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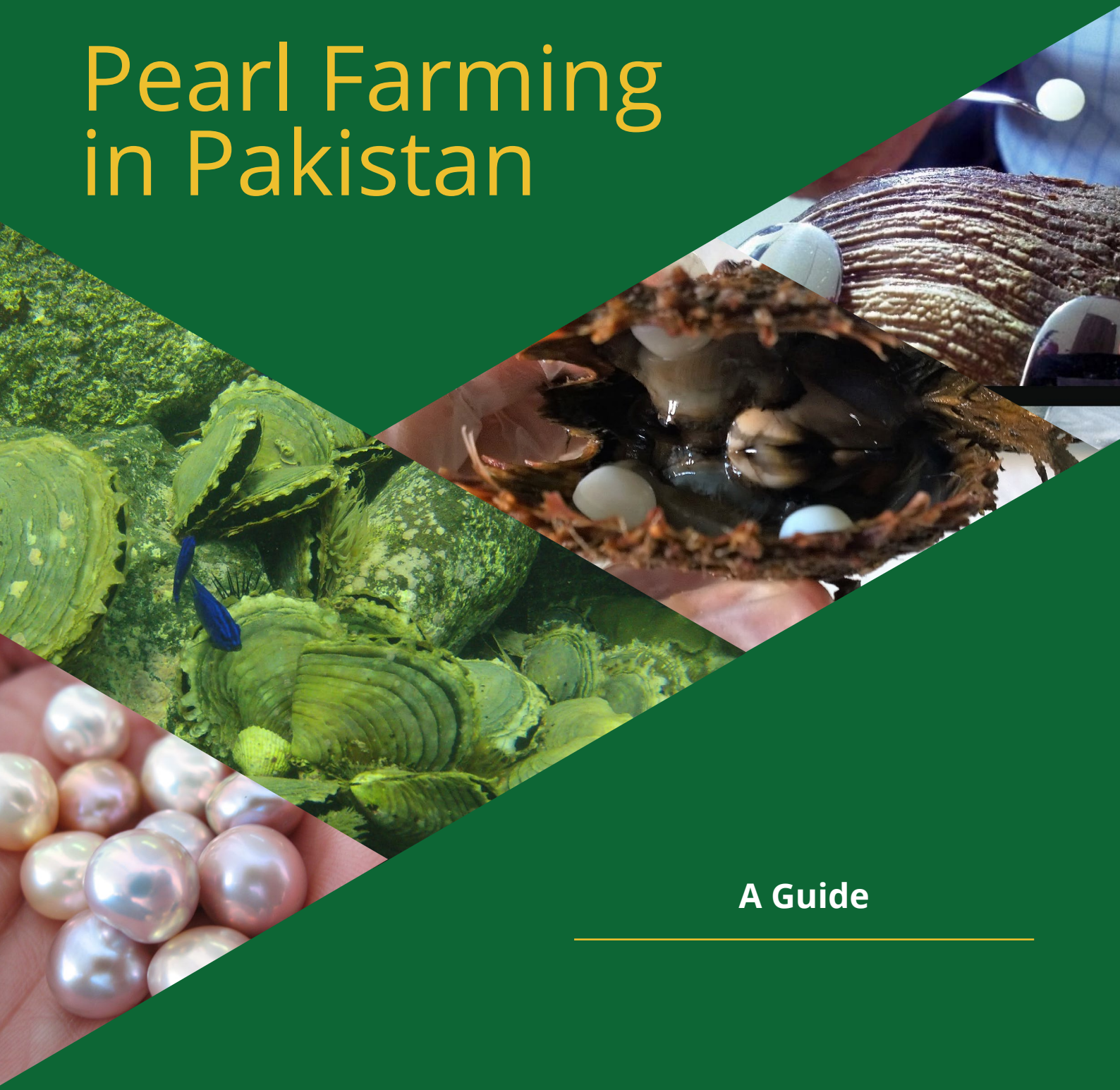
Climate Adaptation and Resilience (CARE) for South Asia Project

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.

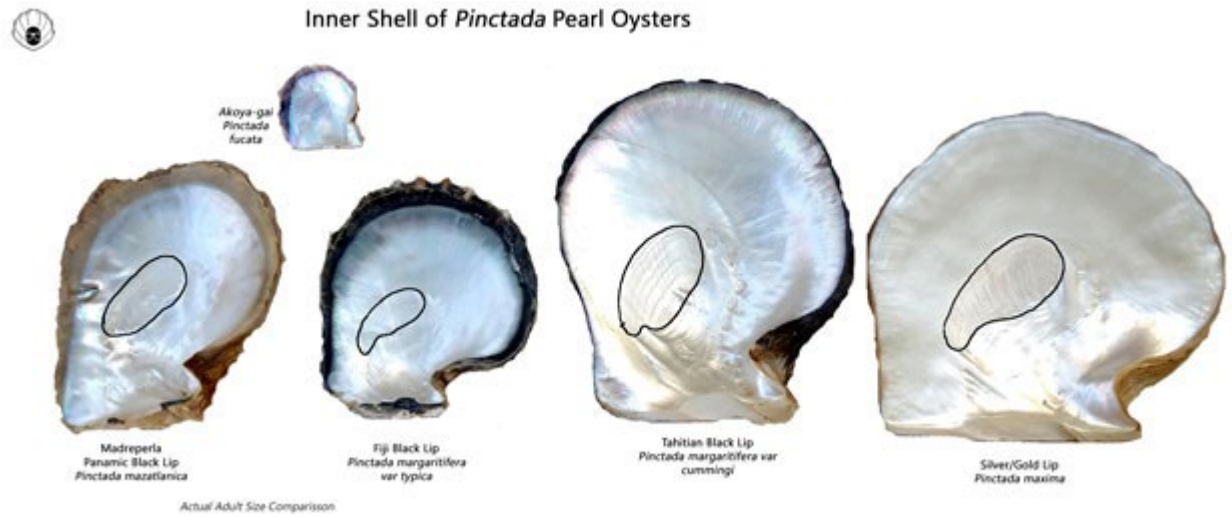

Figure 2: The shells of the most important commercial saltwater pearl bearing species in the world (left to right): the “Panamic Black lip” (Pinctada mazatlanica), the “Akoya-gai” (P. fucata/imbricata), the “Black-lip” (here we have two varieties: P. margaritifera typica and P.m. cummingi), and the “Gold/Silver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

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

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.

