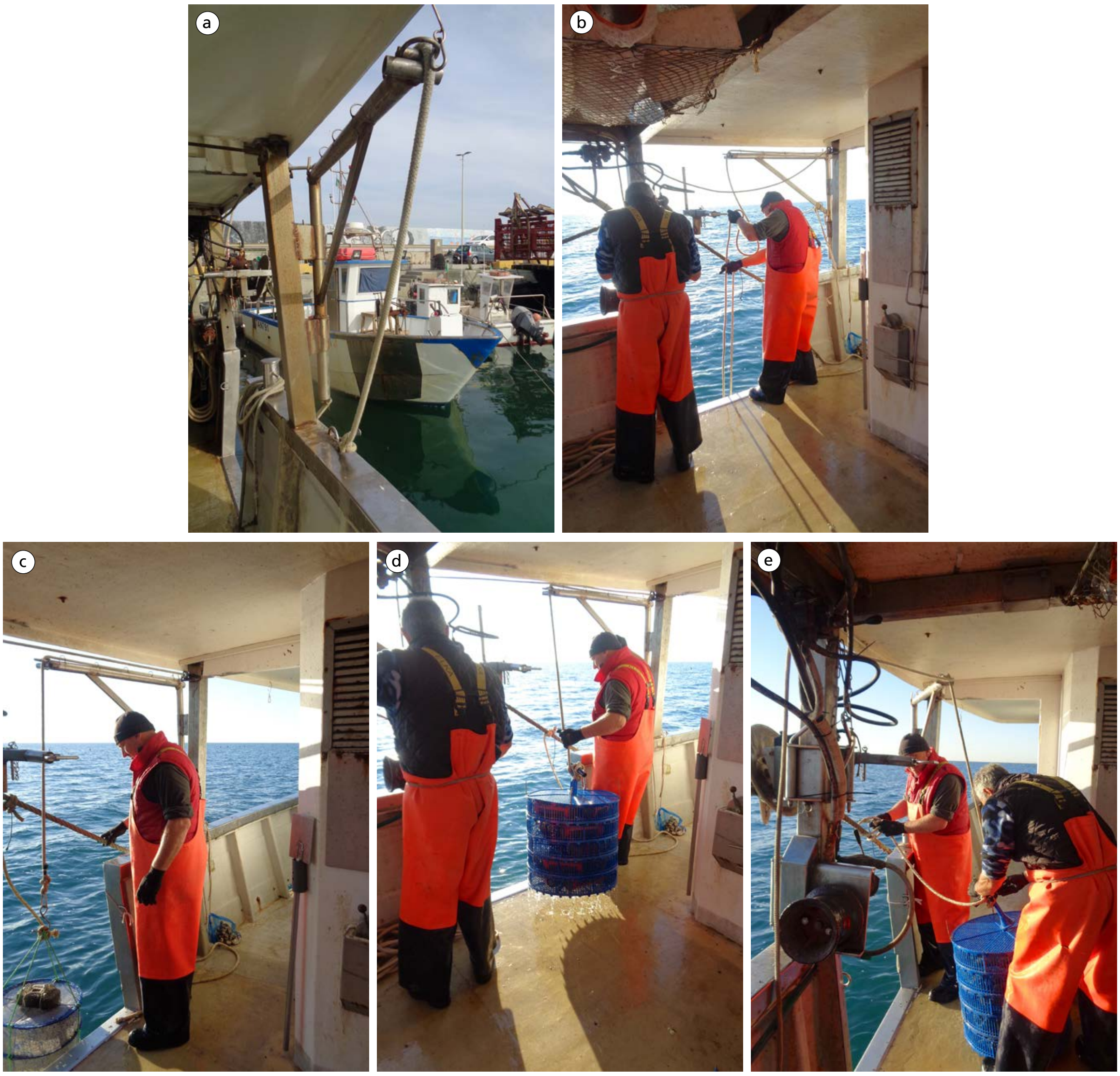
Finally, considering that certain equipment onboard may necessitate either single or three-phase electrical power, it is advisable to install a small generator capable of producing the required power output. This ensures a reliable and versatile power source to accommodate various electrical demands.

Specific on-board equipment

Oyster lantern deck lifting device
Given that oyster lanterns can weigh over 40 kg upon harvesting, a system is required to facilitate the transfer of lanterns from the headline, positioned on the star wheels, to the deck, minimizing the physical strain involved in the process. While the installation of an on-board crane is the optimal solution for this task, it is frequently impractical on a boat not specifically designed for such a purpose.

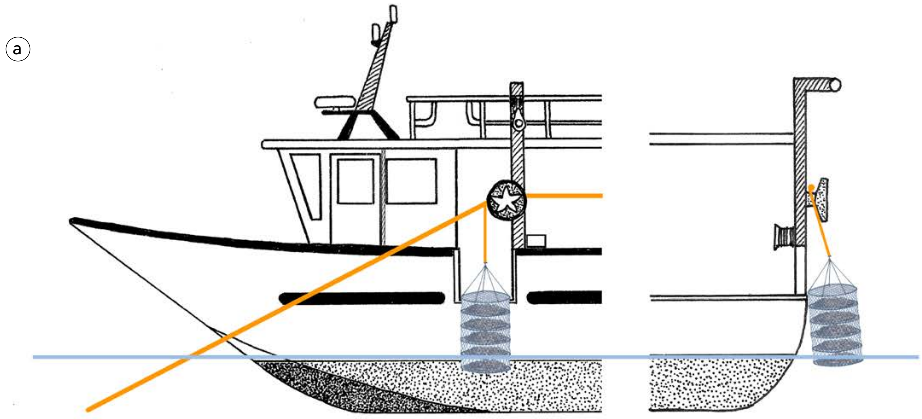
In the presented workboat example, where the installation of a crane was not possible, an alternative system was adopted and positioned near the bow as illustrated in Figure 8.30. This system features a compact rotating derrick equipped with an "S"-shaped grapple at the end of a 16 mm double braid rope, designed to secure the lantern at its upper section. Once the lantern is hooked, the winch is employed to hoist the rope. Once the lantern's bottom aligns with the side opening and reaches deck level, the operator can guide the lantern on board for subsequent operations. An alternative solution could have been to install a sliding metallic arm beneath the deck's roof instead of employing the derrick. These two options are illustrated in Figure 8.31.

FIGURE 8.30
Device and steps for lifting and lowering oyster lanterns onboard the workboat
(a) View of the rotating derrick; (b) hooking the lantern to be lifted; (c) lifting the lantern; (d) hoisting the lantern onboard; and (e) securing the lantern to lowering back at sea

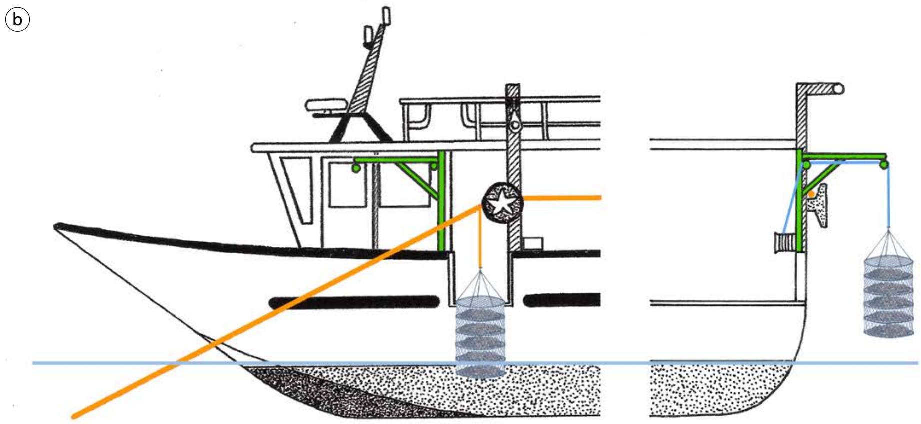


It is important to note that this technical solution imposes a restriction on the use of lanterns exceeding the vertical distance between the deck and the roof. Moreover, the limited width of the opening along the side of the boat increases the difficulty and time involved in the operation, with an increased risk of potential damage to the lanterns.

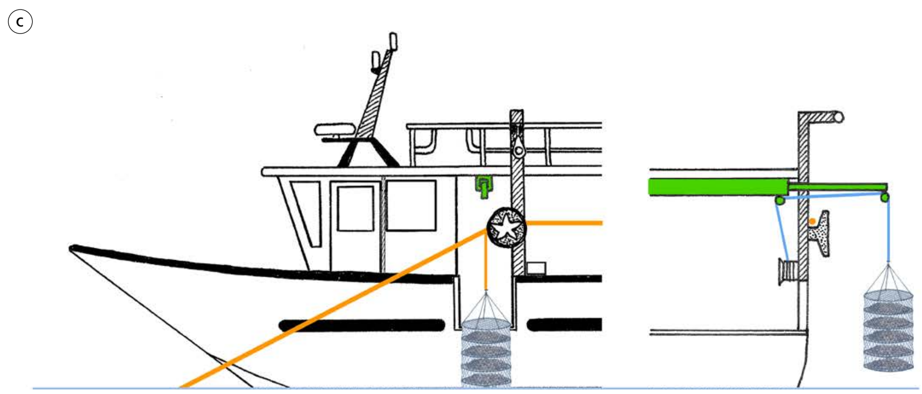
FIGURE 8.31
Different lantern lifting systems
(a) Traditional mussel socks lifting device; (b) vessel fitted with rotating derrick; and (c) fitted with a sliding metallic arm



Lifting lanterns with on-board equipment on a traditional mussel vessel requires some adaptation to prevent lantern damage and enhance efficiency. Two additional and improved devices are detailed in (b) and (c) below.



A rotating derrick paired with a lifting rope, one end of which is equipped with a hook for securing and lifting the lantern, while the other end is wound around the winch.



A robust metallic sliding arm paired with a lifting rope, one end of which is equipped with a hook for securing and lifting the lantern, while the other end is wound around the winch.

Source: Elaborated by the authors.

Graders

The growth rate of individual oysters varies, leading to a diverse range of sizes that will require separation. This task is accomplished through the utilization of grading equipment, as detailed in Section 4.6.2. Two options are available for grading harvested oysters: either loading them into containers for transportation to shore-based facilities or conducting grading on the workboat itself. Undertaking this process onboard presents a dual advantage. Firstly, it eliminates the need for unnecessary transportation of oysters to shore-based facilities and back, saving time and reducing double handling. Secondly, the oysters can be quickly returned to the water reducing possible mortality after the grading process.

On-board grading can be performed using vibration graders or rotating graders (see Section 4.6.2), which are suitable for half-ware or commercial-size product. Conversely, "in-water" graders cannot be utilized onboard due to the oscillations induced by wave action, preventing grading except in completely calm sea conditions.

Bagging machine

If the harvested oysters are destined for sale as live products in their shells, they must be placed into bags or crates for offloading before undergoing additional depuration and/or packaging in a controlled land-based facility.

Pressure washer

If land-based facilities are unavailable for lantern washing, an on-board pressure washer becomes essential for cleaning both equipment and lanterns. Depending on the boat design, two solutions are possible:

- The pressure washer can pump saltwater, allowing the operator to conduct cleaning tasks on the boat, during navigation, or while in the harbour. Lanterns can be emptied and washed while navigating between the harbour and the farm, thereby saving time.
- The pressure washer is only designed to work with freshwater when connected to a supply point in the harbour.

In the first scenario, two potential issues may arise: corrosion of the equipment due to saltwater and the risk of organisms and/or debris in the water column obstructing the water intake. If a freshwater supply point is available at the harbour, the corrosion process can be mitigated by rinsing the equipment when back from the sea. In the second scenario, there is a possibility that harbour authorities or other port users may object to the discharge of dirty water resulting from washing into the harbour.

It should be noted that the initial investment and ongoing maintenance costs for a saltwater washer (including its filtering unit and its connection to the on-board hydraulic or electric power) will be considerably higher than those for a freshwater washer. The latter can be purchased in any hardware store with additional options, such as pressure regulation, which is useful as the water jet pressure required for net lanterns differs from that required for hard plastic lanterns.

Workboat design and variations

The workboat utilized in the described example was initially designed for mussel farming and subsequently adapted for both mussel and oyster farming. Given the evolving nature of long-line oyster farming, which is still in the early stages of development and automation, certain considerations must be taken into account.

Possible adaptations to the workboat and on-board equipment

Certain limitations, such as the maximum weight and dimensions of the oyster culture devices that can be lifted, and the potential risk of damage during lifting operations, can be addressed by employing a crane in lieu of the previously described winch-based system. Workboats equipped with a suitable crane offer numerous advantages, including:

- The ability to lift the headline and place it on the star wheels in a single, swift operation.
- It allows for the lifting and lowering of lanterns onto the deck or over the side of the boat without risking damage to stock or equipment. Additionally, taller lanterns can be accommodated.
- The crane can substitute conveyor belts for landing and loading operations.

Performing these functions on the workboat involves handling heavy items on and off the vessel. Therefore, a crane with adequate reach and lifting capacity is essential for efficient farming operations, as illustrated in Figures 8.32 and 8.33. Further details and recommendations on crane capacities and installation can be found in Section 7.2.3.

FIGURE 8.32
A bivalve long-line workboat equipped with a stern-mounted crane

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It is also important to note that the use of a crane requires a free and unobstructed area, which may lead to a reduction in deck space and storage capacity for farm equipment and empty lanterns. In the design phase of the workboat, it is crucial to consider the diverse tasks at hand, emphasizing the need for an adaptable deck space. A flat and partly open deck configuration is recommended to facilitate easy customization according to the specific tasks to be accomplished.

Finally, the stability of the workboat can be enhanced by employing multihull and pontoon-style hulls.

Possible adaptations according to the availability of land-based facilities
It is also important to assess whether land-based facilities are essential to complement the long-line farm and, if so, determine the optimal size and required functions for these facilities. The necessity for land-based facilities, or lack thereof, will impact the size of the boat required for farming operations.

If the product is intended for meat extraction, space and procedures to facilitate shell hardening, which would have been challenging to carry out on-board, are unnecessary. On the contrary, if the oysters are intended to be sold as raw products in their shells, both hardening and fattening processes will have to be carried out on-board or in land-based facilities.

FIGURE 8.33
Hoisting oyster lanterns aboard a workboat using a crane

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Other challenges arise from the complexities associated with either pre-growing small seed in offshore conditions or grading seed and juveniles on-board which would perfectly justify carrying out these activities on land-based facilities.

Consequently, an in-depth analysis of the proportion of space required between on-board and land-based facilities, along with considerations for offloading/loading conditions, must be conducted during the site survey and project planning phase. The decision on whether to perform specific operations on-board or at land-based facilities will hinge on production objectives and significantly impact the future organization of the farm and associated costs.

To circumvent the need for substantial investments in land-based facilities for oyster pre-growing, hardening or fattening, an effective solution is to initiate the production cycle with partially grown oysters sourced from independent specialist farms capable of supplying such stock and to transfer the end-product to other farms where final hardening and fattening can be carried out.

Optimizing work on-board

Another consideration revolves around the deck space necessary for all handling procedures, from lifting the farmed product to its return to the sea. This allocation is essential to ensure the efficient execution of all necessary procedures. Efficient deck operations are paramount, with a preference for avoiding temporary onboard storage of the farmed product. Such storage not only occupies valuable space but also results in time wastage. In a scenario where only three individuals are involved, all operators would initially harvest, grade and store the oysters in temporary crates. Subsequently, in a separate phase, they would fill the lanterns and return them to the sea. On the other hand, in a 6-person team, three operators would focus on harvesting and grading the product, while the remaining three would handle the filling and re-suspension of the lanterns. This strategy not only enhances efficiency but also opens avenues for further automation and cost savings, as discussed in Section 4.3.2 (see Figures 4.22 and 4.23).

Conclusion on workboat size and design

- A workboat equipped with a crane is the preferable choice.
- Deck space should be carefully organized, considering both onboard tasks and spatial requirements for farming devices, cleaning, maintenance and temporary storage.
- An additional land-based facility, preferably covered and in proximity to the landing site, is necessary for the storage of buoys, lanterns, baskets, etc. This area could also prove beneficial for the cleaning and maintenance of culture devices and unused equipment.
- In the case of oysters produced for raw consumption, it is essential to have land-based facilities integrated into the farm or establish collaboration with an external farm. These facilities are necessary for conducting pre-growing, hardening, and final fattening activities.
- Automation should be explored and developed to reduce the physical strain of handling tasks, enhancing the profitability of offshore farming.

