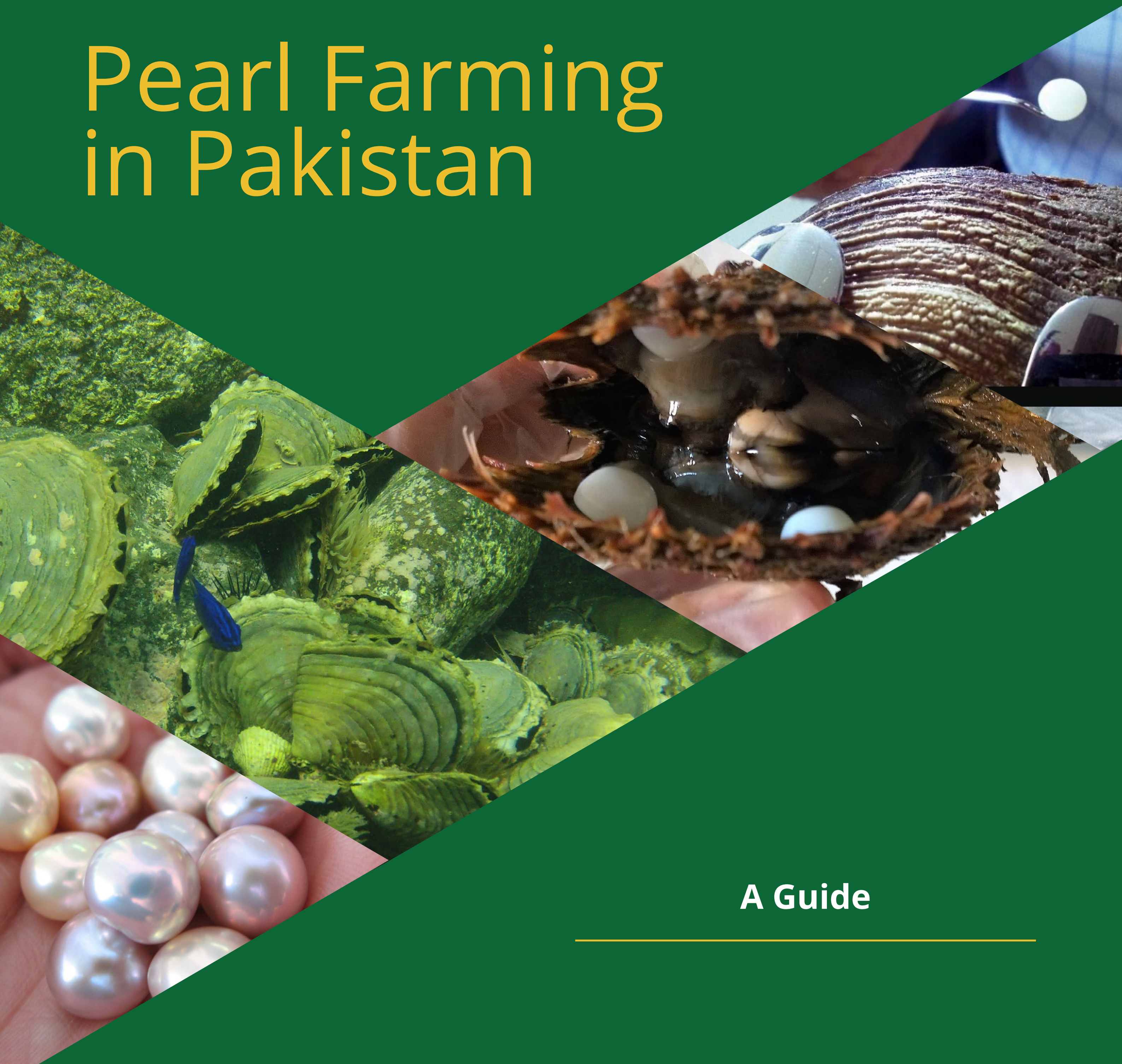
Climate Adaptation and Resilience (CARE) for South Asia Project

Pearl Farming in Pakistan



A Guide

Climate Adaptation and Resilience (CARE) for South Asia Project

Pearl Farming in Pakistan

A Guide

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1. INTRODUCTION

Climate change is increasing the risk to coastal communities in Pakistan. It takes the form of extreme events such as intense storms, floods, coastal erosion, and rising sea levels. Due to socioeconomic and political factors, people are more vulnerable to these hazards today; disasters have a compounding effect, causing significant land and livelihood loss and ultimately resulting in displacement. Pearl farming can be considered a viable alternate livelihood for these coastal communities to build back better. As part of the CARE for South Asia project, the concept of pearl farming is thus being introduced to the country for the first time.

One of the most important things to consider before embarking on a pearl farming venture is to examine the location's history in the pearling scenario, and, in particular, the history and stories that revolve around the ancient pearl fisheries and "pearls of renown", the latter being pearls that have transcended in history due to their beauty, size, and perfection. In the case of Pakistan, following the analysis of both historical accounts and biological data regarding Pakistan's involvement in ancient or recent pearl fisheries, little to almost no information has been found, on the subject.

As most pearl farmers avoid competition by keeping their methods a "trade secret", the pearl farming industry has been difficult for newcomers. And, even if basic methodology is simple to understand, newcomers will find it difficult to obtain some of the more technical details required to learn how to run a farm; this can lead to years of experiments and tests. The guide describes some of the basic methods of pearl farming that have been used on pearl farms found throughout the Pacific rim. With this guide, a prospective pearl farmer may be able to initiate a small, pilot-scale pearl farm on the coastline of Pakistan and will be able to grow it to become a viable economic alternative for the region.

Therefore, the purpose of this guide is to provide principal information for initiating a pearl farming operation on the coast of Pakistan, with the hope of:

a. helping to promote and diversify the aquaculture industry
b. promote a sustainable and viable economic alternative for local coastal communities

Note: The guide is divided into sections, so that each chapter can stand alone.

2. HISTORY OF PEARL FARMING

The origins of pearls are as ancient as humanity; the first historical vestiges of pearl jewelry date back to ancient Persia (circa 520 B.C.) and correspond to a three-string pearl necklace found inside the sarcophagus of a mummified princess (Strack 2006). Ever since pearls became a beloved adornment, they have been referred to as 'tears of the gods', and are known as symbols of power, femininity, spirituality, social status, and wealth (Heffernan 2006). Famous queens such as Marie Antoinette of France, Victoria of England, and Elizabeth II of England adorned themselves with troves of pearls, using them to embellish their dresses and crowns. But men also wore pearls, and this was a trend seen in Europe, the Middle East and Asia, even in the great American civilizations (McLaurin & Arizmendi 2002; McLaurin-Moreno, 2019).

Today, natural pearls are exceedingly rare. The pearls that are now produced are farm-raised (Akamatsu 2015; Southgate & Lucas 2008). While many recognize Kokichi Mikimoto as the father of modern pearl culture, there were two other men involved in this industry at around the same time. One of these was William Saville-Kent, who was the first one to succeed in producing blister pearls and three-quarter pearls in the year 1891, using the silver-lipped pearl oyster *Pinctada maxima.* This happened some years before Mikimoto created the first "cultured pearl" using the Akoya pearl oyster, *P. fucata* (Strack 2006).

And the second man was Gastón Vivés, a Mexican entrepreneur who understood that the pearl fisheries were on the verge of total collapse, and that farming pearl oysters was the only sensible thing to do. He initiated a pearl oyster farm in 1894, on the Island of Espíritu Santo, off the coast of Baja California Sur, in the Gulf of California, Mexico. By 1909 his pearl farm had over 900 employees and 8 million Panamic black-lipped pearl oysters, *P. mazatlanica,* under aquaculture conditions. But his pearls were all natural, not cultured, and he relied on his income from shell sales, pearl meat and natural pearls. Despite his success, the farming operation was closed when the Revolutionary Army attacked and destroyed the farm in 1914.

Figure 1: The three most important Pearl Pioneers of the early 20th Century: William Saville-Kent, Gastón Vivés and Kokichi Mikimoto.

Despite some controversies, the first patents ever registered to produce cultured pearls were awarded in Japan, one to Mikimoto, and a second one to Tatsuhei Mise and Tokichi Nishikawa. Today, the technique known as 'Mise-Nishikawa' is widely used across the world for the commercial production of cultured pearls across at least three different species of pearl oysters (Akamatsu 2015), described below.

1. The “Akoya-gai” pearl oyster - *P. fucata* (70-90 mm shell height), which produces “Akoya pearls” 6.5 to 9.5 mm in diameter with dominant white, cream, and silver colors with rosé overtones.

2. The “Black-lipped pearl oyster” – *P. margaritifera* (120-150 mm shell height), which produces ‘Tahitian Black Pearls’ which are 8 to 16 mm in diameter, with grey to black body colors and green, blue, violet and peacock overtones.

3. The “Silver- and Gold-lipped pearl oysters” - *P. maxima* (200-250 mm shell height), which produce ‘South Sea Pearls’ which are 10 to 22 mm in diameter, with dominant silver-white or cream-golden body color and rosé, blue and golden overtones that are highly valued.

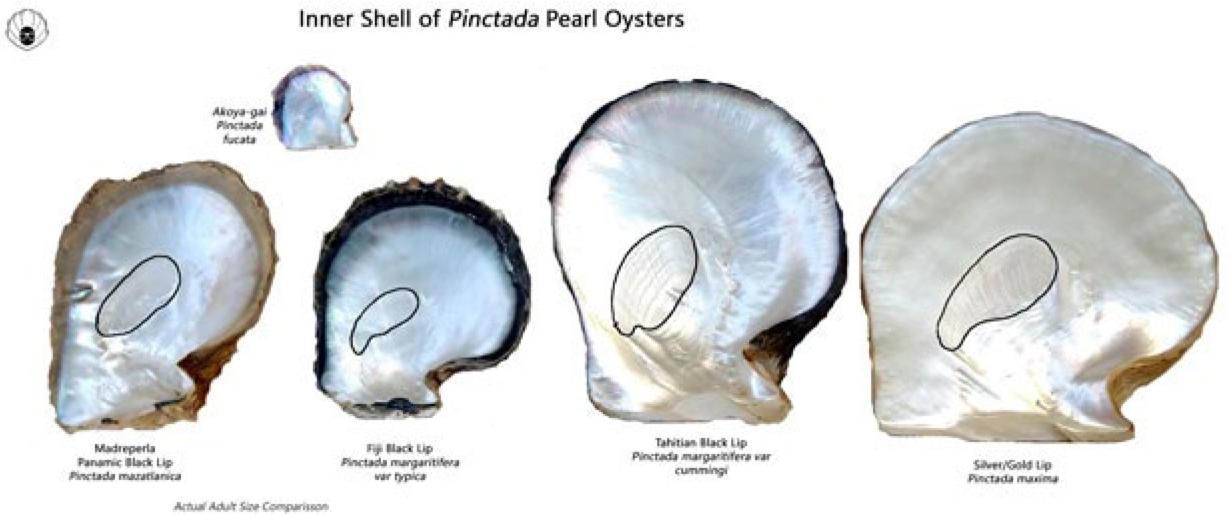

Figure 2: The shells of the most important commercial saltwater pearl bearing species in the world (left to right): the “Panamic Black lip” (Pinctada mazatlanica), the “Akoya-gai” (P. fucata/imbricata), the “Black-lip” (here we have two varieties: P. margaritifera typica and P.m. cummingi), and the “Gold/Silver lip” (P. maxima).

Additionally, we have the “Penguin winged pearl oyster”, Pteria penguin, (160-180 mm), which displays a lustrous, multicolored nacre, but is mainly used for Mabé pearl culture (Southgate et al. 2011; Akamatsu 2015).

3. BENEFITS OF PEARL FARMING

Pearl farming can become an attractive venture due to the high value of the final product - the cultured pearl - and the use of all its sub-products: the shell and meat. Although pearl value varies drastically, depending on their size and quality; large, round pearls of "Gem" grade can be sold for a very good price, and if set in jewelry the value is even greater.

Figure 3: Gem grade Chinese freshwater pearls, sometimes referred to as "Metallics".

One of the advantages of pearl production is that the final product is lightweight and nonperishable. Pearl farming is also a compatible occupation for people like fishermen, and for those that like to work on the water and have boating, diving, and fishing skills. Except for the "pearl grafting process", pearl aquaculture is a simple venture, because pearl oysters do not require artificial feeds or supplementing, water recirculating nor aeration, complicated farm structures, canals nor laboratories, nor constant attention to life-sustaining parameters (oxygen, ammonia, pH, etc.).

Figure 4: A pearl farm using the "long-line" culture system in Mexico.

Pearl farming is a unique industry that as many as 32 countries in the world have found it to be suitable to their local conditions.

The reasons for establishing a pearl culture venture are as varied as the countries themselves, but there are two key elements we can distinguish as being the primary factors:

1. There was a previous experience in the area, with established pearl fisheries. This would be the case of Japan, Australia, Philippines, Myanmar, Indonesia, Mexico, and the United Arab Emirates.

2. There is a suitable resource in the location and the country has very few natural resources to supplement its income. This is the case of many island nations such as French Polynesia, Tonga, Cook Islands and Micronesia.

But pearl farming can also be established in countries that are not in any of these two instances, and such would be the case of Peru and Ecuador, where pearl farming research and efforts are leading to an establishment of this industry, due to diminished fishing resources (as is the case of Peru) or due to the continued growth and diversification of their aquaculture industry (the case of Ecuador). And of course, we also have countries with a rich historical background with pearl fisheries, that have simply been unable to start a pearl farming operation, even when the local resources are available: this would be the case of Panama, Venezuela, and Costa Rica. This helps us understand that the establishment of such an industry is indeed multifactorial, and not simply a matter of setting up a pearl farm in a suitable location.

One of the interesting reasons why pearl farming would also be a valuable natural resource, is due the ability of pearl oysters to capture Carbon Dioxide and transform it into Calcium Carbonate, that we can appreciate in their beautiful shells and the pearls themselves. These mollusks become Carbon entrapment devices. Yet another biologically important reason lies in the fact that pearl farms may enhance natural conditions by offering what is known as the "floating reef effect": the cages, floats and pearl oysters become the home to a multitude of tiny marine plants and invertebrates, which in turn sustain small fishes, which in turn sustain larger species of fish. Pearl farms may have the ability to help recover the local fisheries, under proper fisheries management.

Figure 5: Pearls and mother-of-pearl shells are carbon sequestering agents, as they are made from calcium carbonate, which they absorb from seawater.

Pearl aquaculture is a noble industry to the local communities where it has been established since everyone will be able to find a way to contribute with their work, experience, and creativity:

a. Fishermen can easily work on every aspect of pearl farming, from operating and repairing boats and nets and working in the sea-based farming operation.

b. Women can help clean oysters, harvest pearls, and even cook and sell the "pearl meat"

c. Community members could manufacture mother of pearl handcrafts, buttons, and jewelry, which they can sell to the larger cities and to the tourism industry.

d. Specialized and highly trained aquaculture technicians could perform the delicate "pearl seeding operation" and perform scientific revision on the growth, health and pearl producing potential of the mollusks.

In all, pearl farming can become a viable way to support the livelihood of small coastal communities, if the environmental and biological conditions are adequate and a local or export market is found.

Words of Advice

Pearls are high-value products, and therefore, many people attempt to make a living as pearl farmers. When considering pearl farming as an investment opportunity or as a small business, there are three important things to take into consideration:

1) These ventures require a long-term investment: you must invest time, money, and labor, for several years, until there are profits.

2) Production of high-quality pearls is the key to having a profitable farm. Only 5-10% of each crop of pearls will have “Gem” quality. It is from these few pearls, that about 60-90% of profits will come.

3) Production of high-quality pearls is only possible under certain conditions, and you don’t know if these are met in a location: until you have had a couple of years operation and at least a couple of pearl harvests.

Although pearl farming is simple and “easy” to learn, the main reason newly established pearl farms fail is because farmers cannot invest enough time and money to produce high quality pearls. A period of 3-5 years will be required before the first pearl harvest, and most pearl farmers will not see a profit until a couple of harvests have been produced.

Average quality pearls usually sell for just enough to recover the cost of producing them, and low-quality pearls only bring low income, thus money will be lost in their production. Due to this, strategies must be enacted to increase the operation’s viability, such as enabling a touristic attraction and producing and selling handcrafts, jewelry and even seafood.

Gem-grade quality pearls can only be produced by taking excellent care of the pearl oysters during all farming stages and it also depends on the skills of the grafting technicians.

Before considering initiating a farm, it is to be evaluated whether the farmer/ entrepreneur meets the following criteria:

- Pearl Oyster Spat: There is a need for reliable and locally sourced way to procure your pearl oysters;
- Site Pre-Selection: Feasibility studies for each potential site, leading to selecting a good pearl farm site;
- Having the skilled people that will work on the farm;
- Enough funds to establish and operate the farm;
- Access to grafting technicians or,
- A Training program for pearl technicians, and finally
- The ability to produce income with all the available products of a farm: seafood, seashells, handcrafts, jewelry, pearls, and a touristic attraction.

To successfully establish a pearl farm, it is essential to fulfill the above criterias.

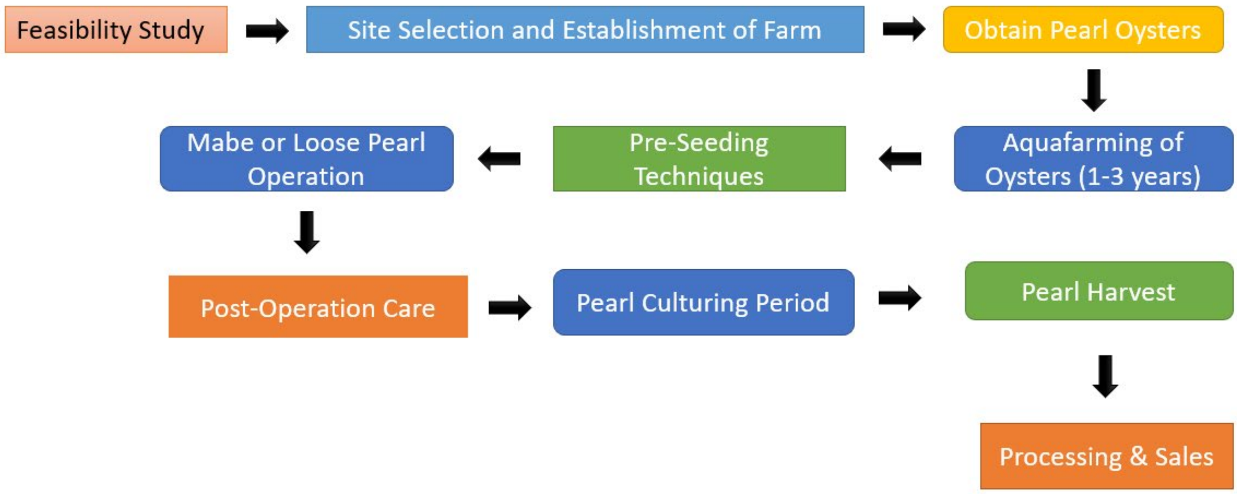

Figure 6: The pearl farming process takes between three to five years and has all these steps involved.

4. BASIC BIOLOGY AND ECOLOGY OF PEARL OYSTERS

4.1 Zoology

Pearl oysters are members of phylum Mollusca and belong to class Bivalvia. Bivalves are easily recognized by having two shells (or valves) that enclose or protect a soft body with a small foot, a byssal gland and paired gills. The common name of "pearl oyster" suggests a close relationship with other types of oysters, such as "edible oysters", belonging to the genera *Crassostrea* and *Ostrea*, but they have important anatomical and behavioral differences, which make them closer to scallops and pen shells.

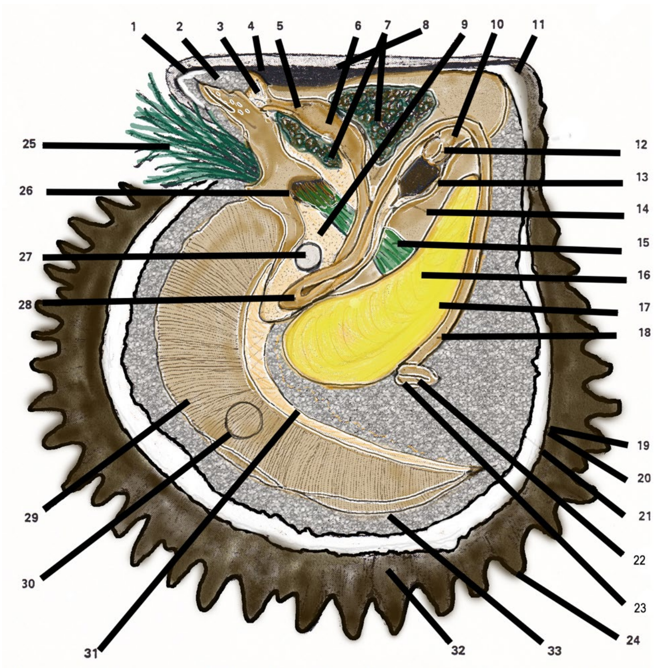

Figure 7: Internal anatomy of the pearl oyster (modified from George, 1978). List of Anatomical features: 1-Foot 2-Hinge 3-Labial Palp 4-Mouth 5-Esophagus 6- Stomach 7-Hepatopancreas 8-Hinhe Ligament 9-Gonad 10-Intestine 11-Nacre 12-Heart/Ventricle 13-Heart/Auricle 14-Pericardial cavity 15-Foot Retractor 16-Smooth part of Abductor Muscle 17-Striped part of Abductor Muscle 18-Rectum 19-Outer fold 20-Middle fold 22-Anal flap 23-Anus 24-Growth Process Spines 25-Byssus 26-Byssal Gland 27- Cultured pearl 28-Intestinal loop 29-Gills 30-Ctenidium 31-Base of Gills 32-Non-Nacreous shell border 33-Right Valve lobe.

Pearl oysters have been reported to live as long as 30 years (Southgate & Lucas, 2009), but this depends on the species involved. Smaller species such as the "Akoya" have much shorter lifespans.

4.2. Reproduction

Pearl oysters are Protandric hermaphrodites, which means that they first attain sexual maturity as males and will eventually become females. The male phase usually occurs during the first 2-3 years of life, with the change to the female phase after this age. The oysters may revert to being males if the conditions are not adequate.

Pearl oysters reproduce by releasing millions of ova and sperm cells into their surrounding environment where fertilization will take place by means of a chance encounter. In about 24 hours, the fertilized eggs develop into a planktonic free-swimming larva known as "trochophore" larva. These larvae remain suspended in the water column for 2-3 weeks before undergoing a major metamorphosis, changing into a juvenile "spat". The foot remains after

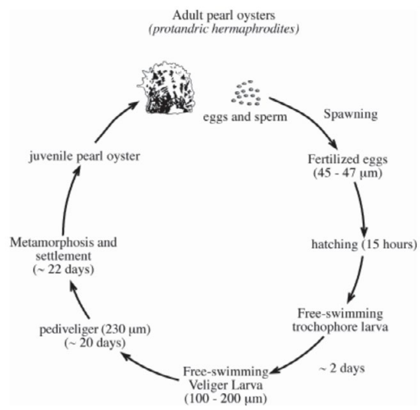

Figure 8: The life cycle of pearl oysters, from Gervis & Sims (1992).

metamorphosis, and the young oyster retains the ability to crawl like a snail for a couple of months even after it attaches itself to any substrate. Pearl oysters can attach and reattach themselves by means of their byssus, which is constantly secreted by their byssal gland, at the base of the foot.

4.3. Environmental Requirements

Pearl oysters thrive in water temperatures that range from 23 to 30°C, with some species tolerating temperatures as low as 16°C, but below 23°C most tropical species of pearl oysters stop growing, do not breed and may even die.

Most pearl oysters spend their adult lives attached to hard substrates by means of their byssus, at depths between 0 and 20 meters, usually found in rocky bottoms, in close association with hard corals (*Porites sp.*) or seagrasses (*Zoostera sp.*), and away from freshwater sources. Pearl oysters are often found in groups or clusters, and if these contain large amounts of individuals they are referred to as “Pearl beds”.

Pearl oysters can also tolerate a range of salinities, at least for a short period of time. They prefer water with higher salinities (31 to 33 ppt), and may die rapidly if exposed to freshwater, as was the case of the great “Chinese Akoya die off” back in the year 2004, when torrential rainfall and river runoffs caused massive mortalities to the Chinese pearl farming industry.

Depending on the pearl oyster species, some of the larger species appear to grow better in transparent waters, free of sediment and organic particles, whereas other species seem to thrive under these conditions.

4.4. Feeding

Pearl oysters feed on microscopic algae and other small particles found in the water column. The branchial lobules (gills) are large and capable of trapping these nutritional particles, and tiny hair-like cilia on the gills are used to move the particles all the way down to the base (cingulum) where they will be transported to the mouth’s entrance thanks to a sub-set of gills known as the “labial palps”. Clear tropical waters contain limited amounts of algae. Therefore, a large amount of water must be filtered daily for the pearl oyster to obtain sufficient food. This is the reason that importance is placed on not crowding pearl oysters on the farm and for keeping the shells clean of organisms that compete for food.

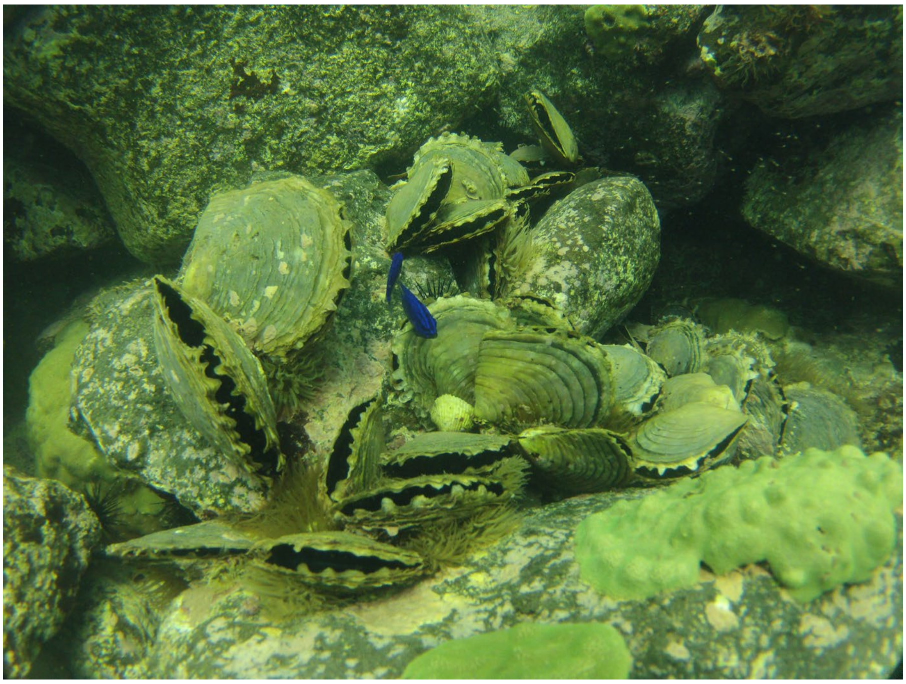

Figure 9: A group of young wild black-lip pearl oysters attached to rocks.

4.5. Common Pearl Oyster Species near Pakistani waters

The pearl oyster species that can be found in Pakistan's coastlines are:

1. The "black-lip pearl oyster" (*Pinctada margaritifera*) which is widely distributed throughout the tropical Indo-Pacific area. There are several varieties or subspecies of black lips, such as:

    a. the Hawaiian black lip, *P. margaritifera galstofii*

    b. the Fiji Black lip, *P. margaritifera cummingi*

    c. the "Persian Gulf pearl oyster", *P. margaritifera persica,* which has also been identified as a producer of pearls in the nearby Persian Gulf.

    2. The "Akoya-gai" or "Lingah" pearl oyster (*P. fucata/imbricata complex species*). This species is nowadays actually considered a complex system of species that are believed to be the same one, but with morphological variations that depend on the local environment.

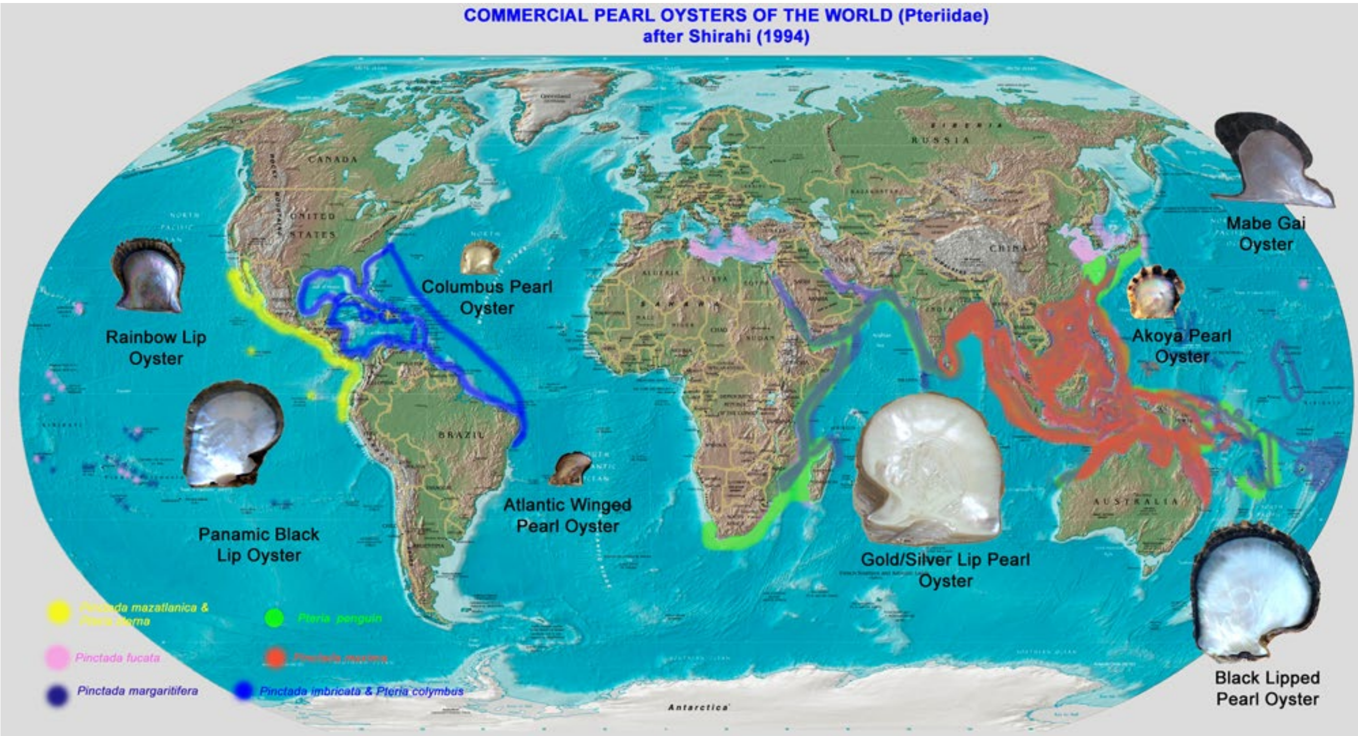

Figure 10: Distribution of the major pearl producing species (adapted from Shirahi, 1994).

5. OVERVIEW OF PEARL FARMING

5.1. Common Pearl Farming Techniques

Pearl farms require simple structures, their main purpose is to provide some means of securing the pearl oysters for easy access and security. There are three basic types of farm structures for bivalves: long-lines, floating rafts, and underwater trestles. You can also use a combination of these, if necessary.

5.1.1. The Longline Method

A longline is simply a main line, made from strong rope held in place by anchor lines and kept near the surface by floats. Proper placement of the anchors and buoys keeps the longline at the correct depth. The longline system can be used to hang spat collectors, pearl nets, lantern nets, pocket nets and chaplets.

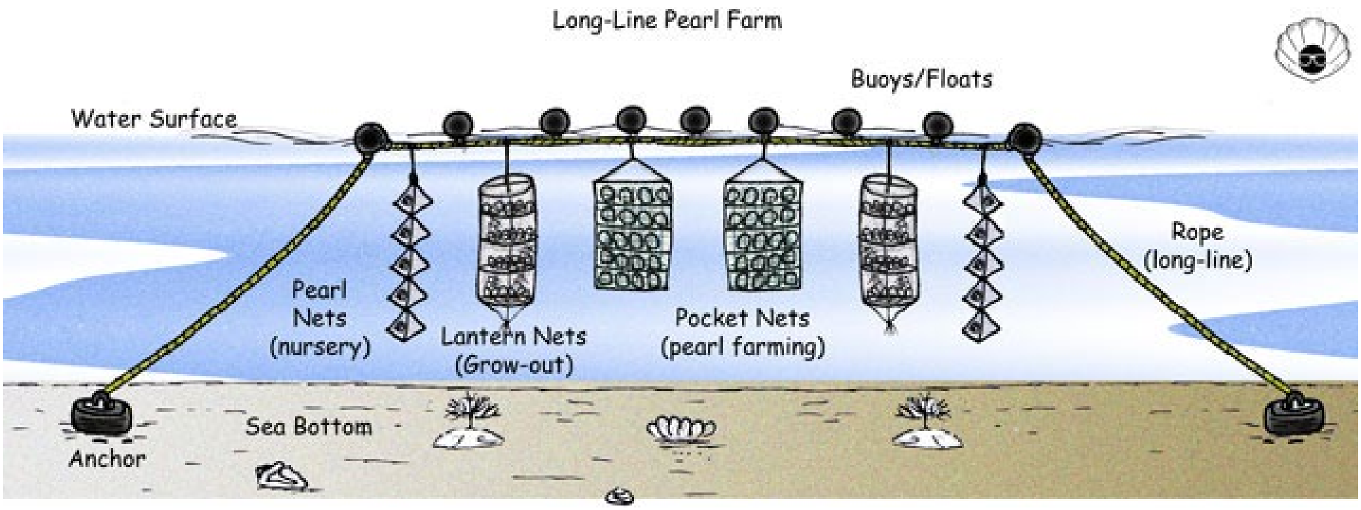

Figure 11: A "longline" aquaculture system.

This method can be used with the farm structure near the surface for easy access, or submerged; to allow the farm to remain hidden and protected from damage from rough weather and boats.

This system allows for low costs, and allows for the lines to be moved to another location by dragging each line with the help of a motorboat. It is also more easily achieved than with traditional farm systems. The usual disadvantage to the longline method is the need to have divers to work on the farm, but this can be easily solved if the lines are on the surface or by means of line-haulers that are placed on the motorboat.

To install a longline system, the first requirement is to plan the length of the lines. For small operations of around 5,000 pearl oysters, lines of 10 meters and all the way up to 50 meters can be used. These lengths allow for easy management. Longer lines may become unwieldy and may become entangled with other lines. The recommendation is to keep them in parallel lines, with a separation of 6 to 10 meters between lines. It takes at least two divers and at least one person in a boat to establish a longline. The polypropylene or nylon rope used for the main line should have a minimum of 18 mm but can be thicker if there are strong currents in the area.

The first requirement is to ready the anchoring system, which usually depend on the type of environment where the farm has been set up. These are usually called *"muertos"* (dead weights) in Mexico. If water currents are strong, it will require better or heavier weights or anchors. If the lines are set on sandy or gravely bottom, there is a need to prepare anchors utilizing old, discarded vehicle tires as the guideline. Use the best tire-size based on how much weight is required to be sustained, with the larger ones used for heavier weights, or use several smaller ones to achieve the same purpose.

If working with a long line that measures 10 meters in length, there is a need for a tension line that is adequate to the depth of the site where the longlines will be placed. If the depth is of 5 meters, it may require the use of about twice as much that length, since the tension line is not placed vertically. The end-line floats are the first ones to be added to the long line and adjusted to the desired depth. Once this part of the setup is done, the long line is left in place for a couple of days to test if it has been properly set: it is always easier to make adjustments when there is no baskets and oysters in place. Some adjusting may be necessary because the ropes tend to stretch, and once again when the baskets are added, since the weight of the oysters may cause the line to sag. Rechecking the depth of the lines weekly and retying some of the anchor lines or adding more floats as the lines stretch are required.

Figure 12: An underwater view of a long-line aquaculture system.

Once the first line is in place, it will be easier to set all subsequent longlines. When aquaculture baskets are hung on the main line, the added weight will cause the line to sag between the points where the floats are attached, so the farmers must be careful not to place more baskets than what the system may sustain, or they will also need to add additional floats. The cages or baskets must be placed at least one meter apart from each other, as to avoid them from touching each other and damaging themselves due to the constant friction.

Farmers must be prepared to check the depth of the entire line at least once every 2-weeks. Once the cages, the pearl oysters, the buoys, and line become bio-fouled, the line may sink out of view rapidly and will make it more difficult to find it. When this happens, farmers must unburden the line by removing cages and transfer them to another one, and start cleaning the floats, cages, and oysters.

5.1.2. Floating rafts

Floating rafts can be used as work units: they serve as a farm to hang the aquaculture cages with their pearl oysters, and also to allow for working on top of them, avoiding the use of land-based facilities. Rafts are commonly used inside protected areas and shallow bays. Rafts are built from lightweight woods, such as bamboo, but also with PVC pipes and aluminum frames. The floats can be made from discarded oil drums, these filled with polyurethane foam (to allow for floatation) and coated with fiberglass (to avoid oxidization) or by purchasing commercial floats.

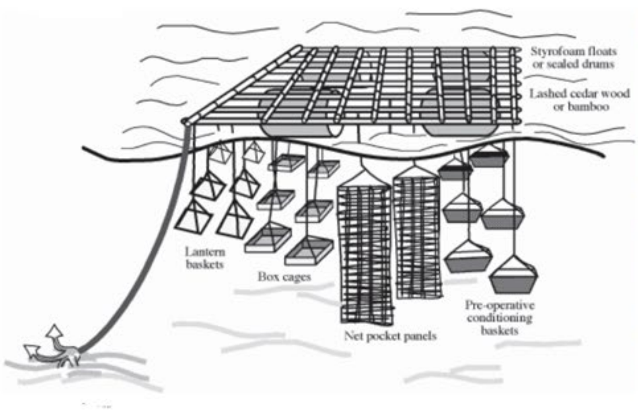

Figure 13: A diagram of a Japanese-style floating raft for pearl culture (from Gervis and Sims, 1992) and photo of a Japanese pearl farmer working on a raft in Ago Bay, Japan (courtesy of Jeremy Shepherd and Pearls as One Course).

Floating rafts can only be used in very calm, protected waters. If there are strong winds, sea-currents or wave action, this system should not be employed. Special attention must be given to their anchoring, to make sure the raft does not break free and away into open waters or to break against coral or rocky reefs.

This system allows for the rafts to be moved to any another location by dragging each raft with the help of a motorboat. This is common practice in Japan, when red tides show up on a bay and may cause massive mortalities, or when other environmental conditions threaten the lives of the pearl oysters.

5.1.3. Underwater trestles.

Underwater trestles can be expensive, since the best ones are made using galvanized or stainless-steel pipes. They can also be built from bamboo or PVC pipes, but these materials may not last long and are prone to other problems, galvanized steel pipes trestles can last up to 10 years. Underwater trestles can be used to culture pearl oysters at any stage of their life cycle, and using any kind of cage, but since sea-currents may cause the material to suffer from “fatigue” over time, they should be mostly used with chaplets or pocket nets, which offer better behavior under the effect of underwater sea-currents.

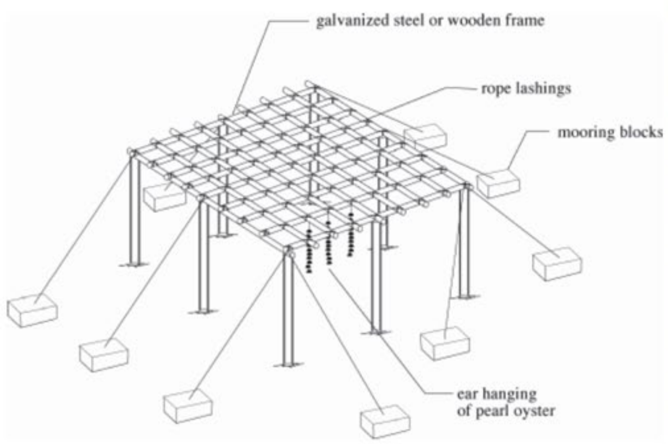

Figure 14: Underwater trestle system for pearl culture. Diagram taken from Haws (2002). Photo of divers working on a trestle at 20 meters depth.

Trestles are a good system in sites where water temperatures can reach temperatures above 32C, or where tropical storms (typhoons or hurricanes) or intense wave action are a constant concern. This is because the trestles can be located at any depth, and at 10 meters you will have less problems with water temperature, freshwater discharges and wave/wind action. Another great thing about this system is that it negates the use of floats or buoys, which can be expensive and there is less worrying about the constant cleaning of the equipment, but the deeper these are set will mean that SCUBA or Hookah diving will be required.

5.2. The Pearl Farming Cages

There are many different kinds of cages that are used to hold pearl oysters in their different stages of life. For adult pearl oysters we use: chaplets, lantern nets, pocket (panel) nets and even floating or submerged rigid plastic trays. For pearl oyster spat, the usual cages are pearl nets and lantern nets. Pearl farmers must decide the best cages, based upon their location and budget. Chaplets (also referred to as "ear hanging") are the least expensive but allows oysters to become the target of predatory fishes (such as the parrot, trigger, and puffer fishes), so if these are found in your location it is best to not use it at all.

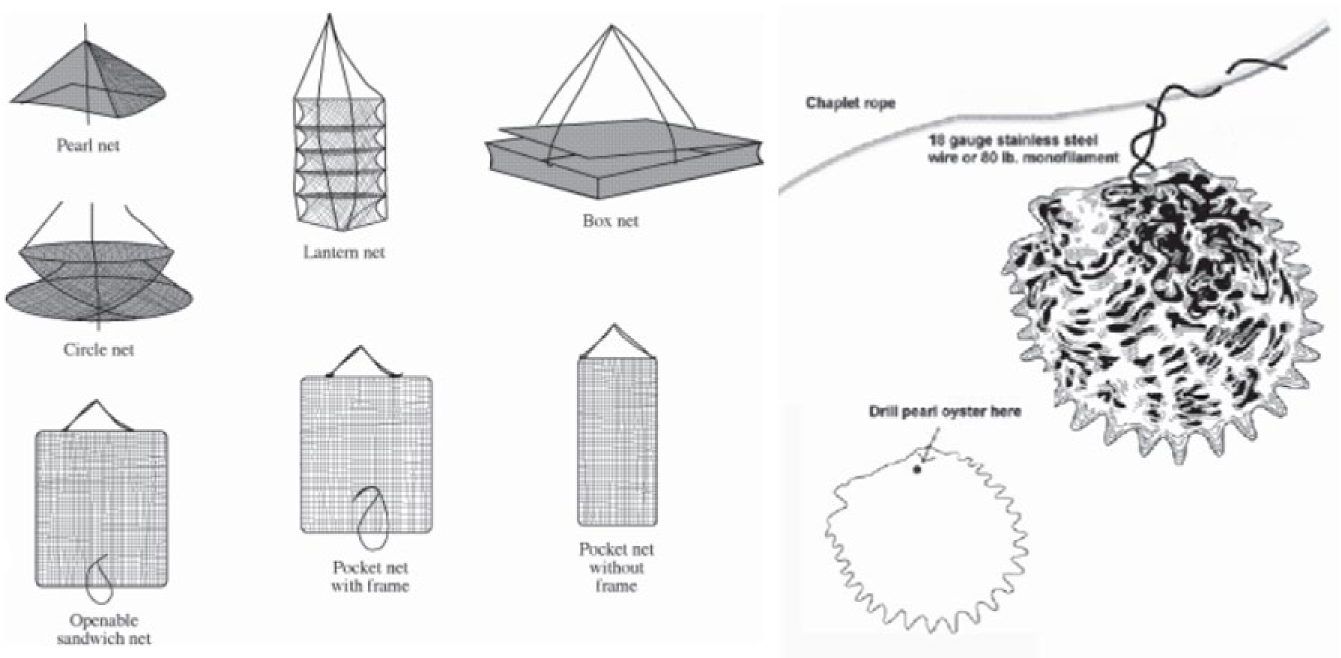

Figure 15: Different varieties of bivalve culture cages that are used in the pearl farming industry. Images from Gervis and Sims (1992) and Haws (2002).

Other pearl culture cages, such as lantern, sandwich, pocket panels, box, circle or pearl nets, excel at protecting pearl oysters from predators, but can be expensive and must be purchased -or locally manufactured- using special materials, mainly UV treated polyethylene mesh of varying sizes.

A typical farmer's strategy usually consists of employing pearl nets for the nursery stage, then moving to lantern nets for grow-out and finally the use of panel nets for pearl culturing. If chaplets are employed, they are usually used with larger oysters (3 to 6 years old) and constant inspection must be performed to review if the oysters are fine, especially at the beginning of any new pearl farming operation.

The pearl culture cages -and their valuable cargo- must be cleaned once every one to three months, depending on the level of fouling, this will be different for each location and constant monitoring must

Figure 16: Adult pearl oysters that have been cleaned and are ready to be returned to their culture cages.

be done by the pearl farmers until they learn the way the environment interacts with the aquaculture cages and the pearl oysters.

Pearl oysters are taken out of their cages and placed in trays, their numbers, and those of dead oysters, are recorded for analysis. Before cleaning, pearl oysters may have attached to each other and they need to be "de-clumped" (separated from each other); this is done by using a sharp knife, which is used to cut the byssus. If we pull-on the byssus, we risk killing or damaging the pearl oyster beyond repair, so this step is utterly important.

Figure 17: An adult pearl oyster covered with 2-month-old biofouling, in need of cleaning.

For cleaning, pearl oysters must always remain under the shade and if placed inside water, this must be freshly pumped seawater (if on land facilities) or in trays in the sea (can be on the shore or from a platform) while they await cleaning. Cleaning is done with cleavers, unless the pearls oysters are still small and with soft shells, in this case butter knives are best. The shells are softly scraped to remove the algae and invertebrates that are growing on top of them, taking care to notice if there are unusually high numbers of certain species such as:

- Red-orange-yellow sponges
- Barnacles
- Ascidians
- Polychaete worms
- Snails

The pearl cages must also be cleansed to use them again. This can be done in several ways, each depending on the speed at which the cages are required to be used again: if we are at limited capacity, we will need them as soon as possible. If this is the case the best alternative is to use a water-pressured sprayer, or to brush the cages with hard-fiber brushes. If time is not a concern, the cages can be placed on the ground to dry under the sun for up to a week, until all offending epibionts fall off naturally.

Figure 18: A pearl farmer cleaning nets with the help of a high-pressure water hose or spray.

5.3. Site Selection

Selecting best farm site is the most important factor to produce the best possible cultured pearls. The farm's location determines if the farmer's new venture is biologically and economically feasible. The local environmental conditions have a direct effect on:

- the health of the pearl oysters, and their growth
- the quality of the produced pearls
- the farm's safety, from thieves or fishing activities and
- the farm's operational costs

Choosing the best site from the very beginning is important, because it is difficult to move a farm once it is established. The best farm sites would have the following traits:

- Clean waters with as little pollution or freshwater influence as possible.
- Bays or lagoons with good water circulation, for oxygen replenishment, waste removal and good nutrition.
- Good depth (5 to 10, even 20 meters), so the farm's structures can be safely and efficiently utilized. Pearl oysters should remain underwater always, at least at 2 meters of depth; areas exposed during low tides are not suitable.
- Offers a nearby land area for establishing of land-facilities, with easy access through the beach or a dock.
- Water temperatures should be constant, with as little drastic changes as possible; preferably within the 20° to 30° C temperature range.
- The location should have living pearl oysters in it, hopefully even pearl beds and there is plentiful "spat" available.

Figure 19: View of a pearl farm in Mexico. This farm is located inside a small open bay, with almost no freshwater supports (except during the monsoon season), with an average depth of 10 meters, and with little human pollution that is taken away from the farm due to the prevailing sea-currents. The bay is enclosed by small hills that offer some protection from southern winds (hurricanes) and this site was chosen due to the presence of a nearby dock (for land activities) equipped with water and electricity and the fact that this bay used to be a "placer" or pearl fishing site in earlier times, pearl oyster spat was abundant in this site.

The presence of pearl oysters - both old and young specimens - or pearl oyster spat is a clear indication that the site's environment is a sound one for pearl oyster farming. However, we would do well not eliminate a location just because it does not have oysters: this could be due to high-natural predation or due to pearl fishery efforts; these areas can potentially be good farm sites if they have the following traits:

a. Water Quality

Pearl oysters thrive in clean seawater, as far away from industrial, oil, and sewage sources. Plastic pollution is also unwanted, but it is the least damaging type, and the farm can establish a "clean-up program" to help alleviate the issue. Areas near large villages or towns will have some form pollution, so farms should be located as far away as possible, or when favorable currents take these pollutants away from the site. Never locate the farm near the mouth of a river or estuary, tropical storms and the monsoon season may bring in a sudden discharge of freshwater, which can be harmful and even kill all pearl oysters. Areas with rough water where sand and silt are stirred up should also be avoided since pearl oysters have trouble feeding in cloudy water.

b. Water Depth

If the farm is in an area shallower than 6 meters, there will be just enough room to use a hanging method (trestles, rafts or longlines), but having deeper waters can be quite helpful for overall pearl farming management. For instance:

- if water temperature increases on the surface, then farmers could help lower the pearl oysters to 10 or more meters of depth, where water is sure to be cooler.
- If barnacle infestation or biofouling is high, lowering the baskets below 5 meters can alleviate this problem.

A site with maximum depth 20 meters is suggested, because it will be safer for the farm's divers.

c. Water Currents and Circulation

Constant sea currents are quite beneficial: water exchange provides a constant supply of oxygen and nutrients to the pearl farm. Sea currents will also carry out the pearl oysters waste products and help prevent their build-up beneath the farm, which could eventually increase water acidity and anoxic (low oxygen) conditions. Areas with fast or rough currents are difficult to work in and sites with stagnant water or rotting seaweed will usually also have anoxic conditions that are best avoided.

d. Farm Surveillance

Pearl oysters and their pearls can become valuable in the location, thus theft by occasional visitors and even local fishermen may become common. Keeping the farm within the farmer's line of sight will help to protect it. Boat traffic or fishing activities may also damage the farm, so discussion with the involved parties to let them know that there is a farm onsite is useful and even placing warning floats that continually flash a warning at night, to avoid these accidents.

Farms may sometimes lose up to 20% of their pearls to theft, thus pearl farms should be kept under surveillance all year round, and any foreign person entering the farm should be warned and asked to leave the premises every time, setting a precedent for the future.

Figure 20: A Tuna fishing vessel near a pearl farm. If this boat had come inside the pearl farm it could have destroyed it. But this did not happen thanks to communication between the pearl farm and the ship's Captain and the lighted buoys set on the perimeter of the farm.

6. OBTAINING PEARL OYSTERS FOR YOUR PEARL FARM

There are three ways to obtain pearl oysters to start a pearl farm:

1. **Collect wild, adult pearl oysters from the Sea:** Wild-caught pearl oysters should only be used when you want to start a small, pilot-scale farm.

2. **Spat collection:** This process involves placing "spat collectors" (different devices, sometimes made from artificial or natural materials) which are left in the water, and which passively attract the pearl oyster's larva, and will supply you with a cheap, seasonal quantity of small pearl oysters in a very sustainable manner.

3. **Hatchery reared Spat:** Specialized labs where adult pearl oysters are matured, their gametes obtained and fertilized, and the larvae raised until they settle and become "spat" (juvenile pearl oysters) and then sold to pearl farmers.

We will discuss each one of these supply methods.

Figure 21: The three main supply sources for a farm's pearl oysters.

6.1. Collect Wild Adult Pearl Oysters

This system is not sustainable, but it can be used for a very small-time frame, to learn about the growth and survival of pearl oysters in a given site or to eventually use them for hatchery spat production. It is best to maintain a large, wild-pearl oyster breeding population nearby, so that enough larvae will be produced for continuous spat collection or to supply the hatchery with healthy pearl oysters when required.

The only pearl producing country that relies on this system is Australia, although some farms in Indonesia and Myanmar may supplement their farms with a small proportion of large, wild-grown pearl oysters. Australia has a well-kept and reliable pearl oyster fishing quota system, but this is not the same anywhere else, and natural pearl oyster populations collapsed due to the fishery of the adult oysters, which are the best breeding stock (remember: older, larger pearl oysters are usually the females).

Wild oysters are also more easily affected by stress by handling and will stop growing or even die. Animals that have grown in a farm will be much better to respond to handling by the farmers.

6.2. Spat collection

Spat collection is the best means of supplying a farm with young pearl oysters. If spat collection is biologically available in your area, it should be your first most means of obtaining pearl oysters. This is also the preferred method to obtain pearl oysters in French Polynesia, the Cook Islands, Fiji, and Mexico.

6.2.1 How does spat collection work?

Pearl oysters undergo several different larval stages after fertilization, and in the last one they are ready to begin an "oyster-like" behavior, by finally settling on a substrate and begin a sedentary lifestyle. The tiny, juvenile pearl oyster that has attached itself to a substrate is called a "spat." Spat are usually visible to the naked eye when they measure at least 1 to 3 mm in size, about the size of a sesame seed!

Figure 22: "Onion mesh bag" type collectors are used in Mexico to effectively capture as many as 1 thousand pearl oysters pats per bag! 1. A line of newly produced "onion bag" collectors. 2. Onion mesh bag collectors in the sea after one month, they appear "inflated" and this means water passage inside the bags is adequate. 3. Two small pearl oyster spats attached to the surface of an "onion bag" type collector. 4. Pearl farmers collecting pearl oyster spat from the onion bag collectors. They do it under direct sunlight to better see the tiny oysters. 5. Black lip pearl oyster spat (Pinctada margaritifera). 6. Panamic black lip oyster spat (P. mazatlanica).

The typical substrate for wild-pearl oysters are rocks, hard and soft corals, and the shells of other bivalves, but they will also settle on vegetation and branches that fall in the sea and even on artificial substrates. When we elaborate an artificial means to attract these young pearl oysters we are in the process of "spat collecting" by means of "spat collectors".

Spat collectors are designed to offer a protected area where spat can settle and grow. Pearl oyster spats prefer to attach to mesh-like or fibrous materials.

Many materials have been used with different degrees of success, such as:

- pearl oyster shells,
- "Onion bags", usually available in different colors and made from polyethylene; these are filled with discarded fishing nets for maximum effectiveness,
- nursery shade cloth (55% shade),

- black plastic strips (polyethylene sheeting),
- coconut husks,
- bundles of bushes or tree-twigs, such as “Japanese Cedar” (*Cryptomeria japonica*), “Mikimiki” (*Pemphis acidulus*) or “Chivato” (*Calliandra sp.*). These bundles may also be covered with a mesh bag or without any,
- Commercially made spat collectors, and even
- Your own farm-raised pearl oysters (piggybacking).
- Plastic mesh-like materials, especially “onion bags”, work best because these are:
- Lightweight and can be stored easily
- Easily available and cheap
- Can be reutilized several times

6.2.2 Selection of a Site for Spat Collectors

Selecting a good area to place spat collectors can be difficult, especially the first time spat collection is attempted in a new area. Open sea areas are quite difficult and small bays or lagoon systems are better, since they have a greater array of currents, micro-currents and eddies that create a better retention rate of pearl oyster larvae. But be mindful that everything can change due to climate change or disruptive events such as “El Niño” or “La Niña”. It is best to place experimental spat collectors in as many places as possible, usually where we can find live pearl oysters.

Locating an adequate spat collecting site may take time, but farmers must start with what they have, and if a site does not yield enough spat, the effort must be increased: if a farm requires 10,000 pearl oysters, we must collect twice this amount of spat, and if we are collecting 10 spats per collector we should then set as many as 2,000 spat collecting units.

Why would we collect twice the needed amount? Because a pearl farmer could expect up to 50% mortality rates at the beginning of his operation (due to all sort of complications, including mishandling and loss), and because the farmer want to use the best pearl oysters for the pearl seeding operation, and usually a 10-15% will not be good for this.

One way of finding a good spat collecting area is by placing spat collectors in a wide area near the farm, as big as it is feasible for the pearl farmers, and to keep adding spat collectors in these places every month and removing the previous ones after 2-3 months of stay in water. Sampling some spat collectors (10 each month) to register the amount and size of spat that have settled, if any.

