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DESIGN OF A CAGE CULTURE SYSTEM FOR FARMING IN MEXICO

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ABSTRACT

The increasing world demand for fish cannot be met by capture fisheries. Aquaculture production is increasing and nowadays cage culture has an important role in meeting the world's fish demand. In Mexico, capture fisheries have not increased in recent years.Its aquaculture production is mainly inland and the cage system for marine fish culture is scarcely used. Based on the necessity to increase fishing production in Mexico, the design of a cage for culture is proposed that can be developed and built in the country. To accomplish this objective, the following tasks were carried out: a) definition of possible species and sites for farming; b) definition of design parameters, and c) proposed cage for farming. The suitability of species was analysed based on biological, marketing and environmental criteria. The site selection was based upon oceanographic and environmental aspects and logistical support for the cage farm. The design parameters for the cage were based upon experiences of cage farming, as well as on guidelines in papers. The proposal was designed through the definition of major systems: structure and floating, service, net bag, moorings and anchor systems. A floating cage with a netting bag for culturing "Black Snook" *(Centropomus nigrescens)* is proposed. It measures 13 m in diameter and 8 m in depth and has a capacity to harvest 17 tons of fish. Black Snook. To encourage this fishery system in Mexico, interdisciplinary work will be necessary to tackle the three main issues on cage culture: biological, engineering and socio-economic. In this project, the engineering issue is addressed as part of the necessary knowledge for the implementation of the cage system. Cage culture could have multiplier effects: provision of jobs for displaced fishermen from traditional fisheries, increased economic inputs, increment fish production and reduced pressure on traditional fisheries, supporting their sustainability.

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1 INTRODUCTION

In Mexico, 88% of the total fish production comes from capture fisheries, while inland aquaculture provides 12%. Of the fish caught, 78% comes from the Mexican Pacific, 20% from the Gulf of Mexico and only 2% from inland waters (INP 2000a). The most important species by volume and value are: shrimp, tuna, sardine and squid. The fishing effort has increased considerably in Mexico, causing reduction in fishing stocks and even collapse of some fisheries.

Generally, the status of Mexican fisheries is not critical. However the high fishing effort has caused damage in some fisheries like: anchovy, abalone, sea urchin and sea cucumber. Other fish stocks are fully exploited, for example: shrimp, shark, octopus and spiny lobster (Table 1).

Table 1: Sustainability status of Mexican fisheries in 1997-1998 (INP 2000a).

Pacific Ocean		**Gulf of Mexico and Caribbean**		**Inland Waters**	
Fisheries	**Status**	**Fisheries**	**Status**	**Fisheries**	**Status**
Shrimp	▦	Shrimp	▦	Pátzcuaro	■
Tuna	□	Sharks	▦		
Small pelagics	□	Tuna	□		
Shark	▦	Red grouper	■		
Oceanic sharks	□	Octopus	▦		
Giant squid	□	Lobster	▦		
Abalone	■	Queen conch	■		
Lobster	□				
Sea urchin	■				
Sea cucumber	■				

= Development potential □ = Fully exploited ▦ = Over exploited ■

In Mexico, 67% of the fisheries (79% of species) are either fully or over exploited and cannot grow more. This applies to 50% of the fisheries and 51% of species in the Pacific coast and 86% of the fisheries and 97% of species in the Gulf of Mexico and Caribbean Sea (Table 2).

Table 2: Sustainability status by fisheries and species (INP 2000a).

Fishery status	**Development potential**		**Fully exploited**		**Over exploited**		**Total**	
Region	**F**	**Spp**	**F**	**Spp**	**F**	**Spp**	**F**	**Spp**
Pacific ocean	5 (50%)	32 (49%)	2 (20%)	24 (36%)	3 (30%)	10 (15%)	10	66
Gulf and Caribbean	1 (14%)	1 (3%)	4 (57%)	26 (90%)	2 (29%)	2 (7%)	7	29
Inland waters					1 (100%)	14 (100%)	1	14
Total	**6 (33.3%)**	**33 (30%)**	**6 (33.3%)**	**60 (46%)**	**6 (33.3%)**	**26 (24%)**	**18**	**109**

F = Fisheries, Spp = species

Due to the critical condition of most of the fish stocks, effort must be directed towards fishing resources that have development potential, with a focus on proposing new alternatives of fish production that does not affect over exploited stocks.

On a global scale, the decline of fish stocks has been a motivating factor for expanding the role of aquaculture in the fishing industry (Baldwin *et al.* 1999). Nowadays, the trend demonstrates that while wild harvest volume remains stable (or is in decline in several fisheries), aquaculture production has increased (FAO 2002). In this case, the system of cage farming (mariculture) has had an important role in meeting the global demand for fish products (Fredriksson *et al*. 1999).

Cage farming is one alternative in order to increase aquaculture production. Aquaculture production in Mexico is mainly inland, in fresh water and saltwater. Species farmed include shrimp, oyster and carp (Conapesca 2003). Mariculture (cage culture) began on a small scale in Mexico around 1999-2000 with blue fin tuna in the North Baja California state, following the experience of countries like Australia. That project has had good economic results for the exports of tuna to Japan, which has encouraged others companies to participate (Biopesca 2001). However, this is the only experience of fin fish cage culture in Mexico. It is possible that the present problems in the expansion of cage culture is the lack of knowledge about cage systems and their designs.

The purpose of this project is to encourage mariculture in Mexico, by proposing a cage for culture that can be developed and built in the country. To accomplish this objective the following tasks were carried out:

a) Definition of possible species and site for farming;
b) Definition of design parameters, and a
c) Proposal of the cage for farming.

2 AN OVERVIEW OF THE CAGE CULTURE SYSTEMS

Capture fisheries have levelled out and aquaculture production has increased. According to Beveridge (1996), the extrapolation of trends suggests that by the end of the first quarter of this century, farmed fish production will have outstripped capture fisheries production and become the most important means of providing fish for food. For example, already in 2001 capture fisheries decreased by 3.2% and aquaculture production increased by 7.2% from the year before. Out of a total aquaculture production of 49.5 Mt, 25 Mt are from mariculture, 22 Mt from fresh water culture and around 2.5 Mt from brackish water culture, (Vannuccini 2003). Cage culture of marine fish has grown rapidly over the last decade in Asia, Europe and Australia, utilizing inshore or offshore net cages (Benetti *et al*.1998). The development of this type of fish production is a long-term solution to meet the global demand for fisheries products and also provides economic opportunities for displaced fishermen (Bucklin and Howell 1998). Mexico, with a coastline of 11,500 km on both Pacific and Atlantic oceans, and 2,500 identified marine species, could develop this type of fish production.

In cage systems there are three important issues: the biological, engineering and socio-economic, which go hand-in-hand in development (Fredriksson *et al*. 1999). In this project, the engineering issue is tackled, reviewing the cage designs and calculations.

The design of the cage is directly related to the chosen site, inshore or offshore. In this respect, Loverich and Gace (1997) state, in their analysis about the effect of currents and waves on several classes of cages for offshore, that the most suitable cage is a self-supporting cage. However for inshore or sheltered sites the conditions change and gravity cages can be used. For example in Mjóifjörður and Akureyri, in Northeast and North Iceland respectively, farmers successfully use gravity cages to culture salmon and cod (Björgvin Harri and Jon Thorvardarson personal comments). Also in Grundarfjördur, in West Iceland, this type of cage is used for cod and, furthermore, these successfully use single point mooring systems to hold down the cages in its place, (Runólfur Guðmundsson personal comments). However, nowadays some countries tend to move the cages offshore due to legal and possible pollution problems, but in the open sea the cages face others problems like strong seas.

Submerged cages could provide a solution (Ben-Yami 1997). In all the cases: inshore, offshore, sheltered or not, the cage structures must withstand the forces of the currents, waves and winds, while holding stock securely. This is the engineering task.

The increase of requirements of the cage, will increase its cost, therefore careful analysis is necessary. In this respect, Huguenin (1997) reviewed the process of cage design and discussed potential problems, as advice to avoid potential pitfalls. However, the calculations were not tackled. In reality the whole calculation process for the cage is not available in one place. Some researchers have written about: current forces (Carson 1988; Aarsnes *et al*. 1990, Beveridge 1996), moorings (Rudi *et al*. 1988, Thoms 1989, Baldwin *et al*. 1999, Goudey *et al*. 2001), structural engineering (Cairns and Linfoot 1990), fish behaviour (Chacon-Torres *et al*. 1988), tests of floats (Slaattelid, 1990), weight and forces on the net (Fridman 1986), and wind and wave forces (Milne 1972, Beveridge 1996). In the appendixes the necessary calculation for the cage design are presented in a logical order.

2.1 Type of mariculture systems

Cages have developed a great deal since their inception and today there is a diversity of types and designs. Also, there are a number of ways to classify types of cages; Beveridge (1996) proposes four basic types (Figure 1):

a) Fixed
b) Floating
c) Submersible
d) Submerged

Fixed cages consist of a net supported by posts driven into the bottom of a lake or river; they are comparatively inexpensive and simple to build, but their use is restricted to sheltered shallow sites with suitable substrates. The floating cages have a buoyant frame or collar that support the bag; they are less limited than most other types of cages in terms of site requirements and can be made in a great variety of designs, and are the most widely used ones. The submersible cages rely on a frame or rigging to maintain shape. The advantage over other designs is that its position in the water column can be changed to take advantage of prevailing environmental conditions. Generally these cages are kept at the surface during calm weather and submerged during adverse weather. The submerged cages can be wooden boxes with gaps between the slats to facilitate water flow and are anchored to the substrate by stones or posts. They are used in flowing waters, while net bag designs are used in lakes (Beveridge 1996).

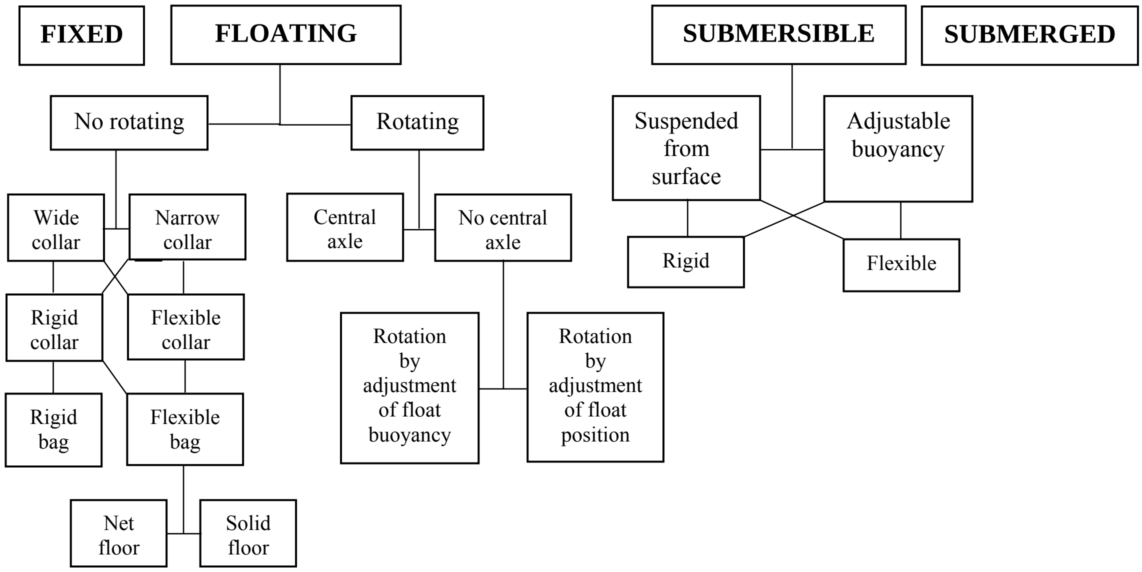

Figure 1: A classification system for cages by way of operating (Beveridge 1996).

Another classification system, which considers technical characteristics, is proposed by Huguenin (1997), Table 3.

Table 3: Classification of cage systems by technical characteristics (Huguenin 1997).

Way of operating	Surface; Submerged.
Place of operating	Marine; Estuarine; Freshwater.
Means of support	Fixed to bottom (usually via pilings) Floating (buoyancy)
Type of structure	Rigid (usually structure and mesh) Flexible (usually mesh only)
Access for servicing	Cat walked No catwalks (usually boat/barge serviced)
Operating parameters	Biomass loading (intensive-extensive) Species and Feeding practices (fed/unfed) (hand/auto)
Environmental severity	Sheltered / exposed / open water

On the other hand, Loverich and Gace (1997) classified the cages into four classes according to the effects of the currents and waves:

a) Gravity cages: rely on buoyancy and weight to hold the shape of the cage and volume against externally applied forces (see Figure 2).
b) Anchor tensioned cages: rely on anchor tension to hold their shape (see Figure 3).
c) Self-tensioned and supporting cages: the self-tensioning structure resists net deformations (see Figure 4).
d) Rigid cages: self-supporting structures made of jointed beams and trusses (see Figure 5).

