FAO
FISHERIES AND
AQUACULTURE
TECHNICAL
PAPER

576

ISSN 2070-7010

Construction and installation of hexagonal wooden cages for fish farming

A technical manual

Construction and installation of hexagonal wooden cages for fish farming

A technical manual

FAO FISHERIES AND AQUACULTURE TECHNICAL PAPER

576

Fabrizio Piccolotti
FAO Consultant
Rome, Italy

and

Alessandro Lovatelli
Aquaculture Officer
Aquaculture Branch
FAO Fisheries and Aquaculture Department
Rome, Italy

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
Rome, 2013

ISBN 978-92-5-107380-3 (print)
E-ISBN 978-92-5-107689-7 (PDF)

Preparation of this document

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

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

Abstract

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

Piccolotti, F. & Lovatelli, A. 2013.
Construction and installation of hexagonal wooden cages for fish farming – A technical manual.
FAO Fisheries and Aquaculture Technical Paper No. 576. Rome, FAO. 76 pp.

Acknowledgements

The lead author wishes to thank the Fisheries and Aquaculture Department of the Food and Agriculture Organization of the United Nations (FAO) for giving him the opportunity to participate in this project to develop the aquaculture sector of the Republic of Djibouti and for the support during the preparation and finalization of this technical document. Sincere gratitude goes to the entire staff of the FAO Office in Djibouti, led by the Representative Ms Ndeye Ticke Ndiaye and her deputy Mr Abdoulkader Ismail, for their warm welcome and invaluable support throughout the project.

The lead author also acknowledges the role played by the Fisheries Department of the Ministry of Agriculture of Djibouti – from its Director, Mr Ahmed Darar Djibril, and the Head of the Fisheries Division, Mr Moustapha Hassan Allaleh, to the technicians Mr Youssouf Ali Youssouf, Mr Ali Guirreh Djama, Mr Maki Houmed Med and Mr Saïd Ahmed Djama. Their support and dedication enabled the successful construction of the marine cages in Loyada. The field team was also composed of fishers from the Loyada community. Sincere thanks are extended to Mr Ahmed Ibrahim Robleh (the Manager of the Loyada fishery), Mr Aden Nauh and the technicians and the fishers concerned.

Thanks are also expressed to Ms Zakia Massik, Ms Tarub Bahri (FAO) and Ms Doris Soto (FAO) for reviewing this document, and for their corrections and valuable suggestions. Ms Marianne Guyonnet of the FAO Fisheries and Aquaculture Department also contributed to the final production of this document. The translation into English of the original French document was made by Mr John Eshun with editorial inputs provided by Mr Michael New. All the drawings were made by Ms Emanuela D'Antoni and the page layout was prepared by Mr José Luis Castilla Civit.

All the photographs were taken by the lead author.

Glossary

Anchor ring: strong iron ring to which a cable or a chain is attached (through a shackle).

Beacon: an object that indicates a hazard or serves as a marker.

Feed conversion ratio: this indicates the relationship between the quantity of feed consumed and the amount of growth, e.g. a value of 1.7:1 means that 1.7 kg of feed are needed to obtain a weight increase of 1 kg in biomass in fish farming.

Fetch: the distance at sea or on a water body across which the wind blows without encountering an obstacle.

Fouling: the spontaneous colonization of a submerged support structure by sessile organisms (algae, molluscs, crustaceans).

Hawser: a large rope (mooring rope or line) used for mooring or towing operations.

Launch: transferring a ship, a cage, etc. into water.

Hatchery: a structure designed to produce the eggs, larvae and fingerlings of fish or other commercial aquatic organisms.

Mark out: delineate a place by placing marker posts.

Moor: drop an anchor or a mooring post into the water to hold an object in place.

Mooring post (or sinker): a concrete slab or other heavy object, placed on the sea bed and connected by a rope or chain to a buoy or other floating object.

Pay out (a line): uncoil a mooring cable from a boat into the water.

Secchi disc: circular disc (about 20 cm in diameter) whose upper surface is divided into four equal parts painted alternately black and white. This is used to measure the penetration of light in water (its transparency). It is submerged at the end of a calibrated line until it disappears from view.