6.2.3 Choosing the best Spat collectors

It is hard to choose the best spat collector if we have not tried all of them, but sometimes we must chose based on the cost in time or money we will spend with our collectors: if some materials are not locally available or are prohibitively expensive, we should try to use what we have at hand and at the best possible price.

6.2.4 Onion Bag Collectors

Some of the best spat collectors are made using “onion bags”, these are plastic-mesh, rectangular shaped bags, used to pack vegetables such as onions and potatoes and can be purchased new or repurposed after they are discarded. These bags are filled with discarded fishing nets (monofilament), bushes or other materials that allow the bags to “expand” and for water to freely pass through them. If the bags “collapse”, spat collection will be affected.

Spat collecting lines have varied lengths, and may be hung vertically or horizontally, depending on the site's depth and the farm's farming system. It is said that closer to the surface you will have better spat yields, but this could be otherwise in your site: always sample all depths in a new area until you find the best site and depth.

If the spat collectors are vertical, they will require a buoy for easy access from the surface, and a dead-weight (*"muerto"*) for the bottom. If they are to be hung horizontally, the farmer must establish the best strategy, which would be like that of many fishing nets: floats on both extreme of a longline, interspaced with several more in between these, depending on the length of the collector line.

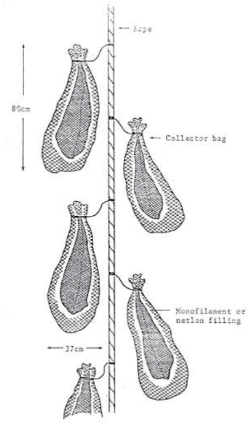

Figure 23: Diagram of a vertical Spat collector bag line system. Taken from NACA-SF/WP/87/1 FAO.

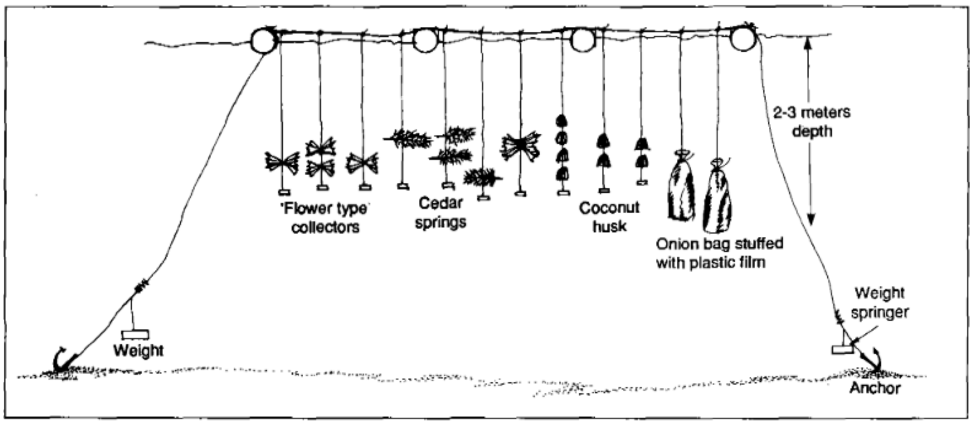

Figure 24: A longline used for spat collectors, with varied collectors. Diagram by Gervis and Sims (1992).

6.2.5 Flower/Ribbon Collector

Another common variety of spat collector is the "flower" or "ribbon" collector, which are made using strips of shade cloth or plastic mosquito mesh. These are made using strips that measure about 100 x 10 cm. These strips are perforated with strong thread to achieve an "accordion" shape. This creates a collector with a good amount of surface area and that offers protected areas where spat are relatively safe from predators.

6.2.6 Plant or Shell Collectors

These collectors are very simple to produce with locally sourced materials. Farmers will have to collect the shells (edible oyster, mussel and scallop shells are very commonly used) or bushes or tree limbs. In the case of plant material, it is very important that they are fresh and not dry.

For shells it is best to use old and sundried shells. You drill a hole through the center of the shells and thread them with some rope and using knots to keep the shells from touching each other. The same technique is used for coconut husks, these can be used in halves or in ¼ slices, with or without their outer husk, but they work better when they have the fibrous husk on them. Remember that these heavier materials will require more floatation.

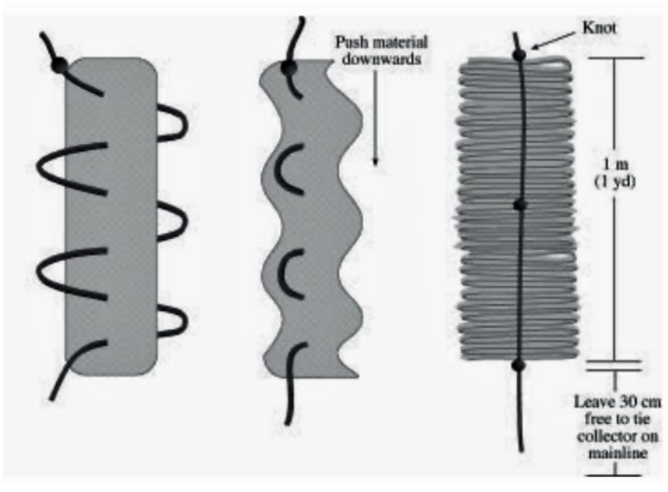

Figure 25: How to make a "Ribbon" or "Flower" spat collector out of plastic mesh. Shade cloth is cut in strips and thread onto a line. The shade cloth is then compressed to form a bushy mass of shade cloth to provide shelter for young spat. Diagram by Haws (2002).

In the case of bushes -such as “Chivato”, “Japanese Cedar” or “Mikimiki”- the branches are cut in lengths of 50 cm (makes it more manageable) and are then tied to the collector line with some thread. If the bushes are difficult to manage, you may place them inside plastic mesh bags or use some thread to make a more compact branch, and easier to handle.

6.2.7 Spawning Season

Natural spawning in pearl oysters occurs at different times of the year, depending on the species of oyster and their location. Typically, spawning occurs in three seasons: February to April, August, September, November, and December. Depending on the target species and the farm’s location, pearl farmers commence setting spat collectors up to one month before the start of the “official” spawning season, which is something they really do not know for sure until they have set out spat collectors every single month of the year or the local research institution has carried out a good gonadic index research, which allows us to scientifically understand the reproductive cycle of a local species of pearl oyster.

It is highly recommended that pearl farmers keep a good record of their spat collectors’ results, including:

- the dates of introduction to the sea,
- the site where the collectors were placed,
- the type of collectors utilized,
- the date when the collectors were taken out of the water
- the different species of pearl oysters present,
- the amount of pearl oysters found, and
- the size of the pearl oysters, usually we include the smallest size, the largest and the average size in millimeters.

If this is done, after one or two years they will have a better idea of the best sites, times and spat collectors to use to obtain pearl oysters for your pearl farm.

6.2.8 How to identify Pearl oyster spat

Pearl oyster spat can is easily identified when they reach a size of at least 0.5 cm. Spat reach this size about 1 month after settling on the collector. Depending on the location, we may have one, two or even three different species of pearl oysters and all of them should be recorded and collected, set aside in different cages, with their own species if possible. If their numbers are too low, let us say a dozen, we can place two different species with low numbers together, and add a tag (with an ID code or number) to so we can easily identify it from others. Never discard spat when in doubt.

Pakistan is located in an area where several species of pearl oysters could potentially be found, thus we could expect to find these:

- Akoya oyster – *Pinctada fucata/imbricata* complex
- Persian Black Lip oyster – *Pinctada margaritifera persica*
- Winged pearl oyster – *Pteria spp*.

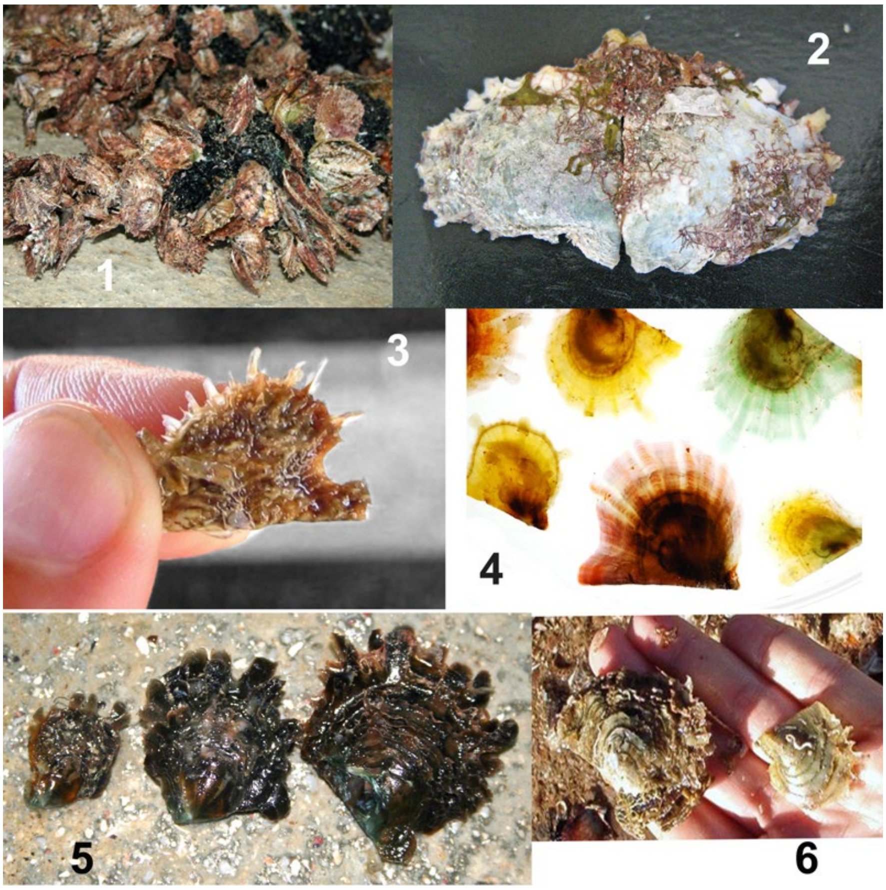

Figure 26: Different species of pearl oyster spat. 1 and 2= Akoya gai (Pinctada fucata/imbricata). 3= Winged pearl oyster (Pteria sterna). 4= Gold lip pearl oyster (P. maxima). 5= Black-lip oyster (P. margaritifera). 6=Panamic black lip (P. mazatlanica).

Different species of pearl oyster spat can be confused with each other, especially when the farmer don't have much experience, but there are two easy ways to easily identify them:

1. Coloration: Black-lips usually have dark-metallic coloration, ranging from bright yellow to emerald-green, coppery, or even black. Akoya are usually a light cream-brown color with dark colored stripes and winged oysters usually have a dull light brown to black coloration.

2. Growth processes: Pearl oysters grow their shells in rings around the "mouth" of the shell, and they lay these shell projections that are a good indicator of health and growth. Pinctada species produce broad and flattened processes, whereas *Pteria* species produce thin spines. Akoya spat may sometimes resemble *Pteria* species in coloration and spine appearance.

6.2.9 Harvesting/Collecting the Pearl Oyster Spat

When spat are large enough to be collected, the pearl farmer must proceed to their harvest, which is a time consuming and delicate endeavor. When does the farmer know when it is the right time to do this operation? It will depend on many factors, some of these are:

1. The minimum size of pearl oyster that can be handled by the pearl cages. If our smallest mesh cage is 5 mm, we cannot place oysters of a smaller size because they will fall out.

2. How fouled the spat collectors have become. If the collectors are fouled they will no longer collect new oysters and the ones already in place may die, it is best to collect these immediately.

3. If the spat has become too large (3-5 cm), they will fall off the collectors or become food for fish predators, so it is best to remove them at once.

4. If when inspecting or sampling the spat collectors, you find too many dead oysters (more than live ones) it is time to harvest the spat.

Once the decision to harvest the spat is made, the process may begin. Depending on the strategy employed to set the spat collectors, their distance from the farm, the amount of farm hands and the quantity of the collectors, there will be different strategies to initiate this process. The first aspect is retrieving the spat collectors.

6.2.10 Bringing the Spat collectors to Work facilities

All pearl farms should have working facilities, and best if these are on-land but very close to the water. In Tahiti they use facilities that are built on the shallow area of the lagoon and that stand on wood-beam posts, so they are on top of water; in Mexico, the farm is in a solid rock and concrete dock, and also surrounded by water; in Japan and the Philippines, the floating rafts can be used as working facilities and in Australia all work takes place on board small boats or large "pearling boats". The strategy employed by the farm will directly influence the strategy for working on the pearl oysters.

Figure 27: Different strategies to working with pearl oysters: 1. Australia uses large, highly technified pearling vessels. 2. China uses low-cost wood shacks for working with oysters, these are close to the farms. 3. A pearling boat used in Indonesia; work takes place on the boat. 4. A shaded area inland and close to the farm is also used in Tahiti. 5. A shaded, mildly technified work area in Mexico, surrounded by water and close to the farm. 6. A large pearlinlg raft in the Philippines, with workers working from boats and on top of the pearling site.

For this Manual it is assumed that prospective pearl farmers will employ land based, shaded facilities that will be located on the beach or shore, close to the pearl farm.

In any case, the spat collectors must be brought to the workers so they may begin harvesting the spat. If the farm is close by, the collectors may be brought in batches, with just enough lines/bags that can be worked in a day or several hours.

Figure 28: Onion bag collectors brought to the pearl farm by boat, for the harvest of spat (Mexico).

Figure 28: Onion bag collectors brought to the pearl farm by boat, for the harvest of spat (Mexico).

If the spat collector lines are places far away from the farm, it is best to bring a larger number of lines or bags, even for several days. It is assumed that, the spat collectors must be placed on a boat and covered from the sun's harmful rays for the duration of the trip. Once the collectors reach the farm, most of the collectors will again be placed in the water (inside or next to the farm) and only those that will be inspected will be taken to the working facilities.

If the work facilities have "work vats", the spat collectors may be placed there while waiting to be inspected and relieved of their precious cargo. Work vats are simple wood (coated with fiberglass and resin, for protection) containers (their shape may vary, from round to square or rectangular) that stand on legs and have a heigh appropriate for workers to work on them from a standing position. These are usually fitted with hoses that will supply them with freshly pumped seawater, and the water either goes through a special drain or overflows through the sides.

Workers must grab a heavy-duty plastic tray and place some spat collectors in it, then take the tray to a place where they can stand or sit as comfortably as possible, either under direct sunlight or very close to it, so they can better observe the collectors and identify the tiny spats. At this point they will proceed to hand-pick the tiny little pearl oysters from the collector's surface.

The workers will also have a plastic bowl, with clean, fresh, saltwater. They will place the tiny spats inside these containers. The water must never be allowed to become dirty, cloudy, or warm, sending the collected spats off to a vat with running saltwater, to be temporarily gathered in a strainer made from plastic shade mesh.

IMPORTANT NOTICE: When handling pearl oysters of any age and size, it is very important to NEVER pull on the oysters to separate them from anything that they have attached to. The byssal threads are connected to the retractor muscle, and if this muscle is torn it may cause irreparable damage to the oyster, even its death. To avoid high mortalities: always CUT the byssus with the help of a sharp object, it can be a scalpel, knife or even a piece of sharp glass.

Figure 29: A wooden, rectangular-shaped "work vat" as used in Mexico. They are colored white to better observe pearl oysters, these are supplied with freshly pumped saltwater. In this photo we observe spat collector bags.

Once all the pearl oysters in a day have been handled, we can proceed to count and separate the pearl oysters, to place them inside their new homes: the nursery system. But before we start describing the aquaculture system, let us describe a simple and effective system to count pearl oysters and place them inside their nursery cages:

To start with all the spats must be in a plastic mesh strainer. If there are some larger oysters (than the average size) it needs to separated immediately, hand-picked and placed in a plastic container with clean water. The same is to be done with the average sized oysters and finally with the under-average (small) spat, which usually goes to the bottom. Farmers should not have 3 groups of differently sized pearl oysters.

Figure 30: A plastic container being filled with oyster spat. When the number of oysters reaches 100, a line is drawn at the level reached by the oysters and subsequently used to avoid counting.

Now, measure some 20 pearl oysters of each size group (and keep track of this data in a notebook). Count 100 oysters from each group and place them inside a clean, clear plastic or glass cup with some water. Draw or paint a line on this container, at the height that this group of 100 pearl oysters reaches. Now, the farmer can just scoop oysters of that same size and to that same level and they can count them as groups of 100 pearl oysters. This is the volumetric method.

Alternatively, if they have a good scale or balance, they may weigh 100 pearl oyster spats for the same effect. The problem with scales is that they get wet and may oxidize and stop working, so the volumetric method is better under these conditions.

6.3. Spat Production in Hatcheries

Pearl oyster hatcheries are one of those installations that are best not to have, but instead have this option offered by a local University, research center or private producer. These are expensive and require highly skilled personnel to run and operate, a single small producer will not be able to pay for the costs of one of these specialized laboratories but if there is one hatchery available, it may offer its services to dozens or hundreds of small producers. For this reason, it would be in the best interest of a Governmental institution, via a State backed research center or University, to offer this valuable service in the case there is a viable opportunity of establishing a socially based pearl farming industry in Pakistan.

Hatcheries must have electricity running 24/7, with backup power in case there are problems with the supply of energy, and they usually have refrigerated areas. If the hatchery is well planned it may serve to produce other commercially viable mollusk species and even fishes, both for aquafarming and for repopulation efforts, to help in the local fishery efforts.

Hatcheries are divided into three main areas:

- Algae Growing Facilities
- Larvae Growing Facilities
- Spat Raising Facilities

6.3.1 Algae Growing Facilities

Algae growing facilities are required to both maintain unique microscopic algae strains and to grow high volumes of these algae strains, to be used as "feed" for the tiny pearl oyster larvae. Depending on the variety of pearl oyster species, this will be easier or more difficult: Philippine private pearl producer "Jewelmer" states that to produce their *Pinctada maxima* spat their lab requires at least 21 different strains of microscopic algae and diatoms. On the other hand, the State-run CREMES laboratory in Mexico uses just 4 strains to produce *Pteria sterna* pearl oyster. Each pearl oyster requires a "unique recipe" that must be researched by experienced and skilled technicians and researchers in this area. The species with the most available knowledge available is the "Akoya" or "Lingah" pearl oyster (*P. fucata/imbricata*).

Figure 31: A hatchery's algae growing facilities. Photo courtesy of "Pearls as One" course/Jeremy Shepherd.

6.3.2 Larvae Growing Facilities

Once the algae production is up and running, the next step is securing the best possible breeders possible. This means having at least ten different organisms, 6-8 females and 4-2 males. Female oysters are usually older, meaning that they are also larger in size.

If no pearl oyster beds are found in Pakistan's waters, the next logical step would be to import (following all the necessary National and Regional guidelines and regulations due to the introduction of an exotic species) the species that would be able to sustain an industry. Again, it must be pointed out that the previous two species mentioned in this manual - the "Lingah/Akoya" and the "Persian Black-lip" pearl oysters (*P. fucata/imbricata and P. margaritifera var persic*a) - are the ones with greater regional potential. These could be obtained from the Persian Gulf, after securing the necessary cooperation from the neighboring Emirate States.

Once this is done, the pearl oysters should undergo a quarantine (following all the necessary National and Regional guidelines and regulations due to the introduction of an exotic species) and finally being able to be used for production. Since many of the oysters die during transportation and quarantine, be sure to secure as close as 100 pearl oysters if possible.

This manual will not go into great detail on the subject, but a more detailed explanation may be found in this document about a Pearl Oyster Hatchery in Vava'u, Kingdom of Tonga, that was published by FAO in 1999.

As a short review on the production of pearl oyster larvae, these would be the required steps for successfully rearing pearl oyster spat:

1. Pearl Oyster Maturation: feeding and maintaining the oysters until they are sexually matured.

2. Pearl Oyster Spawning: the individual spawning of pearl oysters. Only a few males and females are selected for this, with the remainder left behind as backup.

3. Fertilization: Egg and sperm cells are mixed together in the best proportion (usually 10:1 ova:sperm) and allowed to fertilize *in vitro.*

4. Raising the larvae during the embryonic and planktonic stages: depending on the species and the conditions, this period may last between 30 and 42 days.

5. Spat Settlement: Spat collectors are placed inside the tanks to allow for pearl oysters to attach and then these are either transported to the pearl farm or to other tanks for additional growth, since the initial spat are very small and difficult to work with.

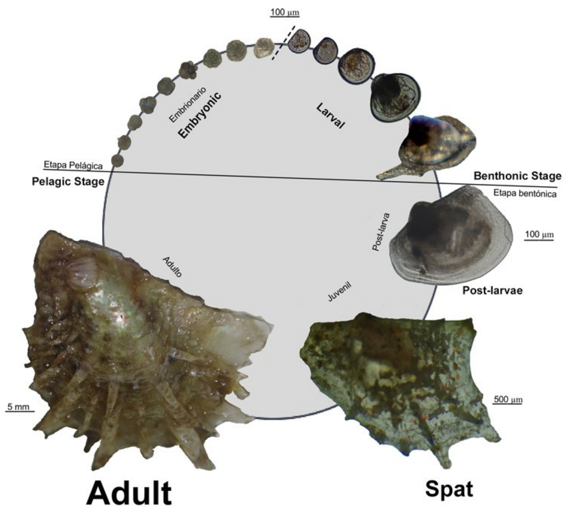

Figure 32: Larval cycle of the "Akoya" pearl oyster (P. imbricata), diagram courtesy of Dr. César Lodeiros.

7. PEARL OYSTER FARMING

This process basically consists of the methodology that will be used to grow the pearl oysters from spat, all the way up to the moment when they are young adults and ready to become operated to grow cultured pearls. This of course means that the pearl farmer has his farm ready in very aspect: longlines, rafts or trestles are ready, and the pearl farming cages are prepped and on the premises.

Regardless of the origin of the farm's spat (wild-collected or hatchery reared), the spat is finally at the farm and at the hands of the pearl farmer, great precaution must be taken to NEVER:

- Expose the pearl oysters to sunlight nor heat
- Allow the spat to dehydrate
- Pull the tiny pearl oysters apart, but gently separate them in your hands or by placing them inside a cup with water and use a spoon, stick or finger to move them and separate from each other.

7.1 The Nursery System

The pearl oysters are separated into size groups and counted into groups of 100 for easier handling, using the technique described previously (volumetric technique). Depending on the farming cages utilized, the way you work with your spat will be different, but the best cage for growing spat (3-50 mm) are the pyramid-shaped "Peal Nets", since these are easy to handle, and it is very easy to extract the pearl oysters from them for periodical cleaning. Depending on the size of the spat and of the environmental conditions (mainly, the local productivity levels), we can place between 300 to 1,000 spats per net.

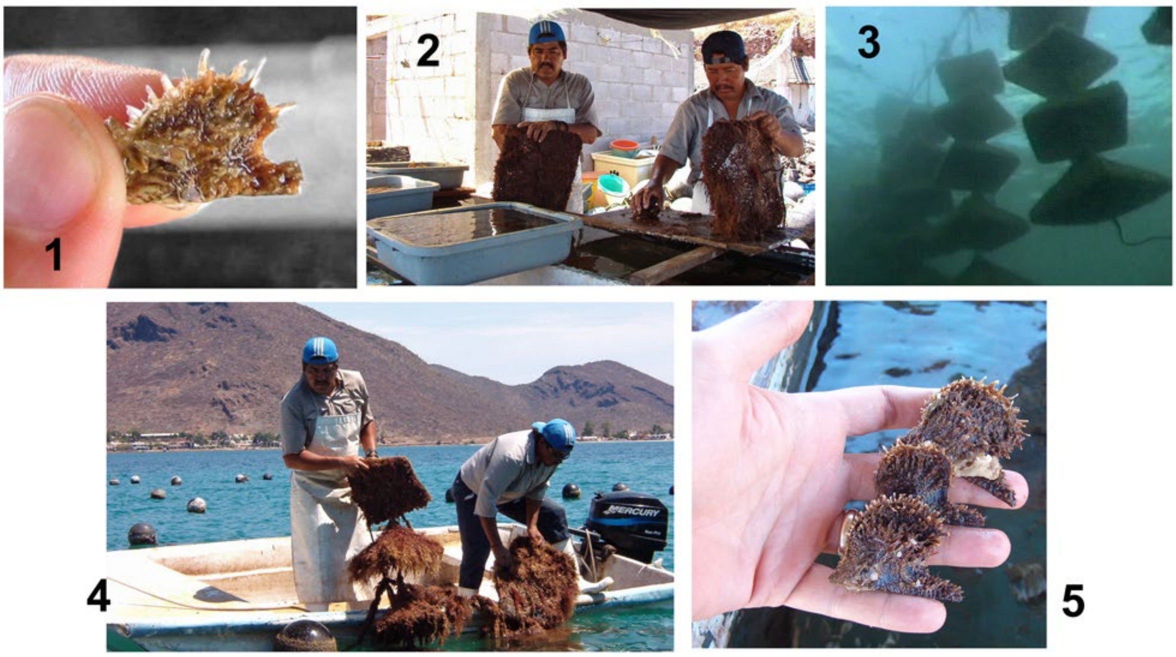

Figure 33: The process of "Nursery" using "Pearl net" style cages. 1. Pearl oyster spat. 2. Placing spat inside pearl nets. 3. Pearl nets hanging from a longline system. 4. Pearl nets taken from the farm for cleaning. 5. Pearl oyster juveniles after 6 months in the nursery system, ready to be transferred to the grow-out aquaculture system.

Pearl nets are tied together to form lines of pearl nets. How many pearl nets are tied together, it will depend on the depth of the culture area, but the best number is between 4 and 6 pearl nets, since this allows for better handling: it is very difficult to manage lines with more pearl nest, but if the farmer decides this is best, he can do it, just being careful to avoid damaging the nest, since they are costly.

Once the pearl oysters attain a minimum size of 5 cm in diameter, we can proceed to the next step in the aquaculture system.

Figure 34: The large abductor muscle of pearl oysters is considered a delicacy in many countries, considered a variety of "Sea Scallop", and depending on the species it may weigh up to 30 grams per piece.

7.2 The Grow Out System

Some people refer to this stage as the "fattening period" because for other species of mollusks it would be the stage previous for their harvest and to be sold as seafood, but this is not the case for pearl oysters, the end of this stage marks an important moment in pearl culture: the "Pearl Seeding Operation" or "Pearl Grafting Operation", and the start of the "Pearl Culture stage".

It is significant to note that pearl oysters are considered a delicacy in many countries, where the "pearl meat" (the large abductor muscle) is utilized and recognized as a variety of "sea scallop", but in Venezuela, the whole pearl oyster meat is considered a valuable nutritional apport and the pearl oysters are fished today mainly for their seafood value. The oysters in Venezuela are eaten whole and raw when they measure between 5 to 6 cm in diameter (Dr. César Lodeiros, personal communication). So, a strategy for Indonesian pearl farmers could be to harvest a certain percentage of their pearl oysters as food, when they are between 6 to 10 months old, as a means to produce some early income, before the pearl harvest takes place, some years after.

The duration of the entire stage depends on the species utilized and on the unique environmental characteristics of the farming site, but we could say that it may take between 8 to 18 months (average is 12 months) to finalize this stage, and some of the pearl oysters will come out of it in less time, and others at a later time: just like with humans and other animals, some pearl oysters grow and mature faster than others. Some pearl farmers choose a group of the fast-growing specimens to have them used to produce lab-grown spat as "breeders" (breeding stock), and others decide to harvest the slow-growing oysters for their meat and shell, since they usually are never good for pearl production.

The Grow out stage usually takes place with the oysters growing inside:

- Lantern nets
- Pocket nets
- Chaplets
- Baskets

7.3 Lantern Nets

The best cages are lantern nets, since they offer great protection to the oysters, they are easy to utilize and not overly expensive. Pocket nets, on the other hand, are more expensive and better to use with larger pearl oysters and chaplets are the most economic, but prone to high mortality rates if predators are found in the area. As an example, mortality rates in lantern nets in Mexico may reach only 10-15% after the entire 12 month grow out period, and chaplets usually attain a 100% mortality rate in the same pearl farm.

Figure 35: Grow out system with "Lantern Nets". 1. A lantern net filled with young pearl oysters (6 months old) and ready to be sent to the farm. 2. Lantern nets in a longline system. 3. "Akoya/Lingah" (P. imbricata) oysters after the grow out period in Venezuela (8 cm in diameter). 4. Handling of lantern nets in a longline system in Mexico. 5. Winged oysters (Pt. sterna) ready for grafting, after the grow out period in Ecuador (10 cm in diameter). 6. A 3-year-old Panamic black-lip oyster (P. mazatlanica) after its grow out and ready to be grafted (12 cm in diameter).

Lantern nets should be inspected every month for the presence of predators, such as murex snails, octopi, and crabs.

7.4 Chaplets

This is a very simple and economic pearl culturing system, sometimes also referred to as "ear hanging" or "rope hanging", and consists of:

- Cleaning the oysters
- Drilling the oyster's shell
- Placing a plastic or steel thread/cable through the drill-hole
- Placing this thread/cable though a rope, with the oyster in it
- Placing the entire rope with oysters in the farm

The oysters are usually placed in pairs with the same thread or cable, to balance the weight on the rope, and they are placed with a minimum distance in between the oysters that are below them. This distance varies but usually it is between 0% (barely touching each other) to 50% (the top oyster will fall to about half the diameter of the oysters below them), but some also prefer to have them well separated, basically the distance of another similar sized pearl oyster.

The greatest inconvenience with this method is PREDATION. It has been mentioned before that predation may reach mortalities as high as 100%, so before selecting this method, care must be taken to analyze this impact.

Figure 36: Rope or "Chaplet" culture. 1. Drilling pearl oysters. 2. Placing oysters on the rope. 3. Rope culture in Fiji.

7.5 Other Cages

There are many other options for pearl farming, such as the use of plastic-mesh boxes, square or round baskets. But these are usually more difficult to manage, the nets are more difficult to find or more expensive.

Nonetheless, the final result is obtaining pearl oysters that are large and healthy enough to be used to produce cultured pearls.

8. PEARL CULTURING

Figure 37: Some of the Pearl Culturing steps that are used in Japan for the Akoya pearl oyster.

This is the last stage of the aquaculture process, and perhaps the most complicated of all stages due to the fact that we must perform one or two delicate operations, in order to induce our pearl oysters to produce cultured pearls. But this process is not solely about the delicate operations, but it must emphasized the need for the extra care and attention that must be given to the pearl oysters during this stage: stress, mistreatment due to rough handling, poor nutrition, fouling, environmental changes, all of these and more may affect the pearl oysters in a way that the beauty and value of the pearls will drop to a point where the pearl farming venture will not be able to be economically sustainable.

The stages of this pearl culturing process are:

1. Pre-Operative
2. Operation, which involves two different procedures for pearl production:

   a. Mabé Pearl Production, and

   b. Cultured (Bead-Nucleated) Pearl Production
3. Post-Operative Care
4. Pearl Culturing in the Farm, and
5. Pearl Harvest

Most of these stages are short, especially when compared to point 4, Pearl Culturing in the Farm, which is the longest at between 10 to 24 months. Why do we have such a wide time variation? The amount of time the farmer spends growing his pearls depends on several factors:

a) The species of pearl oyster produced

b) The nacre growth characteristics of the oysters in their location

c) How expensive Manual labor is in the location

d) The Pearl Market these pearls are aimed at

a. Pearl Oyster Species Selected

The variety of pearl oyster species selected for pearl farming will have a direct impact in the pearl culturing time frame, for instance the smaller-sized species (such as the "Akoya/Lingah") are usually short-lived (5-8 years) and grow faster to the adequate size for pearl production (10-18 months) and will be harvested in a smaller time frame too (10 to 18 months). This would not be the case for larger pearl oysters species that are long-lived (such as the black and silver lipped oysters, that may live up to 20-30 years), and that may take a longer time frame to use for pearl production (24 to 36 months) and their pearls, which will be grown for a longer time period (18 to 36 months) in order to achieve a larger size and value; these larger pearl oysters species may also be re-operated, to be able to produce a second and even a third cultured pearl, so they may spend much longer time periods under this stage.

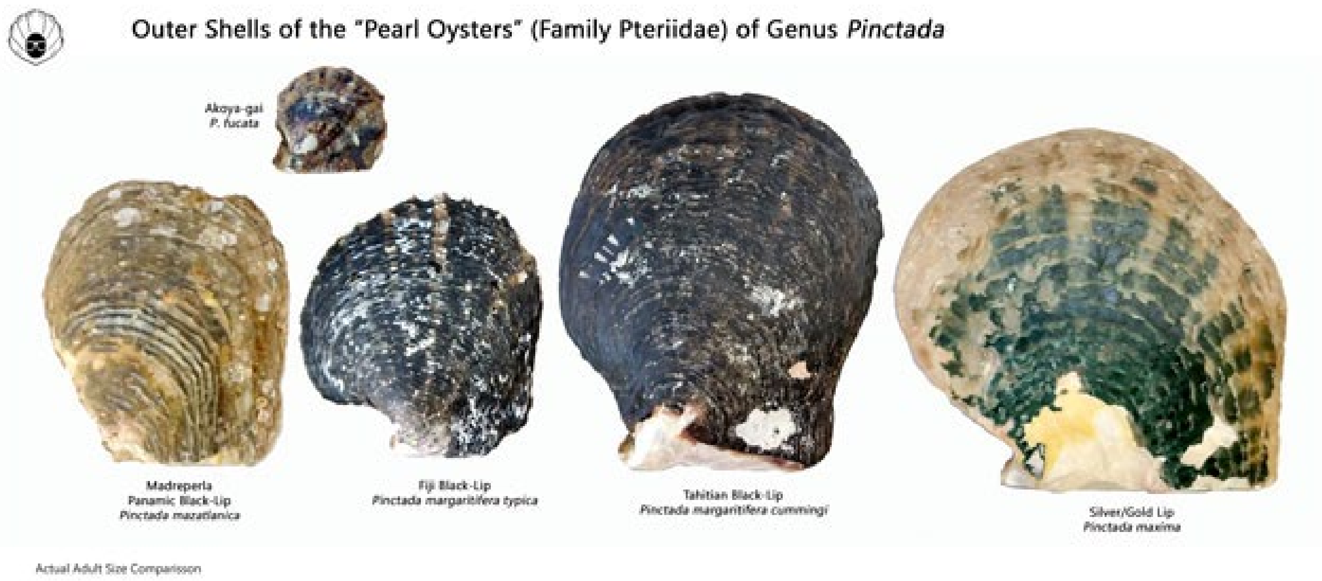

Figure 38: External appearance of some of the most commercially important pearl oyster species in the world. The size of the smallest pearl oyster in this group is for the "Akoya" at 10 cm in diameter, the largest one being the Tahitian black lip at 30 cm.

An interesting approach to this stage would be the use of two or more pearl oyster species in Pakistani waters. This strategy would allow for pearl farmers to be able to harvest pearls faster using the "Akoya" pearl oysters and larger, more valuable pearls in a "black-lip" pear oyster and even Mabé pearls using a "winged pearl oyster", allowing pearl farmers a better economic strategy. Most pearl farmers in the world only use one species of pearl oyster for pearl production, because this allows them to become more efficient and specialized (Japan, Philippines, Australia, Fiji, and French Polynesia) but few others use all available pearl resources to allow them more flexibility and diversification (Mexico, Indonesia, China, and one farm in Australia).

b. Nacre growth characteristics of the oysters in their location

The different pearl oyster species secrete nacre depending on the environmental characteristics of the farm's location. A site with stable water temperatures (23-28°C), excellent water productivity (chlorophyll), clean waters with good oxygen levels will allow the pearl oysters to grow faster, secrete many pearl layers (nacre thickness) and for these layers to be clean and shiny (lustrous), with good body colors and overtones.

The smaller sized pearl oyster species are usually better adapted to grow at lower water temperatures (16-22°C), whereas the larger species usually grow best at higher temperatures (24-30°C); when these species are found outside their best growing temperature margins, they will stunt their growth, and the pearls will also develop more slowly. We never fully understand how pearl oysters will react and grow in a site until we have had at least a couple of pearl harvests, and this information will allow the farmer to choose a better strategy or better species for pearl culture.

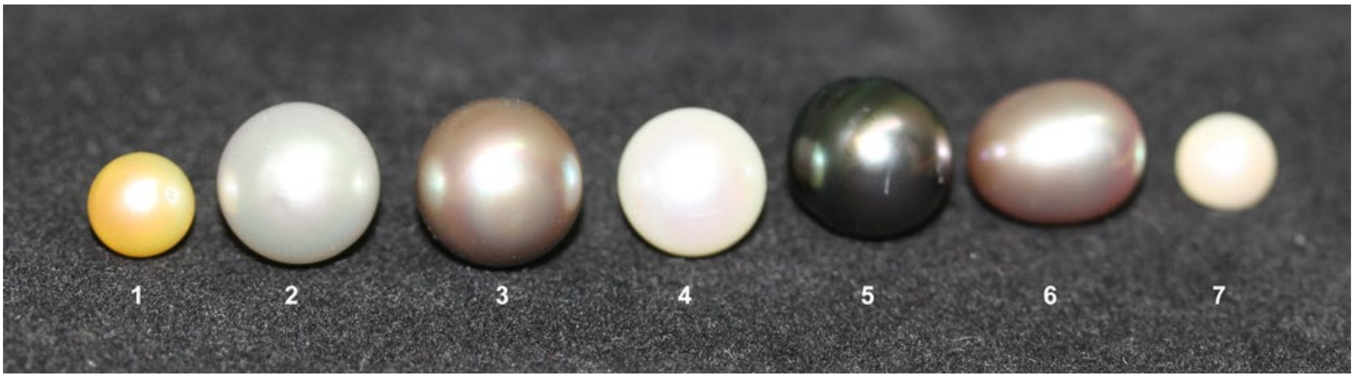

Figure 39: A lineup of different cultured pearls from different species of mollusks. 1. Japanese Akoya pearl (P. fucata/imbricata), 2. Australian South Sea pearl (P. maxima), 3. Mexican Cortez pearl (Pt. sterna), 4. Chinese freshwater pearl (Hyriopsis scheleglii), 5. Tahitian Black pearl (P. margaritifera), 6. Chinese "Metallic" freshwater pearl (Hyriopsis cumingii/schlegelii hybrid), 7. Chinese freshwater pearl (Cristaria plicata).

c. Manual labor costs

This is a very important issue for pearl farmers, but especially sensitive for those established in developed countries. If the strategy involves hiring personnel, this will always be an issue, but if the overall idea is to have a self-employment strategy, then this will not be a problem at all, but a blessing.

Countries such as Australia and Japan always have issues with labor costs, and they have developed opposite strategies to pearl culturing:

- Japan: they shortened the pearl culturing period down to even 8-months, effectively reducing the quality of the Akoya pearl. This happened from the 1970s to the early 2000s and has recently started growing them to 12-14 months to produce higher quality pearls and coinciding with the decrease of Akoya pearls from China.
- Australia: they have increased the duration of the pearl culturing process, in order to continue producing larger and thick coated pearls, to maintain both pearl-quality and good prices.

Labor costs will impact each farm differently, especially in different locations, and if these are set by private investors or local communities, they will use them as an important economical hot spot. It is important to consider that pearl farms will require the assistance and help of many local services such as outboard marine motor mechanics, net weavers, carpenters, repairmen, and will consume local resources such as fuel and oils, electricity, nets, buoys, ropes, etc., then there is the possibility of a pearl farm becoming a touristic attraction (as it has happened in several pearl farms in the United States, Mexico, Australia, United Arab Emirates and French Polynesia), so even more services will be required by tourists in the community, such as guides, food services (restaurants), lodging, touristic boats, etc., thus, a pearl farm has the possibility of generating a very positive economical flux in its location through the integration of all these economic potentials.

d. The Pearl Market

All cultured pearls are geared toward a specific market. Chinese freshwater pearls, on average, are geared towards a price-aware market segment and will therefore command lower prices when compared to saltwater pearls, which are considered premium. Of these higher end pearls, we can find South Sea pearls (Australia, Indonesia, Myanmar, and Philippines) considered as the most valuable, followed by Cortez and J. Hunter pearls (Mexico and Fiji), and finally all Akoya pearls residing on the lower tier (Japan, Vietnam, China).

Because of the existence of this world market, cultured pearls in Pakistan will end up lining up to these established tiers, although the quality achieved will drive the prices down or up. A way to escape this segmentation is by establishing a "new pearl market" by producing a unique "niche pearl". This would mean utilizing a new pearl oyster species, not grown elsewhere and with unique traits.

Figure 40: Different pearl colorations offer the possibility of establishing a "niche market" that allows for different value for these pearls. The uniqueness of the Mexican "Cortez Pearl" allowed it to enter a special market segment and aspire to a higher valued segment.

Of the two species that are considered to have potential for pearl farming in Pakistan, the one that has the highest potential is the "Persian black-lip" (*P. margaritifera persica*) which is not yet grown commercially in any country. The issue with selecting such a species is that most of the expertise on the species will be unavailable and will have to be developed until mastery is achieved, which could take at least a decade; and on the other hand, the "Lingah" pearl oyster (*P. fucata/imbricata*) offers plenty of experienced specialists and knowledge, so the adaptation of this species would be fastest and easier.

8.1. Pre-Operative Stage

This is the first step in the pearl producing strategy of any pearl farm. The selection of pearl oysters will be subject to surgery. The list of things that must be evaluated for this to happen is as follows.

Figure 41: An adult pearl oyster with a high gonadic index (ready to spawn) will have a large gonadic mass, looks full of fat and is heavy. If operated this way, nucleus rejection rate may be quite high.

- Size: Pearl oysters must have a minimum size (usually from 8 to 12 cm in diameter) to be successfully operated. The smaller the oysters, the less efficient the operation is.
- Width: Oysters that are flatter (dorso-ventrally) are not as good as those that are more concave for Mabé pearl production. Thus, if we are selecting oysters for Mabé pearl production we would choose those with wider shells.
- Health: Pearl oysters whose shells seem affected by drilling organisms or feel "light" (lower weight) or have no growth spines/processes, should be sacrificed, or set aside to wait for their recovery. If used, they will die and create another health issue.
- Gonadic Index: This is more difficult to evaluate since we can only see this from the inside. Some farmers will anesthetize a group of 10-12 oysters to evaluate their gonadic index and other prefer to sacrifice them. Regardless, if the oysters are sexually mature, the operation will be technically difficult and pearl quality will be reduced, so it is best to force them to spawn before the operation is performed.

Figure 42: 3-year-old black lip pearl oysters (P. mazatlanica) are relaxed or anesthetized, before the pearl surgery takes place.

Once the oysters are selected, based on the previous list, they may be placed in square plastic boxes or lantern nets under crowded conditions a day before the operation, then placed in plastic trays, saltwater is added, as well as a chemical agent that may act as a relaxant. Forcing the oysters to open is reported to cause massive mortalities (up to 80%), whereas the adequate use of an anesthetic will allow for a survival rate of up to 99% post-surgery. Relaxants are mostly used in Mexico's pearl farms, since it helps for a faster, easier, and safer pearl surgery.

8.2. Pearl Surgery or Implant Stage

This is the surgical stage, the most complicated part of the entire pearl culturing period. It may only last a few minutes and when compared to the entire 4-year pearl farming process it seems unimportant, but it is a crucial step to produce high pearl yields and gem-grade pearls.

There are two different operations, which will allow us to obtain three different types of pearls:

- **Pearl Grafting** (Mise-Nishikawa technique variant): allows the farmer to produce "cultured pearls" (also referred to as "bead-nucleated pearls") and "keshi" pearls.
- **Mabé Pearl Implant:** allows for the production of Blister Cultured pearls, which must be processed to produce Mabé Cultured pearls.

Figure 43: A cultured pearl (bead-nucleated) and a processed Mabé pearl. Two very different pearl types that can be produced in a pearl farm.

The pearl farm's strategy may include:

- **100% Bead-Nucleated Cultured Pearl Production:** this is the common strategy for most pearl farms in Australia, Philippines, China, Japan, UAE, and Vietnam.
- **100% Mabé Blister Pearl Production:** a strategy that was followed by small, community-based pearl farms in islands throughout the Indo-Pacific region such as Papua-New Guinea, Tonga, Zanzibar and in pilot-scale farms in Ecuador and Peru.
- **50:50% Pearl Production:** Although it does not have to be in this perfect combination, it could be 70:30 or any other. This is the strategy followed by Mexican pearl producers, changing the proportion of cultured: Mabé pearls they produce on a year by year basis, depending on market demand or the physiological characteristics of the pearl oysters.

The Pearl Laboratory

The strategy for pearl production may be chosen by the pearl farmers, based on the market they want to reach and many other factors, including the species of pearl oysters being farmed. Regardless, we must have a place where we can perform the pearl operation; this special place is referred to as the "Pearl Lab": a shaded area that is clean, well-lit and has a good, stable table and a comfortable chair. If the lab has running salt-water and electricity, it is a plus, but it is not necessary if we can have fresh, clean water (both salt and fresh water) brought in inside buckets or other containers. A drainage system is very useful to avoid having the laboratory's floor dirty, and all trash generated must be taken out daily.

We will explain each pearl producing process in detail starting at this point.

1. Mabé (Half-pearl) Production

Mabé (also sometimes referred to as "Half-Pearls") production is a simpler pearl farming solution, especially when starting a pearl farm, because:

- Mabé are "easier" to produce
- Mabé have good value

But, on the other hand, these pearls require processing to be used in jewelry. If the pearl farmer wants to sell his "pearls on the shell" he will obtain the lowest possible value on his harvest (USD$1 per shell), but if the farmer decides to process his Mabé he will be able to obtain much better prices, depending of course on the quality and beauty of his product.

Figure 44: A Mabé blister pearl on the shell of an Australian P. albina pearl oyster.

Although Mabé-pearls vary in value depending on their size and quality, large, high quality Mabé pearls may sell from $5-100 USD each (farm direct price). A single pearl oyster can produce between three and eight Mabé-pearls, depending on the size and species of pearl oyster employed, and on the size, shape, and location of the nuclei on the shells.

The ideal pearl oyster size for implanting depends on the species of pearl oyster:

- 8-10 cm in diameter, for smaller species, such as Akoya and Rainbow-lips,
- 12-15 cm in diameter, for larger species such as black and silver lips.

These animals will be between 18-24 months old. This is the best age because the pearl oysters are young and growing and will be able to rapidly deposit the best and most colorful nacre, as opposed to older pearl oysters that will produce less nacre, with less color and luster.

Mabé pearl production has the following stages:

1. Sedation of pearl oysters to start implanting
2. Implanting the pearl oysters
3. Pearl Farming in the Sea
4. Harvesting of Mabé pearls
5. Processing of Mabé pearls, and
6. Setting the pearls on jewelry or selling the Mabé pearls.

2. Sedation of Pearl Oysters

To perform an easy implant operation, the best strategy is to have the oysters fully relaxed. This allows for a better procedure and very low mortality rates. Using the inverse forceps may cause high mortality rates, especially when the person in charge of opening the oysters does not have experience in how to do this.

Pearl oysters should be "pegged" to allow them to open as much as possible, this will make the implant operation easier. These "pegs" or "wedges" are usually purchased commercially but can be made locally from wood or even plastic tubing.

Figure 45: Winged oysters (Pt. sterna) that have been relaxed and pegged for Mabé pearl operation.

3. Implanting the Pearl Oysters

Once the oysters have been pegged, the next part of the process is to prepare the oyster's inner shell for the implant operation. We will now proceed to detach the mantle from the shell with the help of a simple tool -usually tweezers or a small spatula- with no sharp edges for this. The shell can be cleaned with cotton swabs or a small stick with some cotton on top, even paper can be used, in the case there is too much mucus or the shell is wet. With both mantle lobes detached and with the shells clean and dry, we can now perform the Mabé pearl implantation.

Figure 46: Some common Mabé Pearl shapes.

Mabé pearl implants can be made of almost any material, as long as it is non-reactive in nature (it does not cause damage to the animal). Mabé implants have been made from wax, lead, silver, bone, wood, shell, and stones, but the most common implant today is plastic.

The shape of the implant can also be quite varied -as opposed to that of the bead-nucleated pearls, which is always spherical- and you can find them in drop, square, round, diamond, star, ovals, and other shapes…even religious figures, company logos and human faces. These implants range in size from 6 to 18 mm in diameter and cost between $0.05-$0.10 USD per piece. The best sizes to use are between 10 to 14 mm in diameter.

Once we have selected our Mabé pearl implant (shape, size, etc.) we can now proceed to the operation. The process begins by gluing the plastic implant on the inside of the pearl oyster's shell. The implant is glued with the help of a cyanoacrylate adhesive, also referred to as "Crazy Glue", which is easily found at most convenience stores. Once glued the nucleus will slowly become coated with nacre, thus forming a Mabé blister pearl.

Figure 47: A winged pearl oyster being implanted with hemispherical Mabé implants.

Special Advice: The amount of glue to place on the implant is the minimum, just a tiny drop, placed in the center of the implant. When attaching the implant, try not to slide or move the implant, it should stay on the site you placed it, to avoid the oyster from becoming irritated and creating dark spots on the pearl or ruining the pearl.

The required tools are very simple for this operation: tweezers, plastic trays and pegs/wedges.

4. Shell Site Selection for Mabé Pearls

Mabé pearls can be produced in any place inside the pearl oyster's shell, but there are some places that are better to produce high-quality Mabé pearls. Depending on the desired pearl traits, we can also use different sites.

On figure 48 we can see three different sites that are commonly used for Mabé pearl farming. The most used implant site is "A", which usually allows for the production of three Mabé pearls on the shell's "lip" area, which is the most colorful and has the highest growth rate, and this allows for baroque-shaped (asymmetrical) pearls with good nacre coating.

On the other hand, we have site "B" which is mostly used in the older and larger sized silver-lipped oysters (*P. maxima*) and allows for smaller sized Mabé pearls that have a perfect hemispherical shape. The problem with this site is that if it is used in younger animals, the pearl will grow under the abductor muscle and will end up having an unappealing look and low value.

Finally, site "C" is mostly used on winged pearl oysters (*Pt. penguin*) to produce large (16-18 mm) Mabé pearls of perfect hemispherical shape, but with a thin nacre coating. One issue with this operation is that the mantle's sigmoidal muscles must be cut to allow access to this portion of the shell, and this may cause growth problems on the oyster.

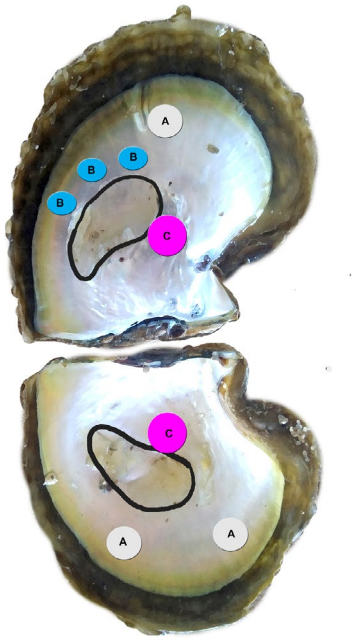

Figure 48: Mabé pearl implant sites. A. The most common site for Mabé pearl production. B. Common site for silver-lip Mabé pearl production. C. Common site used in winged oysters.

Once the oysters are implanted, we allow the implants to attach firmly in about a minute's time. The pearl oysters are then taken back to the farm, placed inside their cages, and then placed back inside the pearl farm. The pearl culturing period will take place between 8 to 18 months, with an average of 12 months, and then it will be time for the Mabé pearl harvest.

Mabé pearl implanted oysters are grown using the same cages as with the grow out period, but at a lesser density, to allow for better growth, thus if the oysters had been grown at a density of 200/m2 they will now be stocked at densities of 150/m2 or even 100/m2.

5. Shell Nucleus implantation Operation

The Pearl Grafting Operation (sometimes referred to as "seeding", "nucleating" or "grafting") used for the production of bead-nucleated pearls is based upon the Mise-Nishikawa patent that started being used in Japan in the early 20th Century. The basis of this operation is the following:

1. Three "ingredients" are required: a pearl oyster, a shell-bead (nucleus) and a piece of mantle tissue (graft).
2. The mantle tissue is obtained from a donor pearl oyster, one donor can supply up to 30 pieces of graft tissue.
3. The perfectly round-shaped shell beads -known as "nuclei"- are mainly made from freshwater pearl mussels from the Mississippi river in the United States of America.
4. The "pearl technician" (surgeon) will insert the bead and the mantle tissue inside a special part of the pearl oyster's gonad (reproductive organ).
5. If the operation was successful, the mantle tissue will become grafted and its cells will reproduce around the shell bead, eventually enveloping it and then covering it with nacre.

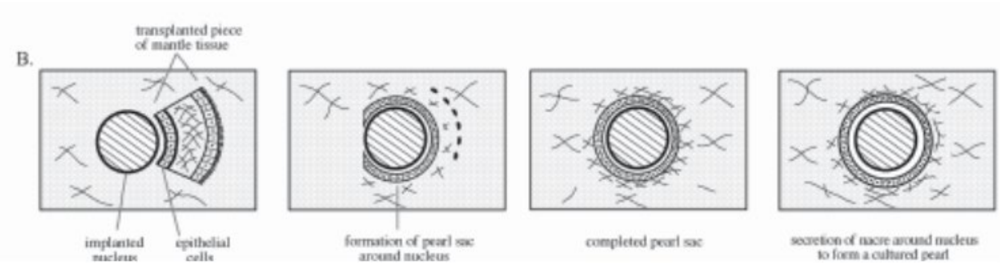

Figure 49: The "Pearl Sac" theory as understood in pearl culturing: the nucleus is in contact within the graft tissue and surrounded by the oyster's gonad; the tissue will graft and grow around the bead, until fully coating it and creating the cultured pearl. Diagram from Wada (1973).

Figure 50: A pearl technician performing the pearl grafting operation on a Rainbow lip pearl oyster in Mexico.

Pearl Grafting is a surgical procedure that should be performed by a qualified seeding technician. A technician can teach anybody how to perform the operation, but to successfully become a skilled technician will require years of training, practice, and dedication. According to a study by Nava et al. (1996) a pearl grafter must train on at least 7,000 pearl oysters just to find out if he is suitable for the job, and to achieve this number of oysters he would have to operate some 100 pearl oysters daily for 70 days. If he is not a successful pearl tech, the pearl farm risks losing 7,000 good pearl oysters for pearl production, but this can be mitigated by also using these same organisms for producing Mabé pearls, so at the very least the farm will still obtain at least a thousand commercial grade Mabé cultured pearls for sale.

The seeding operation is a very stressful process for the pearl oysters, and may very well cause high oyster mortalities, for this reason, pearl oysters must be handled carefully and with great hygiene, before, during and after the operation is performed. Choosing the best time to operate is also crucial, trying always to choose the time of the year with the lowest temperature possible and with no rainfall, as to ensure the lowest bacteria concentrations possible in seawater.

Good technicians are in high demand and work for many pearl farms spread in a region. Technicians will sometimes work for a share of the harvest's value, but on average they will demand a cash payment of $3-$6 USD per grafted oyster, as well as all his living expenses while at the farm. Good technicians can operate on anywhere between 100 to 300 pearl oysters per day, considering a 6 to 8-hour workday, but this will depend on many factors. As a rule of thumb, farmers should avoid hiring technicians that work too fast or too slow: the fast ones may be trying just to obtain more money, but not operating as well as they should, and the slow ones will cost you too much time in expenses. A good seeding number is about 150 to 200 pearl oysters per day.