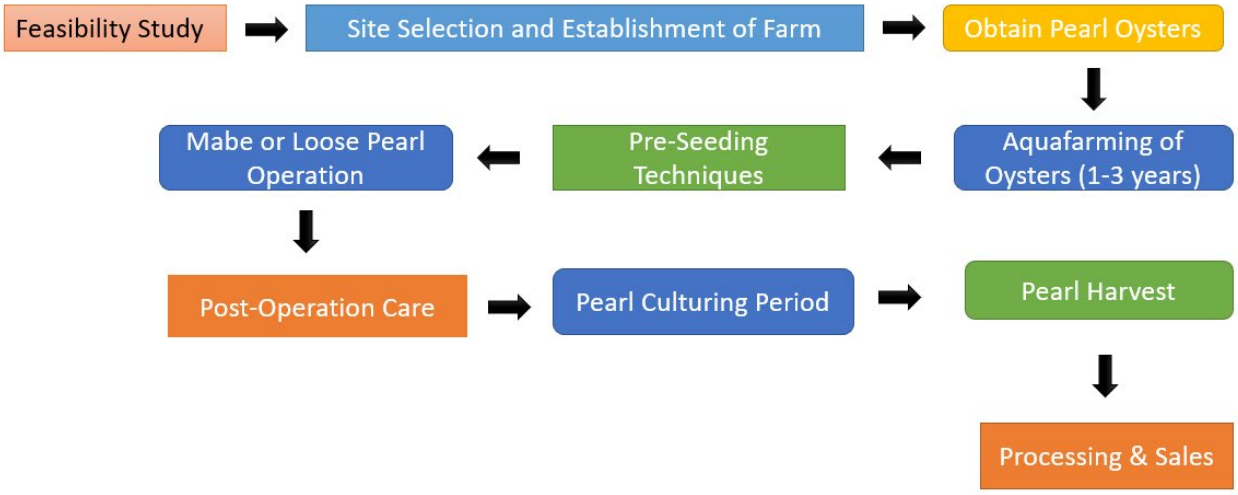

Figure 6: The pearl farming process takes between three to five years and has all these steps involved.

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.

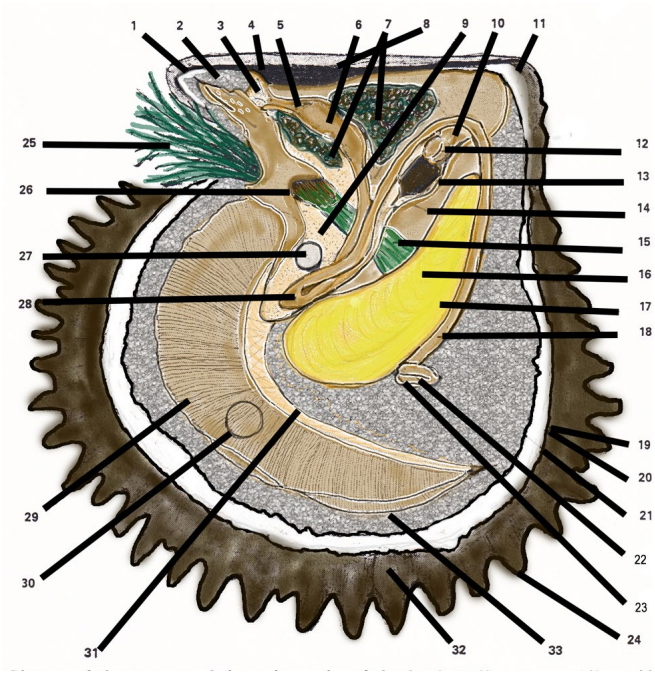

Figure 7: Internal anatomy of the pearl oyster (modified from George, 1978). List of Anatomical features: 1-Foot 2-Hinge 3-Labial Palp 4-Mouth 5-Esophagus 6- Stomach 7-Hepatopancreas 8-Hinhe Ligament 9-Gonad 10-Intestine 11-Nacre 12-Heart/Ventricle 13-Heart/Auricle 14-Pericardial cavity 15-Foot Retractor 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

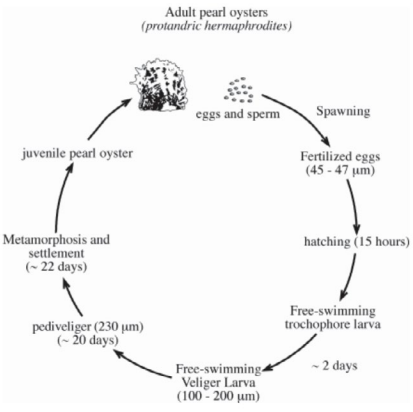

Figure 8: The life cycle of pearl oysters, from Gervis & Sims (1992).

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.

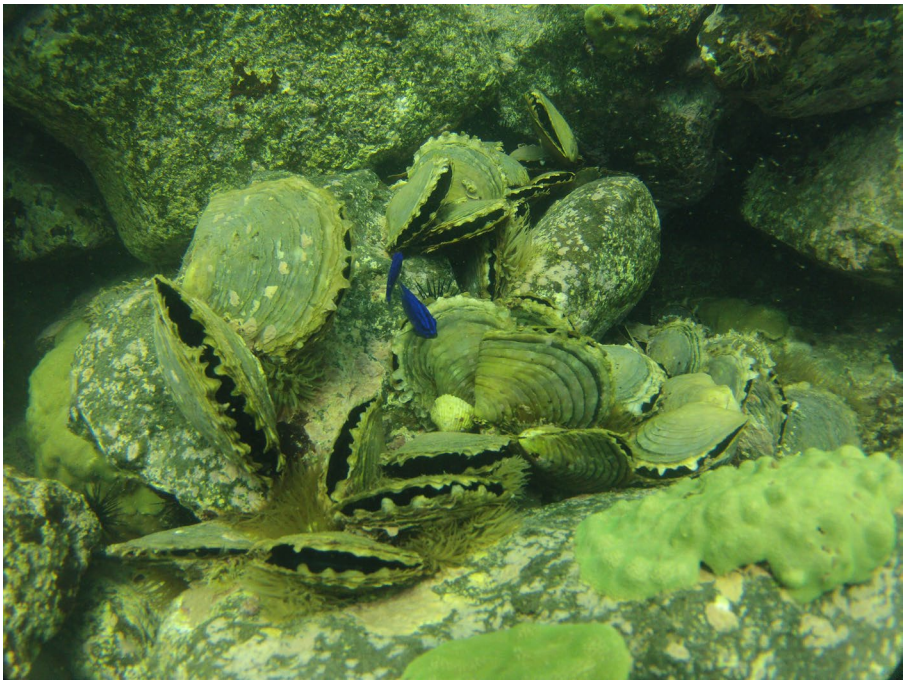

Figure 9: A group of young wild black-lip pearl oysters attached to rocks.

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.