These considerations collectively contribute to the efficiency, organization, and overall success of the farming operation.

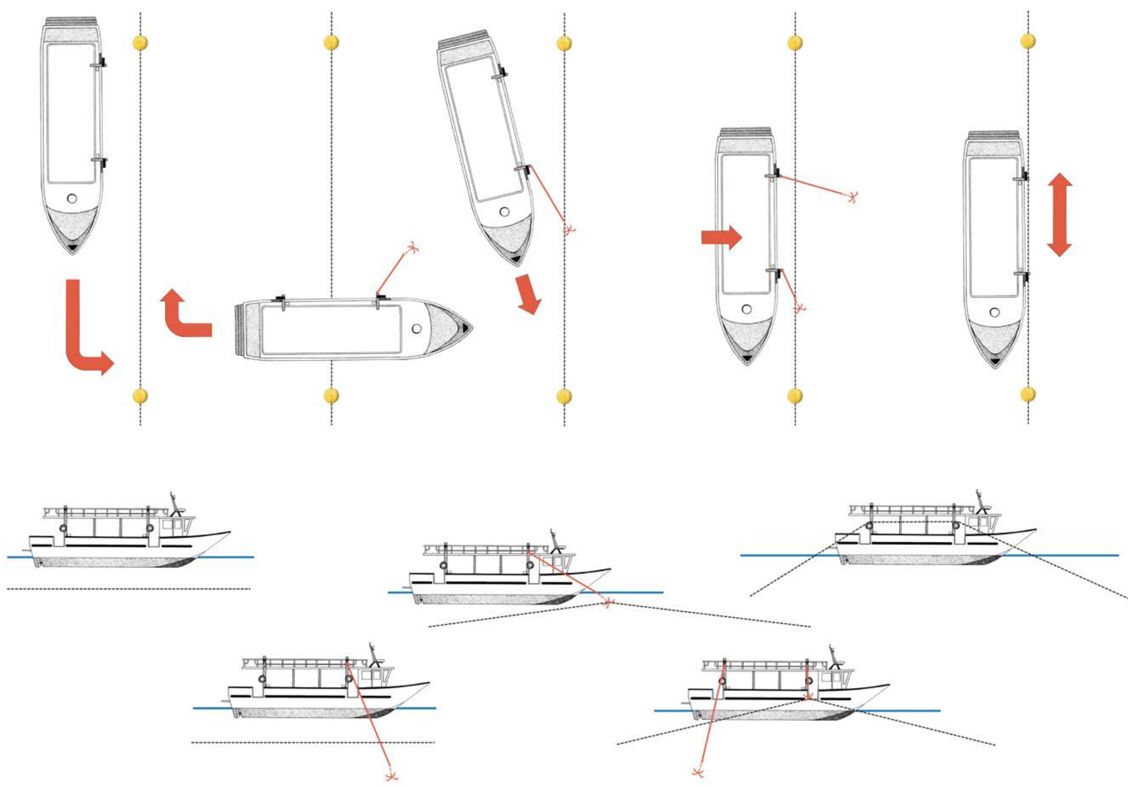
The challenges highlighted above underline the necessity of conducting mussel and oyster farming separately on dedicated long-lines and utilizing specially designed workboats. Tailoring the design of the vessel to the specific operating environment is crucial, and it is recommended to engage with a local and experienced boatyard. Such collaboration will also ensure ongoing maintenance support to keep the boat in optimal operating condition. Effective collaboration between the farmer and the company responsible for building the workboat is crucial for a successful design. It is important to emphasize that the design of long-lines, workboats, and potential land-based facilities are interdependent aspects that should not be addressed in isolation.

8.2.4 Headlines lifting techniques

The headline lifting procedure illustrated in Figure 8.34, requiring a minimum of two operators, can be divided into five steps:

1) While the boat navigates parallel to the headline to be lifted, the boat captain turns the boat in the direction of the headline and positions it perpendicular to the headline, ensuring that less than half of the total length of the vessel is over the headline. It is crucial to keep the vessel's propellers as far away as possible from both the headlines and the ropes of the buoys to prevent entanglement.
2) Once the boat is in position, a second operator deploys the bow anchor overboard, giving it enough time to sink below the depth of the headline. Following this, the boat captain reverses the boat and keeps it at an angle of 20–50° to the headline. This manoeuvre allows the anchor to hook onto the headline. When the rope is under tension, the operator winds it up on the winch and begins pulling to keep it taut.
3) As the second operator manoeuvres the bow of the boat close to the headline by pulling the rope of the stern anchor, the captain reverses direction, moving the boat forward. Once the boat is once again parallel and in proximity to the headline, the captain places the two motors in the neutral position and shifts to the bow winch, taking over from his colleague, who now moves to the stern.
4) The second operator deploys the stern anchor over the headline, allowing it time to sink below the depth of the headline. Upon feeling tension on the rope, the operator promptly winds it up on the winch and begins pulling to maintain tension on the rope.

FIGURE 8.34
The workboat successive manoeuvres to hook and lift a headline onto the star wheels



Source: Elaborated by the authors.

5) The second operator proceeds to manoeuvre the stern of the boat near the headline by pulling the rope of the stern anchor. At this point, with both anchors securing the headline suspended over their respective star wheels, the operators slowly release the winches simultaneously to facilitate the lowering of the headline onto the star wheels.

8.3 FARMING PRACTICES

This chapter provides guidance on the farm management practices essential for the successful growth of oysters from the "T6" spat size to market size in offshore conditions. It is important to note that information pertaining to dividing and grading schedules, as well as the quantity of oysters introduced into lanterns, serves merely as guidance. Each culture site is characterized by its distinct environmental parameters, influencing the growth and development of the oysters. Consequently, farmers must formulate a management strategy tailored to these site-specific factors.

Several specific issues are associated with offshore long-line cultivation:

- Oysters are permanently submerged throughout the cultivation cycle, engaging in continuous filter feeding. This results in accelerated growth compared to oysters farmed in the intertidal zone under identical climatic conditions. Moreover, in regions with elevated water temperatures, growth rates further escalate, significantly impacting product quality.
- In contrast to oysters cultivated in bags on trestles or directly on the seabed, those on long-lines experience constant tumbling induced by currents and waves. This tumbling is highly variable, challenging to regulate, and contingent upon diverse factors, including seasonal weather patterns, the configuration and choice of containment devices, their suspension method, as well as the shape, volume, and positioning of buoys, along with oyster densities.

- In comparison to littoral waters, offshore waters frequently exhibit reduced nutrient levels.
- Oyster handling time is much longer compared to alternative cultivation techniques, primarily due to the distance from the shore, the manoeuvres required to lift the headlines, on-board operational complexities, and often limited automation.
- Biofouling poses a potential issue as culture structures are consistently submerged and are never exposed to either air or sunlight.

These constraints may have an impact on both the quality of oysters and the profitability of the operation, potentially leading to the following outcomes:

- Oysters may incur damage during handling and harvesting, attributable to their generally thin and brittle shells.
- There is a risk of low meat content (see Section 2.2.2).
- Development of small and weak adductor muscles, leading to a reduced shelf life (see Section 2.2.3).
- Frequent occurrence of irregular shells with anomalous proportions in terms of length, width and thickness (see Section 2.2.4).
- The operation may incur relatively high investment and production costs, further impacting overall economic viability.

If oysters are cultivated solely for their meat, the aforementioned considerations can be disregarded, and the cultivation strategy should be oriented toward achieving the maximum meat content in the shortest time possible. It is important to note that this specific strategy is not addressed in the current chapter.

However, if oysters are intended for sale as a raw product, three distinct approaches can be considered:

- Execute the complete production cycle, spanning from "T6" spat to commercial size, within offshore conditions.
- Initiate the offshore production cycle by introducing pre-grown oysters that have already achieved optimal shell shape and strength, as well as robust adductor muscles.
- Transfer oysters of commercial size to more suitable sites for a final fattening/hardening period.

In all these scenarios, the farmers must recognize that meat content, shelf life and shell characteristics of the oysters are interdependent and cannot be addressed in isolation. The ultimate quality of the product hinges on the comprehensive farming strategy employed, starting from the nursery stage.

The cultivation strategy outlined in the following sections delineates the techniques employed to execute the complete production cycle in offshore conditions, with a focus on addressing various compromises to mitigate the aforementioned disadvantages.

The key strategies can be summarised as follows:

- Implementing the appropriate hanging layout and maintaining optimal oyster densities within the farming holding devices are crucial for achieving "optimal tumbling." Oysters must be evenly distributed and free to move in their container, facilitating partial erosion of the shell margins, enhancing a desirable shell shape and optimal meat content. However, a delicate balance must be struck to avoid scenarios where oysters clump together, resulting in only external oysters achieving normal growth rates, or excessive movement leading to the complete destruction of shell margins and reduced survival rates.
- Grading practices must be sufficiently "rough" to stimulate oysters to thicken their shells and prioritize meat production over shell growth.
- Maintaining an appropriate low-density stocking level is essential to facilitate effective "tumbling" and compensate for the comparatively low nutrient levels in offshore waters.

Both oyster grading and lantern hanging practices are relevant during both the pre-growing and growing stages. These aspects are introduced below, with detailed information provided in Sections 8.3.1 and 8.3.2.

Grading

The grading process enables several different outcomes:

Size-based separation: Grading primarily involves separating oysters based on size, ensuring that individuals within a batch are grouped with others of similar size. This is crucial to provide every oyster with the opportunity to feed and grow without facing competition for nutrition. If larger, faster-growing oysters coexist closely with smaller, slower-growing counterparts, the larger individuals may dominate the nutrient competition. If this persists, the smaller oyster can become a "runt", permanently stunted and unlikely to reach marketable size. On the other hand, timely separation allows slower-growing oysters to comfortably reach market size, albeit with a slightly prolonged culture period.

Shell conditioning: Tumbling during grading will knock off some of the new shell growth around the frill, encouraging the oysters to increase meat content, thicken their shells and develop an even shape, particularly desirable if the oysters are sold in their shells.

Removal of predators and competitors: Oyster predators that entered the lanterns in their juvenile form can pose a threat when they reach a size and strength enabling them to pry open the oysters or cause damage to their shells. During the grading process, the oysters are thoroughly washed, and any predators and food competitors are removed. Post-grading, the oysters are reintroduced into clean lanterns. In fact, regular cleaning of the culture devices and the cultured oysters is crucial in maintaining a constant flow of oxygen and nutrient-rich waters over the oysters, thereby enhancing their growth.

Monitoring and data collection: The grading process offers an opportunity to measure stock development accurately, assess quality and record growth data and enables farmers to take adaptive measures.

In the farm example described in this chapter, manual grading is done during the nursery and pre-growing stages, from "T6" to 3–5 g oyster spat. Subsequently, mechanical grading is carried out during the growing stage until the oysters attain the desired commercial size.

Lanterns hanging

In the specific farm example presented in this chapter, consistent hanging practices are employed for all lanterns, spanning from the nursery stage to the growing stage.

Lanterns are hung along the headline, maintaining a distance of 1.5–2.5 m apart (the space between the two suspension ropes). During winter, this distance is increased to minimize the likelihood of lanterns coming into contact with each other, while in spring and summer, a shorter distance is applied to enhance farm production, considering the reduced risk of contact and the higher concentration of phytoplankton.

Concerning the distribution of buoys, the traditional system involves the use of 130 L bi-conical floating intermediate buoys positioned every 10 meters along the headline, resulting in each buoy supporting five lanterns. However, this technique has the drawback of inducing uneven tumbling among the lanterns with those closer to the buoys experience more pronounced tumbling compared to those situated farther away. Potential solutions include deploying a greater number of smaller buoys, requiring more time for hanging, or exploring alternatives such as submerged or cylindrical buoys with reduced resistance in vertical motion. A long-term solution, ensuring uniform tumbling force and potentially lowering production costs, is yet to be extensively studied. Sections 4.3.2 and 4.6.1 provide insights into the use of floats in oyster lantern farming and considerations regarding buoys, presenting possible solutions for achieving desired tumbling levels and automating handling processes. Figure 4.34 summarizes the complex interaction between the environment, farm design and farming practices which ultimately affects the quality of the oysters produced.

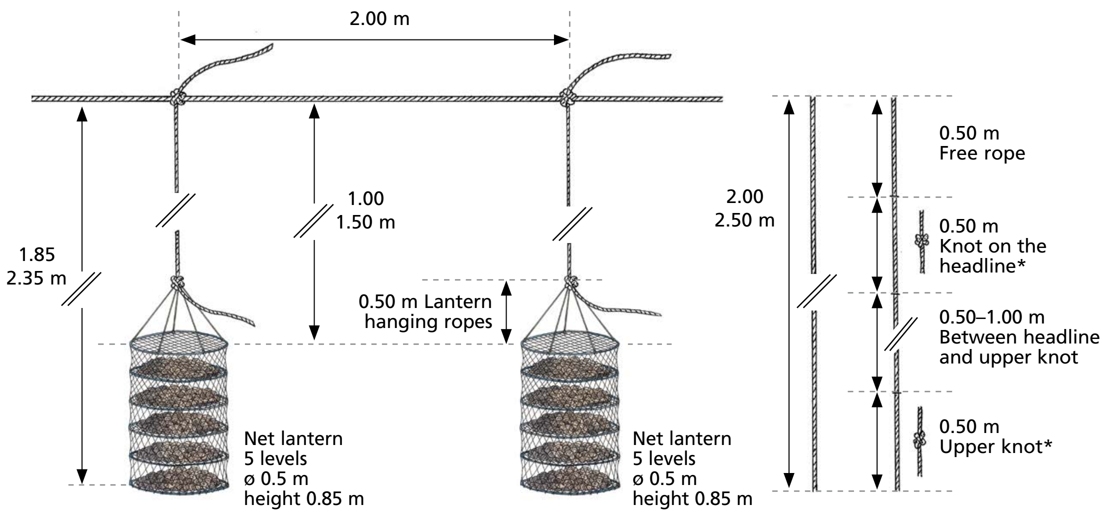
All lanterns should be hung at a consistent depth beneath the headline, positioning the top of the lantern approximately 1.0–1.5 m below the headline rope. This arrangement ensures that in the event of contact between neighbouring lanterns, the impact is lateral, minimizing the risk of damage compared to situations where the bottom of one lantern strikes the side or top of another. Observations suggest that hanging lanterns at a depth less than 1.0 m from the headline can lead to contact with the headline rope, frequently resulting in damage of the containers.

The ropes for lantern nets must be 2–2.5 m in length:

- 0.5 m of free rope above the headline (can be utilized to attach an identification sign).
- 0.5 m of rope utilized to tie the knot around the headline.
- 0.5–1 m of rope between the knots on the headline and the lantern itself.
- 0.5 m of rope used to tie the knot to secure the lantern (see Figure 8.20).

The distance between the headline and the top of the lantern will be 0.5–1.0 m, plus an additional 0.5 m accounting for the hanging ropes of the lantern (Figure 8.35).

FIGURE 8.35
Example of a rope unit required to suspend a lantern net from the supporting headline



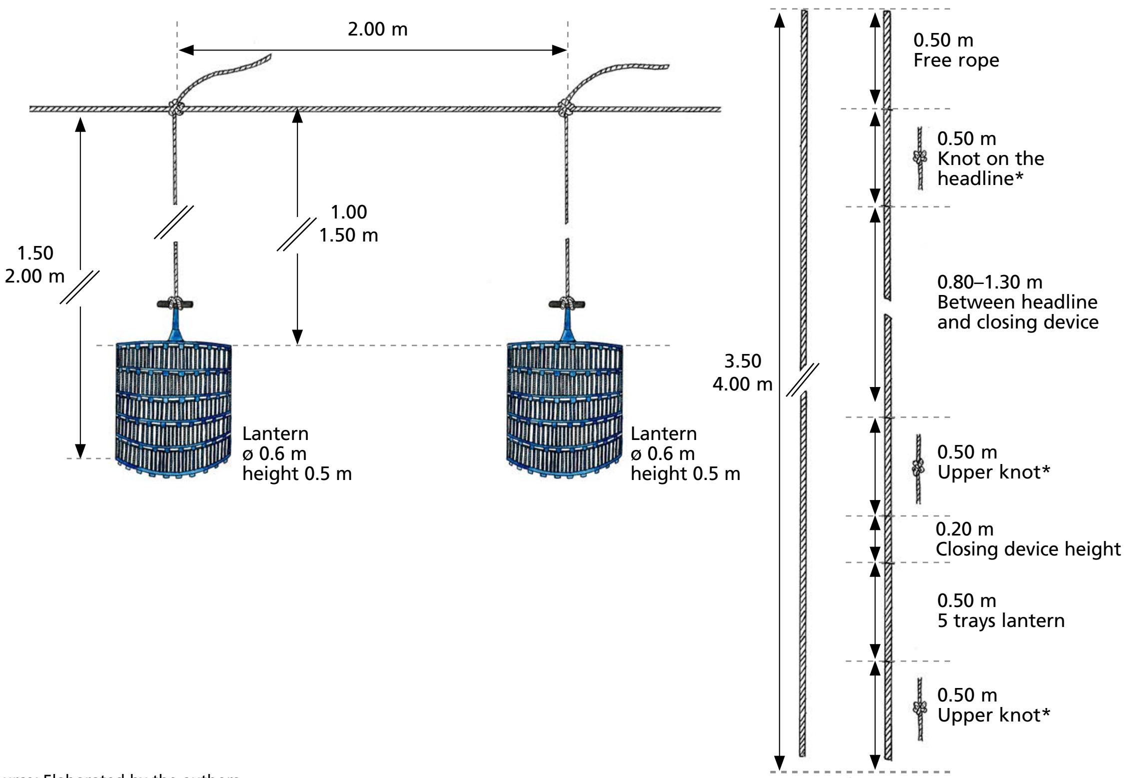
Source: Elaborated by the authors.