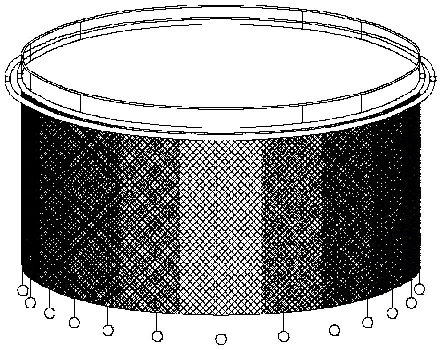

Figure 2: Gravity cage class (Loverich and Gace 1997).

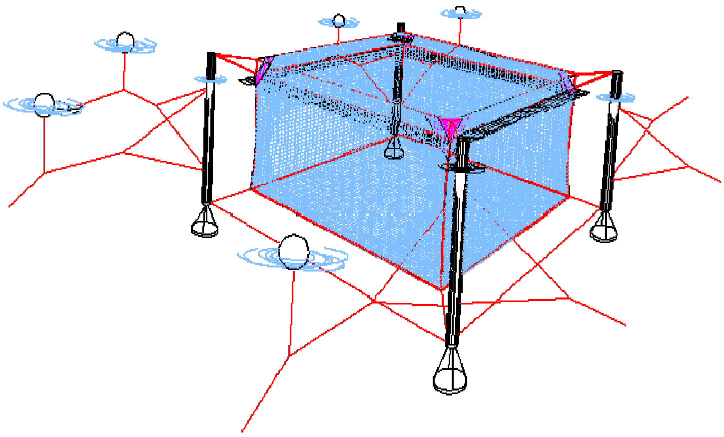

Figure 3: Anchor tensioned cages class (Loverich and Gace 1997).

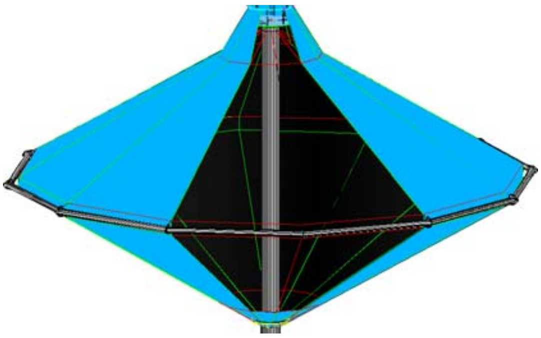

Figure 4: Self-tensioned and supporting cages class (Loverich and Gace 1997).

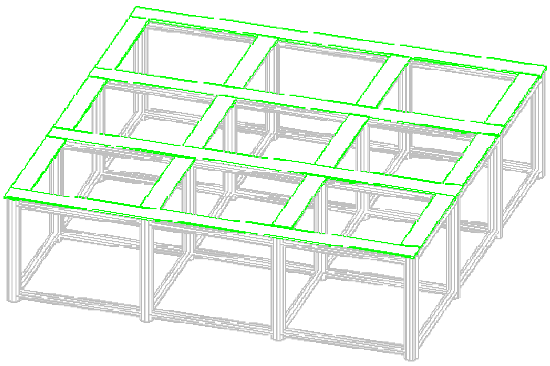

Figure 5: Rigid cages class (Loverich and Gace 1997).
Loverich and Gace (1997) concluded that gravity cages are unsuitable for using in the open ocean and there is growing evidence that they are even a poor cage class to use in sheltered sites. This is because these cages lose their shape with increasing currents. However, gravity cages can be designed with suitable moorings to maintain their shape for good performance, mainly for sheltered waters, like the case of some cages in Iceland for example. On the other hand, gravity cages have an advantage over the others in terms of: resources for construction and operation, level of technology required for construction, ease of management, adaptability, and economic performance, mainly for inshore waters. This is because these cages do not require high technology, require inexpensive materials, their structure and deployment is simple and their management is easier.

2.2 Identification of the components and devices of cage cultures

The different class of cages can be built in several types and sizes; however most of them present the following common components: floating system, mooring system, anchor system, net cage and services system (Figure 6).

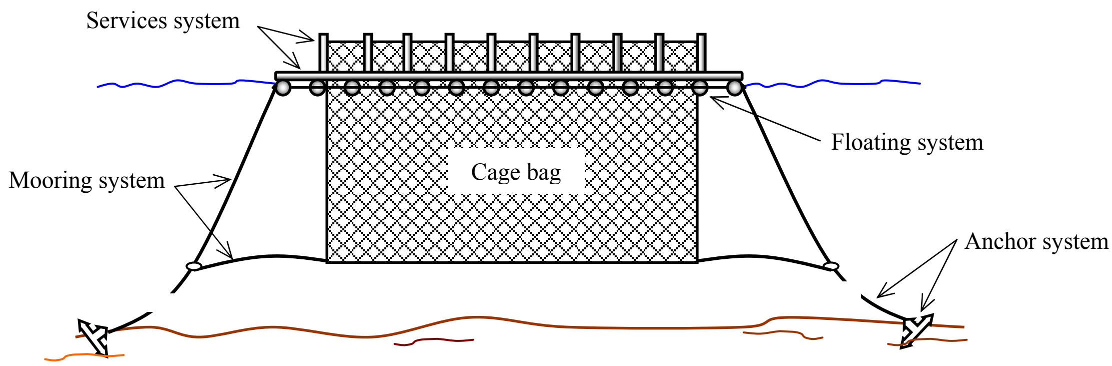

Figure 6: Principal components of the cage for farming.

Floating system: Provides buoyancy and holds the system at a suitable level in the surface of the water. In some cages this component is an important part to hold the shape of the cage. Common flotation materials include metal or plastic drums, high-density polyethylene (HDPE) pipes, rubber tires and metal drums coated with tar or fibreglass. Fibreglass drums or buoys are preferred as they can last for many years although the initial cost is comparatively high. Styrofoam blocks, covered with polyethylene sheets provide good buoyancy and may last for as long as 5 years under tropical conditions (Chua and Tech 2002). The buoyant force varies depending of size and materials used. The assembly of the system can be by connectors, stitching or tying.

Services system: This is the system required for providing operating and maintenance services, for example: feeding, cleaning, monitoring or grading. One way to provide this is by a catwalk around the cage or along part of the cage. Some cages use their flotation collars like catwalks and access for these services. These flotation collars are made of metal or plastic pipes with or without additional internal or external floats. The assembly with the cage or its structure is by connectors or ties using ropes. The size depends on the cage design. The initial cost of catwalks could be relatively high, but the services are indispensable. Alternative methods to provide these services are by access from a boat or a more stable platform such as a barge or a raft (Huguenin 1997).

Cage bag: The function of the bag is to contain and protect the fish and to provide a marine habitat. The net is normally flexible and made of synthetic netting of nylon or polythene fibres reinforced with polythene ropes, although recently new stronger materials like Spectra or Dynema have appeared. The nets are kept stretched vertically with weights at the bottom of the cage or fastened by rope to the framework depending of the type of cages (Chua and Tech 2002). Rigid cages made of metal netting (galvanized mesh, copper-nickel mesh or vinyl-coated mesh) mounted on rigid metal frameworks also are used. The flexible net bag is most used due to cost (Huguenin 1997).

Mooring system: This holds the cage in the suitable position according to the direction and depth decided in the design, and sometimes helps to maintain the shape of the cage. The mooring joins the cage at the anchor system. A mooring system must be powerful enough to resist the worst possible combination of the forces of currents, wind and waves without moving or breaking up (Thoms 1989). The materials used in the mooring systems are sea steel lines, chains, reinforced plastic ropes and mechanical connectors. The mooring force capacity depends on both the material and size, and can be adjusted to the requirements. Attachment to the system is by metallic connectors and ties.

Anchor system: This holds the cage and all the components in a particular site in the seabed and is connected to the cage by the mooring system. There are basically three types: pile anchors, dead weight anchors and anchors that get their strength by engaging with the seabed. Pile anchors are buried piles in the seabed, they are effective, especially for systems where a small space is necessary, they are driven into the seabed usually by a pile hammer from a barge on the surface; but, they are expensive to buy and install. Dead weight anchors are usually concrete blocks. Their one big advantage is that they are fairly consistent in holding power (Thoms 1989).

Hard sand, rock or gravel make no difference to concrete blocks, they can resist at least their own weight in water and in soft seabed conditions, they may do considerably better than that. However it is unlikely that they will hold more than 3-5 times their own weight under any condition.

The third type is mooring anchors which have to hold into a particular seabed when pulled from one direction only; they are made of steel and should slip easily into the seabed without disturbing the soil in front of it. If the substrate in front of the anchor is left without fracture and compact the holding power will be increased enormously (Thoms 1989). The anchors are joined to the mooring system usually by chains and metallic connectors.

3 METHODS

Selection of species to be farmed and the site for the cage culture and considering biological and oceanographic parameters, involve other important parameters such as: source of seed stocks, harvesting parameters and marketing arrangements, capacity, biomass loading, location regards services and maintenance and system life time (Huguenin 1997).

Most of these issues need long and careful research work. However, for the purpose of this project, which is, to present an integral method for designing a cage for culture and to apply it to Mexico, some of this data was taken from other research works and information gathered in examination visits to cage farms in the West, North, and Northeast of Iceland. Due to this, this project does not include the social, political and legal aspects that could be equally important in the selection of sites or species.

The species were analysed with biological, marketing and environmental criteria, reviewing global and local importance, distribution, size, climate, biology and commercial price. The reviewed species were:

a) Pacific sierra *(Scomberomorus sierra)*
b) Common snook *(Centropomus undecimalis)*
c) Pacific red snapper *(Lutjanus peru)*
d) Black Snook *(Centropomus nigrescens)*

The chosen species was ordered by: classification, biometry, habitat, feeding, locomotion, behaviour/habits and reproductive cycle.

The selection of the site was based upon the oceanographic features, environmental aspects and logistical support for the cage farm. The environment of the chosen species and sheltered places were major requirements for the selection. The study zone was the Gulf of California in the Mexican Pacific. Papers on hydrographical studies in this place were reviewed. Data was gathered for the chosen site on location, extension, currents, tides, depth, temperature and salinity.

The design parameters for the cage were based on experiences of cage farming in Iceland, as well as on guidelines from published studies. The fact that this is the first proposed experimental cage to be built and developed in Mexico was a major consideration at this point. In this design the following aspects were considered: capacity, stocking density, time of culture and size of fish in the stocking and harvest.

The cage for the proposed Mexican species was designed through the definition of its major systems with the emphasis on the design requirements. These systems are: structure and floating, service, cage bag, moorings and the system of anchor.

The size and shape of the cage were firstly defined applying the criteria of Huguenin (1997) and Beveridge (1996); the structure and floating system was defined on the basis of experience of Norwegian systems used by Icelandic farms. The mesh and net panel sizes were calculated applying the criteria of Fridman (1986). The weight and flotation of the cage was calculated applying formulas and data defined by Prado (1990). The current, wind and wave forces applied in the cage were calculated applying the criteria of Milne (1972), Fridman (1986), Carson (1988) and Beveridge (1996). The mooring and anchor systems were proposed with basis in the chosen site, experience of Norwegian systems and advice of Thoms (1989). The materials and specifications of the cage for different work conditions are presented in tables in this project. All calculations for the design are presented in the appendixes.

4 RESULTS

4.1 Determination of candidate species to culture

The selection of fish for culture should be based on biological criteria, such as physiological, behavioural characteristics and level of domestication; marketing criteria, for example demand, price, process and production for its trade; and environmental criteria, for example: temperature, distribution and habitat for the growth (Chua and Tech 2002).

Of prime importance, and probably first to be judged, are those properties that may be classified as consumer or market acceptance characteristics (Webber and Riordan 1976). People must want or be encouraged to want the resultant aquaculture food product. Otherwise there is no justification for the considerable effort required to domesticate and manage the culture of any new species. On this basis, the variables to analyse and choosing the possible species to culture in Mexico included: global and local importance, marketing, biology, distribution and environment.

Out of the four candidate species, Black Snook *(Centropomus nigrescens)* was selected as the most promising one. It is a demersal marine species that enters freshwater, mangrove areas and lagoons, capable of inhabiting both fresh and saltwater. It is an excellent quality fish, quite commercial, has high potential for export and fetches a good price (INP 2000a). The Black Snook(local name "Robalo prieto del Pacífico" (Figure 7), is found in the Eastern Pacific (Southern Baja California and mouth of the Gulf of California) it has high tolerance to temperature changes and salinity, is capable of living in shallow or deep waters and has a relatively short life-span of 7 years (Bussing 1995). These criteria, for candidate species, are recommended by Webber and Riordan (1976).

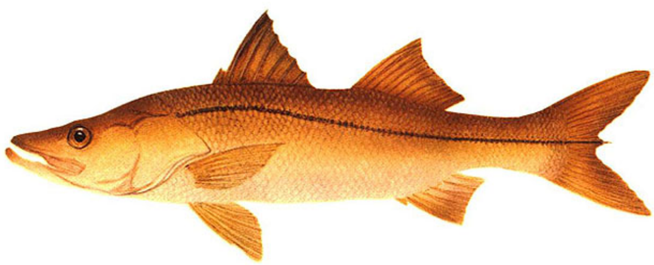

Figure 7: Black Snook *(Centropomus nigrescens)* (FAO 2004).