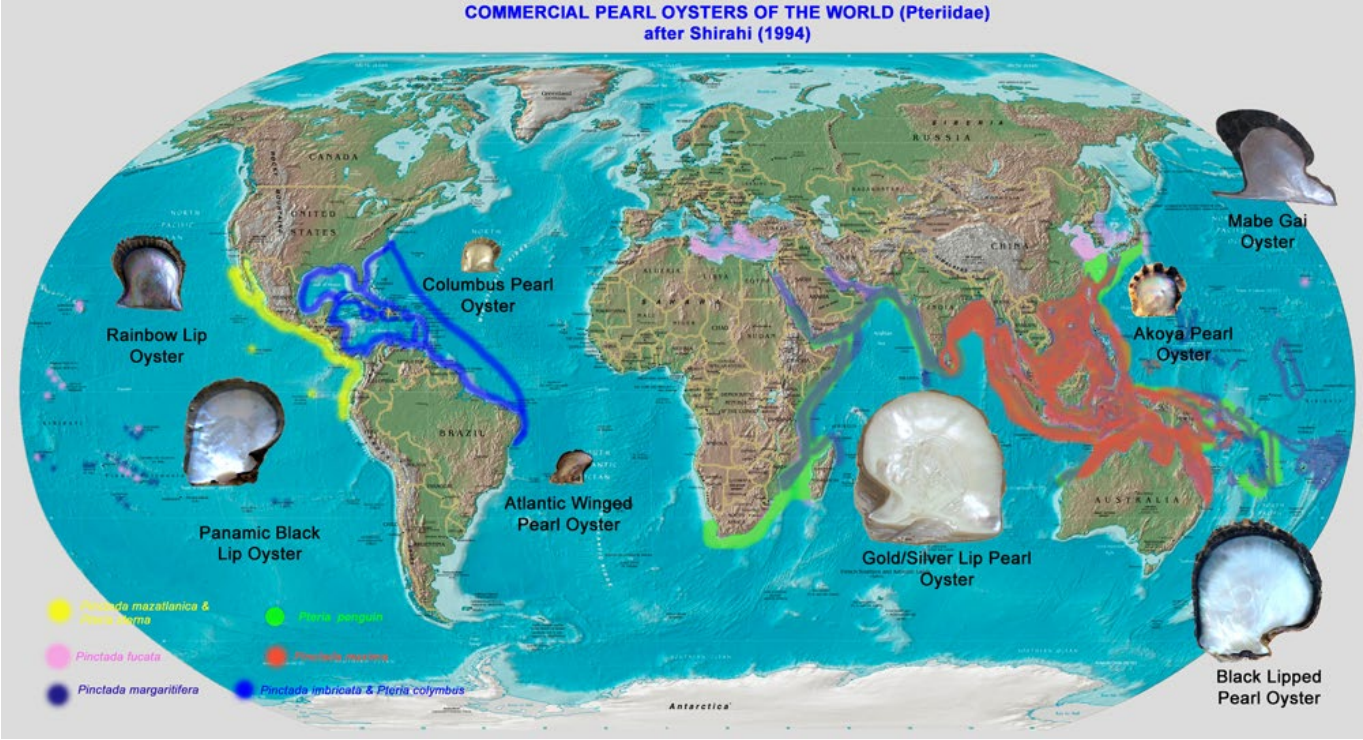

Figure 10: Distribution of the major pearl producing species (adapted from Shirahi, 1994).

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.

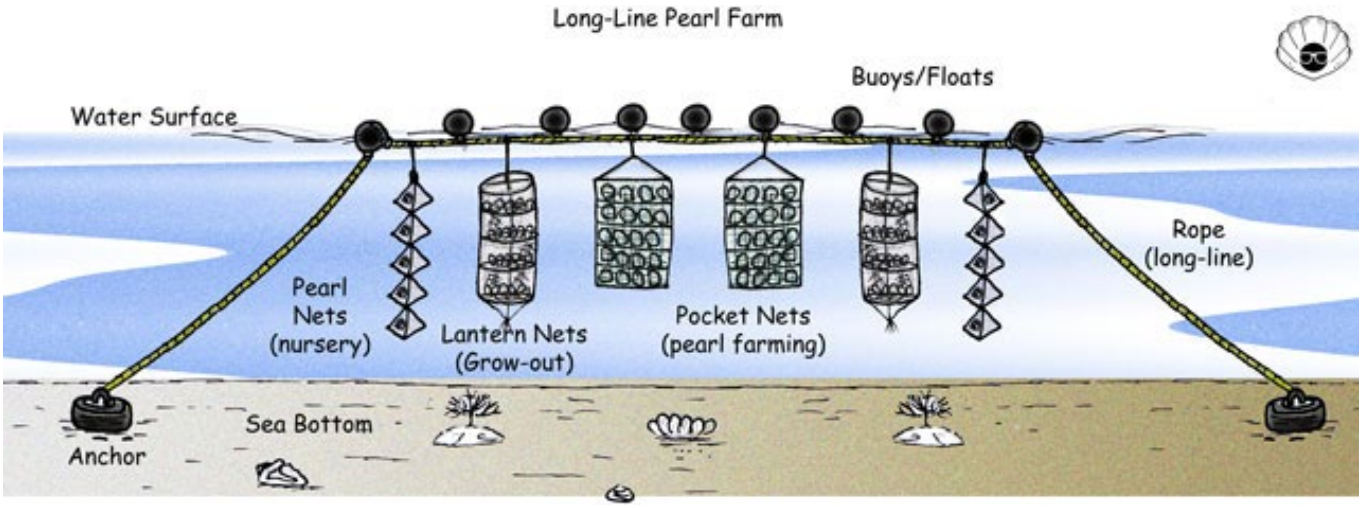

Figure 11: A "longline" aquaculture system.

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.