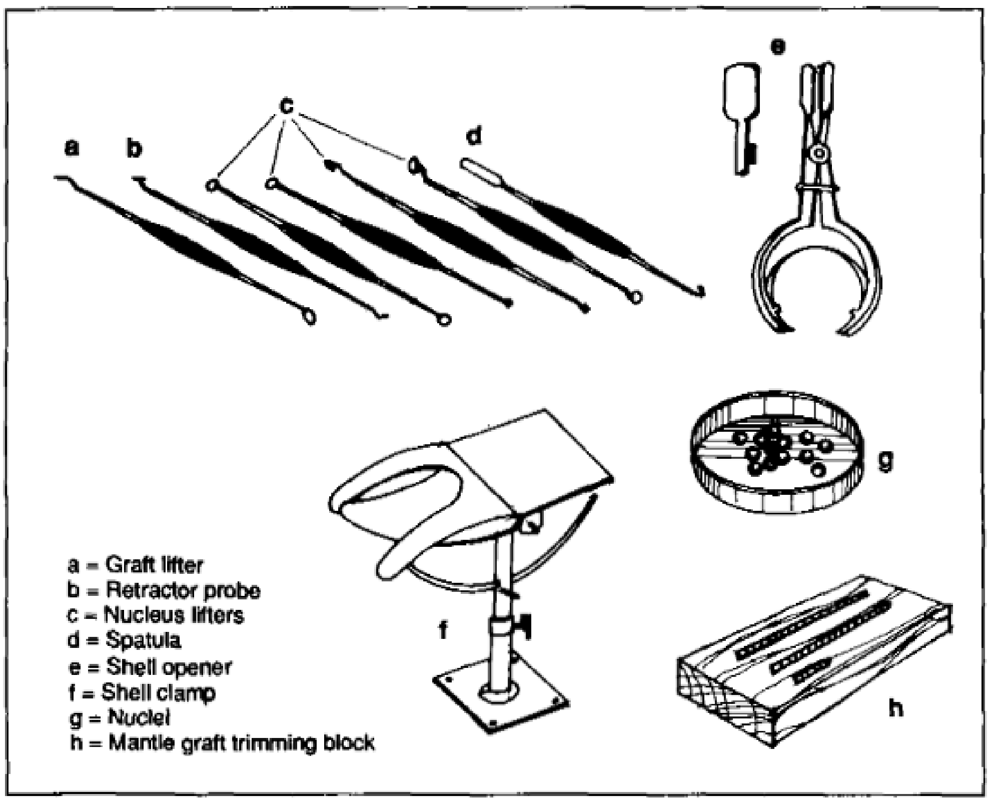

Figure 51: Pearl grafting toolset, according to Gervis & Sims (1992).

This pearl grafting operation -as opposed to the Mabé pearl implant operation- requires the use of specialized surgical tools, including:

- Operating table and chair or stool
- Pearl oyster stand, to support the pearl oyster at eye-level and allow the technician to use both hands
- Scalpel and scissors
- A special, mantle cutting board. Glass makes for the best material.
- A speculum or inverse forceps, to open the pearl oysters (rarely used if oysters are anesthetized)
- Nucleus holders, in assorted sizes to complement the bead sizes that will be used
- Shell nuclei, which come in sizes from 6 to 14 mm
- Retractors

- Tissue inserter
- Tissue cutting knife
- Small plastic spatula

All tools and the working area (table) must be cleaned before and after the operation, as well as disinfected with alcohol. The operating tools must also be washed in between operations. This is done by having a small, wide-mouthed container with clean freshwater, where the instruments are rapidly but vigorously washed, and this water must be renewed for every 15-30 pearl oysters operated to always have a clean environment.

Light Source: It is important to have good lighting conditions, but the source of light should not be geared towards the eyes of the technician at work, neither from the front or sides. Light must come from behind, thus if setting up a lab, it is important to know where the windows will be situated or how to place the operating tables.

Start of the Grafting Operation: Preparing Saibo

The first step required is to locate a good number of possible graft-donor oysters. These animals are usually first recognized from their exterior characteristics: good size, good growth processes and good weight, with the external shell looking healthy (not attacked by drilling organisms). These animals are then extracted and kept separate from the others, to be sacrificed: a sharp, slender knife is carefully inserted between the shells to cut them in half, avoiding damaging the mantle. Then the shells are inspected for their color, luster, and beauty. If these criteria are met, the mantle is excised from the shells and prepared, but if these criteria are not met, the entire animal is discarded.

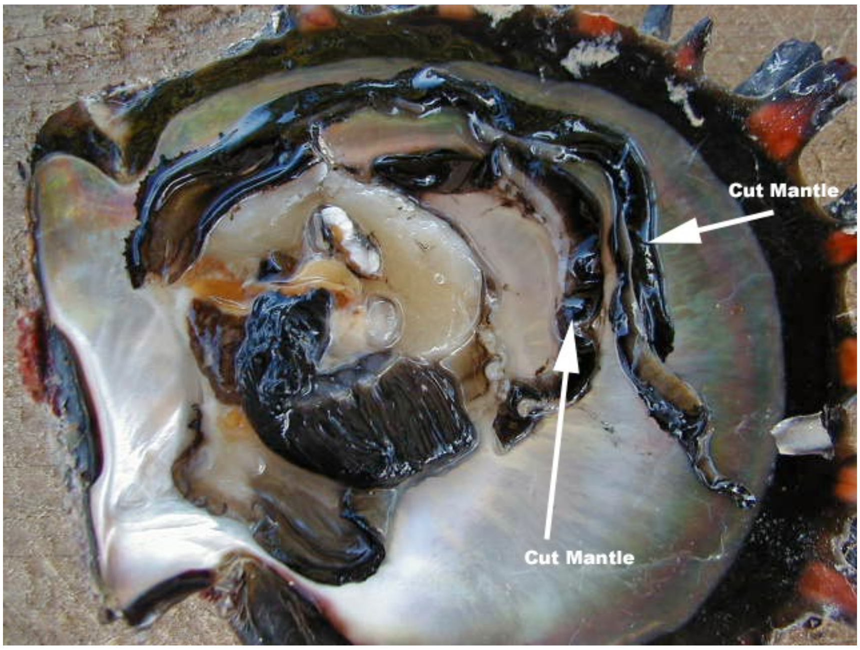

Figure 52: A sacrificed Black-lip donor oyster. The appropriate mantle portions have been cut to be used for Saibo.

In Mexico, a better method was found, with the help of the narcotization process: the best pearl oysters can be examined directly, with the help of a small spatula and some light. If the oysters meet the selection criteria, they will be separated until needed. When the donor oyster is required, the technician will only cut away one mantle lobe -with the help of scissors- which will allow this oyster to recover the missing portion in time (Southgate and Lucas, 2008).

Once the mantle is removed from the donor oyster, it is carefully washed in saltwater or using paper towel or a piece of sponge; we want to remove as much of the mucus and “ink” that might be present on the mantle, to avoid bacterial formation. Now, these mantle strips must be cut, first by removing the “frilled edge” (this is the area of the mantle that contains the chemoreceptors, tentacles and “eyes” of the oyster, and that do not produce nacre), and finally they are cut onto small squares or rectangles, measuring anywhere between 2x2 mm (for small nuclei) or up to 6x6 mm (for large nuclei), the rule of thumb is to have a size that is about 1/4 of the size of the nucleus inserted. The Japanese refer to these mantle pieces as Saibo.

Figure 53: Saibo prepared for pearl grafting operation. The unusable portion of the mantle (frilled edge) is removed.

Inserting the Nucleus and Saibo

The next step, once the saibo is ready to be used (it may remain viable for up to 2 hours, if continuously wet with fresh and clean saltwater) we need to have the pearl oyster ready for the operation: open and pegged, so it will not close during the surgery. The oyster is placed on a pearl stand, which will secure it into place during the operation.

At this stage we also have our nuclei prepared. This means that all the different beads are separated by size, and they are all perfectly clean and devoid of dust, water, and grime. It is always a good idea to add nuclei to a small, shallow container in groups of 50 or less, this minimizes their exposure to the environment.

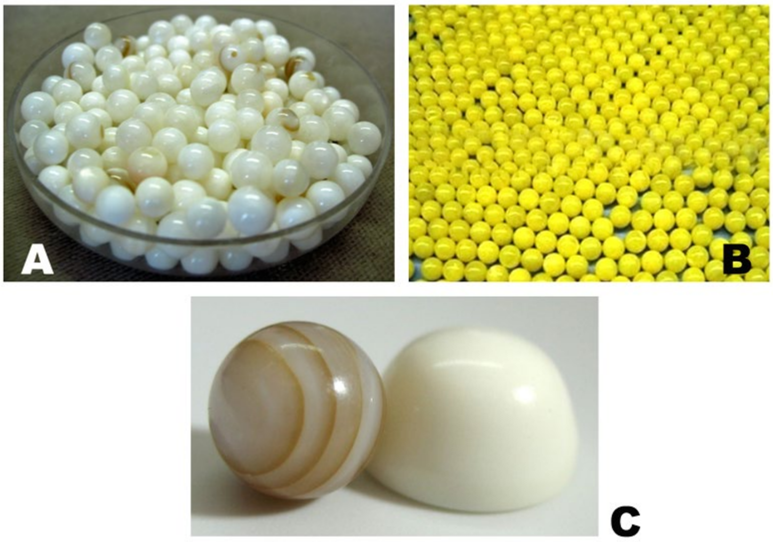

Figure 54: Different nuclei used for pearl culturing. A. Traditional shell nuclei, on a shallow container. B. Non-traditional shell nuclei: these are bio-coated nuclei, basically covered in a wide-spectrum antibiotic coating that allows for better pearl production. C. A large (10 mm) "stained" shell nucleus next to a 14 mm Mabé pearl implant.

Before the nucleus and the saibo can be inserted, the pearl oyster must undergo a cut into its body -just a bit smaller than the size of the nucleus that will be inserted- at around the base of the oyster's foot, since that part of the oyster's skin is stronger and more flexible. This cut is done with a sharp scalpel.

The next step is the "tunnel", this one is done with the help of a tool known as the "tunneler" and is a spear-head shaped tool that is carefully guided to one of the many "pearl sac sites". There are several sites used for pearl production within the oyster's gonad. But here are three that are the most popular and that can be seen in figure 55. The most popular site is at the front of the gonad, near the intestinal loop, but two other sites are found behind the byssal gland and attachment, very close to the gonopore.

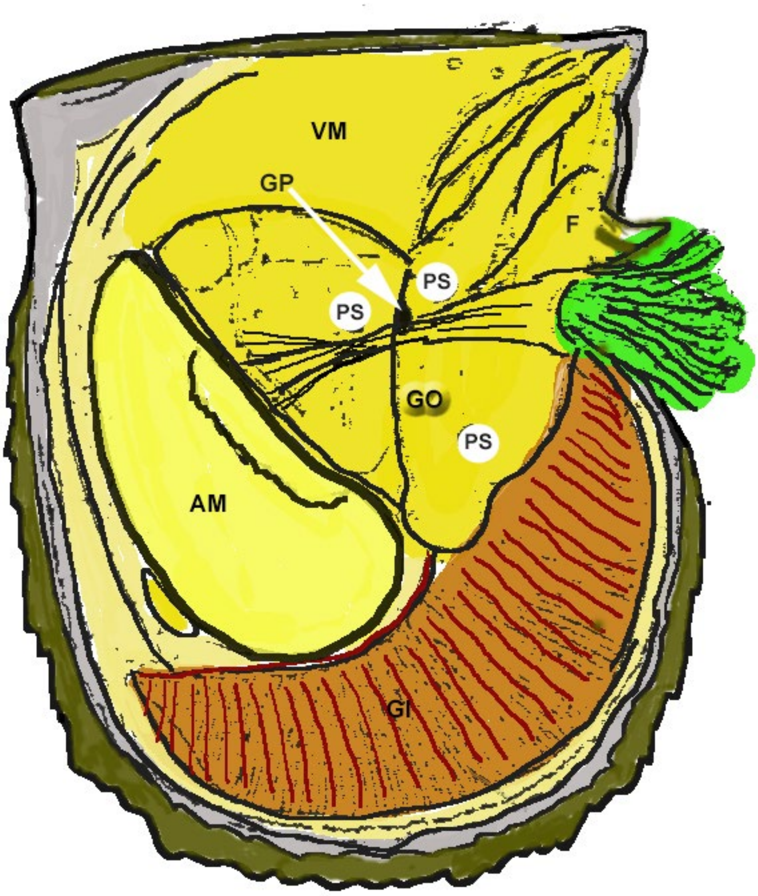

Figure 55: A diagram of a pearl oyster and its common pearl-sac sites. AM= Abductor Muscle. GI= Gills. VM= Visceral Mass. GO= Gonad. F= Foot. GP=Gonopore. PS= Pearl producing sites. Diagram modified from Tamura (1966).

Once the tunnel is made, the technician can now proceed to insert the nucleus or saibo. There is no correct or incorrect way to insert any of these two: either can go in first that the other, depending on the technician's preference.

Nuclei are picked up with a special tool called "nucleus holder/pusher", which has a tiny cup-like ending and must be dipped in water to hold the nucleus thanks to water adhesion. The nucleus is pushed at the entry point at the base of the foot and then slowly and carefully pushed towards the pearl producing site. Once this is done, the saibo or graft tissue is picked up with a needle-like tool called "tissue picker" and the same operation is repeated, with the saibo being deposited on top of the bead. The entire operation may take from 30 to 60 seconds, depending on the technician.

At this moment, the oyster must be taken back as fast as possible to the pearl farm. They are sometimes placed inside a square-shaped "catch bag" made of plastic mesh and then placed back inside a protective cage in the farm.

A specialized training program can be prepared for this very purpose and to train the future pearl seeding specialists of Pakistan.

8.3. Post-Operative Care

The first 20-40 days after the operation has been performed are critical: this is when the highest mortality rates or nucleus rejections occur. During this period, the saibo will be forming what is known as the "pearl sac", which is the organ in charge of producing the cultured pearl.

We must check the operated pearl oysters carefully, if possible, inside the ocean to avoid further disturbing them. What we want to make sure is that we remove all the dead oysters because this will keep the oyster's environment in better conditions (less bacterial growth) while recovering. Nucleus rejection is analyzed with the help of catch bags or x-ray analysis, the latter being much more complicated and expensive. Oysters that have expelled their nucleus are separated from those that kept their bead. Pearl oysters are allowed to recover for at least 30 days after the operation is performed. Catch-bags are removed, and oysters are placed in the final pearl cage that has been selected by the pearl farmer.

Figure 56: Keshi pearls have no nucleus inside (non-bead nucleated) cultured pearls.

The separated pearl oysters (those that have rejected their nucleus) can be:

1. Kept producing keshi pearls
2. Allowed 2-3 months to fully recover and then operated to produce Mabé pearls
3. Harvested for their meat and shell

"Keshi pearls" (the word Keshi is Japanese and means "poppy seed") are formed when the nucleus is rejected, but the saibo tissue remains inside the gonad and begins forming a small, baroque shaped pearl. Keshi pearls are very attractive and have good demand and may help supplement some of your farm's revenue.

8.4. Pearl Farming Period

After the post-operative stage, we will finally commence the pearl farming period, which is the last stage of the pearl culturing process: this is when we are finally producing the cultured pearls, and because of that we must be very careful in keeping the pearl oysters under the best conditions possible:

- Avoid overcrowding
- Use careful manipulation
- Avoid exposure to sudden temperature changes
- Avoid the sun and heat
- Carefully clean the oysters once every 1-2 months
- Tag each cage with an identification code, to easily recognize each group of oysters.

Figure 57: Pocket Nets or Panels are commonly used for the pearl production stage.

Pearl oysters are usually kept in pocket nets, but may be kept in chaplets, lantern nets or any other type of cage. Pocket nets allow for easy handling, perfect water flow for the best feeding and oxygen intake of the oysters, to count them easily and for easy and fast cleaning. Once this process begins, the pearl farmer will have to wait at least 18 months to harvest his pearls and achieve a minimum pearl coating of 0.8 mm, but hoping for at least 1.0 mm for better thickness, which means the pearls are more durable and valuable.

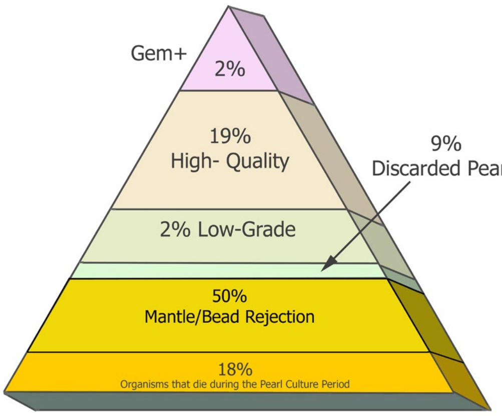

Figure 58: The pearl production pyramid for Mexico's "Cortez Pearl". This diagram describes the percentage of pearls that will be produced at the moment of harvest, as well as the oysters that die during the 18-month culture period. Data provided by Enrique Arizmendi of "Perlas del Mar de Cortez" in 2021.

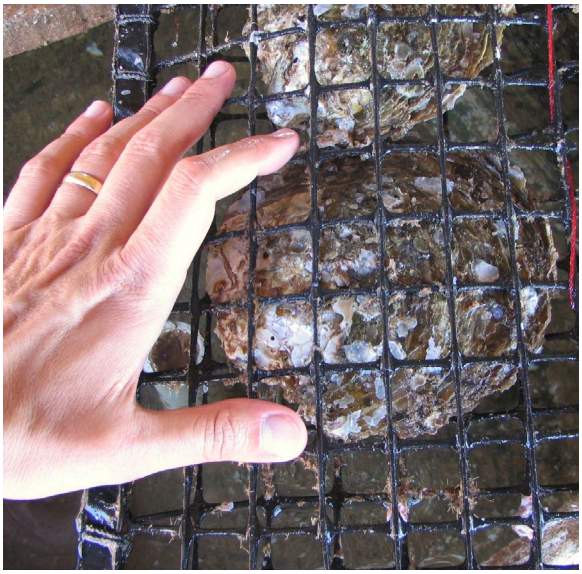

Figure 59: A black-lip pearl oyster inside its pocket-net and ready for harvest.

If the pearl oysters are cared and their stress levels are reduced to a minimum, the environment is clean and parameters adequate (temperature, salinity, currents, chlorophyll, etc.) the farmer will have a good opportunity of producing enough pearls and a good proportion of the higher-grade pearls.

In the case of "Akoya pearls", the best grade pearls (Gem) usually constitute 5% of a pearl harvest, with about 25% of commercial grade pearls and 15% of low-grade pearls. During the pearl culturing period, many pearl oysters will die naturally (20-50%), with 5% of the pearls having a low quality that they must be destroyed. This data is usually represented in a pyramid, and each pearl variety will have its differences.

8.5. The Pearl Harvest

After the pearl culturing period (at least 12 months for Mabé pearls and 18 months for cultured pearls) is over, we are ready to begin with the pearl harvest. This process involves bringing the oysters back to the land-based facilities and extracting them from their cages, into separate groups (using the tags) so the pearl farmer can analyze the information from each group. The pearl oysters are hand-cleaned and then placed inside plastic trays with no water and in a shaded area. They can be left under these conditions for about 30 minutes, and they will begin to open, making the harvest easier.

Pearl oysters are taken to a table, so the farmers do not have to bend over and hurt their backs during harvest. A pearl harvest may last 6 or more hours of the day. Using a short knife to cut the abductor muscle and separate the shells is the usual method of sacrificing the mollusks, but a hard-plastic spatula may be used when harvesting oysters bearing Mabé pearls, since the hard metal may scratch and damage these pearls.

Harvesting Mabé-pearls

The pearl harvesting effort is divided into teams, depending on the amount of people involved in this step. If we have only two people one of them will become the "matador" or "sacrificer", in charge of cutting the pearl oysters in half and the second person will oversee the separation of the shells and the removal of the soft tissues. The shells are separated into plastic trays, one for each of these:

- Shells with good Mabé pearls
- Shells without Mabé pearls

- Shells that may or may not have a Mabé pearl, but that display a large problem that makes the pearl unsaleable

Figure 60: Steps for pearl harvesting. A. farmers place clean pearl oysters in trays and register their data. B. Oysters in trays are kept waiting for 30-minutes so they may open. C. The pearl harvest team gets ready to sacrifice the oysters. D. The "Matador" uses a plastic spatula to sacrifice the oysters. E. A sacrificed pearl oyster, shells separated. F. A plastic tray with shells with no Mabé pearls. G. A tray with the pearl oyster's soft tissues. H. A tray with harvested Mabé pearls on their shell.

The soft tissues are also thrown into a large plastic tray and after 15-30 minutes it must be taken to another person who will be separating the tissues into two or three different portions:

- The large, valuable Abductor muscle or "Pearl Meat"
- The smaller foot and retractor muscle, which resembles "snail meat", and
- The rest of the soft tissues (visceral mass, gills, and mantle)

While separating the meat, the people performing this task may also try to locate keshi and natural pearls. These smaller pearls are a valuable product for the farm.

The edible portions of the meat are washed to remove mucus, and then packed in plastic bags in portions of 500 or 1000 grams, and then placed inside ice-chests to avoid the meat from spoiling and for having it sold to the local fish-market or to prepare for local consumption. In Mexico, the price of the larger abductor muscle is between $7 to $10 USD/Kg and the smaller "snail-like" meat is sold for $1 to $3 USD/Kg. The rest of the meat can be used for fish, octopus, or crab bait, to feed domestic animals or even to compost as plant fertilizer.

The Mabé pearl shells must still be processed, but this is usually done after the pearl harvest takes place. The shells must be washed thoroughly with marine water and then left to dry in a shaded area. Once the farmers have finished harvesting and the shells have dried, these are taken to undergo the first step of the Mabé pearl processing.

Processing to Produce Mabé Pearls

Mabé -or half-pearls- can be sold either "on-the-shell" (un-processed) or fully processed. The farmer will obtain the best prices if he proceeds to fully process and add value to his product by making jewelry. The strategy followed by the pearl farmer will depend on his capacity to work the Mabé or if he has a local pearl market available.

Figure 61: A winged oyster shell (Pt. penguin) with a large Mabé blister pearl in it. This is an unprocessed Mabé pearl and will attain the lowest possible value. Photo courtesy of the Pearl-Guide.com forum.

The processing of Mabé pearls requires skill, training, and the appropriate tools. The steps involve (also, see figure 62):

a. cutting around the Mabé blister pearl, removing it from the shell (1 & 2)

b. washing the blisters in water for a couple of hours or overnight (3)

c. separating the pearl's dome from the implant and flat shell (4 & 5)

d. Drawing the Mabé's shape with a felt-tip pen (6)

e. filling the pearl's dome with a colorless, epoxy resin (7)

f. sanding the base and adding a flat piece of shell as a backing (8)

g. cut or sand the pearl into the selected shape and then polish it (9).

Mabé pearls can be extracted from the shell by means of tile-cutting saws, a small Dremel-type tool or even with a hand-held jigsaw or hacksaw. The best results are obtained with the larger tile cutting tools, and these also add water to the process to avoid the production of "pearl dust" which is quite harmful to the lungs. People working on pearl shell should always wear goggles to protect their eyes and a face mask to avoid breathing shell particles.

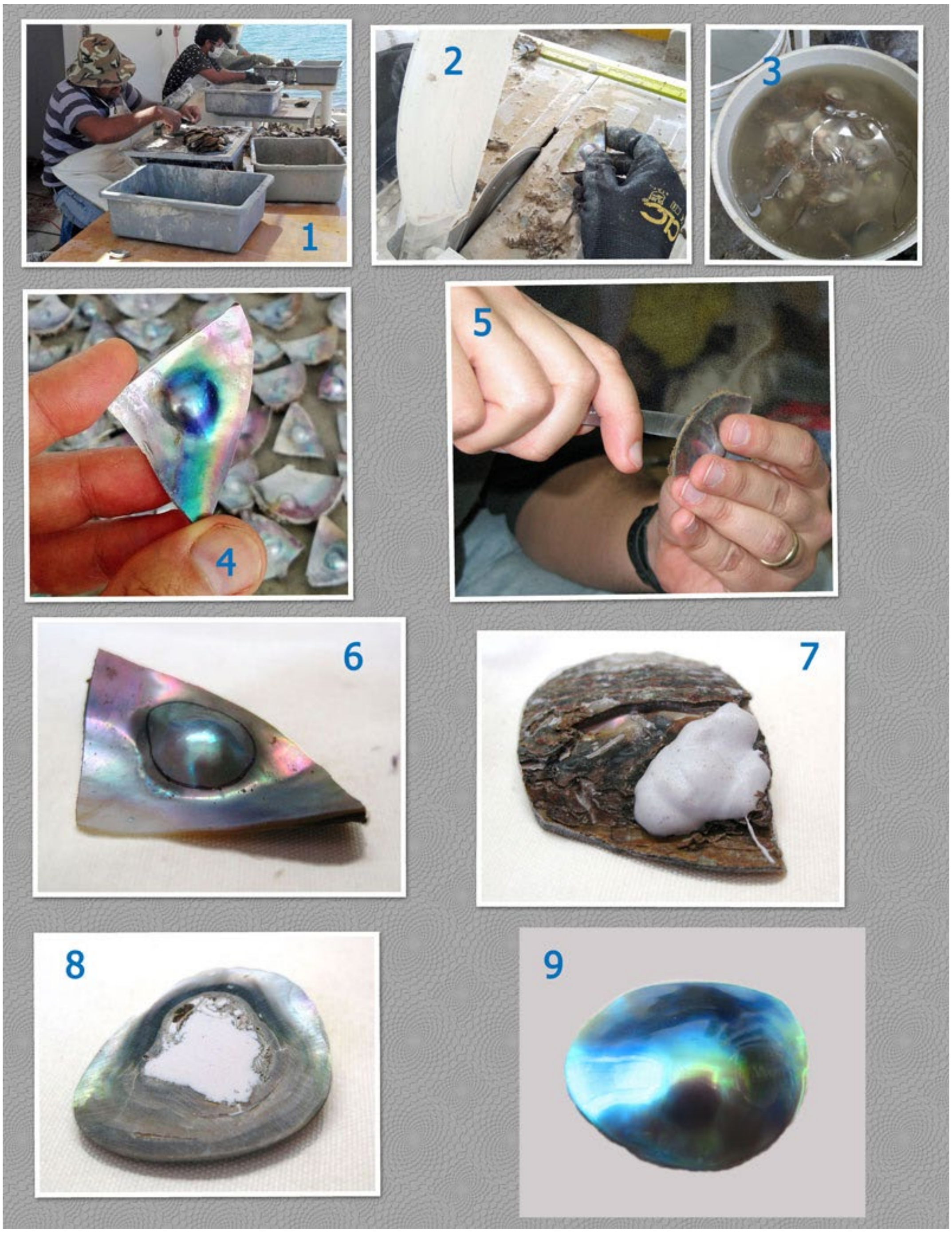

Figure 62: Steps involved in Mabé pearl processing. Details explained in the text.

The usual Mabé pearl harvest will allow the farmer to attain close to 100% yields, but upon closer inspection the number of saleable pearls is usually close to 50 or 60% which is not bad, especially considering that every pearl oyster is implanted with three nuclei, so at least we have 1.5 Mabé pearls per pearl oyster, thus if we wanted 5,000 Mabé pearls we would best implant some 3,500 pearl oysters.

Cultured Pearl Harvest

Harvest pearls when the nacre layer is at least 1 mm (0.5 mm on each side) thick, but for better quality -and value- we should strive for 1.6 mm (0.8 per side) of nacre. The amount of nacre has a direct influence on the overall quality of the pearl, including its durability and beauty.

The best quality pearls have a nacre layer at least 2-3 mm thick, which takes a minimum of 18 to 24 months in most areas, and this is usually referred to as "South Sea Quality". Avoid producing pearls with thin nacre by harvesting early. If farmers are not sure if the pearls have a thick enough layer of nacre to be harvested, harvest a few and drill them, then examine the drill hole for thickness, although this may be difficult if the farmer has little experience, so another option is to select the lowest quality pearls from the pre-harvest and cut them in half or sand-them away using coarse sandpaper. The pearls will look like the ones in figure 63 and will allow the farmer to correctly measure nacre thickness.

Figure 63: Two cultured pearls cut in half (actually, sanded away) to reveal the shell nucleus. The Cortez pearl on the left side has a thick nacre coating (2 mm or South Sea Quality) and the "Akoya pearl" on the right has a very thin coating (0.1 mm).

Figure 64: Freshly harvested pearls have a thin protein film on them, which makes them look dull and less appealing, so they must be thoroughly cleaned before grading.

Post-Harvest

Pearls have a thin mucus covering when harvested, and it will make the pearls look dull and unappealing, so pearl farmers will immediately place the pearls in plastic trays or containers with clean freshwater. After harvesting, they are thoroughly washed and finally left to dry in a secure (you do not want the pearls becoming misplaced) and shaded area. If the pearls still look dull, they will have to be further cleaned.

There are two ways to clean pearls, and this depends on the harvest size. If the farmer has a large harvest (over 10 thousand pearls) he/she may use "salt tumblers", if the number of pearls is low, he/she may use mineral oil baths. Since a new farm will usually start with small harvests, the "mineral oil bath" will be referenced here:

1. In an adequately sized glass or plastic container (1 liter is a good size, but maybe smaller), the farmer will deposit his pearls and then will add mineral oil until all pearls are fully covered.
2. The pearls are kept in the oil for anywhere between 4 to 8 hours.
3. The pearls are drained with the help of a plastic mesh (which does not absorb oil) or strainer
4. The mineral oil is recollected and can be reused.
5. The pearls are deposited on a shallow tray, on top of a cotton towel and as much as the oil is removed from them.
6. This process can be done daily, there is no need to wait for the entire pearl harvest to be done.

Figure 65: A daily harvest of pearls, after cleaning in a mineral oil bath.

A crucial aspect of the Pearl Culture process is the part of keeping detailed records or logs of the pearl grafting and harvesting of the oysters. Pearl farmers should keep detailed annotations of the whole process:

- the number of pearl oysters that were seeded,
- the number of pearl oysters that rejected their beads,
- mortality of oysters,
- number of harvested pearls, and their type (Mabé, cultured or keshi, even naturals if any),
- performance of each technician,
- Water temperatures during seeding and harvest.

Figure 66: An entire farm's pearl harvest, packed in plastic bags.

Grading Pearls

Once all pearls have been harvested, they must be graded, with the defective pearls being discarded or kept aside. If the pearl farmer does not have enough experience to grade his pearls, he should wait for someone to visit his farm and collect the pearls, or for him to head out to a place where the pearls will be assessed for quality. They should be kept in Ziploc-style bags, and all pearls should be counted at least three times, to ensure we have a correct number.

The person that does the grading will belong to a specialized Gem laboratory, trade company, University or government institution that will oversee this service to the fledgling farmers. The best strategy would be for all pearl farmers to - eventually - learn this process, at least partially, but in the meantime, we require an authoritative figure that will be able to standardize the grading as much as possible and disallow the sale of low-grade pearls.

A specialized training program can be prepared for this very purpose and to train the future pearl grading specialists and sales personnel of Pakistan.

9. FARM MANAGEMENT CHECKLIST

Tending to the farm is the crucial ingredient to produce healthy pearl oysters and fine quality pearls. Growing pearl oysters is like growing vegetable crops: the farm is at the mercy of the environment and must be tended daily.

The following are some of the most important farm activities:

- Weekly Maintenance: be sure to inspect the farm's lines, floats, buoys, and anchoring system for any maintenance needs.
- Constantly monitor for missing lines and floats.
- Weekly snorkeling dives to check if any of the pearl cages or oysters have fallen to the bottom or have been stolen.
- Keep a record of pearl oyster mortality and the possible reason behind this (predators, cage fell, temperature, etc.).
- Perform constant checkups to ensure your pearl oysters and cages are clean.
- Avoid polluting your farm: never discard the oyster's dead flesh or the biofouling in your farm's site. If possible, take these out to the sea into an active outward flowing current or dig a hole and place the contents there; they are excellent for composting.
- Train all staff to properly take care and handle the pearl oysters; anybody pulling on the oysters, having them fall or exposed to sunlight and heat is unwarranted
- Protect the farm from theft: buoys and floats are expensive and a valuable target for fishermen; pearl oysters may not be a target at the beginning, but as pearl farming becomes an important local resource, some people will attempt to steal them to obtain pearls.
- Be careful when transporting your live pearl oysters from one place to another: never transport them inside water, but always keep them humid and as fresh as possible.
- Always work with your pearl oysters as near as possible to seawater.
- Monitor the farm's waters and your pearl cages for predators: if a school of predator fish arrives at the farm, they can destroy the oysters in chaplets, and octopi, crabs or carnivorous snail larvae may swim inside your cages, grow rapidly, and destroy many of the oysters.
- Conduct pre-harvests before the actual harvest takes place; this allows to evaluate the quality of the next pearl harvest, allowing the farmer to make the decision to harvest earlier or later than he/she had originally planned.

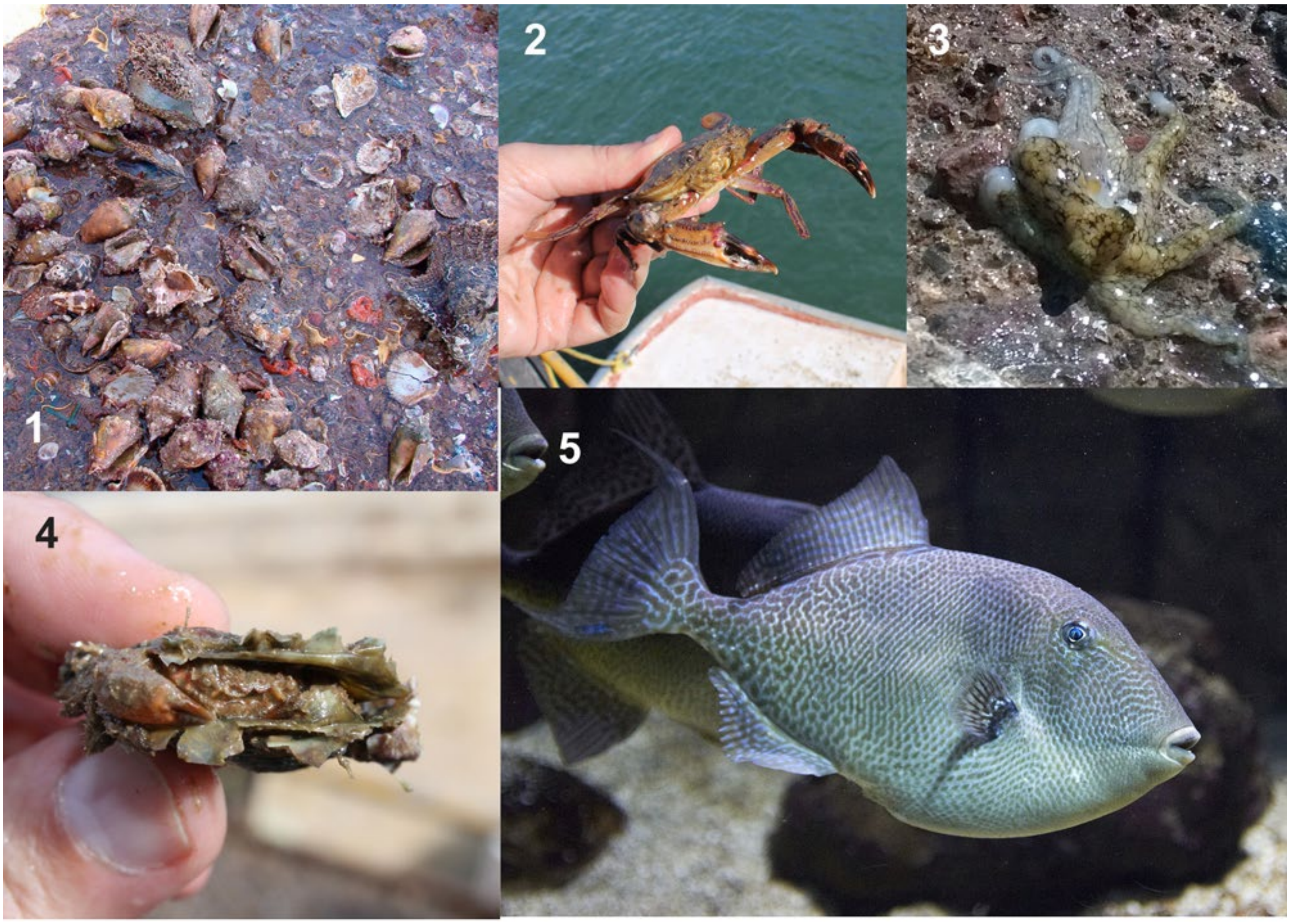

Figure 67: Typical predators that are found inside the pearl cages in a pearl farm. 1. Carnivorous snails can reach the pearl cages when they are planktonic larvae and will grow and eat your oysters; 2. Swimming crabs are capable of destroying your spat, juveniles and even adult oysters; 3. Octopus are devastating predators that can swim into your cages and escape before you can catch them; 4. Predator crabs can devour your spat and even hide inside the shell of their prey; 5. Predatorial fishes (such as this Trigger fish) can devastate your pearl oysters, especially when placed in chaplets (this last photo is by Max_Ryazanov, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=22289394)

10. FRESHWATER PEARL FARMING

This Manual focuses on the most viable pearl farming option for any country, which is Saltwater Pearl production. A list of the pros of Marine Pearl Farming is indicated here:

- Marine pearls (MC) are worth anywhere between twice as much or even up to 5 times as much as freshwater pearls (FWP). Saltwater operations are thus, more profitable.
- Freshwater farms are under harsher environmental conditions than marine farms, since the ocean is immense and capable of sustaining better environmental conditions such as:
  - i. Dissolved Oxygen levels
  - ii. Stable pH
  - iii. Pollutants are more easily diluted
  - iv. Stable Water Temperatures
- There is far less competition over the sea than over freshwater resources, due to agriculture, animal husbandry, industrial and human population requirements.

On the other hand, the cons of Fresh Water Pearl farming, are:

- Pearly Mussels are much more difficult to breed in hatcheries due to their unique breeding biology, which requires a Glochidium stage as a pseudo-parasite in the gills of certain species of fish (Figure 69).
- If these fishes are over-exploited or unavailable, it will be very difficult to breed them and pearl farm stocking will depend on harvesting wild-caught mussels, which is not sustainable.
- China has proprietary techniques for pearly mussel, so these can be had for a price. It will probably require the introduction of a Chinese fish species (exotic species).
- Pollution on ponds, lakes and rivers is increasing worldwide. Due to this fact, China is closing many of its freshwater pearl farms and enticing the establishment of new farms in the Ocean.

10.1 Introduction and history of freshwater pearls

Freshwater pearls have been obtained from all over the world since ancient times, but the Asian continent has been plentiful in the availability of pearly mussel species or Unionids. In China, the variety of the pearly mussels is abundant, with pearl fisheries having carried on for thousands of years, especially in the rivers of Manchuria. Pearls and their nacreous shells were used as valuable tributes and tax payment and preferred over gold and jade due to their beauty (Kunz and Stevenson 1908; Akamatsu 2015).

Pearl farming commenced in early times, some say as early as the11th Century, where it is believed that Chinese monks placed small lead images of the Buddha inside the shells of mussels that they would grow in ponds. Later, these animals were harvested and the "pearly miracles" would be there for all to see; even used in the adornment of temple walls (Kunz and Stevenson 1908; Strack 2008; Akamatsu 2015).

Figure 68. An ancient Chinese pearl mussel shell bearing several "pearl Buddha" figurines. These were probably the first variety of "cultured blister pearls" in the world. Photo from Saucedo et al. 2020.

Countries such as China, Japan, Scotland, Germany, Russia and the United States of America have been celebrated by their beautiful natural pearl productions, but in all cases the fisheries were faced by overfishing and or municipal or industrial pollution and collapsed (Kunz and Stevenson 1908; Strack 2008).

Today, China is the largest producer of freshwater cultured pearls worldwide, accounting for 98% of global production. Although current statistics are not accurate due to the large extension of the territory and the increasing number of unregistered pearl farms, over 1500 tons of pearls are produced in China every year, coming mostly from non-beaded pearls. Nevertheless, as in Japan, China faces severe problems that include the heavy contamination of water bodies, depletion of natural stocks due to overfishing and recent declaration of the *Cristaria plicata* mussel as endangered species at some prefectures in China (Saucedo *et al.* 2020).

10.2. Pearl mussel biology and ecology

Freshwater mussels (Unionidae) are large, long-lived bivalve mollusks that live in the sediments of rivers, streams, and to a lesser extent lakes and ponds. They are variously pigmented, with some being uniform dark brown or black to bright yellow. Many species have distinctly colored rays and chevrons and bumps or ridges, or both. According to Shirahi (1994) there are around 700 different pearly mussel species in the world.

Figure 69: Shells of some varieties of freshwater pearl mussels (family Unionidae).

Unionids are found anchored unto the substrate, mostly with only their siphons exposed. As all other filter feeders, they create inhalant current to draw in water from which they capture fine organic matter such as microscopic algae and detritus. Many species are slow growing and long-lived animals, living for as long as 100 years. Most species are sessile, moving only short distances their entire life. They move by means of their muscular fleshy foot, which is extended out from their shell to move short distances or burrow into the sediment. Movement often is triggered by changing water levels or changes in environmental conditions (Tucker and Theiling 1999).

Most mussel species require flowing water and coarse gravelly substrates, whereas others survive well in silty lake-like conditions in backwaters. Water and sediment quality are important habitat criteria. During periods of stress (e.g., temperature extremes, drought, pollutants), many species will burrow deep into the sediment and "clam up," sometimes surviving until the stressor has passed. Mussels serve as good indicators of ecosystem health because they are relatively long-lived and sessile and depend on good water quality and physical habitat. Municipal pollution (sewage) has been blamed for mussel die-offs in the United States of America (Tucker and Theiling 1999).

Reproduction

One of the most unusual biological traits of the Unionids is their unique breeding and life cycle, sometimes considered semi-parasitic. This creates technological problems that must be resolved to establish any sustainable pearl farming operations. An entire quote by Helfrich et al. (1997) on this unique reproductive strategy will be placed here:

> *"The freshwater mussel has a unique life cycle, to include a short parasitic stage attached to a fish. The life of a mussel can be partitioned into five distinct life stages: (1) a larva (called glochidium) developing in the gill of a female mussel, (2) a free drifting glochidium expelled from the female mussel, (3) a parasitic glochidium attached to the gills or fins of a living host fish, (4) a free-living juvenile mussel, and (5) the adult mussel. Reproduction occurs when the male mussel releases sperm into the water column, which is siphoned into the female mussel to fertilize the eggs. Reproduction may be triggered by increasing water temperatures and day length. Development and retention of larvae (smaller than a pinhead) within the female may last 1 to 10 months. Glochidia generally are released from the female in the spring and early summer (April to July). These tiny creatures drift in the water seeking a suitable fish host. Timing is critical for these larvae, for they cannot survive long outside of the female mussel or without a host fish. Unlike oysters and clams, [most] freshwater mussels require a fish host in order to complete their life cycle. As parasites, glochidia are dependent on fish for their nutrition at this part of their life. Some mussels may depend only on a single fish species, whereas others can parasitize many different fishes. The attachment of glochidia causes no problems for the host fish. If they find a host fish, they clamp onto the gills or fins and remain attached for one to four weeks while transforming into a juvenile mussel. As juveniles, they drop off the fish and begin their free-living life. If glochidia do not find a suitable host fish within a few days of drifting in the water column, they die. To help ensure that they find a host fish, some species of mussels have developed special adaptations. Some adult female mussels have enlarged mantle tissue called mantle flaps that look like prey (worms, insect larva, or small fish) and which attract a fish looking for food. When fish nip at these structures, resembling potential food items, the female releases glochidia into the water column which clams onto the gills or fins of the fish host."*

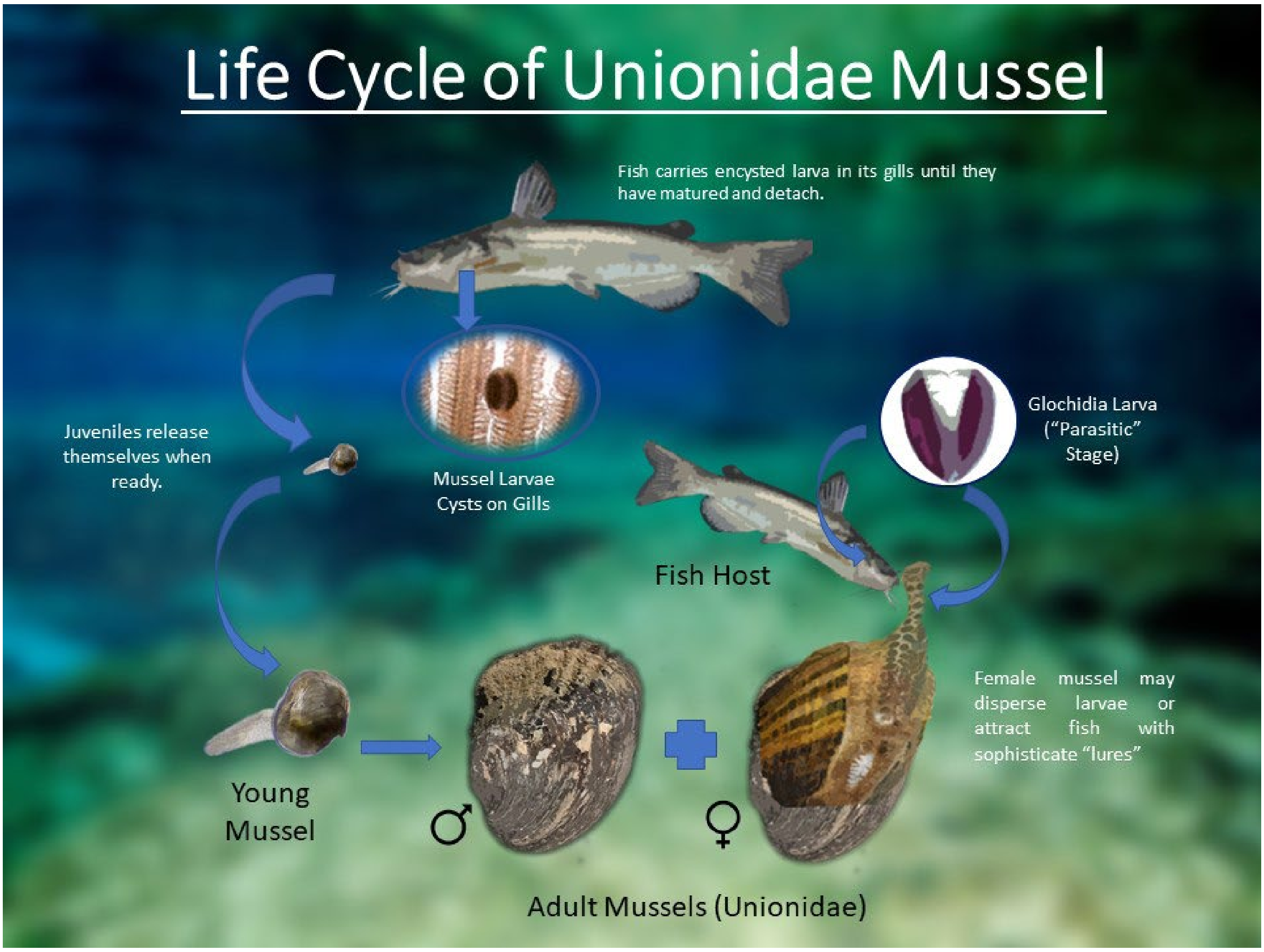

Figure 70: The unique lifecycle of Pearly Mussels (family Unionidae) involves a "parasitic" larval stage referred to as "glochidia", where the larva are either discharged outside of the body of the female or the organism utilizes a "fish lure" to attract fish that will ingest the "larval sac" and thus become "infected" and will both protect and carry the mussels off to greater distances. Without their fish hosts, the larvae will die.

10.3. Overview of freshwater pearl farming

There are at least 4 species of pearly mussels that have been used for commercial cultured pearl production. These are:

Figure 71. Shell of the Cockscomb Mussel, Cristaria plicata, that was the most important producer of freshwater pearls in the 20th Century.

1. Cocks Comb or Karasu-gai – *Cristaria plicata*

Initially used in Japan and later in China to produce small, baroque-shaped, all-nacre (non-beaded) cultured pearls that were initially referred to as "rice krispies" and these pearls flooded the world markets in the 1970s and 1980s. This species has become endangered and is rarely used today for pearl production.

Figure 72. An Ikecho-gai mussel from a farm in Lake Kasumigaura, Japan.

2. Biwa Pearl Mussel or Ikecho-gai – *Hyriopsis schlegeli*

The Ikecho-gai mussel of Japan was grown successfully in Lake Biwa by Dr. Fujita in 1914, were tissue-seeded and all-nacre pearls (without a bead), that displayed uniquely different shapes, colors and high luster were distinctively different from those seen in marine pearls. Their unique free shapes (baroques) allowed for a unique use of these pearls, but production dwindled and finally collapsed due to industrial and agricultural pollution of the lake. Production of this species restarted in Lake Kasumigaura, where a couple of pearl farmers have a small production of bead-nucleated pearls known as "Kasumi Pearls". It may measure up to 20 cm in length.

3. Triangle Sail Mussel or San Jiao Bang Mussel - *Hyriopsis cummingii*

A close relative of the Biwa mussel, but that has been considered less desirable due to the inferior beauty of its pearls. It is a large mussel (16 cm in length) that has been the main producer of freshwater cultured pearls in China since the 1990s.

The last mussel in this list is not actually a species, but a hybrid between the Biwa and the Triangle Sail mussels, which is actively being used in China to produce the latest and most beautiful of the freshwater pearls that have been produced and created since the last decade: Fireballs, Edisons, Soufflés and Coins, to name a few.

Figure 73. Triangle shell mussel from Vietnam. Hyriopsis cummingii.

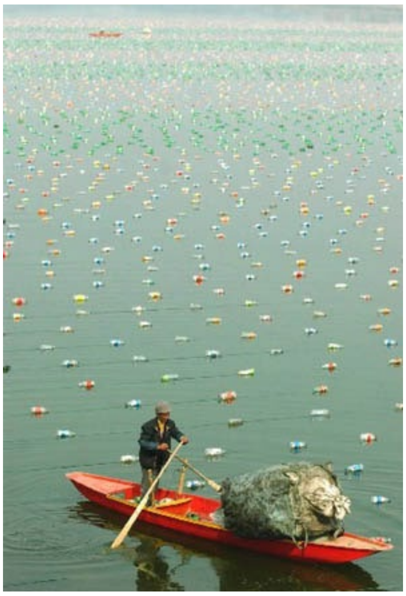

Figure 74: A Chinese freshwater pearl farm that uses plastic bottles as floats. Photo by Xinhua News Agency August 13, 2007.

Aquaculture development

A key factor that has influenced aquaculture development in China is to be found in the national policy on land and water development, where priority has been given to water conservation measures. This has led to the nationwide construction of water control structures for flood prevention and stabilization of river flows. Lake levels have been likewise controlled by the construction of hydraulic structures and sluices at the main river connections, and new water bodies have been developed such as dams and reservoirs. These efforts have given China tangible benefits in agriculture production, including aquaculture. All water surfaces are utilized for aquaculture production. The use of these areas is manifested in their slogan "Wherever there is water, there must be fish" (FAO 1976).

Pearl farming in China usually happens in a polyculture environment, in areas with rice fields, waterfowl production (ducks and geese), fish culture (carps) and pearl mussels. In this manner, pearl production is much more profitable than as a standalone operation. Most pearl farming operations are actually "mussel farming" ventures that sell their adult pearly mussels to actual pearl producers, which will then employ them for actual pearl production.

Freshwater pearl production can be a very simple and rural activity, suitable for many people, with the pearl seeding operation -as was the case with saltwater pearls- being a delicate operation that requires skilled technicians. As a matter of fact, there is not one single technique, but a multitude of techniques, which would make this even more difficult.

Figure 75: A freshwater pearl farm in Japan. Lake Kasumigaura. This pearl farm was almost destroyed when the 2011 Tsunami flooded the lake with pollutants and saltwater.

Pearl seeding techniques for pearl production are quite advanced in China and Japan, but other countries are actively researching these techniques, mainly Mexico and India. Mexico has developed techniques both for cultured and mabé pearls, but the country has only few areas suitable for freshwater pearl production, since most of the country is semi-desertic.

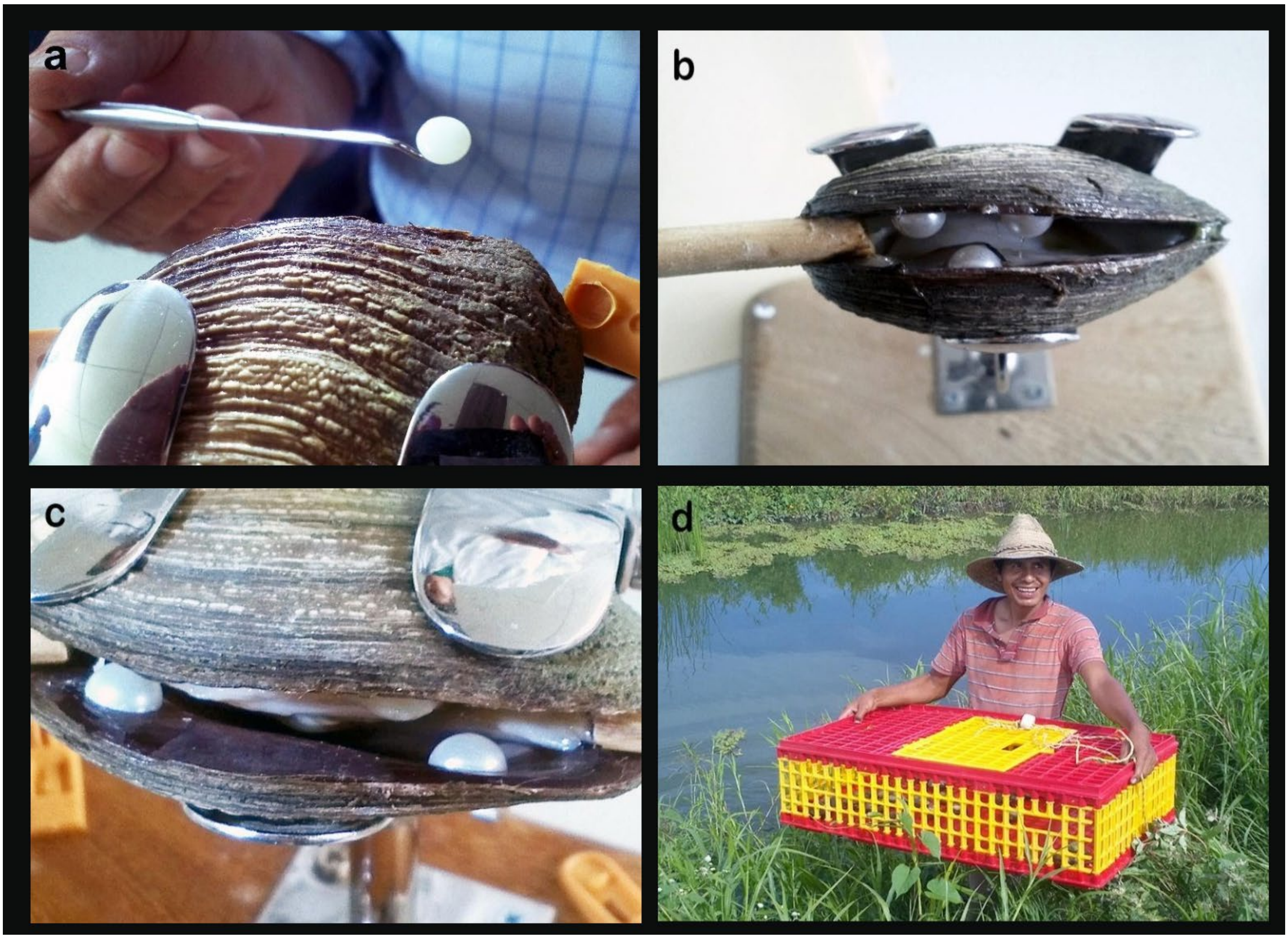

Figure 76: Techniques to produce cultured and Mabé pearls in Mexico, utilizing native pearly mussel species in the State of Tabasco, where vast freshwater sources are still available. Photos by P. Saucedo (Saucedo et al. 2020)

10.4. Threats to freshwater pearl production

The following excerpts are taken directly from Tucker and Theiling's excellent chapter (1999) on freshwater mollusks and require no changes. They focus on the most important threats to freshwater pearl mussels in the Mississippi River Basin of the United States of America, but this translates into any other region of the world where both humans and unionidae can be found living in proximity.