Even if this species has not been cultured before, Benetti *et al.* (1995) report that successful spawning and rearing of a local species of this snook *(Centropomus* *nigrescens)* through the larval and juvenile stages was accomplished experimentally in Ecuador. Even though the growth rate was low, Benetti *et al.* (1995) state that the first small-scale experimental trials were conducted and that a possible reason for the low growth rate was that the nutritional and environmental parameters might have been unsuitable. The experimental trials of spawning and rearing developed previously with snook will be analysed and it will also be necessary to carry out biological complementary studies in Mexico, as it will be the first trial to culture this species in cages. Biological and environmental characteristics of the Black Snook are presented in Table 4.

Table 4: Characteristics of Black Snook *(Centropomus nigrescens)* (Bussing 1995, INP 2000a and Quiroga *et al*. 1996).

Parameters	**Characteristics**
Family:	Centropomidae (Snooks), sub-family: Centropominae
Order:	Perciformes (perch-like)
Class:	Actinopterygii (ray-finned fishes)
Maximum size:	123 cm TL (male/unsexed); max. published weight: 26.2 kg
Environment:	Demersal; freshwater; brackish; marine
Climate:	Tropical; 33°N - 20°S
Distribution:	Eastern Pacific: southern Baja California, Mexico and mouth of the Gulf of California to northern Colombia.
Habitat:	They inhabit soft and sandy bottoms, usually at depths of less than 20 m and alternate in inshore seawaters, estuaries, rivers and brackish lakes, demonstrating a wide tolerance to salt concentration. Also, the fact they inhabit shallow waters, suggest tolerance of high changes in temperature; they are most active in temperatures of 20 – 26°C, below 16 °C they are inactive, becoming sluggish and below 15°C they are in danger of dying.
Feeding:	They are tertiary consumers, adults are voracious carnivores, feeding on several juvenile species of fishes, like anchovy, sardine, sea catfish, mojarra, red drum, pompano; crustaceans like shrimps, crabs and molluscs like clams and snails. In their juvenile phase they feed on zooplankton.
Reproductive cycle:	The gravid female migrates to the mouth of the river where she was spawned, during a full moon phase to release her eggs. The female releases about two million eggs and the male swims along side fertilizing the eggs as they are spawned. The male sperm requires a certain salinity of water to be activated, having no effect if the water is less than 15 ppt salinity. The nearly transparent larva drift in the estuarine tides and feed on smaller organisms for three to four weeks, at 9.5 mm the post-larval fish-like Snook migrates from the tidal estuary into calmer mangrove creeks and canals. Here they feed on copepods and grow about an inch a month. In the first year the Snook grows to 30.5–35.5 cm. feeding on increasingly larger live preys, always in close association with mangrove areas. Within four years they are about 61–66 cm. long and sexually mature males. Snook are protandric hermaphrodites, meaning they start life as males and later develop into females. They become sexually mature females at about six or seven years. Before this change the males prefer estuary habitats but may stay close to shore migrating to the mouths of rivers during the full moon phase to spawn with the female that is coastal oceanic oriented. At six or seven years the female is about 66 to 76 cm long weighing ten to fifteen pounds.

Snook is caught in the Mexican Pacific during the rainy season, near river mouths and coastal lagoons. Annual catch ranges between 5500-6500 t/year but local demand far exceeds supply (INP 2000b).

On the other hand, Benetti *et al*. (1998) present a study of feasibility of candidate species of marine fish for offshore cage culture in the Gulf of Mexico. Benetti used biological and marketing criteria to rank species into experimental, technological and economical feasibility levels; for example, the Red drum (*Sciaenops ocellatus)* obtained the highest commercial feasibility for culture offshore.

However, in this first trial cage design for Mexico the effort will be focussed on inshore culture. Black Snook is an active swimmer fish, that moves between brackish and seawater for feeding. It is a voracious carnivore that can feed on several species of fishes, crustaceans or molluscs. It usually inhabits depths of less than 20 m.

4.2 Site to place the cage

According to the nature of the Black Snook, a suitable place for its culture should meet the following criteria: water temperature: 20°-26°C, depth of 20 m, close to the shore, relatively near to the mouth of a river, estuary or in brackish lakes and preferably in the range of its natural distribution. Bays, straits and inland seas are ideal sites for cage culture provided these sites protected from strong winds and rough weather and have sufficient water movements (Chua and Tech, 2002).

The chosen site to place the cage is the Santa María La Reforma Bay in the oriental coast of Gulf of California, located in 24°43’–25°15’N and 107°55’-108°23’W, in the state of Sinaloa (Figure 8). The Black Snook inhabits this region and is adapted to it physiologically and behaviourally, which is important in the candidate species (Webber and Riordan 1976). In addition, this site was chosen considering oceano-graphical features and the possibility of logistical support and environmental aspects, like servicing the cage, distance or accessibility between the cage site and support facilities, distance to industrial or municipal plants and drainage discharges.

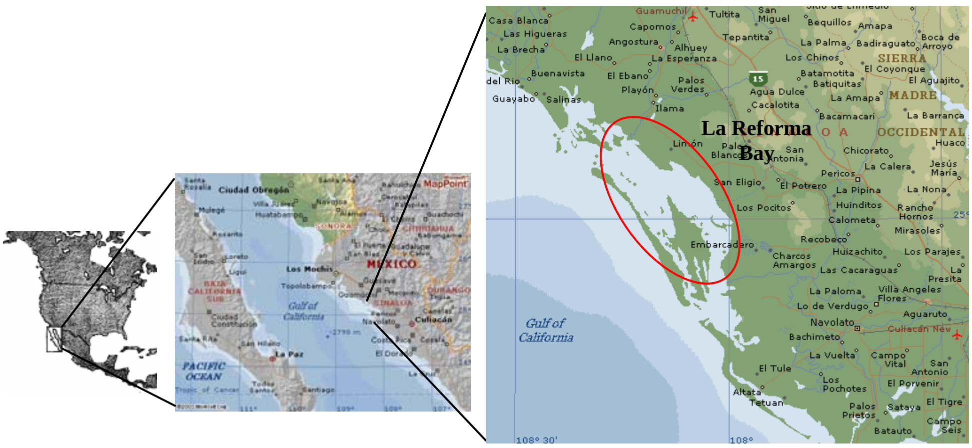

Figure 8 : The “Santa María La Reforma” Bay, Gulf of California, site proposed for the deployment of the cage for culture Black Snook.

The bay is located 35 minutes from the Topolobampo Port by sea and 25 minutes from the Angostura town by road. According to Serrano (2003), this bay is really a coastal lagoon system of 586 km^2, with an estimated volume of 1907 km^3 and maximum depth of 27.8 m. It is within the hydrological basin of the Mocorito River, which has an area of approximately 7171 km^2. The highest current velocities are registered in the mouths of the coastal lagoon, in the North 1.8 ms^{-1} and the South until 1.2 ms^{-1} (Figure 9). However, their channels are located behind, which serve for ebb and flow of the tide, register current velocities until 1 ms^{-1} and in the bays and coves the current is no bigger than 0.2 ms^{-1}. The tidal height is 1.74 m at the mouths.

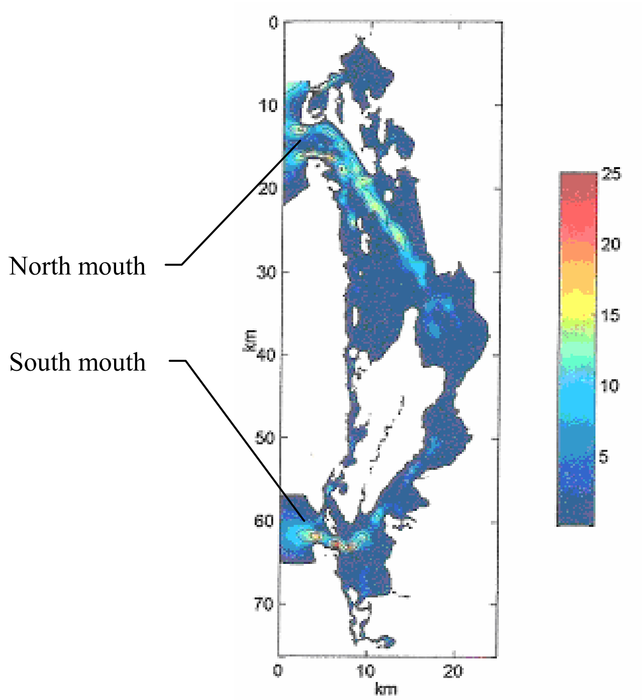

Figure 9: Bathymetry of the “Santa María La Reforma” Bay, Gulf of California (Serrano 2003).

The surface temperature in the Gulf zone is between 22 and 26°C with deviations of 3°C from the seasonal climatology due to “El Nino” which occurs every 4-7 years (Lavín *et al*., 2003). In another study of a lagoon system adjacent to the Santa María La Reforma Bay, salinities ranged between 29-35 ppt (Phleger and Ayala-Castaneda 1967).

4.3 Design parameters of the cage

The determination of the optimum sizes for both individual cages and for the total cage system involves a complex process, including consideration of the initial cost, operations, risks, marketing, and management difficulties. For example, decisions made for a variety of sheltered locations and conditions indicate optimal individual cage sizes with considerable variations in the order of 500-2000 m^3 for salmonid species (Huguenin 1997). Other important aspects in the determination of cage size are stocking density and maximum carrying capacity. The value for the maximum carrying capacity is very difficult to determine as it is a function of the incoming water quality and quantity and the physiology of the organism at that particular stage of development, which is not constant but varies with time and conditions. However, some guidelines can be provided, the maximum density, usually at harvest, for sites with good water quality and circulation is in the range of 16-24 kg/m^3 for most New England cage systems, 20 kg/m^3 in Norwegian operations and about 30 kg/m^3 in more intensive Scottish cages (Huguenin 1997). Considering that this is the first experimental cage for farming Snook in Mexico, the size and carrying capacity of the cage was based upon some of these previous guidelines and the biology of the Snook, which grows approximately 30.5–35.5 cm in the first year in the wild (Bussing 1995).

Based on this, a cage of approximately 1000 m^3 is proposed, with a stocking density of 20-30 fish m^{-3} of 23-25 cm length. The period of culture is estimated at 6-8 months, when fish should have reached an average of 800 g and a density in the cage of approximately 16 kg/m^3. The range of mortality is not known. In this first phase, the source of fish will be young fish caught in traps in the same zone, following the experience of other countries, like for example Iceland with the cod.

In addition to the technical and operative characteristics stated above, it is important to specify that this cage will be deployed in sheltered waters. Other important considerations to bear in mind for the design of the cage include: the ability to construction it using light weight materials, its towing capacity (for protection in case of bad weather), and the deployment on site of staff and maintenance issues.

4.4 Proposal of the cage for culture in Mexico

According to the natural conditions of the species and site selected, the technical characteristics proposed for the Black Snook cage are presented in Table 5.

Table 5: Technical characteristics of the cage for farming Black Snook *(Centropomus nigrescens)* in "Santa María La Reforma Bay", Gulf of California.

Method of operating	Surface: La Reforma Bay is not an exposed site and the wave forces are not high. This reduces the complexity of the system.
Place of operating	Marine: The Black Snook *(Centropomus nigrescens)* is a marine species.
Support	Floating: They are less restrictive in terms of site selection, suitable substrates and depth of waters.
Type of structure	Rigid: The cage needs some structure to maintain its shape (collar or framework). This facilitates the mooring system.
Access for servicing	Cat walked: To facilitate the operation and maintenance. The net bag could be supported by a buoyant framework and at the same time, be used as a catwalk.
Operating parameters	Biomass loading: Extensive, due to it is the first experimental cage and the information is limited.
	Feeding: By hand and fresh feeding.
Environmental severity	Sheltered: Bay and bars.

4.4.1 Structure and floating system

The proposed cage has a circular shape as this shape makes the most efficient use of materials and thus lowest costs per unit volume. Also, observations made on the swimming behaviour of fish, suggest that circular shapes in a plan area are better in terms of utilization of space. Corners of rectangular shapes are little utilized (Beveridge 1996). This is demonstrated in Figure 10.

The sizes of the cage are 13 m in diameter and 8 m in depth. It is assumed that depths greater than 10-12 m would be poorly used by fish and a cage depth of 3-10 m would be acceptable for most species (Beveridge 1996). In addition, in accordance with the habits of the Black Snook, which can live in deep or shallow waters, this size is suitable. The net bag will have a volume of 1062 m^3 with a capacity, at harvest, of approximately17 tons.