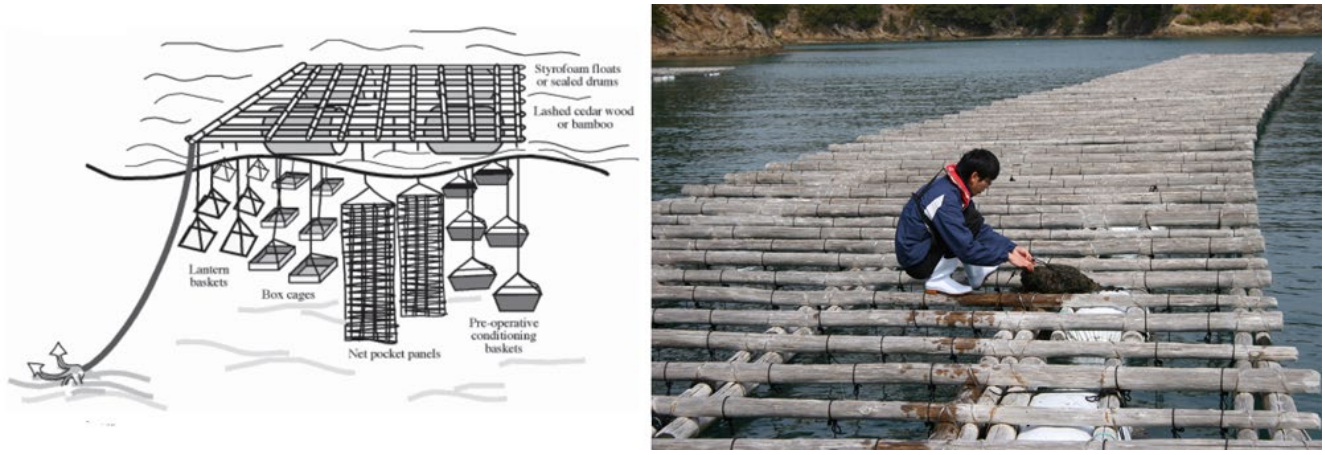

Figure 13: A diagram of a Japanese-style floating raft for pearl culture (from Gervis and Sims, 1992) and photo of a Japanese pearl farmer working on a raft in Ago Bay, Japan (courtesy of Jeremy Shepherd and Pearls as One Course).

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.

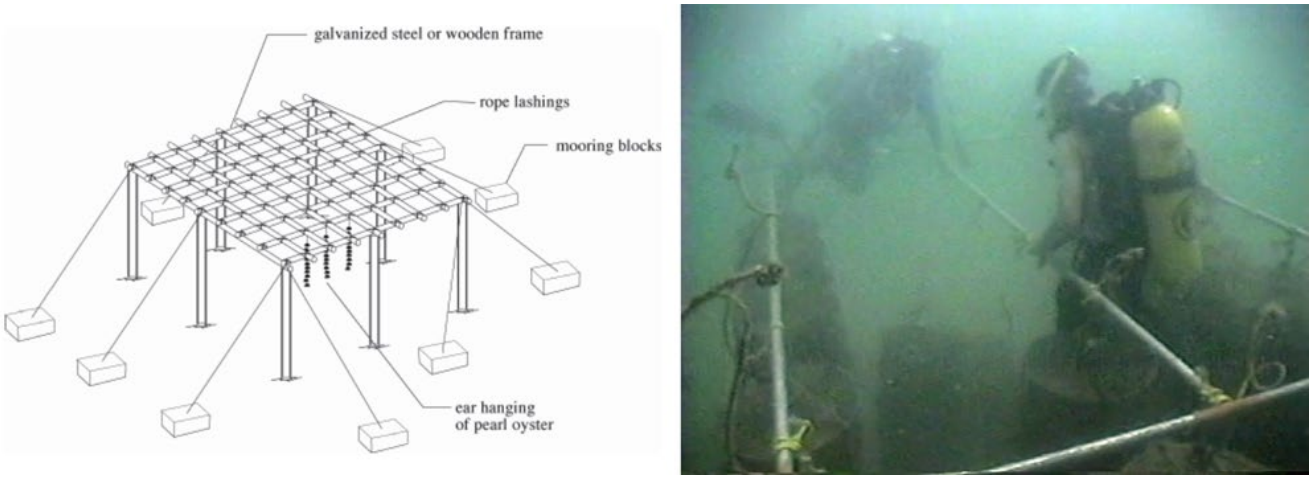

Figure 14: Underwater trestle system for pearl culture. Diagram taken from Haws (2002). Photo of divers working on a trestle at 20 meters depth.

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.

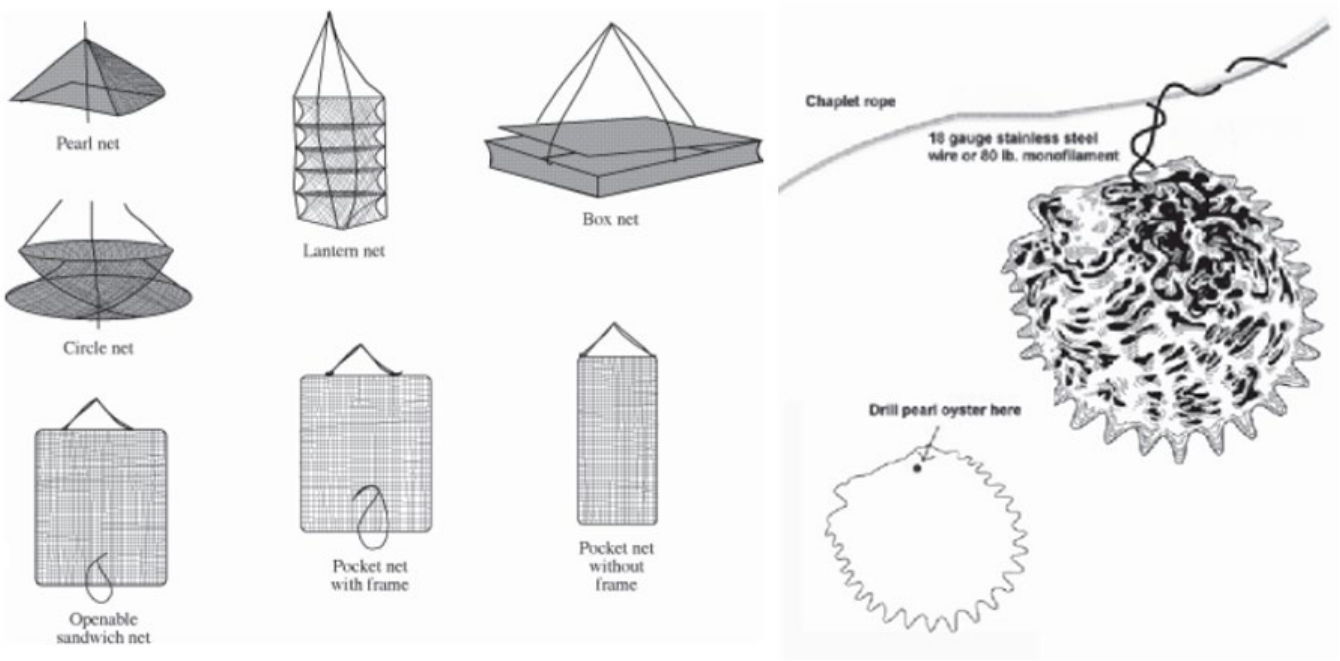

Figure 15: Different varieties of bivalve culture cages that are used in the pearl farming industry. Images from Gervis and Sims (1992) and Haws (2002).

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.

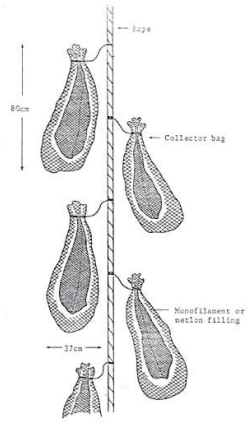

Figure 23: Diagram of a vertical Spat collector bag line system. Taken from NACA-SF/WP/87/1 FAO.