The ropes for hard plastic lanterns must be 3.5–4 m in length:

- 0.5 m of free rope above the headline (can be utilized to attach an identification sign).
- 0.5 m of rope used to tie the knot around the headline.
- 0.8–1.3 m of rope between the knots on the headline and the lantern itself.
- 0.5 m of rope used to tie the knot to secure the lantern (see Figure 8.22b).
- 0.2 m of rope through the lantern locking device (Figure 8.22b);
- 0.5 m of rope through the 5 circular tray levels of the lantern.
- 0.5 m of rope used to tie the knot under the lantern (see Figure 8.22a).

The distance between the headline and the top of the lantern will be 0.8–1.3 m, plus an additional 0.2 m accounting for the length of the lantern locking device (Figure 8.36).

FIGURE 8.36
Example of a rope unit required to suspend a hard plastic lantern unit from the supporting headline



Source: Elaborated by the authors.

When various lanterns are filled and hung on the same day, it is advisable to position lanterns containing the same type of stock and filled with similar densities next to each other along the same section of the headline. This practice of grouping similar lanterns and stocks should also be applied to lanterns graded on different days over a period not exceeding two weeks.

Recent adaptation to climate change

In the context of the Adriatic Sea, the current manifestation of climate change is distinguished by an elevation in the maximum forces exerted upon long-lines and a decline in phytoplankton concentration attributed to diminished precipitation. The heightened frequency and intensity of storm events necessitate consequential adjustments in long-line design and aquaculture strategies to effectively contend with these challenges. Key adaptations include:

- The minimum recommended depth for long-line farms should be elevated from 10 to 15 meters.
- The traditional positioning of the headline, typically 4–5 m beneath the sea surface, should be adjusted to a deeper depth.
- Mooring blocks, conventionally weighing between 10–12 tonnes, ought to be upgraded to a range of 15–20 tonnes.

These adaptations dictate that oyster farming operations must be conducted at increased depths to mitigate the impact of storm-induced forces on equipment. Consequently, this shift will result in a diminished availability of plankton for oysters, as compared to conditions prevailing a few meters below the sea surface.

The collective effect of decreased phytoplankton availability, coupled with the relocation to deeper waters where concentrations are anticipated to be lower, is likely to result in a foreseeable decline in the achievable farming densities in the proximate future.

8.3.1 Strategies for seed introduction and pre-growing

The formulation of a seed introduction strategy necessitates thorough consideration of the following constraints:

- The nursery and pre-growing stages conducted in offshore conditions, as detailed below, do not adhere to fully standardized protocols. The stock necessitates frequent handling, and the ultimate outcome, in terms of survival and product quality, exhibit considerable variation among batches, also influenced by seasonal trends.
- Pre-grown oysters represent a scarce commodity with limited availability in the market. They generally command elevated prices and pose challenges in terms of both transportation logistics and cost. Moreover, the transfer of pre-grown oysters from the Atlantic coast to the Mediterranean Sea introduces challenges in acclimating the oysters to distinct environmental conditions. The risks of mortality during transport and adjustment to the new farming conditions escalate progressively as the oysters increase in size.
- Since 2008, notable mortalities attributed to OsHV-1 µvar have been documented in spat and juveniles across most production areas (Section 2.1). The optimal strategy to mitigate mortalities caused by OsHV-1 µvar remains uncertain. The availability of "resistant strains" is limited, and their impact on survival rates is yet to be comprehensively assessed.

Considering the above constraints, the establishment of land-based facilities and the utilization of a Flupsy would undoubtedly represent an optimal solution for this stage of the production cycle. Chapter 5 of this manual comprehensively outlines this option, although it is not addressed in the current section.

In the context of the farm exemplified in this manual, this section delineates the practices adopted when initiating the production cycle from a "T6" spat size and explores potential variations that could be adopted to further improve the nursery and pre-growing phases.

Spat size

The use of pearl nets (see Figure 4.28 and Table 8.1) in offshore exposed conditions is not recommended for small spat sizes. Suspending lanterns individually is labour-intensive, and even when utilizing ballasts, there is a risk of entanglement or excessive rolling around the headline.

Lanterns with 0.8 × 0.8 mm or 1.8 × 2.0 mm net mesh (see Table 8.1) have been tested using "T3" spat (30 000 spat/kg or 0.04 g average weight/spat). However, the mesh quickly becomes clogged due to biofouling and pseudofaecal deposits from the oysters, necessitating the lifting of lanterns for cleaning at least every two weeks, rendering the handling process time-consuming.

In many cases it has been observed that the production costs associated with cultivating oyster spat from "T3" to "T6" using either pearl or lantern nets surpassed the price differential between these two sizes when procuring the spat directly from a hatchery. This is probably due to the fact that nursery and pre-growing stages conducted in land-based facilities, as opposed to open sea conditions, are more cost-effective. As a matter of fact, a hatchery or nursery handling millions of spat can invest in appropriate equipment (such as an in-water grader) and amortize the associated costs. However, such investments are economically unjustifiable for the relatively small quantities handled by a standard oyster farm.

Consequently, in offshore conditions, it is recommended not to introduce spat smaller than "T6" size group.

Spat origin and transport

As highlighted in preceding chapters, seed can be either hatchery-produced or obtained through natural spat settlement, as detailed in Section 4.1 where various spat collection techniques are outlined.

Historically, attempts by long-line farms in the Adriatic Sea to recruit oyster spat yielded unsatisfactory results, likely due to insufficient numbers of wild and farmed cupped oysters generating inadequate larvae concentrations during settlement periods. However, the probable expansion of oyster farming and related farmed stocks, coupled with advancements in recruitment techniques, is expected to address this issue in the foreseeable future. Notably, adhering to current specifications for organic shellfish production involves commencing with natural spat. Consequently, the additional cost associated with purchasing or recruiting natural spat could potentially be offset by the enhanced market value of organic oysters upon sale.

Alternatively, procuring hatchery-produced spat offers several key advantages:

Homogeneity of size: Batches obtained from hatcheries exhibit a high degree of size uniformity due to repeated grading operations. This characteristic minimizes the need for additional grading procedures during the nursery stage.

Disease resistance: As a result of recent advances in selection techniques, hatchery-produced spat, through selected stocks and controlled breeding environments, typically demonstrates enhanced resistance to diseases, particularly OsHV-1 µvar, resulting in lower mortality rates.

Summer harvest capability: Opting for triploid oysters in hatchery purchases allows for harvesting throughout the summer season, unlike diploid oysters that become milky. This capability enables continuous sales throughout the entire year.

A comprehensive comparison of the advantages between acquiring hatchery-produced spat and collecting natural spat is detailed in Tables 4.1 and 4.2.

Regarding the constraints associated with stock transportation (generally done without water) it is crucial to minimize the seawater temperature difference between the departure and destination sites. Similarly, excessive temperature fluctuations during transportation can lead to mortalities, and hence should therefore be avoided. Ideally, oysters should be transported under controlled conditions, maintaining a temperature difference of less than 5 °C between the departure and destination points and during transport. Furthermore, considering the factors believed to trigger OsHV-1 outbreaks in juveniles, both departure and destination seawater temperatures should be below 16 °C.

Transporting limited quantities of oyster seed stock using appropriately fitted trucks can be quite costly. For this reason, the transportation of seed or half-size products is generally made by shipping companies, that transport commercial-size products at low temperatures (4–6 °C), leading to frequent temperature shocks for the transported seed. In these conditions, small volumes of spat ranging from T6 to T12 in size (refer to Table 4.3) can be conveniently packed into sealed polystyrene boxes as this method effectively shields them from temperature shocks. For larger-sized spat, transportation necessitates the use of net bags, exposing the oysters directly to ambient temperature variations, thereby inducing stress and posing a consequent risk of mortality upon reintroduction to the sea.

When transporting seed under the T15 size group (see Table 4.3) in polystyrene boxes, it is important that the boxes are as thick as possible and securely sealed. The duration of transport should be minimized, preferably within less than 48 hours between harvesting and transfer back to the sea for further farming. Upon opening the box, the seed must be gradually acclimatised to the water temperature of the destination site. When transporting large quantities of seed above the T15 size group in net bags, utilizing a dedicated vehicle equipped with temperature control capabilities becomes a viable option. This approach helps mitigate stress on the oysters, which may otherwise occur when relying on standard shipping companies.

Timing for spat introduction

The optimal timing for introducing the oyster spat onto the farm site depends on various factors:

Seawater temperature: Considerations for seasonal seawater temperatures are essential in meeting the metabolic requirements of oysters and mitigating potential impacts of OsHV-1 µvar on their survival (increased mortalities generally occur when seawater temperature raises >16 ºC).

Food availability: The availability of phytoplankton is most critical given it is the primary food source for the small and fast growing oyster spat.

Biofouling: The utilization of small mesh size containers that are prone to rapid obstruction poses a substantial challenge when nursery and pre-growing stages are carried out during intense biofouling periods.

Seed introduction: Staggered seed introduction is important to guarantee a continuous supply of commercial-sized products throughout the year, particularly during peak demand seasons. The process must be carefully planned to prevent overlapping with seed grading and other farm activities.

Weather conditions: Access to offshore farm site may be hindered during the winter months due to adverse weather conditions.

The final spat introduction plan must therefore intricately balance the aforementioned factors. Considering the prevailing environmental conditions in the central Adriatic Sea, three distinct temporal windows throughout the year emerge as the most optimal for seed introduction, as illustrated in Table 8.2.

Late winter and early spring spat introduction

The late winter and early spring period are deemed optimal for spat introduction, owing to a combination of conducive conditions. Introducing "T6" spat in multiple batches over a 2-month period will enable the farmer to harvest and sell commercial-sized products for 8–10 months, following a cultivation period ranging from 15 to 22 months.

The introduction of spat during winter, strategically implemented 4–5 months prior to the seawater temperature reaching the critical 16 °C mark (end of April), has demonstrated the favourable adaptability of spat to prevailing farm conditions. Survival rates of spat during this winter introduction were comparable to those observed in early spring introductions, but the necessity of conducting pre-growing activities during winter, a period characterized by heightened storm risks and challenges in accessing the farm, has yielded contrasting results with the loss of lanterns and the development of misshapen oysters, attributed to delays in stock division and grading procedures.

Late spring spat introduction

Continuing the introduction of seed in late spring is likely to extend the period during which oysters can be brought to market. In most cases, survival rates and yields of spat are observed to be lower due to OsHV-1 µvar mortalities, even if it was noted that outbreaks over 16 °C did not occur systematically. In comparison to earlier introductions, growth is expected to be faster due to optimal environmental conditions and increased levels of phytoplankton. This will require lower stocking densities within the culture containers and an increased frequency of activities such as grading and cleaning.

Autumn spat introduction
Introducing spat during periods of lower temperatures and relatively low phytoplankton concentrations necessitates the adoption of a strategy involving lower stocking densities within the culture containers to ensure an adequate food supply for oyster growth. Special consideration should be given to mussel spat fouling during this time. It is important to note that washing the lanterns from the outside may force small mussels through the mesh, where they can mix with the oyster spat. Once this mixing occurs, it becomes extremely difficult to separate the mussels from the oysters.

Quantities and batches size
In addition to establishing the optimal introduction period for oyster spat, it is advisable to implement a strategy that utilizes multiple small to medium batches, rather than relying on one or two larger batches. This approach is recommended as a risk mitigation measure, considering the significant variability in survival rates observed among different batches. Typically, a survival rate of 20–30 percent from "T6" size seed to final harvesting is considered a standard outcome. The initial 2–3 months of the production cycle, known as the nursery phase, is identified as the most vulnerable period leading to mortalities. Therefore, with an average projected weight of 80 g, the expected production is estimated to fall within the range of approximately 1.5 to 2.5 tonnes per 100 000 "T6" oysters.

TABLE 8.2
Best periods for seed introduction

Month	Average temperature (°C)	Phytoplankton availability	Fouling	Farm access	Selling period
January	12	Low	High (mussels)	Limited	--
February	11	Low	High (mussels)	Limited	--
March	**11**	**Medium**	**Medium**	--	--
April	**14**	**High**	**Medium**	--	--
May	**18**	**High**	**Medium**	--	--
June	23	High	High	--	--
July	26	Medium	High	--	X
August	27	Low	High	--	X
September	24	Medium	Medium	--	--
October	**20**	**High**	**Medium**	--	--
November	16	Medium	High (mussels)	Limited	--
December	14	Medium	High (mussels)	Limited	X

Notes: Months in **dark green** (March and April) is the best period for introducing the spat in the farm site; Months in **light green** (May and October) alternative period.

Source: Elaborated by the authors.

Nursery and pre-growing schedule starting from "T6" spat
Lanterns fitted with "Rachel nets" and the Velcro closing system (see Figures 8.17 and 8.18) have proven to be the most suitable solution during the pre-growing phase of oyster spat. Alternatives such as using small net or plastic bags containing the spat and placed within the trays of hard plastic lanterns (see Figure 4.15) are deemed unsuitable. These latter solutions restrict water flow to the oysters and necessitate excessive handling. Similarly, the use of stacked hard plastic perforated trays (see Figure 4.16) is not preferred. This is due to the trays not maintaining a horizontal position, causing the seed to gather in one corner rather than being evenly distributed across the bottom of the tray.

When using the preferred lantern nets, it is important for the mesh size to be substantially smaller than the width of the oyster shells. This prevents oysters from becoming trapped in the mesh, growing into an "8" shape and potentially damaging the net.

The following pre-growing protocol has been established based on this fundamental rule:
1. Introduction of "T6" spat into lanterns with a 2 × 3 mm mesh for a period of 1–1.5 months.
2. Division and transfer into lanterns with a 3.5 × 5 mm mesh for an additional period of about 1–1.5 months.
3. First grading by hand and transfer into lanterns with a 3.5 × 5 mm mesh for small and medium-sized oysters, and into lanterns with a 4.5 × 6 mm mesh for larger oysters for another period of 1.5–2 months.
4. Second grading by hand and transfer into lanterns with a 4.5 × 6 mm mesh for small and medium-sized oysters, and into lanterns with a 9 × 9 mm mesh for larger oysters for another period of 2.0–2.5 months.

During each period, it is recommended to clean or change periodically the lanterns and to move/wash the spat. The procedure for changing the lantern is that described in points 1 to 4 above and points 7 to 8 described below in "Stage 2". If possible, short periods of exposition to the air (few hours) should be planned.

Depending on seawater temperature and batch growth rate, the nursery and pre-growing stages will last approximately 5.5–7.5 months with the spat reaching an average weight of 3–5 g. The duration will be shorter with higher temperatures and longer with lower temperatures.

Handling

To execute the nursery and pre-growing stages efficiently, certain fundamental operations must be undertaken, and these are described below.

Biofouling management

During the pre-growing period, while using lanterns with small mesh sizes, the risk of biofouling is considerable. If the nets become clogged, water cannot penetrate correctly into the lantern culture chambers. This can lead to a reduction in the quantity of phytoplankton available to the oysters, resulting in reduced growth rates and increased oyster size heterogeneity. Furthermore, reduction in the water flow may cause mass mortalities due to a lack of oxygen. For these reasons, biofouling on the lanterns needs to be periodically removed, and cleaning actions should be taken whenever necessary.