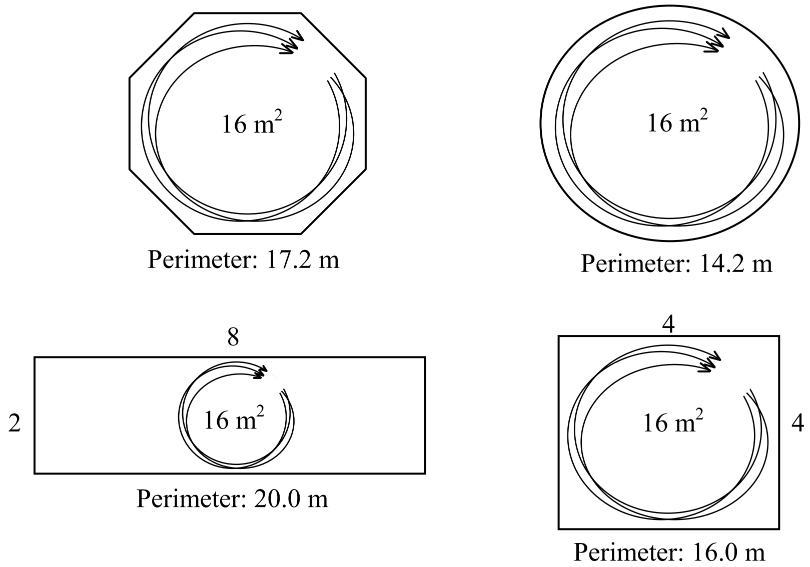

Figure 10: Perimeter lengths of different cage shapes for the same surface area and the circular swimming pattern of fish (modified from Beveridge 1996).

The cage will use collars of high-density polyethylene (HDPE) pipes for structure and, the same time, for flotation and ballast (Figure 11). The HDPE pipes are highly flexible structures and are used in the most of circular cages (Slaattelid 1990). This material has been used successfully in ring cages in Iceland (Jon Thorvardarson, pers.com.The HDPE is available in Mexico and is inexpensive.

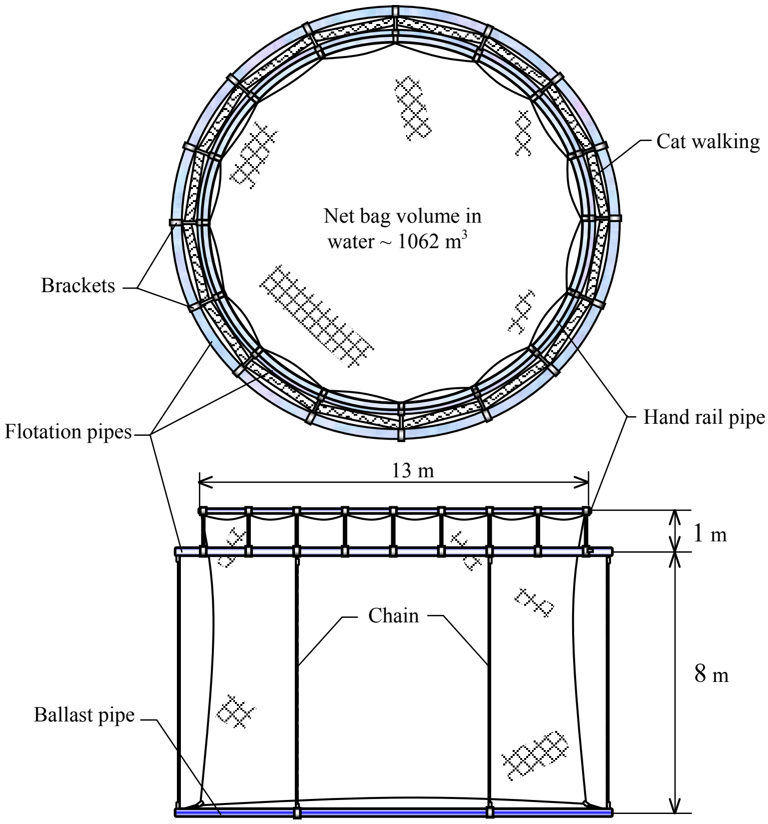

Figure 11: General view of the proposed cage for farming Black Snook in Mexico.

The cage will use two flotation pipes filled by expanded polystyrene as a precaution in case of damage, avoiding loss of flotation force. The ballast pipe will have holes for the free flow of the water and will use metal lines inside for increasing the weight.
This system is used in Norway and Iceland with good performance (Figure 12). The handrail pipe will not have material inside. The pipe ends will be joined by using a welding process for plastics.

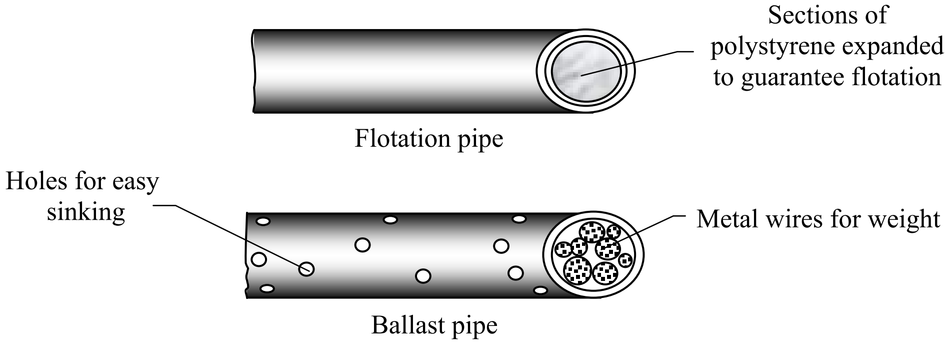

Figure 12: Details of the proposed flotation and ballast pipes made of high-density polyethylene (HDPE).

The two pipe rings for flotation and brackets will join the handrail. These brackets will give support to the rings and, at the same time, it will form part of the catwalk. The brackets will be made of galvanized steel to avoid corrosion and be fitted to the diameter of the pipes (Figure 13). The measurements of handrail and catwalk will be according to the anthropometry of the fishermen in Mexico. In this case, Vázquez (1997), suggests in his human factors study, that the maximum height for handrails and banisters should be approximately 100 cm and a minimum width for corridors and catwalks approximately 60 cm (Appendix 1).

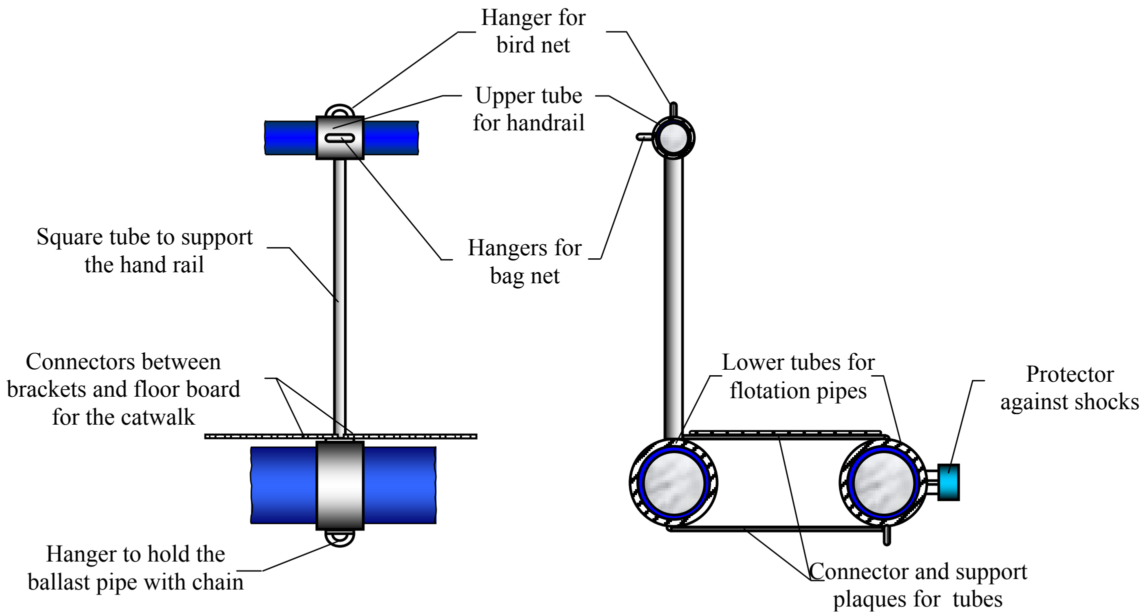

Figure 13: Brackets to hold the flotation and handrail pipes forming the structure of the cage and supporting the floorboards of the catwalk.

4.4.2 Service system

The catwalk goes round the entire cage; its purpose is to supply support and to make maintenance, feeding, cleaning and other required activities easy. This catwalk will be built of polyethylene panels with stainless steel joints connected between the brackets.

At the same these connections will hold the brackets in their place to avoid movements in the rings and loss of shape (Figure 14). The polyethylene has the strength, flexibility and lightness necessary for the catwalk in the cage.

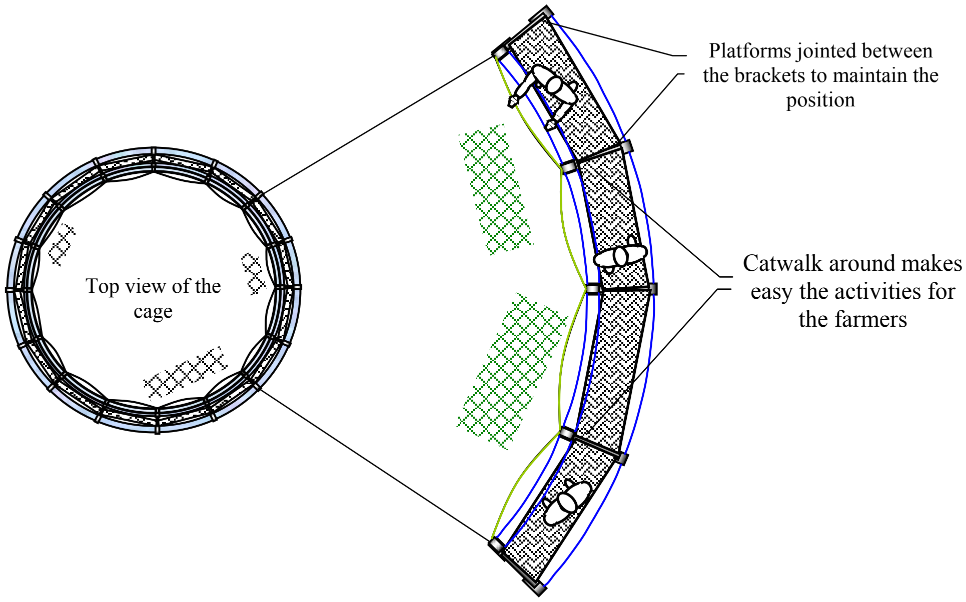

Figure 14: The catwalk around the cage will hold the brackets in its place and will facilitate feeding and maintenance**.**

4.4.3 Cage bag

The cage bag is of flexible mesh material, in this case polyamide (PA) which offers economic and technical advantages such as breaking strength, resistance to fouling and resistance to abrasion, in comparison with polyester (PES), polypropylene (PP) or polyethylene (PE) (Prado 1990, Beveridge 1996). The shape of the cage bag is a cylinder with a bottom lid and dimensions of 13 m of diameter and 9 m of depth (8 m under water and 1 m above the surface). This net bag is fitted to the upper and lower pipe rings by rope joints, which hold it and maintains its cylindrical shape.

The cage net is made of multifilament with mesh opening of 38.1 mm and diameter of 2.0 mm, according to the mesh size of gillnets recommended by Fridman (1986) in order to prevent the escape of the small fish in the stocking (22.9 cm). The net panel is hung with a hanging ratio (E) of 0.71 to produce square meshes, which helps against fouling and, also, the surface covered is at a maximum, which means less material is needed (Prado 1990, Appendix 2).

The net meshes will be impregnated with a special anti bio fouling material to prevent growth caused by the high temperature and sun at the chosen site. Surrounding vertical and horizontal ropes, which are used for joining the net to the rings, reinforces this cage bag. The upper side of the cage bag, above the surface, is joined to the hangers in the brackets near to the handrail for lateral protection (Figure 15).

The cage has an optional light upper net for protecting against fish eating birds. This net can be made of PA with a mesh opening of 102 mm. This optional bird net is hung on top of the brackets.

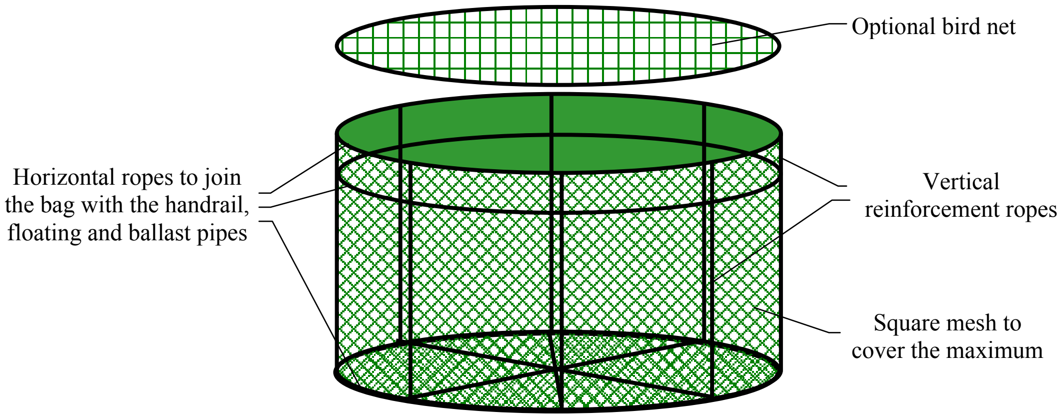

Figure 15: Cylinder cage bag with vertical and horizontal ropes for reinforcement and joints with the rings.