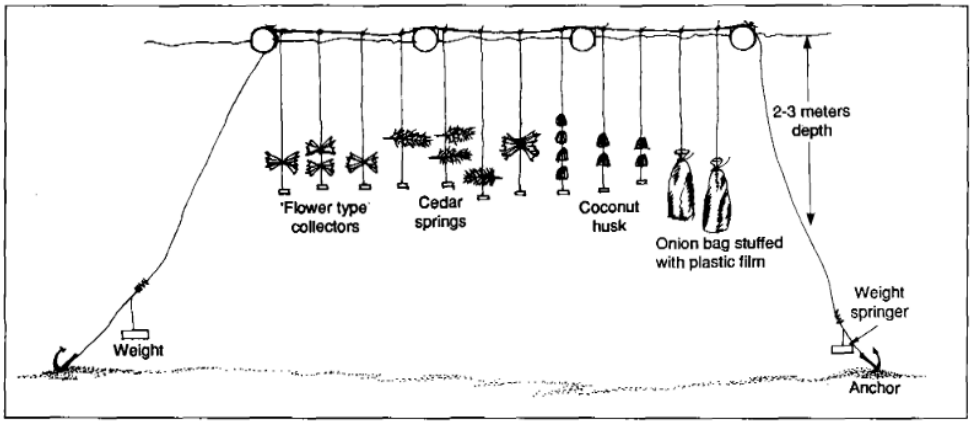

Figure 24: A longline used for spat collectors, with varied collectors. Diagram by Gervis and Sims (1992).

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.

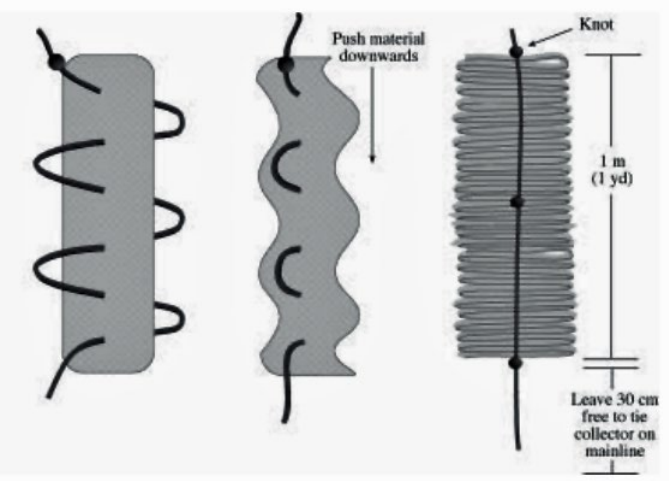

Figure 25: How to make a "Ribbon" or "Flower" spat collector out of plastic mesh. Shade cloth is cut in strips and thread onto a line. The shade cloth is then compressed to form a bushy mass of shade cloth to provide shelter for young spat. Diagram by Haws (2002).

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*.

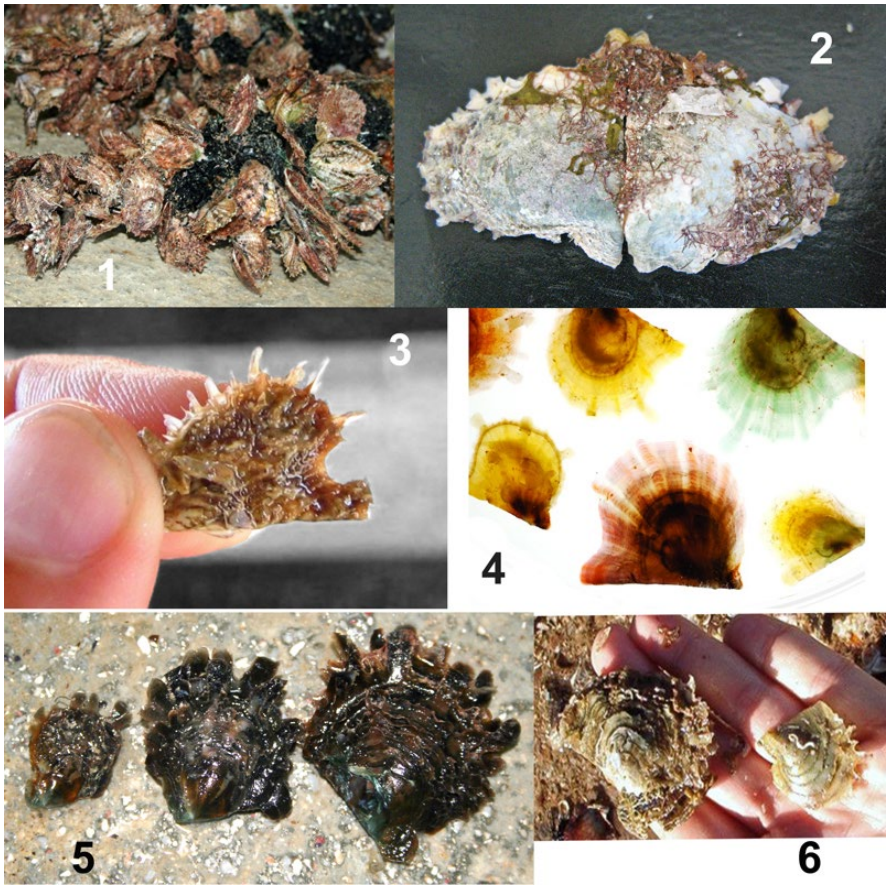

Figure 26: Different species of pearl oyster spat. 1 and 2= Akoya gai (Pinctada fucata/imbricata). 3= Winged pearl oyster (Pteria sterna). 4= Gold lip pearl oyster (P. maxima). 5= Black-lip oyster (P. margaritifera). 6=Panamic black lip (P. mazatlanica).

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

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

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*).

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.

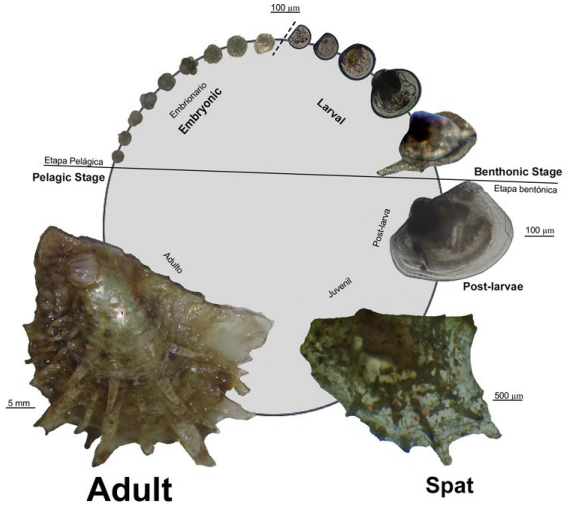

Figure 32: Larval cycle of the "Akoya" pearl oyster (P. imbricata), diagram courtesy of Dr. César Lodeiros.