Introducing spat during periods of high fouling and when mussel reproduction is at its maximum level should be avoided. If it is not possible and excessive fouling is observed, it is recommended to clean the lanterns externally and paying attention not to damage the cultured products and pushing the fouling organisms present outside the nets into the culture chambers. Once inside the lanterns, these organisms will grow and compete for the available food.

Cleaning the lantern from the outside using a pressure washer, even if regulated to low pressure, can lead to the undesired entry of the fouling organisms in the culture chambers. This should be avoided at all costs, especially when fouling organisms are small enough to pass through the net mesh. In such cases, it is advisable to employ a hand scraper to detach and eliminate fouling from the exterior.

Furthermore, it is recommended to thoroughly clean empty lanterns to ensure that nets are completely free of any obstructions. Allowing the empty lanterns to air dry alone is insufficient to remove the fouling organisms.

Grading by hand

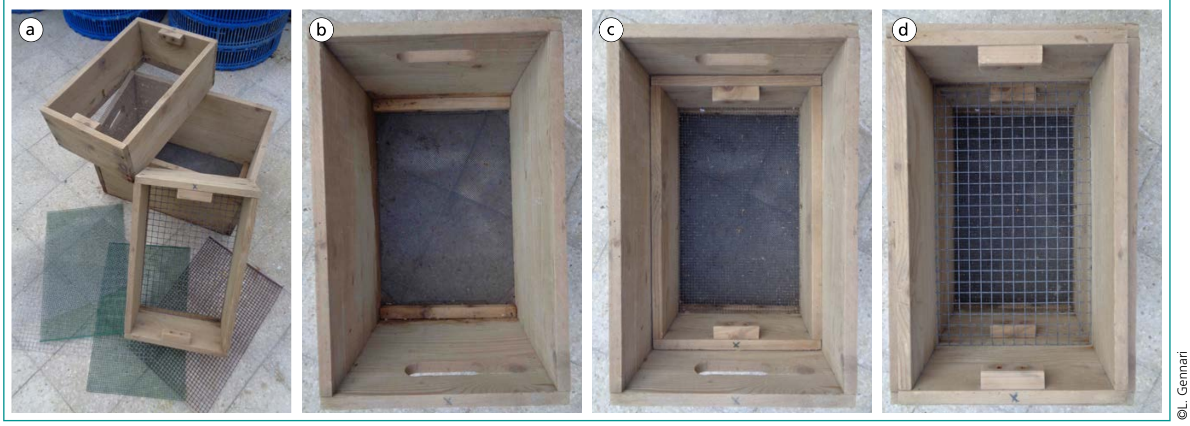
Spat grading can be accomplished using a straightforward homemade floating grader and a plastic bin filled with clean seawater. Opting for such a unit allows the grading to be performed by a single operator. For farms where the quantity of introduced oyster spat does not exceed 500 000 unit/year, a single grader with the following elements and dimensions is sufficient (Figure 8.37a):

- One external wooden frame measuring 55 × 35 × h 35 cm fitted with a 2 × 2 mm mesh that allows water and suspended debris to flush out, while retaining spat above the "T2" size group (Figure 8 37b).
- One "lower" internal wooden sieve measuring 50 × 30 × h 17 cm fitted with a mesh size that allows small spat to go through while retaining medium-sized spat. This frame is inserted inside the larger external frame (Figure 8.27c).
- One "upper" internal wooden sieve measuring 50 × 30 × h 17 cm fitted with a mesh size that allows medium spat to go through, while retaining larger spat. This second frame is inserted inside the larger external frame and place on top of the lower internal sieve.

The lower section of the two internal frames is designed to be unscrewed for the purpose of changing the grading nets. To facilitate this, interchangeable nets can be securely fastened along the bottom using a support of identical dimensions, which is screwed onto the base. It is recommended that the nets be either of steel or resistant plastic, and the mesh size can vary from 5 × 5 mm to 20 × 20 mm.

The entire grading apparatus is operated while floating in a large plastic bin (capacity 250–300 L).

FIGURE 8.37
Design of a homemade wooden oyster spat floating grader
(a) Elements of the grader; (b) empty external frame; (c) external frame fitted with the lower internal sieve; and (d) fitted with the upper internal sieve



Closing and opening the lanterns

As the spat are very small, the lanterns must be closed accurately to prevent the seed from escaping or falling through the different lantern levels. When preparing the lanterns, the open space between the levels must first be sewn on the intermediate ring of both parts of the opening, leaving only a gap of 8–10 cm. This space is necessary to facilitate easy filling and emptying. Subsequently, when closing the lanterns by overlapping the Velcro strips, it is crucial to position the external net as closely as possible to the intermediate internal ring. To achieve this, the lantern should be laid on the ground or deck and kept under tension by tying the suspension rope to a part of the boat. Simultaneously, the bottom of the lantern should be kept taut by the operator. Skilled operators can maintain the lantern in position between their two legs while using both hands to securely overlap the Velcro strips. It is recommended to start from the bottom, progressively moving to the upper part of the lantern. Some suppliers recommend using a support frame to keep the lanterns open in the desired position. Alternatively, without the need for a support frame, another solution involves employing two operators.

Ballasting the lanterns

Because lanterns filled with small seed are exceptionally light, and the initial weight of oysters is below 5 kg per lantern, it is advisable to incorporate ballast (approximately 3 kg) on the topside of the lanterns. This addition helps prevent the lanterns from rolling around the headline rope or colliding with each other continuously. Small concrete blocks, securely fastened onto the lanterns, can serve this purpose (see Figure 8.21).

Stage 1 – Spat introduction

Lanterns, featuring five tiers and fitted with a mesh size of 2 × 3 mm, are filled with “T6” spat (4 000/6 500 spat/kg; average weight 0.15–0.25 g/unit) in accordance with the densities shown in Table 8.3 and Figure 8.38.

- Small spat weighing 0.15 g are introduced at a starting density of 1.5 units/cm^2, corresponding to 2 400 spat/level or 0.35 kg/level.
- Larger spat weighing 0.25 g are introduced at a starting density of 0.9 units/cm^2, corresponding to 1 450 spat/level or 0.35 kg/level.

Depending on the selected stocking density, the number of lanterns required for the purchased weight of oyster spat can be determined. Alternatively, based on the available number of lanterns, the total number of spat needed to fill each level at the desired stocking density can be calculated.

Weighting the spat for each level would be too time-consuming and it is suggested to use a volumetric measurement method. A scale with a minimum accuracy of 10 g will be required to determine the volume corresponding to the weight of spat to be introduced in for each lantern level. To prevent inaccuracies in weighting on the boat when moving, it is preferable to perform this operation before starting to fill the lanterns on land-based facilities or on the workboat when in the harbour.

Stage 1 will last around 1.0–1.5 months depending on seawater temperature. Periodic inspections of fouling and cleaning operations must be conducted when necessary.

Stage 2 – First sorting and partitioning

Following a duration of 1.0–1.5 months, each lantern is lifted onboard to thin out the number of spat. In the absence of any abnormal mortalities, the spat originating from a single lantern is evenly distributed into two distinct lanterns. These recipient lanterns are equipped with a mesh size measuring 3.5 × 5 mm each:

1. Clean the external surface of the lantern net with a scraper. Then, clean the boat deck prior to opening the lantern.
2. Unfasten the Velcro strip along the whole length of the net, turn the lantern over, and gently shake it to remove all the spat. This operation is better done by two operators. Verify that the contents in all levels of the lantern net have been removed and set aside the lantern for further cleaning.
3. Collect the spat dispersed on the floor and place them into a perforated plastic box (4 × 4 mm holes).
4. Gently wash the spat until the effluent water flowing from the box appears clean.
5. Following drainage, record the total spat weight, and then collect a representative sample of 100 live oysters to calculate the average weight of a single spat.
6. Divide the entire batch into 10 sub-batches to be introduced in the 10 levels of the two new lanterns.
7. Close the new lanterns securely and affixing the ballast on the top. These lanterns can be kept on-board for 12–24 hours if covered with a damp blanket. It is advisable not to retain the stock on-board when the difference between the air and seawater temperature exceed ±10 °C.
8. Transfer the newly filled lanterns into the sea.

If mortalities have occurred during Stage 1, due to an OsHV-1 outbreak or other factor, new lanterns should be prepared with spat densities shown in Table 8.3 and Figure 8.38.

Stage 2 will last approximately 1.0–1.5 months depending on seawater temperature. Periodic fouling inspections and cleaning operations must be conducted when required.

Stage 3 – First grading by hand

Following an additional 1.0–1.5 months from the first division, the lanterns are once again lifted on-board for further grading. In contrast to the lantern-by-lantern separation procedure in Stage 2, this stage necessitates a four-step grading process, as described below. Small- and medium-sized oysters are transferred into lanterns fitted with a mesh size of 3.5 × 5 mm, while larger oysters should be placed into lanterns with a mesh size of 4.5 × 6 mm.

Step 1 – Emptying lantern-by-lantern and determining total spat weight

1. Clean the external surface of the lantern net with a scraper. Then, clean the boat deck prior to opening the lantern.
2. Unfasten the Velcro strip along the whole length of the net, turn the lantern over, and gently shake it to remove all the spat. This operation is better done by two operators. Verify that the contents in all levels of the lantern net have been removed and set aside the lantern for further cleaning.
3. Collect the spat dispersed on the floor and place them into a perforated plastic box (4 × 4 mm holes).
4. Gently wash the spat until the effluent water flowing from the box appears clean.
5. Once all the lanterns are all empty, gather together the harvested spat.
6. Weigh all the boxes containing the juvenile oysters, following thorough draining, to determine the total seed weight.

Step 2 – Grading test

The purpose of the grading test is to determine the appropriate grading mesh size for achieving proportionate size classes: the smaller grade should be more than 25 percent of the total weight of oysters before grading, while the bigger grade should be less than 50 percent of the total weight of oysters before grading. A result with a 30 percent small size oysters, 45 percent medium size oysters and 25 percent big size oysters would be most desirable, while a proportion of 10, 80 and 20 percent, respectively, would be inappropriate.

Step 3 – Grading procedure

1. Submerge the external sieve frame in water and fix the two inner sieves in the prescribed order: first, the one with the smaller mesh size, followed by the one with the larger mesh size, as detailed in Grading by hand and illustrated in Figure 8.37.
2. Introduce 1–2 kg of spat into the upper sieve, and manually agitate the mass until only larger oysters remain in the upper inner sieve. Extract the upper sieve and transfer the retained oysters into an assigned perforated plastic container. Set aside the upper sieve for subsequent grading operations.
3. Repeat the identical procedure for the lower inner sieve, transferring medium-sized oysters into a separate designated perforated plastic container.
4. Retrieve the smallest oysters from the external sieve and transfer them into a third dedicated perforated plastic container.
5. Replicate steps 1 to 4 until all the spat have undergone grading.
6. Upon completion of the grading process, thoroughly wash the oysters in all three containers, ensuring they are kept segregated throughout.

Step 4 – Filling the new lanterns size-class by size-class

For each size-class:

1. After draining the containers holding the oyster, record the total spat weight, and then collect a representative sample of 100 live oysters to calculate the average weight of a single spat.
2. Divide each size class batch into sub-batches to be introduced in single compartment of the new lanterns according to the densities reported in Table 8.3 and Figure 8.38.
3. Close the lanterns securely and affixing the ballast on the top. These lanterns can be kept on-board for 12–24 hours if covered with a damp blanket. It is advisable not to retain the stock on-board when the difference between the air and seawater temperature exceed ±10 °C.
4. Transfer the newly filled lanterns into the sea.

Stage 3 will last approximately 1.5–2months depending on seawater temperature. Periodic fouling inspections and cleaning operations must be conducted when required.

Stage 4 – Second grading by hand

After an additional period of 1.5–2 months following the initial grading, the lanterns can be lifted on board for a subsequent grading session. The initial grading yielded three distinct size classes (small, medium and large). Each of these classes should undergo separate grading, employing the same four-step procedure as described above but utilizing grading nets with larger mesh sizes. Consequently, upon completion of the grading operation, nine new size classes will emerge from the originally introduced batch.

This fourth growth stage is expected to last for 2.0–2.5 months, depending on seawater temperature.

Spat size and stocking density summary

Table 8.3 offers guidance on the recommended densities of oyster seeds for placement within the lanterns. It is important to note that these figures serve as guidance only, and adjustments should be made to align with the specific environmental conditions at each individual farm site.

TABLE 8.3
Relationship between spat size, mesh size and densities in pre-growing lanterns

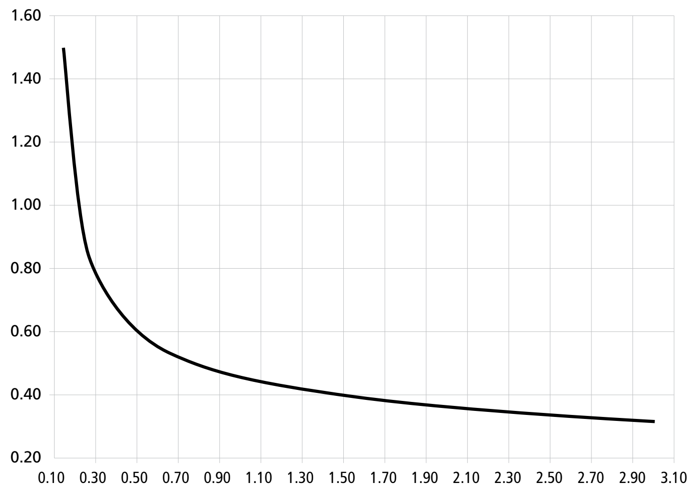
Oyster spat size	≥ T6	≥ T8	≥ T10	≥ T12
Approximate number of spat/kg	6 500 4 000	3 000 1 500	1 250 700	700 350
Average spat weight (g)	0.15 0.25	0.35 0.65	0.80 1.40	1.50 3.00
Lantern mesh size	2 × 3 mm	2 × 3 mm	3.5 × 5 mm	4.5 × 6 mm
Lantern diameter	45 cm	45 cm	50 cm	50 cm
Surface area of each level	1 590 cm^2	1 590 cm^2	1 960 cm^2	1 960 cm^2
Recommended number of spat/cm^2	1.50 0.90	0.72 0.55	0.50 0.40	0.40 0.30
Approximate number of spat/level	2 400 1 450	1 150 900	1 000 800	800 600
Weight of spat/level (kg)	0.35 0.36	0.40 0.60	0.80 1.10	1.20 1.80
Weight of spat/lantern (5 levels lanterns)	1.8 1.8	2.0 3.0	4.0 5.5	6.0 9.0

Source: Elaborated by the authors.

8.3.2 On-growing strategy and technique

In the illustrated farm case study, following the 5.5–7.5 months of the nursery and pre-growing stages detailed in Section 8.3.1, oysters reaching an average weight of 3–5 g are transferred to stacked hard plastic lanterns (see Figures 8.17a and 8.23) or knotted net lanterns (see Figures 8.17d and 8.19). The on-growing stage generally extends from 9 months for faster-growing oysters to 15 months for slower-growing counterparts. Consequently, the initial commercial-sized oysters become available for sale between months 15 and 16 after the introduction of "T6" spat, while slower-growing stock oysters will not be ready for sale until months 20–23. During the grading process, approximately 5 percent of the oysters, due to their smaller size, do not attain commercial size and are discarded. These "runts", even when placed in a bag with similarly sized oysters, remain permanently stunted and will never attain a marketable size.

FIGURE 8.38
Abacus of oyster spat number/cm^2 depending on average spat weight (g)



Source: Elaborated by the authors.

Recommended lanterns mesh size based on product size

Ensuring the proper stocking of oysters in lanterns with the correct mesh size is important to prevent stock loss while optimizing water flow through the lanterns. Ideally, oysters should be housed in lanterns with the widest possible net mesh aperture to allow adequate influx of nutrient-rich water. However, the mesh size must be sufficiently small to prevent oysters from either slipping out of the lantern or becoming lodged and growing into the net mesh. Striking a balance between these considerations is crucial.

This judgment should be based on the physical size of the oyster, not its weight, as the relationship between the two can vary significantly due to factors such as meat content, shell density, and shell shape. For instance, a slower-growing oyster with a thicker, deeply cupped shell and high meat content may weigh substantially more than a quickly grown oyster with a thin, shallow cupped shell and low meat content of the same size. Consequently, oysters of similar weight may be well-suited to a specific mesh size, while others might fall through the gaps. Thus, the critical factor in determining the appropriate mesh size is the size of the shell.