"After World War II, agriculture experienced a dramatic shift toward row crop agriculture (corn and soybeans) that emphasized mechanized farming and a heavy reliance on agrichemicals. Land-use practices for much of the period between the 1950s and the present have focused on getting the maximum possible acreage into production. Wetlands were drained, fields were tiled to drain water rapidly, and streams were channelized to speed tributary flow to larger rivers. Deep plowing, which leads to high soil erosion rates, also was a common practice. The combination of intensive land use and stream channelization resulted in high rates of soil loss. The soil washed into streams and larger rivers as fine silts and clay that filled interstitial spaces in gravel beds. In many areas siltation occurred at such high rates that backwaters and side channels were filled with fine sediment

The effect of expansive wing dam construction in the last 100 years has been equally dramatic. These dams act to slow flow and modify hydraulic patterns of flow in channel border habitats important to mussels. It differs from the other dams in that it has a hydroelectric power plant and creates a near-permanent obstruction for fish migrations. The blocked migration of skipjack herring, the only known host of the ebony shell mussel, has been implicated in the near eradication of this mussel species.

Mussels are affected by a variety of factors related to sedimentation. The first impact is direct burial. Mussel beds located near tributary inflows and slow flowing areas where silt settles can be covered deep enough to suffocate the population. A second longer-lasting impact is habitat alteration. Where sedimentation occurs on gravel beds, the silt fills the interstitial spaces that mussels inhabit. Flow through the gravel is inhibited and algal and microbial communities change. Some species are able to survive in the modified habitat, but many less tolerant species drop out of the community (Waters 1995). Juvenile survival in silt-impacted mussel beds (even hardy species) may be reduced, which can limit recruitment in the entire bed.

The third major agricultural impact is in the form of chemical contamination and nutrient enrichment. Pesticides were detected in the flesh of Illinois River mussels in 1971 but concentrations were not high (Starrett 1971). Chemical contaminants are a concern because they bind with suspended and settled sediment. Mussels are nonselective filterers and therefore contaminants have the capacity to bioaccumulate in the long-lived mussels. Nutrients promote plant and noxious algal growth that can disrupt flow over mussel beds and inhibit feeding."

Figure 77: A toxic blue-green algae bloom in a Chinese river.

In all, the threats to freshwater resources are much higher than those present is a marine environment, and this must be taken into account when thinking about a pearl farming venture.

The Government of China has recently prohibited the opening up of new freshwater pearl farms. Instead, it offers investments in saltwater pearl farms and has banned new farms since 2007, due to severe blue-green algae outbreaks that are endangering domestic water supplies (Xinhua News Agency August 13, 2007) (Pearl-Guide News).

10.5. Harvesting and Marketing of Freshwater Pearls

Cultured pearls are harvested in great numbers in China, with hundreds of people employed in the process of shucking the mussels, removing the meat and piling the empty shells. The process of removing the pearls from the meat either involves simple manual extraction (done with larger pearls) or the meat is simply thrown into large containers and then taken to mechanical macerators, so the pearls break free and drop to the bottom of the containers, then the water -full of organic wastes- is thrown out and the pearls are rinsed until clean. All this water is discharged into the area surrounding the farm, where it helps in the process of eutrophication, thus deteriorating water quality.

Figure 78: A freshwater pearl harvest in China.

After the pearls are harvested, they are sent to pearl processing centers, to be processed (bleached and polished) and then separated by sizes and shapes, and finally to be graded and valued. The lower quality pearls will be sent to extra processing, such as dyeing (artificial coloration) in order to still produce money out of an unsaleable product.

Figure 79. Gem Grade freshwater pearls. Photo courtesy of Jeremy Shepherd and Pearl-Guide.com

Gem grade pearls account for less than 1% of the pearl harvest, and these pearls attain better prices.

Most freshwater pearls attain prices that are several times lower than those of saltwater pearls, this being due to:

1. Freshwater pearls have historically been considered less valuable than saltwater pearls.

2. Freshwater pearl production is much higher than saltwater pearl production.

3. Freshwater pearls are considered a commodity more than a luxury product.

As a reference, of the above we have the recent online prices of online pearl jewelry retailer www.pearlparadise.com and we can find a 16 inch 7.5 to 8.0 mm white “Freshadama” (the equivalent of Akoya’s “Hanadama” or “Gem” quality) for just $495 USD, whereas it Japanese Akoya pearl counterpart is $2,595 USD.

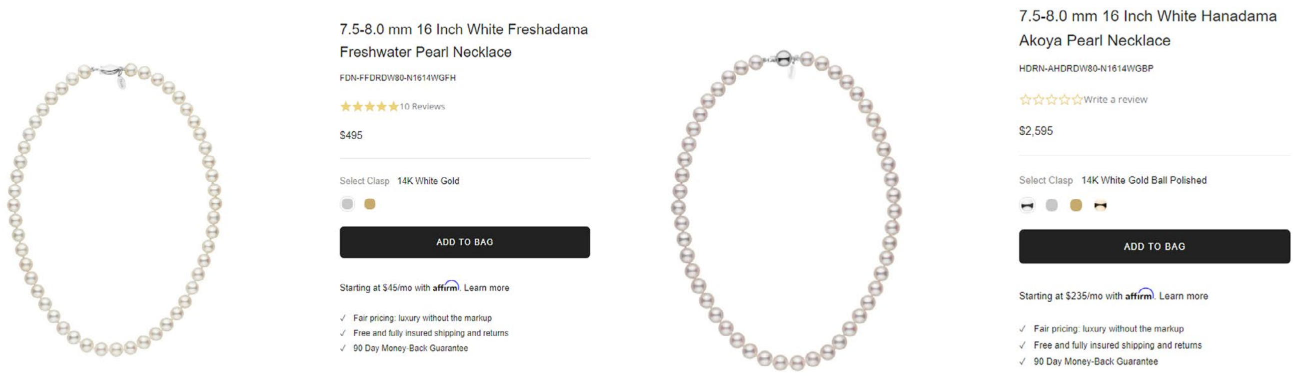

Figure 80. Two similar pearl strands, both 16 inches in length and of equal quality, but one is freshwater (left) and the other one is saltwater (Japanese Akoya). The price differential is enormous, with the saltwater strand being worth over $2000 USD more than the Chinese product. Products on display on April 9th of 2022 at www.PearlParadise.com

11. PEARL SALES AND OTHER FARM PRODUCTS

Most small-scale pearl farmers will only sell their pearls to direct buyers who often show up at the farm during or after a harvest. The entire harvest is purchased and paid at a very low average cost pearl, and this is the easiest solution for many pearl farmers, but it is also the least economically satisfying solution: selling the entire harvest provides the farmer with instant cash, but this should be done only if there are no other options. This is what is known as a "wholesale sale".

To obtain the most economic resources from your pearl harvest, pearl farmers should try to diversify their sales options. This is done for many reasons, the most important being that you do not depend on a single source that may "disappear" from one day to another, but this is also done to improve the economic resources that can be garnered by retail sales, as opposed to wholesale sales.

The sale options available for pearl farmers can be varied, and these are some of the possibilities:

1. Wholesale: Sell lots of pearls to one or more large buyers. The farmer gets less money, but faster.
2. Direct to Jewelers: Sell small lots or individual pearls to local jewelers. They will hopefully pay more, but sometimes they ask to pay the pearls once the product is sold. This is a form of consignation sale, and not a very good option for the farmer.
3. Direct Sale to Designers: these represent a unique proposition since designers will pay better prices, but oftentimes purchase less pearls, but they pay immediately.
4. Retail - Direct Sales to Walk-In Clients: Visitors will show up at the farm and purchase pearls. You secure the best sales price and are paid immediately. This is one of the best options if you have a constant flux of visitors.
5. Retail - Internet Direct Sales: Pearl farmers can open a "Virtual Store" on the Internet and sell their pearls locally, regionally, or all over the world. This requires some technical abilities and the need to ship the pearls from the farm.

Figure 81: Some Sale options for pearl farmers: (left to right) Gem & Jewelry trade shows, direct sales (retail) and Internet direct sales.

One of the best options available for pearl farmers is to utilize tourism to obtain sales. If the farm is located close to a tourist attraction, the farm can be prepared to accept visitors that would like to know and educate themselves about pearls and pearl farming; they would be able to visit the farm's store and purchase the following.

- Seashells, including pearl on the shells ($1 to $10 USD per shell)
- Mother-of-Pearl handcrafts and jewelry ($1 to $30 USD per piece)
- Loose (unset) Cultured Pearls and Mabé Pearls ($5 to $100 USD per piece)
- Silver pearl jewelry ($3 to $300 USD per piece)

- 14K Gold pearl jewelry with pearls ($50 to $1,000 USD per piece)
- Pearl Necklaces ($50 to $5,000 USD per piece)

If this is a possibility, it can offer a unique economic perspective to a town or village, where some of the inhabitants will be able to offer their local services to the visitors, in the form of food, cultural activities, lodging, fishing, or sightseeing trips.

The government can also find ways to increase tourist affluence in the town or village, by means of promotion.

Glossary

- **Akoya-Gai:** The Japanese name of the Pinctada imbricata (=*fucata/radiata*) pearl oyster used in Akoya pearl production.
- **Akoya keshi:** small pearl found in the Akoya mollusk where it forms as a byproduct of the pearl culturing process.
- **Akoya pearls:** Natural or cultured pearls from an Akoya pearl oyster.
- **Baroque:** A pearl shape; stands for irregular and asymmetrical shape.
- **Bead-and-tissue-cultured pearl:** A freshwater or saltwater cultured pearl whose growth is started by implanting a shell bead nucleus and a donor-mollusk mantle-tissue piece in the mantle, gonad, or another body part of a host mollusk.
- **Bead-cultured pearl:** A freshwater or saltwater cultured pearl whose growth is started by implanting a shell bead nucleus in an existing pearl sac from which a first-generation cultured pearl was removed.
- **Bivalve:** A mollusk from the class *Bivalvia* having a two-part shell attached by a hinge.
- **Biwa pearl:** Pearl grown in *Hyriopsis schlegeli* freshwater mussel in Lake Biwa, Japan. The term is often incorrectly used to describe freshwater pearls in general.
- **Black-lipped pearl oyster:** refers to those pearl oyster species that possess a dark-colored "lip" on their shell. It includes the *Pinctada margaritifera, Pinctada mazatlanica* and *Pinctada galtsoffi* mollusks.
- **Black pearl:** A pearl of naturally dark colors produced by the *Pinctada margaritifera*, *Pinctada margaritifera cumingi, Pinctada mazatlanica* and *Pteria sterna* mollusks.
- **Blister pearl:** Pearl attached to the shell of the host mollusk. These can occur naturally when a pearl sac bonds with the upper mantle or by human intervention when a hemispherical nucleus is attached to the inner shell by a grafting technician.
- **Buoys:** Used to float lines from which mollusks are hung in net panels or other holding devices.
- **Button pearl:** A dome shape pearl with a flat side. Button shapes are classified as high or low depending on the height of the dome.
- **Byssus:** Structure composed of thread-like tissue that bivalve mollusks use to anchor themselves to a solid external surface.
- **Calcareous concretion:** Whether nacreous or not, all pearls are calcareous concretions.
- **Calcite:** A form of natural calcium carbonate that, together with aragonite and conchiolin, makes up the structure of nacre.
- **Calcium carbonate:** Pearls are MAINLY composed of calcium carbonate ($CaCO_3$) and other elements and substances.
- **Ceylon pearl mollusk:** The *Pinctada imbricata* mollusk known for producing natural pearls in the Gulf of Mannar, the Red Sea and the Persian Gulf. According to some taxonomists, it was formerly considered a distinctive species known as *Pinctada radiata.*
- **Chau:** Historical unit of weight used in the natural pearl trade in India, also called *chov.*
- **Chaplets:** Line extensions of a pearl farm's long-line system that are secured to the shells.
- **CIBJO:** (*Confederation Internationale de la Bijouterie, Joaillerie et Orfebrerie*), also known as the World Jewellery Confederation, is an international confederation of jewelry, gemstone, horology, and silverware trade organizations. CIBJO publishes The Pearl Book: Natural, Cultured & Imitation Pearls: Terminology & Classification.

- **Circled pearl:** Pearl with raised concentric rings around its surface, thought to be produced by the developing pearl rotating during growth. Also known as a Circlé or "ringed" pearl.
- **Composite cultured blister pearl:** See *Mabé.*
- **Concentric structure:** The layering of calcium carbonate crystals that is characteristic of natural pearls, tissue-cultured pearls, bead-cultured pearls, and the nacre layer of bead-and-tissue-cultured pearls.
- **Cultured pearl:** Pearl produced by the human insertion of a bead, a tissue graft, or a bead and tissue graft in a freshwater mussel or saltwater mollusk.
- **Diffraction:** One of the ways nacre layers interfere with light, causing light to split into its component colors (the spectrum), one or more of which can be displayed as overtone and/or orient.
- **Drop:** A symmetrical pearl shape that's round on one end and tapers to a point on the other. The shape can be short or long and takes its name from a water drop or teardrop.
- **Dust pearl:** Historical term describing a natural pearl smaller than 2 mm. See seed pearl.
- **Egg shape:** Oval shaped pearls.
- **EGL:** European Gemological Laboratory.
- **Epithelial cells:** Cells on the shell side of a mollusk's mantle tissue that produce mother of pearl and nacre.
- **Epithelial graft tissue:** Piece of mantle tissue from a donor mollusk implanted with a mother-of-pearl bead in the gonad or other body part of a host mollusk to produce a cultured pearl; or implanted with or without a bead in the mantle of a host mollusk to produce a cultured pearl.
- **First-generation cultured pearl:** Freshwater or saltwater cultured pearl whose growth is started by implanting a tissue piece, or a bead nucleus and tissue piece, in a host mollusk that has not grown a pearl before.
- **Floor system:** Method of pearl farming used in Australia where mollusks are placed in baskets attached to posts or fences and left on the seabed. Also known as "Bottom Culture".
- **Free suspension:** Method of pearl farming where mollusks are suspended in wire or nylon panels. Also known as "Suspension Culture System".
- **Ganglia or ganglions, plural, ganglion, singular:** Groups of nerve cells that constitute the primitive nervous system of a bivalve mollusk.
- **Gastropod:** Univalve mollusk, including land and sea snails, with a head and eyes and a foot to move about.
- **Gem quality/grade:** Perfectly clean pearl exhibiting fine color and luster.
- **Gold-lip pearl oyster:** the *Pinctada maxima* mollusk used to produce of natural-color golden South Sea pearls. The outer edges of the shell interior are golden in color.
- **Gonad:** the reproductive organ of an oyster or mussel. It's the general organ where a bead nucleus or nuclei and donor-mollusk tissue piece or pieces are implanted to produce cultured pearls.
- **Graft tissue:** Donor-mollusk mantle tissue piece implanted with or without a bead nucleus in a host mollusk to produce a cultured pearl.
- **Graft:** To insert a piece of graft tissue with or without a bead nucleus in a host mollusk to induce it to produce of a cultured pearl. Also known as *Saibo*.
- **Grain:** Unit of weight associated with natural pearls. One grain equals 0.25 carat.
- **Hama-age:** Newly harvested cultured akoya pearls in Japan.

- **Hanadama:** Highest quality portion of a cultured akoya pearl harvest.
- **Hankei:** Japanese name for a cultured blister pearl. See Mabé pearl.
- **Hardness:** Pearls range from 3.5 to 4.5 on the Mohs hardness scale.
- **Harvest:** Removing cultured pearls from mollusks on a pearl farm.
- **Hypostracum:** Mother-of-pearl layer of a pearl-bearing bivalve mollusk shell, the shell layer adjacent to the mantle.
- **Indicator pearl:** Small South Sea pearl (also known as a baby pearl) harvested from *Pinctada maxima* after six to eight months so a larger nucleus can be inserted in the existing pearl sac. These pearls are smaller and have thin nacre. Indonesia is the main producer.
- **Interference:** Interference of light by nacre creates the iridescent play of color on the surface of a pearl. Refraction, diffraction and/or thin-film interference occur as light penetrates extremely thin nacre layers.
- **Iridescence:** Play of color over the surface of a pearl as interference divides white light into its component colors.
- **Japanese lingah:** Popular name for the *Pinctada fucata martensi* mollusk.
- **Japanese pearl mollusk:** Akoya pearl mollusk.
- **Jewelmer:** Philippine producer and wholesaler of South Sea pearls, primarily those produced by the gold-lip *Pinctada maxima* pearl mollusk.
- **Kago:** Japanese term for pearl mollusk baskets suspended from longline systems.
- **Kan:** Historical Japanese weight unit used to valuate pearls. One kan equals 1,000 *momme* (see), 3.75 kilograms and 8.26 pounds.
- **Kangaroo basket (Pocket Nets):** Culture basket in which pearl oysters are stored for a brief period after the grafting process. These baskets have individual pockets meant to catch expelled nuclei.
- **Koao:** Coral platforms on which pearl farms are built on Manihiki atoll in the Cook Islands.
- **Kashra:** Historical Persian quality factor describing blister pearls.
- **Lantern baskets:** Baskets used to hold young mollusks when suspended from lines during saltwater pearl culture. Method is most often used for akoya mollusks for a brief period after they are bred in hatcheries.
- **Longline systems:** Horizontal lines stretched between buoys and anchored to the bottom at both ends. Chaplets (vertical lines) with baskets or net panels of nucleated mollusks are suspended underwater from the longlines.
- **Luster:** Quantity and quality of light reflected from the surface or just under the surface of a natural or cultured pearl.
- **Mabé:** Originally, the Japanese trade term for an assembled blister pearl grown in *Pteria penguin*. In Japanese, that mollusk's name is Mabé-gai, hence the pearl's name. Today, the word is used to describe any assembled blister pearl.
- **Mantle:** Organ lining the shell of freshwater and saltwater bivalve mollusks.
- **Mantle graft tissue:** A tiny piece of tissue cut from a donor mollusk's mantle and implanted with or without a bead nucleus in a host mollusk to produce a cultured pearl. The outer epidermis of the mantle is made up of epithelial cells that secrete nacre.
- **Mollusk:** Any invertebrate belonging to the phylum Mollusca. Includes clams, mussels, oysters, scallops, conchs, snails, abalone, chitons, squids and octopi.
- **Momme:** Japanese weight unit used to valuate cultured pearls. One momme equals 3.75 grams.

- **Mother-of-pearl (MOP):** Iridescent layer (*principally calcium carbonate and conchiolin*, see) lining the inner shell of some mollusk species. When it coats a bead to form a cultured pearl or is part of a natural, tissue-cultured or keshi pearl, it's called *nacre* (see).
- **Muta'a:** Historical Persian quality factor describing baroque pearls.
- **Nabatee:** Arabian term for sugar used to describe pearls from the Persian Gulf that had a slightly off-white, yellowish color.
- **Nacre:** Aragonite and calcite platelets bound together by conchiolin that completely compose bivalve and abalone natural pearls, Keshi, tissue-cultured freshwater pearls, and the coating on the nucleus of bead-cultured and bead-and-tissue-cultured pearls.
- **Nacreous:** Composed of nacre.
- **Nacre thickness:** Measured in whole and decimal fractions of millimeters, the depth of the nacre layer on the bead nucleus of bead-cultured and bead-and-tissue-cultured pearls. Not a consideration for natural and cultured pearls composed entirely of nacre (see Nacre).
- **Nimro:** Historical Persian quality factor for natural blister pearls.
- **Nishikawa, Tokishi:** Credited with Tatsuhei Mise (probably erroneously), with discovering the bead-and-tissue method of whole pearl culture.
- **Non-beaded cultured pearl:** Cultured pearl grown without a bead nucleus.
- **Non-nacreous pearl:** Natural pearl lacking a nacreous surface layer. Also referred to as "Porcelaneous Pearls".
- **Non-nucleated cultured pearl:** Cultured pearl grown without using a bead nucleus.
- **Nucleus:** Shell bead implanted inside a host mollusk, most often with a tissue piece, to become the core of a cultured pearl.
- **Nuggets:** Semi-round pearls that resemble gold nuggets.
- **Orient:** Optical phenomenon that produces iridescent colors on the surface of some natural and cultured pearls. These factors help create orient: reflection, refraction, diffraction, and thin-film interference.
- **Oriental pearls:** Historical commercial term for natural marine pearls from the Persian Gulf and the Red Sea.
- **Oval:** Natural or cultured pearl in an oval or egg shape.
- **Overtone:** Secondary color(s) on the surface of a natural or cultured pearl. It is created by nacre layers interfering with white light and splitting it into its component colors.
- **Oyster:** Common name correctly applied to some bivalve mollusks and incorrectly to others. No bivalve mollusk that produces nacreous natural or cultured pearls is a true oyster. It accurately refers to "Edible Oysters" of the Ostreidae family.
- **Oyster pearls:** Chalk-like natural concretions produced by edible oysters (Family Ostreidae), of low to no commercial value.
- **Peacock:** Color most often associated with pearls produced by black-lip pearl oysters (*Pinctada margaritifera* and *Pinctada mazatlanica*). It is a dark green gray to blue gray with rosé to purple overtones.
- **Pear:** Drop pearl shaped like a pear.
- **Pearl:** Nacreous or non-nacreous concretion formed as a progressive secretion of calcareous layers, found naturally and circumstantially within a mollusk.
- **Pearl powder:** Ground nacre form pearls, often used in medicines and cosmetics.

- **Pearl sac:** Formed from epithelial cells that envelop an intruder or a bead nucleus, it deposits nacre and forms a natural or cultured pearl.
- **Pearl sieves:** Used to sort cultured pearls by size.
- **Pearl Peeling:** Removing the outer nacre layers of a cultured pearl in the hope of improving its quality.
- **Periostracum:** Outer layer of a bivalve mollusk shell, formed mainly of conchiolin.
- **Pinna pearls:** Natural nacreous or non-nacreous pearls produced in mollusks from the *Pinna* or *Atrina* genus; often called "pen shell pearls".
- ***Pinctada:*** Mollusk genus in the family Pteriidae. It is the most important genus in saltwater cultured pearl production.
- ***Pinctada chemnitzi:*** Native to China and parts of Japan, the pure species, and its hybrid with *Pinctada imbricata* are used to produce Akoya cultured pearls in those countries. Now considered part of the *Pinctada imbricata* complex species.
- ***Pinctada fucata martensi:*** Historically, the Japanese Akoya pearl mollusk. The species is now used there and in China to produce akoya cultured pearls. It is often cross bred with *Pinctada chemnitzi*. Now considered part of the *Pinctada imbricata* complex species.
- ***Pinctada imbricata:*** Most experts today consider this species name encompasses every pearl oyster species called "Akoya" regardless of geography. As is true elsewhere in taxonomy, other researchers disagree.
- ***Pinctada margaritifera:*** The black-lip pearl mollusk; the variety *Pinctada margaritifera* cumingi is used to produce Tahitian and Cook Islands cultured pearls.
- ***Pinctada martensi:*** Yet another synonym for *Pinctada imbricata* and *Pinctada fucata martensi*.
- ***Pinctada maxima:*** The silver-lip or gold-lip pearl mollusk; used to produce South Sea cultured pearls.
- ***Pinctada mazatlanica:*** the "Panamic Black Lipped Pearl Oyster" or "Madreperla Panámica", a close-relative of *Pinctada margaritifera*, it is native to the Gulf of California (Sea of Cortez) and the Mexican and Central American Pacific Ocean. Known for producing some of the world's most dazzling natural pearls in the world, such as: La Peregrina, La Pellegrina, the Big Lemmon and many others.
- ***Pteria penguin:*** Mollusk originally used to produce assembled cultured blister pearls. In Japanese, its name is *Mabé-gai*.
- ***Pteria sterna:*** Rainbow-lip mollusk used to culture pearls in the Gulf of California (Sea of Cortez).
- **Rainbow pearl:** From Pteria sterna but may exhibit colors like those of pearls from the black-lip mollusk (Pinctada margaritifera).
- **Red tide:** Profuse hyperproduction of algae, called an algal bloom. It weakens or kills pearl-bearing mollusks by consuming most or all the dissolved oxygen in the water and/or poisoning them when the algae die and putrefy. It's not a true tide, and it's not always red.
- **Red Sea cultured pearl:** Cultured pearl produced in the local black-lip (*Pinctada margaritifera erythraensis*) mollusk in the Red Sea.
- **Round:** Perfectly round pearl, or one with diameters that don't vary by more than 2 percent.
- **Saibo:** To insert a piece of graft tissue with or without a bead nucleus in a host mollusk to induce it to produce of a cultured pearl.
- **Saltwater pearl:** Natural or cultured pearl produced by a saltwater mollusk.

- **Seabed (Bottom Culture) system:** Method of farming South Sea pearls in which *Pinctada maxima* mollusks are placed in baskets or panels secured to posts on the sea floor. The method is still used today in northwestern Australia but was most popular in the first decades of pearl farming there.
- **Second-generation cultured pearl:** Freshwater or saltwater cultured pearl whose growth is started either by implanting a shell bead nucleus in an existing pearl sac from which a first-generation cultured pearl was removed, or by letting the mollusk grow a beadless cultured pearl in an existing pearl sac from which a first-generation cultured pearl was removed.
- **Second grafts:** Cultured pearls grown in existing pearl sacs after the first harvest; same as *second-generation cultured pearl*. The term is misleading because there is no tissue graft involved.
- **Seed pearl:** Natural pearl less than 2 mm in diameter.
- **Semi-baroque pearl:** Off-round, asymmetrical pearl but not as irregular as a baroque pearl.
- **Semi-round pearl:** Off-round pearl having a symmetrical shape or a slight deviation of symmetry. To be semi-round, a pearl's diameters must vary by more than 2 percent. Also called near-round.
- **Shireen:** Historical Persian quality factor describing natural pearls of remarkably high luster and excellent shape.
- **Sijni:** Historical Persian quality factor describing natural pear-shaped pearls.
- **Silver-lip mollusk:** *Pinctada maxima* mollusk that has silver rather than gold inner shell edges; used to culture South Sea pearls.
- **South Sea pearl:** Natural or cultured pearl produced by the *Pinctada maxima* mollusk.
- **Third-generation cultured pearl:** Freshwater or saltwater cultured pearl whose growth is started either by implanting a shell bead nucleus in an existing pearl sac from which a second-generation cultured pearl was removed, or by letting the mollusk grow a beadless cultured pearl in an existing pearl sac from which a second-generation cultured pearl was removed.
- **Third graft:** Cultured pearl grown in an existing pearl sac after the second harvest. The term is inaccurate because no tissue graft is involved.
- **Three-quarter (3/4) cultured pearl:** Bead-and-tissue-cultured pearl, most often akoya, that is worked to remove an imperfection, leaving a flat portion of the nucleus exposed. The flat side is usually half-drilled and mounted on a post in a setting that conceals the worked side.
- **Tissue-cultured pearl:** Freshwater cultured pearl whose growth is started by implanting a donor-mollusk mantle-tissue piece in a host mollusk's mantle.
- **Tissue method:** Implanting a freshwater host mussel with a donor-mussel mantle-tissue piece to start the growth of a beadless cultured pearl.
- **Underwater platform:** Used in French Polynesia as a temporary care station from which mollusks are suspended after implantation of a bead nucleus and donor-mollusk tissue piece.
- **Wedge:** Used to separate the valves of a host pearl mollusk so a donor-mollusk tissue piece or bead and tissue piece can be implanted. Can be made of bamboo wood, other woods and now mostly plastic.

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TEKNIK BUDIDAYA TIRAM MUTIARA (*Pinctada maxima*) DI BALAI PERIKANAN BUDIDAYA LAUT (BPBL) SEKOTONG, LOMBOK BARAT, NUSA TENGGARA BARAT

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FAKULTAS PERIKANAN DAN KELAUTAN
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RINGKASAN

FARADINA RIZKA SAFIRA. FAZHA NINDYA KIRANA. LUTFIYAH TARI. Teknik Budidaya Tiram Mutiara (*Pinctada maxima*) Di Balai Perikanan Budidaya Laut (BPBL) Sekotong, Lombok Barat, Nusa Tenggara Barat. Dosen Pembimbing Nina Nurmalia Dewi, S.Pi., M.Si.

Budidaya Tiram Mutiara di Indonesia memiliki potensi yang besar. Tiram mutiara merupakan komoditas yang penting di Indonesia karena memiliki nilai jual yang tinggi dan juga sebagai penyumbang devisa yang cukup besar bagi negara. Praktik budidaya yang kurang optimal, minimnya pengetahuan, dan kurangnya perhatian terhadap aspek lingkungan menyebabkan rendahnya kualitas budidaya yang ada di Indonesia. Budidaya yang tidak terstandarisasi dan penerapan teknologi yang masih terbatas menyebabkan hasil produksi seringkali tidak memenuhi standar kualitas yang diharapkan. Hal ini berdampak pada daya saing produk tiram mutiara di pasaran. Tiram mutiara memiliki potensi yang sangat tinggi hingga dibutuhkan pengelolaan dan pengembangan yang baik. Praktik Kerja Lapangan ini bertujuan untuk mengetahui teknik budidaya tiram mutiara di Balai Perikanan Budidaya Laut Lombok, NTB.

Praktik kerja lapang ini dilaksanakan pada tanggal 24 Juni 2024 hingga 23 Agustus 2024 di Balai Perikanan Budidaya Laut (BPBL) Sekotong, Lombok Barat, Nusa Tenggara Barat. Metode kerja yang digunakan dalam Praktik Kerja Lapang ini adalah deskriptif dengan pengambilan data primer dan data sekunder. Data primer diambil dan diperoleh dari pengambilan data secara langsung melalui wawancara, partisipasi aktif, dan observasi. Data sekunder diambil dan diperoleh dari literatur.

Teknik pemijahan tiram mutiara (*Pinctada maxima*) meliputi kegiatan seleksi induk, persiapan wadah pemijahan, dan proses pemijahan. Seleksi induk dilakukan dengan pengecekan tingkat kematangan gonad pada induk tiram mutiara untuk mengetahui apakah induk tiram siap pijah. Persiapan wadah pemijahan yaitu 2 container box, keranjang penetasan, dan bak fiber 3 ton. Proses pemijahan dilakukan di *hatchery* dengan metode thermal shock dengan perbandingan induk jantan dan induk betina adalah 1:2.

Teknik pemeliharaan larva dan benih tiram mutiara (*Pinctada maxima*) meliputi kegiatan persiapan wadah pemeliharaan, pemeliharaan benih, dan monitoring perkembangan larva. Pada persiapan wadah pemeliharaan larva dilakukan menggunakan bak fiber 3 ton dengan proses pemeliharaan meliputi pembersihan wadah sebelum digunakan, pengisian air laut yang disaring menggunakan filter fisika berupa pasir silika dan arang, penempelan larva pada kolektor. Pada pemeliharaan benih tiram mutiara dimana pemeliharaan benih dilakukan setelah telur menetas selama proses pemijahan. Selama masa pemeliharaan larva tiram tersebut, 3 hari sekali bak akan dibersihkan dan di ganti airnya, sedangkan larva kerang mutiara akan disaring dengan saringan bertingkat dengan ukuran 50, 60, dan 80 mesh. Pemberian kolektor sebagai tempat menempel benih tiram mutiara dimulai pada umur ke 15 hari dengan kapasitas 200 kolektor

per bak fiber atau 40 kolektor per gantungan pipa. Monitoring perkembangan larva terbagi menjadi 4 fase yaitu fase D, fase Umbo, fase Plantygrade, dan fase Spat.

Teknik pembesaran tiram mutiara meliputi kegiatan persiapan wadah pembesaran, penurunan spat ke laut, dan pembesaran tiram mutiara. Teknik pembesaran tiram mutiara dimulai dari fase spat berumur 30 hari dengan ukuran 2 cm, diawali dengan persiapan wadah yaitu pocket net, keranjang tento, dan waring. Kemudian penurunan spat ke laut dengan menempelkan kolektor pada pocket. Pembesaran tiram mutiara dilakukan dengan penjarangan dan pembersihan tiram selama sebulan sekali. Pergantian waring dilakukan selama 2 minggu sekali. Kepadatan penebaran tiram mutiara dalam pocket net disesuaikan dengan ukuran pocket, terdapat 6 jenis pocket yaitu pocket timbangan, A12, A18, A30, keranjang tento dan insersi.

Manajemen pakan pada tiram mutiara dilakukan sejak tiram berukuran larva fase *D-Shape*. Kultur dan dilakukan penyesuaian suhu hingga suhu stabil, setelah itu diberikan pakan dengan frekuensi pemberian pakan 1 kali sehari pada siang hari pukul 13.00 setiap harinya. Banyaknya 24 liter untuk 6 bak, pemberian pakan dilakukan alat bantu berupa gelas ukur bervolume 2L dengan masing-masing 4L pada setiap bak pemeliharaan. Pemberian pakan dua kali sehari dengan jenis spesies *C. simplex*, *C. calcitrans*, dan *C. gracilis* dengan perbandingan 1:1:1 setiap jenis. Kepadatan plankton dalam setiap bak pembenihan sebanyak 1,417 x 1010 .

Kualitas air pada pemeliharaan larva tiram mutiara menunjukan hasil yang optimal dimana suhu berkisar antara 27-29°C, salinitas 32 ppt, pH 8.2, kadar oksigen terlarut berkisar antara 5.3-6 mg/L, nitrit berkisar antara 0.005-0.008 mg/L, nitrat berkisar antara 0.01-0.03 mg/L, dan ammonia berkisar antara 0.04-0.05 mg/L. Kualitas air pada pemeliharaan induk tiram mutiara menunjukan hasil yang optimal. Suhu berkisar antara 28-29°C, salinitas berkisar antara 32-36 ppt, pH 8.1-8.3, kadar oksigen terlarut berkisar antara 5.9-6.9 mg/L, nitrit berkisar antara 0.002-0.009 mg/L, nitrat berkisar antara <0.01-0.02 mg/L, dan ammonia berkisar antara 0.03-0.09 mg/L. Pada budidaya tiram mutiara (Pinctada maxima) sering menghadapi berbagai macam hama seperti teritip, keong laut famili Cypraeidae, *Polychaeta*, *Monoplex pilearis*, dan kepiting. Upaya yang dilakukan yaitu pembersihan cangkang serta penggantian waring dan keranjang.

SUMMARY

FARADINA RIZKA SAFIRA. FAZHA NINDYA KIRANA. LUTFIYAH TARI. Cultivation Technique of Pearl Oyster (*Pinctada maxima*) at Balai Perikanan Budidaya Laut (BPBL) Sekotong, West Lombok, West Nusa Tenggara.

Pearl Oyster cultivation in Indonesia has great potential. Pearl oysters are an important commodity in Indonesia because they have a high selling value and are also a significant contributor to foreign exchange for the country. Sub-optimal cultivation practices, lack of knowledge, and lack of attention to environmental aspects lead to the low quality of cultivation in Indonesia. Non-standardized cultivation and limited application of technology mean that production often does not meet the expected quality standards. This has an impact on the competitiveness of pearl oyster products in the market. Pearl oysters have a very high potential that requires good management and development. This Field Work Practice aims to find out pearl oyster cultivation techniques at Balai Perikanan Budidaya Laut Lombok, NTB.

This field internship was carried out from June 24, 2024 to August 23, 2024 at Balai Perikanan Budidaya Laut (BPBL) Sekotong, West Lombok, West Nusa Tenggara. The working method used in this field internship is descriptive with primary data collection and secondary data. Primary data is taken and obtained from direct data collection through interviews, active participation, and observation. Secondary data is taken and obtained from the literature.

Pearl oyster (*Pinctada maxima*) spawning techniques include broodstock selection, spawning container preparation, and spawning process. Broodstock selection is done by checking the level of gonad maturity in pearl oyster broodstock to determine whether the oyster is ready to spawn. Preparation of spawning containers, namely 2 container boxes, hatching baskets, and 3-ton fiber tanks. The spawning process is carried out in the hatchery using the thermal shock method with a ratio of male and female broodstock of 1:2.

The larval and seed rearing techniques for pearl oysters (*Pinctada maxima*) included preparation of rearing containers, seed rearing, and monitoring of larval development. The preparation of larval rearing containers is carried out using a 3-ton fiber tub with the rearing process including cleaning the container before use, filling seawater filtered using a physical filter in the form of silica sand and charcoal, attaching larvae to the collector. In pearl oyster seed rearing where seed rearing is carried out after the eggs hatch during the spawning process. During the oyster larvae rearing period, every 3 days the tanks will be cleaned and replaced with water, while the pearl clam larvae will be filtered with a multilevel filter with sizes 50, 60, and 80 mesh. The provision of collectors as a place to attach pearl oyster seeds begins at the age of 15 days with a capacity of 200 collectors per fiber tub or 40 collectors per pipe hanger. Monitoring of larval development is divided into 4 phases, namely the D phase, Umbo phase, Plantygrade phase, and Spat phase.

The pearl oyster enlargement technique includes the preparation of enlargement containers, spat dropping into the sea, and pearl oyster enlargement. The pearl oyster enlargement technique starts from the 30-day-old spat phase with a size of 2 cm, starting with the preparation of containers, namely pocket nets, tento baskets, and waring. The spat was then dropped into the sea by attaching the collector to the pocket. Pearl oyster enlargement is carried out by thinning and cleaning oysters once a month. The nets are changed every two weeks. The stocking density of pearl oysters in the pocket net is adjusted to the size of the pocket, there are 6 types of pockets, namely pocket scales, A12, A18, A30, tento basket and insertion.

Feed management on pearl oysters is carried out since the larval size of the D-Shape phase. Cultures and temperature adjustments are made until the temperature stabilizes, after which feed is given with a frequency of feeding once a day at noon at 13.00 every day. The amount of 24 liters for 6 tanks, feeding is done by a tool in the form of a measuring cup with a volume of 2L with 4L each in each maintenance tub. Feeding twice a day with the types of species C. simplex, C. calcitrans, and *C. gracilis* with a ratio of 1:1:1 each type. Plankton density in each hatchery tank was 1.417 x 1010 .

Water quality in pearl oyster larvae rearing showed optimal results where temperature ranged from 27-29°C, salinity 32 ppt, pH 8.2, dissolved oxygen levels ranged from 5.3-6 mg/L, nitrite ranged from 0.005-0.008 mg/L, nitrate ranged from 0.01-0.03 mg/L, and ammonia ranged from 0.04-0.05 mg/L. Water quality in pearl oyster broodstock rearing showed optimal results. Temperature ranged from 28-29°C, salinity ranged from 32-36 ppt, pH 8.1-8.3, dissolved oxygen levels ranged from 5.9-6.9 mg/L, nitrite ranged from 0.002-0.009 mg/L, nitrate ranged from <0.01-0.02 mg/L, and ammonia ranged from 0.03-0.09 mg/L. The cultivation of pearl oysters (*Pinctada maxima*) often faces a variety of pests such as barnacles, sea snails of the Cypraeidae family, *Polychaeta*, *Monoplex pilearis*, and crabs. Efforts made are shell cleaning and replacement of nets and baskets.

KATA PENGANTAR

Puji syukur kami panjatkan kepada Allah SWT, karena berkat rahmat-Nya kami dapat menyelesaikan laporan akhir Praktik Kerja Lapangan (PKL) ini dengan judul "Teknik Budidaya Tiram Mutiara (*Pinctada maxima*) di Balai Perikanan Budidaya Laut (BPBL) Sekotong, Lombok Barat, Nusa Tenggara Barat”.

Laporan ini disusun sebagai bentuk pertanggungjawaban atas kegiatan PKL yang memberikan banyak pengetahuan dan pengalaman berharga tentang budidaya tiram mutiara. Selama pelaksanaan kegiatan, kami mendapatkan banyak pengetahuan dan pengalaman berharga mengenai teknik budidaya Tiram Mutiara yang tidak hanya bermanfaat bagi diri kami, tetapi juga diharapkan dapat memberikan kontribusi positif bagi pengembangan sektor perikanan di Indonesia. Kami mengucapkan terima kasih kepada semua pihak, terutama Balai Perikanan Budidaya Laut Lombok dan para pembimbing, yang telah mendukung kami.

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I PENDAHULUAN

1.1 Latar Belakang

Tiram mutiara (*Pinctada maxima*) merupakan produsen dari mutiara berupa butiran permata yang dihasilkan oleh tiram laut dan air tawar (Al-Habib dkk., 2018). Indonesia merupakan negara penghasil mutiara dengan julukan south sea pearl setara dengan mutiara produksi Australia, Filipina, dan Myanmar (Poernomo, 2008). Indonesia menjadi 25% teratas sebagai produsen mutiara dunia bersama Australia (Sudewi dkk., 2010). Produksi mutiara dari *Pinctada maxima* di Indonesia dapat mencapai hampir 4 ton per tahun (Zhu dkk., 2019). Kegiatan ekspor mutiara ke 9 negara meliputi Hongkong, Australia, Jepang, dan China menyumbangkan hingga 45.293 ribu US$ pada tahun 2016 yang terdiri dari 68% mutiara dari alam dan 32% hasil budidaya (Trademap, 2017).

Kegiatan budidaya tiram mutiara (*Pinctada maxima*) cukup terbilang banyak dan tersebar di hampir seluruh wilayah indonesia, namun kegiatan budidaya tersebut mengalami hambatan pada ketersediaan benih baik dari segi kuantitas maupun kualitas. Pada saat ini Indonesia menempati peringkat ketiga dalam kualitas mutiara jika dibandingkan dengan negara-negara lain. Hal ini karena rendahnya produksi dan kualitas mutiara yang dihasilkan dari proses budidaya yang dilakukan serta karena kualitas tiram mutiara sebagai penghasil mutiara yang kurang maksimal dan memadai. Hingga saat ini, keperluan akan tiram mutiara (*Pinctada maxima*) untuk budidaya yang menghasilkan mutiara masih bergantung pada pengumpulan dari alam. Situasi ini menjadi semakin mengkhawatirkan ketika eksploitasi alam terus meningkat, mengancam keseimbangan populasi tiram mutiara di habitat alaminya (Wibowo, 2016). Kegiatan budidaya dilakukan dengan pemanfaatan benih dari alam yang jumlahnya sangat fluktuatif, tergantung musim, dan memiliki ukuran yang tidak seragam yang menyebabkan tidak sesuai dengan standar untuk diambil sehingga membutuhkan waktu dan tambahan biaya dalam hal pemeliharaan untuk mencapai ukuran yang standar. Pengambilan benih untuk budidaya dari alam akan menyebabkan penurunan produksi tiram mutiara pada kemudian harinya (Al-Habib dkk., 2018).

Salah satu wilayah di Indonesia yang banyak mengembangkan budidaya tiram mutiara adalah Pulau Lombok Nusa Tenggara Barat (NTB). Hal ini karena perairan lombok memiliki parameter hidrometeorologi berupa kecepatan arus, suhu permukaan laut, dan salinitas dengan skor tinggi yang sesuai untuk budidaya tiram mutiara (Al-Habib dkk., 2018). Pada tahun 2001 jumlah pengusaha budidaya tiram mutiara di Pulau Lombok Nusa Tenggara Barat (NTB) tercatat sebanyak 38 perusahaan dan 3 diantaranya merupakan perusahaan asing dengan luas areal usaha 33.550 ha (Fathurrahman dan Aunurohim, 2014). Usaha budidaya mutiara di perairan Nusa Tenggara Barat (NTB) semakin meningkat seiring dengan meningkatnya permintaan pasar domestik dan internasional. Tempat budidaya tiram mutiara di Lombok berada pada Balai Perikanan Budidaya Laut (BPBL) Sekotong, Lombok Barat, Nusa Tenggara Barat, budidaya tiram. Balai yang berdiri sejak tahun 1990 merupakan salah satu unit pelaksana teknis (UPT) Direktorat Jenderal Perikanan Budidaya, Kementerian Kelautan dan Perikanan yang dibangun untuk mengembangkan perikanan budidaya di wilayah Nusa Tenggara Barat. Hingga saat ini BPBL Lombok terus mengalami perkembangan pesat dibidang budidaya perikanan laut, dengan komoditas yang dibudidayakan antara lain, ikan bawal bintang, kakap putih, ikan hias laut, abalon, tiram mutiara, rumput laut kultur jaringan, dan lobster.

Kegiatan budidaya tiram mutiara meliputi kegiatan pemijahan, pembenihan, pendederan, dan pembesaran. Pemijahan merupakan proses memperoleh benih tiram mutiara dengan cara meningkatkan tingkat kematangan gonad yang sempurna pada induk. Kemudian dilakukan proses pembuahan pada sel sperma dan telur induk tiram mutiara (Wardana dkk., 2014). Pembenihan dan pendederan pada budidaya tiram mutiara ditujukan untuk menghasilkan benih tiram mutiara yang memiliki kualitas tinggi sehingga dapat meningkatkan target produksi. Pada proses ini larva melalui fase kritis sehingga perlu perhatian khusus dalam menanganinya hingga larva menjadi tiram mutiara (Kotta, 2018). Larva yang telah berkembang menjadi tiram mutiara selanjutnya dipelihara dalam kegiatan pembesaran. Pembesaran tiram mutiara dilakukan untuk menghasilkan tiram mutiara dewasa sehat dengan kualitas yang baik. Kegiatan ini biasanya dilakukan di tengah laut menggunakan substrat. Rangkaian kegiatan budidaya tersebut dilakukan dengan memperhatikan manajemen kualitas air dan pakan untuk menunjang kegiatan budidaya sehingga menghasilkan produksi tiram mutiara yang maksimal (Astriwana dkk., 2008).

Berdasarkan uraian diatas, maka akan dilakukan kegiatan Praktik Kerja Lapang (PKL) mengenai Teknik Budidaya Tiram Mutiara (*Pinctada maxima*) terutama pada manajemen budidaya, manajemen pakan, dan manajemen kualitas air di Balai Perikanan Budidaya Laut (BPBL) Sekotong, Lombok Barat, Nusa

Tenggara Barat. Sekaligus memahami permasalah yang ada dengan memadukan teori yang diperoleh dari perkuliahan dengan kenyataan yang di lapangan.

1.2 Tujuan

1. Mengetahui manajemen budidaya pada Tiram Mutiara (*Pinctada maxima*) di Balai Perikanan Budidaya Laut (BPBL) Sekotong, Lombok Barat, Nusa Tenggara Barat
2. Mengetahui manajemen pakan pada Tiram Mutiara (*Pinctada maxima*) di Balai Perikanan Budidaya Laut (BPBL) Sekotong, Lombok Barat, Nusa Tenggara Barat
3. Mengetahui manajemen kualitas air pada Tiram Mutiara (*Pinctada maxima*) di Balai Perikanan Budidaya Laut (BPBL) Sekotong, Lombok Barat, Nusa Tenggara Barat

1.3 Manfaat

1. Mahasiswa mampu meningkatkan pengetahuan mengenai manajemen budidaya pada Tiram Mutiara (*Pinctada maxima*) di Balai Perikanan Budidaya Laut (BPBL) Sekotong, Lombok Barat, Nusa Tenggara Barat
2. Mahasiswa mampu meningkatkan pengetahuan mengenai manajemen pakan pada Tiram Mutiara (*Pinctada maxima*) di Balai Perikanan Budidaya Laut (BPBL) Sekotong, Lombok Barat, Nusa Tenggara Barat
3. Mahasiswa mampu meningkatkan pengetahuan mengenai manajemen kualitas air pada Tiram Mutiara (*Pinctada maxima*) di Balai Perikanan Budidaya Laut (BPBL) Sekotong, Lombok Barat, Nusa Tenggara Barat

II TINJAUAN PUSTAKA

2.1 Tiram Mutiara (*Pinctada maxima*)

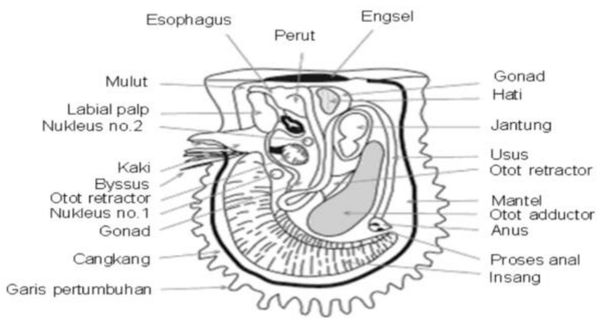
Tiram mutiara (*Pinctada maxima*) merupakan salah satu sumber daya laut Indonesia yang berasal dari famili Pteridae. Tiram mutiara juga dibudidayakan secara luas di dunia, khususnya di Australia dan Asia Tenggara (Putra dkk., 2022). Tiram mutiara memiliki tubuh yang lunak dengan sepasang cangkang yang tidak simetris dan keras (Supii, 2022). Klasifikasi tiram mutiara menurut Al-Habib dkk. (2018) ialah sebagai berikut:

Kingdom	: Animalia
Sub kingdom	: Invertebrata
Filum	: Molusca
Kelas	: Pelecypoda
Ordo	: Anisomyaria
Famili	: Pteridae
Genus	: *Pinctada*
Spesies	: *Pinctada maxima*

2.1.1 Morfologi Tiram Mutiara (*Pinctada maxima*)

Tiram mutiara memiliki sepasang cangkang yang melekat pada bagian punggung dimana terdapat engsel yang berguna untuk melindungi bagian dalam tubuh yang lunak sehingga terhindar dari benturan dan serangan dari hewan lain. Sepasang cangkang pada tiram mutiara memiliki bentuk yang tidak sama, salah satu cangkang memiliki bentuk lebih cembung dibandingkan cangkang yang lainnya. Pada bagian dalam cangkang terdapat *nacre* yang dapat membentuk lapisan mutiara yang mengkilap. Tiram mutiara dewasa memiliki warna cangkang kuning tua hingga kecoklatan, cangkang bagian (*narce*) dalam berwarna putih keperakan.

Tiram mutiara memiliki organ seperti gonad, hati, perut, kaki, mantel, otot adductor, dan otot retractor (Kotta, 2018).



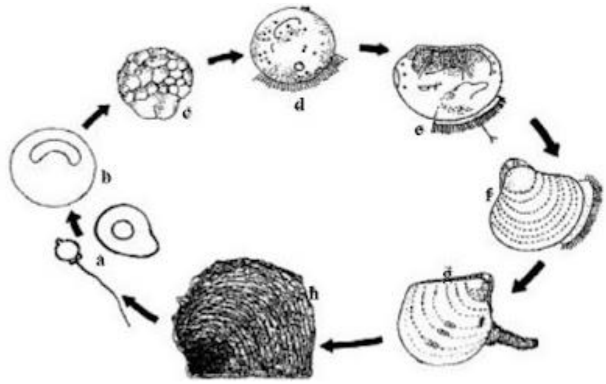
Gambar 1. Tiram Mutiara *(Pinctada maxima*)
Sumber: Supii, 2022

2.1.2 Habitat dan Penyebaran

Tiram mutiara (*Pinctada maxima*) memiliki habitat yaitu pada perairan dangkal dimana daerah tersebut merupakan perairan berpasir atau pasir berkarang (Mandosa dkk., 2023). Selain itu, tiram mutiara juga dapat ditemukan di dasar laut dengan kedalaman mencapai 20-60 m. Daerah penyebaran tiram mutiara yaitu dari laut Arafuru, Australia bagian Utara, Filipina, Myanmar, Thailand, Papua Nugini, dan Indonesia. Di Indonesia, tiram mutiara banyak tersebar di daerah Indonesia bagian Tengah dan Timur (Supii, 2022).

2.1.3 Siklus Hidup dan Reproduksi

Tiram mutiara termasuk dalam organisme *protandrous hermaprodite* dimana pada usia 3-4 tahun tiram mutiara mengalami fase sebagai jantan dengan ukuran 110-120 mm dan selanjutnya akan berubah menjadi individu betina. Tiram mutiara yang berukuran panjang cangkang 170 mm akan berkelamin jantan 50% dan berkelamin betina 50%. Kemudian, tiram mutiara yang telah berukuran 190 mm seluruhnya akan berjenis kelamin betina. Tiap individu tiram mutiara dapat menjadi jantan dan berubah menjadi betina pada beberapa musim pemijahan (Supii, 2022). Tiram mutiara melakukan pembuahan secara eksternal di dalam air dengan sperma dari tiram jantan yang terlebih dahulu keluar lalu 45 menit kemudian telur dikeluarkan dan dibuahi (Kotta, 2018).



Gambar 2. Siklus Hidup Tiram Mutiara (a. Telur dan sperma; b. Telur dibuahi; c. Pembelahan sel; d. Gastrula; e. Larva; f. Stadia umbo; g. Spat; h. Dewasa).
Sumber: Winanto, 2009

2.1.4 Kebiasaan Makan

Tiram mutiara merupakan biota laut yang dapat memilih makanan sesuai dengan kebutuhannya. Tiram mutiara akan memakan seluruh fitoplankton yang ada di lingkungannya. Selain itu, tiram mutiara cenderung menyukai makanan yang berukuran lebih kecil (Rizaki dkk., 2021). Tiram mutiara juga merupakan organisme filter *feeder* dimana organisme tersebut membutuhkan pakan seperti mikroalga yang memiliki kandungan nutrisi baik (Supii, 2022).

2.2 Teknik Budidaya Tiram Mutiara

Budidaya merupakan suatu kegiatan pemeliharaan biota akuatik dalam sistem yang terkontrol sehingga dapat dilakukan pengawasan terhadap pertumbuhan dan perkembangannya. Upaya ini dilakukan dengan tujuan mencapai keuntungan bersama, terutama pada budidaya tiram mutiara. Budidaya tiram memiliki potensi besar untuk meningkatkan produksi budidaya laut di Indonesia (Taqwa, 2019). Keberhasilan budidaya tiram mutiara sangat ditentukan oleh beberapa faktor budidaya, diantaranya proses pemijahan, pembenihan, dan pembesaran.

Budidaya tiram mutiara dilakukan dengan beberapa metoda. Metoda tersebut antara lain: Metoda rakit apung (*floating raft method*), metoden dasar (bottom method) dan metode tali rentang (*long line method*), masing-masing dilengkapi dengan keranjang pemeliharaan (*pocket*). Metoda yang umumnya digunakan dalam budidaya tiram mutiara di Indonesia yaitu metoda rakit apung dan tali rentang. Metoda dasar hanya unggul dari segi keamanannya saja, sedangkan untuk perawatan relatif lebih sulit (Taufiq dkk., 2007).

Kegiatan budidaya tiram mutiara yang dilaksanakan di Balai Perikanan Budidaya Laut (BPBL) Sekotong, Lombok Barat, Nusa Tenggara Barat, menggunakan teknik budidaya longline. Longline merupakan tempat menggantung pocketnet dan wadah penjarangan di laut. Tiram mutiara dibudidayakan dengan menggunakan metode longline sebagai tempat menggantungkan poket yang berisi spat pada tali panjang yang disebar di laut. Tali dengan panjang 500 meter dari garis pantai yang terdiri dari satu tali utama, tali gantung, dan pelampung serta jangkar (Dipa, 2022).

2.2.1 Pembenihan Tiram Mutiara

Proses pembenihan merupakan pemeliharaan biota akuatik dengan tujuan menjaga kualitas benih tetap baik sehingga menghasilkan individu yang baik ketika telah masuk ke proses pembesaran (Supi, 2022). Kegiatan pembenihan tiram mutiara dilakukan setelah melalui proses pemijahan. Kegiatan selanjutnya dilakukan inkubasi pada bak bervolume 3 ton dalam keadaan gelap dan diberi aerasi keras sehingga dihasilkan pembuahan secara merata dan sempurna. Cahaya sangat mempengaruhi lebar sempitnya bukaan cangkang tiram mutiara. Semakin kecil intensitas cahaya, semakin besar peluang cangkang membuka lebar. Hal ini diperlukan agar tiram mutiara dapat mengeluarkan sperma/telur serta melakukan proses pengambilan makanan (Sujoko, 2010). Telur yang terbuahi berbentuk bulat mengapung di permukaan air maupun melayang di bak, sedangkan telur yang tidak terbuahi mengendap di dasar bak. Kemudian dilakukan penyaringan setelah 2 jam dan dicuci dengan air laut. Telur ditetaskan pada bak bervolume 3 ton dalam waktu 18 jam dengan aerasi kecil dan dan dalam keadaan gelap. Larva yang telah menetas disaring dan dicuci kemudian larva ditebar dengan kepadatan 800 ribu ekor larva per 3 ton bak. Jika diameter larva telah berukuran 40-60 mikrometer, perlu dilakukan penggantian air rutin selama 3 hari sekali sekaligus penyaringan larva sesuai ukuran larva dengan menggunakan plankton net bertingkat ukuran 40 µm, 60 µm, 80 µm, 100 µm, 120 µm, 150 µm, 180 µm, 200 µm, 220 µm, dan 250 µm (Astriwana dkk., 2008).