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.

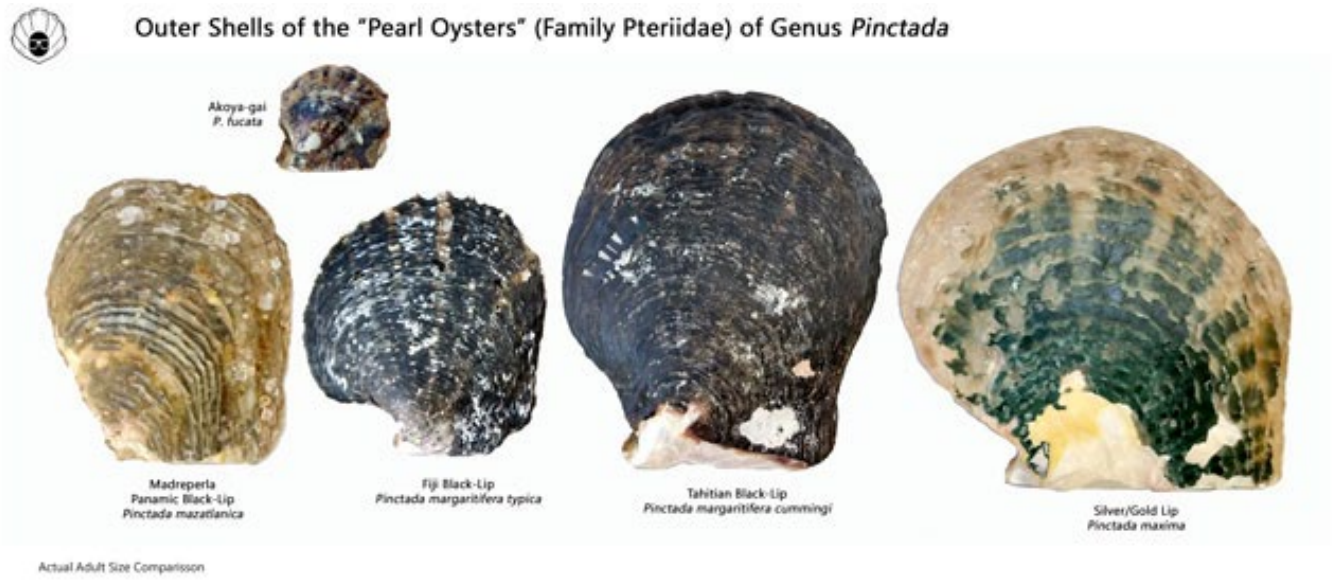

Figure 38: External appearance of some of the most commercially important pearl oyster species in the world. The size of the smallest pearl oyster in this group is for the "Akoya" at 10 cm in diameter, the largest one being the Tahitian black lip at 30 cm.

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.

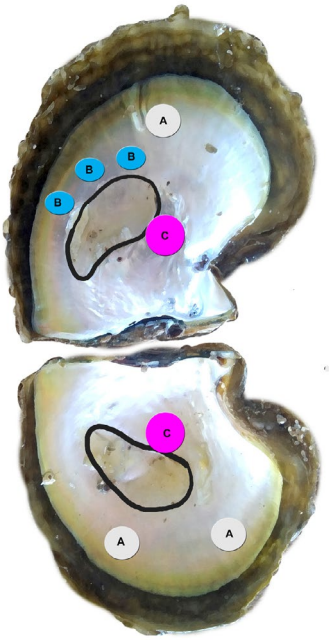

Figure 48: Mabé pearl implant sites. A. The most common site for Mabé pearl production. B. Common site for silver-lip Mabé pearl production. C. Common site used in winged oysters.

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.

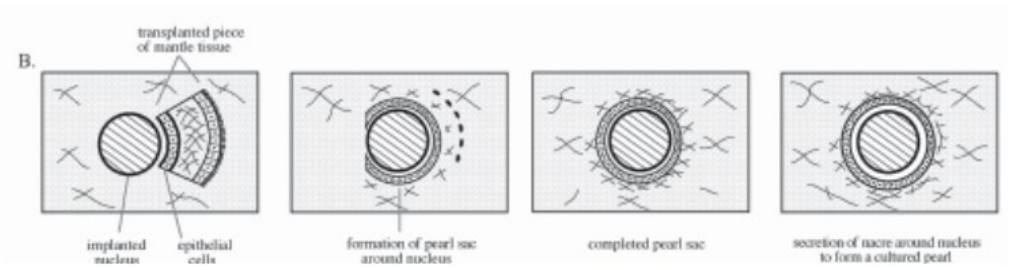

Figure 49: The "Pearl Sac" theory as understood in pearl culturing: the nucleus is in contact within the graft tissue and surrounded by the oyster's gonad; the tissue will graft and grow around the bead, until fully coating it and creating the cultured pearl. Diagram from Wada (1973).

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.

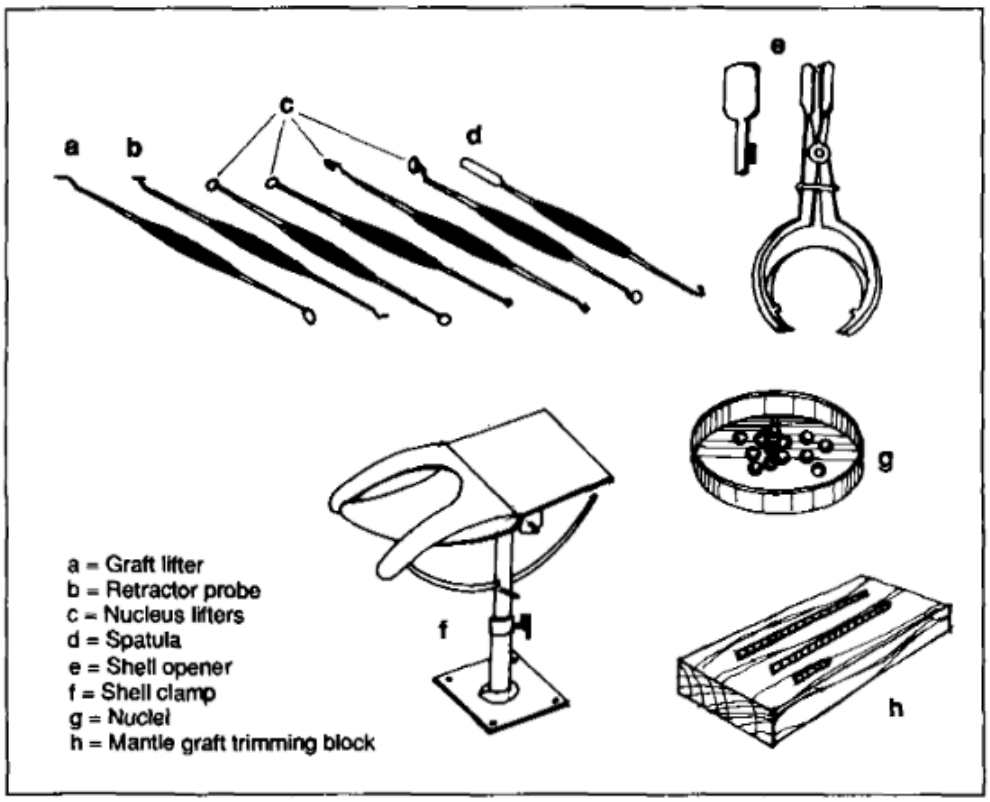

Figure 51: Pearl grafting toolset, according to Gervis & Sims (1992).