To prevent shells from becoming lodged and nets from being punctured by oysters growing through the mesh, timely and accurate grading is essential. This ensures the formation of batches containing oysters of similar size.

Size homogeneity can be assessed either through visual inspection or by calculating the coefficient of variation (CV) on a representative sample of 30 oysters. The coefficient of variation is determined by dividing the standard deviation by the average, then multiplying the result by 100: CV = (Sn-1/m) × 100.

During grading operations, the appropriate mesh size can be determined based on the following basic principles:

- The average thickness of the oyster should be larger than the shorter side of the mesh.
- The average width of the oyster should be approximately twice the length of the mesh diagonal.
- The CV should be less than 30 percent.

TABLE 8.4
Relationship between oyster size and mesh size in on-growing lanterns

Mesh size			Oyster size		
Short side (mm)	Long side (mm)	Diagonal (mm)	Width (mm)	Thickness (mm)	Weight (g)
9	9	12.7	22–28	11–14	5–10
15	15	21.2	42–45	20–22	25–30
21	21	29.7	50–51	26–27	45–50

Source: Elaborated by the authors.

TABLE 8.5
Minimum oyster size (average weight) based on the mesh size of lanterns

Lantern mesh size	Minimum oyster size (g)
Net lanterns with 9 × 9 mm	≥5
Hard plastic lanterns with 9 × 70 mm	≥10
Net lanterns with 15 × 15 mm	≥25–30
Net lanterns with 21 × 21 mm	≥45–50

Source: Elaborated by the authors.

The rules defining the relationship between mesh size and oyster width and thickness are explained in Table 8.4, while the correlation between mesh size and the average weight of oysters is summarized in Table 8.5.

When employing hard plastic lanterns with oysters weighing between 10–20 g, it is advisable to securely close the lanterns to prevent the product from escaping through the gaps between two trays. Securing the closure of a hard plastic lantern to prevent oyster loss is illustrated in Figure 8.23.

Recommended grading frequency and stocking densities

During the on-growing stage, the oysters will be regularly removed from the lanterns, mechanically graded and transferred into new lanterns every 2–4 months. The grading frequency will be done from every 4 months in cold periods (10–15 °C) to every 2 months in warm periods (20–27 °C). Recommended stocking densities for lanterns with a diameter of 50 cm are summarized in Table 8.6.

Periodical mechanical grading operations will be of primary importance to ensure that batches are of homogeneous size, to harden the shells and to increase the meat content according to the strategy described at the beginning of this section. Between grading operations it is recommended to take the lanterns out of the water for 6–10 hours.

TABLE 8.6
Correlation between oyster size and stocking densities in growing lanterns

Oyster size	From 3–20 (g)	From 20–50 (g)	Over 50 (g)
Approximate number of oysters/kg	250 50	50 20	<20
Average weight of oyster (g)	3–5 20	20 50	>50
Weight of oysters/lantern level (kg)	3	4	5
Approximate number of oysters/lantern level	750 150	200 80	<80
Weight of oysters/lantern of 5 levels (kg)	15	20	25

Source: Elaborated by the authors.

Mechanical grading

The equipment manufactured for grading the oysters are shown in Section 4.6.2. For oysters produced in long-line offshore cultivation, horizontal vibrating graders and rotating graders are the most suitable and widely employed. Both types offer the advantage of gently knocking and tumbling the oysters, thereby eliminating the fragile portions of the shell margins. This process results in thicker and stronger shells, with an increase in meat content during the month immediately following grading. For farms producing large quantities, particularly where automation is necessary and costly equipment can be economically amortized, the use of a linear or circular calibrator is recommended. Lastly, square or rectangular grids are typically favoured over grids with parallel bars.

In the showcased farm example, grading is performed through the utilization of a horizontal vibrating grader, as shown in Figure 4.36. The complete equipment comprises a loading tank, a conveyor belt for transporting oysters to the grader, a washing unit (10 L/min pump) integrated into the conveyor, and a vibrating grader equipped with two grids. The grader is designed with four interchangeable grids, detailed in Table 8.7. To enhance the grading process, it is recommended to include an intermediate 25 × 50 mm grid. Table 8.7 also outlines the anticipated grading outcomes based on the selected grid.

TABLE 8.7
Oyster sizes post-grading based on the utilized grading grid

Grading grid size	Smaller oysters (g)	Larger oysters (g)
17 × 35	<10	>10
21 × 42.5	<25	>25
28 × 55	<45	>45
32 × 60	<65	>65

Source: Elaborated by the authors.

The conveyor speed and vibration frequency can be adjusted to provide the operator with sufficient time to facilitate the passage of smaller oysters through the grid before reaching the next stage and to release any oysters that may become stuck.

For an efficient grading operation, it is advisable to have three individuals managing the grading line:

- One operator is responsible for feeding oysters into the loading tank and removing the baskets of graded oysters.
- Another operator assists with the grading process on the first grid.
- A third operator assists with the grading process on the second grid.

Grading procedure

The initial step takes place on the workboat, where lanterns are lifted from the sea, emptied, and oysters are transferred into perforated baskets with a capacity of 15–20 kg. Subsequently, these oysters undergo grading either on-board or at dedicated land-based facilities. Before grading, the oysters can be stored at ambient temperature for 1–2 days without any issues. This allows for the flexibility of grading during adverse weather conditions when accessing the farm may not be feasible.

Before commencing the grading of an entire batch, it is essential to conduct a preliminary test to determine the appropriate grids to be used. Like for manual grading, the objective is to achieve size classes that are over 25 percent and under 50 percent of the initial batch before grading. Additionally, the test provides the opportunity to adjust the conveyor speed and vibration level.

Once the selected grids are installed

1. Fill the loading tank with water, prepare the oysters for grading near the tank, and position the baskets for graded oysters under each discharge (two discharges under the grids where small and medium-sized oysters fall through, and a third discharge after the second grid for bigger-sized graded oysters).
2. Start loading the oysters to be graded and activate the conveyor, pump and grader.
3. While grading, ensure that approximately 90 percent of the oysters capable of passing through the grid indeed fall through. If not, adjust the conveyor speed by reducing it, and consider increasing the vibration level.
4. While grading, keep the two grids clear of any oysters that may become stuck in the frame, as this progressively diminishes grading efficiency. It might be advisable to periodically pause grading to clear the grids.
5. Finally, the operator must ascertain the total weight and average weight of the oysters in each size class. Average weight should be calculated based on a representative

sample of at least 30 oysters. The number of oysters can be determined by dividing the total weight by the average weight. Ensure that all data is accurately recorded.

Following grading, as the outer edges of the shells may incur partial damage, hindering the oysters' ability to retain water between their valves, it is important to promptly return the oysters to the sea. This should be done within 12 hours after the completion of the grading process. Commercial size oysters cannot be sold directly after grading; they must be retained at sea for at least another month to facilitate recovery before the final harvesting.

Filling and closing the lanterns

Based on the size classes of the graded oysters (total and average weight), as well as the recommended densities (see Table 8.6) and mesh sizes (see Tables 8.4 and 8.5), the farmer can decide the appropriate lanterns to be used and the quantity required.

Subsequently, the farmer can adopt one of two strategies:

- Calculate the weight of oysters needed to fill each level by dividing the total weight of oysters by the number of lantern levels.
- Calculate the number of oysters required to fill each level by dividing the total number of oysters by the number of lantern levels.

Filling the lanterns by determining the weight of oysters to be introduced at each lantern level

This strategy is suitable for small-sized oysters with an average weight under 50 g, where manually counting the oysters would be excessively time-consuming.

1. Prepare the empty lanterns. Net lanterns should be secured to a fixed point using their ropes and positioned on the floor (whether on a workboat or at land-based facilities) with the open part facing upward. This arrangement ensures the stability of the lantern without requiring additional support during the filling of different levels. In the case of hard plastic lanterns, the upper trays should be removed from the central rope, while the bottom tray can remain with the rope inserted, with all the trays laying on the floor and visible.
2. Through visual appraisal, partition the entire batch into several plastic baskets of equal weight, corresponding to the number of lanterns to be created.
3. Similarly, through visual appraisal, further subdivide the baskets that contain oysters for a single lantern into individual plastic baskets equivalent to the number of lantern levels. When filling hard plastic lanterns, dosing can be directly performed into the trays without using intermediate baskets. However, with net lanterns, this operation cannot be accomplished directly through visual appraisal due to the increased difficulty in judging if the correct dosage has been achieved.
4. Proceed to fill the lanterns, utilizing one final basket to top up each level.
5. Close the lanterns.

Filling the lanterns by determining the number of oysters to be introduced in each lantern level

This strategy is well-suited for large-sized oysters with an average weight over 50 g, where counting is a more efficient method than initially dividing them into baskets, as described in the preceding technique.

1. As above.
2. Fill the lanterns by counting the oysters and introducing the previously calculated number of oysters into each level. When introducing the oysters, avoid dropping them from excessive heights.
3. Close the lanterns.

Closing the "knotted nets" lanterns
The lanterns must be sealed using a thin plastic cord (see Figure 4.27). It is advisable to begin from the bottom of the lantern, where the plastic cord can be securely fastened in a permanent manner to avoid loss during the process of emptying and cleaning the lantern. The plastic cord should be threaded through all the meshes along the edge of the opening, alternating from one side to another, effectively stitching the opening together. In the case of relatively large oysters, it is possible to skip a mesh, running the cord through every other one.

While passing the thin cord through each supporting level of the lantern, it must be inserted inside the metallic frame to prevent damage in case neighbouring lanterns come into contact. Once the cord reaches the top of the lantern, it should be tied in a way that facilitates easy untying during grading and/or emptying operations.

For a skilled operator, the process of closing a lantern with a 9 × 9 mm mesh size typically takes between 5 to 10 minutes.

Closing the hard plastic lanterns
After filling all the trays, they can be stacked by threading the central rope through the central hole. Prior to securing the upper knot, it is crucial to verify that the rope is adequately tightened. When dealing with small oysters that may escape the space between two trays due to the elasticity of the central rope, it is advisable to incorporate lateral cords or metallic frames on the sides (refer to Figure 8.23). This additional measure helps guarantee the stack's integrity and prevents any gaps between the trays.

Lantern cleaning
It is essential to clean the culture devices after utilization to ensure that oysters receive the maximum flow of nutrients and dissolved oxygen, facilitating their growth. The cleaning process can be carried out using a pressure washer equipped with a rotating nozzle and pressure adjustment (Figure 8.39). For net lanterns, the washing pressure should be maintained at less than 150–200 bars, whereas lanterns or baskets made from hard plastic can withstand higher pressures. Typically, pressure washing alone may not be sufficient to eliminate all organisms contributing to fouling. Organisms such as barnacles, serpulids, and ascidians may persist and need to be manually removed after a week of drying.

FIGURE 8.39
Hard plastic lantern cleaning using a high pressure washer

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8.3.3 Harvesting strategy
Under the previously outlined cultivation conditions in the central Adriatic Sea, the harvesting process commences 15–16 months after the introduction of "T6" spat. This coincides with the faster-growing oysters achieving the commercial No. 3 size, ranging between 66 and 85 g (refer to Table 2.5).

In preparation for harvesting and subsequent commercialization, oysters must undergo careful grading in the preceding operation, ensuring they meet the following criteria:

- Each batch must exhibit appropriate size homogeneity, achieved through grading within the last two months.
- Oysters should have fully recovered and regrown shell margins, facilitating moisture retention within the shells when out of the water. This feature contributes to a desirable shelf life.
- The external surface of the shell must be clean and free from fouling.
- For diploid oysters, the presence of "milky" oysters should be absent.

To allow complete recovery from the shell damage incurred during the grading process, it is advisable to schedule harvesting approximately one month after grading during warmer periods and two months after grading in colder conditions.

When harvesting before sale, a comprehensive assessment of product quality is imperative. This entails a thorough analysis of key factors that customers prioritize, including size, meat quality and taste, meat-to-shell ratio, and shell shape and appearance if the oysters are intended for markets serving them in their shells. A detailed discussion of these aspects is provided in Section 2.2. The significance of each factor can vary depending on the target market and may influence the pricing of the oysters.

Product quality assessment

The choice between diploid and triploid oysters significantly influences their condition and suitability for harvesting, particularly in the summer months. The differences between diploid and triploid oysters are discussed in Section 4.1. As the water temperature rises in late spring and into summer, diploid oysters enter the gamete-producing phase. Prior to and during the release of gametes into the water, the oysters become "milky", affecting the taste, appearance and texture of the meat. Following gamete release, the meat may deflate and become thin, further compromising its quality. Harvesting diploid oysters during this period is not advisable. In contrast, triploid oysters, being essentially sterile, maintain their condition throughout the summer, enabling year-round harvesting if necessary. To facilitate targeted harvesting, triploid and diploid oysters should be kept on separate headlines.

Due to their higher growth rate, the initial oysters harvested in each production cycle may have thin, fragile shells. This can pose challenges during opening, with the superior valve being prone to breakage. This issue, affecting approximately 5 percent of the final production, is more pronounced in long-line cultivation. These fragile oysters, however, find utility in other applications such as processed meats where shell integrity is less critical. It is essential to note that attempts to harden these fast-growing oysters are challenging and may result in increased mortality rates.

Aligning with market demand

There are specific times of the year when the demand for oysters reaches its peak, often linked to public holidays, feasts, festivals or traditional celebrations. In considering harvesting and production strategies, it is important to account for these periods of intense demand. This ensures that the farm maintains an adequate supply of market-size oysters to meet market requirements.

For instance, along the Adriatic Sea coast, demand surges from Easter to summer holidays (April to August) and during December for the Christmas and year end festivities. Given that diploid oysters are marketable from December to May (see Figure 8.40) having commercially viable triploid oysters in late summer becomes essential to guarantee a consistent and uninterrupted supply.

The most sought-after oyster sizes in the market are generally No. 4 and No. 3. Strategically aligning production with these market preferences ensures optimal market responsiveness and enhances the farm's overall profitability.

Storage conditions and practices

Oysters cultivated in offshore conditions typically exhibit a shorter shelf life compared to those produced in intertidal areas or those subjected to a hardening process. Therefore, careful attention to packaging and storage is paramount:

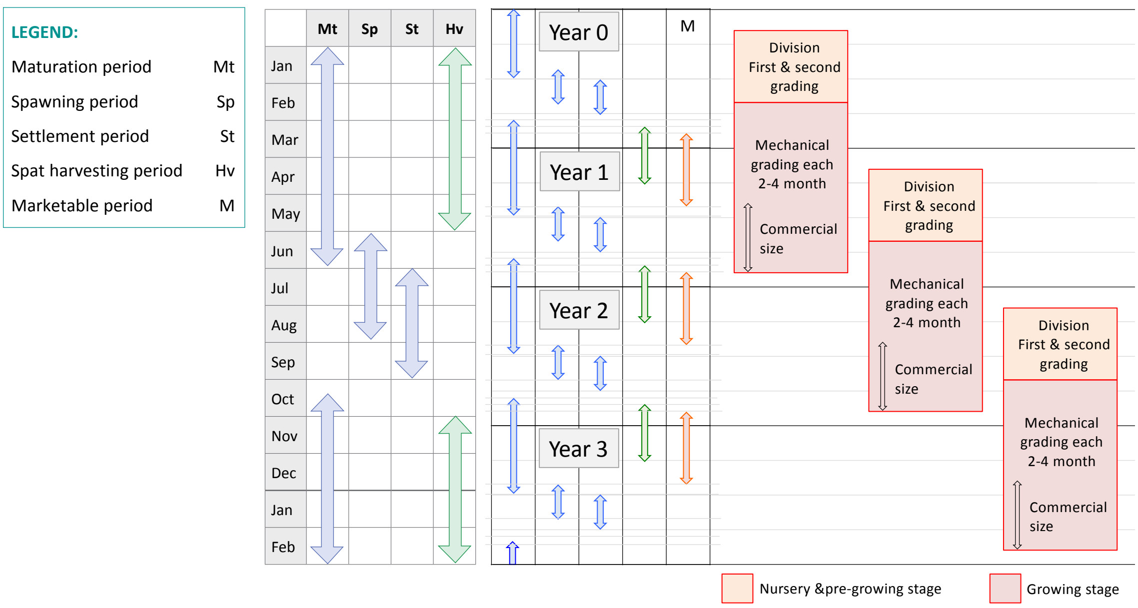
- Harvested oysters should be packed promptly.
- During packaging, ensure that oysters are placed horizontally with their inferior valve positioned underneath.
- Close the packaging securely to immobilize the oysters and prevent any movement or gaping. This safeguards against the loss of water held within their shells.
- Once packaged, promptly store the oysters at a temperature of 5–6 °C.