Stadia larva tiram mutiara terdiri dari *D-Shape*, Umbo 1, Umbo 2, Umbo 3, Planty grade, dan Spat. Pada fase *D-Shape* berlangsung selama 1-5 hari, larva mulai diberi pakan dengan fitoplankton sebagai sumber nutrisi yang bersifat makronutrien maupun mikronutrien. Ukuran larva telah mencapai 70 mikrometer dengan tubuh menyerupai huruf D. Pada fase ini tubuh larva tiram mutiara ditutupi cangkang tipis sehingga dapat disebut fase kritis bagi larva (Winanto, 2004). Setelah larva memasuki umur 6 hari, larva mengalami metamorfosis menjadi fase umbo 1 dengan ditandai tubuhnya hampir bundar. Kemudian bermetafosis menjadi fase umbo 2 dimana tonjolan pada dorsal mulai terlihat, dan tonjolan terlihat jelas pada fase umbo 3. Pada fase ini larva terlihat bergerak dengan cara berputar-putar. Fase *plantygrade* ditandai dengan terlihatnya titik hitam (*eye spot)* pada cangkang larva dan penonjolan kaki (*ped*) serta mulai terlihat lembaran-lembaran insang. Fase ini adalah masa kritis kedua dimana tumbuh akar bisus sehingga akan berenang terus menerus untuk mencari tempat/media yang benar-benar cocok untuk menempel. Larva akan menetap pada substrat pada fase spat, tubuhnya hampir berbentuk tiram mutiara dewasa (Kotta, 2017).

2.2.1.1 Teknik Pemijahan Tiram Mutiara

Proses pemijahan merupakan proses perkawinan yang dilakukan induk jantan dan induk betina dimana keduanya mengeluarkan sel sperma dan sel telur secara eksternal (di luar tubuh). Pemijahan pada umumnya dilakukan dalam usaha pembenihan dengan tujuan melestarikan dan menghasilkan benih unggul yang memiliki nilai jual tinggi. Sedangkan pada usaha pembesaran, pemijahan dilakukan untuk mendapatkan calon induk baru yang memiliki kualitas lebih baik (Khairuman, 2002). Pemijahan tiram mutiara di Balai Budidaya Laut Lombok dapat dilakukan dengan 3 metode dalam proses budidaya yaitu secara alami, donor sperma, dan kejut suhu. Pemijahan secara alami dilakukan terhadap tiram mutiara jantan maupun betina yang telah matang gonad. Induk tiram mutiara yang matang gonad sempurna, cangkang luar dibersihkan hingga tidak ada kotoran yang menempel. Kemudian bilas hingga bersih dengan air tawar dan induk ditandai dengan kode jantan atau betina sesuai dengan kondisi gonadnya. Induk dikeringanginkan selama 10-15 menit, sambil menyiapkan air laut bersih untuk media tempat pemijahan (bak fiber volume 100L atau 200L). Induk dimasukan dalam bak fiber tanpa menggunakan aerasi, apabila selama 30 menit atau 60 menit pertama tidak terjadi respon pemijahan, air media diganti dengan membuang air media sebelumnya. Proses ini dapat berlangsung antara 4-5 kali sampai terjadi pemijahan. Setelah terjadi pemijahan, yang ditandai dengan keluarnya sperma terlebih dahulu dan disusul dengan keluarnya sel telur. Sel telur dan sel sperma yang sudah tertampung pada bak pemijahan diinkubasi selama 60-90 menit tanpa aerasi, agar proses pembelahan berlangsung sempurna (Wardana dkk., 2014).

Pemijahan dengan metode donor sperma dan kejut suhu dilakukan secara berkelanjutan, dimulai dengan metode donor sperma. Donor sperma dilakukan dengan membunuh salah satu induk dan mengambil spermanya kemudian mencacahnya lalu disebarkan ke dalam wadah pemijahan. Kemudian dilanjutkan dengan metode *thermal shock* (kejutan suhu panas), yaitu menaikkan suhu pemeliharaan 27°C ke 33°C. Induk yang berasal dari wadah donor sperma dipindahkan ke dalam wadah yang suhunya sudah dinaikkan kemudian didiamkan sebentar (20 – 30 menit) lalu dipindahkan lagi ke dalam wadah lain (bak fiber 3 m^3) dengan suhu air normal yaitu 27°C. Pemijahan induk tiram mutiara berhasil ditandai dengan keluarnya sperma dan telur 15 – 30 menit setelah perlakuan kejut suhu disertai membukanya cangkang dari tiap-tiap induk. Setelah itu induk jantan akan mengeluarkan sperma terlebih dahulu lalu induk betina mengeluarkan telurnya kemudian. Setelah sperma dan telur sudah keluar, maka harus segera dipindahkan ke dalam bak berukuran 3m^3 lainnya secara hati-hati. Pemijahan dengan metode ini dapat dilakukan 2-3 kali. Adapun pada perlakuan digunakan perbandingan indukan jantan-betina yaitu 1 : 3 (Astriwana dkk., 2008).

Kegiatan pemijahan dengan menggunakan metode pemijahan buatan yaitu donor sperma dan kejut suhu. Kegiatan pembenihan dilakukan di bak selama 18 jam, kemudian disaring dan ditebar dengan kepadatan 800 ribu ekor larva per 3 ton bak. Fase perkembangan larva dan pembesaran yang akan dilaksanakan di tengah laut lombok menggunakan substrat. Selain itu, penting untuk memperhatikan manajemen kualitas air dan pakan sebagai penunjang kegiatan budidaya (Astriwana dkk., 2008).

2.2.2 Teknik Pendederan Tiram Mutiara

Pendederan adalah kegiatan lanjutan setelah proses pemeliharaan spat di hatchery dan pemindahannya ke laut. Menurut Kristiningrum dan Bendjamin (2018), proses ini dilakukan dengan metode *longline* dan pada satu siklus diperlakukan waktu 12 bulan dengan ukuran spat antara 6-8 cm. Metode *longline* digunakan untuk menggantung pocket yang berisikan spat kolektor hingga anti spat berukuran siap panen. Pendederan dilakukan dengan memasukkan indukan tiram ke dalam keranjang kawat dan digantung pada rakit dengan kedalaman kurang lebih 7 meter. Pendederan tiram mutiara ini diatur dalam SNI 7874:2013 yang berisikan tentang hal-hal yang perlu diperhatikan antara lain lokasi, kualitas air, konstruksi longline, spat, serta peralatan dan sarana penunjang. Dalam proses ini juga melewati seleksi penjarangan. Penjarangan memiliki tujuan untuk mengurangi tingkat kepadatan spat persatuan ruang yang dilakukan pada saat pembongkaran spat pada kolektor.

2.2.3 Teknik Pembesaran Tiram Mutiara

Pembesaran merupakan kegiatan pemeliharaan benih tiram mutiara pada fase spat hingga tiram mutiara siap untuk dipanen. Dalam proses ini termasuk dengan proses insersi nukleus atau pembentukan mutiara. Mutiara murni dibentuk dengan masuknya benda asing dalam rubah tubuh tiram. Dalam tiram budidaya, campur tangan manusia terjadi saat proses memasukkan benda asing ke dalam tubuh tiram. Benda asing yang dimasukkan dikenal dengan nukleus mutiara dan lapisan jaringan lunaknya dinamakan saibo. Tiram mutiara dengan kualitas mutiara yang baik memiliki umur sekitar 2 tahun dengan masa pemeliharaannya. Setelah proses insersi, selanjutnya dilakukan proses tento atau kegiatan membolak balikkan posisi tiram yang bertujuan untuk menjaga kebersihan dari hama, organisme, dan predator. Pemeliharaan akan berlangsung selama 1-2 tahun dengan pengecekan berkala 1 bulan sekali (Astriwana dkk., 2008).

2.2.3.1 Monitoring Pertumbuhan Tiram

Pertumbuhan larva dimonitoring dengan pengambilan sampel dan proses penjarangan dengan tujuan untuk menghasilkan spat yang berukuran seragam. Spat yang memiliki ukuran yang sama satu sama lain akan memiliki kompetisi makanan yang kecil. Menurut Katto (2017) sampling diawali dengan pengambilan 10 liter dan diambil 1 ml dari wadah sampling untuk dilakukan pengamatan di bawah mikroskop. Jumlah larva yang didapatkan akan disesuaikan dengan volume sampel yang diambil. Dilanjutkan dengan proses pengamatan mikroskop yang berisi tentang perhitungan kepadatan dan pengamatan apakah larva akan memakan pakan yang diberikan.

2.3 Manajemen Pakan

Pemberian pakan pada tiram mutiara dilakukan sejak tiram berukuran larva fase *D-Shape.* Menurut penelitian sebelumnya yang dilakukan oleh Kotta (2017) beberapa makanan yang diberikan berupa fitoplankton jenis *Ishocrysis galbana*, *Nannochloropsis* sp, dan *Pavlova lutheri*. Fitoplankton *Isochrysi*s *galban*a diberikan sampai fase Umbo 2, dosis pakannya pada awal pemberian mencapai 1000 ml/bak, dosisnya akan menyesuaikan ukuran serta umur larva dan perubahan stadia/fase larva. Menurut Sujoko (2010), setiap harinya larva akan bertumbuh antara 5-10 mikrometer dan mengakibatkan akan ada penambahan jenis dan dosis pakan menjadi pakan campuran antara 3 jenis pakan yaitu *Isochrysis galbana*, *Nannochloropsis* sp, dan *Pavlova lutheri* dengan perbandingan 1:1:1. Pemberian pakan campuran dilakukan setelah larva tiram mencapai fase Umbo 3. Pencampuran dilakukan dengan rata pada toples dan ditebar pada media pemeliharaan secara perlahan-lahan sesuai dosis yang seharusnya diberikan. Umumnya pemberian pakan dilakukan dengan teko plastik bervolume 2 liter dan diberikan sebanyak 2 kali sehari pada pagi dan malam berjarak 12 jam.

2.4 Manajemen Kualitas Air

Keberhasilan dalam budidaya ditunjang oleh beberapa faktor. Salah satunya adalah manajemen kualitas air. Secara umum kualitas air dapat diartikan sebagai faktor fisika, kimia, dan biologi yang mempengaruhi manfaat penggunaan air bagi manusia ataupun keperluan budidaya ikan. Untuk menjaga kualitas air yang baik, diperlukan pemeliharaan lahan budidaya yang merujuk pada berbagai aspek dan tindakan seperti keberlanjutan lahan tempat budidaya dilakukan. Pemeliharaan lahan adalah suatu pendekatan yang mencakup aspek seperti kondisi tanah, kebersihan lahan, pengelolaan air, serta keberlanjutan lingkungan. Kualitas air dalam budidaya adalah salah satu faktor yang mempengaruhi kelangsungan hidup, perkembang biakan, pertumbuhan dan produksi dari biota yang dipelihara. Air sebagai media budidaya harus disesuaikan dengan keadaan di alam serta sesuai dengan kemampuan organisme dalam menyesuaikan diri. Parameter yang berpengaruh terhadap pertumbuhan spat tiram mutiara diantaranya adalah suhu, salinitas, kecepatan arus dan pH (Kota, 2016).

2.4.1 Suhu

Suhu merupakan salah satu parameter lingkungan yang berpengaruh langsung terhadap organisme. Suhu permukaan laut di perairan dapat berubah-ubah setiap musimnya. Perairan di lombok memiliki suhu berkisar dengan 22-29°C. Nilai suhu ini cocok dengan kegiatan budidaya tiram mutiara. Untuk negara indonesia yang memiliki iklim tropis, pertumbuhan yang baik dicapai pada suhu 28-30°C (Sutaman, 1993). Menurut (Astriwana dkk., 2008), musim yang paling potensial untuk dilakukan budidaya tiram mutiara adalah kisaran bulan JJA (Juni-Juli-

Agustus). Pengaruh suhu sangat menentukan keberhasilan pembenihan induk. Hal ini dibuktikan dengan penelitian yang dilakukan oleh Hamzah (2015) yang menyatakan bahwa terjadi kematian massal pada anakan tiram mutiara bersama dengan naiknya suhu harian (Kristiningrum dan Bendjamin, 2018)

2.4.2 Salinitas

Salinitas merupakan jumlah garam yang terdapat dalam suatu volume tanah atau air (Nusantara dkk., 2021). Menurut Walid dan Darmawan (2017) salinitas adalah kadar garam yang terlarut dalam air. Salinitas memiliki peranan penting dalam penetasan telur, pembentukan lapisan mutiara, dan pertumbuhan tiram mutiara. Hamzah (2015) mengemukakan bahwa kisaran kualitas air masih layak untuk pemeliharaan tiram mutiara yaitu berkisar antara 32-33 ppt, dan umumnya salinitas pada media pemeliharaan akan menurun akibat turunnya hujan dan masuknya debit air tambahan dari sungai sungai. Menurut Fathurrahman dan Aunurohim (2014) salinitas yang tergolong aman untuk kelangsungan hidup tiram mutiara berkisar antara 15-35 ppt, dimana salinitas 18 ppt dibutuhkan untuk pertumbuhan normal dan untuk produksi mutiara yang berkualitas baik dibutuhkan salinitas 21 ppt atau lebih.

2.4.3 Kecerahan

Kecerahan pada suatu perairan merupakan suatu keadaan dimana cahaya matahari dapat menembus lapisan air pada kedalaman tertentu. Kecerahan sangat penting bagi budidaya karena berhubungan dengan kedalaman penetrasi cahaya yang dibutuhkan oleh organisme. Kedalaman penetrasi cahaya yang semakin besar maka nilainya semakin baik. Pada budidaya tiram mutiara, penetrasi cahaya yang baik ialah lebih besar dari 5 meter (Sahusilawane dan Tomatala, 2014). Selain itu, lama penyinaran dapat mempengaruhi buka dan tutupnya cangkang. Cangkang tiram mutiara akan terbuka sedikit ketika ada cahaya serta akan terbuka lebar ketika gelap (Jamilah, 2015).

2.4.4 Kadar Oksigen Terlarut

Kadar oksigen terlarut atau *dissolved oxygen* merupakan parameter kualitas air yang dapat digunakan untuk menentukan mutu air. Oksigen terlarut menjadi faktor pembatas bagi kelangsungan hidup dan perkembangan tiram mutiara. Perubahan pada oksigen terlarut dapat menyebabkan kematian pada organisme. Kandungan oksigen terlarut minimum 5 mg oksigen setiap liter atau 5 ppm dapat mempertahankan kehidupan hewan akuatik (Awaluddin dkk., 2013). Menurut Sinaga dkk. (2015) mengatakan bahwa kadar oksigen terlarut yang optimal agar tiram mutiara dapat hidup baik di perairan yaitu berkisar 5,2-6,6 mg/L.

2.4.5 pH

pH atau derajat keasaman merupakan jumlah atau aktivitas ion hidrogen yang ada pada suatu perairan. Umumnya, nilai pH dapat dikatakan sebagai besarnya tingkat keasaman atau kebebasan suatu perairan. Perairan dapat dikatakan netral apabila memiliki nilai pH 7. Sedangkan, perairan yang memiliki nilai pH kurang dari 7 dapat dikatakan perairan tersebut bersifat asam serta perairan dengan pH lebih dari 7 yaitu memiliki sifat basa. Pada pH 6,75-7,00 aktivitas tiram akan meningkat. Sedangkan, pada pH 4,0-6,5 akan mengalami penurunan. pH perairan yang melebihi 9 akan menyebabkan tiram mutiara berhenti berproduksi (Tasaes dkk., 2022). Menurut penelitian Sahusilawane dan Tomatala (2014) mengatakan bahwa nilai pH optimal yang dibutuhkan tiram mutiara untuk berkembang biak dan tumbuh dengan baik yaitu berkisar antara 7,9-8,2.

2.4.6 Nitrit

Senyawa nitrit pada perairan biasanya ditemukan dalam jumlah yang sedikit karena senyawa tersebut memiliki sifat yang tidak stabil di perairan. Perairan yang terdapat nitrit disebabkan oleh hasil reduksi senyawa nitrat atau oksidasi amonia oleh mikroorganisme serta datang dari hasil ekskresi fitoplankton (Simbolon, 2016). Nitrit dengan kadar melebihi 0,05 mg/L dapat bersifat toksik bagi biota laut. Selain itu, nitrit memiliki sifat lebih toksik terhadap manusia dan hewan (Supii dan Arthana, 2009).

2.4.7 Nitrat

Senyawa nitrat merupakan suatu bentuk nitrogen utama di perairan alami. Terbentuknya nitrat yaitu berawal dari amonium yang masuk ke dalam badan sungai, salah satunya yaitu melalui limbah domestik dengan adanya aktivitas mikroorganisme di dalam air, seperti bakteri nitorumonas. Mikroorganisme akan mengubah amonium menjadi nitrit yang kemudian berubah menjadi nitrat dengan adanya proses oksidasi oleh bakteri (Mustofa, 2015). Nitrat juga merupakan nitrogen yang memiliki peran sebagai nutrien utama bagi pertumbuhan tanaman dan alga. Nitrat dapat menjadi indikator kesuburan perairan karena dapat mendukung pertumbuhan fitoplankton. Pakan alami seperti fitoplankton juga dibutuhkan oleh tiram mutiara pada masa pertumbuhan dari anakan hingga besaran. Kandungan nitrat yang baik untuk organisme budidaya yaitu berkisar 0,2525-0,6645 mg/L (Jamilah, 2015).

2.4.8 Ammonia

Senyawa amonia merupakan salah satu nitrogen anorganik yang larut dalam air. Amonia dapat dikatakan sebagai salah satu indikator pencemaran organik di perairan dimana berasal dari hasil proses pembusukan bahan-bahan organik secara anaerob oleh mikroba. Tingginya kandungan amonia pada suatu perairan dapat menyebabkan warna air keruh dan menghasilkan bau yang tidak sedap (Simbolon, 2016). Ammonia yang terdapat pada perairan berasal hasil dan proses metabolisme organisme akuatik. Kadar amonia yang diperbolehkan dalam kadar mutu air laut bagi biota laut ialah 0,3 mg/L (Fathurrahman dan Aunurohim, 2014).

2.5 Monitoring Hama dan Penyakit

Hama dalam artian luas merupakan bentuk gangguan baik pada manusia, ternak, ataupun tanaman. Pengertian hama secara sempit adalah suatu hewan dalam satu kegiatan budidaya yang merusak atau aktivitas hidupnya dapat menimbulkan kerugian secara ekonomis. Tetapi potensi mereka sebagai hama nantinya perlu dimonitor dalam suatu kegiatan yang disebut pemantauan atau monitoring. Kerugian secara langsung yang ditimbulkan oleh hama adalah jumlah ikan berkurang karena dimangsa, persaingan dalam pemanfaatan oksigen serta pakan (Rahmaningsih, 2018)

Penyakit adalah gangguan pada kondisi tubuh dan organ yang diakibatkan oleh adanya perubahan dari tubuh ikan yang disebabkan oleh organisme yang menempel pada bagian tubuh ikan yang luka. Penyakit pada ikan dibedakan menjadi dua, yaitu penyakit infeksius seperti bakteri, virus, parasit, dan jamur serta penyakit non-infeksi seperti stress, tumor, gangguan gizi pakan, dan traumatik. Sumber penyakit yang sering menyerang ikan dikelompokkan menjadi hama, parasiter, dan non-parasiter. Hama adalah hewan yang berukuran lebih besar dan mampu menimbulkan gangguan pada ikan yang terdiri dari predator, kompetitor, dan pencuri. Parasiter adalah penyakit yang disebabkan oleh aktivitas organisme parasit, seperti virus, bakteri, jamur, protozoa, cacing, dan udang renik. Non-parasiter adalah penyakit yang disebabkan bukan oleh lingkungan, pakan, dan keturunan (Suwarsito dan Mustafidah, 2011).

Budidaya tiram mutiara memiliki kemungkinan mengalami penyakit bahkan kematian. Salah satu penyebab berkurangnya laju pertumbuhan hingga kematian yang disebabkan oleh *biofouling* (Organisme penempel) yang umumnya hidup dengan cara melekat pada keranjang ataupun cangkang tiram yang dipelihara. Adanya *biofouling* bervariasi tergantung pada waktu dan kondisi perairan. Dampak terserangnya tiram mutiara dengan organisme ini adalah tiram menjadi kerdil (Jefri dkk., 2017).

Upaya yang dilakukan untuk meminimalisir adanya hama, penyakit, dan predator adalah dengan menjaga salinitas air untuk selalu stabil dan sesuai dengan kebutuhan komoditas, menjaga suhu air, pemilihan kondisi lokasi budidaya dengan tingkat kecerahan yang bagus, serta lokasi tidak pada perairan dasar dan berlumpur.

III RENCANA KEGIATAN

3.1 Waktu dan Tempat

Praktik kerja lapang ini dilaksanakan di Balai Perikanan Budidaya Laut (BPBL) Sekotong, Lombok Barat, Nusa Tenggara Barat. Kegiatan Praktik Kerja Lapang dilaksanakan mulai tanggal 24 Juni 2024 hingga 23 Agustus 2024. Kegiatan penyusunan laporan dilakukan di Universitas Airlangga Fakultas Perikanan dan Kelautan.

3.2 Metode Kerja

Metode kerja yang digunakan dalam Praktik Kerja Lapang ini adalah deskriptif. Metode ini merupakan metode penelitian yang digunakan untuk menggambarkan masalah yang terjadi pada masa sekarang atau yang sedang berlangsung dengan tujuan untuk mendeskripsikan apa yang sedang terjadi sebagaimana mestinya pada saat penelitian dilakukan (Nana Sudjana dan Ibrahim, 1989). Menurut Mohammad Ali (1982), metode penelitian deskriptif digunakan untuk memecahkan sekaligus menjawab permasalahan yang terjadi pada masa sekarang. Metode ini diawali dengan pengumpulan, klasifikasi, dan analisis atau pengolahan data, membuat kesimpulan, dan laporan dengan tujuan utama untuk membuat penggambaran tentang suatu keadaan secara objektif dalam suatu deskripsi.

3.3 Metode Pengumpulan Data

Data yang dikumpulkan dalam Praktik Kerja Lapang ini yaitu data primer dan data sekunder. Data primer berupa data observasi dan wawancara, sedangkan data sekunder berupa dokumentasi yang terkumpul selama kegiatan berlangsung.

3.3.1 Data Primer

Data primer merupakan data asli atau data baru yang didapatkan saat dilakukannya kegiatan. Data primer didapatkan dengan cara pengumpulan secara langsung. Teknik yang digunakan untuk mengumpulkan data primer antara lain metode survey, partisipasi aktif, dan observasi. Pengambilan data primer dalam kegiatan ini dilakukan dengan pencatatan data hasil berdasarkan observasi maupun wawancara dengan pihak terkait dari Balai Perikanan Budidaya Laut (BPBL) Sekotong, Lombok Barat, Nusa Tenggara Barat (Jaya dkk., 2020). Data primer yang akan diambil pada Praktik Kerja Lapang ini meliputi. Teknik budidaya, manajemen pakan, dan manajemen kualitas air.

a. Metode Wawancara

Wawancara merupakan metode pengumpulan data dengan melakukan pertemuan dua orang untuk bertukar informasi dan ide melalui tanya jawab (Jaya dkk., 2020). Wawancara pada Praktik Kerja Lapang ini dilakukan dengan melakukan tanya jawab dengan pegawai balai, pembimbing lapang, atau orang yang bersangkutan mengenai seluruh teknik budidaya tiram mutiara di Balai Perikanan Budidaya Laut (BPBL) Sekotong, Lombok Barat, Nusa Tenggara Barat.

b. Metode Partisipasi Aktif

Partisipasi aktif merupakan kegiatan seorang peneliti yang ikut serta dalam kegiatan secara langsung dilapangan (Nazir, 1998). Metode ini ditujukan seorang peneliti untuk mendapatkan data melalui pengamatan dan penelitian dalam kegiatan sehari-hari Balai Perikanan Budidaya Laut (BPBL) Sekotong, Lombok Barat, Nusa Tenggara Barat yang meliputi Teknik budidaya tiram mutiara, pembenihan, pemijahan, pendederan, pembesaran, manajemen pakan, manajemen kualitas air, serta hama dan penyakit kegiatan lainnya yang berkaitan dengan Praktik Kerja Lapang yang dilakukan.

c. Metode Observasi

Observasi merupakan pengumpulan data dengan melakukan pengamatan di lapangan mengenai objek yang diteliti secara langsung di balai Perikanan Budidaya Laut (BPBL) Sekotong, Lombok Barat, Nusa Tenggara Barat dan kemudian dicatat (Jaya dkk., 2020). Observasi dilakukan terhadap berbagai hal yang berhubungan dengan kegiatan pemijahan, pembenihan, pendederan, dan pembesaran meliputi persiapan kolam, pengukuran kualitas air, pembuatan pakan, pemberian pakan, hama dan penyakit, dan pemanenan.

3.3.2 Data Sekunder

Data sekunder merupakan data yang diperoleh secara tidak langsung dari sumbernya. Data ini didapat dari dokumentasi, laporan pemerintah, pustaka-pustaka, buku-buku, dan sebagainya yang tidak perlu diolah lagi. Sumber data sekunder ini tidak langsung memberikan data pada pengumpul data. Data sekunder sebagai pelengkap data primer yang diolah lebih lanjut untuk menghasilkan informasi yang kuat (Tersiana, 2018). Data sekunder dalam Praktik Kerja Lapang ini berkaitan dengan manajemen budidaya, pakan dan kualitas air Tiram Mutiara.

IV HASIL DAN PEMBAHASAN

4.1 Keadaan Umum Lokasi Praktik Kerja Lapangan

Praktik kerja lapang dilakukan di Balai Perikanan Budidaya Laut Sekotong, Lombok Barat, Nusa Tenggara Barat. Keadaan umum lokasi praktik kerja lapang menjelaskan mengenai sejarah balai, letak geografis balai, struktur organisasi, sarana dan prasarana. Selain itu juga terdapat fasilitas pendukung dan peralatan pendukung.

4.1.1 Sejarah Balai Perikanan Budidaya Laut Lombok Barat

Pada tahun 1992, Loka Budidaya Laut Lombok (LBL-Lombok) merupakan subsenter dari Balai Budidaya Laut Lampung. Loka tersebut dibangun di Dusun Gerupuk, Desa Sengkol, Kecamatan Pujut, Kabupaten Lombok Tengah. Pembangunan loka tersebut bertujuan untuk mengembangkan budidaya laut di kawasan tengah Indonesia. Pada tahun 1994, terjadi perubahan pada subsenter dimana berganti menjadi Unit Pelaksana Teknis (UPT) yang berdiri sendiri dibawah naungan Direktorat Jendral Perikanan Departemen Pertanian. Pada tahun 2000, Perikanan LBL Lombok berdiri dibawah Departemen Eksplorasi Laut. Pada tahun 2004, proyek SPL-OECF memberikan fasilitas berupa produksi benih tiram mutiara dan sarana pembenihan ikan di lokasi baru yaitu Dusun Gili Genting, Desa Sekotong Barat, Kecamatan Sekotong Barat, Kabupaten Lombok Barat. Pada tahun 2006, Loka Budidaya Laut Lombok berubah menjadi Balai Budidaya Laut Lombok dimana dilakukan wilayah pengembangan diseluruh provinsi di Pulau Kalimantan, Jawa, Bali, Nusa Tenggara Barat, dan Nusa Tenggara Timur. Kemudian, Balai

Budidaya Laut Lombok berubah kembali menjadi Balai Perikanan Budidaya Laut yang berada di Dusun Gili Genting, Desa Sekotong Barat, Kecamatan Sekotong Barat, Kabupaten Lombok Barat.

4.1.2 Letak Geografis Balai Perikanan Budidaya Laut Lombok Barat

Balai perikanan Budidaya Laut Lombok terletak di Dusun Gili Genting, Desa Sekotong Barat, Kecamatan Sekotong Barat, Kabupaten Lombok Barat, Provinsi Nusa Tenggara Barat. Balai Perikanan Budidaya Laut (BPBL) tersebut berada pada posisi geografis 115°46’-116°28’ BT dan 8°55’ LS serta berada pada ketinggian 5 meter di atas permukaan laut. Batasan dari lokasi Balai Perikanan Budidaya Laut (BPBL) yaitu sebelah timur berbatasan dengan Dusun Pengawisan. Sebelah selatan berbatasan dengan Desa Kedaru. Sebelah barat berbatasan dengan Dusun Gili Genting. Serta pada sebelah utara berbatasan dengan Selat Lombok. Balai ini memiliki daerah dengan luas area 30.000 m^2 atau sekitar 3 Ha.

4.1.3 Struktur Organisasi

Struktur organisasi Balai Perikanan Budidaya Laut Sekotong, Lombok Barat, Nusa Tenggara Barat yaitu terdiri atas:

1. Kepala Balai
2. Kasubag Umum
3. Kelompok Jabatan Fungsional Umum dan Kelompok Jabatan Fungsional Tertentu

4.1.4 Sarana dan Prasarana

Sarana dan prasarana pemijahan, pembenihan, dan pembesaran pada Balai Perikanan Budidaya Laut Sekotong, Lombok Barat yaitu keramba jaring apung, longline, dan *hatchery* tiram mutiara.

Gambar 3. Keramba jaring apung

Keramba jaring apung merupakan tempat pemeliharaan berbentuk persegi dengan rangka terbuat dari plastik serta memiliki pelampung dari drum plastik agar tempat pemeliharaan tetap terapung dalam air (Hendrajat, 2018). Selain itu dibawah keramba jaring apung terdapat pemberat atau jangkar yang berfungsi menjaga keramba jaring apung tetap pada posisinya jika terkena ombak laut. Keramba jaring apung yang digunakan BPBL Sekotong, Lombok menggunakan "AQUATEC" dengan bahan High Density Polyethylene (HDPE). Jumlah petakan sebanyak 4 petakan dengan ukuran masing-masing 3 x 3 meter. Umur teknis keramba jaring apung ini dapat mencapai 30 tahunan.

Gambar 4. *Longline*

Longline merupakan tempat penggantungan pocket tiram mutiara yang terdiri dari tali gantungan, pelampung bulat, dan pemberat. Tali gantungan pocket tiram mutiara terbuat dari tali PE berukuran 22 mm dengan panjang 100 meter. Jarak antara bola pelampung longline yaitu 5 meter dan terdapat tali gantungan dengan jarak antar tali 80 cm dengan panjang tali ke bawah 2,5 meter dan 3 meter. Jumlah gantungan dalam setiap longline yaitu 100 tali gantungan.

Gambar 5. *Hatchery* Tiram Mutiara

Hatchery tiram mutiara merupakan tempat yang disediakan untuk melakukan proses pemijahan dan pembenihan tiram mutiara. Hatchery tiram mutiara memiliki keadaan yang gelap dan tenang agar membantu pertumbuhan dan meminimalisir tingkat stres pada tiram mutiara. Sarana pada *hatchery* yaitu terdapat bak fiber 3 ton, filter air, dan tempat kultur pakan larva tiram mutiara.

Gambar 6. Laboratorium Kesehatan Ikan dan Lingkungan

Laboratorium kesehatan ikan dan lingkungan merupakan laboratorium yang digunakan sebagai tempat pengecekan dan penyimpanan data parameter kualitas air. Laboratorium ini juga digunakan untuk tempat pengamatan kesehatan ikan serta meganalisis penyakit yang menyerang biota atau komoditas yang dibudidayakan.

Gambar 7. Asrama

Pada Balai Perikanan Budidaya Laut Lombok ini menyediakan asrama dimana asrama tersebut merupakan tempat singgah yang disediakan untuk mendukung berbagai kegiatan seperti kegiatan kunjungan, praktik, magang, maupun penelitian yang dilakukan oleh tamu atau mahasiswa.

4.2 Manajemen Budidaya Tiram Mutiara (*Pinctada maxima*)

Budidaya merupakan kegiatan perikanan yang menghasilkan organisme akuatik dalam lingkungan yang terkontrol dengan tujuan memperoleh keuntungan (Kristiningrum dan Bendjamin, 2018). Manajemen budidaya tiram mutiara (*Pinctada maxima*) di BPBL Sekotong, Lombok Barat terdiri dari teknik pemijahan tiram mutiara (*Pinctada maxima*), teknik pemeliharaan larva dan benih tiram mutiara (*Pinctada maxima*), dan teknik pembesaran tiram mutiara (*Pinctada maxima*).

4.2.1 Teknik Pemijahan Tiram Mutiara (*Pinctada maxima*)

Pemijahan merupakan proses induk betina mengeluarkan sel telur dan induk jantan mengeluarkan sperma yang kemudian diikuti dengan perkawinan. Pemijahan menjadi salah satu proses reproduksi yang menentukan kelangsungan hidup suatu spesies (Bahrudin dkk., 2023). Teknik pemijahan tiram mutiara (*Pinctada maxima*) di BPBL Sekotong, Lombok Barat dilakukan dengan kegiatan seleksi induk, persiapan wadah pemijahan, dan proses pemijahan tiram mutiara (*Pinctada maxima*).

1. Seleksi Induk

Seleksi induk merupakan kegiatan yang menentukan induk siap pijah dengan melihat tingkat kematangan gonadnya. Kegiatan seleksi induk di BPBL Sekotong, Lombok Barat akan dilakukan setiap 1 bulan sekali saat musim telur tiba.

Hal ini sesuai dengan penelitian Aprisanto dkk. (2008) seleksi tingkat kematangan gonad dilakukan setiap 1 bulan sekali untuk memastikan bahwa induk tersebut siap dipijahkan atau tidak.

Kegiatan seleksi induk di BPBL Sekotong, Lombok Barat dimulai dengan pengambilan tiram mutiara di longline, kemudian dibawa ke keramba jaring apung untuk melakukan pengecekan. Induk tiram mutiara yang dilakukan pengecekan berusia 2,5-4 tahun yang memiliki panjang cangkang >12 cm. Induk tiram mutiara ditempatkan ke dalam bak besar berisi air agar cangkangnya terbuka, kemudian masukan forsep untuk menahan cangkang agar tidak tertutup dan dilakukan pengecekan dengan spatula. Pengecekan ini bertujuan untuk melihat apakah sperma/telur pada tiram sudah matang atau belum. Menurut Khairiyak dkk, (2017) Semakin tinggi tingkat kematangan gonad individu kerang makan akan semakin besar atau luas tutupan gonad yang menyelimuti organ dalam cangkang dan memiliki warna yang cenderung semakin mencolok. Perbedaan penampakan gonad jantan dan betina berada pada warna, dimana gonad betina memiliki warna yang kuning atau orange lebih mencolok dibandingkan gonad pada jantan yang memiliki warna putih susu. Gonad tersebut bisa berkembang menutupi hampir seluruh jaringan lunak, dan menutupi 60 - 80% jaringan lunak pada saat matang.

(a) (b)

Gambar 8. Induk Matang Gonad (a. Betina; b. Jantan)

Pada hasil seleksi tiram pada bulan Agustus didapatkan 21 ekor induk jantan dan 17 ekor induk betina yang sudah matang gonad. Induk yang matang gonad dipisahkan dari calon induk yang lain. Kemudian induk dibersihkan sampai benar-benar bersih dengan menggunakan pisau, lalu dibilas lagi menggunakan air laut, induk betina yang sudah matang gonad tanda di bagian cangkangnya dengan cara dipotong berbentuk segitiga, sedangkan induk jantan dibiarkan begitu saja. Hal ini dilakukan agar saat pemijahan lebih mudah untuk diketahui jantan betinanya. Induk yang telah bersih dibawa menuju *hatchery* untuk dilakukan pemijahan.

2. Persiapan Wadah Pemijahan

Persiapan wadah pemijahan dilakukan setelah melakukan seleksi induk. Sebelum proses pemijahan, induk ditampung dan dipuasakan (yokusei). Menurut kristiningrum dkk., (2018) Proses ini bertujuan untuk mengurangi asupan makanan ke dalam tubuh kerang untuk merangsang kerang mutiara agar memijah. Metode ini dilakukan selama kurang lebih 24 jam. Setelah proses pemuasan dilakukan, bak kontainer sebanyak dua disiapkan untuk tempat indukan memijah. Salah satu dari bak kontainer diisi air panas dengan suhu 39-40°C dan bak kontainer lainnya diisi air dengan suhu pemeliharaan yaitu 26-28 °C. Selain itu, dibutuhkan keranjang penetasan dan bak fiber 3 ton untuk proses penetasan larva tiram mutiara.

3. Proses Pemijahan

Pemijahan merupakan proses perkawinan antara induk jantan dan induk betina. Pemijahan tiram mutiara (*Pinctada maxima*) dapat dilakukan dengan 3 cara yaitu secara alami, semi buatan, dan buatan. Pemijahan secara alami adalah pemijahan yang dilakukan secara begitu saja tanpa ada bahan lainnya dan campur tangan manusia. Sedangkan pemijahan semi buatan yaitu pemijahan tiram mutiara yang dilakukan dengan memberikan rangsangan sperma (donor sperma) untuk mempercepat kematangan gonad (Astriwana dkk., 2003).

Proses pemijahan di BPBL Sekotong, Lombok Barat dilakukan dengan pemijahan buatan melalui metode kejut suhu (Thermal shock), dimana suhu secara berangsur angsur dinaikkan dan diturunkan untuk memicu pemijahan. Pada metode ini dilakukan penampungan indukan pada bak fiber yang diisi air laut dengan suhu pemeliharaan tiram yaitu 26-28 °C. Kemudian dilanjutkan dengan respon stress atau usaha untuk membuat induk kerang stress dengan cara menguras total air dalam bak dan dikeluarkan dan dibiarkan di udara terbuka selama kurang lebih 2-3 jam dengan tujuan agar otot induk kerang melemas sehingga kerang mutiara membuka cangkangnya.

Gambar 9. Proses pemijahan tiram mutiara

Tiram mutiara setelah dipuasakan selama 2-3 jam, kemudian dimasukkan dalam bak kontainer yang berisi air dengan suhu pemeliharaan yaitu 26-28 °C kemudian selang 30 menit kerang dimasukkan ke dalam bak kontainer yang berisi air dengan suhu 38°C - 40°C. Apabila perlakuan kenaikan suhu tersebut (fluktuasi suhu) tidak membuat kerang memijah, maka dilanjutkan dengan memindahkan kerang ke bak plastik dengan suhu awal (suhu normal). Perlakuan ini akan dilakukan berulang kali sampai indukan tiram terangsang dan berhasil melakukan pemijahan, perbandingan induk jantan dan induk betina adalah 1:2.

Fertilisasi (pembuahan) pada kerang akan terjadi secara eksternal di dalam air setelah diawali dengan pengeluaran sperma kerang jantan (sperma yang keluar berbentuk seperti asap dan akan terlihat jelas menggunakan senter). Sedangkan untuk indukan kerang betina telurnya akan keluar selang 40 menit kemudian berbentuk telur kecil yang sangat lembut, dengan syarat tempat memijah harus dalam keadaan gelap dan tenang.

Gambar 10. Proses penetasan larva tiram mutiara

Ketika kedua indukan berhasil memijah, indukan kerang betina akan di pindahkan ke dalam keranjang yang telah diberi pemisah dengan tali di dalam bak fiber 3 ton, kemudian sperma induk kerang jantan yang telah diambil akan dituang ke dalam bak fiber 3 ton setelahnya dipasangkan aerasi. Telur kerang mutiara ditebar dan dipelihara pada bak fiber yang berkapasitas 3m^3 dengan kondisi lingkungan sekitar harus dalam keadaan gelap dan tenang.

Telur yang sudah dimasukkan dalam bak fiber 3 ton akan dibiarkan selama kurang lebih satu hari untuk ditetaskan. Setelah satu hari telur akan disaring menggunakan jaring sesuai ukurannya yaitu 50, 60, dan 80 mesh dan disimpan sementara di dalam wadah lain sambil menunggu bak yang dijadikan wadah pemijahan tadi di bersihkan. Penyaringan pertama kali dilakukan dengan tujuan untuk menyaring telur yang telah menetas dan yang gagal menetas. Menurut Bahrudin dkk., (2023) Persentase penetasan telur kerang mutiara yang dicapai dengan menggunakan metode kejut suhu memiliki tingkat keberhasilan yang lebih dari 50%. Perhitungan jumlah larva dilakukan dengan sampling air hingga didapatkan sampel 1 ml. Sampel dihitung menggunakan alat sedgewick didapatkan hasil sebanyak 215 individu/ml.

4.2.2 Teknik Pemeliharaan Larva dan benih Tiram Mutiara (*Pinctada maxima*)

Pemeliharaan larva tiram mutiara dilakukan selama 30 hari setelah tiram mutiara menetas. Larva tiram mutiara memiliki umur hingga 14 hari dimana tiram mutiara masih bersifat planktonis. Tiram mutiara mulai menempel pada umur 15 hari hingga 30 hari, pada umur ini telah menjadi benih tiram mutiara.

1. Persiapan Bak Pemeliharaan Larva Tiram Mutiara (*Pinctada maxima*)

Pemeliharaan larva tiram mutiara dilakukan di *hatchery* tiram mutiara BPBL Sekotong, Lombok menggunakan bak fiber 3 ton. Persiapan bak pemeliharaan dengan cara menggosok keseluruhan bagian dalam bak fiber menggunakan spon dan sabun cuci piring, lalu dibilas menggunakan air laut. Kemudian bak fiber didiamkan hingga kering. Pada saat memulai pemeliharaan larva bak diisi air laut hingga penuh serta diberi aerasi. Proses pengisian air bak pemeliharaan larva dan benih tiram mutiara menggunakan jenis filter fisika. Media penyaring filter fisika yang digunakan pada budidaya tiram di BPBL Sekotong, Lombok yaitu pasir kaca dan arang. Menurut Silaban dan Santoso (2012) Filter fisika berfungsi untuk memisahkan partikel-partikel tersuspensi dalam air yang berukuran lebih dari 5 mikrometer. Proses ini dilakukan dengan melewatkan air melalui media penyaring yang dapat menangkap partikel padat dalam air, sehingga air yang masuk ke wadah budidaya sudah bebas dari partikel tersebut.

Alat lainnya untuk menunjang pemeliharaan benih tiram mutiara (*Pinctada maxima*) yaitu kolektor yang terdiri dari beberapa kelengkapan alat berupa pemberat, gantungan dari benang nilon kecil, dan paralon. Kolektor berfungsi sebagai substrat untuk tempat menempel benih tiram mutiara (spat). Pembuatan kolektor diawali dengan pemotongan kolektor dengan panjang 30 cm dan lebar 20 cm. kemudian dilakukan pengikatan benang nilon di bagian atas kanan dan kiri sebagai alat pegangan pada pipa paralon. Lalu pada bawah tengah kolektor dipasang pemberat. Setelah pembuatan kolektor, simpan kolektor dalam *styrofoam*.

2. Pemeliharaan Benih Tiram Mutiara (*Pinctada maxima*)

Pemeliharaan benih tiram mutiara dilakukan setelah telur menetas selama proses pemijahan. Pada tahap tersebut telur telah memasuki stadia larva. Pemeliharaan benih tiram dilakukan di dalam *hatchery* karena tiram mutiara membutuhkan lingkungan yang tenang dan minim cahaya untuk meminimalisir pertumbuhan bakteri yang merugikan. Selain itu juga perlu keadaan yang steril karena benih tiram mutiara sangat sensitif terhadap bakteri yang masuk dalam perairan sehingga mempengaruhi kualitas airnya. Selama masa pemeliharaan larva tiram tersebut, 3 hari sekali bak akan dibersihkan dan di ganti airnya, sedangkan larva kerang mutiara akan disaring. Menurut Awaluddin dan Muklis (2013), Pergantian air dilakukan setiap tiga hari sekali dimana air yang lama diganti dengan air yang baru secara keseluruhan. Proses ini dilakukan dengan cara menguras seluruh air dalam bak menggunakan selang spiral sekaligus menyaring benih tiram menggunakan saringan bertingkat dengan ukuran 50, 60, dan 80 mesh. Penggunaan saringan secara bertingkat bertujuan untuk menghindari benih tiram mutiara yang tidak tersaring. Setelah disaring benih tiram mutiara dipindahkan ke dalam bak fiber lain yang telah disiapkan sebelumnya.

Gambar 11. Pemberian kolektor

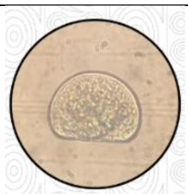
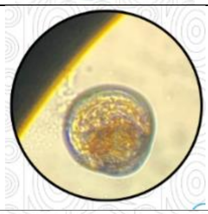
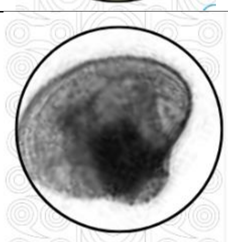
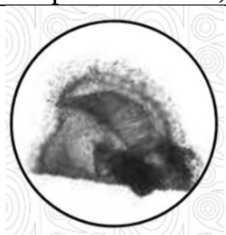
Pemberian kolektor sebagai tempat menempel benih tiram mutiara dimulai pada umur ke 15 hari dengan kapasitas 200 kolektor per bak fiber atau 40 kolektor per gantungan pipa. Kepadatan tiap kolektor rata-rata 50 hingga 100 larva tiram yang menempel per kolektor atau sekitar 10.000 hingga 20.000 per bak fiber. Kolektor yang telah siap diikat pada pipa diatas bak fiber 3 ton. Pemanenan benih dapat dilakukan pada saat benih tiram mutiara telah mencapai fase spat. Menurut Wirasatriya dkk., (2004) pada saat larva tiram mutiara telah mencapai ukuran pediveliger tepatnya hari ke 15 dilakukan pemasangan kolektor dengan warna gelap yang tergantung dalam bak fiber. Benih tiram mutiara tetap hidup jika dapat menemukan kolektor yang sesuai untuk menempel, namun benih yang tidak dapat menemukan kolektor yang sesuai akan tenggelam dan menempel pada bak fiber dengan arti benih tiram mutiara mengalami kematian.

3. Monitoring Perkembangan Larva Tiram Mutiara (*Pinctada maxima*)

Perkembangan larva tiram mutiara terbagi menjadi 4 fase yaitu fase D, fase Umbo, fase Plantygrade, dan fase Spat. Pada proses pengamatan hari ke 3 larva memiliki bentuk menyerupai huruf D, sehingga larva masih pada fase D. Penyaringan hari ke 6 dilakukan pengamatan kembali terlihat larva berbentuk hampir bundar, dengan sedikit menonjol pada dorsal. Tidak hanya itu, larva bergerak menggunakan silianya secara berputar.

Hal ini sesuai dengan penelitian Kotta (2018) bahwa larva berumur 18-20 jam masuk pada fase D dengan ukuran 60- 80μm dan bentuk menyerupai huruf D. Pada fase D tiram mutiara bersifat planktonis dimana terlihat aktif berenang di permukaan air. Cangkang tiram mutiara masih tipis sehingga menjadi masa kritis bagi larva untuk menyesuaikan bukaan mulutnya. Larva tiram mutiara mengalami metamorfosis menjadi fase umbo pada hari ke 6, dimana ditandai dengan bentuknya yang hampir bundar dengan tonjolan pada dorsal namun masih belum terlihat. Pada fase umbo ini, larva memiliki ukuran 80-180μm dan ditandai dengan berkembangnya organ kaki yang berfungsi untuk bergerak aktif, sehingga larva dapat berputar putar menggunakan silianya. Kemudian masuk pada fase peralihan yakni fase plantigrade menjadi spat pada umur 15-20 hari. Fase ini ditandai dengan terlihatnya titik hitam pada cangkang larva dan tumbuhnya cangkang baru sepanjang periphery. Selain itu juga memproduksi benang-benang byssus untuk menempelkan diri pada substrat. Hal ini membuat fase *plantygrade* menjadi fase kritis kedua karena larva berusaha mencari tempat menempel yang benar benar cocok. Oleh karena itu, larva yang mulai tumbuh menjadi spat harus diberikan substrat supaya tidak menempel pada bak pemeliharaan. Fase spat merupakan fase terakhir pada perubahan bentuk larva tiram mutiara, dimana bentuk tubuhnya telah menyerupai tiram mutiara dewasa.

Tabel 1. Perkembangan larva tiram mutiara

Gambar	Keterangan
	Fase D / *D Shape* - Umur 18-20 jam
	Fase Umbo - Umur 6-15 hari
 Sumber: Aprisanto dkk., (2008)	Fase *Plantygrade* - Umur 15-20 hari
 Sumber: Aprisanto dkk., (2008)	Fase Spat - Umur >20 hari

4.2.3 Teknik Pembesaran Tiram Mutiara (*Pinctada maxima*)

Teknik pembesaran tiram mutiara dimulai dari fase spat berumur 30 hari dengan ukuran 1-1,5 mm hingga menjadi induk tiram mutiara dengan usia 2,5-4 tahun dan ukuran >12 cm. Pembesaran tiram mutiara dilakukan di Keramba Jaring Apung Balai Perikanan Budidaya laut Sekotong, Lombok Barat.

1. Persiapan Wadah Pembesaran

Proses pemeliharaan pada pembesaran tiram mutiara diawali dengan persiapan wadah di keramba jaring apung. Proses persiapan meliputi persiapan pocket, keranjang, waring, dan alat pembersih cangkang kerang (pisau dan batu asah). Pocket yang digunakan pada pembesaran tiram mutiara terdiri dari pocket timbangan, pocket biasa dengan jenis A12, A18, dan juga A30, keranjang tento, dan juga pocket insersi. Masing-masing pocket dan keranjang tersebut memiliki fungsi tersendiri. Berikut ini adalah gambar pocket dan keranjang untuk pembesaran tiram mutiara yaitu sebagai berikut :

Tabel 2. Macam-macam pocket net tiram mutiara

Jenis	Gambar	Keterangan
Pocket spat		Kolektor
Pocket timbangan (76 cm x 46 cm)		Kolektor
Pocket A12 (kapasitas 10 kamar atau 100 keping tiram mutiara)		Tiram 3-4 cm
Pocket A 18 (kapasitas 6 kamar atau 30 keping tiram mutiara)		Tiram 5-7 cm
Pocket A 30 (kapasitas 4 kamar atau 8-10 keping tiram mutiara)		Tiram 8-10 cm
Pocket insersi (kapasitas 1 kamar atau 1 keping tiram mutiara)		Insersi mutiara
Keranjang tento (kapasitas 10-20 keping tiram mutiara)		Tiram induk

Waring merupakan pembungkus pocket untuk melindungi pocket net dari ancaman biota lain. Waring terdapat dua jenis yaitu waring putih dan waring hitam.

Waring putih memiliki ukuran size 5 milimeter yang digunakan untuk kolektor. Sedangkan waring hitam memiliki ukuran 10 milimeter yang digunakan untuk spat dan indukan.

2. Penurunan Spat ke Laut

Spat yang telah berumur 30 hari diturunkan ke laut tepatnya pada keramba jaring apung tiram mutiara untuk dilakukan pemeliharaan. Penurunan spat dilakukan dengan mengeluarkan kolektor tempat menempel tiram mutiara dari bak fiber 3 ton. Kemudian kolektor dijahit pada pocket spat, lalu membungkus pocket spat menggunakan waring mesh size 5 mm. Setelah itu mengikatnya menggunakan tali pada bagian atas agar waring tidak lepas dari pocket spat. Selanjutnya menempatkannya pada tali keramba jaring apung. Pergantian waring dilakukan selama 2 minggu sekali agar kotoran yang menempel pada waring pembungkus tidak mempengaruhi pertumbuhan benih tiram. Pada setiap pocket spat berkapasitas 4 kolektor. Tiram mutiara akan melalui fase kritis, di mana kematian massal sering terjadi, biasanya dari penurunan spat ke laut hingga mencapai ukuran 3-4 cm. Oleh karena itu, perlu dilakukan pemeriksaan atau pemantauan secara rutin setiap dua minggu hingga satu bulan sekali. Pemantauan ini dilakukan untuk memastikan apakah kerang mutiara tersebut tumbuh dan hidup dengan baik atau tidak.

Kematian massal ini diduga sebagai dampak dari pergeseran musim yang dipicu oleh pemanasan global. Pergeseran musim ini menyebabkan perubahan drastis pada beberapa parameter kondisi perairan, yang turun dan naik di luar batas toleransi kehidupan anakan kerang mutiara. Dugaan ini didukung oleh hasil penelitian di dua lokasi berbeda, yaitu perairan Sulawesi Tenggara dan Nusa

Tenggara Barat. Penelitian menunjukkan bahwa rata-rata kematian massal anakan kerang mutiara mencapai 68,57%, seiring dengan peningkatan suhu harian dari 29°C menjadi 31°C di perairan Buton, Sulawesi Tenggara (Hamzah dkk., 2008; Hamzah, 2007).

3. Pembesaran Tiram Mutiara

Penjarangan pada pembesaran tiram mutiara juga perlu dilakukan untuk mengurangi kepadatan tiram mutiara pada pocket net. Penjarangan dilakukan dengan cara memotong bagian bisus dan menempelkan pada substrat baru yaitu pocket timbang, kemudian dimasukkan pada waring dan diikat ujungnya menggunakan tali. Kemudian digantung pada keramba jaring apung tiram mutiara dengan metode timbangan (horizontal). Penjarangan biasanya dilakukan pada saat tiram mutiara telah berukuran kurang lebih 2 cm. Proses penjarangan juga diikuti dengan proses pembersihan tiram mutiara dengan cara pergantian waring dan membersihkan cangkang tiram dari biofouling yang menempel dengan menggunakan pisau.

Gambar 12. Penjarangan

Kepadatan penebaran tiram mutiara dalam pocket net disesuaikan dengan ukuran pocket. Pembesaran tiram mutiara di Balai Perikanan Budidaya Laut

Sekotong, Lombok Barat menggunakan 6 jenis pocket dengan kepadatan tebar sebagai berikut :

Tabel 3. Jenis pocket pemeliharaan induk

Jenis pocket	Peruntukan	Padat tebar
Timbangan	Kolektor	4 lembar
A 12 (10 kamar)	Ukuran 3-4 cm	100 ekor
A18 (6 kamar)	Ukuran 5-7 cm	30 ekor
A 30 (4 kamar)	Ukuran 10 cm dan calon induk	8 ekor
Keranjang tento	Induk >10 cm	10-20 ekor
Insersi	Induk >13 cm	1 ekor

Kepadatan penebaran tiram mutiara pada pocket net juga sangat mempengaruhi tingkat pertumbuhannya. Tiram mutiara semakin bertambah ukuran membutuhkan pocket net yang lebih besar pula. Pergantian pocket net dilakukan pada saat penjarangan. Pemeliharaan tiram mutiara di laut tidak perlu rutin pemberian pakan karena tiram akan memfilter plankton dengan sendirinya dari arus dan gelombang yang melewatinya.

4. Perbedaan Induk Tiram Mutiara (*Pinctada maxima*)

Induk tiram mutiara pada BPBL Sekotong, Lombok Barat terdiri dari induk alam dan induk breeding. Induk alam merupakan induk yang berasal dari pembesaran spat dari keturunan perkawinan antara induk alam. Induk alam tiram mutiara pada BPBL Sekotong, Lombok Barat diambil dari dasar laut dengan cara menyelam, biasanya membeli induk alam di para penyelam. Sedangkan induk breeding adalah induk hasil dari budidaya menggunakan metode kejut suhu. Kedua indukan tiram mutiara tersebut memiliki beberapa perbedaan dari segi ukuran dimana induk alam memiliki ukuran yang lebih lebar dari induk breeding. Terlihat dari segi warna cangkang, induk alam terlihat lebih pekat dan terang sedangkan induk breeding terlihat berwarna pucat dan pudar. Cangkang induk alam lebih tipis dan kurus, sedangkan induk breeding memiliki cangkang yang tebal dan gemuk. Menurut Wardana dkk. (2014) induk yang diperoleh dari budidaya terlihat memiliki bentuk tubuh sedikit bulat dan cangkang tebal berwarna krem terang, sedangkan induk dari perairan alam memiliki bentuk tubuh membulat dengan cangkang tipis berwarna coklat hijau pekat dan garis-garis cangkang yang nampak jelas.

4.3 Manajemen Pakan Tiram Mutiara (*Pinctada maxima*)

Pakan menjadi faktor penyebab utama rendahnya kelulushidupan bagi larva tiram mutiara. Hal ini berkaitan dengan ukuran pakan yang kurang sesuai dengan bukaan mulut dan kandungan nutrisi yang kurang memadai untuk pertumbuhan organisme yang dibudidaya.