4.4.4 Moorings system

The chosen site is a sheltered bay and possible high currents are only present in the mouths (Serrano 2003). At the exact site, maximum current velocities do not exceed 1 ms^{-1}. A system of moorings with a single fixed point in the seabed can be used, like the Froya System of Norway (Fröyaringen 2003). This type of mooring system is relatively inexpensive, easy to build and set. It offers operational advantages since it allows the cage to drift around the anchor with the current to the point of least resistance, which exerts the least force on the system. This movement allows having a wide field of seabed and could reduce accumulated waste and pollution problems. Preliminary analyses of the benefits of this system indicate a two-fold to 70-fold reduction in deposition of waste on the seabed, depending on mooring geometry and current type (Goudey *et al*. 2001). To avoid the possibility of bag shape deformation caused by possible high currents, the mooring uses a system of six joint points to the cage, three in the upper side attached to the floating pipe and the others three in the lower side attached to the ballast pipe. This connection up and down in the rings of the cage assures to maintain the shape in any position irrespective of the currents. This mooring is formed by one metal multi connector pipe and braided ropes, which are attached to the brackets in the rings. The possible shock loads will be counteracted using a system of hung weights located between the metal multi connector pipe and the anchor. This system ensures soft movements of the cage with the currents by absorbing possible shocks. The vertical position of the weights depends on the forces acting upon it, thus acting like a shock absorber (Figure 16).

4.4.5 Anchor system

The site is characterised by a soft seabed and there are generally no high currents. Therefore the anchor system of dead weight type is proposed for easy building and

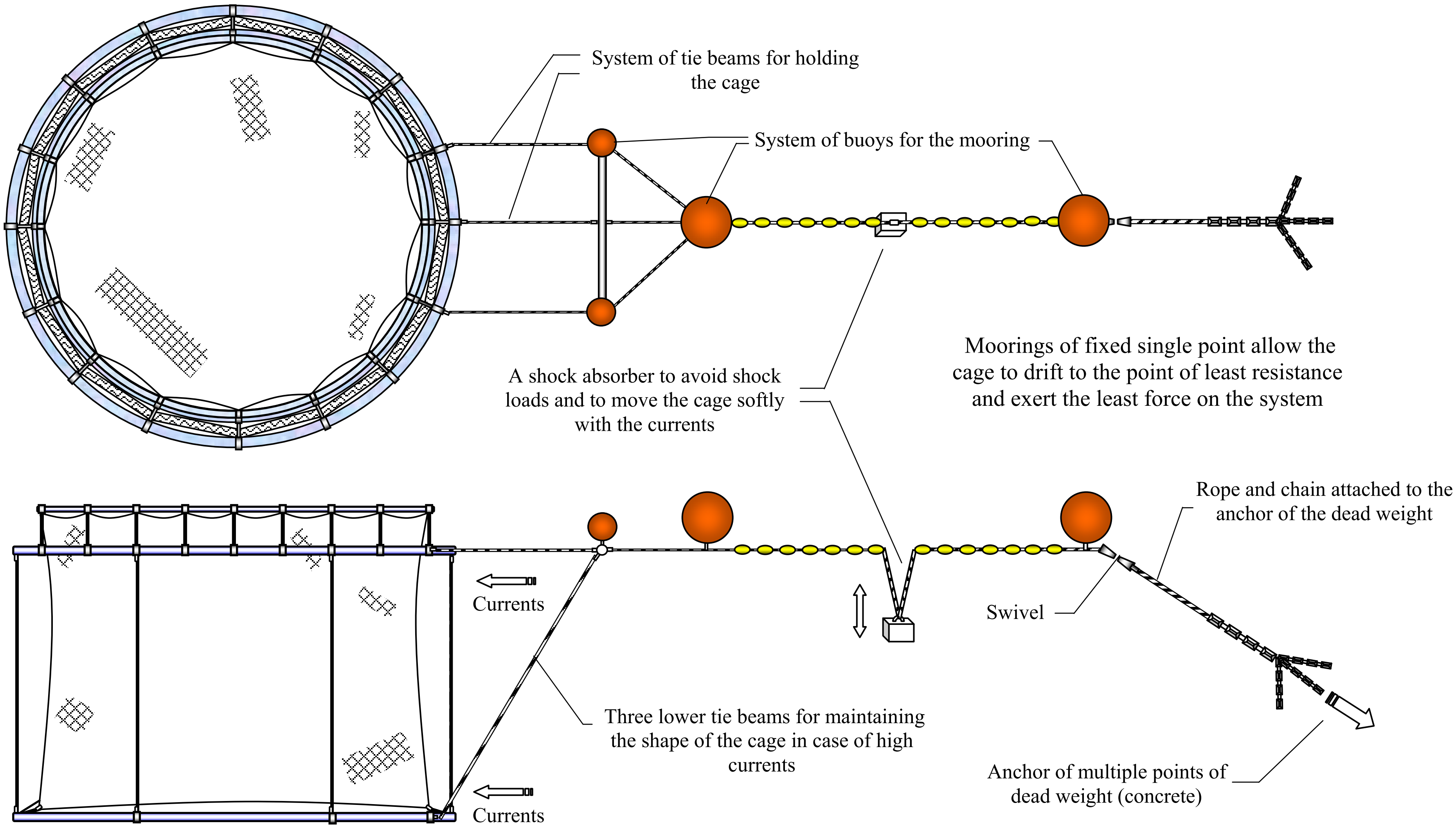

Figure 16: Moorings and anchor systems proposed for the cage for farming Black Snook in Santa María La Reforma Bay, Gulf of California.

setting. Furthermore, this anchor system is known to have good performance on this type of seabed (Thoms 1989). The anchor is connected to the mooring system by ropes and chains. This anchor system is formed by a system of concrete blocks joined together by chains and connected to a buoy by a braided rope. Several concrete blocks instead of one make the building, moving and setting of the system easy. Also, this allows having several points of anchoring. The concrete blocks have concave shapes in the bottom to take advantage of the suction effect. These mooring and anchor systems allow the cage to be disconnected easily and quickly in case of bad weather and the cage can be towed to a safe place without loosing its shape (Figure 16).

4.4.6 Specifications of the cage

The components of the cage were determined upon on the basis of the work conditions, present loads, suitable and available materials. The work conditions are given by the chosen site, in this case, a sheltered place, maximum velocity of currents $1ms^{-1}$, site depth of 14 m for setting, sandy seabed and 1.7 m of maximum tidal fluctuation. The loads were divided in two types:

a) *Static loads*, which are verticals and they are caused by the action of the gravity with reaction in the buoyancy of the cage. These depend on area and density of the netting, weights of frame components, weight of rigging, weight of ballast and, in opposition, the flotation force.

b) *Dynamic loads*, which are mainly horizontals and they are caused by the currents, winds and waves with reaction in the moorings and anchors of the cage. These depend of material used, shape of panel, size of the mesh, current velocity and density of water.

The size and type of materials were result of work requirements and the process for building it in Mexico. Also, some decisions were based upon experiences in cages farms in Iceland. The list of materials for the cage is presented in Table 6, and the general arrangement of parts in Figure 17; all the computation procedures are presented in Appendixes 2-10.

To compute the static loads in the cage, the relation between the weight of the cage with its components like the descendent force, and the capacity of flotation like the ascendant force was estimated. The weight, without moorings, was computed for three conditions:

a) Clean cage in the air
b) Clean cage in the water
c) Foul cage in the water

The knowledge of the cage weight allows to determinate the necessary flotation force (Table 7) computation procedures in Appendixes 3 and 5.

Table 6: Specifications of the cage parts.

Part	Material	Size	Quantity
. Net side panel	Polyamide (PA)	OM 38.1 mm - Ø 2.0mm	1050 x 236 meshes
. Net bottom panel	Polyamide (PA)	OM 38.1 mm - Ø 2.0mm	~341 x 341 meshes
. Bag ropes	Polypropylene (PP)	Ø 20 mm	192 m
. Floating pipe inner	Polyethylene (HDPE)	Ø 25 cm; 10 mm thickness	41 m
. Floating pipe outer	Polyethylene (HDPE)	Ø 25 cm; 10 mm thickness	45 m
. Handrail pipe	Polyethylene (HDPE)	Ø 12 cm; 8 mm thickness	41 m
. Ballast pipe	Polyethylene (HDPE)	Ø 25 mm; 10 mm thickness	45 m
. Auxiliary float	Polystyrene expanded	≤Ø 22 cm	284 kg
. Sinkers of ballast	Steel wire rope	Ø= 25.4 mm	223 m
. Chains to hold	Steel short-link chain	Ø= 11 mm	48 m
. Catwalk platform	Galvanized steel plate	60 cm X 250 cm X 3.17 mm	16
. Brackets	Galvanized steel	≈ 60 cm X 90 cm	16
. Moorings tube	Galvanized steel tube	Ø 15 cm X 0.6 thickness	6 m
. Moorings rope	Polypropylene (PP)	Ø 24 mm; for 8.5 tons	48 m
. Moorings rope	Polypropylene (PP)	Ø 26 mm; for 10 tons	12 m
. Moorings rope	Polypropylene (PP)	Ø 40 mm; for 23.6 tons	32 m
. Moorings rope	Polyamide (PA)	Ø 36 mm; for 24.8 tons	9 m
. Moorings chain	Steel	Ø 26 mm; for 21 tons	49 m
. Moorings swivel	Stainless steel	57 mm; for 17 tons	1

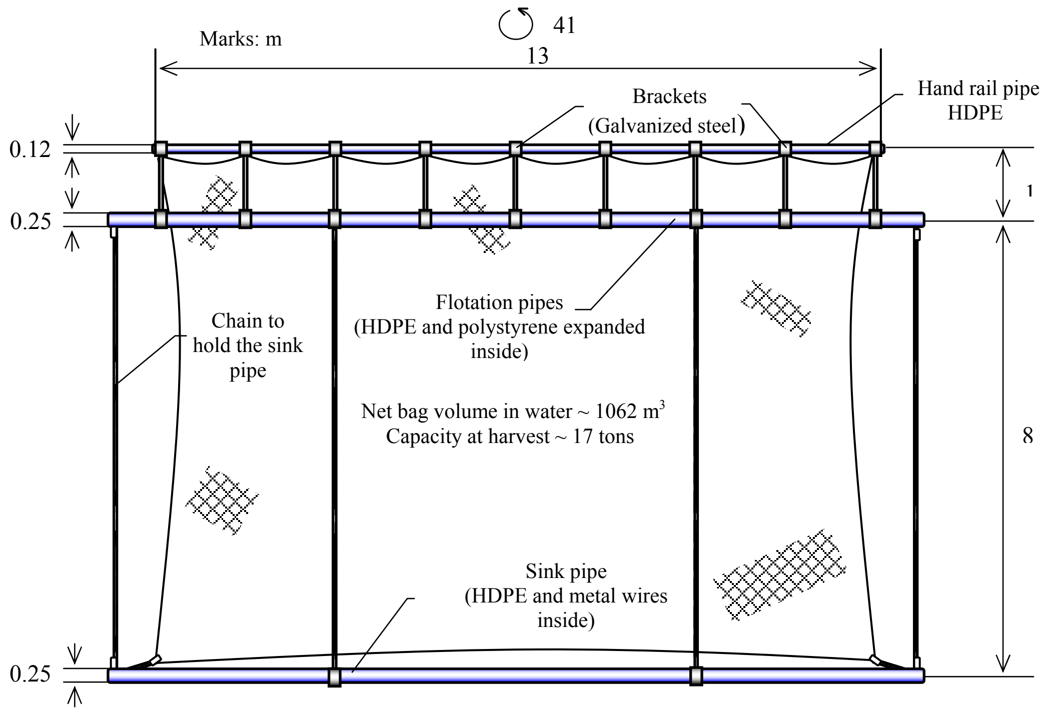

Figure 17: General arrangement of parts of the cage.

Table 7 : Weight of the cage for different conditions.

In the air with clean cage		**In the water with clean cage**		**In the water with fouled cage**	
Component	Weight (kgf)	Component	Weight (kgf)	Component	Weight (kgf)
Cage bag	160	Cage bag	16	Cage bag	89
Ropes	35	Ropes	-5	Ropes	35
Floating pipe (inner)	293	Floating pipe (inner)	-23	Floating pipe (inner)	23
Floating pipe (outer)	320	Floating pipe (outer)	-26	Floating pipe (outer)	26
Handrail pipe	109	Handrail pipe	109	Handrail pipe	109
Brackets	357	Brackets	357	Brackets	357
Cat walk panels*	446	Cat walk panels	446	Cat walk panels	446
Ballast pipe	320	Ballast pipe	-26	Ballast pipe	26
Wire ropes inside	647	Wire ropes inside	563	Wire ropes inside	675
Chains	125	Chains	109	Chains	130
Total	2812kgf	Total	1520kgf	Total	1916kgf

* Calculated for galvanized steel plaque.

An emergency flotation based in the model of Froya cage (Fröyaringen 2003) is proposed in case of damage in the pipes. This emergency floatation is given by expanded polystyrene placed into the pipes; the ratio between the air and polystyrene is 20%-80% inside the pipes. This assures enough ascendant force to counteract the descendent force of cage weight and maintaining it in the surface. In Table 8 the flotation forces for different conditions is presented. Computation procedures are shown in Appendixes 4 and 6.