These measures contribute to maintaining the freshness and quality of the oysters throughout the storage period.

8.3.4 Farming calendar

The farming calendar (Figure 8.40) refers to the reproduction and settlement timing of Pacific oysters in the central Adriatic Sea as described in Section 2.1.

FIGURE 8.40
Offshore Pacific oyster production cycle and farming schedule in the central Adriatic Sea



Source: Elaborated by the authors.

8.3.5 Maintenance of farm equipment

Farmers must perform various routine tasks to maintain all equipment used in oyster production at the correct standard. The marine environment poses challenges to equipment longevity and safe operation therefore, regular checks and servicing of all farm equipment are essential. Table 8.8 below outlines some of the key items that should undergo regular inspection:

Navigational markers inspection and repair

Ensuring that navigational markers are functioning correctly and are in good repair is essential for the security of all sea users. When operating on the farm and weather permitting, a systematic check of all navigational markers should be conducted. Any missing markers should be promptly replaced. It is advisable to have an emergency marker ready for immediate deployment in case of marker loss.

TABLE 8.8
Inventory of farm items requiring regular maintenance

Equipment item	Task frequency
All workboat machinery	**Daily** – Check before use.
Freshwater washdown of equipment	**Daily** – After each use, when possible.
Greasing	**Weekly or monthly** – Particular attention should be paid to equipment that is used daily.
Hydraulic hose replacement	**Monthly** – Check for signs of wear and abrasion.
Hydraulic valves and fittings	**Monthly** – Check for signs of corrosion and ensure that the protective coverings are undamaged.
Anodes	**Quarterly inspection** – Replace anodes, as necessary.
Workboat engine	Service intervals should align with the manufacturer's recommendations based on engine hours and usage.
Workboat hull	**Annually** – Check hull integrity, apply antifouling coating and replace anodes, as necessary
Navigational markers	Full inspection **annually**, but farm workers should be vigilant each time they are on site. Lighting systems should be inspected every 3 months. Repairs when required
Long-lines	Full inspection **annually**, but farm workers should be vigilant each time they are on site. Repairs when required
Containment devices	Repair or replace when required

Source: Elaborated by the authors.

Every 3 months, a night inspection should be carried out on the lighting systems to verify their functionality.

Professional divers should conduct an annual inspection of mooring lines and anchoring devices. Any deteriorated parts should be replaced or repaired as needed to maintain the integrity of the system.

Long-lines inspection and repair

Maintaining the integrity of the long-lines is vital to prevent product loss. While working on the farm, all operators should regularly verify that the long-lines are secure and have not deviated from their original positions. Since headlines and associated buoys are typically aligned or parallel, any misalignment or incorrect positioning should be readily apparent. If an abnormality is observed, a detailed inspection will be necessary, with prompt repair of any identified damage.

The farm owner should have a comprehensive register containing the following details:

- Date of installation for each anchoring device, specifying type and weight.
- Date of installation for each mooring line, including details on rope diameter and material.
- Date of installation for each headline rope, with information on rope diameter and material.
- For all the aforementioned components, document the date of any inspections, intervention, and note upcoming maintenance tasks.

Professional divers should conduct an annual inspection of mooring lines and anchoring devices. Any deteriorated parts identified during the inspection should be promptly replaced or repaired as necessary to uphold the equipment's reliability and safety.

Workboat

Before setting out to sea each day, it is essential to conduct thorough checks on the workboat's engines. Verify the oil levels (engine, gearbox, hydraulic), coolant level and fuel level to ensure the vessel's seaworthiness. Additionally, once the engine is running, inspect the saltwater cooling system to confirm the correct discharge flow.

Mechanical breakdowns of any propulsion unit at sea can pose serious risks to the boat crew. Therefore, it is important to adhere to regular servicing of the main engines in accordance with the manufacturer's guidelines to mitigate the risk of such incidents.

All anodes safeguarding metallic components (such as propellers, shafts and the hull if built in steel) should undergo inspection every quarter and be replaced before reaching a state of ineffectiveness due to deterioration.

All safety, navigation and lifting equipment should be in good condition and certified by a qualified inspector if the local regulations mandate it.

The hull of the vessel is prone to corrosion and deterioration. Consistent checks are crucial to preserve hull integrity and prevent water leaks. An annual hauling of the vessel is necessary for a thorough hull inspection and the application of an antifouling coat. This protective measure safeguards the hull, mitigates biofouling, improves hydrodynamics, and reduces fuel costs. In the case of metal-hulled vessels, regular inspection and replacement of anodes affected by galvanic corrosion are essential.

Hydraulic hose replacement

If the operator is utilizing hydraulic-powered equipment, such as star wheels, winches, cranes and derricks, regular checks should be conducted on all hydraulic hoses for signs of wear and abrasion. Hoses exposed to environmental elements, especially UV light and saltwater, are prone to deterioration over time. The rupture of a hose under pressure can pose a hazardous situation for individuals working onboard. Moreover, the discharge of hydraulic oil into the seawater can have adverse environmental effects and must be prevented at all costs.

Hydraulic valve and fittings protection

Many of the metallic fittings, including hose connectors and hydraulic valves, are susceptible to corrosion and should be protected from the elements. Whenever feasible, these fittings should be wrapped in corrosion prevention sealing tape or sprayed with a corrosion prevention solution to maintain their integrity.

Grading and processing equipment

All equipment exposed to seawater should be rinsed with freshwater, whenever feasible. Despite being constructed from stainless steel, items may still succumb to corrosion under specific conditions, albeit at a less accelerated rate and severity compared to conventional steel. Machinery with movable components, such as graders, may malfunction due to the accumulation of debris and salt deposits. Consequently, it is advisable to undertake periodic cleaning to mitigate the detrimental effects on operational efficiency.

Greasing

Routine lubrication of equiment components necessitating maintenance should be performed in strict accordance with the manufacturer's scheduled maintenance requirements.

Containment devices repair

Over time, oyster containment devices may incur damage, necessitating maintenance to prevent oyster loss through openings in the nets of lantern nets or through the walls of hard plastic lanterns or baskets.

In the case of rips appearing in the lantern net mesh, the most expedient and efficient repair technique involves the use of a needle and thread. For larger tears, affixing a patch of comparable mesh size over the damaged section is recommended (Figure 8.41). The use of heavy-duty cable ties is discouraged as they introduce abnormal tensions to the mesh, potentially exacerbating future damage.

FIGURE 8.41
Net repair of a lantern net

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FIGURE 8.42
Repair of a hard plastic lantern

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Conversely, for the structural integrity of the devices constructed with hard plastic mesh, repairs can be easily executed using heavy-duty cable ties (Figure 8.42).

8.3.6 Monitoring and traceability

The collection of data concerning key parameters influencing the growth and development of the oysters constitutes an important asset for farmers. This information proves instrumental in guiding operators on optimizing farm production and fostering operational efficiency. Over the course of multiple years, cumulating data from each growing season facilitates the establishment of a discernible pattern in stock management. This pattern, in turn, facilitates informed decision-making for the operator, encompassing aspects such as optimal timing for seed procurement, seed quantity required, strategic implementation of stock management practices like grading, and the anticipated harvesting timelines for distinct oyster batches.

Parameters that can be easily monitored and recorded are:

- Water temperature.
- Estimation of phytoplankton concentration using a Secchi disk.
- Date of the different operations (grading, harvesting, etc.).
- Oyster size determined through systematic sampling.
- Oyster numbers and mortalities through counting.
- Oyster meat-to-shell ratio.
- Sale prices.

From these datasets, additional key elaborations can be conducted to evaluate the following outcomes:

- Average growth rate differentials contingent upon batches, seasons, and employed farming techniques.
- Duration of the production cycle and beginning/end of commercialisation for each farmed batch.
- Final yield, expressed as harvested weight per 100 000 seed introduced.

All the data that is collected should be recorded in a stock management document so that it can be easily accessed. Data recording and management can be facilitated through custom Microsoft Excel documents or specific software packages designed for shellfish production businesses.

8.4 MAIN CONSTRAINTS

The technical constraints extensively examined in this chapter represent the main factors constraining the advancement of offshore oyster farming, with the overarching goal of yielding high-quality oysters for direct sale in the raw, unprocessed oyster market:

- Unfavourable conditions for controlled pre-growing, considering both technical and economic issues.
- Lower quality of the pre-grown seed, exerting a negative impact on the final product quality.
- Reduced shelf life due to the complexity of implementing hardening strategies.
- Fragility of shells and pronounced variability in their shapes.
- Relatively modest profitability.

Nevertheless, if offshore farming is exclusively oriented toward oyster meat production for subsequent processing, where shell characteristics and shelf life bear no significance, cost-effectiveness can probably be guaranteed through the industrialization of the production process. This entails the vertical integration of the production chain, spanning from spat to the processed and transformed final product. Additionally, adopting a circular economy approach, wherein recycled shells find utility in other applications, further enhances efficiency and sustainability. Such an evolution not only contributes to improved carbon sequestration but also aligns with a comprehensive Life Cycle Assessment (LCA), encapsulating the entire cycle from cradle to market.

This novel approach would entail:

- Improved economies of scale and vertical integration within the production process.
- Elevated levels of automation to enhance operational efficiency.
- Diversification through product transformation.
- Adoption of a circular economy model, leveraging main by-products such as shells for alternative applications.
- Potential transition to the paradigm of "precision aquaculture."

8.4.1 Environmental constraints

In contrast to intertidal and nearshore sites, which are significantly influenced by environmental factors emanating from the adjacent land, offshore sites exhibit more consistent conditions in terms of salinity, water quality, and the risk of eutrophication. Two primary environmental constraints are associated with offshore farming:

- Phytoplankton concentrations are typically lower offshore due to the progressive dilution of nutrient run-off from the land.
- Farm sites are significantly affected by storms, given their typical exposure in offshore locations.

Furthermore, these two constraints are worsening due to the impacts of climate change:

- Changes in precipitation patterns, marked by heightened rainfall within compressed temporal intervals, has an impact on the biological cycle of phytoplankton, altering species concentrations and dominance, and consequently the quantity and size of the available phytoplankton cells.
- The escalation in both the force and duration of storm events further amplifying the challenges posed by these constraints.

8.4.2 Conflicts in site availability and licensing

Concerning the risks associated with potential conflicts arising from other human activities, offshore locations present two salient advantages:

Reduced visibility from shore: The majority of offshore farms are situated beyond the "visible field" from the shoreline. This spatial configuration mitigates visual impact concerns and enhances the aesthetic integration of offshore installations.

Lower human activity density: Offshore locations exhibit a decreased density of human activities when compared to foreshore sites, thus minimizing the potential for interactivity conflicts.

Furthermore, the transition to offshore installations prompts governing authorities to proactively address pertinent licensing challenges. This includes the establishment of comprehensive regulatory frameworks for fully offshore sites and addressing the complexities associated with licensing mixed activities within designated zones. Examples of such intricacies involve reconciling potential cohabitation scenarios, such as wind farms coexisting with the shellfish industry, or the implementation of Integrated Multi-Trophic Aquaculture around fish cages. Effectively navigating these licensing challenges is imperative for the sustainable and harmonious development of diverse activities within offshore zones.

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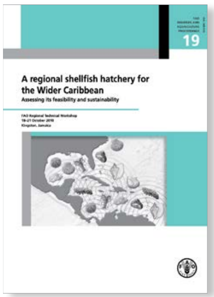

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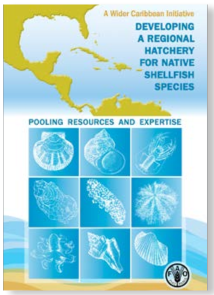

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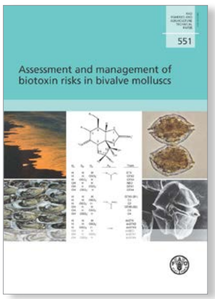

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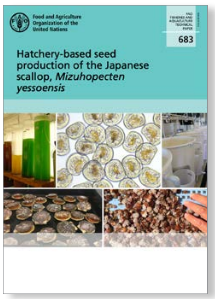

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Glossary

Adductor muscle	The large circular and central muscle that pulls the two valves together.
Algae	Aquatic plants that reproduce by cell division or spores.
Biofouling	Presence of organic growth on the outer surface of the oyster shell or on farming structures.
Bivalve	Mollusc having a shell made of two valves that are joined by a hinge.
Coupelle	Support deployed on the field for oyster seed recruitment.
Diploid	In genetics and biology, the term diploid refers to the cell containing two sets of homologous chromosomes wherein each chromosome in a set is obtained from each of the two-parent cells.
D-larva	The second free-swimming planktonic larval stage of oysters (first veliger stage).
Downwelling	In hatchery terminology, a growing system in which a flow of water is induced vertically, in a downward motion, from the top to the bottom of the holding container on which the spat rest (compare with upwelling).
Embryo	Early stages of development of an organism prior to larval stage.
Exposure	The risk of damages in case of exceptional events (storms, tempest or typhoon) and the deterioration of the farm components under the continuous effect of waves and winds.
Fertilization	Union of egg and sperm.
Fetch	The distance over the water that the wind has blown without hindrance in the direction of the farm site before impact with the cultivation equipment. For a given wind direction, fetch is calculated as the distance between the farm and the opposite coastline.
Gamete	Mature, haploid, functional sex cell capable of uniting with the alternate sex cell to form a zygote: sperm or egg.
Gametogenesis	Process by which eggs and sperm are produced.
Gill	A leaf-like appendage that functions in respiration and filtration of food from water.
Gonads	The primary sexual organ: testis producing sperm or ovary producing eggs.
Hermaphrodite	An organism that has both male and female sex organs at the same time or in alternate periods of their life cycle.
Intertidal zone	The area of the foreshore that is exposed to air over low tide (without seawater).
Larva	A stage of bivalves from the embryo to metamorphosis.
Live weight	Weight of the live oyster including shell, body and intra-valves water.
Mantle	The soft fold enclosing the body of a bivalve that secretes the shell.
Mean tidal range	Vertical distance between the mean high water (average high tide level) and the mean low waters (average low tide level).

Meat content	Quality criteria expressed as a percentage that reflects the weight of the meat (after draining) in relation to the total weight of the oyster before opening.
Metamorphosis	In bivalves, the period of transformation from the larval to the juvenile stage.
Pediveliger	The last free-swimming planktonic larval stage of oysters (forth veliger stage) characterized by the presence of a velum, an umbone and a sensitive foot needed for further settlement and attachment.
pH	Expression of the acidity or alkalinity of a solution, for instance for seawater.
Protandrous	A hermaphrodite organism that has the male reproductive organs coming to maturity before the female ones.
Pseudofaeces	False faeces, waste material not taken into the digestive tract.
Seed recruitment	Providing suitable substrates onto which the oyster larvae can attach themselves at the end of their planktonic stage when settlement occurs.
Return time	For extreme events (storms, tempest or typhoon), the average time between two occurrences.
Salinity	Measure of the amount of salt dissolved in water, for instance in seawater.
Seed	A young oyster with no specific definition to size.
Settlement	Behavioural process when mature bivalve larvae seek a suitable substrate for attachment.
Shelf life	Period of time that the oysters can remain alive and suitable for human consumption once they have been removed from the water.
Spat	A newly settled or attached bivalve (also called post-larval or juvenile in bivalves).
Spawning	Release of the gametes (sperm and eggs).
Subtidal zone	The area of the shallow waters just after the "intertidal zone" before moving towards the open sea.
Triploid	Compared to diploids, triploids organisms have an additional set of chromosomes.
Trochophore	The first free-swimming planktonic larval stage of oysters.
Umbo	Beak-like projections at the dorsal part of the shell; it is the oldest part of a bivalve shell (also called the umbone).
Umboned veliger	The fourth free-swimming planktonic larval stage of oysters (third veliger stage) characterized by the presence of a velum and an umbone.
Upwelling	In hatchery terminology, a growing system in which a flow of water is induced vertically, in an upwards motion, through the base of the holding container whose bottom surface is made of a fine mesh on which the spat rest (compare with downwelling).
Veliger	The third free-swimming planktonic larval stage of oysters (second veliger stage) characterized by the presence of a velum.
Velum	Ciliated locomotory organ of the veliger larva.
Wave height	The vertical distance between the crest (peak) and a neighbouring trough of a wave and twice the amplitude.