4.3.1 Jenis Pakan

Pemberian pakan di Balai Perikanan Budidaya Laut Lombok dilakukan pada larva Tiram Mutiara yang dipelihara pada bak fiber berukuran 3 ton. Berbeda dengan larva, Tiram yang sudah berumur 30 hari dilakukan pemindahan larva spat ke laut dan dibiarkan untuk mencari makanannya sendiri. Menurut Taufiq dkk. (2012) Tiram Mutiara masuk ke dalam golongan *filter feeder*, sehingga pada saat di alam makananya berupa berbagai partikel yang tersuspensi dalam air seperti bakteri, plankton, mikro zooplankton, detritus, dan bahan organik tersuspensi lainnya.

Pakan yang diberikan pada larva berupa pakan alami yang terlebih dahulu di kultur. Pakan alami adalah bahan pakan yang diambil dari organisme hidup dalam bentuk dan kondisinya seperti sifat-sifat keadaan di alam. Sesuai dengan pernyataan Sartika dkk. (2021) Organisme pakan alami yaitu organisme hidup yang dipelihara dan dimanfaatkan sebagai pakan dalam proses budidaya perairan.

Pemberian pakan umumnya dilakukan dengan berbagai macam jenis plankton yang terkandung di dalamnya. Jenis pakan yang digunakan dalam pemeliharaan larva tiram mutiara diberikan 3 jenis *Chaetoceros* yang terdiri dari *C. gracilis, C. simplex*, dan *C. calcitrans*. Menurut Sudirman dkk. (2013) Chaetoceros memberikan perlindungan biota dari faktor eksternal yakni pengaruh silikat yang dapat menyokong pertumbuhan cangkangnya.

Balai Besar Penelitian dan Pengembangan Budidaya Laut Gondol, menerapkan kombinasi *Isochrysis* sp., *Pavlova* sp., *Chaetoceros* sp., dan *Nannochloropsis* sp. Pemilihan pakan larva tiram mutiara pada Balai Perikanan Budidaya Laut Lombok sejalan dengan penelitian Putra dkk. (2018) yang menyebutkan bahwa ukuran sel dari Chaetoceros sp yang lebih kecil dibandingkan jenis pakan lain dan juga diketahui memiliki pola gerakan yang pasif sehingga memudahkan bagi spat mengkonsumsi pakan tersebut. Hal ini sesuai dengan pernyataan Wilbur dan Yonge (1966) bahwa pemangsaan fitoplankton itu berdasarkan ukuran dari sel tersebut.

4.3.2 Metode Pemberian Pakan

Pemberian pakan terlebih dahulu dilakukan kultur pakan yang digunakan setelah 3-5 hari, setelah siap dijadikan pakan selanjutnya dikeluarkan dari Lab Kultur dan dilakukan penyesuaian suhu hingga suhu stabil, setelah itu diberikan pakan dengan frekuensi pemberian pakan 1 kali sehari pada siang hari pukul 13.00 setiap harinya. Banyaknya 24 liter untuk 6 bak, pemberian pakan dilakukan alat bantu berupa gelas ukur bervolume 2L dengan masing-masing 4L pada setiap bak pemeliharaan. Kepadatan plankton dalam setiap bak pembenihan sebanyak 1,417 x 10^{10} atau 14.170.000 sel/hari atau 2.360 sel/ml.

Salah satu jenis diatom yang populer dan sesuai untuk larva dan spat kerang mutiara pada masa pembenihan adalah jenis *Chaetoceros* sp. Plankton ini memiliki kandungan nutrisi yang baik. Menurut Isnansetyo (1995) kandungan nutrisi pada *Chaetoceros* sp. yaitu protein 35%, lemak 6,9%, karbohidrat 6,6% dan kadar abu 28%. Selain kandungan nutrisi yang tinggi, *Chaetoceros* sp juga memiliki ukuran sesuai dengan mulut larva yakni 15-20 μm.

Metode pemberian pakan yang dilakukan merupakan metide ad libittum atau menyediakan makanan sebanyak yang diinginkan oleh hewan, tanpa adanya batasan jumlah. Metode ini dilakukan pada fase larva bertujuan untuk mendukung pertumbuhan optimal pada larva hewan. Menurut Agung dkk. (2021) penggunaan pakan alami dilakukan dengan tujuan, agar pakan selalu tersedia sehingga larva daat makan kapanpun tetap tersedia. Perlu adanya monitoring pemantauan secara berkala untuk menyesuaikan keadaan lingkungan hidup dan mmebuang sisa pakan yang tidak digunakan

4.3.3 Kultur Pakan Alami

Kultur pakan alami diawali dengan persiapan alat dan bahan yang dibutuhkan saat kultur dilakukan. Persiapan wadah dimulai dengan menyiapkan 1 buah tong air 150 liter yang sudah dalam kondisi bersih kemudian diisi dengan air laut yang sudah di filter 3 kali.

(a)

(b)

(c)

(d)

Gambar 13. Kultur Pakan Alami (a) Pemberian pupuk pada kultur, (b) Pemberian bibit pada kultur, (c) Kultur massal pakan, (d) Pencampuran berbagai jenis plankton untuk pakan

. Tujuan menggunakan air ini yaitu agar mendapatkan air yang benar-benar bersih sehingga plankton yang kultur bisa hidup dengan Pengisian klorin sebanyak 50 ml ke dalam tong air agar menghambat pertumbuhan serta membasmi bakteri. Siapkan wadah toples plastik liter sebanyak 10 buah dan penutupnya, setelah itu siapkan juga pupuk-pupuk yang mau diberikan untuk mengkultur pakan yaitu pupuk kw21 dan silikat buah pipet. Tiga puluh menit dari pemberian tio sulfat ke dalam tong air, maka langkah selanjutnya yaitu mengisi air tersebut ke dalam 10 buah toples plastik dengan menggunakan gelas ukur 2 liter, masing-masing toples diisi sebanyak liter air atau diisi sebanyak 6 kali dengan menggunakan gelas, kemudian toples tersebut diaerasi (Kotta, 2017).

Pada tahap awal siapkan botol duran 900 ml ini diisi dengan air laut yang telah disaring terlebih dahulu, lalu dibawa ke laboratorium untuk disterilisasi menggunakan autoklaf. Setelah itu dibawa kembali ke ruang pakan alami tiram mutiara untuk di kultur. Prosedur kultur pakan dilakukan dengan terlebih dahulu mensterilkan tangan menggunakan alkohol, setelah itu barulah mulai mengkultur pakan. Pada kultur bibit murni akan diberi sebanyak 2 ml pupuk KW 21 yang berwarna merah muda menggunakan gelas ukur pada setiap botol yang akan di kultur. Setelah itu menambahkan kembali bibit murni yang telah dikultur ke dalam botol kultur. Wulandari dkk. (2022), menyatakan, metode sterilisasi basah dilakukan menggunakan autoklaf yang dioperasikan dengan uap air di bawah tekanan. Botol kultur terlebih dahulu di sterilisasi menggunakan autoklaf sebelum digunakan sebagai wadah media. Pengaturan waktu yang biasa digunakan dengan metode sterilisasi basah ini adalah 10-15 menit. Kondisi tersebut sangat efektif untuk membunuh bakteri dan spora jamur.

Pada kultur massal, dilakukan dengan penggunaan wadah toples yang diisi air laut yang disterilisasi menggunakan tio-sulfat sebanyak 50ml. Masing masing toples diisi dengan 12 liter air dan ditambahkan pupuk KW21 sebanyak 15ml, dilanjutkan dengan memasukkan bibit murni plankton, Plankton yang merupakan diatom diberi tambahan pupuk silikat untuk membantu pertumbuhan plankton diatom tersebut sebanyak 5 ml dan mencantumkan nama serta tanggal kultur pada setiap toplesnya. Perubahan air media pada awal di kultur akan berwarna terang sedangkan hasil kultur berumur minimal 4 hari sudah nampak keruh. Keruhnya warna media menandakan banyaknya fitoplankton yang tumbuh akibat perkembangan fase pertumbuhan. Warna media yang keruh menunjukkan pertumbuhan fitoplankton yang signifikan akibat perkembangan fase pertumbuhan. Hal ini sesuai dengan pernyataan Prasetyo dkk. (2022), Seiring bertambahnya waktu kultur, warna media kultur berubah dari coklat keemasan menjadi coklat tua. Warna coklat keemasan pada budidaya diduga disebabkan oleh C. calcitrans yang merupakan diatom yang terutama mengandung pigmen karotenoid. Warna medium pada kultur fitoplankton merupakan warna pigmen utama pada sitoplasma.

4.7 Manajemen Kualitas Air Tiram Mutiara (*Pinctada maxima*)

Kualitas air merupakan salah satu faktor penting untuk mendukung keberhasilan budidaya tiram mutiara sehingga tiram mutiara tersebut dapat tumbuh dengan optimal. Pada Balai Perikanan Budidaya Laut (BPBL) Sekotong, Lombok Barat, Nusa Tenggara Barat, pemeliharaan larva tiram mutiara dilakukan menggunakan media bak fiber serta pemeliharaan induk tiram mutiara dilakukan di laut menggunakan metode *longline.* Parameter kualitas air yang diuji yaitu suhu, salinitas, pH, oksigen terlarut (DO), nitrit, nitrat, dan ammonia.

4.7.1 Sistem Pengelolaan Air

Air laut yang digunakan untuk kegiatan budidaya tiram mutiara berasal dari teluk sekotong dimana teluk tersebut dekat dengan *hatchery* tiram mutiara. Air laut disedot dari bibir pantai menggunakan pompa melalui pipa PVC. Kemudian, air laut tersebut ditampung dalam tandon beton. Pada tandon tersebut air difilter menggunakan filter fisika dengan memasukan berupa kapas kedalam pipa PVC yang kemudian dialirkan ke *hatchery* tiram mutiara. Di *hatchery* air laut yang digunakan untuk pemeliharaan larva tiram akan difilter lagi menggunakan pasir silikat dan arang. Kemudian, air yang akan digunakan untuk kultur pakan alami akan difiltrasi kembali dengan sistem filtrasi bertingkat menggunakan busa karbu. Filtrasi tersebut bertujuan untuk menyaring air dari partikel dan kontaminan yang dapat menurunkan kualitas air, seperti partikel padat, bahan organik, bakteri, debu, dan kotoran.

(a) (b)

Gambar 14. Filtrasi air. (a) Filtrasi air untuk pemeliharaan, (b) Filtrasi air untuk kultur pakan alami

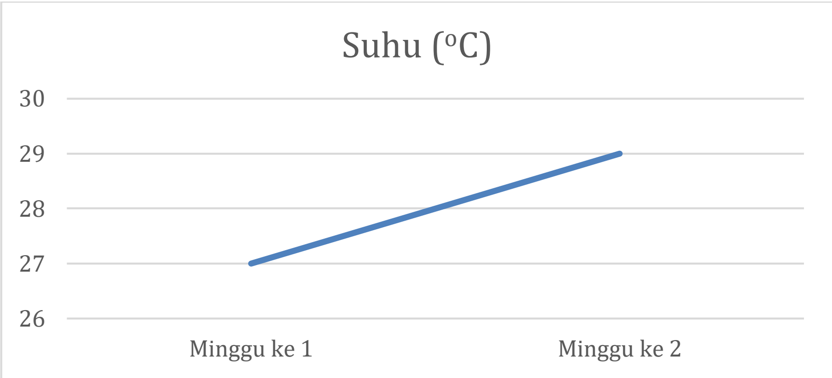
4.7.2 Kualitas Air Pemeliharaan Larva Tiram Mutiara

Kualitas air sangat penting dalam pemeliharaan larva tiram mutiara. Pemeliharaan larva tiram mutiara dilakukan menggunakan media berupa bak fiber.

Pengujian kualitas air pada bak pemeliharaan tiram mutiara dilakukan sebanyak satu kali dalam seminggu. Berdasarkan data kualitas air pada tabel berikut menunjukan bahwa air media pemeliharaan larva tiram mutiara *(Pinctada maxima)* berada dalam kondisi yang cukup baik.

1. Suhu

Suhu air media pemeliharaan larva tiram mutiara pada grafik tersebut memperoleh hasil berkisar antara 27-29°C. Suhu pemeliharaan larva tersebut menunjukan hasil optimal untuk pemeliharaan larva.

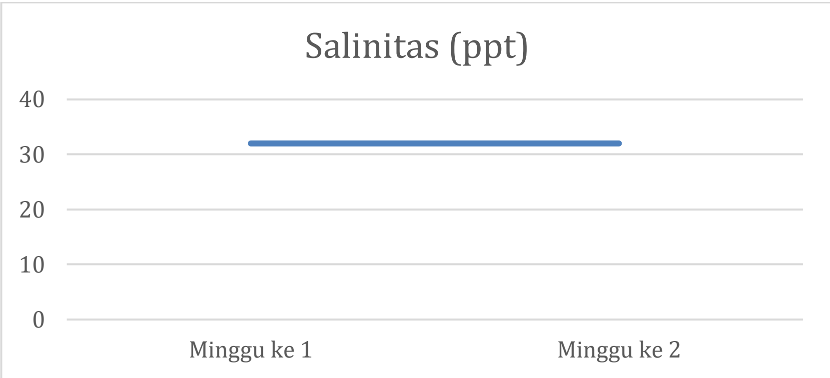


Gambar 15. Grafik pengukuran suhu pemeliharaan larva

Suhu optimal untuk pemeliharaan larva tiram mutiara menurut Awaluddin dan Mukhlis (2013), yaitu berkisar antara 25-30°C. Suhu yang tidak optimal dapat menyebabkan stres pada larva tiram yang kemudian dapat menyebabkan kematian larva. Larva tiram mutiara sangat sensitif terhadap perubahan suhu. Oleh karena itu, suhu pada bak pemeliharaan larva harus selalu terjaga.

2. Salinitas

Salinitas yang diperoleh pada media pemeliharaan larva tiram mutiara yaitu 32 ppt. Dari hasil pengukuran tersebut dapat diketahui bahwa salinitas pada media pemeliharaan tiram mutiara sudah optimal.

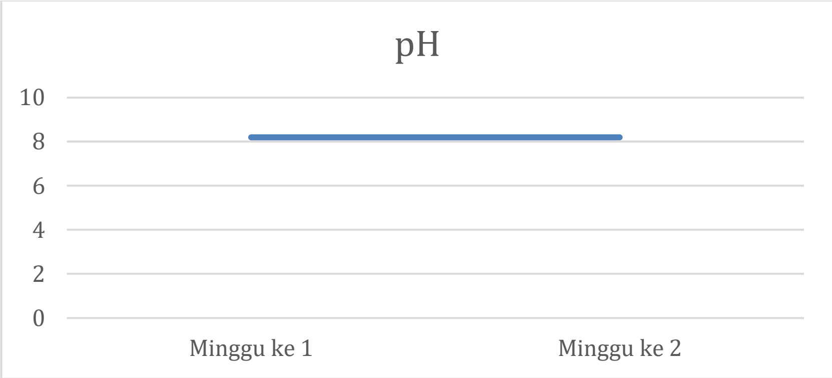


Gambar 16. Grafik pengukuran salinitas pemeliharaan larva

Menurut Winanto (2004) dalam Awaluddin dan Mukhlis (2013) mengatakan bahwa nilai salinitas yang optimal untuk digunakan untuk pemeliharaan larva tiram mutiara yaitu berkisar antara 32-35 ppt. Salinitas yang tidak optimal dapat menghambat pertumbuhan larva. Selain itu, salinitas optimal dapat meningkatkan kelangsungan hidup larva tiram mutiara hingga mencapai stadia spat.

3. Derajat Keasaman (pH)

Derajat Keasaman atau pH pada media pemeliharaan larva sudah optimal karena hasil pengukuran media pemeliharaan larva tiram mutiara yang telah dilakukan memperoleh nilai pH yaitu 8,2.

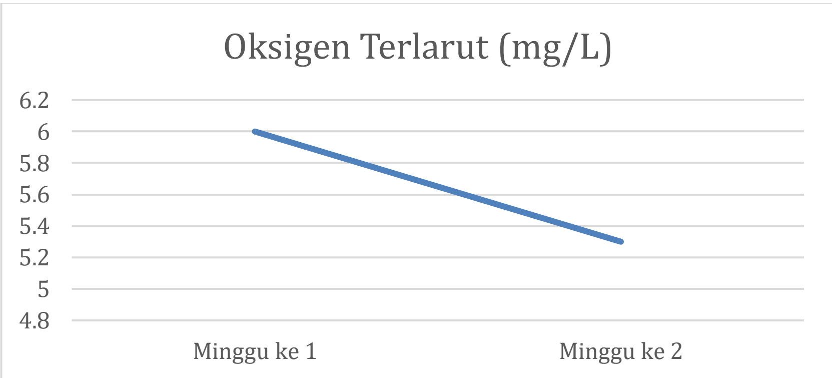


Gambar 17. Grafik pengukuran pH pemeliharaan larva

Menurut Winanto (2004) dalam Awaluddin dan Mukhlis (2013) mengatakan bahwa nilai optimal pH pada pemeliharaan larva tiram mutiara yaitu berkisar antara 7,9-8,2. Perubahan pH dapat mengakibatkan terganggunya sistem penyangga sehingga dapat menyebabkan tidak seimbangnya kadar CO_2.

4. Kadar Oksigen Terlarut (DO)

Hasil pengukuran DO pada media pemeliharaan larva tiram mutiara yaitu berkisar antara 5,3-6 mg/L. Kadar oksigen terlarut tersebut menunjukan hasil optimal sehingga baik untuk pemeliharaan larva tiram mutiara.

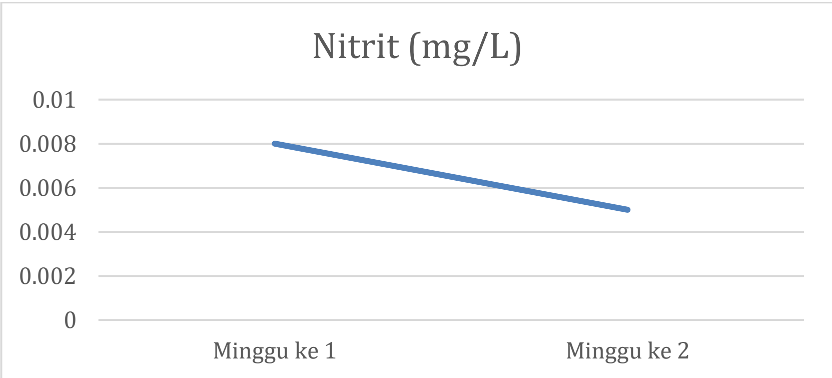


Gambar 18. Grafik pengukuran oksigen terlarut pemeliharaan larva

Menurut Winanto (2004) dalam Awaluddin dan Mukhlis (2013) mengatakan bahwa kadar oksigen terlarut yang optimal pada pemeliharaan larva tiram mutiara yaitu 5,2-6,6 mg/L. Kadar oksigen terlarut (DO) dalam pemeliharaan dapat digunakan sebagai penentu mutu air. Konsentrasi oksigen terlarut yang mengalami perubahan dapat menyebabkan kematian pada organisme.

5. Nitrit

Pemeriksaan kandungan nitrit pada media pemeliharaan larva tiram mutiara menunjukan hasil berkisar antara 0,005-0,008 mg/L. Hasil nitrit tersebut menunjukan hasil yang optimal.

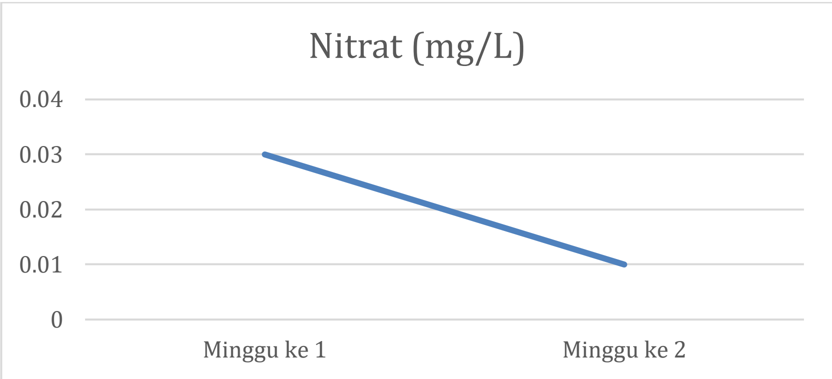


Gambar 19. Grafik pengukuran nitrit pemeliharaan larva

Menurut Fathurrahman & Aunurohim (2014) menyatakan bahwa nilai optimal kandungan nitrit pada media pemeliharaan larva yaitu kurang dari 0,06 mg/L. Kandungan nitrit yang berlebih dapat menyebabkan stress sehingga pertumbuhan akan terganggu.

6. Nitrat

Pemeriksaan yang dilakukan untuk mengetahui kandungan nitrat pada media pemeliharaan larva memperoleh hasil berkisar antara 0,01-0,03 mg/L dimana dari hasil tersebut dapat dikatakan optimal.

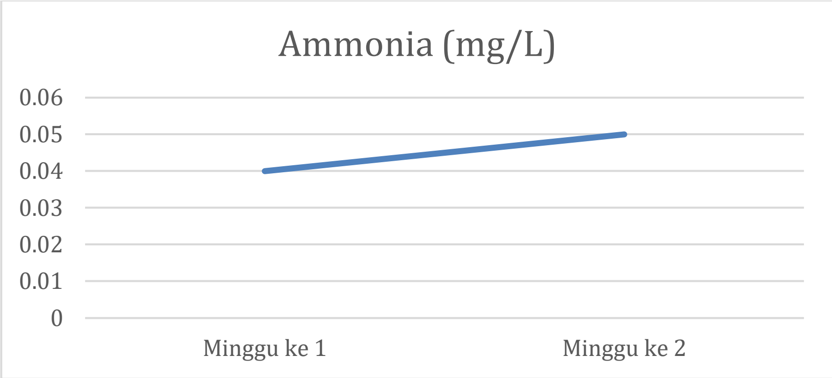


Gambar 20. Grafik pengukuran nitrat pemeliharaan larva

Menurut Iyen dkk. (2021) mengatakan bahwa kandungan nitrat yang optimal bagi pemeliharaan larva yaitu kurang dari 0,1 mg/L. Kadar nitrat yang berlebih dapat menurunkan kualitas air sehingga berdampak pada larva tiram.

7. Ammonia

Kandungan ammonia pada media pemeliharaan larva menunjukan hasil yang optimal. Hasil pemeriksaan kadar ammonia yang diperoleh pada media pemeliharaan larva yaitu berkisar antara 0,04-0,05 mg/L.



Gambar 21. Grafik pengukuran ammonia pemeliharaan larva

Menurut Fathurrahman & Aunurohim (2014) menyatakan bahwa kandungan ammonia yang optimal bagi pemeliharaan larva yaitu kurang dari 0,3 mg/L. Peningkatan kadar ammonia pada media pemeliharaan yaitu karena adanya proses metabolisme.

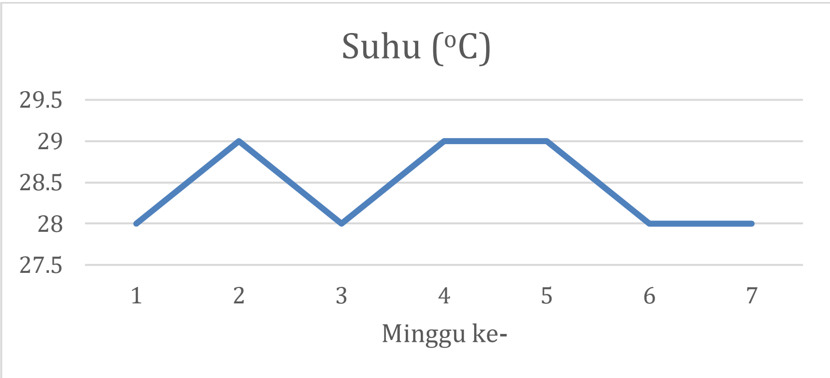
Pemeliharaan larva tiram mutiara di Balai Perikanan Budidaya Laut (BPBL) Sekotong, Lombok Barat, Nusa Tenggara Barat menggunakan bak fiber yang diberi aerasi untuk menjadi kadar oksigen terlarut. Untuk menjaga kualitas air pemeliharaan larva tiram mutiara, dilakukan pergantian air 24 jam setelah pemijahan berlangsung dengan tujuan untuk menghilangkan sisa-sisa sperma pada bak pemeliharaan. Kemudian, dilakukan pergantian air sebanyak tiga hari sekali yang bertujuan untuk membuang sisa-sisa pakan sehingga menjaga kualitas air tetap stabil.

4.7.3 Kualitas Air Pembesaran Induk Tiram Mutiara

Pembesaran induk tiram mutiara dilakukan di laut menggunakan metode *longline*. Selain penting untuk pemeliharaan larva, kualitas air juga berperan penting dalam pemeliharaan induk tiram mutiara. Pengujian kualitas air di *longline* dilakukan sebanyak satu kali dalam seminggu. Berdasarkan data kualitas air pada tabel berikut menunjukan bahwa air pada pemeliharaan induk tiram mutiara *(Pinctada maxima)* berada dalam kondisi yang cukup baik.

1. Suhu

Suhu air pada saat pemeliharaan induk tiram mutiara yaitu berkisar antara 28-29°C. Berdasarkan hasil pengukuran suhu pada pemeliharaan induk dapat dikatakan optimal.

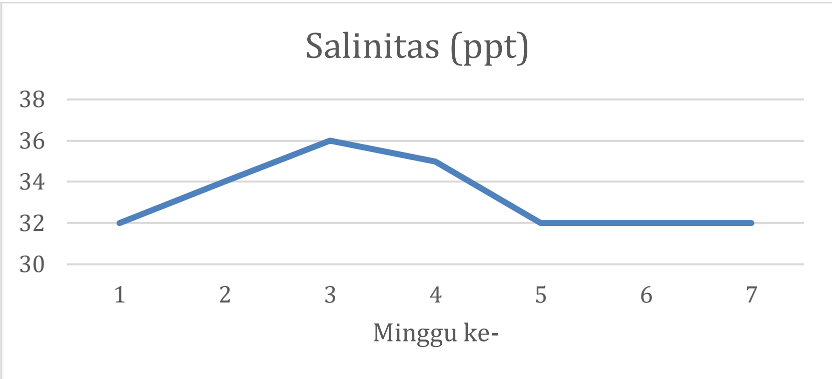


Gambar 22. Grafik pengukuran suhu pembesaran induk

Menurut Al Habib dkk. (2018) menyatakan bahwa suhu optimal untuk budidaya tiram mutiara yaitu 28-30°C. Suhu merupakan salah satu parameter yang berpengaruh langsung terhadap organisme dimana berguna untuk mengatur metabolisme tubuh suatu organisme sehingga perubahan suhu yang tidak sesuai dapat berpengaruh pada organisme untuk mengkonsumsi oksigen.

2. Salinitas

Salinitas yang diperoleh pada saat pemeriksaan pada pemeliharaan induk tiram mutiara yaitu berkisar antara 32-36 ppt dimana salinitas tersebut dapat dikatakan cukup optimal.

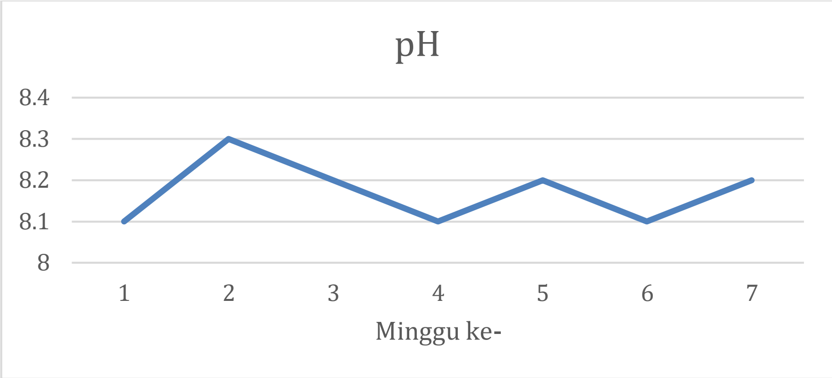


Gambar 23. Grafik pengukuran salinitas pembesaran induk

Menurut Al Habib dkk. (2018) menyatakan bahwa nilai salinitas yang optimal yang digunakan untuk pemeliharaan induk tiram mutiara yaitu berkisar antara 32-35 ppt. Kadar salinitas yang tidak sesuai dapat mempengaruhi kualitas mutiara yang terbentuk dalam tubuh tiram mutiara.

3. Derajat Keasaman (pH)

Derajat Keasaman atau pH pada pemeliharaan tiram mutiara sudah optimal. Hasil pH selama pengukuran pada media pemeliharaan induk tiram mutiara yaitu berkisar antara 8,1-8,3.

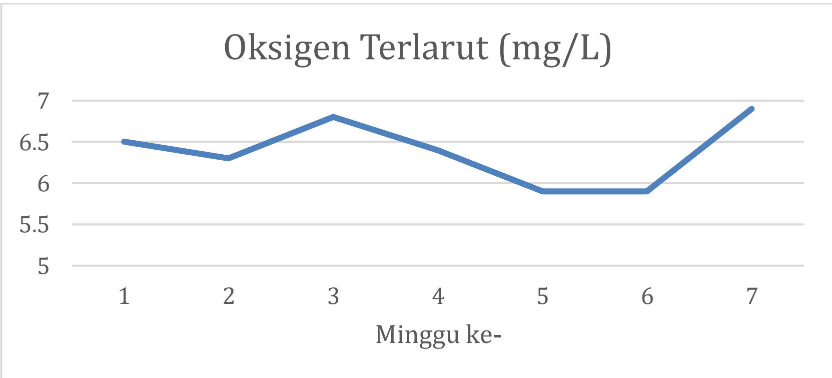


Gambar 24. Grafik pengukuran pH pembesaran induk

Menurut Fathurrahman dan Aunurohim (2014) mengatakan bahwa nilai optimal pH pada pemeliharaan tiram mutiara yaitu berkisar antara 7-8,5. Pertumbuhan tiram mutiara dipengaruhi oleh pH. Perairan yang terlalu asam dapat menyebabkan menurunnya pertumbuhan tiram mutiara. Selain itu, pH yang melewati ambang batas dapat menyebabkan kematian pada tiram mutiara.

4. Kadar Oksigen Terlarut (DO)

Kadar oksigen terlarut pada pemeliharaan tiram mutiara yaitu berkisar antara 5,9-6,9 mg/L. Berdasarkan hasil pengukuran kadar oksigen terlarut tersebut dapat dikatakan cukup optimal.

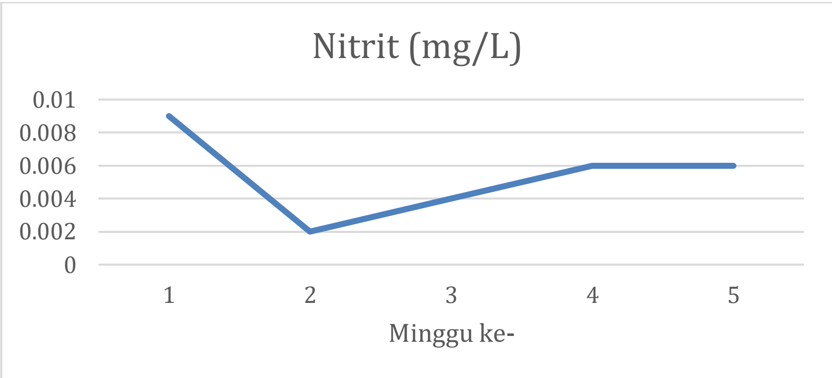


Gambar 25. Grafik pengukuran oksigen terlarut pembesaran induk

Menurut Fathurrahman dan Aunurohim (2014) menyatakan bahwa DO optimal pada pemeliharaan tiram mutiara yaitu 5,2-6,6 mg/L. Kadar oksigen terlarut (DO) dalam pemeliharaan dapat digunakan sebagai penentu mutu air. Konsentrasi oksigen terlarut yang mengalami perubahan dapat menyebabkan kematian pada organisme (Romimohtarto, 1991 dalam Awaluddin dan Mukhlis, 2013).

5. Nitrit

Pemeriksaan kandungan nitrit pada saat pemeliharaan tiram mutiara menunjukan hasil yang berkisar antara 0,002-0,009 mg/L dimana hasil tersebut dapat dikatakan optimal.

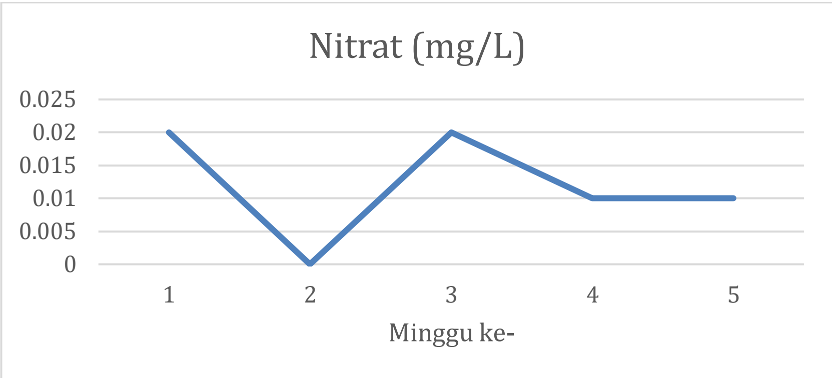


Gambar 26. Grafik pengukuran nitrit pembesaran induk

Menurut Fathurrahman dan Aunurohim (2014) menyatakan bahwa nilai optimal kandungan nitrit pada pemeliharaan yaitu kurang dari 0,06 mg/L. Kandungan nitrit yang melebihi 0,06 mg/L dapat dikatakan toksik bagi organisme perairan sehingga menghambat pertumbuhan tiram.

6. Nitrat

Pemeriksaan yang dilakukan untuk mengetahui kandungan nitrat pada pemeliharaan tiram mutiara menunjukan hasil berkisar antar <0,01-0,02 mg/L dimana dari hasil tersebut dapat dikatakan optimal.

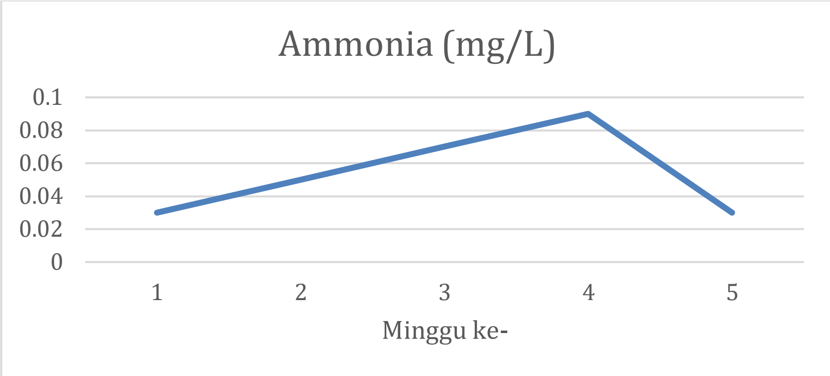


Gambar 27. Grafik pengukuran nitrat pembesaran induk

Menurut Iyen dkk. (2021) mengatakan bahwa kandungan nitrat yang optimal bagi tiram mutiara yaitu kurang dari 0,1 mg/L. Kadar nitrat yang berlebih dapat menyebabkan eutrofikasi yang memicu pertumbuhan alga sehingga dapat mengurangi kadar oksigen dalam air.

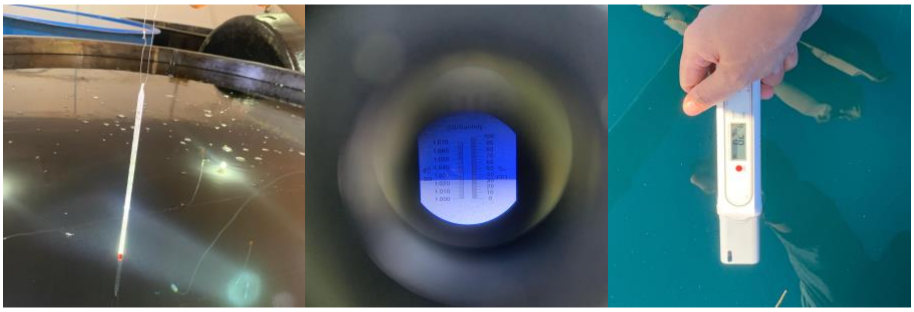
7. Ammonia

Pada pemeriksaan kandungan ammonia pada pemeliharaan tiram mutiara menunjukan hasil yang optimal dimana hasil yang didapat yaitu berkisar antara 0,03-0,09 mg/L.



Gambar 28. Grafik pengukuran ammonia pembesaran induk

Kandungan ammonia yang optimal bagi budidaya tiram mutiara yaitu kurang dari 0,3 mg/L. Pada perairan, ammonia berasal dari hasil proses metabolisme organisme akuatik (Fathurrahman & Aunurohim, 2014).



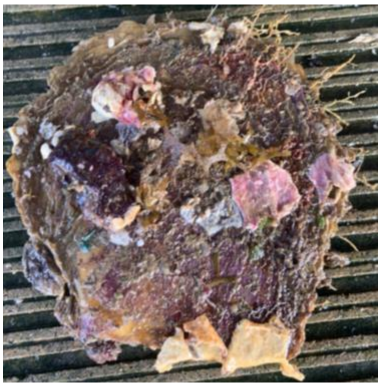
(a) (b) (c)

(d) (e)

Gambar 29. Pengujian Kualitas Air. (a) Suhu, (b) Salinitas, (c) pH, (d) Oksigen, (e) Nitrit, Nitrat, dan Amonia

4.8 Monitoring Hama dan Penyakit

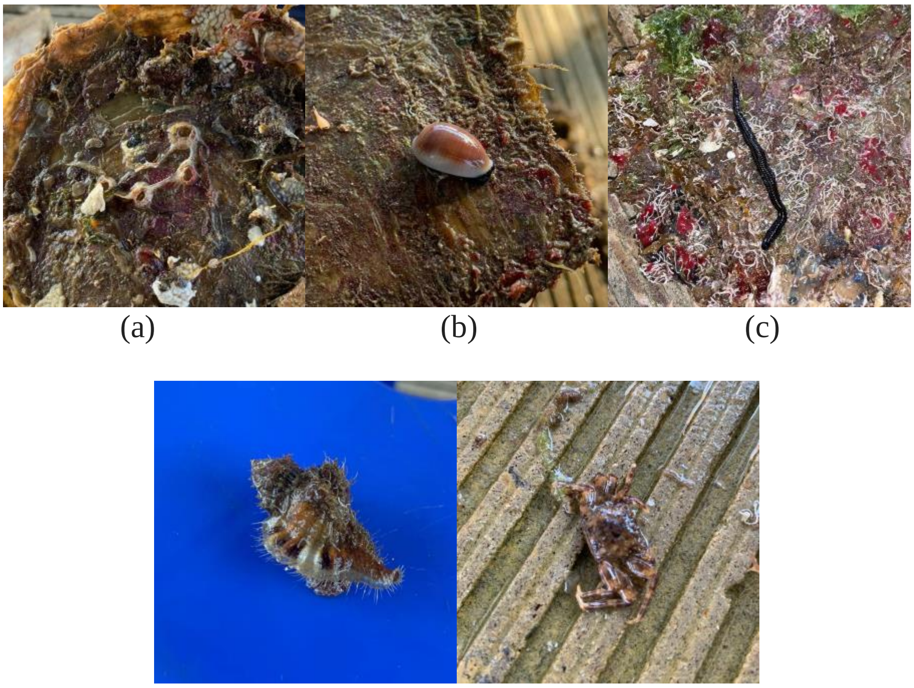
Pada budidaya tiram mutiara (*Pinctada maxima*) sering menghadapi berbagai macam hama dan penyakit dimana dapat mempengaruhi pertumbuhan dan produksi tiram mutiara tersebut. Pada kegiatan budidaya tiram mutiara, salah satu penyebab berkurangnya laju pertumbuhan dan kematian pada tiram mutiara yaitu karena adanya *biofouling*. *Biofouling* merupakan organisme penempel yang biasanya melekat pada keranjang maupun pada cangkang tiram yang dibudidayakan. *Biofouling* yang menempel pada cangkang dapat menyebabkan kerusakan pada cangkang sehingga menghambat laju pertumbuhan. Keberadaan *biofouling* dapat dipengaruhi oleh kondisi perairan tempat budidaya tiram mutiara dilakukan (Jefri dkk., 2017).



Gambar 30. Biofouling pada cangkang tiram mutiara

Hama yang banyak ditemukan pada tiram mutiara yaitu teritip dimana teritip tersebut menempel pada permukaan cangkang tiram mutiara. Keong laut famili Cypraeidae, hama ini biasanya ditemukan didalam tubuh tiram mutiara dan dapat memakan daging tiram mutiara sehingga menyebabkan kematian pada tiram. *Polychaeta* merupakan cacing laut yang banyak ditemukan pada tiram mutiara.

Cacing ini dapat menyebabkan lubang pada cangkang tiram mutiara sehingga mengakibatkan kematian dan menurunkan kualitas dari tiram mutiara tersebut. *Monoplex pilearis* merupakan hama yang banyak ditemukan pada tiram mutiara dan dapat memakan daging tiram mutiara dan mengakibatkan kematian. Selain itu, kepiting juga banyak ditemukan pada tiram mutiara dan mengakibatkan kematian pada tiram.



(a) (b) (c)

(d) (e)

Gambar 31. Hama pada tiram mutiara (a) Teritip, (b) Cypraeidae, (c) Polychaeta, (d) Monoplex pilearis, (e) Kepiting

Upaya yang dilakukan oleh Balai Perikanan Budidaya Laut (BPBL) Sekotong, Lombok Barat, Nusa Tenggara Barat, untuk menghindari menurunnya pertumbuhan hingga kematian pada tiram mutiara yang disebabkan oleh hama yaitu dengan rutin melakukan pembersihan cangkang dan penggantian waring serta keranjang. Pembersihan ini dilakukan setiap sebulan sekali. Pembersihan cangkang tiram mutiara dilakukan dengan menyikat menggunakan pisau. Pembersihan waring dan keranjang dilakukan dengan menjemur waring dan keranjang hingga kering, lalu disemprot menggunakan air. Hama yang menempel pada keranjang atau waring dapat dibersihkan menggunakan pisau.

V PENUTUP

5.1 Kesimpulan

Kesimpulan yang didapat dalam praktik kerja lapang ini adalah kegiatan budidaya tiram mutiara meliputi pemijahan tiram mutiara, pembenihan tiram mutiara, dan pembesaran tiram mutiara.

1. Kegiatan pemijahan tiram mutiara dilakukan di *hatchery* BPBL Sekotong, Lombok Barat yang diawali dengan seleksi tingkat kematangan gonad, persiapan bak untuk pemijahan, dan metode pemijahan menggunakan kejut suhu tinggi yaitu 39-40°C. Penyaringan dilakukan setelah proses penetasan, didapatkan hasil perhitungan jumlah larva 215 individu/ml.
2. Kegiatan pembenihan tiram mutiara dilakukan di *hatchery* BPBL Sekotong, Lombok Barat yang diawali dengan persiapan bak untuk pemeliharaan larva dan benih, penyaringan dan pergantian air setiap tiga hari sekali, dan pemasangan kolektor sebagai tempat menempel. Pemberian pakan dua kali sehari dengan jenis spesies *C. simplex, C. calcitrans*, dan *C. gracilis* dengan perbandingan 1:1:1 setiap jenis. Kepadatan plankton dalam setiap bak pembenihan sebanyak 1,417 x 10^{10} . Pengukuran kualitas air dengan parameter suhu, salinitas, pH, DO, nitrit, nitrat, dan amonia termasuk optimal.
3. Kegiatan pembesaran tiram mutiara dilakukan di keramba jaring apung BPBL Sekotong, Lombok Barat yang diawali dengan penurunan spat menggunakan pocket spat dalam keramba jaring apung, penjarangan, pergantian waring setiap 2 minggu sekali, pembersihan tiram mutiara

sebanyak 1 bulan sekali. Pengukuran kualitas air dengan parameter suhu, salinitas, pH, DO, nitrit, nitrat, dan amonia termasuk optimal.

4. Kualitas air pada pemeliharaan larva tiram mutiara menunjukan hasil yang optimal dimana suhu berkisar antara 27-29°C, salinitas 32 ppt, pH 8,2, kadar oksigen terlarut berkisar antara 5,3-6 mg/L, nitrit berkisar antara 0,005-0,008 mg/L, nitrat berkisar antara 0,01-0,03 mg/L, dan ammonia berkisar antara 0,04-0,05 mg/L. Kualitas air pada pemeliharaan induk tiram mutiara menunjukan hasil yang optimal. Suhu berkisar antara 28-29°C, salinitas berkisar antara 32-36 ppt, pH 8,1-8,3, kadar oksigen terlarut berkisar antara 5,9-6,9 mg/L, nitrit berkisar antara 0,002-0,009 mg/L, nitrat berkisar antara <0,01-0,02 mg/L, dan ammonia berkisar antara 0,03-0,09 mg/L.

5.2 Saran

Perlu pengembangan metode budidaya dengan mengadopsi teknik dan teknologi terbaru yang dapat meningkatkan efisiensi dan hasil panen. Selain itu, penting untuk mengelola lingkungan dengan baik, termasuk pengelolaan limbah dan pemantauan kualitas air secara rutin. Rekomendasi juga mencakup program pelatihan untuk petani lokal guna meningkatkan keterampilan mereka, serta diversifikasi usaha dengan mencoba jenis tiram atau produk turunan baru untuk meningkatkan pendapatan. Strategi pemasaran yang lebih efektif, seperti kerjasama dengan restoran dan pemasaran online, perlu dipertimbangkan untuk memperluas jangkauan pasar. Terakhir, penelitian lebih lanjut mengenai spesies tiram dan keterlibatan komunitas dalam program budidaya dapat memperkuat dukungan sosial dan ekonomi di sekitar usaha ini.

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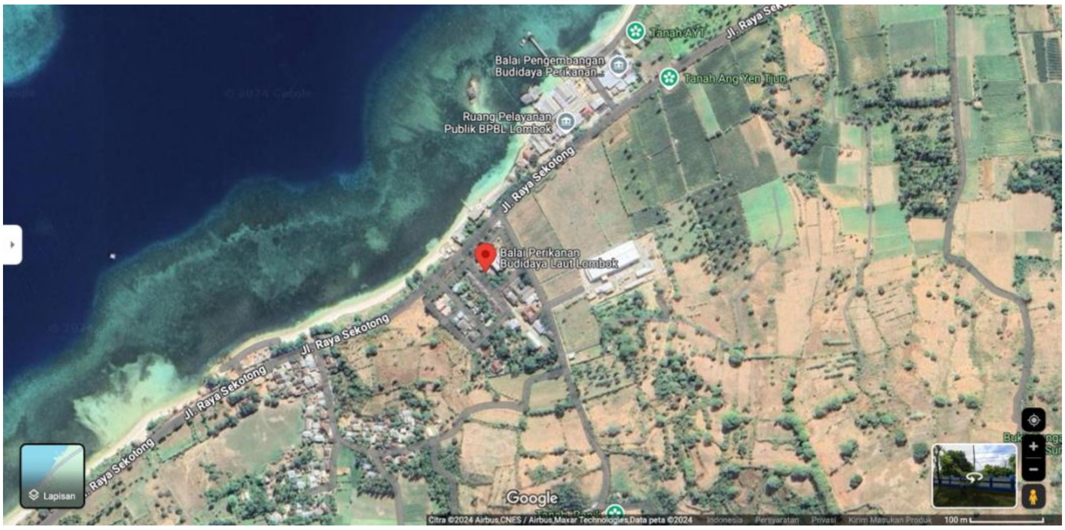
LAMPIRAN

Lampiran 1. Peta lokasi Balai Perikanan Budidaya Laut (BPBL) Sekotong, Lombok Barat, Nusa Tenggara Barat



Lampiran 2. Denah lokasi Balai Perikanan Budidaya Laut (BPBL) Sekotong, Lombok Barat, Nusa Tenggara Barat

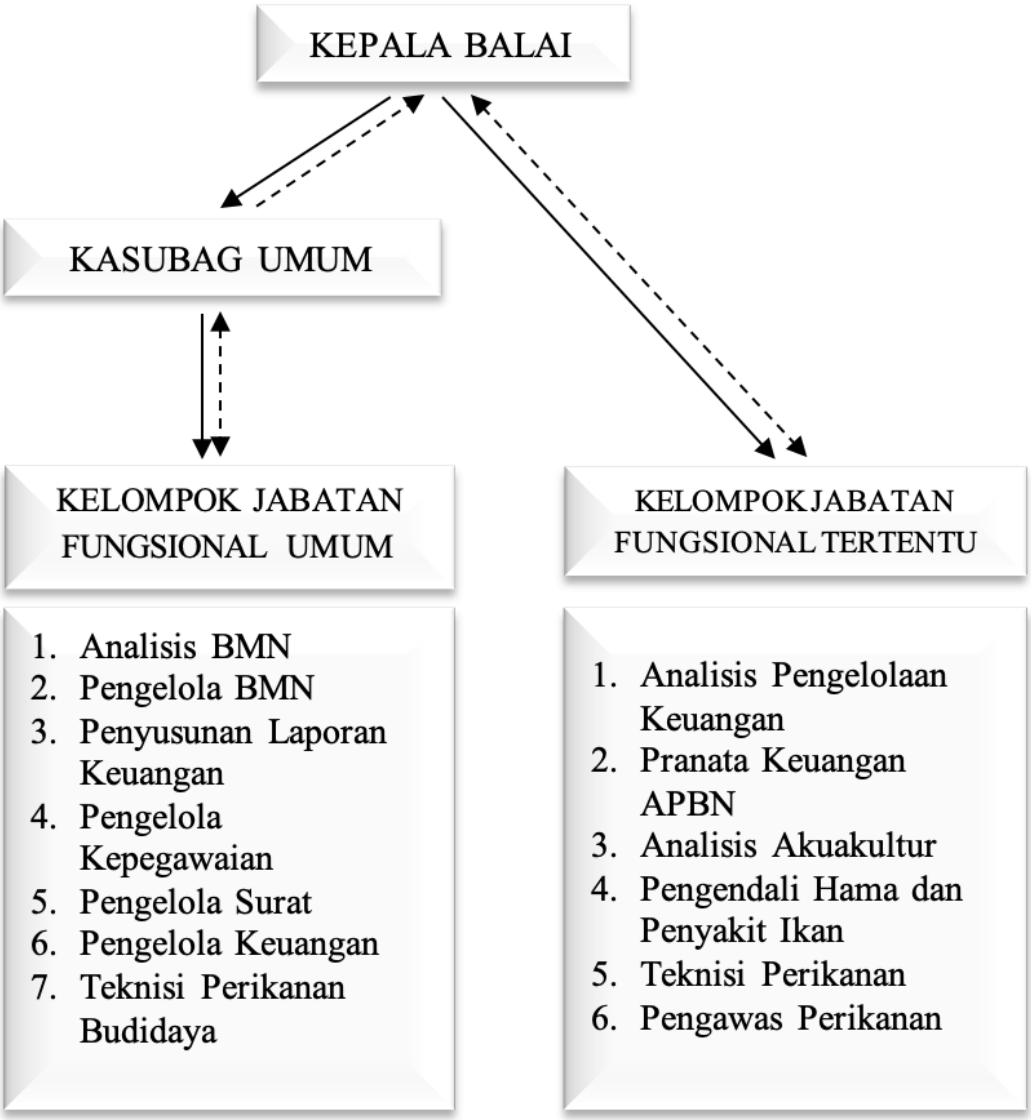
Lampiran 3. Data pengukuran parameter kualitas air pemeliharaan larva tiram mutiara

Parameter	Minggu ke-		Optimal	Sumber Pustaka
	1	2		
Suhu (°C)	27	29	25-30	Awaluddin dan Mukhlis (2013)
Salinitas (ppt)	32	32	32-35	Awaluddin dan Mukhlis (2013)
pH	8,2	8,2	7,9-8,2	Awaluddin dan Mukhlis (2013)
DO (mg/L)	6	5,3	5,2-6,6	Awaluddin dan Mukhlis (2013)
Nitrit (mg/L)	0,008	0,005	<0,06	Fathurrahman & Aunurohim (2014)
Nitrat (mg/L)	0,03	0,01	<0,1	Iyen dkk. (2021)
Ammonia (mg/L)	0,04	0,05	<0,3	Fathurrahman & Aunurohim (2014)

Lampiran 4. Data pengukuran parameter kualitas air pembesaran induk tiram mutiara

Parameter	Minggu ke-							Optimal	Sumber Pustaka
	1	2	3	4	5	6	7		
Suhu (°C)	28	29	28	29	29	28	28	28-30	Al Habib dkk. (2018)
Salinitas (ppt)	32	34	36	35	32	32	32	32-35	Al Habib dkk. (2018)
pH	8,1	8,3	8,2	8,1	8,2	8,1	8,2	7-8,5	Fathurrahman & Aunurohim (2014)
DO (mg/L)	6,5	6,3	6,8	6,4	5,9	5,9	6,9	5,2-6,6	Fathurrahman & Aunurohim (2014)
Nitrit (mg/L)	0,009	0,002	-	-	0,004	0,006	0,006	<0,06	Fathurrahman & Aunurohim (2014)
Nitrat (mg/L)	0,02	<0,01	-	-	0,02	0,01	0,01	<0,1	Iyen dkk. (2021)
Ammonia (mg/L)	0,03	0,05	-	-	0,07	0,09	0,03	<0,3	Fathurrahman & Aunurohim (2014)

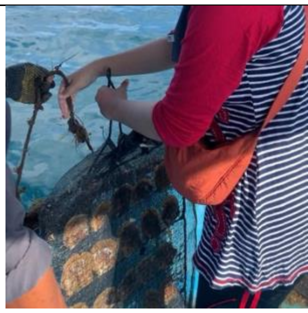
Lampiran 5. Susunan organisasi Balai Perikanan Budidaya Laut (BPBL) Sekotong, Lombok Barat, Nusa Tenggara Barat



Lampiran 6. Dokumentasi kegiatan pemijahan dan pemeliharaan larva tiram mutiara

 Persiapan induk siap pijah	 Persiapan wadah pemijahan	 Pemijahan dengan kejut suhu
 Peroses pemetasan telur	 Pengamatan larva tiram mutiara	 Pemberian pakan pada larva tiram mutiara
 Pergantian air	 Persiapan kolektor	 Persiapan tali untuk menggantung kolektor

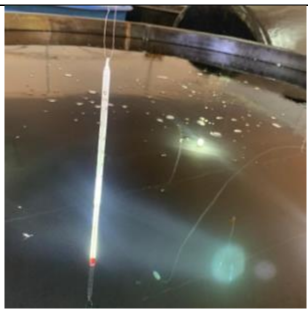
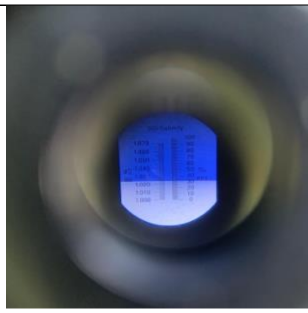
Lampiran 7. Dokumentasi kegiatan pemeliharaan tiram mutiara

 Pengambilan pocket tiram mutiara dari *longline*	 Pembersihan cangkang tiram mutiara dari hama	 Penggantian pocket
 Pembersihan benih tiram mutiara	 Pengembalian tiram mutiara ke *longline*	 Pembersihan pocket dan waring

Lampiran 8. Dokumentasi kegiatan kultur pakan alami

 Persiapan air untuk kultur pakan alami	 Persiapan wadah kultur pakan alami	 Kultur pakan alami skala kecil
 Pemberian air pada wadah kultur	 Pemberian aerator	 Pemberian pupuk KW21
 Pemberian bibit plankton	 Pemberian label yang menunjukan jenis dan tanggal kultur	 Pencampuran beberapa jenis plankton sebelum diberikan pada larva tiram mutiara

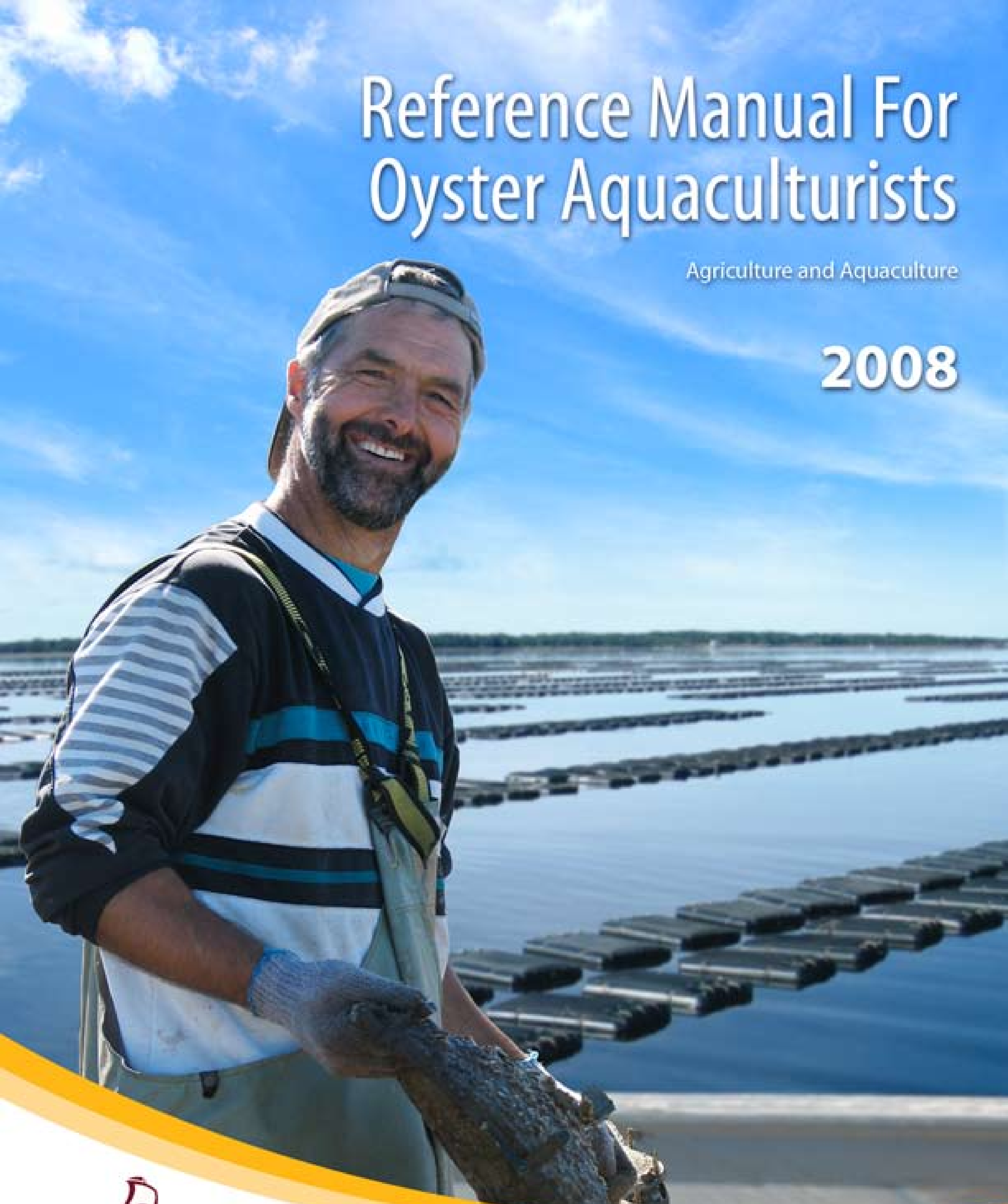
Lampiran 9. Dokumentasi kegiatan Pengecekan kualitas air

 Pengukuran suhu menggunakan termometer	 Pengukuran pH menggunakan pH meter	 Pengukuran salinitas menggunakan refraktometer
 Pengukuran oksigen terlarut menggunakan DO meter	 Pengukuran nitrit, nitrat, dan ammonia	 Pengukuran nitrit, nitrat, dan ammonia dengan metode spektrofotometri

Reference Manual For Oyster Aquaculturists

Agriculture and Aquaculture

2008



New Nouveau Brunswick
Be...in this place • Être...ici on le peut

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The Reference Manual for Oyster Aquaculturists was prepared by Sylvio Doiron, a shellfish culture biologist at the Department of Agriculture and Aquaculture.
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All of the photographs of equipment and materials used in oyster aquaculture were taken on the sites of those producers.