Shackle: A U-shaped piece of metal secured with a shackle pin or bolt across the opening; used to link two sections of a chain.

Specific growth rate: a technical term in fish farming to indicate the daily growth rate in terms of percentages.

Stocking: the process of putting fingerlings into a cage.

Stocking density: this indicates the quantity of fish (in kilograms) in relation to the volume of the cage (in cubic metres).

Teredo worms: bivalve molluscs (= lamellibranchs) with very long bodies, wormlike, that bore holes in wood submerged in seawater or brackishwater. Also known as shipworms.

Twine number: this indicates the size of the mesh twine and it is expressed in two figures (e.g. 201/70), the first of which indicates the linear weight of the primary fibre that makes up the twine (i.e. 210 is the weight in grams of a fibre 9 000 m long), while the second (in this case 70 but can range from 12 to 400) refers to the number of twisted fibres that constitute the net twine.

Uncoil: a marine term meaning to uncoil a cable that was coiled or rolled in the form of a circle.

Contents

Preparation of this document iii
Abstract iv
Acknowledgements ix
Glossary x

1. Introduction **1**

2. Selection of site and suitable species **3**
2.1 Site selection 3
Environmental aspects 4
Hydrodynamic and geological factors 4
Physicochemical, ecological and biological factors 7
Logistical and sociocultural factors 10
2.2 Selection of suitable species 11
Economic aspects 11
Physiological aspects 12
Technical aspects 12

3. Choice of cage model **15**
3.1 Basic criteria 15
Economic factors: cost and benefit analysis 16
Technical factors 18

4. Components of a hexagonal wooden cage **23**
4.1 Cage model 25
The frame 26
The flotation system 27
The mooring system 28
The net 30

5. Cage construction **35**
5.1 Preparation of the mooring posts 36
5.2 Fixing of the wooden structure 38
5.3 Preparation of the flotation system 42

6. Cage installation at the farming site **45**
6.1 Marking of mooring points 47
6.2 Preparation of mooring lines 48
6.3 Installation of mooring posts and mooring of the cage 52
6.4 Attachment of the net 54

References and suggested reading **59**

Appendixes

Appendix 1 – Calculation of the surface area, volume and buoyancy of a body 61
Appendix 2 – Knots 65
Appendix 3 – Composition of concrete 69
Appendix 4 – Technical characteristics of ropes 73
Appendix 5 – Calculation of location of the mooring posts 75

LIST OF TABLES

1 Main advantages and disadvantages of cage culture 4
2 Principal factors, method of measurement and acceptable values 5
3 Relationship between the wind speed and the swell 7
4 Relationship between the characteristics of a site and the most suitable cage model 21
5 Materials necessary for a hexagonal wooden cage 24
6 Relationship between fish size (groupers) and net mesh 33

LIST OF FIGURES

1 Major interactions between the cage and the environment 6
2 The perimeters of four different cage models with the same surface area 19
3 Water exchange is better in square and rectangular cages than in cylindrical ones (of the same volume and mesh length) 19
4 For the same current speed, complete water exchange inside the cage occurs more frequently in smaller cages 20
5 (a) Top view; (b) side view of the cage 25
6 How floats prevent accidental immersion of a cage 29
7 Design of a net with all the technical specifications 32
8 A corner of the cage and the distance between the components 38
9 Schematic drawings illustrating the correct insertion of the bolts, plates and washers 41
10 The area occupied by the mooring system in relation to that of the cage 47
11 Installation of provisional marker buoys at the cage farm site 48
12 First phase of attachment of the net 57
13 Second phase of attachment of the net 57

LIST OF BOXES

1. Main features of the fish farming net 31
2. Principal features of the Loyada site, Djibouti 45

LIST OF PLATES

1 (a) Five hexagonal wooden cages placed in an exposed site in the Republic of Djibouti; (b) hexagonal cages, unitary and modular structures in an exposed site in Viet Nam; (c, d) square cages in modular structures in two highly protected bays in Viet Nam 8

2 (a) Freshwater well, (b) ice-making machine, (c) generator, (d) space outside for construction work 10

3 (a) Cobia (*Rachycentron canadum*) juveniles fed with low-value fish; (b) example of feed used 13