Appendices

Appendix I – **Food safety considerations for production and processing of bivalve molluscs**

by
Esther Garrido Gammaro
FAO, Fisheries and Aquaculture Division
Rachel Hartnell
Centre for Environment, Fisheries and Aquaculture Science (CEFAS)

INTRODUCTION

Bivalve molluscs, including oysters, mussels, scallops and clams, play a crucial role in the aquatic food supply chain. Bivalve mollusc production has the benefits of not requiring substantial initial investments, not requiring the use of feeds or antibiotics, and providing employment opportunities for numerous coastal communities. In 2018, the global production of bivalve molluscs reached approximately 17.7 million tonnes mainly (about 80 percent) sourced from aquaculture. This substantial output generated an estimated first-sale value of USD 34.6 billion (FAO, 2020).

Bivalve molluscs are filter-feeding organisms, and as such possess the ability to accumulate microorganisms, chemical contaminants and toxins that may be present in the environment within which they are grown. This necessitates stringent food safety standards during their production and marketing to safeguard consumers and facilitate international trade. Regulatory frameworks established by national food safety and public health agencies, along with fisheries and aquaculture authorities, should encompass both domestic and international aspects of production and processing.

Adherence to Article 3 of the Agreement on the Application of Sanitary and Phytosanitary Measures (SPS) under the World Trade Organization (WTO) is crucial. According to this article, Member countries are required to base their measures on international standards, guidelines, or recommendations. The Codex Alimentarius Commission (CAC) serves as the recognized international standard-setting body under the SPS agreement for food safety. This ensures that the production and trade of bivalve molluscs meet globally accepted standards, promoting consumer protection and facilitating smooth international commerce.

INTERNATIONAL GUIDANCE

The Codex Alimentarius Commission (CAC) has developed a Standard for Live and Raw Bivalve Molluscs (FAO and WHO, 2015). Within the Codex Code of Practice (COP) for Fish and Fishery Products (FAO and WHO, 2020), there is a dedicated section on the processing of live and raw bivalve molluscs (Section 7). This section provides comprehensive guidance on the necessary steps throughout the entire food chain to produce a product which meet the requirements of the Codex Standard. The COP provides information on prerequisite programmes, sanitary surveys, the classification, and monitoring of growing areas to manage risks associated with microbiological and chemical contamination, as well as concerns related to phytoplankton and biotoxins. Moreover, specific guidelines within the CAC address particular issues, including the management of pathogenic *Vibrio* spp. (FAO and WHO, 2010), human pathogenic viruses (FAO and WHO, 2012), and methodologies for determining marine biotoxins (FAO and WHO, 2016). Application of this collective guidance helps to ensures the implementation of standards to produce live and raw bivalve molluscs, promoting food safety across the industry.

Further technical guidance to produce microbiologically safe bivalve molluscs is given in the Joint FAO-WHO Technical Guidance for the Development of the Growing Area Aspects of Bivalve Mollusc Sanitation Programmes (FAO and WHO, 2021). The guidance is intended for primary production of molluscs for consumption live or raw bivalve molluscs in estuarine or marine environments, although many of the principles may be applicable to freshwater molluscs. The FAO-WHO Technical Guidance offers in-depth scientific insights and explanations as a complement to Section 7.2 of the COP (detailed below). This guidance extends to the assessment and monitoring of areas utilized for relaying (Section 7.4 of the COP). Similar evaluation and monitoring procedures, guided by the same principles, may also be applied to areas used for conditioning and wet storage in the natural environment (Section 7.6.2). While the primary focus of the FAO-WHO Technical Guidance centres on the identification and control of microbiological hazards, it includes references to relevant Codex standards and other international guidance addressing public health risks associated with chemical hazards, phytoplankton and biotoxins. The recommendations provided in the FAO-WHO Technical Guidance are particularly broad in their applicability when common principles are pertinent to the control of multiple risks. This general applicability is evident in sections such as the Growing Area Risk Profile (Section 2), Growing Area Assessment (Section 3), Growing Area Management (Section 6), and Growing Area Review (Section 7).

BIVALVE MOLLUSC SANITATION PROGRAMMES

The FAO-WHO Technical Guidance provides detailed scientific and technical information on the steps required to be undertaken by Responsible Authorities and other actors to establish new bivalve mollusc production areas. These are described in brief in the following sections.

1. Growing area risk profile (GARP)

Completion of the GARP by the Responsible Authority is the first step to determine whether, in principle, commercial bivalve mollusc production can be established in a new area. It comprises the acquisition, recording and assessment of available information and data on location of the proposed growing area, bivalve mollusc species to be harvested, intended use of the product, potential hazards requiring control, relevant epidemiological data, and the national, regional, or local capabilities and capacities to undertake assessment and monitoring (e.g. resources, laboratories, trained fisheries officers).

The GARP is typically conducted through a desk study, providing essential insights for subsequent stages of the assessment, monitoring and classification process. In specific situations, the GARP may reveal that an area is unsuitable for harvest, thereby prompting the allocation of resources to ensure that harvesting is prevented. The depth of information collected for a risk profile need only be sufficient for the Responsible Authority to make a go-no-go decision regarding the potential development of the growing area. Any surplus data can be summarized and retained for the next step, known as the growing area assessment. Additionally, the risk profiling process may highlight data gaps, prompting decisions on how to address these gaps in the subsequent growing area assessment. This iterative approach ensures that decisions are well-informed and supported by a comprehensive understanding of the risks associated with the growing area.

2. Growing area assessment (GAA)

The GAA builds upon information and data obtained in the GARP, through the inclusion and analysis of additional data (either existing data or new data obtained through a targeted survey – for example, of specific pathogens or faecal indicator organisms such as *Escherichia coli* or other faecal coliforms). Additionally, practical observations of the area are typically conducted through a shoreline survey.

The primary objective of the GAA is to formulate a comprehensive plan for ongoing monitoring. This plan encompasses crucial elements such as the identification of monitoring point locations, the types of samples to be collected—typically from either water or bivalve molluscs—and the specific hazards to be monitored, along with the recommended monitoring frequency. The aim is to ensure that the future monitoring programme is representative of the entire growing area, thereby enabling the effective control of any potential public health risks.

Moreover, the GAA provides valuable insights into post-harvest treatments that may be necessary before introducing the product to the market. By addressing these aspects, the GAA plays a pivotal role in safeguarding public health and establishing a robust foundation for a comprehensive and effective monitoring programme.

3. Growing area monitoring (GAM)

Monitoring of a growing area to provide additional evidence for the presence and concentration of faecal indicators and/or specific hazards is crucial for the classification and effective management of the growing area. Section 7.2.1 of the Codex COP envisions that monitoring can encompass water, bivalve molluscs and/or sediments. Internationally recognized Good Aquaculture Management (GAM) often relies on the determination of E. coli or faecal coliform levels, either in water or bivalve molluscs, collected consistently over time. These indicators are employed to assess the risk of faecal borne pathogens. The data generated through GAM enable predictions of the near- to mid-term sanitary quality of the growing area based on historical data. This prediction informs decisions about whether bivalve molluscs can be harvested and consumed raw directly from the growing area or if post-harvest processing is necessary. Primary monitoring, involving frequent sampling and testing, is often employed to establish an initial classification. This is followed by ongoing monitoring at less frequent intervals. Over time, individual monitoring results contribute to the determination of conditional classifications and may inform other risk management actions. While monitoring is essential for verifying the accurate classification of an area, it should be noted that monitoring programs alone cannot fully capture the risk associated with individual hazards. This limitation arises for several reasons:

- the hazard may not always be present in the potential source(s);
- even if always present, the concentration in the source(s) may vary with time (season, weather, time of day); or
- the hazard may only be present, or may only be present in high concentrations, after unexpected events.

4. Classification

Classification consolidates the findings from GARP, GAA, and GAM, offering a comprehensive risk categorization for a growing area. This facilitates the application of standard risk management protocols and post-harvest processing requisites, such as depuration, relaying in clean water or heat treatments. Classification establishes a unified framework of controls enforceable by regulators, aiding industry planning, and ensuring easy comprehension for purchasers. Typically subject to annual reviews, classifications may undergo adjustments, especially when extensive datasets from multi-year GAM programmes are available. Trend analyses derived from such data can inform long-term classifications or “conditional” classifications based on seasonal or other variables (e.g., rainfall). This dynamic approach may elevate sanitary status during specific periods, potentially reducing the necessity for year-round post-harvest measures and proving advantageous for the industry.

5. Growing area management

The Responsible Authority must possess the capacity and resources to monitor and evaluate changes that impact the status of growing areas with respect to the identified hazards and their mitigation. This entails the ability to apply criteria influencing classifications, including any conditional classifications, as well as conducting continuous surveillance activities. Additionally, the Responsible Authority should be equipped to carry out essential investigations and management actions, such as enforcing no-harvest policies during closures or increasing processing requirements. These capabilities may be shared with other regulatory bodies, as stipulated in regulations or binding agreements, such as Memoranda of Understanding.

The Responsible Authority is mandated to disclose the boundaries and classification status of each growing area, along with any criteria governing conditional classifications or the imposition of closures. Furthermore, the Authority should ensure timely communication of the effective periods of such closures or reclassifications. This information must be disseminated directly to harvesters, wholesalers and other stakeholders. Clarity in communication is crucial, including unambiguous directives that prohibit harvesting during closures and which detail any supplementary post-harvest processing requirements following a reclassification. Additionally, stakeholders should receive explicit communication when a closure is lifted, ensuring comprehensive awareness and adherence to regulatory changes.

6. Growing area review

This part of the sanitation programme involves a systematic and scheduled assessment, reevaluating the ongoing relevance of GARP and GAA, coupled with an analysis of monitoring data. The objective is to ascertain whether adjustments to classification status and management plans are warranted. The review process is important in identifying changes within the area that might affect the range of hazards that are of concern, and in identifying changes in the level of risk from identified hazards. A study by Hay and co-workers (Hay, B., McCoubrey, D.J. and Zammit, A., 2013) identified that the absence of a formal and structured review tended to lead responsible bodies to assume that no such changes had occurred. This assumption proved to be a pivotal factor contributing to sanitation programme shortfalls, ultimately leading to bivalve-associated viral outbreaks in Australia and New Zealand.

BIVALVE MOLLUSCS AND MARINE BIOTOXINS

Marine biotoxins are poisonous substances that can accumulate in the tissues of some species of bivalve molluscs. Contamination usually occurs through filter-feeding on certain species of toxin-producing phytoplankton which occur naturally in marine or estuarine environments. Consumption of bivalve molluscs contaminated with these biotoxins can lead to serious illness. Section 7 of the COP for Fish and Fishery Products (FAO and WHO, 2020.) requires that Responsible Authorities control for marine biotoxins in bivalve molluscs in commercially harvested growing areas. The COP also recommends complimentary phytoplankton monitoring and observations of growing areas for signs that may indicate the presence of a toxic event (e.g., dead or dying birds, mammals or fishes). It is further indicated that monitoring programmes for toxins in bivalve mollusc flesh and phytoplankton levels in water consider seasonal variability and the presence of new or emerging toxin or toxin producing species. An FAO-WHO guidance document on management of marine biotoxins in growing areas, similar to the existing FAO-WHO Technical Guidance for the Development of the Growing Area Aspects of Bivalve Mollusc Sanitation Programmes is in preparation.

In countries or trading blocs with well-developed bivalve mollusc industries and mature regulatory frameworks, including the European Union, Republic of Korea, the

Russian Federation, the United Kingdom of Great Britain and Northern Ireland, and the United States of America, four groups of biotoxins are generally regulated in live bivalve molluscs either directly in the growing area, at the end-product stage or both. Regulated groups of biotoxins can cause:

- Paralytic shellfish poisoning (PSP) – caused by saxitoxins (STX)
- Amnesic shellfish poisoning (ASP) – caused by domoic acid (DA)
- Diarrhetic shellfish poisoning (DSP) – caused by the lipophilic toxins, okadaic acid and dinophysistoxins
- Azaspiracid shellfish poisoning (AZP) – caused by azaspiracids

In addition, the lipophilic toxins also include additional toxins such as yessotoxins and pectenotoxins, which may have regulatory limits but show little evidence of human health issues. In most countries, biotoxin testing is supplemented with phytoplankton monitoring in the growing area waters.

Direct, regular monitoring for marine biotoxins in bivalve molluscs in growing areas against legal maximum permitted limits, enables management actions such as short-term harvesting prohibitions to be put in place by the Responsible Authorities. This prevents product with a higher risk of causing human intoxication entering the food supply chain. Ongoing monitoring of certain species of phytoplankton can provide early warnings of toxic phytoplankton blooms, which allow management actions to reduce consumer risks such as modifying harvesting practices, increased growing area testing for biotoxins or enhanced end-product testing. Countries or trading blocs set out maximum permitted levels of biotoxins in national legislation.

CAC standard for Live and Raw Bivalve Molluscs (FAO and WHO, 2015) sets out maximum permitted levels in the edible parts of live bivalve molluscs:

Name of biotoxin groups	Maximum level/kg of mollusc flesh
Saxitoxin (STX) group	≤0.8 milligrams (2HCl) of saxitoxin equivalent
Okadaic acid (OA) group	≤0.16 milligrams of okadaic equivalent
Domoic acid (DA) group	≤20 milligrams domoic acid
Brevetoxin (BTX) group	≤200 mouse units or equivalent
Azaspiracid (AZP) group	≤0.16 milligrams

Source: Elaborated by the authors.

Sampling frequency within official monitoring programmes for marine biotoxins can vary both within and between countries, but should be based upon risk, with increased monitoring (sampling) undertaken during periods of the year where there is an increased likelihood of the presence of toxin producing phytoplankton.

ADDITIONAL CONSIDERATIONS

A complete bivalve mollusc food safety programme includes several elements in addition to those relating to Responsible Authority controls of the growing area. These are covered in Section 7 of the Codex COP (FAO and WHO, 2015) and the Codex Standard for Live and Raw Bivalve Molluscs (FAO and WHO, 2020) and include:

- Harvesting and transportation
- Relay
- Depuration
- Processing
- Lot identification
- Recall procedures
- Composition and quality
- Specified limits for contaminants and hygiene indicators
- Labelling and storage

Other requirements not related to food safety may also be required to satisfy international trade and may be relevant for consideration for production for domestic trade. One significant aspect is the monitoring and control of diseases of bivalve molluscs. Information on this aspect is available from the World Organisation for Animal Health (http://www.oie.int/), the European Union Reference Laboratory for Molluscs Diseases (http://www.eurl-mollusc.eu/) and the United States National Oceanic and Atmospheric Administration (http://www.noaa.gov/).

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Appendix II – Cupped oysters aquaculture production 2010–2020

GENERAL NOTES

1) Production quantities of fish, crustaceans and molluscs are expressed in live weight, that is the nominal weight of the aquatic organisms at the time of capture.

2) Several countries still report their fisheries and aquaculture production at an aggregated level – due to deficiencies in their data collection and reporting systems – which can include production for many species. In these circumstances the production data presented at individual species items are therefore likely to be underestimated. Therefore, when examining the statistics for a particular species, it should be noted that an unknown proportion of the production for that species might have been reported by the national office under the generic, family or order name of the species, or even higher aggregated levels such as, for example, "Marine fishes nei" or "Freshwater fishes nei". Consequently, the production at species level may, in some cases, be underestimated and not reflecting the real production of the individual species.

3) Where necessary, any data published in previous releases of this dataset have been revised. Where the figures in the current release differ from those previously published, the amended data represent the most recent version. Some statistics provided to FAO by national offices, in particular those for the last year, are provisional and may be amended in future editions as better information becomes available and updates are made by national partners.

Symbols used

" "	=	Official value (no symbol associated)
" E "	=	FAO estimate from available sources of information
" nei "	=	Not elsewhere included

Symbols associated to value " 0 "

" M "	=	Data not available; unobtainable; data not separately available but included in another category
" "	=	Nil or zero
" N "	=	More than zero but less than half the unit used

Source: **FAO.** 2022. *Fishery and Aquaculture Statistics. Global production by production source 1950–2020 (FishStatJ)*. In: FAO Fisheries and Aquaculture Division [online]. Rome. Updated 2022. www.fao.org/fishery/statistics/software/fishstatj/en

Taxonomy note

Following the reclassification of Pacific cupped oysters from the genus Crassostrea to the newly designated genus Magallana by the Word Register of Marine Species (WoRMS), FAO Fisheries and Aquaculture data now recognizes these oysters under two distinct names:

- ASFIS specie name "Pacific cupped oyster", ASFIS specie scientific name "*Magallana gigas*";
- ASFIS specie name "Cupped oyster nei", ASFIS specie scientific name "*Crassostrea* spp.".