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2008 Edition

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INTRODUCTION

When it comes to the Maritime provinces, the activity that immediately springs to mind is fishing. New Brunswick has a well-established fishery. The harvesting of a number of species of fish and crustaceans generates considerable economic spinoffs along the entire east coast as well as in the Bay of Fundy area. Snow crab, lobster, and herring top the list in terms of monetary value.

Aquaculture has become a major industry in New Brunswick. In 2001, Atlantic salmon production yielded revenues of about $223 million. Shellfish aquaculture is gaining ground as well. Mussel production exceeds 1,000 metric tons and is expanding rapidly.

Oyster aquaculture had been attracting the interest of oyster producers for several years but was unable to really stand out. Then, the development of a new rearing method changed the industry's profile. Rearing in oyster bags gave a boost to oyster aquaculture on New Brunswick's east coast.

The New Brunswick Department of Agriculture, Fisheries and Aquaculture has always supported the development of this industry. Over time, it became increasingly necessary to write a reference guide for oyster aquaculturists because the *Oysterculturist Manual* (Ferguson, 1984) only partly fulfilled its role of providing information.

This manual is intended for a novice clientele and includes a section on oyster biology. The information presented covers the basics regarding this species. For more detailed information, it would be advisable to consult specialized manuals. This document looks as well at such topics as site selection, rearing methods, spat supply, and production plans.

OYSTER BIOLOGY

The oyster produced in New Brunswick is the eastern oyster (*Crassostrea virginica* Gmelin), although other species, such as the European oyster (*Ostrea edulis*) and the Pacific oyster (*Crassostrea gigas*) are reared elsewhere in the world.

TERMINOLOGY

The only oyster species reared on New Brunswick's east coast is the eastern oyster, also known as the Atlantic oyster. Its scientific name is *Crassostrea virginica* (Gmelin, 1791). The French term for the species is "huître américaine." (Figure 1)

Figure 1 Eastern oyster (*Crassostrea virginica*)

In the Bay of Fundy, the flat, or European, oyster (*Ostrea edulis*) (Figure 2) has been introduced and shows good potential. However, on the province's east coast, trials have shown that it cannot survive the winter there.

Figure 2 European oyster (*Ostrea edulis*)

Another well-known species is the Pacific oyster (*Crassostrea gigas*) (Figure 3). It is reared around the world but has never been introduced in New Brunswick.

Figure 3 Pacific oyster (*Crassostrea gigas)*

DISTRIBUTION

The eastern oyster is found along the eastern coasts of North and South America. Its range extends from the Gulf of St. Lawrence in Canada to the Gulf of Mexico and also includes the coasts of Brazil and Argentina. This oyster is found mainly in estuaries and coastal regions with reduced salinity.

The eastern oyster is harvested commercially and intensively in all areas where it reproduces naturally. Its habitat varies from soft silty soils to rocky bottoms, and it settles on appropriate substrates in both intertidal and subtidal zones. In New Brunswick, oysters are found all along the province's east coast (Figure 4).

Under optimum conditions, oysters can live for more than 20 years. The species' tolerance limits are vast. The eastern oyster can live in areas where the water temperature ranges between –2°C and 36°C. It also tolerates wide variations in salinity. Optimum salinity conditions have been determined to range between 14 g/L and 28 g/L, but the eastern oyster survives in more extreme situations where the salinity fluctuates between 1.5 and 39 g/L.

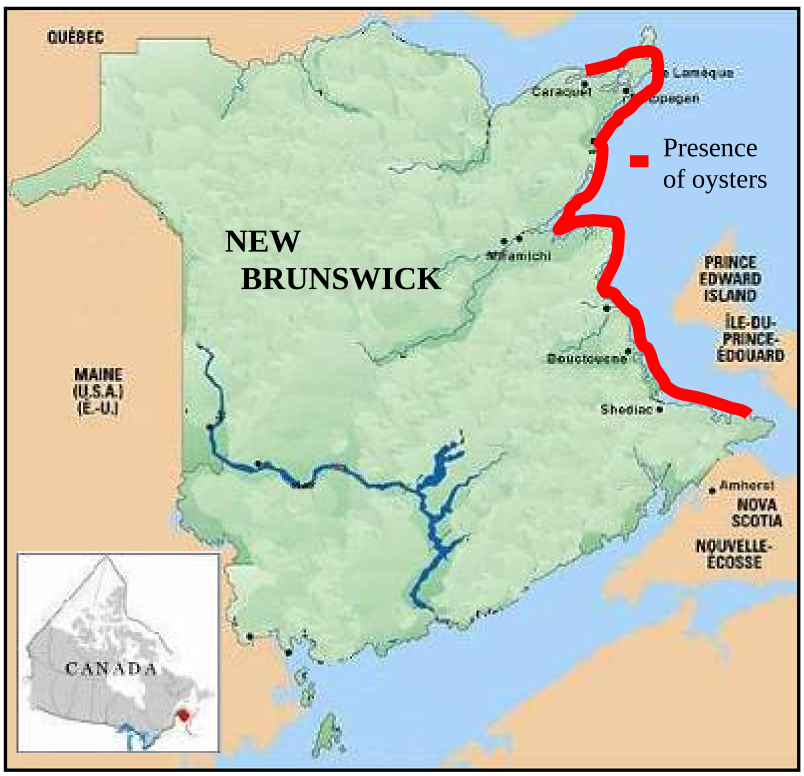

Figure 4 **Map of New Brunswick**

In New Brunswick, oysters are present in all the estuaries from Caraquet Bay in the north to Cape Tourmentine (Confederation Bridge) in the south.

ANATOMY

The eastern oyster is a bivalve mollusc. The meat (soft part) is protected by two asymmetrical valves made of calcareous material (Figure 5) that are twice as heavy as water and about 95% calcium carbonate. Oysters generally lie on the sea bottom on their left valve, which is concave. The top right valve is generally flatter. A tough elastic ligament that enables the valves to open is located on the anterior part. The valves shut forming a water-tight and air-tight seal by means of an adductor muscle that holds them together.

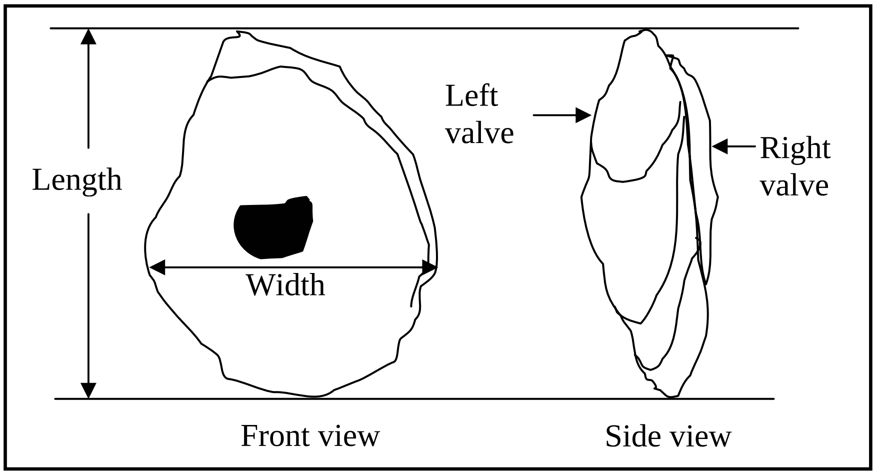

Figure 5 Illustration of the two valves of an oyster

On the inside is the meat, which is made up of all the oyster's organs (Figure 6).

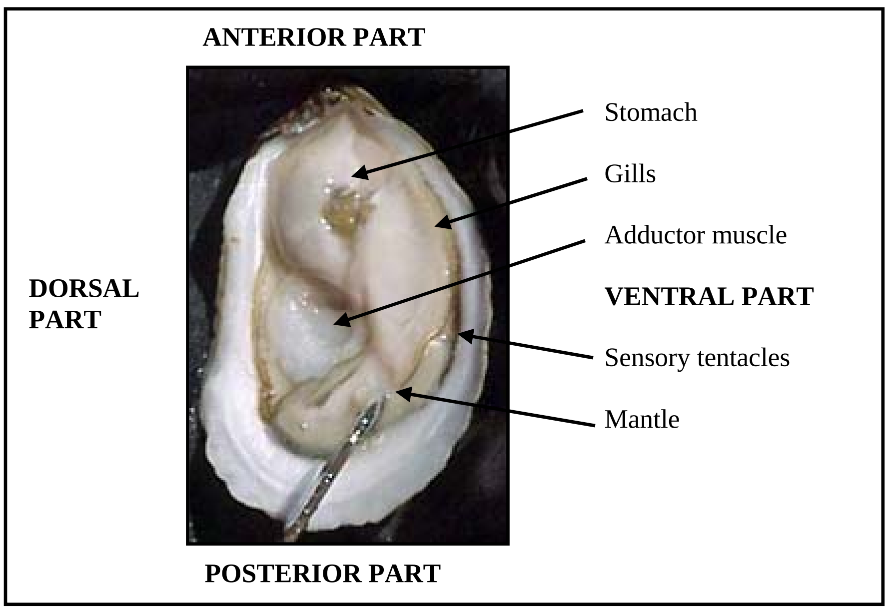

Figure 6 View of the internal parts of an oyster

GROWTH

Oysters feed by filtering water, which contains its food. Their diet consists of microscopic animals and algae and any suspended material that is small enough to pass through their gills. The food travels through the gills to the palps and then to the mouth thanks to the rhythmic movements of thousands of small hairs found in the gills.

Like any cold-blooded animal, oysters depend on the temperature of the environment to control their metabolism. When submerged at temperatures that suit them, oysters feed continuously. The optimum ingestion rate is achieved at 25°C. An oyster larger than 76 mm can filter between 9 and 13 litres of water per hour. When the water temperature drops below 4°C, oysters stop feeding completely. They can survive for long periods of time without feeding.

The mantle secretes the shell material, which is built up from the inside of the valves. The anterior end where the hinge is located is the oldest part of the oyster. In New Brunswick, oysters can grow from May to September, but most growth takes place in May and June. Oysters that grow naturally on the bottom take four to seven years to reach a size of 76 mm (Figure 7). With the new rearing methods, this period is reduced considerably. Oysters placed in floating bags can grow to 76 mm in less than four years. An oyster’s shape is affected by rearing conditions such as density, whereas on the sea bottom, it is controlled mainly by the quality of the substrate.

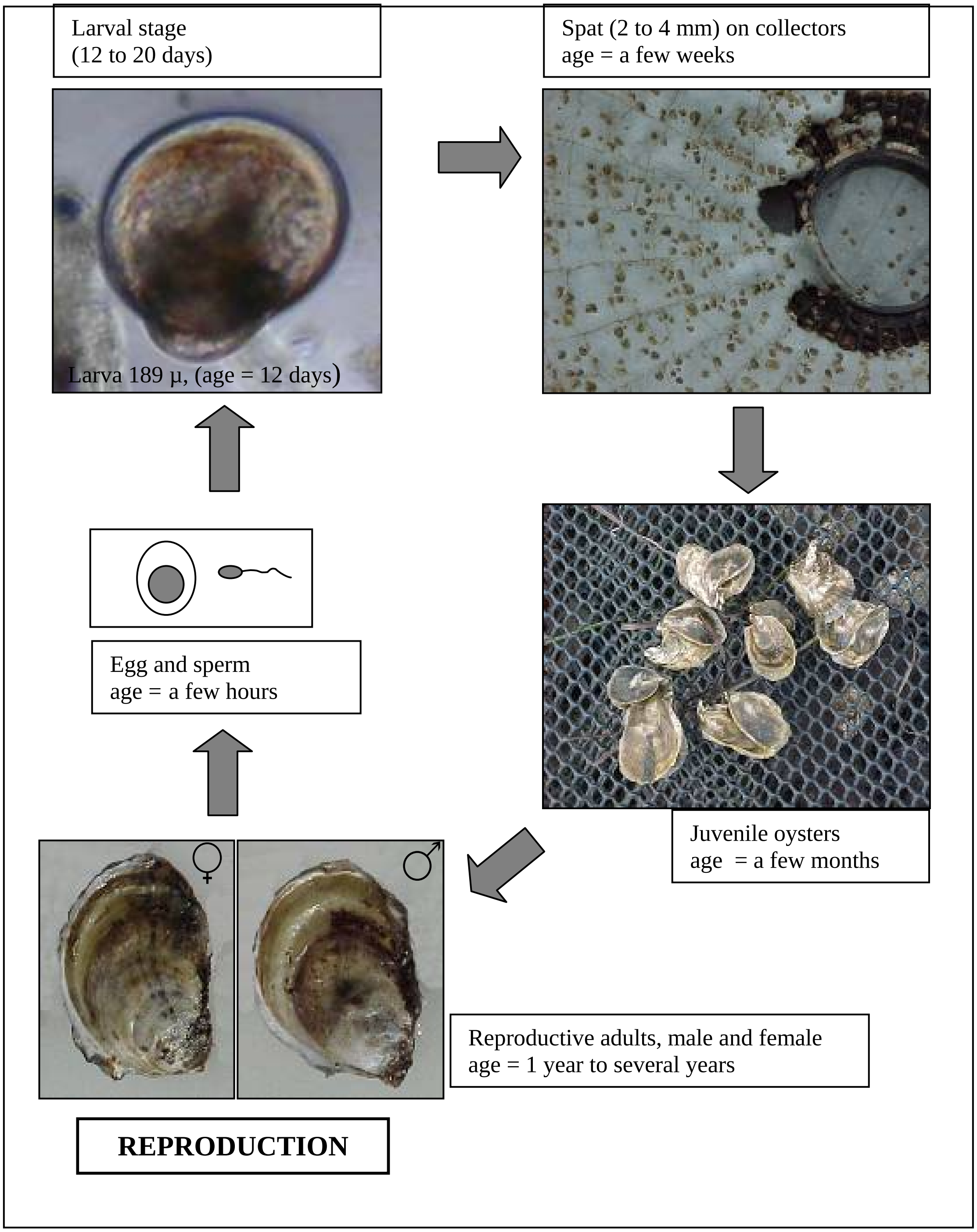

Figure 7 **Life cycle of the oyster**

REPRODUCTION

The eastern oyster is a species that undergoes sex reversal. There are male oysters and female oysters, but they change sex every year. After spawning, the oyster enters a period of sexual rest. At that time, the reproductive organs shrink, and it is impossible to determine the animal's sex.

In June, oysters prepare for spawning. They are then said to be "milky" (the meat takes on a whitish appearance). Temperature triggers spawning. Once the water temperature reaches 20°C, the female oysters clap their valves together and release millions of eggs into the marine environment. The males do their part as well, releasing an even greater number of sperm.

Fertilization takes place in the water, and 24 hours later, a larva (Figure 8) capable of free movement travels with the tidal currents. The length of the larval period varies depending on the conditions in the marine environment. If the water temperature remains above 20°C and sufficient quantities of food are available, the larval period lasts for only a few weeks.

When the larva reaches the size of 300 microns, a distinctive black dot can be observed through a microscope. The larva is then said to be "eyed." At that point, it is ready to settle on some sort of substrate. A larva newly attached to a collector/substrate is called a "spat." Spat collection generally takes place in July but can go on until August.

In the fall, the size of the spat will vary depending on the growing conditions on the collector. Oyster spat can grow to a size of more than 15 mm by the fall if they settle on a collector that provides enough growing space.

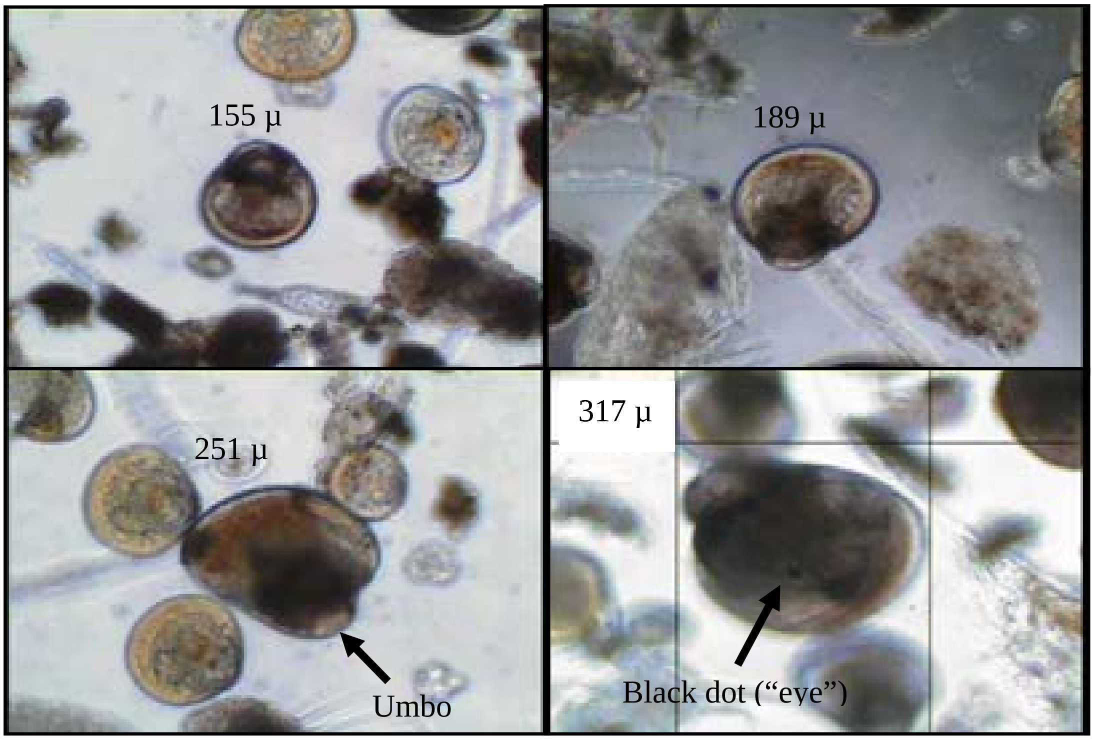

Figure 8 **Oyster larvae of different sizes**

The umbo forms at the point where the two valves meet and becomes protuberant early in the larva's development.

RECRUITMENT

Recruitment in the natural environment is highly variable and depends on many factors. The success of collecting spat on collectors depends largely on the whims of Mother Nature. Major fluctuations in recruitment have been observed in certain bays. For example, in Caraquet Bay, there have been years where the number of larvae was too small to justify the setting of collectors, whereas the following season, the same collectors were loaded with spat. For its part, Bouctouche Bay has always had very impressive collection rates. Figure 9 shows a good collection on the top of a Chinese hat.

Figure 9 Oyster spat on a Chinese hat

PREDATORS

In the natural environment, the eastern oyster has many predators, which vary according to the distribution area. In New Brunswick, the main predators are the rock crab (*Cancer irroratus* Say), the mud crab (*Neopanope sayi* Smith), the American lobster (*Homarus americanus* Milne-Edwards), and the Northern sea star (*Asterias* v*ulgaris*). There are other lesser known predators such as oyster borers (small gastropods) and various types of marine worms.

A study by Elner and Lavoie (1983) showed that oysters between 10 and 35 mm in length were easy prey for rock crab and American lobster. Oysters on the sea bottom are particularly vulnerable to predators, but oyster bag rearing practices make it possible to limit predation.

DISEASES AND PARASITES

Diseases are caused by pathogens such as viruses, bacteria, parasites, and fungi. Diseases can also be caused by stress associated with certain environmental factors.

Malpeque disease is probably the most well-known disease in the Maritimes owing to the losses it caused in the past century. Our oysters survived, and today, the stock has been sufficiently re-established to support a commercial fishery in a number of the province's bays. The pathogen that causes this disease has not yet been identified.

At present, there are no known diseases that regularly cause significant losses in our region. Even though the diseases affecting oysters are not common in our region, we must be vigilant because our neighbours to the south, in the United States, are battling several diseases that are decimating their oyster stocks. Dermo disease, caused by a parasite (*Perkinsus marinus*), and the chronic infections caused by MSX (*Haplosporidium nelsoni*) and SSO (*Haplosporidium costali*) are having devastating effects on oyster populations on the American east coast. MSX and SSO were observed for the first time on Canada's east coast in 2002. In France, the parasite *Bonamia* almost wiped out the European oyster (*Ostrea edulis*) population.

Although these parasites have long been the subject of research, much remains to be discovered about their biology. For example, the life cycles have not been defined, and their propagation methods are not known. Oyster aquaculturists are therefore well advised to follow strict introduction and transfer standards in order to avoid contamination by these undesirable parasites.

Boring sponges (*Cliona ssp.*) (Figure 10) have been reported throughout the Maritimes. The large number of tunnels bored by this sponge weaken the shell considerably. The sponge is relatively small and yellow in colour. It is a filtering organism and uses the shell of the oyster as its home. The holes about 1 mm in circumference on the surface of the shell are used as an entrance and to evacuate water.

Figure 10 Oyster shell bored into by a sponge

The sponge propagates in two ways. First, it lays eggs that become larvae that swim in the marine environment. The larvae are carried by the currents. They attach themselves to a shell and start to bore holes. The second method is emigration. The sponges move from infected shells to other shells with which they are in contact. This method of propagation is much quicker.

Infested oysters can be treated. Soaking them in a strong brine for about five minutes is a good way to kill boring sponges. Oysters that have been exposed to the air for over an hour need to be soaked for only one minute.

A boring sponge infestation can be controlled with preventive measures. Two effective ways of preventing an infestation are cleaning infested shells off the bottom before starting a sizeable rearing operation and treating the oysters with brine on a regular basis.

FOULING ORGANISMS, COMPETITORS, ETC.

Almost all of the rearing techniques employed today use structures that float on the surface of the water or are suspended in the water column. These structures provide a collection surface for a multitude of marine organisms.

The blue mussel (*Mytilus edulis*) settles on anything that offers an adequate substrate. Cultivated oysters and the structures in which they are held sometimes become covered in mussel spat, which reduces oyster growth considerably. If measures are not taken to eliminate the accumulation of mussel spat, cleaning will be difficult and costly.

Besides mussels, barnacles and oyster spat may also invade the rearing structures and the older oyster stock. They too compete for food. Oyster aquaculturists have to clean these organisms off their oysters in order to prepare them for sale. (See **Harvesting** section.)

Many types of algae in the marine environment attach themselves to the walls of rearing structures as well. They are generally very prolific and quickly block orifices, thereby limiting water circulation. Oyster growth may be compromised.

The algae codium (*Codium fragile*), also called the "oyster thief," has been present in New Brunswick for a few years now. It attaches itself to oysters on the sea bottom and, when it is voluminous enough, drifts away with the currents, carrying the oyster with it.

Tunicates are marine invertebrates. There are several species of tunicate in the coastal waters of the Maritime provinces. Prince Edward Island and Nova Scotia are battling an infestation of tunicates. A non-indigenous species, *Styela clava* (Figure 11), invades rearing structures off the coast of P.E.I., while an indigenous species, *Ciona intestinalis* (Figure 12), does the same off Nova Scotia. These species not only compete for food, but they make harvesting more difficult.

In the bays of New Brunswick, Chinese hat collectors are sometimes covered with a tunicate that is the shape and size of a grape (Figure 13). It is called the sea squirt (*Molgula manhattensis)*. At the moment, this creature is less of a problem than the tunicates in the other Maritime provinces.

Photo: Neil McNair (PEI-DFAE)

Figure 11 ***Styela clava* (P.E.I.)**

Rearing structure made up of four superimposed oyster bags.

Photo: Clair Carver

Figure 12 ***Ciona intestinalis* (N.S.)**

Tunicates contribute an additional weight of 10 to 20 kg per bag.

Figure 13 *Molgula manhattensis* **(Tunicate or sea squirt)**

NUTRITIONAL VALUE

Although oysters do not appear so, they are actually very lean. Oysters contain on average only one or two grams of fat per 100 grams of meat, and they are real cocktails of minerals (copper, selenium, iodine, zinc, iron, etc.) and vitamins (B12, A, E, PP, B1, and B2) In fact, two or three oysters can meet the daily zinc requirements of an adult. Oysters are also a source of protein: 12 to 15 are enough to replace meat at a meal.

SITE SELECTION

A good site must offer both protection and food. It is therefore important to measure all the physical parameters affecting site quality on the basis of the rearing method being considered. The main parameters that make it possible to assess the true potential of a site are as follows:

SURFACE AREA

Obviously, the size of a site has to meet production requirements. Oyster aquaculturists must obtain an aquaculture lease for a site from the New Brunswick Department of Agriculture, Fisheries and Aquaculture. They may apply for a location suited to aquaculture that has the required dimensions and has never been designated as an aquaculture site before. They may also apply for vacant lots. In that case, it is sometimes necessary to combine several non-adjacent lots to obtain the surface area necessary for the production being contemplated.

CURRENTS

In most of the estuaries on New Brunswick’s east coast, the velocity of the currents is not high. It generally provides good water exchange. Sometimes a strong wind combined with a tidal current can cause fairly violent eddies. The situation must be carefully assessed. If, however, the currents are truly weak, water exchange could be insufficient to meet the requirements of a sizeable rearing operation. Slower growth and silting can result from such a phenomenon.

PREVAILING WINDS

The prevailing winds can interfere considerably with certain types of rearing operations. The winds create a surface wave that has an impact on off-bottom rearing equipment and can harm new oyster growth. If the prevailing winds persist, annual growth is reduced significantly. In the past, strong winds have washed ashore oysters reared on shallow sites. It is therefore necessary to select sites that are sheltered from the prevailing winds. If this is not possible, the use of a breakwater may be recommended. An effective breakwater remains to be developed.

ACCESSIBILITY

The distance between the rearing site and the offloading site can be a major constraint to the management of aquaculture operations. Fuel costs will be proportionate to the distance to be covered.

Certain sites are hard to get to at low tide. Oyster aquaculturists therefore have to adapt to the tidal cycle, which does not always keep traditional hours.

DEPTH

Depth should be assessed on the basis of rearing requirements. The storage of oyster aquaculture equipment on the sea bottom during the winter is limited by depth. The space required between the bottom and the surface below the layer of ice at low tide must therefore be calculated. This calculation must take into account maximum ice thickness (Figure 14).

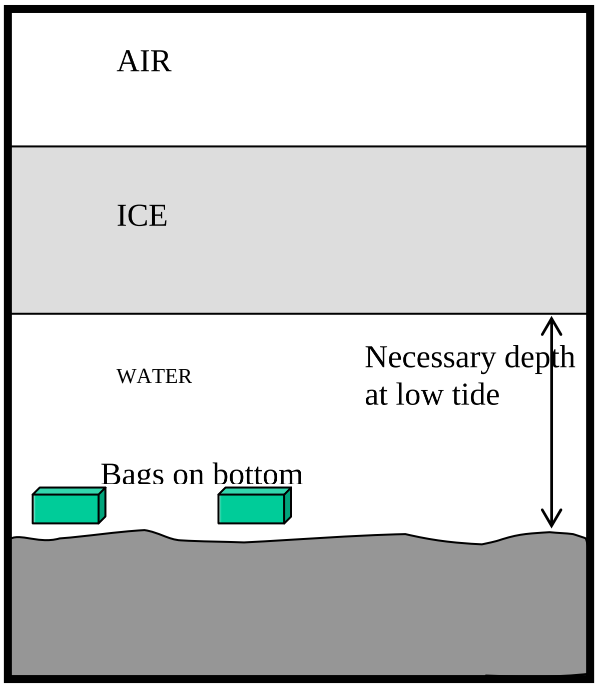

Figure 14 Arrangement of bags on the bottom during the winter

The arrow indicates the distance to be calculated for safe overwintering.

During the summer, the site's depth is determined on the basis of the work method and the type of rearing. On a shallow site, work can be done on foot, whereas deeper sites require the use of a boat or a work platform.

RIPARIAN OWNERS AND OTHER USERS

Oyster aquaculture is expanding rapidly and takes place in an environment – the sea – where people engage in a wide range of commercial and recreational activities and there are sensitive ecosystems.

Aquaculturists seeking to obtain a site on which to practise modern oyster aquaculture must take these factors into account. They should look first for sites that interfere with other users as little as possible.

GROWING AREA CLASSIFICATION

Three classifications are used in the Canadian Shellfish Sanitation Program: “Approved,” “Conditionally Approved,” and “Closed.” Each classification is related to the bacteriological quality of the growing waters, the actual and potential sources of pollution, and to some extent, the shellfish resource utilization of the area.

Approved Growing Areas

General definition - shellfish growing areas may be designated as “Approved” if the following conditions are met:

a) the area is not contaminated with faecal material, poisonous or deleterious substances or marine biotoxins to the extent that consumption of the shellfish might be hazardous;

b) the median or geometric mean faecal coliform Most Probable Number (MPN) of the water does not exceed 14/100 mL, and not more than 10% of the samples exceed a faecal coliform MPN of 43/100 mL, for a five-tube decimal dilution test.

Conditionally Approved Growing Areas

General definition - shellfish growing areas may be designated as “Conditionally Approved” if the following conditions are met:

a) during those times when harvesting is permitted, the area meets all of the requirements of an “Approved” area;

b) conditions which preclude harvesting in areas designated “Conditionally Approved” must be:

1) easily identified by routine measurement and reporting; and

2) predictable and/or controllable.

Closed Growing Areas

General definition - shellfish growing areas are designated as “Closed” under any of the following conditions:

a) the area is contaminated with faecal material, poisonous and deleterious substances to the extent that consumption of the shellfish might be hazardous;

b) the median faecal coliform Most Probable Number (MPN) of the water exceeds 14/100 mL, and/or more than 10% of the samples exceed a faecal coliform MPN of 43/100 mL, for a five-tube decimal dilution test;

c) the paralytic shellfish poison (PSP) concentration is 80 micrograms per 100 grams (80 µg/100 g) and/or amnesic shellfish poisoning (ASP) concentration is 20 micrograms per gram (20 µg/g) of edible portion of raw shellfish meat, or other neurotoxic shellfish poison is found in detectable levels (taken from the Canadian Shellfish Sanitation Program – *Manual of Operations* – Growing Area Survey and Classification).

Unclassified Growing Areas

Unclassified growing areas are managed as closed growing areas because no sampling has been done there for classification purposes. The current leasing policy of the New Brunswick Department of Agriculture, Fisheries and Aquaculture does not authorize the obtaining of leases in unclassified growing areas.

LEASES AND LICENCES

You are the lessee of a site if you hold an aquaculture licence in good standing issued by the Province of New Brunswick and you have your lease in your possession. To obtain these documents, you must apply to the New Brunswick Department of Agriculture, Fisheries and Aquaculture. Applying for an aquaculture licence or a site lease requires a monetary investment.

The steps in the process that cost money are as follows:

- Applying for an aquaculture site;
- Applying for an aquaculture licence;
- Taking out newspaper ads.

If the application is approved and a site may be allocated, the costs are as follows:

- Cost of surveying the site;
- Annual cost of lease;
- Annual cost of aquaculture licence.

A number of resource persons with different federal and provincial departments have to evaluate your application for an aquaculture site and licence. The process is therefore relatively long. All applications relating to sites on which rearing structures are to be placed will require an environmental impact assessment in order to meet the standards of the *Canadian Environmental Assessment Act*. Submission of an application does not necessarily mean the application will be approved. The final decision is based on the review of the application.

SITE MARKING

When you lease an aquaculture site, you are responsible for identifying the precise boundaries of the site. Site marking policies have been established by the Canadian Coast Guard (CCG) and take precedence over the marking policies of the New Brunswick Department of Agriculture, Fisheries and Aquaculture. In the event of a CCG exemption, the provincial policies will apply.

These policies pertain to the size, shape, and colour of the buoys that must be used. They describe the anchoring methods and the criteria concerning spacing between the buoys. In addition, they specify what information must be printed on the buoys.

SPAT SUPPLY

To establish stable production, oyster aquaculturists must obtain spat every year. There are three ways of obtaining spat: collection in the natural environment, purchase of spat from a specialized producer, and purchase of spat from a shellfish hatchery. Remote setting could eventually be added to this list.

Each method has its own individual characteristics. Table 1 provides information about the three sources of spat.

TABLE I Origin of spat and information

COLLECTION IN NATURAL ENVIRONMENT		SHELLFISH HATCHERY
OYSTER AQUACULTURIST PRODUCER	SPECIALIZED PRODUCER	
Inexpensive	Supply according to availability	Uniform spat size
Collection varies from year to year	Prices vary according to size	Available in the spring
Large spat (5 - 15 mm)	Several size groups (5 - 45 mm)	Small spat (2 - 5 mm)
Collection in summer	Possibility of shortening the buyer's rearing cycle	Possibility of genetic selection
Must have collectors and manage setting		Limited availability at present
Collection not guaranteed		

SHELLFISH HATCHERY

A shellfish hatchery is a business that specializes in the production of juvenile molluscs. Oysters, soft-shell clams, surf clams, and quahaugs are the species most in demand in the Atlantic provinces.

Operating a hatchery involves four stages that are equally important: food production, broodstock conditioning, mollusc larvae rearing, and spat rearing.

The construction and operation of a hatchery require considerable expertise. The paragraphs that follow provide a brief description of the stages involved in operating a hatchery. For more information, specialized reference manuals should be consulted.

Food Production

The food used in shellfish hatcheries consists of living single-celled algae. With strains purchased from specialized laboratories, the different species of algae develop in transparent tanks containing several litres of seawater that was filtered and purified beforehand. The algae are exposed to light on a continuous basis, and nutrient salts are added regularly to the culture medium. The algae room (Figure 15) is separate from the hatchery's other units because the culture conditions require rigorous controls. Air and water temperature must remain constant while the hatchery is in operation.

Broodstock conditioning and larvae production require a large quantity of food. A hatchery therefore needs several litres of food every day. The principle is simple. The algae are inoculated into small flasks. When the algae density per millilitre of water is sufficient, the content of the flasks is poured into 20-litre bottles. After about seven days, the algae density per millilitre increases from a few hundred cells per millilitre to several million. The bottles are then used to feed the mollusc larvae and to inoculate 170-litre containers. A week later, the contents are used to feed the broodstock or the spat.

Figure 15 Algae room

The 20-litre bottles can be seen on the shelves, and the 170-litre containers are located at the back of the room.

Broodstock Conditioning

The broodstock are the parents. They were either taken from the natural environment or have been part of the hatchery's stock for several years. The broodstock are placed in tanks where water circulates continuously or in a closed loop and is kept at a desired temperature for conditioning. The water is filtered, and food is added to it. Under these conditions, it is possible to have broodstock that are ready for reproduction within four to eight weeks.

Once the broodstock are properly conditioned, they are placed in small tanks of clean water, and a stimulus is used to induce spawning. In the eastern oyster, an increase in water temperature of a few degrees is sometimes enough to induce spawning. The females' eggs and the males' sperm are collected and mixed together to produce fertilization. Twenty or so males and females can easily produce some 10 million larvae in a single spawning.

Larval Rearing

Once the eggs have been fertilized, they are placed in rearing tanks. The eggs need about 24 hours to be transformed into free-swimming larvae.

The rearing environment is a closed-loop system. The larvae are placed in tanks containing several hundred litres (Figure 16) of filtered, purified water kept at a constant temperature. They are fed microscopic algae regularly. Every two or three days, the rearing tanks are emptied, washed, and disinfected. The larvae are collected on different filters and sorted. They are then put back into the clean tanks.

Figure 16 Larval rearing tank (1,100 litres) in a multifunctional room

The larvae remain in the tanks until they undergo metamorphosis and become sedentary. At that point, they are placed in growout structures designed for spat. A larval cycle can last between 10 and 20 days depending on the species. For instance, it take the eastern oyster from 15 to 20 days to go from fertilized egg to spat.

Spat Rearing

Spat are a bit more robust than larvae. They are more tolerant of changes in the rearing conditions. Several types of tanks have been designed for spat rearing. Upwellers and downwellers are two types of tanks commonly used in hatcheries (Figure 17).

Figure 17 Downweller system used in hatcheries

Each grey tube can hold several thousand spat.

During this last stage in the hatchery rearing cycle, the spat grow from a few hundred microns in size to about 5 mm. During that time, the tanks must be cleaned every day and the spat fed continuously. Individuals are sorted out to eliminate the slow-growing ones. Once the spat reach a certain size, they need a large amount of food and must be transferred to rearing structures outside the hatchery.

A commercial hatchery can supply millions of oyster spat to oyster aquaculturists. The spat are purchased in the spring when they are about 5 mm in size.

COLLECTION IN THE NATURAL ENVIRONMENT

Oyster aquaculturists and seed oyster producers set a large quantity of collectors in the water every year to collect spat. The collectors used are Chinese hats and plastic tubes (Figure 18). Other collectors such as the Pleno, grooved tubes, smooth tubes, and shells have been tested but with mixed results.

The spat are generally removed from the collectors in September (or the following year). After the spat are removed, they are placed in 2- or 4-mm bags. These are overwintered until May either in cages that can hold a total of five bags or individually. In May, the volume per bag is reduced to meet production assumptions.

Figure 18 Oyster collectors

On the left is a stack of Chinese hats, and on the right, a six-pack collector consisting of six 45-cm sections of drain pipe.

Collection on Collectors

Introduced in New Brunswick in the 1970s, the Chinese hat has proved to be an effective collector. For the past few years, a home-made collector developed by oyster aquaculturists has been used. It consists of six sections of drain pipe (six-pack). The popularity of this collector stems from the fact that it is much less expensive and easier to remove the spat from. The collection rates for the two types of collectors are comparable because the collection surface area is about the same. Both types of collectors need to be limed.

The text below is based on the *Oysterculturist Manual*. The description of how to lime Chinese hat collectors is included in this guide as a reminder.

Liming of Chinese Hat Collectors

Liming is usually done in June. It involves rolling the stacks of Chinese hats in a mixture in a liming tub (Figure 19).

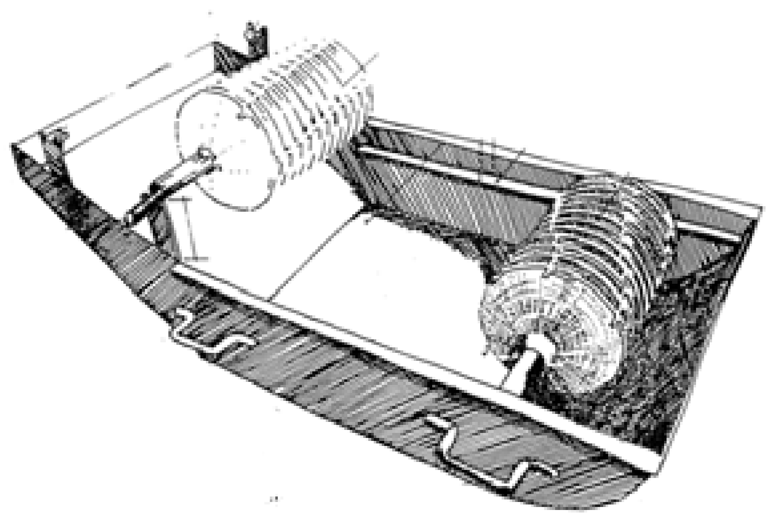

Figure 19 Liming tub

The mixture is made of equal volumes of cement, slaked lime, and moderately fine sand. Enough water is added to give it the consistency of purée required to produce a uniform layer of about 2 mm.

After being rolled in the mixture, the stack of collectors is put on a rack to drain and then placed upright on a box covered in wire mesh to collect the surplus mixture. This surplus can be reused.

A 23-kg bag of lime, a 40-kg bag of cement, and an equivalent amount of sand is enough to lime between 15 and 18 stacks of Chinese hats. An additional 10 to 15% will be required for stacks that have never been limed before.

The mixture is checked throughout the liming process to ensure uniform consistency.

To obtain excellent results, five or six persons must work together. They will have to protect their hands from the lime and cement. Such a team can lime 600 stacks of collectors in an eight-hour work day.

The stacks of Chinese hats will have to be kept out of the wind and sun and sprayed with water for three or four days after they are limed. This is necessary to prevent the mixture from hardening too fast, forming cracks, and being worn away by waves and currents. That would result in losses for the oyster aquaculturist.

After three or four days, the stacks of Chinese hats are taken outside to allow the mixture to harden and to be washed by the rain. The stacks should be left outside for two weeks before they are used to collect spat.

Collection Yield

One stack of Chinese hats can collect between 5,000 and 100,000 spat, but when the spat are removed, a yield of 5,000 is considered acceptable. At that density, the spat can reach a size of more than 10 mm by the fall. Conversely, a collection of 100,000 spat per hat is problematic. There is competition for space and food. The final size in the fall will be only a few millimetres.

It is fairly easy to estimate the number of spat collected on Chinese hats. The area of the top of a hat is 900 cm^2. The oyster aquaculturist has only to count the number of spat on a 100-cm^2 surface (10 cm x 10 cm) on 10 or so randomly selected hats and do the appropriate multiplications. The underside and top of the hat must be assessed separately since collection often varies considerably between the two surfaces.

Spat Removal

Spat removal consists in stripping the cement and the oysters off the collector. This can be done manually or mechanically. The manual method is used when the oyster aquaculturist does not have many collectors. For large quantities of collectors, a stripping machine is generally used.

a) Manual Method

An oyster aquaculturist can dismantle the Chinese hats one by one manually and remove the spat from 25 stacks of Chinese hats in a day. This method involves separating and flexing the hats to remove the oysters. It is easy to remove the spat from six-packs as well. They must be compressed enough to break the cement.

b) Mechanical Method

Mechanical spat removal is done using a stripping machine (Figure 20) designed for Chinese hats. Oyster aquaculturists using more than 100 collectors need a stripping machine. With this machine, they can remove the spat from 25 stacks per hour with the help of two workers. It can be shared by several oyster aquaculturists to reduce costs.

Stripping machines compress the collectors, thereby breaking the cement on the surface of the hats. Spat removal can be done in the oyster aquaculturist's shed or on the rearing site. Stripping machines are not 100% effective. There are always a few oysters and some cement left on the hat after removal. That is why a final manual stage is required.

Spat can also be mechanically removed from six-packs using a stripping machine designed specifically for that type of collector.

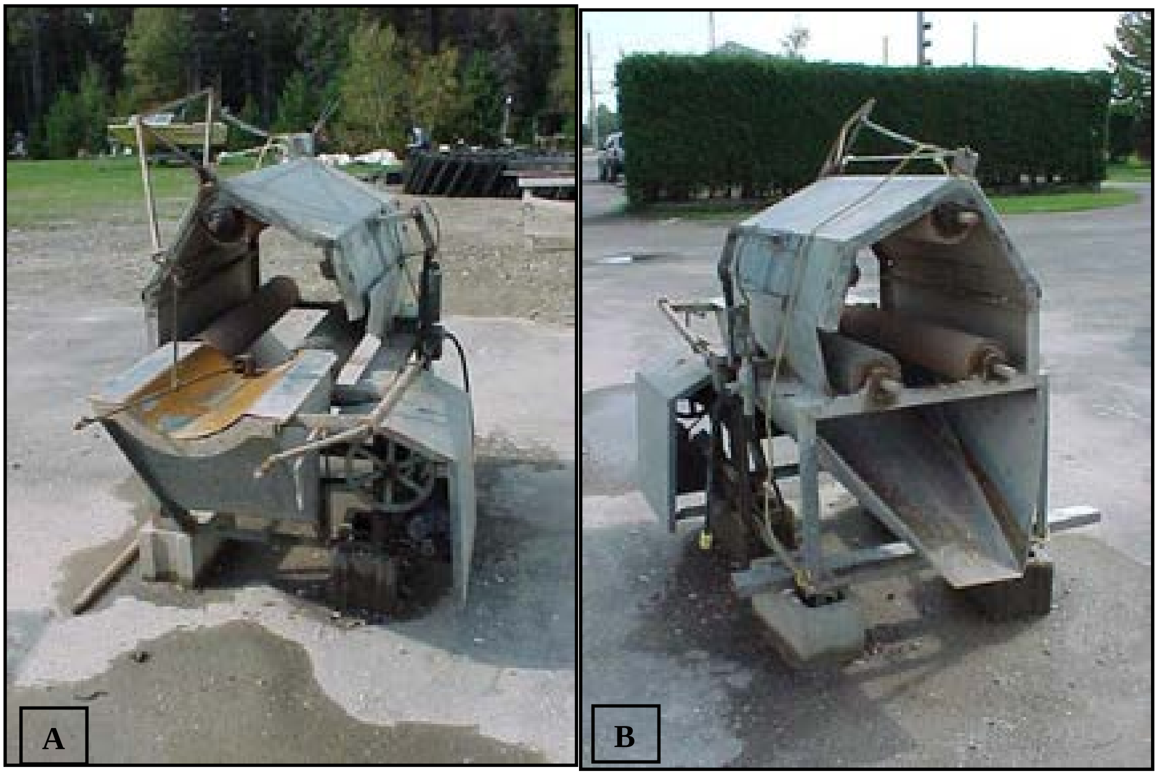

Figure 20 Stripping machine (A – entrance B – exit)

This machine runs on an electric motor and can operate with a water jet as well.

REMOTE SETTING

This technique is used extensively on the American west coast. Remote setting consists in submerging the collectors in tanks filled with seawater containing oyster larvae that are ready to settle. Oyster aquaculturists can therefore use this method in the spring to obtain a supply of spat instead of waiting for natural collection, which takes place in the summer.

The larvae come from shellfish hatcheries. This technique is used mainly to make up for a lack of collecting in the natural environment or irregular collecting. Trials involving Chinese hats have been done in New Brunswick, and the results show that there are certain advantages to remote setting. Spat that are remotely set in early May achieve a final size in the fall that is greater than that of naturally collected spat. However, the additional costs associated with food, heating the water, and equipment make this practice non-cost effective. In any case, spat collection in the natural environment is very regular in New Brunswick, and there is no evidence of any need to develop this technique.

TRIPLOID OYSTERS

Triploid oysters have an additional set of chromosomes. This abnormality causes sterility, meaning that the oysters cannot reproduce. There are two ways of producing sterile oysters: the reproduction of individuals from tetraploid oysters (four sets of chromosomes) and induction by chemical treatment. Figure 21 illustrates the natural reproduction process and manipulated reproduction.

There are certain advantages to rearing sterile individuals. All of the oysters’ energy goes towards growth and not towards reproduction. Growth can be faster, but the main advantage is that sterile oysters will stay plump during the summer. Normally, the meat index of oysters that reproduce is considerably lower after spawning.

In Europe, especially France, and on the west coast of the United States, the use of triploids oysters is growing. The technique has been refined, and hatcheries have mastered the triploid production process with Pacific oysters. However, the results are different on the east coast of North America. Trials have been carried out, but triploidy has not yet had a significant impact on oyster aquaculture.

Triploid oysters are produced in hatcheries through the application of a special treatment to fertilized eggs. After normal fertilization, the progeny contain the same number of chromosome pairs (two copies of each chromosome) as the parents, with half of the information coming from the male and the other half from the female. Following triploidy induction, the progeny contain three copies of each chromosome.

Spermatogenesis is the process by which sperm are produced. The spermatocyte is the specialized cell that produces sperm. A spermatocyte contains all of an animal’s genetic information and generally produces four sperm, each containing half of the male’s genetic information.

Oogenesis is the process by which the oocytes produce female gametes (the eggs). In oysters, the egg contains double the amount of the mother’s genetic material. It releases the surplus after fertilization by the sperm.

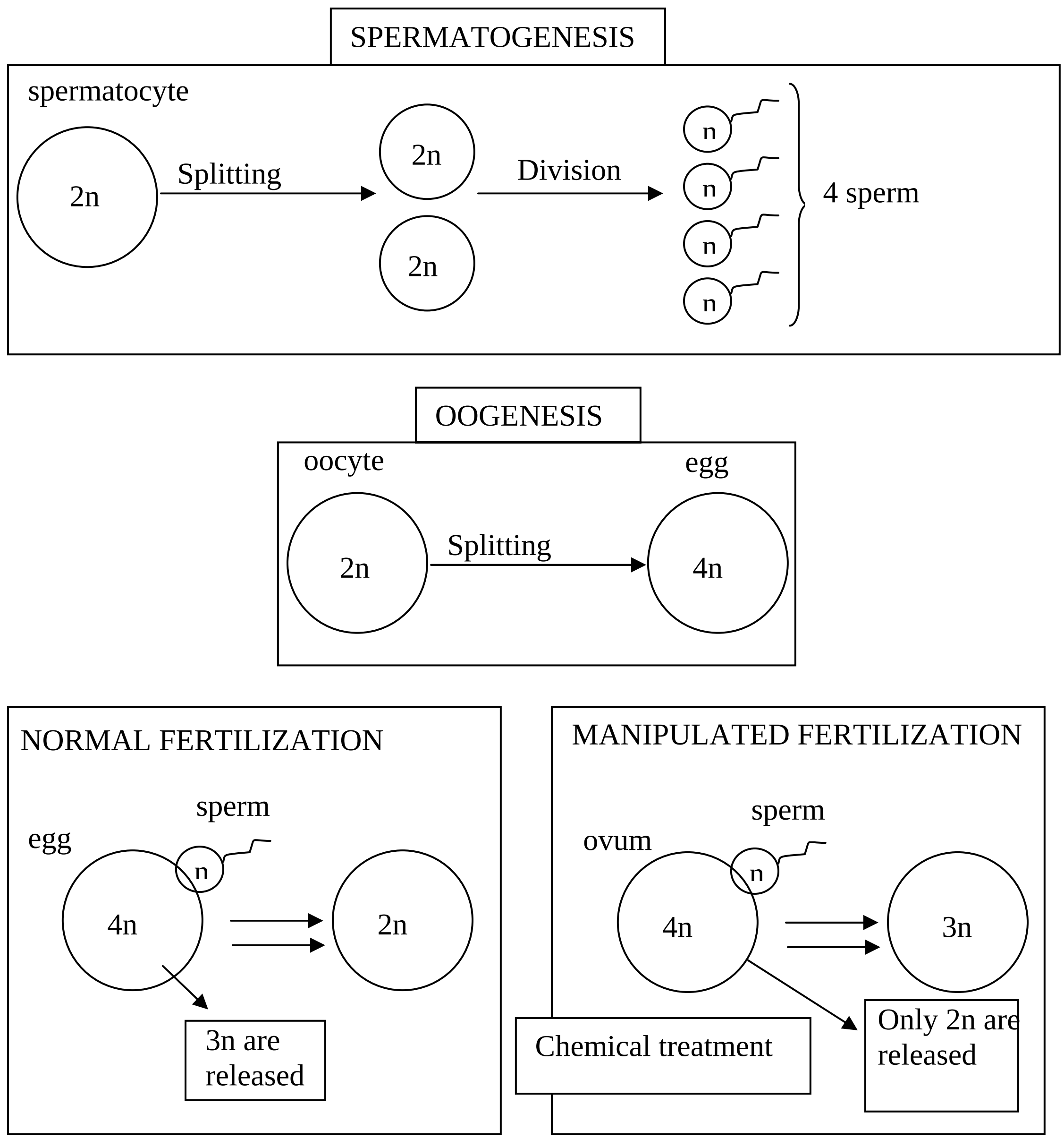

Figure 21 **Description of triploidy**

NORMAL FERTILIZATION produces a diploid individual (2n) containing the same number of chromosomes as the parents, whereas MANIPULATED FERTILIZATION produces a sterile triploid individual (3n).

NURSERY

Any rearing device in which seawater circulates can be considered a nursery system. A nursery is defined more specifically as a rearing facility for juvenile animals. Oyster bags are used as a nursery system when the size of the oysters ranges between 5 and 15 mm. However, there are devices used only for rearing juveniles that would not be cost effective to operate for the production of commercial-sized individuals.

FLUPSY

A Flupsy is a nursery system that promotes the growth of oyster spat and spat of other species of commercial value (Figures 22, 23 and 24). The word Flupsy comes from a combination of three words: <u>Fl</u>oating <u>Up</u>weller <u>Sy</u>stem.