Table 8: Nominal and effective floatation forces of the cage.

Conditions	**Weight (kgf)**
. Nominal flotation force (F_n)	3359
. Emergency flotation force (F_e)	2630
. Effective flotation for clean cage (F_c)	1839
. Effective flotation for foul cage (F_f)	1443
. Emergency effective flotation for clean cage (F_{ec})	1110
. Emergency effective flotation for foul cage (F_{ef})	714

The loads caused by the currents, wind and waves against the cage were considered to compute the dynamic forces. These forces act on different parts of the cage, but all of them drag and deform its shape. The knowledge of these forces is necessary for the computation of the mooring and anchor systems. The currents act mainly on the cage bag and rigging under the water, the load depends on the current velocity, density of water, material, shape and size of the mesh. Water flowing through a mesh or netting panel imposes loads, which are transmitted to the supporting frame, collar and mooring system.

In this case the loads imposed for the current forces were determinate for different work conditions. The results are summarized in Table 9 and the computation shown in Appendix 7.

Wind forces act mainly in the cage superstructure, formed by handrail, brackets and freeboard netting. Generally the main load of the wind is against the netting, but its effect is almost 40 times less than the effect of the currents (Thoms 1989), due to the density of the air and the exposed area, which is smaller in relation to the current forces.

In this case for example, for an extreme wind velocity of 150 km/s (41.7 m/s), the load on the cage is 187 kgf, which is no major problem in the system (the computation procedure is shown in Appendix 8).

Table 9: Current forces applied to the cage under different work conditions.

Clean cage Current velocity 0.75 ms^{-1}		**Foul cage Current velocity 0.75 ms^{-1}**		**Foul cage Current velocity 1 ms^{-1}**	
Component	Force (kgf)	Component	Force (kgf)	Component	Force (kgf)
Net panel	1460	Net panel	3028	Net panel	5384
Floating pipe	128	Floating pipe	154	Floating pipe	274
Ballast pipe	128	Ballast pipe	154	Ballast pipe	274
Horizontal ropes	20	Horizontal ropes	24	Horizontal ropes	43
Vertical ropes	31	Vertical ropes	37	Vertical ropes	66
Chains	25	Chains	30	Chains	52
Total	1792 kgf	Total	3427 kgf	Total	6093 kgf

The wave force acts mainly in the ring area of the cage. To calculate it, the horizontal and vertical orbital velocities of the water particles must be known. These can be derived from information on prevailing wave periods, wave heights and water depth at the site. In this case, as the chosen site is sheltered, it is possible that there will be no high waves. However, a hypothetical wave force was calculated using the recommendations of (Beveridge 1996).

The result was a force of 1789 kgf (the computation procedure is shown in Appendix 9). The wave forces are important due to the prolonged exposure to these cyclical loadings. In this case the flexible rings or collars allow for good absorption of these forces and possible deformations are minimized.

The moorings and anchor system and their components were proposed based upon the calculated forces on the cage, some considerations of Thoms (1989), and observations of systems in Iceland. Extreme work conditions, a fouled cage and a current velocity of 1.0 ms^{-1} with loads of ~6100 kgf were considered.

It is proposed to utilize a multiple dead weight anchor formed by 3 concrete blocks of 2.1 tons each, 6.3 tons in total; partially buried in the sea bed with a concave shape in the bottom to take advantage of the cohesion phenomenon. The moorings ropes have a safe factor of ~4. The arrangement and parts are presented in Appendix 10.

5 RECOMMENDATIONS

If cage farming systems are to be encouraged in Mexico, careful interdisciplinary work tackling the three main issues of cage culture (biological engineering and socio-economic considerations) are necessary. The focus of the present project has been mainly on the engineering of a cage. Some of the data used will be updated with specific studies in Mexico.

The engineering part tackled in this project has focused on inshore cage culture as a beginning of this activity in Mexico. Proposals for offshore cage culture must be analysed separately. The guide presented for the calculations of the cage in this project is an attempt to take the reader through a step-wise designing process.

However not all cases are the same; therefore, this guide must be used with care and adapted according to requirements. The topic of anchors must be discussed more thoroughly if the guidelines for calculations are to be general increased.

Beveridge (1996) and Fridman (1986) present some equations for anchors. However, nowadays new systems of moorings and anchors for cages are being used and these equations cannot be easily applied. This project does not probe this area fully and thus more work is required here. Another factor, wind is also not fully addressed in this project. In some places waves caused by winds can have affects on cages.

On the other hand, the experience gained and research carried out already in other countries in relation to cage culture are important references and guides to finding the best proposal. We can find technologic, socio-economic and biological information that can facilitate the work and can assist in the decision-making. For example, with respect to suitable candidate species of marine fish for cage culture, Benetti *et al.* (1998) present a complete study with feasibility levels for offshore farming in the Gulf of Mexico. Davis *et al.* (1998) present a summary of potential commercial species for mariculture for the same area.

Finally, it is important to point out that the cage culture has been and is being used successfully in several countries around the world. Mexico can take advantage of these experiences and can expand the development of this activity. This can create jobs for displaced fishermen from traditional fisheries, increased economic inputs, increment fish production, and reduce pressure on traditional fisheries, supporting their sustainability.

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LIST OF REFERENCES

Aarsnes, J. V., Rudi, H., and Loland G. 1990. *Current forces on cages and net deflection*. In: Engineering for Offshore Fish Farming. Thomas Telford *ed.* London.

Baldwin, K., Celikkol, B., Steen, R., Michelin, D., Muller, E. and Lavoie, P. 1999. Open ocean aquaculture engineering: mooring & net pen deployment. *Marine Technological Society Journal* 34:53-58.

Benetti, D., Acosta, C. and Ayala, J. 1995. *Cage and pound aquaculture of marine finfish in Ecuador*. World Aquaculture 26(4): 7-13.

Benetti, D., Clarck, A., and Feeley, M. 1998. *Feasibility of select candidate species of marine fish for cage aquaculture development in the Gulf of Mexico with novel remote sensing techniques for improved offshore systems monitoring*. Robert R. Stickney, Compiler. Proceedings of Third International Conference on Open Ocean Aquaculture. Sea Grant College Program Publication. Corpus Christi, Texas, U.S.A.103-119 pp.

Ben-Yami, M. 1997. *Open ocean aquaculture- an update*. Infofish International 5/97: 21-25

Beveridge, M. C. 1996. *Cage Aquaculture*. 2nd ed. Fishing New Books Ltd., Oxford, U.K., 346 pp.

BIOPESCA 2001. *Granja acuícola de engorda de atún aleta azul, (Thunnus thynnus orientales), Salsipuedes, B.C.* Estudio técnico económico y financiero para proyectos acuícolas. Asesores en Biología Pesquera, S.A. de C.V. 92 pp.

Bucklin, A. and Howell, H. 1998. *Progress and prospects from the University of New Hampshire open ocean aquaculture demonstration project*. Robert R. Stickney, Compiler. Proceedings of Third International Conference on Open Ocean Aquaculture. Sea Grant College Program Publication. Corpus Christi, Texas, U.S.A. 7-30 pp.

Bussing, W.A. 1995. *Centropomidae. Róbalos*. In W. Fischer, F. Krupp, W. Schneider, C. Sommer, K.E. Carpenter and V. Niem (eds.) Guia FAO para Identification de Especies para lo Fines de la Pesca. 3 Vols. p. 987-995. FAO, Rome.

Cairns, J. and Linfoot, B. 1990. *Some considerations in the structural engineering of sea-cages for aquaculture*. In: Engineering for Offshore Fish Farming. Thomas Telford ed. London, pp. 63-77.

Carson, R. M. 1988. *Engineering analysis and design of cage systems for exposed locations*. In: Aquaculture Engineering Technologies for the Future. Papers from Symposium held at the University of Stirling, Scotland. EFCE Publication no. 56, Hemisphere Publishing Corp., New York. London 77-96.

Conapesca, 2003. *Boletín de indicadores de la producción pesquera*. Comisión Nacional de Pesca, Dirección general de Planeación, Programación y Evaluación. SAGARPA. Mexico. http://www.sagarpa.gob.mx/conapesca/planeacion/boletin.htm, 10th February 2004.

Chacon-Torres, A. Ross, L. and Beveridge, M., 1988. *The effects of fish behaviour on dye dispersion and water exchange in small net cages*. Aquaculture, 73 (1-4) 283-293.

Chua, T.E. and Tech, E. 2002. *Introduction and history of cage culture*. CAB International. Eds. P.T.K. Woo, D.W. Bruno and L.H.S. Lim. 40 pp.

Davis, D.A. Arnold, C.R. and Holt, G.J., 1998. *Research summary on potential mariculture species for the Gulf of Mexico*. Robert R. Stickney, Compiler. Proceedings of the Third International Conference on Open Ocean Aquaculture. Sea Grant College Program Publication. Corpus Christi, Texas, U.S.A.120-131 pp.

FAO 2004. www.fishbase.org, 10th February 2004.

FAO, 2002. *The state of world fisheries and aquaculture 2002*. FAO (United Nations Food and Agriculture Organization. http://www.fao.org/sof/sofia/index_en.htm, 10th February 2004

Fredriksson, D. Swift R. Muller, E. Baldwin, K. and Celikkol, B. 1999. *Open ocean aquaculture engineering: system design and physical modelling*. Marine Technological Society, Journal 34: 41-52.

Fridman, A. L. 1986. *Calculations for fishing gear designs*. FAO of the United Nations. Fishing News Books Ltd., Oxford, U.K. 241 pp.

Fröyaringen As 2003. *Single point mooring/tandem mooring (SPM system)*. www.froyaringen.no, 10th February 2004.

Goudey, C.A. Loverich, G. Kite-Powell, H. and Costa-Pierce, B. A. 2001. *Mitigating the environmental effects of mariculture through single-point moorings (SPMs) and drifting cages.* ICES Journal of Marine Science, 58: 497-503.

Huguenin, J. 1997. *The design, operations and economics of cage culture systems*. Aquacultural Engineering 16:167-203.

INP, 2000a. *Sustentabilidad y pesca responsable en Mexico, evaluación y manejo 1999-2000*. Instituto Nacional de Pesca, SAGARPA, Mexico. 958 pp. http://inp.semarnat.gob.mx/Publicaciones/Sustentabilidad/default.htm, 10th February 2004

INP, 2000b. *Carta Nacional Pesquera 2000*. Instituto Nacional de Pesca, SAGARPA, Mexico. http://inp.semarnat.gob.mx/CNP/anexo.htm, 10th February 2004.

Lavín, M., Palacios-Hernández, E. and Cabrera C., 2003. *Sea Surface temperature anomalies in the Gulf of California*. Geofísica Internacional, Vol. 42, (3):363-375.

Loverich, G. and Gace, L. 1997. *The affect of currents and waves on several classes of offshore sea cages*. Ocean Spar Technologies, LLC. Open Sea Aquaculture 97. Maui, Hawai. 131- 144 pp.

Milne, P.H., 1972. Fish and shellfish farming in coastal waters. West Byfleet, Surrey, Fishing News Books Ltd., 208 p.

Phleger, F.B. and Ayala-Castaneda, A. 1967. *Marine geology of Topolobampo lagoons, Sinaloa, Mexico*. Memoirs of International Symposium. Lagunas Costeras. UNAM-UNESCO, Mexico, D.F.,101-36.

Prado, J. 1990. *Fisherman's workbook*. Fisheries Industries Division, FAO. Fishing News Books Ltd., Oxford, U.K. 180 pp.

Quiroga B. C. C. F. Solís C. & J. Estrada G. 1996. *La pesquería de robalo en Mexico. Pesquerías Relevantes de Mexico. XXX Aniversario del INP*. SEMARNAP/INP. (II): 559 – 578.

Rudi, H. Aarsnes, J. and Dahle, L. 1988. *Environmental forces on floating cage system, mooring considerations*. In: Aquaculture Engineering Technologies for the Future. Papers from Symposium held at the University of Stirling, Scotland. EFCE Publication no. 56, Hemisphere Publishing Corp., New York. London 97-122.

Serrano, D. 2003. *Reporte técnico de la hidrodinámica y batimetría del sistema lagunar de "Santa María La Reforma"*. Informe técnico de proyecto. Secretaría de Medio Ambiente, Recursos Naturales y Pesca (no publicado). Mexico.

Slaattelid, O. 1990. *Model tests with flexible circular floats for fish farming*. In: Engineering for Offshore Fish Farming. Thomas Telford, London, pp. 93-106.