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.

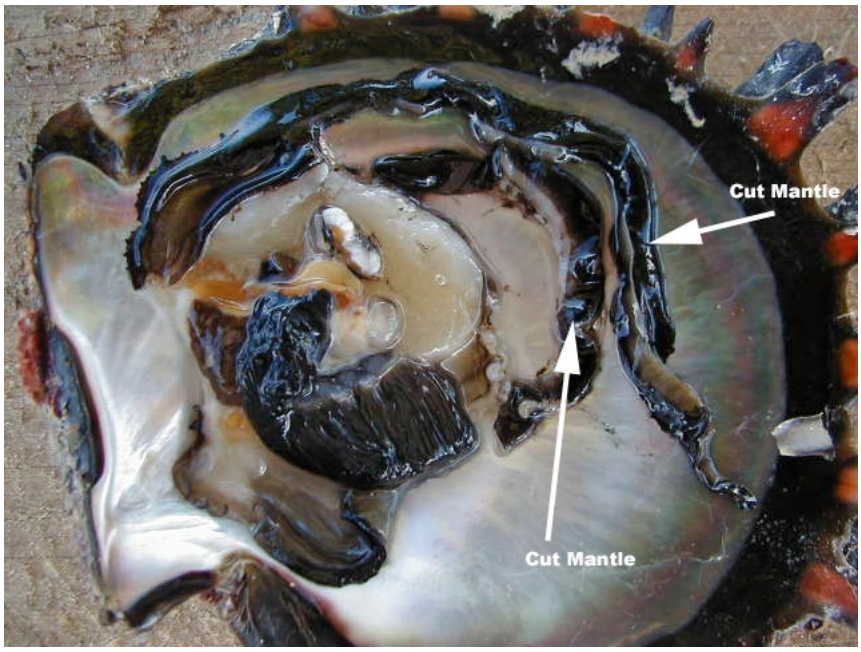

Figure 52: A sacrificed Black-lip donor oyster. The appropriate mantle portions have been cut to be used for Saibo.

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.

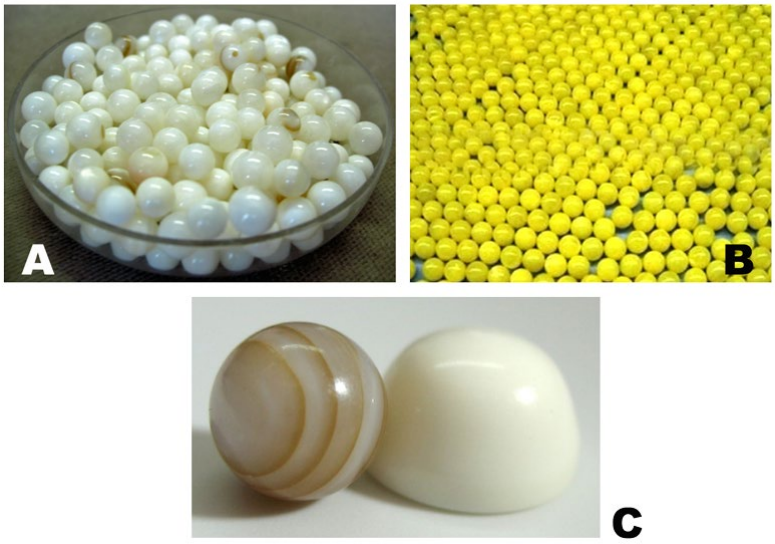

Figure 54: Different nuclei used for pearl culturing. A. Traditional shell nuclei, on a shallow container. B. Non-traditional shell nuclei: these are bio-coated nuclei, basically covered in a wide-spectrum antibiotic coating that allows for better pearl production. C. A large (10 mm) "stained" shell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

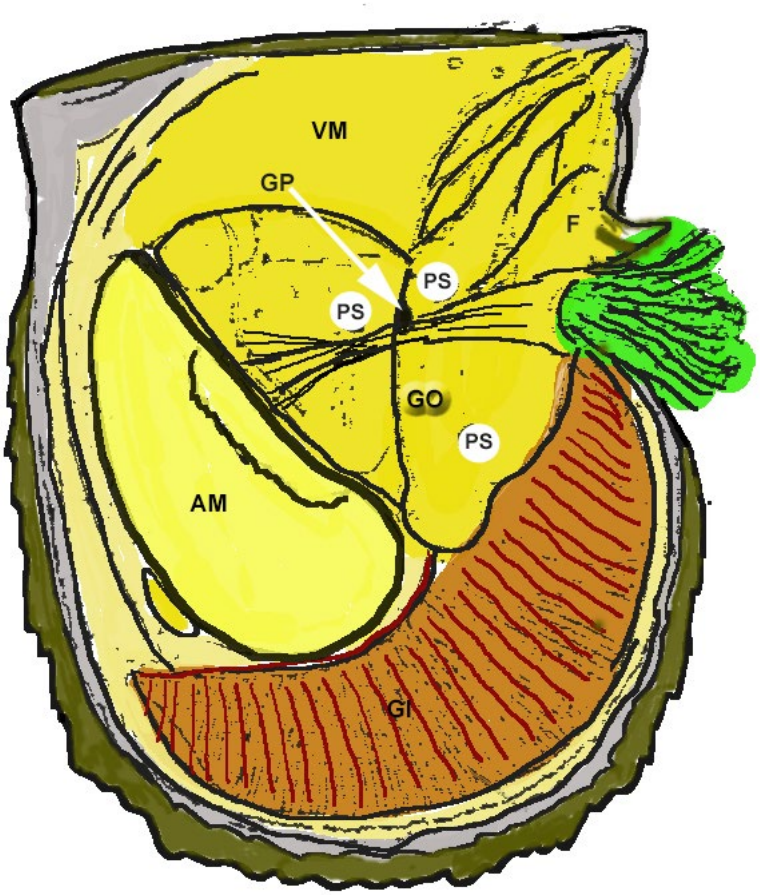

Figure 55: A diagram of a pearl oyster and its common pearl-sac sites. AM= Abductor Muscle. GI= Gills. VM= Visceral Mass. GO= Gonad. F= Foot. GP=Gonopore. PS= Pearl producing sites. Diagram modified from Tamura (1966).