Upwelling is the principle by which the water at the bottom rises to the surface. A Flupsy is actually a device that creates an upwelling current through cubical bins, allowing water to flow up through the screened bottoms. The bins are located on either side of a central channel that is an integral part of a floating platform. A propeller at the channel's exit creates the current. A sealed electric motor turns the propeller.

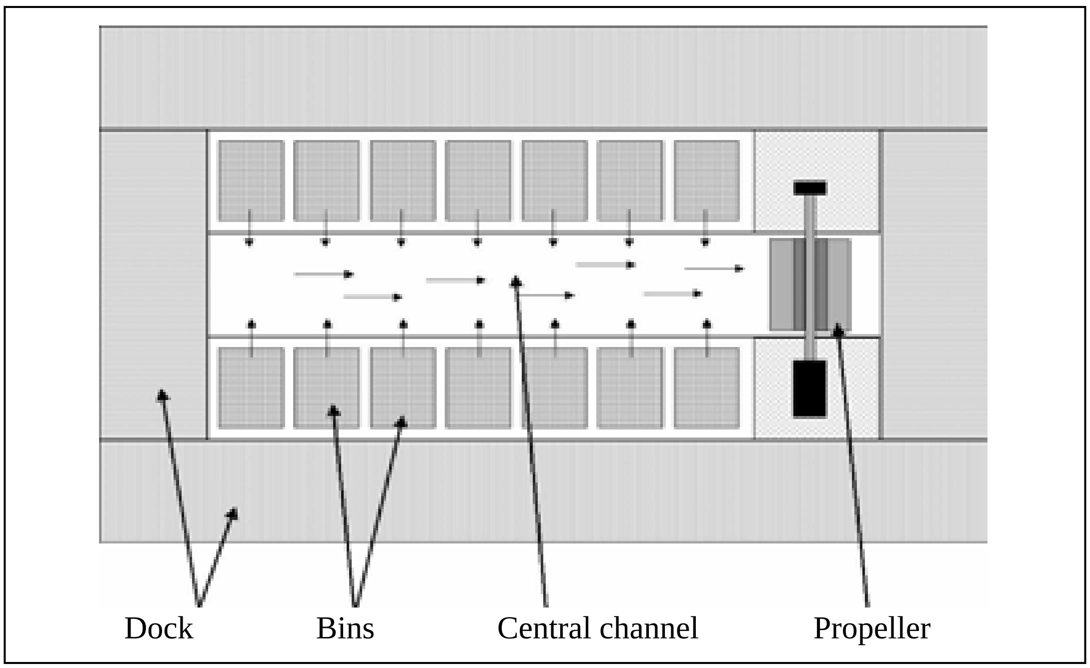

Figure 22 Diagram of a Flupsy - overhead view

The arrows in the central channel show the direction of the current created by the propeller.

The mollusc spat are placed on the screen on the bottom of the bins. The fast-circulating water (several thousand litres per minute) carries large quantities of food to the thousands of spat in the bins. Although the density is high, growth is still considerable owing to the ratio of flow to biomass. A 5-mm oyster can grow to 15 mm in four weeks.

There can be several million spat in a Flupsy at the same time. Cleaning is essential. The bins must be removed by means of a winch, and the bins and the molluscs they contain must be washed. This has to be done at least once a week.

A Flupsy is used for specific purposes. It would not be cost effective to build a Flupsy to bring spat to market size. A Flupsy is quite expensive to build. In addition, the locations where such a device can be installed are limited.

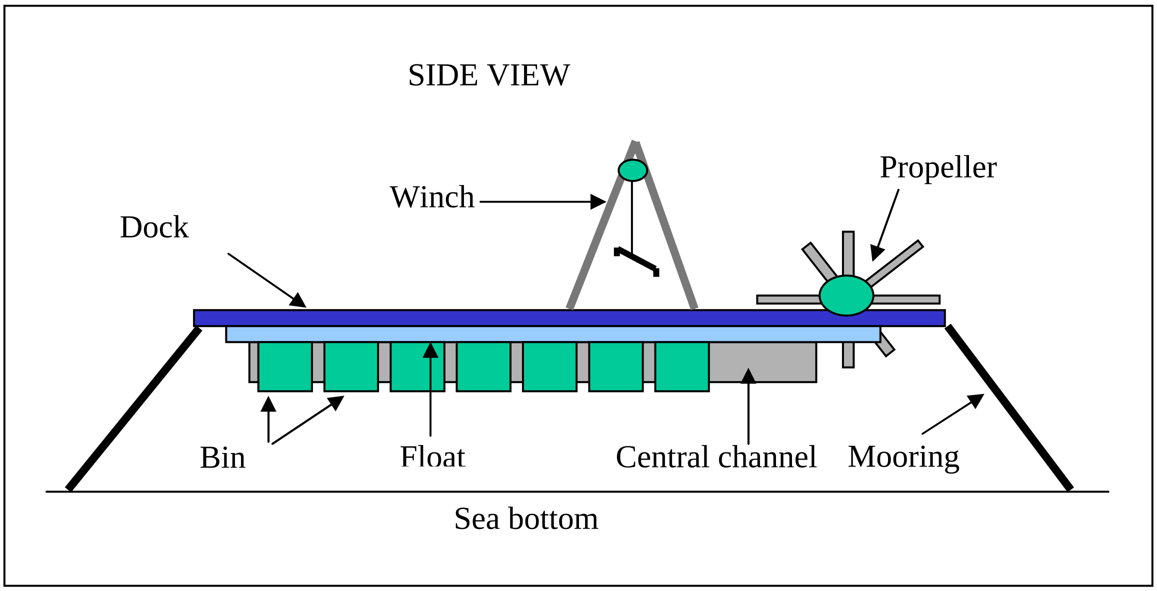

Figure 23 Illustration of a Flupsy

No dimensions are given because the size of a Flupsy varies depending on the production requirements.

Figure 24 Samples of two types of construction

The upper photo shows a Flupsy made of wood and metal, while the bottom one shows a Flupsy made of metal.

REARING METHODS

This guide looks only at off-bottom rearing methods since bottom culture was described exhaustively in the *Oysterculturist Manual* (Ferguson,1984).

In the late 1990s, oyster bag rearing trials attracted the interest of oyster aquaculturists. Oyster growth was unprecedented, making it possible to anticipate marketing the product in a short period of time. There are definite advantages to using this method: control of the stock, reduced losses owing to predation, easier harvesting, excellent meat quality, and attainment of commercial size in less than four years.

FLOATING BAGS

The floating bag technique uses a series of oyster bags maintained on the surface of the water in which the oysters are reared. Two cylindrical buoys attached to either side of the bags (Figure 25) keep them afloat. There are almost as many ways of arranging the bags on the surface of the water as there are oyster aquaculturists. The technique described in this manual is based largely on the one currently used in New Brunswick.

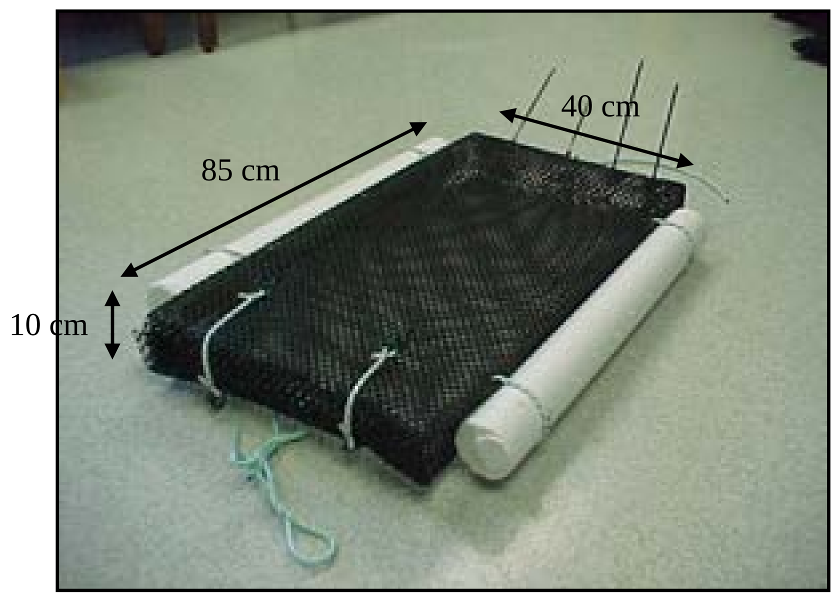

Figure 25 **Oyster bag**

Oyster bag made of fairly rigid plastic netting (Vexar) attached to two polystyrene cylindrical buoys with elastic bands.

Layout of Longlines

A typical longline consists of two rows of about 50 bags (Figure 26). The bags are kept together by a system of ropes and rigid crossbars. The longline is anchored to the bottom by metal screw anchors driven into the sediment. These screw anchors are securely attached to the longline and eliminate any risk of drag, something that conventional anchors cannot do. A longline is about 60 metres long and 2.4 metres wide, and the crossbars are placed at both ends and regularly spaced to keep the tension between the lines.

The cylindrical buoys attached to the bags keep the longlines afloat. The distance between the longlines must be sufficient to allow for navigation and to provide access to the bags: it is generally between 5 and 7 metres.

Leaving a space of a few centimetres between the bags makes handling them possible (rotation of the bags) and prevents the floats from being damaged. Both ends of the bags are secured to the tension lines by central fasteners.

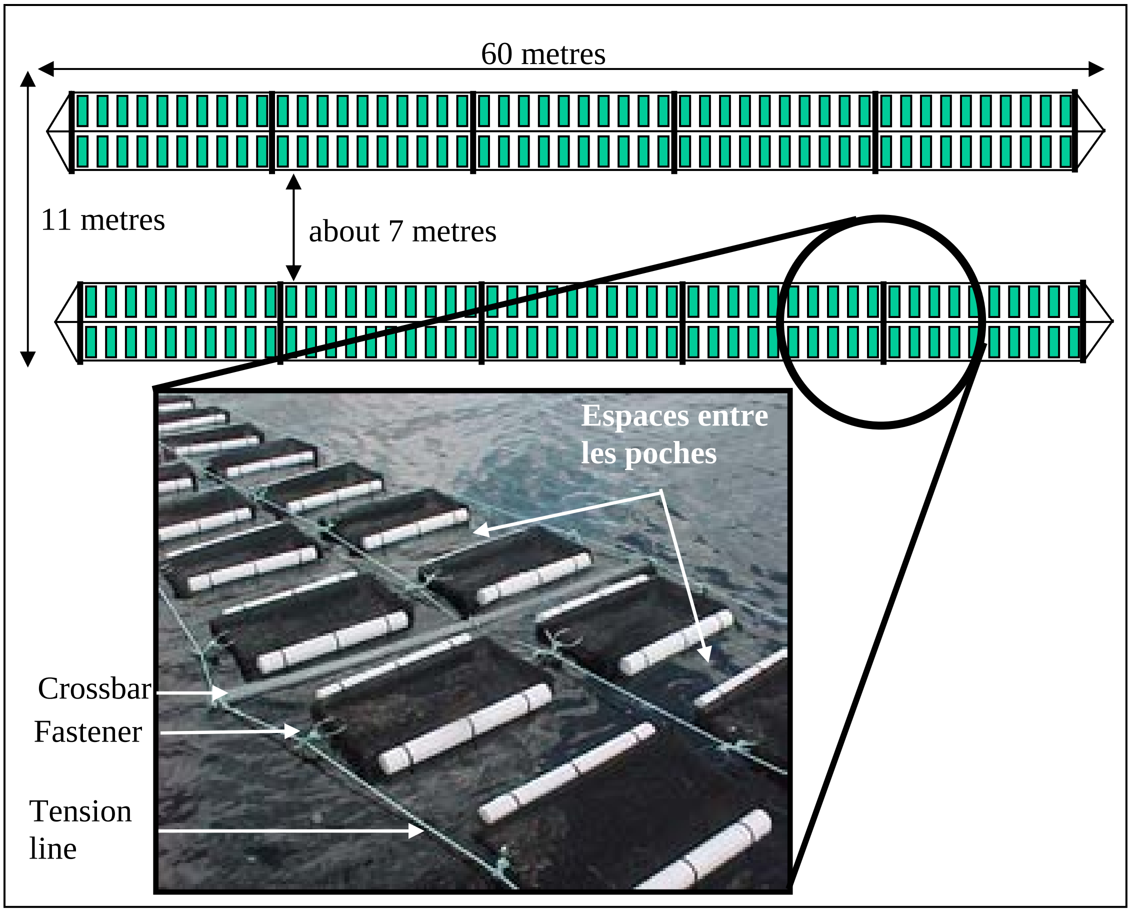

Figure 26 **Oyster bag longline**

The figure shows the layout of two 100-bag longlines on the water surface. In the photo, the tension maintained between the lines and the bags is quite visible.

Anchoring

To maintain the oyster bag longlines on the surface, oyster aquaculturists quickly realized that conventional anchors were inadequate. They therefore borrowed a technique used by mussel aquaculturists to anchor their longlines (Figure 27). This consists of a screw anchor attached to a metal rod. This type of anchor can be driven into the sediment by hand, although a hydraulic device does the job more easily. It is better to set the anchors in the winter because the ice offers stable support. It is also easier to measure the exact distance between the anchors.

Anchor size varies according to the type of bottom: the softer the bottom, the larger the diameter of the screw anchor. The screw anchors used range between 10 and 15 cm in diameter. The length of the rod varies as well, but there no specific standards (about 50 cm). The screw anchors are driven into the sediment until the rod is completely buried.

The anchor cables are attached to the screw anchors before they are driven in, otherwise it would be impossible to find them again.

Figure 27 Helical screw anchor and hydraulic device

On the left, a screw anchor, and on the right, a hydraulic device used to drive the screw anchors into the sediment.

Density

Density is defined by the number of individuals per surface unit. Bag density is expressed in terms of the number of oysters in the bag (200, 500, 1000, etc.) or in terms of volume (litre) or weight (kilogram). Density has an effect on oyster growth and is closely related to the number of bags required for rearing. Table II shows the commonly used densities and the number of bags required to produce 500,000 oysters.

TABLE II Rearing density and bags required

Year	Purchase	Number of oysters	Density (oysters/ bag)	Number of bags	Number of bags to be purchased
Year 1	Current year	500,000	1,000	500	**500**
		Bags required →		500	
Year 2	Current year	500,000	1,000	500	**1,000**
	Preceding year	500,000	500	1,000	
		Bags required →		1,500	
Year 3	Current year	500,000	1,00	500	**2,500**
	Preceding year	500,000	500	1,00	
	Preceding year	500,000	200	2,500	
		Bags required →		**4,000**	
	Sale in fall	500,000	200	2,500	Bags released

Why is it necessary to vary the number of oysters per bag? The rim that forms around the valves as the oyster grows is very fragile and breaks easily. Growth is reduced if the oyster is shaken too vigorously and for too long. Small oysters are shifted easily within the bag, which moves under the action of the waves. Having a sizeable mass of oysters in a bag stabilizes it and limits movement. The weights and volumes corresponding to the suggested densities are shown in Table III.

Having a large number of small oysters in a bag provides stability owing to the additional weight. Waves have less of a hold on the bags because they are less buoyant. Older oysters are larger and heavier. They take up more room in the bags. In order not to overload the bags, density is reduced.

As the preceding paragraph shows, density plays a positive role in stock management, but it can be a limiting factor as well. Growth may be reduced if there are too many oysters in a bag.

TABLE III Suggested rearing densities

AGE CLASS	OYSTER SIZE (mm)	DENSITY (oysters/bag)	WEIGHT (kg)	VOLUME (L)
1	15 – 25	1000 – 1500	2 - 3	4.0
2	25 – 50	500	4 – 5	4.0
3	50 - 75	200 - 250	4 - 6	6.0

Here is a quick and easy method of determining the number of oysters placed in a bag. A 1-litre container can be used in nearly all situations.

1) Fill the container completely, and count the oysters.
2) Do this 10 times.
3) Note the number of oysters each time.
4) Add up the results of the 10 samples, and divide by 10. This gives the average number of oysters in the container.

Example: The oysters in 10 1-litre containers are counted:

1.	245 oysters	6.	236 oysters
2.	255 oysters	7.	242 oysters
3.	229 oysters	8.	258 oysters
4.	261 oysters	9.	253 oysters
5.	267 oysters	10.	274 oysters

This adds up to 2,520 oysters. Divide by 10 (the number of samples), which gives an average of 252 oysters per litre. If the target density is 1,000 oysters per bag, then four litres of oysters (4 x 252 = 1,008) must be placed in the bag. This can be done manually or mechanically using a bag filler/weigher. (See photos in appendix.)

Sorting

Oysters grow at different rates even though they may belong to the same age class. The oysters in a bag may not all reach market size at the same time. Oyster aquaculturists must therefore sort their stock.

Sorting is done in the spring and summer. Sorting in the fall is not recommended as it may cause the oysters stress, which they will have difficulty coping with as winter approaches. Oysters will probably not be able to repair a broken shell at that time of year since their metabolism slows down considerably as the water temperature drops.

For small quantities of oysters, sorting can be done by hand using a table to which a metal screen has been attached. The mesh size matches the size of the oysters to be placed in bags. This is a home-made method, and a skilled oyster aquaculturist can easily build this type of sieve using wood and screening. For larger operations, sorting machines have been developed to carry out this task, which would otherwise take up a great deal of time and require numerous employees. There are two types of machines operating on two different principles.

The first type (Figure 28) is simple and less costly. It consists of a cylinder made of mesh that turns on an axis with different-sized openings. After being fed into the top, the oysters pass through the mesh owing to the rotating action and fall into containers placed under the sorting machine.

Figure 28 Oyster sorting machine (home-made)

This sorting machine has several sections that make it possible to sort oysters of different sizes. The oysters fall into the tubs that can be seen at the base.

A different type of sorting machine (Figure 29) was designed in Europe where oyster aquaculture is highly developed. Made of stainless steel, it consists of a series of superimposed screens that have different-sized openings and are agitated by means of vibrating movements.

Figure 29 Vibrating screen (commercially manufactured)

In the top photo, the arrow points to where the oysters come out. In the bottom photo, note the wheels for moving the sorting machine. With this vibrating screen, four sizes of oysters can be sorted simultaneously.

Overwintering

Oysters lower their metabolism when the water temperature drops below 10°C. They stop filtering completely below 4°C. They do not feed at all during the winter.

In October, as the cold season approaches, oyster aquaculturists start preparing the bags for winter storage. They are placed on the bottom of their lease or suspended out of the reach of ice. Two overwintering methods have been developed. Oyster aquaculturists who use the first method submerge the oysters in growout bags and have only to remove the floats for them to sink to the bottom.

Oyster aquaculturists who use the second method have another series of bags for overwintering. Oysters that spent the summer in growout bags are transferred to overwintering bags. Since they are no longer feeding, between 20 and 22 litres of oysters can easily be placed in one bag. The bags are attached to a line placed on the bottom or suspended in the water column. However, it must be ensured that, as soon as the water warms up above 4°C in the spring, the oysters are re-suspended and the densities are reduced to maximize growth and prevent suffocation. Figure 30 illustrates the layout of a submerged longline. Details concerning overwintering longlines are provided in Appendix III.

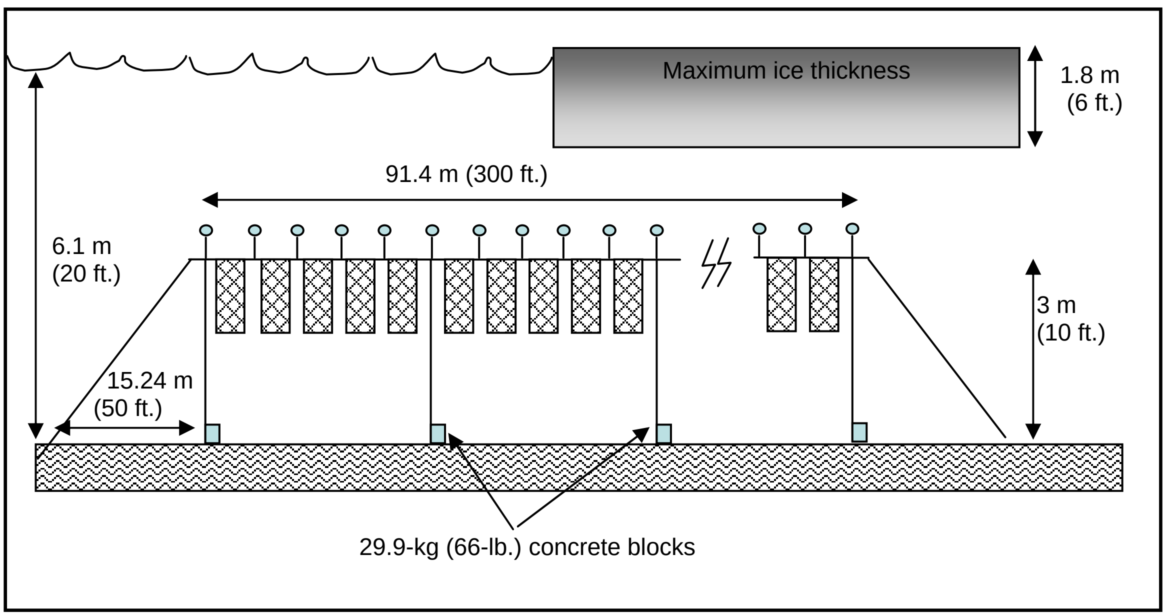

Figure 30 Diagram of a submerged longline

Yield

An oyster's growth is inversely proportional to its size. When an oyster is small, it grows much more quickly than when it is large. Under good rearing conditions, it is estimated that a 15-to-20-mm oyster in a floating bag can grow to more than 65 mm in three growing seasons (May to October). Table IV shows the growth rates that are possible under optimum growing conditions.

TABLE IV Oyster growth under optimum conditions

YEAR	INITIAL SIZE (mm)	TOTAL GROWTH (mm)	FINAL SIZE (mm)
YEAR 1 (May to October)	15 - 20	15 - 25	30 - 45
YEAR 2 (May to October)	30 - 45	10 - 20	40 - 65
YEAR 3 (May to October)	40 - 65	5 - 15	45 - 70
YEAR 4 (May to October)	45 - 70	5 - 10	50 - 80

Growth is affected by various factors, and the optimum rates are not always achieved. The wide discrepancies in Table IV reflect that fact.

Mortality rates have been scientifically monitored since rearing oysters in bags first began. Under optimum conditions, mortality rates are estimated to be less than 5% per year, but rates can vary considerably depending on local factors.

Constraints

There are certain advantages to rearing oysters in oyster bags, but there are real constraints as well. Any equipment placed in the aquatic environment quickly becomes a collector for a multitude of marine organisms. Oyster bags are no exception to the rule. The spat of mussels, barnacles, and oysters sometimes settle in large numbers on the bags as well as on the cultivated oysters themselves.

Cleaning off the mussel and oyster spat that settle on a producer's stock can and will result in additional costs during harvesting and during the production cycle. Some oyster aquaculturists have moved their oyster aquaculture tables to the intertidal zone to prevent undesirable organisms from collecting on their stock, but that option is available to only to a small percentage of aquaculturists. A brushing machine designed in Europe makes it possible to clean a large quantity of oysters in a short period of time (see **Harvesting** section).

Innovation

The rearing technique used today is constantly evolving. Various elements will probably undergo modification in the near future, such as:

bag closure method
method of attaching bags to tension lines
shape and size of overwintering bags
location of floats
polystyrene floats versus high-density polyethylene floats
PVC crossbars versus metal bars (rebars)
method of reducing fouling organisms.

The floating bag rearing technique shows real potential, but it must be adapted to the needs of each oyster aquaculturist and each site in order to maximize cost effectiveness. However, caution must be exercised during innovation trials. Making changes to structures and procedures does not always provide adequate solutions to all the problems although, generally speaking, all changes cost the producer money. It is better to carry out small-scale trials and observe the results than to invest in large-scale projects that do not meet all the objectives that have been set.

BAGS ON TABLES

This rearing technique has been adapted from the French oyster aquaculture industry. The French have been producing thousands of metric tons of Pacific oysters on their coast for decades using this method. With a few minor modifications, the technique can easily be adapted to our conditions. The oyster bags are spread out on metal tables about 45 cm high, 1 m wide, and 3.3 m long.

Arrangement of Tables

The tables (Figure 31) are normally placed in the intertidal zone of the rearing site. That makes it easier for oyster aquaculturists to get to their structures and carry out maintenance work at low tide. The bags are securely attached to the tables to prevent them from being washed away by currents or waves. To eliminate the problem of corrosion, the tables are galvanized. Although this increases the cost of the tables by 50%, their greatly extended service life justifies the expense.

Figure 31 Oyster rearing in bags on tables

Density

Density in the Vexar bags varies according to the size of the oysters. Approximately 1,000 oysters 20 mm in size are placed in the bags the first year. Density is reduced to about 500 the second year and to between 200 and 250 the third year. The quantity of oysters in the bags is reduced to maximize growth and enhance quality.

Sorting

Sorting can be done in the spring before the bags are placed in the water and during the summer. The advantages of sorting are the same as those mentioned in the section on the sorting of floating bags.

Overwintering

Overwintering the bags and tables requires a great deal of time and energy. Different options are available, including the following:

> Moving the tables and bags to a deeper part of the site so ice does not damage them.
>
> Removing the bags from the tables, and overwintering them on a location on the site where there is no risk of ice damage. They are attached to a line anchored to the bottom or suspended in the water column. The tables are stored on dry land.

Yield

Rearing oysters in bags on tables is not very different from rearing them in floating bags. Yields are similar, in terms of both growth and survival rate. (For more details, refer to the section Floating Bags - Yield.)

Constraints

Ice is a major constraint for this rearing practice. The tables have to be moved to deeper locations on the site or removed from the water. The availability of sites suited to this rearing method is limited. The popularity of this technique is therefore limited as well. In addition, it requires boats equipped with powerful winches capable of moving around a great deal of equipment.

FRENCH LONGLINE (Research and Development)

In Thau Pond in the Mediterranean area, oyster aquaculturists have developed another rearing method. They cement oysters to strings and suspend them in the water from metal supports. Similar trials have been carried out in northeastern New Brunswick, with promising results. Unfortunately, few aquaculture sites on the province's east coast are suited to this rearing technique, mainly because of the shallowness of the oyster aquaculture sites. However, an attempt was made to adapt the technique, and oysters cemented to strings were suspended horizontally at the surface of the water (Figure 32).

Figure 32 Experimental French longline

Oysters cemented to strings attached to a longline maintained at the surface of the water by buoys.

At the moment, it is difficult to describe the technique because there are still too many technical details to be worked out. Nonetheless, this rearing method shows some potential. On first observation, we noted that oysters take on a more cupped shape and that growth is comparable to that obtained in floating bags. However, marine fouling organisms (Figure 33) are much more of a problem with this method than with the floating bag method.

Figure 33 Marine fouling organisms

Algae can clearly be seen attached to the oysters. Oyster spat (not visible) are another type of fouling organism.

Cementing of Oysters

The process of preparing the strings and cementing the oysters to them is well established in the Mediterranean area. This is the technique that was used here. First, to cement the oysters to the string, a support made especially for that purpose is required. It is made from sheets of wavy fiberglass attached to a wooden structure. In pairs, the oysters are placed between the waves at regular intervals of about 10 cm. The right valve is placed against the sheet of fiberglass, and the hinges of the two oysters must be touching. When the fiberglass panels are full, a piece of string is placed on the oysters and attached at either end of the support to nails that were hammered into the concave part of the wave beforehand (Figure 34). A mixture of cement and water with a consistency similar to that of cold molasses is placed on the string and the oysters. A third oyster is then pressed into the cement above each group of oysters (Figure 35). This must be left to dry for 24 hours. The supports filled with strings of oysters can then be taken to the rearing site.

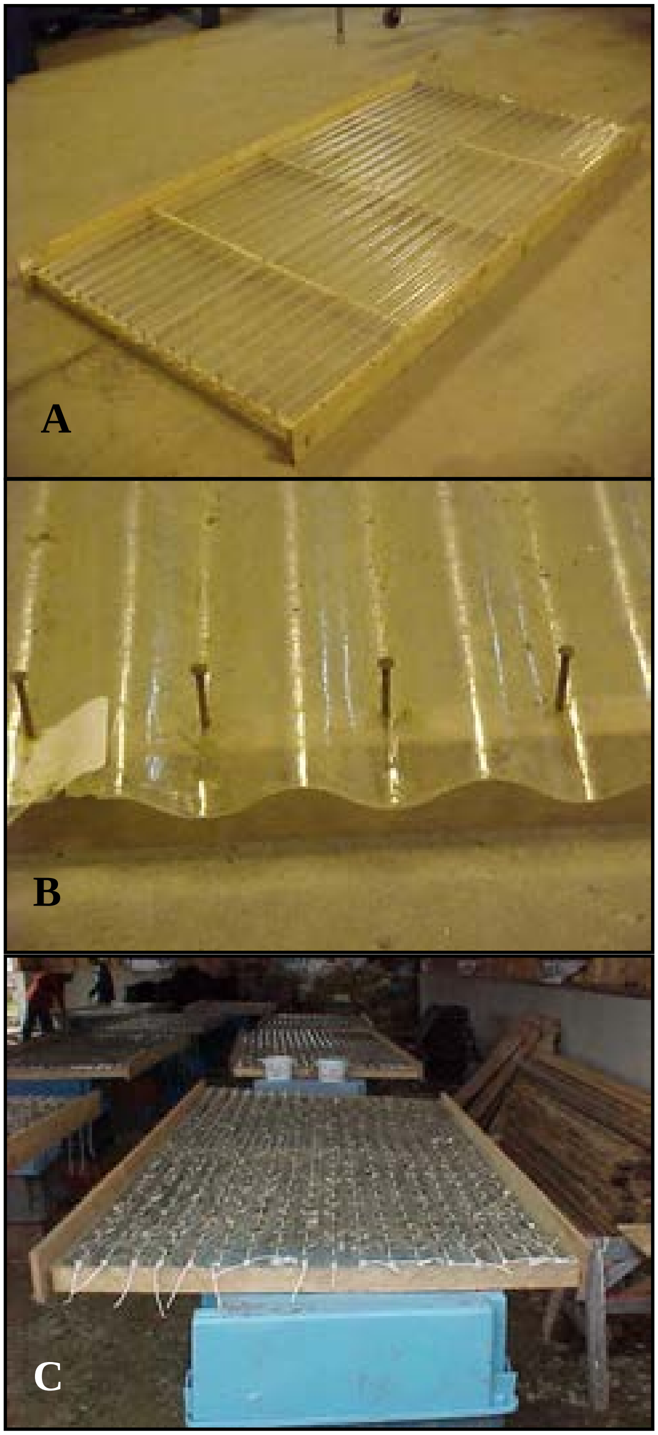

Figure 34 **Cementing support**

A) Wooden support with sheet of wavy fiberglass.
B) End of support showing the waves and the nails used to attach the strings.
C) Support filled with oysters on which strings have been placed.

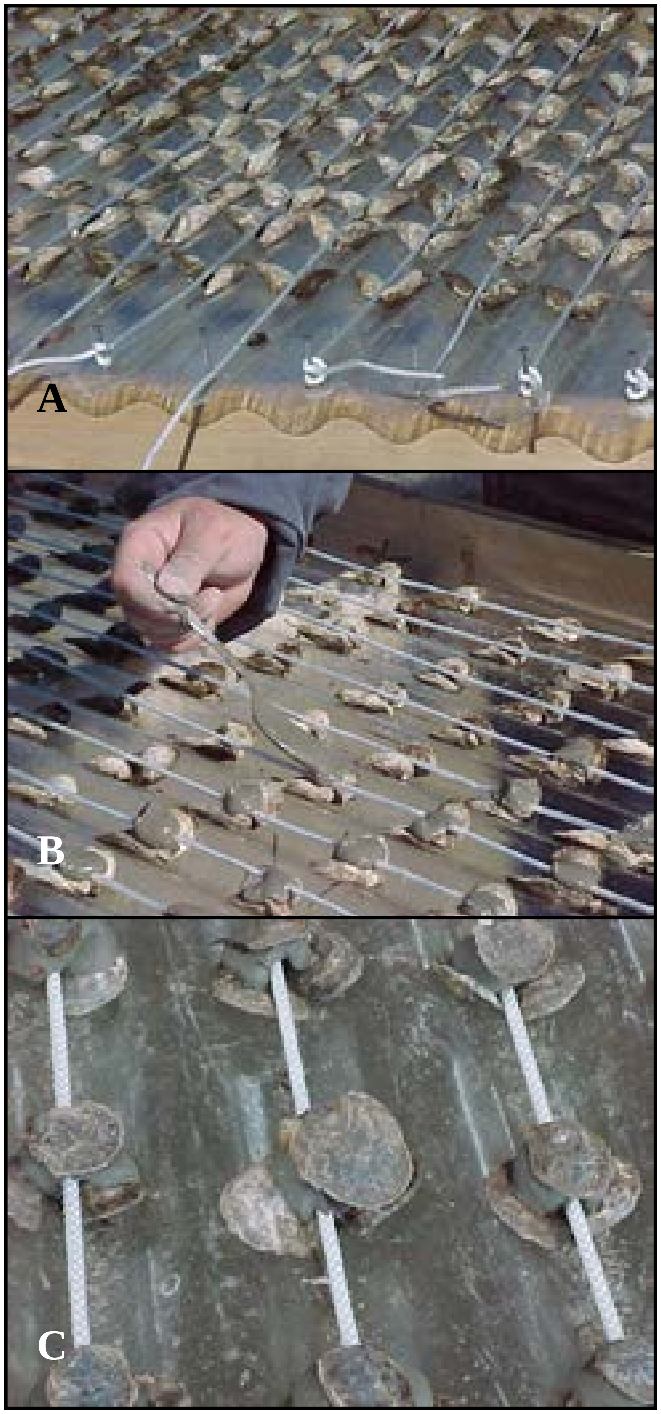

Figure 35 **Cementing of oysters**

A) Oysters ready to be cemented. Note that the right valve is on the bottom.
B) A small amount of cement is applied to the oysters and the strings.
C) A third oyster is pressed into the cement. The process is completed, and the support must be left to dry for 24 hours.

Setting of Longlines

Trials were carried out on a deep (3 metres), sheltered site (Figure 36). Except for a few details, the same technique as the one used in the Mediterranean was tested. The results were very favourable.

Figure 36 Oysters on strings suspended from rafts

The strings are about two metres long**.**

On other leases where the water is often less than a metre deep, the technique must be adapted considerably. The structure that was used consisted of three parallel lines kept afloat on the surface of the water by means of conventional buoys (Figure 37).

Figure 37 Experimental longline

After this manual is published, further testing of rigid structures will likely be carried out. Problems that will need to be addressed include keeping the new structure afloat, controlling fouling organisms, overwintering, and harvesting. The technique's economic feasibility must be taken into account in well.

HARVESTING

In New Brunswick, until quite recently, oysters were harvested from early fall until early winter. Harvesting was mainly a fishing activity. Quebec and Ontario consumers love seafood from the Atlantic provinces, and during the fall they organize their oyster parties. In France, almost the entire oyster production is sold before Christmas. Our American neighbours eat large quantities of oysters in the fall as well. Product availability has conditioned people to eat oysters in the fall. This seems to be an international tendency.

Oyster harvesting has always been done in the fall not only because the demand is higher then but also because fisheries legislation did not allow harvesting during the other seasons. Today, oyster aquaculture is truly a full-time year-round activity. In order to enable the oyster aquaculture industry to develop, agreements have been signed between oyster aquaculturists and the Department of Fisheries and Oceans. Those agreements allow oyster aquaculturists to harvest their product throughout the year. Also, they do not need to comply with size limits.

The use of oyster bags facilitates harvesting. It is easy for oyster aquaculturists to determine the number of bags they need to remove from the water because they know how many oysters the bags contain. In addition, they can do this year-round because bags on longlines are readily accessible at the water surface or through a hole in the ice (Figure 38).

Figure 38 Harvesting through the ice

Oyster aquaculturists have to prepare their oysters for sale. They must sort and clean them. Sorting is generally done in the summer. The oysters are separated on the basis of size, i.e., oysters larger than 75 mm are placed together in a series of bags and oysters between 65 and 75 mm are placed in other bags. The latter are cocktail oysters. Although tough, oysters are living animals. They must be handled carefully in order not to harm them. Oysters must not be left in the sun for too long. Also, care must be taken not to break the shell. An oyster that loses its intravalvular liquid will quickly die. Oysters must be stored in a cool place between handlings.

Oysters are cleaned during the sorting process. That is when fouling organisms such as algae, barnacles, mussels, and oyster spat are removed. The quantity of oysters to be cleaned will dictate the method used. Cleaning can be done by hand with an oyster gauge (Figure 39). This tool is used to check the size of the oyster, but it also serves as a lever to dislodge the spat of other mollusc species. For large quantities of oysters, a mechanized oyster washer can be used (Figure 40). This device has proved to be highly effective for cleaning the surface of oyster shells. The cleaning is quite vigorous and can break the shell's rim. It is therefore suggested that cleaning be done after the fouling organisms have finishing settling but early enough in the season for the oyster to regrow its shell. August is a good time for this operation. The washer takes up little room and can easily be used on an oyster aquaculture boat.

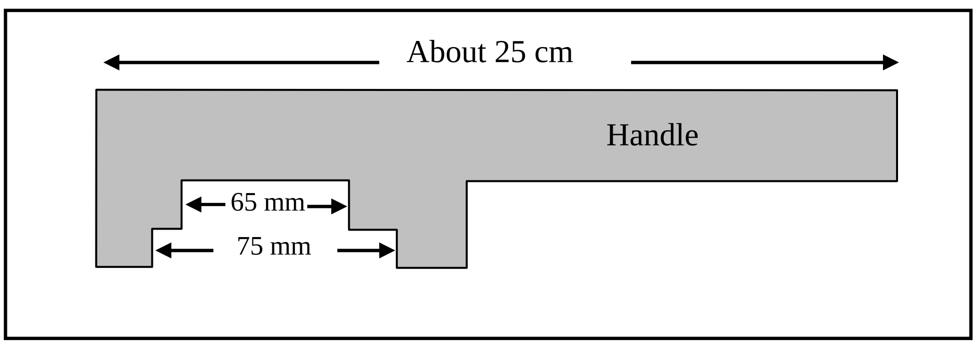

Figure 39 **Oyster gauge**

Made of metal, it is flat (about 5 mm thick), and the handle can be made of metal pipe about 25 mm in diameter.

Figure 40 Oyster washer

The motor above the washer turns a series of brushes with stiff bristles that destroy barnacles and oyster spat and remove mussels. The process is done with water.

PROCESSING

Processing is defined as any operation that involves handling the product to prepare it for sale. Before being shipped, oysters are washed, sorted, and packaged, and the containers are labelled. If the oysters are exported outside the province, the processing plant must be certified by the federal government. For local markets, the processing plant needs only provincial certification. (See *Fish Processing Act*.)

Washing

The oysters are placed on a table and sprayed with a hose. The water removes the sediment and mud that have accumulated on the shell. A pressurized stream of water is not used because that would break the shells before packaging.

Sorting

Oysters are sorted on the basis of size to differentiate between cocktail oysters and larger oysters. They are also sorted on the basis of their morphological appearance. A good quality oyster must be fairly thick and have an adequate length-to-width ratio. The shell must be clean and solid. A damaged shell allows the liquid to leak out, and the oyster will not survive storage in good condition. In processing plants, staff are employed to sort the oysters according to four grades (Figure 41) based on a coefficient calculated as follows:

Example of calculation: Oyster 76 mm long and 50 mm wide
$76 \text{ mm} \div 50 \text{ mm} = 1.52 \Rightarrow$ Choice

This grade applies mainly to oysters raised using bottom culture methods or fished on public beds. Oysters produced in oyster bags are sold as two grades based on length. Cocktail oysters are between 65 mm and 75 mm, while oysters larger than 76 mm are sold as an aquaculture product at the legal commercial size. It should be noted that oysters produced in oyster bags generally fall into the first two quality grades according to the grading method illustrated in Figure 41.

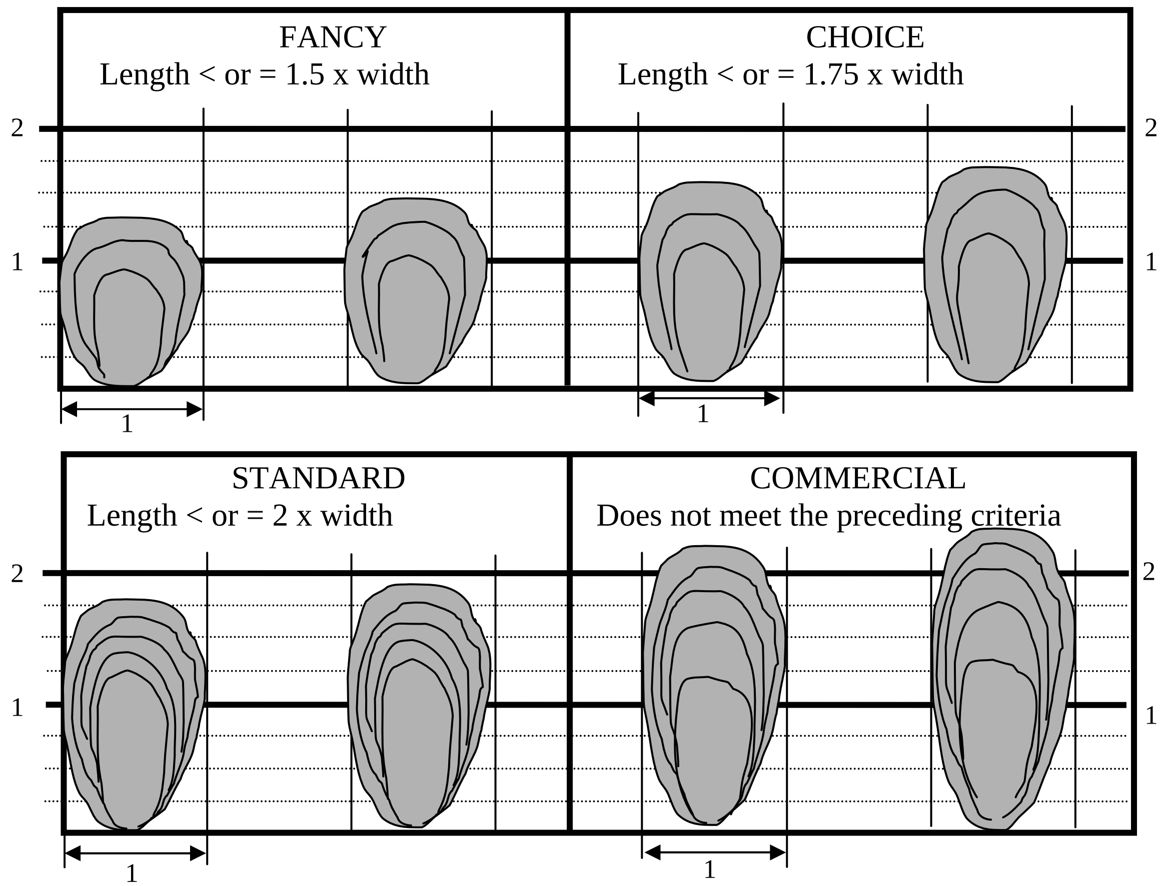

Figure 41 **Grades of oysters**

Although many plants have workers to do the sorting (Figure 42), there is a device, called an oyster grader, that can sort mechanically (Figures 43 and 44). A conveyor belt carries the oysters to an image analyzer, which determines the oyster's shape. A computer controls the doors that push the oysters into the appropriate compartments.

Figure 42 Workers assigned to oyster sorting and packaging

Figure 43 End of an oyster grader

The doors are located between the two conveyor belts and push the oysters into the appropriate bins.

Figure 44 Side view of an oyster grader

The collection bins for the different grades of oysters.

Packaging and Labelling

Packaging must be done carefully. Specific numbers of oysters are placed in the boxes. They are laid on their left valves so that the internal liquid remains in the shell. The boxes are then shut and sealed, and labels are placed on the boxes.

The labelling of marine products is regulated with a view to protecting consumer health. However, good labelling has other benefits. A properly labelled product is easy to identify. Consumers can readily locate the products they like, and the information on the labels helps them to ascertain the quality of the product, as well as its origin, date of packaging, and so forth.

The operation of a processing plant is a regulated activity. Anyone considering going into processing should check into and become familiar with the relevant legislation. The investment required to start up and operate a processing plant amounts to several thousand dollars, so it is an expense that should not be taken lightly.

DEVELOPMENT OF A SHELLFISH ENTERPRISE

In New Brunswick, oyster aquaculture was long perceived as a secondary seasonal activity. It generated extra income for a number of inshore fishermen at the end of the fishing season. Today, oyster aquaculture creates full-time jobs and requires major investments. Oyster aquaculturists must be well organized to market the oysters they have been cultivating for three or four years on an ongoing basis.

New entrants to the industry have to develop a strategy that will enable them to identify the opportunities and challenges they face. The business plan is an essential tool for that purpose.

BUSINESS PLAN

"A good business plan is a kind of 'reality check.' It helps you to identify the challenges as well as the opportunities your business will face. It forces you to clearly identify your target markets and your competition. It pushes you to think through your operational and financial requirements and how you will handle sales and promotion." (Taken from *Planning for Success – Your guide to preparing a business plan*). Developing a business plan is demanding work that requires the right knowledge. In some cases, it is advised that a professional be engaged to design the business plan. Even if the plan is prepared by a third party, the oyster aquaculturist's input is essential. For more information about business plans, the financial agencies that have guides on this subject should be consulted.

A business plan is made up of several important sections, including the following: Cover Page, Table of Contents, Executive Summary, The Business, The Opportunity, Financial Data, and Production Plan. The guides that are available clearly explain the different steps in a business plan. The section of the business plan that requires the oyster aquaculturist's input is the production plan. The main components of a production plan are described on the following pages.

PRODUCTION PLAN

A production plan describes the technical aspects of the enterprise. It details a number of essential elements, including the following:

Rearing Method

The rearing method used forms the basis of the production plan. It helps to determine the space required to achieve the production targets. In addition, it affects the amount of time required to grow the stock to commercial size and makes it possible to determine how many workers will be required during a given production season. The quantity and type of equipment necessary are directly related to the rearing method and the scale of production.

Use of Space

This depends on the production cycle. To establish a viable operation, it is important to identify the surface area required to meet the production targets. The surface area used for immediate production, for overwintering, and for navigation corridors must all be taken into account (Figure 45). The amount of space necessary to float 20 oyster bag longlines is equal to one hectare. Navigation corridor requirements will be determined on the basis of local occupancy rates. Normally, overwintering spaces are located in the deep part of the lease, whenever possible.

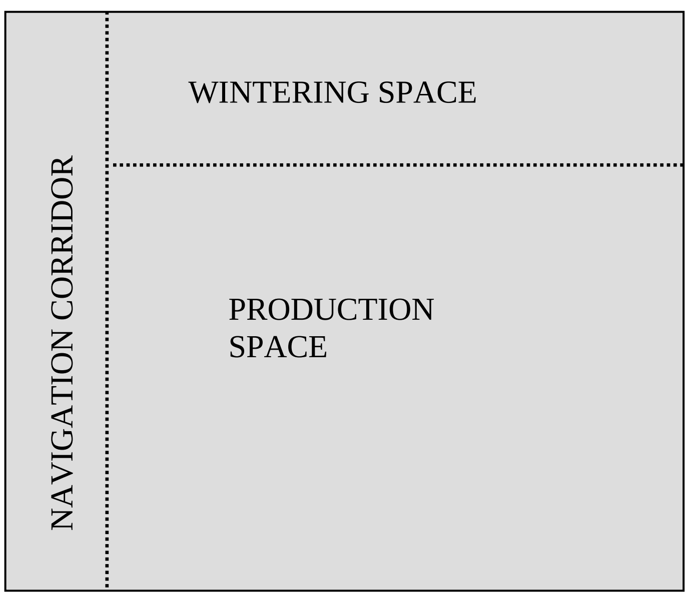

Figure 45 Diagram illustrating the use of an aquaculture lease

Note that the dots are positioned arbitrarily and that the defined areas are not to scale.

Production Cycle

The time required to grow oyster spat to commercial size defines the production cycle. The production cycle determines when the product will be marketable. The survival rate must be known as well. These parameters have an impact on the amount of equipment required and the revenue generated. Table V illustrates the fluctuations in a stock consisting of 500,000 seed oysters purchased annually and reflects a survival rate of 95% per year. The initial size of the oysters varies from 15 to 20 mm, and all of the stock is sold after spending three years in bags. The obvious advantage of purchasing spat is the possibility of selling all of the stock in the third year. If the production assumptions are met, the oysters should be larger than 65 mm.

TABLE V Changes in production over the years

YEAR	Number of individuals being reared				
	Year 1	Year 2	Year 3	Year 4	Year 5
Year 1	500,000	475,000	451,250		
Year 2		500,000	475,000	451,250	
Year 3			500,000	475,000	451,250
Year 4				500,000	475,000
Year 5					500,000
Sale			(451,250)	(451,250)	(451,250)
Total stock	500,000	975,000	975,000	975,000	975,000

Table VI depicts the production cycle of an enterprise that collects spat. A production cycle based on spat collection is longer than the production cycle of an enterprise that buys spat. Savings on supplies justifies this approach.

TABLE VI Production cycle

BEGINNING OF CYCLE ⇒	**FIRST SUMMER** 0 to 4 months - July to October SPAT (2 to 15 mm)	**OVERWINTERING** November to April
FOURTH SUMMER 38 months + September to June Marketing of cocktail and legal-sized oysters (70 mm and over)		**SECOND SUMMER** 11 to 16 months - May to October **JUVENILE OYSTERS** (15 to 45 mm)
OVERWINTERING November to April	**THIRD SUMMER** 23 to 28 months - May to October **ADULT OYSTERS** Marketing of cocktail oysters (45 to 70 mm)	**OVERWINTERING** November to April

Workforce

There are certain times during a production year when more workers are required. This is the case in spring and fall when the rearing equipment must be set out or stored for the winter. When the rearing cycle is over, additional staff has to be hired to carry out the harvesting activities. It is important to determine the number of workers accurately since that is a major operating expense for an enterprise. Unfortunately, there is no model for forecasting labour requirements. Each enterprise is unique and will have its own specific labour needs.

Equipment

The rearing method and the scale of production are the parameters that have a direct impact on equipment needs. Equipment purchasing costs are the highest during the first years of production. Many materials specific to the different rearing methods are available, and there are a large number of suppliers. It is therefore recommended that the suppliers be consulted in order to obtain the best equipment at the best price. Supply and delivery times are other considerations that must be taken into account. It is important to plan the purchase of equipment properly because certain preparatory work takes time. For example, if oyster bags are purchased in the fall, they can be prepared during the winter, a season that is generally less busy. A section of this manual looks at oyster aquaculture equipment.

CONCLUSION

The growing interest in shellfish aquaculture resulted in an influx of people to the offices of the New Brunswick Department of Agriculture, Fisheries and Aquaculture. However, the *Oysterculturist Manual* (Fergusson, 1984), which used to be distributed as a reference guide, no longer met the industry's needs. Editing it therefore seemed to be the logical next step, but once the project got under way, it became apparent that it would be impossible to edit the manual while incorporating all the new developments in the industry. The amount of information to be included was just too large.

The Department therefore decided to write a new manual adapted to today's needs. It should be noted, however, that this manual is destined to the same fate as the previous one. The concepts looked at in this manual, including biology and development of a production plan, will remain current for many years, but the rearing techniques, equipment, and operations will inevitably change over time.

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APPENDIX I CONVERSION TO INTERNATIONAL SYSTEM

Distance		Equivalent in metres
1 millimetre	=	0.001 metre
1 centimetre	=	0.01 metre
1 decimetre	=	0.1 metre
1 metre	=	1 metre
1 decametre	=	10 metres
1 hectometre	=	100 metres
1 kilometre	=	1000 metres

LENGTH

1 kilometre	= 0.5396 nautical mile
1 kilometre	= 0.62137 mile
1 metre	= 1.0936 yard
1 metre	= 3.2808 feet
1 metre	= 39.37 inches
1 mile	= 1.6093 kilometre
1 mile	= 5,280 feet
1 nautical mile	= 1.1515 mile
1 foot	= 30.48 cm
1 inch	= 25.4 mm
1 yard	= 0.91 metre

AREA

1 acre	= 43,560 square feet
1 acre	= 4,047 square metres
1 hectare	= 2.471 acres
1 hectare	= 107,640 square feet
1 hectare	= 10,000 square metres

MASS

1 gram	= 0.0352 ounce
1 pound	= 0.454 kg
1 pound	= 454 grams
1 kilogram	= 2.2 pounds
1 kilogram	= 1,000 grams
1 ounce	= 28.3 grams
1 metric ton	= 1,000 kg
1 metric ton	= 2,200 pounds

VOLUME

1 gallon (imp.)[1]	= 4.54 litres
1 litre	= 0.22 imp. gallon
1 litre	= 1 cubic decimetre
1 litre	= 35.2 ounces (imp. fl.)[2]

* [1] imp. = imperial
* [2] imp. fl. = imperial fluid

APPENDIX II HOW TO OPEN AN OYSTER


1. Insert the knife between the two shells at the hinge.

2. Twist the wrist to separate the shells.


3. Insert the knife into the oyster and cut the muscle.

4. Remove the top shell.

Note: To enjoy oysters raw, it is recommended that the surplus liquid be poured out. That way, you can fully appreciate the taste.

APPENDIX III OVERWINTERING SPECIFICATIONS

Lines

1. A line is 91.44 metres (300 feet) long.
2. Scope lines are 15.24 metres (50 feet) long.
3. Lines are spaced 7.62 metres (25 feet) apart.
4. Lines are anchored at the ends with metal screw anchors.
5. Struts are inserted every five bags [about 3 metres (10 feet)].
6. Struts are maintained on the bottom with 29.5-kg (65-lb.) weights.
7. Approximately one buoy is required per bag.

Yield

1. Possibility of four lines per acre.
2. Possibility of 150 oyster bags suspended in a row on a line.
3. Estimated density of 1,000 oysters per bag, all sizes combined.
4. Yield of 600,000 overwintered oysters per acre.

TABLE I

ANNUAL PRODUCTION TARGET	250,000	500,000	1,000,000	1,500,000	2,000,000	5,000,000
Overwintering area required (in acres)	1.25	2.50	5.00	7.50	10.00	25.00

NOTE 1: The production cycle is based on three years.

TABLE II

ANNUAL PRODUCTION TARGET	250,000	500,000	1,000,000	1,500,000	2,000,000	5,000,000
Overwintering area required (in acres)	1.7	3.3	6.7	10.0	13.3	33.3

NOTE 2: The production cycle is based on four years.

APPENDIX IV   EQUIPMENT

Any developing industry needs specialized equipment to achieve its objectives. Oyster aquaculture is no exception. Since oyster bags came into use, a range of specialized products has made its appearance. Improvements are made to this equipment every day, and further adjustments will be required over the years. The following list shows the variety of equipment most commonly used today.

To give the bags their square shape, a bag press is required. Here are two examples:
The photo on the left shows a commercially made bag press, while the photo on the right shows a home-made one that is just as effective.

To close the bags, the ends have to be cut in four different places. Oyster aquaculturists have developed a machine to do this: the bag cutter. The model below is one example, and several other types are available as well.

To bend the hooks, an iron pipe with a notch at one end is simple and effective.

Attaching the bags to the longlines is a process that takes time and energy. Oyster aquaculturists have developed a toggle-and-loop system that makes the job easier. The system was adapted from the technique used to moor lobster traps. The disc in the photo on the left is made of rubber, but there are discs made of PVC, vinyl, and other materials.

Boats:

A number of factors have an impact on the effectiveness of a boat or a work platform. Since most oyster aquaculture sites are located in shallow bays, it is recommended that boats with a shallow draft be used.

The size of a work platform varies according to the needs of the enterprise.

In France, oyster aquaculturists use scows to move around on their sites and transport their equipment. In New Brunswick, there is a growing interest in flat-bottom boats, but the types of construction are as varied as they are numerous. The two examples below show two models made of fiberglass.

To place large quantities of oysters in bags, a piece of equipment made in Europe can be ordered from different French companies. It is called a bagging and weighing machine. The oysters are poured into a hopper at the lower end of a conveyor belt, which carries them to the bag opening. Once the set weight has been reached, the conveyor stops automatically.