4 Preparation of feed: (a) chopped fish in Viet Nam; (b) filleting of low-value fish in Africa 13

5 (a) Circular cage in high density polyethylene tubes (HDPE) used in small-scale aquaculture in Viet Nam; (b) example of a dual cage system, floating structure in HDPE and wooden frame to support the net; (c) the movements of the workers from one cage to another during feeding operations is easier with modular structures; (d) sorting and examination of the fish stock in modular hexagonal cages 15

6 (a) Cutting a threaded rod into pieces; (b) welding of the nut to form the head of the bolt; (c) 20 cm bolt obtained; (d) iron bolts, bars and plates made by a blacksmith. 17

7 Assembling of components by local workers 17

8 Hexagonal cages placed in an exposed site 23

9 (a) Detail of the walkway; (b) feeding of fish 26

10 (a) Knotted net; (b) knotless net 32

11 A flat open area is required for the construction of cages. 36

12 Old tyres used for the construction of concrete blocks lined up on plastic bags 36

13 The drums of the floating system are initially used in the preparation of the mooring posts 36

14 Arrangement of chains 37

15 Crossed iron bars in the tyres 37

16 The tyres are filled with concrete 38

17 Mooring posts prepared and left to dry 38

18 Tools required for cage assembly 39

19 (a) Arrangement of the first lower beams; (b) verification of the distance between the parallel beams 39

20 Arrangement of upper beams 40

21 Verification of the length of the internal sides 40

22 (a) Drilling of holes in the beams; (b) the holes for the insertion of the bolts are ready 41

23 (a) Bolt insertion; (b) all four bolts properly inserted in the first corner 41

24 Tightening of screws 42

25 (a) Spreading of glue; (b) tightening of the screw cap 42

26 (a) Fixing the first rope on one end of the drum; (b) fixing the third (top left) rope to the drum, with the bottom right still to be added 43

27	Installation of drums under the cage	43
28	(a) Tying of drum to the beam; (b) drum securely tied with the four ropes to the cage	43
29	(a) Completed cage ready for use; (b) cage ready to be towed to the installation site	44
30	Completed cage being hand-carried across the beach	44
31	Provisional marker buoys delimiting the farm site	49
32	(a) Coiled rope on delivery; (b) reach in and take hold of the inside end; (c) draw it out holding the rope end; (d) pull out the entire length of the rope	50
33	Protection of the rope with adhesive tape	50
34	Preparation of four identical mooring lines	51
35	Sequence for correctly tying the mooring line to the chain link and protecting it from rubbing against the chain	51
36	(a) Coiling the mooring line; (b) coiled mooring line, ready to be lowered into the water	52
37	(a) Mooring posts correctly arranged on the boat; (b) mooring lines being tied to the chain	52
38	Lowering the mooring posts into the sea	53
39	(a) Tying the two towing ropes to two adjacent corners; (b) towing of the cage	53
40	Mooring of the cage	54
41	Moored cages ready for the nets to be attached	54
42	(a) Net delivered with its identification label; (b) examination of net before it is fixed onto the cage; (c) net roof; (d) label with the technical specifications and registration number	55
43	Knots used for tying the ropes to the loops of the net	56
44	Ballast weights to be tied to the bottom of the net after it is attached to the cage	56
45	Three nets ready to be installed loaded onto the boat	56
46	(a) First phase of attachment of the net; (b) second phase of attachment of the net	58
47	(a) Corner of the net fully stretched by the ballast; (b) iron plate used as a ballast; (c) wall of the cage fully stretched after attachment of the ballasts; (d) fixing of net completed	58

1. Introduction

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

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

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

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

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

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

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

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

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

2. Selection of site and suitable species

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

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

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

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

2.1 SITE SELECTION

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

TABLE 1
Main advantages and disadvantages of cage culture

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

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

Environmental aspects

The environmental study comprises the following elements:

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

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

Hydrodynamic and geological factors

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

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

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

TABLE 2
Principal factors, method of measurement and acceptable values

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

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

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

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

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

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

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

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

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

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

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

FIGURE 1
Major interactions between the cage and the environment

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