Aquaculture production of "Pacific cupped oyster" (Tonnes – Live weight)

ASFIS species (Name)	Pacific cupped oyster										
ASFIS species (Scientific name)	*Magallana gigas*										
	Year										
Country (Name)	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Australia	3 848	3 889.93	3 901	3 301.03	3 386.29	3 365.68	3 029.45	3 004.25	2 976	3 004.25	2 882.65
Canada	7 550	6 242	6 487	6 452	6 184	6 587	8 797	8 012	7 178	7 786	5 149
Channel Islands	924	997	774.5	928.1	1 274.5	1 703.4	1 494	1 312.2	1 383	1 280.83	1 010.22
France	79638	77 881	79 221	76 007.5	73 508	64 179.8	77 135.4	84 025.2	91 455	84 759.54	79 500 E
Ireland	6942	7 665	7 313	8 181.4	8 887	9 073	7 636.43	9 821.9	10 122	10 460	9 242
Japan	200 298	165 910	161 116	164 139	183 685	164 380	158 925	173 900	176 698	161 646	158 900
Korea, Republic of	267 776	281 022	284 856	239 779	283 232	265 432	268 973	315 255	303 200 E	326 190	300 084
Mexico	2 858	1 963	2 479	1 974.66	3 525	4 275.77	5 932.49	7 533.84	4 978.93	3 489.4	3 873.24
Morocco	283.57	215	243.5	278	302	289	376	411	349.37	423.15	345
New Zealand	2439	1 804	1216	1 497	1 509	1909	1 946	1 834	1 992	1 871	1 364
Portugal	318.6	373	338.3	399.19	471.17	575.58	623.52	825	1 153.85	1 689.89	3 293.24
Spain	600.3	1 023.88	561.8	547.02 E	558.04 E	668.97 E	634.5 E	806.12 E	745.59 E	893.72	830.81
Taiwan Province of China	36 056	34 642.6	26 923	27 792.74	25 276.41	21 865.7	22 339.33	23 178.65	22 035.26	19 392.12	19 165.1
United Kingdom	1 149.6	754	1 206	1 260.59	1 540.3	1 821.54	2 165.68	2 248.82	2 220.25	2 679.89	2 200 E
United States of America	29 169	29 718	31 529	23 381	29 116	29 116	25 296	25 845	23 797	26 199.88	21 311.6
Others	818.98	867.74	912.91	906.23	1 143.08	1 287.41	1 424.04	1 242.82	1 197.39	1 573.71	1 141.76

Aquaculture production of "Cupped oyster nei" (Tonnes – Live weight)

ASFIS species (Name)	Cupped oysters nei										
ASFIS species (Scientific name)	*Crassostrea spp.*										
	Year										
Country (Name)	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Brazil	1908 3 535 235 E	2 288 E 3 580 474 E	2 475 E 3 783 999 E	2 100 E 4 037 709 E	2 500 E 4 159 382 E	2 400 E 4 380 578 E	2 300 E	2 300 E	1 700 E	1 900 E	1 700 E
China	E	E	E	E	E	E	4 660 434	4 879 422	5 139 760	5 225 595	5 424 632
China, Hong Kong SAR	636	318	488	572	641	583	684	625	747	620.1	630.7
Malaysia	812	626	696	698	780	793.82	801.57	1 402.24	455.22	1 568.28	135.45
Netherlands	3 860	2 569.8	2 327.4	2 750	2 885	2 800 E	3 300 E	2 250 E	2 200 E	2 300 E	2 200 E
Portugal	...	...	...	...	...	...	...	337	2 287.28	2 344.12	294.5
Russian Federation	7	3	45	54	57	36	216	531	2114	3 297	4 102
Thailand	28 090	8 377	16 129	17 595	12 838.53	19 870	20 212	21 921	14 051	17 904	15 747
United States of America	180	196	1 273	1 273	2 173	1 220	2396	2 639	2 639	329.1	822
Australia	...	...	...	...	...	...	...	...	...	...	...
El Salvador	5 E	5 E	10 E	10 E	10 E	10 E	10 E	15 E	15 E	15 E	10 E
Israel	0	0	0	0	...	...	...	...	...	...	...
Italy	0.1	8.7	...	...	...	...	...	...	...	...	...

Aquaculture production value of "Pacific cupped oyster" (USD 1 000)

ASFIS species (Name)	Pacific cupped oyster										
ASFIS species (Scientific name)	*Magallana gigas*										
	Year										
Country (Name)	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Australia	20 084.33	24 074.75	24 234.81	21 351.59	20 451.5	17 699.6	15 764.15	20 147.17	21 461.51	18 273.94	21 167.32
Canada	8 692.54	8 474.03	10 281.94	12 150.69	11 755.09	11 280.64	11 148.76	10 987.72	10 125.95	11 496.14	7 682.31
Channel Islands	3 426.56	3 833.75	3 637.31	4 352.78	6 291.45	5 452.06	4 417.65	3 614.15	4 594.43	4 087.16	3 237.9
France	447 983.03	527 061.55	498 844.36	503 356.02	444 409.39	366 868.02	430 294.04	469 381.66	444 898.58	437 805.88	398 986.23
Ireland	26 689.06	39 476.55	46 226.64	49 765.66	52 184.23	39 058.45	36 685.1	48 598.8	52 356.86	50 585.92	43 491.45
Japan	383 072.18	382 447.12	381 474.63	308 825.46	342 366.18	317 438.13	325 582.32	298 192.09	307 772.43	285 205.75	286 229.46
Korea, Republic of	146 801.43	174 967.84	156 988.4	127 665.2	191 540.19	161 941.44	148 926.42	189 682.46	187 542.69	196 325.74	223 244.14
Mexico	4 758.81	2 968.99	3 595.36	3 409.35	1 362.32	3 607.15	10 829.86	10 515.89	7 254.55	5 615.32	5 716.94
Morocco	537.82	548.25	450.48	497.62	906	550.51	1 150.14	1 331.55	1 488.89	1 759.99	1 453.11
New Zealand	9 577.91	5 700.69	7 290.38	8 642.62	9 138.37	14 777.04	15 267	15 728.47	16 649.87	16 172.29	11 790.81
Portugal	933.45	1 542.02	1 138.77	1 309.52	1 327.01	1 123.96	1 808.26	2 935.76	6 649.7	9 269.76	13 428.65
Spain	1 545.34	2 940.95	1 978.62	2 110.49	2 463.49	2 419.06	2 263.46	2 790.58	2 728.77	3 182.83	2 903
Taiwan Province of China	157 656.76	179 626.19	119 535.22	206 782.65	175 826.49	168 887.81	143 882.72	143 215.75	140 753.87	117 091.35	125 517.64
United Kingdom	6 883.25	6 040.3	8 334.69	6 221.56	6 673.38	6 400.68	7 982.76	9 650.59	9 261.89	10 533.8	8 685.71
United States of America	37 628.01	44 577	55 491.04	81 599.69	46 294.44	46 294.44	56 410.08	53 499.15	82 813.56	52 831.93	37 423.4
Others	4.807	5.403	6.371	5.335	6.599	6.445	6.800	6.747	7.426	11.569	7.006
Total	**1.261.077**	**1.409.683**	**1.325.874**	**1.343.376**	**1.319.588**	**1.170.244**	**1.219.213**	**1.287.019**	**1.303.779**	**1.231.807**	**1.197.964**
Algeria	0.27	0	0	1.42	80.67	163.87	69.08	570.3	657.67	231.88	262.88
Argentina	25	233.57	44.08	44.08	12.63	16.57	14.16	20.29	4.49	14.49	1.7
Bulgaria	0	0	0	0	0	0	0	0	0	47.92	31.45
Chile	282	0	0	0	249	0	129	171.54	229.59	1326	282
Costa Rica	90.33	206.66	283.36	440.2	367.81	411.55	383.67	368.27	362.24	388.22	164.13
Ecuador	16.38	0	0	0	0	22.78	54.26	180	360	487.5	487.5
Germany	954.52	1 002.21	925.05	956.25	956.52	798.85	720	720	720	720	450
Italy	131.25	270.05	422.69	516.17	899.17	739.08	737.34	752.51	486.34	577.65	1 091.24
Namibia	700	1 578.08	2 899.59	1 667.06	2 083.78	1 811.96	1 714.48	1 691.99	1 347.94	1 862.97	1 326.19
New Caledonia	855.25	399.94	334.05	345.31	345.41	0	0	0	0	0	0
Romania	0	0	0	0	1.03	0	0	0	0	0	0
Senegal	0	0	0	0	455.69	1 390.37	1 425.57	0	0	0	0
Singapore	58.64	58.87	107.84	69.34	5.02	0.26	3.33	6.12	4.96	4.23	28.74
South Africa	1658.74	1 632.11	1 293.1	1 262.34	1 078.45	955.25	1 214.41	1 948.36	2 783.16	5 297.46	1 972.87
Tunisia	34.58	21.31	61.46	33.24	63.62	134.58	335.19	257.91	349.47	251.02	226.5
United Arab Emirates	0	0	0	0	0	0	0	60	120	360	680.74

Aquaculture production value of "Cupped oyster nei" (USD 1 000)

ASFIS species (Name)	Cupped oysters nei										
ASFIS species (Scientific name)	*Crassostrea* spp.										
	Year										
Country (Name)	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Brazil	4 960,8	3 829.68	3 548.26	2 921.96	4 483.73	2 971.41	2 165.4	2 882.76	1 954.12	2 023.09	1 800.52
China	2 594 862.49	3 093 529.54	3 568 311.06	4 114 425.47	4 483 813.8	4 656 554.41	5 019 287.42	5 255 137.49	5 535 521.52	5 627 965.82	5 842 328.66
China, Hong Kong SAR	1 029.83	513.93	902.21	1 160.08	1289.59	1 289.83	1 288.3	1 668.11	2 169	1 788.46	1 935.05
Malaysia	1 206.14	1 652.03	1 099.3	1 065.6	1 537.64	1067.14	1 771.57	1 478.72	1 092.54	7 226.72	233.17
Netherlands	5 117.27	3 577.05	2 990.22	3 652.32	7 719.11	12 737.21	14 245.84	17 029.94	11 951.26	5 664.54	8 845.17
Portugal	0	0	0	0	0	0	0	1 126.88	8 103.52	10 496.73	992.31
Russian Federation	9.1	3.9	58.5	70.2	74.1	46.8	280.8	690.3	3 171	4 945.5	6 645.24
Thailand	21 544.8	6 509.19	14 062.54	15 151.3	10 767.22	22 479.64	22 667.96	29 187.7	13 116.53	24 138.92	13 386.89
United States of America	1 877.4	1 513.12	5 753.96	5 753.96	6 888.41	6 697.8	7 858.88	8 392.02	8 392.02	1 046.54	5 359.44
Others	8	20	15	15	15	15	15	23	23	23	15
Total	**2.630.616**	**3.111.148**	**3.596.741**	**4.144.216**	**4.516.589**	**4.703.859**	**5.069.581**	**5.317.616**	**5.585.494**	**5.685.319**	**5.881.541**
Australia	0	0	0	0	0	0	0	0	0	0	0
El Salvador	7.5	7.5	15	15	15	15	15	22.5	22.5	22.5	15
Israel	0	0	0	0	0	0	0	0	0	0	0
Italy	0.64	12.11	0	0	0	0	0	0	0	0	0

2019–2020 Aquaculture production of Pacific cupped oysters (Tonnes live weight & USD 1 000)

ASFIS species (Name)	Pacific cupped oyster		Cupped oysters nei						
ASFIS species (Scientific name)	*Magallana gigas*		*Crassostrea* spp.						
	Tonnes (live weight)				**Value (USD 1 000)**				**Ex-Farm price**
Country (Name)	**2019**	**2020**	**Mean**	**%**	**2019**	**2020**	**Mean**	**%**	**USD/kg**
China	5 225 595	5 424 632	5 325 114	89.51%	5 627 966	5 842 329	5 735 147	82.52%	1.08
Korea, Republic of	326 190	300 084	313 137	4.95%	196 326	223 244	209 785	3.15%	0.74
Japan	161 646	158 900	160 273	2.62%	285 206	286 229	285 718	4.04%	1.80
France	84 760	79 500	82 130	1.31%	437 806	398 986	418 396	5.64%	5.02
United States of America	26 529	22 134	24 331	0.37%	53 878	42 783	48 331	0.60%	1.93
Taiwan Province of China	19 392	19 165	19 279	0.32%	117 091	125 518	121 304	1.77%	6.55
Thailand	17 904	15 747	16 826	0.26%	24 139	13 387	18 763	0.19%	0.85
Ireland	10 460	9 242	9 851	0.15%	50 586	43 491	47 039	0.61%	4.71
Canada	7 786	5 149	6 468	0.08%	11 496	7 682	9 589	0.11%	1.49
Portugal	4 034	3 588	3 811	0.06%	19 766	14 421	17 094	0.20%	4.02
Mexico	3 489	3 873	3 681	0.06%	5 615	5 717	5 666	0.08%	1.48
Russian Federation	3 297	4 102	3 700	0.07%	4 946	6 645	5 795	0.09%	1.62
Australia	3 004	2 883	2 943	0.05%	18 274	21 167	19 721	0.30%	7.34
United Kingdom	2 680	2 200	2 440	0.04%	10 534	8 686	9 610	0.12%	3.95
Netherlands	2 300	2 200	2 250	0.04%	5 665	8 845	7 255	0.12%	4.02
Brazil	1 900	1 700	1 800	0.03%	2 023	1 801	1 912	0.03%	1.06
New Zealand	1 871	1 364	1 618	0.02%	16 172	11 791	13 982	0.17%	8.64
Malaysia	1 568	135	852	0.00%	7 227	233	3 730	0.00%	1.72
Channel Islands	1 281	1 010	1 146	0.02%	4 087	3 238	3 663	0.05%	3.21
Spain	894	831	862	0.01%	3 183	2 903	3 043	0.04%	3.49
China, Hong Kong SAR	620	631	625	0.01%	1 788	1 935	1 862	0.03%	3.07
Morocco	423	345	384	0.01%	1 760	1 453	1 607	0.02%	4.21
Others	1 589	1 152	1 370	–	11 592	7 021	9 306	-	-
	5 909 212	**6 060 566**	**5 984 889**	–	**6 917 126**	**7 079 505**	**6 998 316**	-	-

Appendix III – **Secchi disk**

The "Secchi disk" is a tool created in 1865 by Angelo Secchi and is commonly used to measure the water transparency in both fresh and seawater bodies.

It consists of a 30 cm (12 inches) circular disk with a black and white design as illustrated in Figure A3.1. The disk is suspended on a graduated rope and is lowered slowly in the water until the point where it disappears. The measure will be the depth where the disk is no longer visible to the naked eye.

The Secchi disk can be home-made. It is important that the material the disk is heavy enough for the disk to sink rapidly and vertically when lowered into the water. Where necessary, an additional ballast can be fixed underneath. The rope graduation is usually made each 0.5 metre.

Measurement depends mainly on two factors that are the phytoplankton concentration and the turbidity due to suspended matter in the water. When operating in open sea, turbidity is usually negligible, so phytoplankton concentration is the most important factor. In eutrophic seawater, the disk will disappear 1–2 m from the water surface. In oligotrophic water, the Secchi disk can still be viewed at depths of more than 5–10 m.

FIGURE A3.1
Secchi disk

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Notes and observations

The purpose of this manual is to give the reader a foundation of practical knowledge regarding all aspects of Pacific oyster cultivation. It is targeted at new entrants to the market wishing to establish a farm, and existing operators who wish to develop their farms and explore new cultivation techniques. The methodologies described can be applied both to low-tech, low budget, small-scale farming operations and to high-tech, big budget, industrial scale aquaculture production enterprises. This guide focuses on the functional expertise and technical equipment required to construct and manage an operational farm in the diverse environmental and physical locations in which they can be situated, from the initial stages of finding and selecting a suitable site, to the conclusion of the first production cycle and harvesting the crop.

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