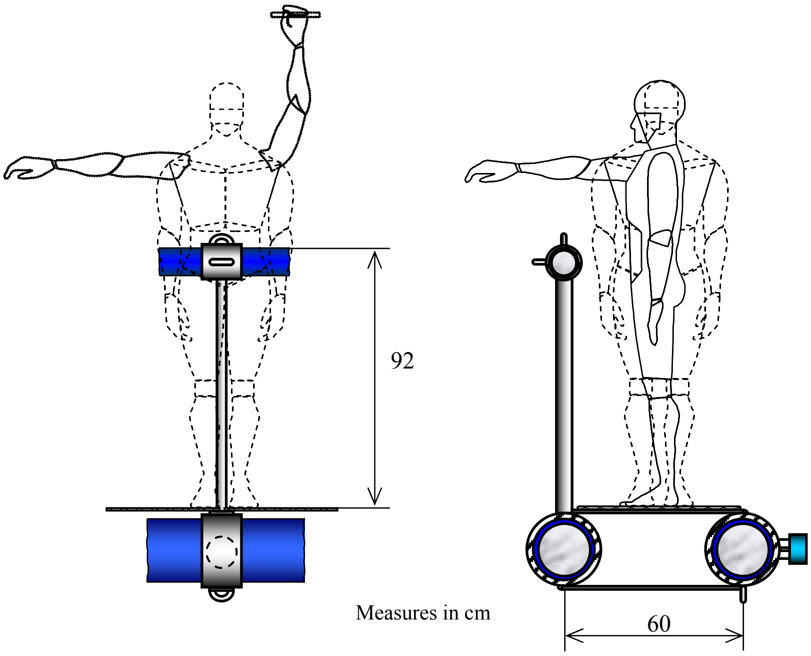
Thoms, A. 1989. *Pointers to safer moorings*. Fish Farmer. 12 (3), 27-28.

Vannuccini, S. 2003. *Overview of fish production, utilization, consumption and trade based in 2001data*. FAO, Fishery Information, Data and Statistics Unit. 18 pp.

Vázquez, A. 1997. *Human factors study in the shrimp vessels of Mazatlán, Sin.* Proceedings of the IV National Congress of Sea Science and Technology. Mexico. 94 pp.

Webber, H.H. and Riordan, P.F. 1976. *Criteria for candidate species for aquaculture*. Aquaculture, 7: 107-123

APPENDIX 1: MEASUREMENTS OF BRACKET FOR THE HANDRAIL AND CATWALK ACCORDING TO ANTHROPOMETRY OF THE FISHERMAN IN MEXICO.



APPENDIX 2: MESH DIMENSIONS AND NET PANEL

1. The size of the mesh was defined on the basis of recommendations by Beveridge (1996). The largest mesh size and thinnest twine diameter possible was chosen. The smaller the mesh, the greater the projected area, which causes increased current loads, decreased water flow through the cages and increased fouling. With the minimum size of fish in the stocking, the formula of Fridman for gill net was applied to know approximately the size of mesh for trap this species and with this data, to reduce the mesh size.

$$OM = L_f \cdot K^{-1} \quad \text{(Fridman, 1986)}$$

Where:
OM: mesh opening (mm);
L_f: average length of fish one wants to catch (mm);
K: coefficient according the species;
K= 5 for long thin fish;
K= 3.5 for averaged shaped fish (neither very thick nor thin), this is the case for Black Snook;
K= 2.5 for very thick, wide or high shaped fish;

2. The area of the net panel was calculated as the perimeter of the cylindrical bag (L) times depth (H). Primary and secondary hanging ratios (E_1 and E_2) of 0.707. The number of stretched meshes (N_{sm}) and the number of rigged meshes (N_{rm}) for the length and height of the panel of net was calculated with:

$$N_{sm} = L \cdot OM^{-1} \text{ (for the length)}$$
$$N_{sm} = H \cdot OM^{-1} \text{ (for the height)} \quad \text{(Prado, 1990)}$$

$$N_{rm} = N_{sm} \cdot E_1^{-1} \text{ (for the length)}$$
$$N_{rm} = N_{sm} \cdot E_2^{-1} \text{ (for the height)} \quad \text{(Prado, 1990)}$$

3. The surface covered by the netting (S: m^2) was calculated using:

$$S = E_1 \cdot \sqrt{(1- E_1^2)} \cdot L \cdot H \cdot OM^2 \quad \text{(Prado, 1990)}$$

APPENDIX 3: WEIGHT OF THE CAGE COMPONENTS

4. The weight of the netting in the air (W_{na}: kg) was calculated using:

$$W_{na} = [H_b \cdot L_{sn} \cdot (R_{tex}/1000) \cdot k] / 1000 \quad \text{(Prado, 1990)}$$

Where:
H_b: number of bars in the height of the netting (2 x number of meshes);
L_{sn}: stretched length of netting (m);
R_{tex}: size of twine in the netting, (m kg^{-1});
k: knot correction factor to take in account the weight of the knots, table 10;

Table 10: Knot correction factor (k) for different netting panels, Prado, 1990.

Stretched mesh size (mm)	Twine diameter (Ø) mm							
	0.25	0.50	0.75	1.00	1.50	2.00	3.00	4.00
20	1.20	1.40	1.60	1.80	-	-	-	-
30	1.13	1.27	1.40	1.53	1.80	2.07	-	-
40	1.10	1.20	1.30	1.40	1.60	1.80	-	-
50	1.08	1.16	1.24	1.32	1.48	1.64	1.96	-
60	1.07	1.13	1.20	1.27	1.40	1.53	1.80	2.07
80	1.05	1.10	1.15	1.20	1.30	1.40	1.60	1.80
100	1.04	1.08	1.12	1.16	1.24	1.32	1.48	1.64
120	1.03	1.07	1.10	1.13	1.20	1.27	1.40	1.53
140	1.03	1.06	1.09	1.11	1.17	1.23	1.34	1.46
160	1.02	1.05	1.07	1.10	1.15	1.20	1.30	1.40
200	1.02	1.04	1.06	1.08	1.12	1.16	1.24	1.32
400	-	1.02	1.03	1.04	1.06	1.08	1.12	1.16
800	-	-	-	1.02	1.03	1.04	1.06	1.08
1 600	-	-	-	-	-	1.02	1.03	1.04

5. The weight of the netting in the water (W_{nw}: kg) was calculated as:

$$W_{nw} = W_{na} \cdot (1 - \gamma_w/\gamma_m)$$

(Fridman, 1986)

$$W_{nw} = W_{na} \cdot E_\gamma$$

Where:
γ_w: density of water (kg m^{-3}); fresh water 1000, sea water 1026;
γ_m: density of material (kg m^{-3}); in this case polyamide (PA) 1140;
E_γ: coefficient of buoyancy or sinking force; for polyamide in sea water 0.10+.

This calculation was also done for the bottom net panel and the weights were added.

6. The weight of netting ropes in the air (W_{ra}: kg) was calculated as:

$$W_{ra} = L_r \cdot W_r$$

Where:
L_r: total length of rope (m);
W_r: weight of rope (kg m^{-1}); in this case polypropylene (PP)

7. The weight of netting ropes in the water (W_{rw}: kg) was calculated applying the equation of point (5). The density of polypropylene is 900 kg m^{-3} and the coefficient of buoyancy force in sea water -0.14.
8. The weight of the pipes for flotation in the air (W_{pfa}: kg) was calculated using:

$$V_{epf} = (\pi \cdot D / 4) \cdot L_p \qquad \text{(Prado, 1990)}$$

$$V_{ipf} = (\pi \cdot d / 4) \cdot L_p$$

$$V_{cpf} = V_{epf} - V_{ipf}$$

$$W_{pfa} = V_{cpf} \cdot \gamma_m$$

Where:
V_{epf}: volume considering the exterior diameter of the pipe for flotation (m^{-3});
D: exterior diameter of the pipe (m);
L_p: total length of the pipe (m);
V_{ipf}: volume considering the interior diameter of the pipe for flotation (m^{-3});
D: interior diameter of the pipe (m);
V_{cpf}: cylinder volume of the pipe (m^{-3});
γ_m: density of pipe material (kg m^{-3}), in this case: high density polyethylene 950.

9. The weight in water of the flotation pipes (W_{pfw}: kg) was calculated applying the equation of point (5); in this case, high density polyethylene (HDPE) floats. The coefficient of floating force for HDPE in sea water is -0.08. The material used for all the pipes is the same.

10. The weight of the handrail pipe (W_{ph}: kg) was calculated applying the equation of point (8).

11. The weight of the ballast pipe in the air (W_{pba}: kg) and the water (W_{pbw}: kg) were calculated applying the equations of point (8) and (5). This pipe has holes in the shell for allowing water flow and facilitating the sinking. However, the weight was taken as the entire pipe. Inside of this ballast pipe are old steel wire ropes as sinkers.

12. To calculate the weight of brackets (W_b: kg) this was divided in parts, (fig.18). The material used is galvanized steel with density of 7800 kgm^{-3}. For the handrail and flotation tubes, were applied the equations of point (8). The weight of the column square tube (W_{st}: kg) was calculated as:

$$V_{est} = H_{est} \cdot L_{st} \cdot W_{est}$$

$$V_{ist} = H_{ist} \cdot L_{st} \cdot W_{ist}$$

$$V_{st} = V_{est} - V_{ist}$$

$$W_{st} = V_{st} \cdot \gamma_m$$

Where:
V_{est}; V_{ist}: volume considering the exterior and interior measurements (m^{-3});

H_{est}; H_{ist}: exterior and interior height of the tube (m);
L_{st}: length of the tube (m);
W_{est}; W_{ist}: exterior and interior width of the tube (m);
V_{st}: volume of the tube (m^{-3});

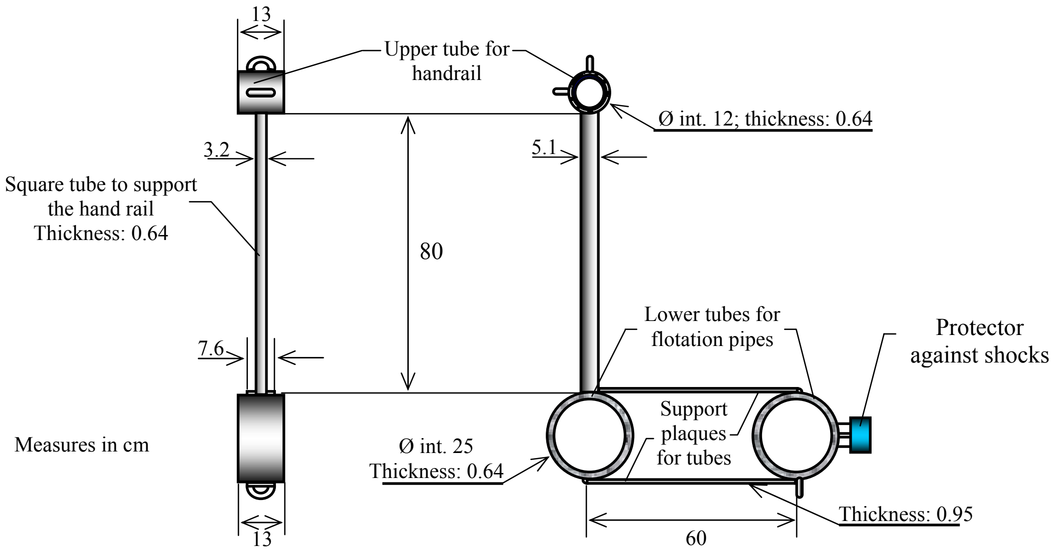


Figure 18: Parts and measures of the bracket.

The weight of the connector plaques and hangers were calculated by means of their volumes and the density of material (γ_m). The weight of parts were added to get the weight of one bracket (W_b) and then multiplied by the number of brackets (16) to obtain the total weight of the brackets (W_{tb}: kg).

13. The approximate weight of platform panel for the catwalk (W_p: kg) was calculated by means of its volume and the density of material (γ_m). For the calculations, galvanized steel was used. The approximate measurements of the panel are presented in fig. 19. The weight of the panel was multiplied by the number of panels (16) to obtain the total weight of the panels (W_{tp}: kg).

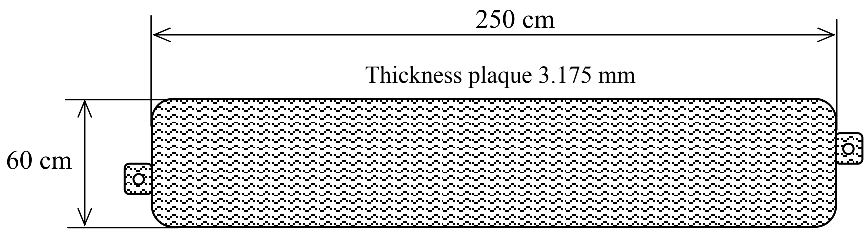


Figure 19: Approximate measurements of panels for the catwalk.

14. The approximate weights of the cage in air (W_{aca}: kg) and in water (W_{acw}: kg), without ballast sinkers were determined by:

$$W_{aca} = W_{na} + W_{ra} + W_{pfa} + W_{ph} + W_{pba} + W_{tb} + W_{tp}$$

$$W_{acw} = W_{nw} + W_{rw} + W_{pfw} + W_{ph} + W_{pbw} + W_{tb} + W_{tp}$$

15. In a case of a fouled cage, there are no fixed rules because the conditions of the sites are different. However, based in some recommendations, (Chua and Tech 2002, Huguenin 1997, Beveridge 1996) the weight was calculated applying the same equations expounded above with the following conditions:
a) For the net panel, the twine diameter was assumed to growth of 3-fold due to the fouling. With this, the net weight was increased 5.5.
b) In the case of the ropes, polypropylene (PP) is a floating material (E_γ = -0.14), hence, its own air weight was taken as its fouling weight.
c) For the chains was added 20% over its weight in the water.
d) In the case of the pipes, polyethylene (PE) is floating material (E_γ = -0.08), hence, its floating force was taken as its fouling weight.
e) For the wire ropes of the ballast was added 20% over its weight in the water.
f) The weight of rest of components was taken equal (they work in air).

The approximated weights of the fouled cage in the water were calculated accordingly (W_{afw}: kg).

APPENDIX 4: FLOTATION FORCE OF THE CAGE

16. The flotation force of the cage with only air inside the pipes (F_p: kg) was calculated by means of the flotation force of the inner (F_{pi}: kg) and outer (F_{po}: kg) pipes using:

$$F_{pi} \text{ or } F_{po} = V_{ipf} \cdot \gamma_w \qquad \text{(Prado, 1990)}$$

$$F_p = F_{pi} + F_{po}$$

Where:
V_{ipf}: volume considering the interior diameter of the pipe for flotation (m^{-3}), previously defined;
γ_w: density of water (kg m^{-3}); sea water 1026.

17. An emergency flotation force (F_e: kg) was proposed to prevent the sinking of the cage in case of damage to the pipes. It is formed by expanded polystyrene inside the flotation pipes. The stuffed of polystyrene expanded inside of the pipes depend of the available materials; in this case is proposed one stuffed of 80% of V_{ipf} for each pipe.

$$F_e = W_{ef} \cdot E_\gamma \qquad \text{(Prado, 1990)}$$

$$W_{ef} = V_{ef} \cdot \gamma_m$$

$$V_{ef} = V_{ipf} \cdot 0.80 \qquad \text{for each pipe}$$

Where:
W_{ef}: weight in the air of material for emergency flotation (kg);
E_γ: coefficient of buoyancy force; for polystyrene expanded in sea water -9.26;
V_{ef}: volume of material for emergency flotation (m^{-3});
γ_m: density of material (kg m^{-3}), for polystyrene expanded 100.
V_{ipf}: volume considering the interior diameter of the pipe for flotation (m^{-3}), previously defined.

18. The nominal flotation force of cage with 20% of air and 80% of polystyrene expanded inside of pipes (F_n: kg) was determined as:

$$F_n = F_e + 0.20 \cdot F_p$$

APPENDIX 5: BALLAST AND TOTAL WEIGHT OF THE CAGE FOR DIFFERENT CONDITIONS

19. The approximate weight in the water of the fouled cage (W_{afw}) was subtracted to the emergency flotation (F_e) to know the maximum available force to hold the ballast and chains in conditions of fouling (F_b: kg). This available force was taken as reference to choose the weight of ballast sinkers for assuring flotation under the worst possible conditions. In the case of cages without structure the weight of ballast is very important as currents deform the bag shape. In this design, the pipe rings (structure) and moorings keep the bag shape too.

$$F_b = F_e - W_{afw}$$

20. The weights in air and water of sinkers (W_{sa}: kg and W_{sw}: kg), and chains to hold the ballast (W_{cha}: kg and W_{chw}: kg), were calculated in the same way as netting ropes, points (6) and (7). In this case, old steel wire ropes were used as sinkers. The weight per meter of steel ropes and chains depends on size, but the coefficient of sinking force (E_γ) for steel in sea water is +0.87. To consider the weight in the water of fouled chain (W_{fw}: kg) and fouled wire ropes (W_{fsw}: kg), were added 20% over their weights in the water.

21. The total weight in air and water for a clean cage (W_{ta}: kg and W_{tw}: kg), and for a fouled cage in the water (W_{tfw}: kg) were determined as:

$$W_{ta} = W_{aca} + W_{sa} + W_{cha}$$

$$W_{tw} = W_{acw} + W_{sw} + W_{chw}$$

$$W_{tfw} = W_{afw} + W_{fsw} + W_{fw}$$

APPENDIX 6: EFFECTIVE FLOTATION FORCE OF THE CAGE

22. The effective flotation forces for a clean and fouled cage (F_c: kg) and (F_f: kg) were determined as:

$$F_c = F_n - W_{tw}$$

$$F_f = F_n - W_{tfw}$$

23. The emergency effective flotation forces for clean and fouled cages (F_{ec}: kg) and (F_{ef}: kg) were determined as:

$$F_{ec} = F_e - W_{tw}$$

$$F_{ef} = F_e - W_{tfw}$$

APPENDIX 7: CURRENT FORCES APPLIED TO THE COMPONENTS OF THE CAGE

24. To calculate the loads of currents to the net panel (L_n: kg), the cage bag area in front of the current was taken to be plane panel, perpendicular to the current force. This represents the worst possible situation and maximum load. In this design of the one fixed point for moorings, one face of the bag will be always in front of currents.

    The actual working area (A_a: m^2) was calculated as:

$$A_a = l \cdot h \qquad \text{(Fridman, 1986)}$$

Where:
l: Length of the netting or the mounted length of the main mounting rope, in facing the current (m).
h: height of the netting or the mounted length of the side hanging line, in facing the current (m)

Then the fictitious area of net panel (A_f: m^2) was calculated as:

$$A_f = A_a / E_1 \cdot E_2 \qquad \text{(Fridman, 1986)}$$

Where:
E_1 and E_2: Primary and secondary hanging ratios, previously determined.

The projected area (A_p: m^2) in facing the current was calculated as:

$$A_p = 2 \cdot A_f \cdot (d / 2{\cdot}a) \cdot (1 + k_k \cdot d / 2{\cdot}a) \qquad \text{(Fridman, 1986)}$$

Where:
d: diameter of the mesh twine;
a: length of the mesh bar;
k_k: coefficient of the knot-area, typically is 10.1 for square-knot, 9.7 for single-knot and 14.8 for double-weavers-knot netting.

Finally the current loads in the net panel (L_n) were calculated as:

$$L_n = C_d \cdot \rho \cdot V^2 (A_p / 2) \qquad \text{(Milne, 1972)}$$

Knotted materials: $C_d = 1 + 3.77\,(d/a) + 9.37\,(d/a)^2$

Knotless materials: $C_d = 1 + 2.73\,(d/a) + 3.12\,(d/a)^2$

Where:
C_d: coefficient of drag of the material (dimensionless);
ρ: mass density of water (kg s^2 m^{-4}); fresh water = 100 and seawater =105;
V: current velocity (ms^{-1}).

The current forces in clean netting, C_d was calculated using the original measurements of the mesh; for calculating loads in fouled netting (L_{nf}: kg) the twine thickness was increased 3 times. For the calculation, the current velocity was: 0.75 ms^{-1} (~ 1.5 knots) and, for security, one extreme velocity of 1.0 ms^{-1} (2.0 knots); this was done for all the components of the cage affected by the current.

25. To calculate the current loads to the floating pipes (L_p: kg) and ballast pipe (L_b: kg), the pipes are considered as structures in facing the currents. In this case, due to be two floating pipes, it was considered one complete submerged in front of the currents. The ballast pipe was calculated in the same way.

$$L_p \text{ or } L_b = A_{pb} \cdot q \cdot C_b \qquad \text{(Fridman, 1986)}$$

$$A_{pb} = L_b \cdot D_b$$

$$q = \rho \cdot V^2 / 2$$

Where:
A_{pb}: projected reference area for the resistance of the component (m^2);
L_b: length of the body in front of the current (m);
D_b: diameter or height of the body in front of the current (m);
q: hydrodynamic stagnation pressure (kg m^{-2});
C_b: Drag coefficient of the body. Values for some typical body shapes are given in the table 11;
ρ: mass density of water (kg s^2 m^{-4}), previously determined;
V: current velocity (ms^{-1}), previously determined.

Table 11: Drag coefficients (C_b) for certain body shapes (Fridman 1986).

Body shape	**C_b**	**Flow direction (V)**	**Reference area (A)**
Circular or square plate	1.1	Normal to face	Surface of one side
Sphere	0.5		Diametric plane
Ellipsoid	0.06	Parallel to major axis	Maximum circular section
Ellipsoid	0.6	Normal to major axis	Maximum elliptical section
Circular cylinder	1.2	Normal to axis	Length x diameter
Circular cylinder	0.1	Parallel to axis	Cross-section area
Rectangular cylinder or prism	2.0	Normal to axis	Frontal (length x width)
Hemispherical cup	0.38	Axial, onto outside	Frontal ($\pi \cdot r^2$)
Hemispherical cup	1.35	Axial, into inside	Frontal ($\pi \cdot r^2$)
60° cone	0.52	Axial onto apex	Base
30° cone	0.34	Axial onto apex	Base

To calculate the current loads for fouled pipes (L_{pf}: kg) and (L_{bf}: kg), the drag coefficient is unknown. In this case, was considered a growth of 20% in the area exposed in front of the current force. This was taken upon some recommendations of design purposed by Milne (1970) cited per Beveridge (1996).

26. To calculate the current loads to the horizontal and vertical ropes (L_{hr}: kg) and (L_{vr}: kg), these were considered as straight lines in facing the current flow, and were applied the equations of point (25). In this case, the drag coefficient for ropes (C_r) depends mostly on the angle between the rope and flow direction. It also depends on the type of rope, its material, the degree of wear and on the Reynolds number. The dependence of C_r on angle α according to measurements with a 16 mm diameter steel wire rope is shown in the Table 12; because the pattern of dependence of C_r on α is similar also for other types of rope, this data can be used to determine their drag. To calculate the current loads in fouled ropes (L_{hrf}: kg) and (L_{vrf}: kg) was considered a growth of 20% in the exposed area to the currents, according with the stated in point (25).

Table 12: Drag coefficients for straight ropes (C_r) according with angle (α) of the current flow (Fridman 1986).

Angle of the flow current (α)	C_r	Angle of the flow current (α)	C_r
0	0.12	50	0.70
10	0.20	60	0.90
20	0.32	70	1.12
30	0.41	80	1.25
40	0.56	90	1.30

27. To calculate the current loads in chains (L_{ch}), these were taken as full straight ropes and were calculated applying the equations of the point (25) y the conditions for ropes stated in point (26). The current loads in fouled chains (L_{chf}) were calculated in the same way those other components.

28. The total current force applied in clean cage (L_c: kg) and fouled cage (L_f: kg) for different velocities of currents were obtained using:

$$L_c = L_n + L_p + L_b + L_{hr} + L_{vr} + L_{ch}$$

$$L_f = L_{nf} + L_{pf} + L_{bf} + L_{hrf} + L_{vrf} + L_{chf}$$

APPENDIX 8: WIND FORCES APPLIED IN THE SUPERSTRUCTURE OF THE CAGE

29. The loads of the wind in the superstructure of the cage (L_w: kg) was calculated using:

$$L_w = 0.0965 \cdot A \cdot V^2$$ (Boven, 1968, cited by Beveridge, 1996)

Where:
A: sum of the areas of parts exposed to the wind, -freeboard netting, handrail, floats-, (m^2);
V: wind velocity (ms^{-1}).

APPENDIX 9: WAVE FORCES APPLIED TO THE CAGE

30. To calculate the wave forces acting on a cage collar, the horizontal and vertical orbital velocities of the water particles (μ: ms^{-1}) and (ω: ms^{-1}) must be known, (Beveridge 1996). These can be calculated as:

$$\mu = \left\{ \{\pi \cdot H_w \cdot \cos d \cdot [2 \cdot \pi (z + d)/L_w]\} / t_w \cdot \sin d \cdot (2 \cdot \pi d / L_w) \right\} \cos \theta$$

$$\omega = \left\{ \{\pi \cdot H_w \cdot \sin d \cdot [2 \cdot \pi (z + d)/L_w]\} / t_w \cdot \sin d \cdot (2 \cdot \pi d / L_w) \right\} \sin \theta$$

(Muir Wood & Fleming 1981, cited by Beveridge 1996)

Where:
H_w: wave height (m);
d: depth of water (m);
z: variation from mean water level (m);
L_w: wave length (m);
t_w: wave period (s);
θ: angle of wave relative to the structure (°)

According to Milne (1972), μ is unlikely to exceed 2 ms^{-1} in most fish farming conditions, and thus this value can be used for designing purposes for marine cages. Beveridge (1996), proposes that the equation for calculating the drag forces exerted by currents on netting is applicable. The force exerted on the collar by the wave (L_{sw}: kg) can be described by an equation similar to that derived for effect of currents:

$$L_{sw} = K_d \cdot \rho \cdot \mu^2 \cdot A$$

Where:
K_d: dimensionless constant, similar to C_d for netting, whose value depend of the material and shape of the collar, in this case for approximately calculations can be taken the values of table 9.
ρ: mass density of water (kg s^2m^{-4}); for seawater 105.
μ: horizontal component of wave particle orbital velocity; for marine cages 2ms^{-1};
A: area of the cage collar perpendicular to the wave train (m^2).

The vertical component of wave particle maximum orbital velocity (ω) is approximately 83% of the μ, (Wiegel 1964, cited by Beveridge 1996).

APPENDIX 10: GENERAL ARRANGEMENT OF PARTS, DIMENSIONS AND MATERIALS OF THE MOORING AND ANCHOR SYSTEMS FOR THE CAGE.