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.

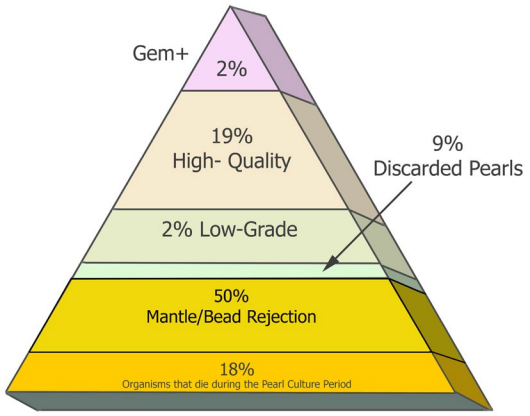

Figure 58: The pearl production pyramid for Mexico's "Cortez Pearl". This diagram describes the percentage of pearls that will be produced at the moment of harvest, as well as the oysters that die during the 18-month culture period. Data provided by Enrique Arizmendi of "Perlas del Mar de Cortez" in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

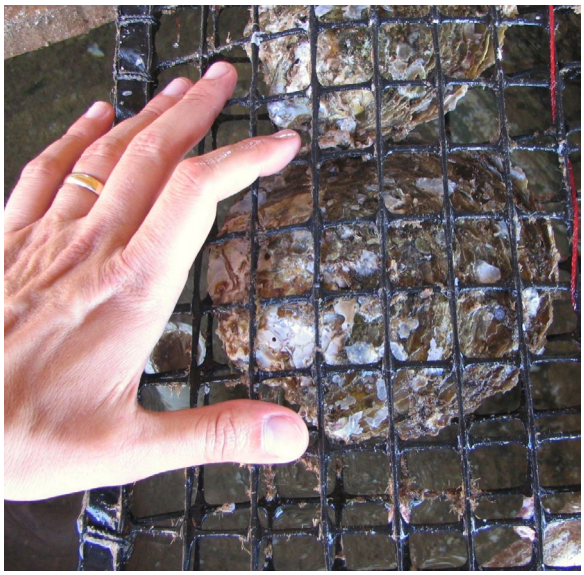

Figure 59: A black-lip pearl oyster inside its pocket-net and ready for harvest.

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.

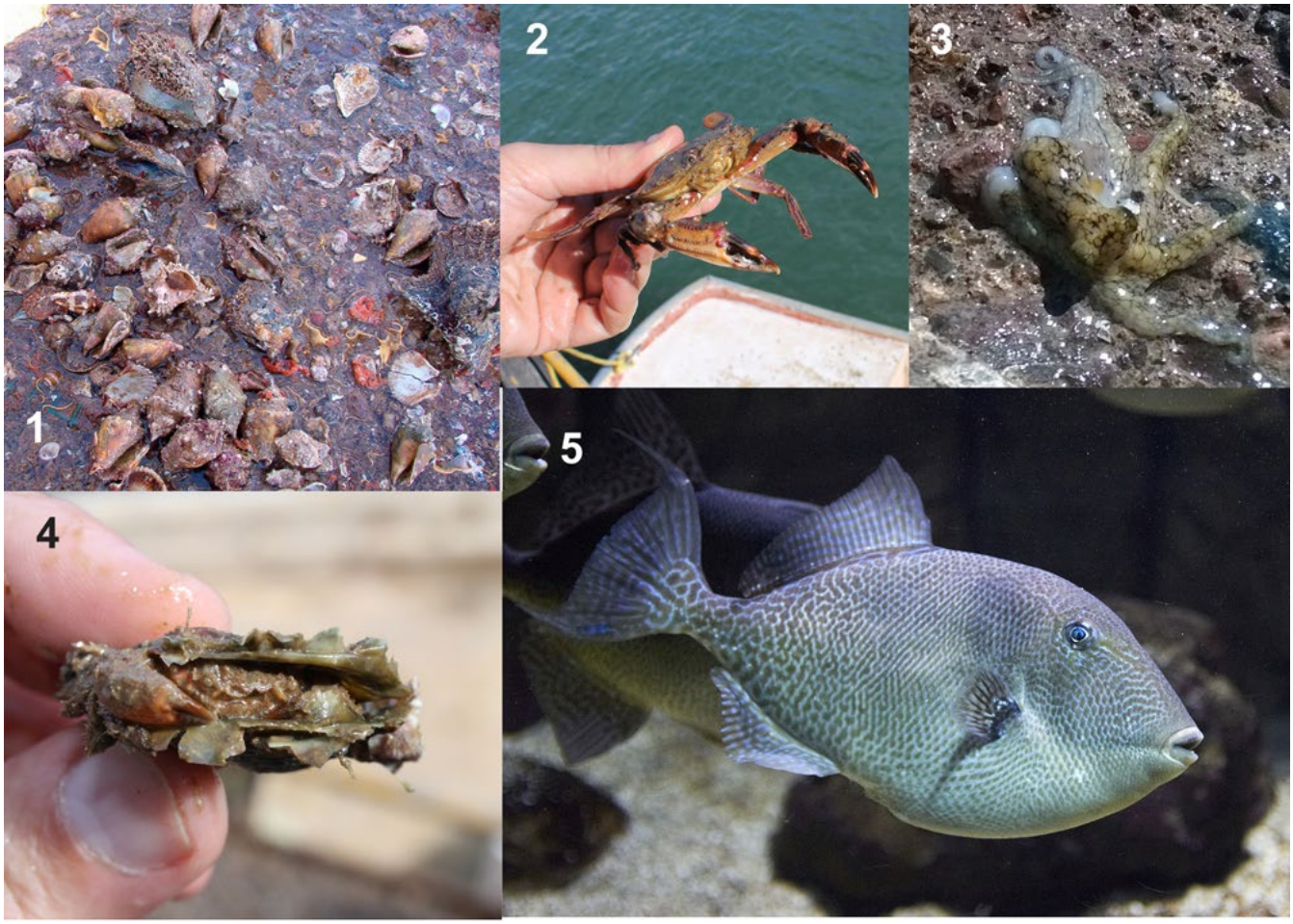

Figure 67: Typical predators that are found inside the pearl cages in a pearl farm. 1. Carnivorous snails can reach the pearl cages when they are planktonic larvae and will grow and eat your oysters; 2. Swimming crabs are capable of destroying your spat, juveniles and even adult oysters; 3. Octopus are 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

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

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.

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."

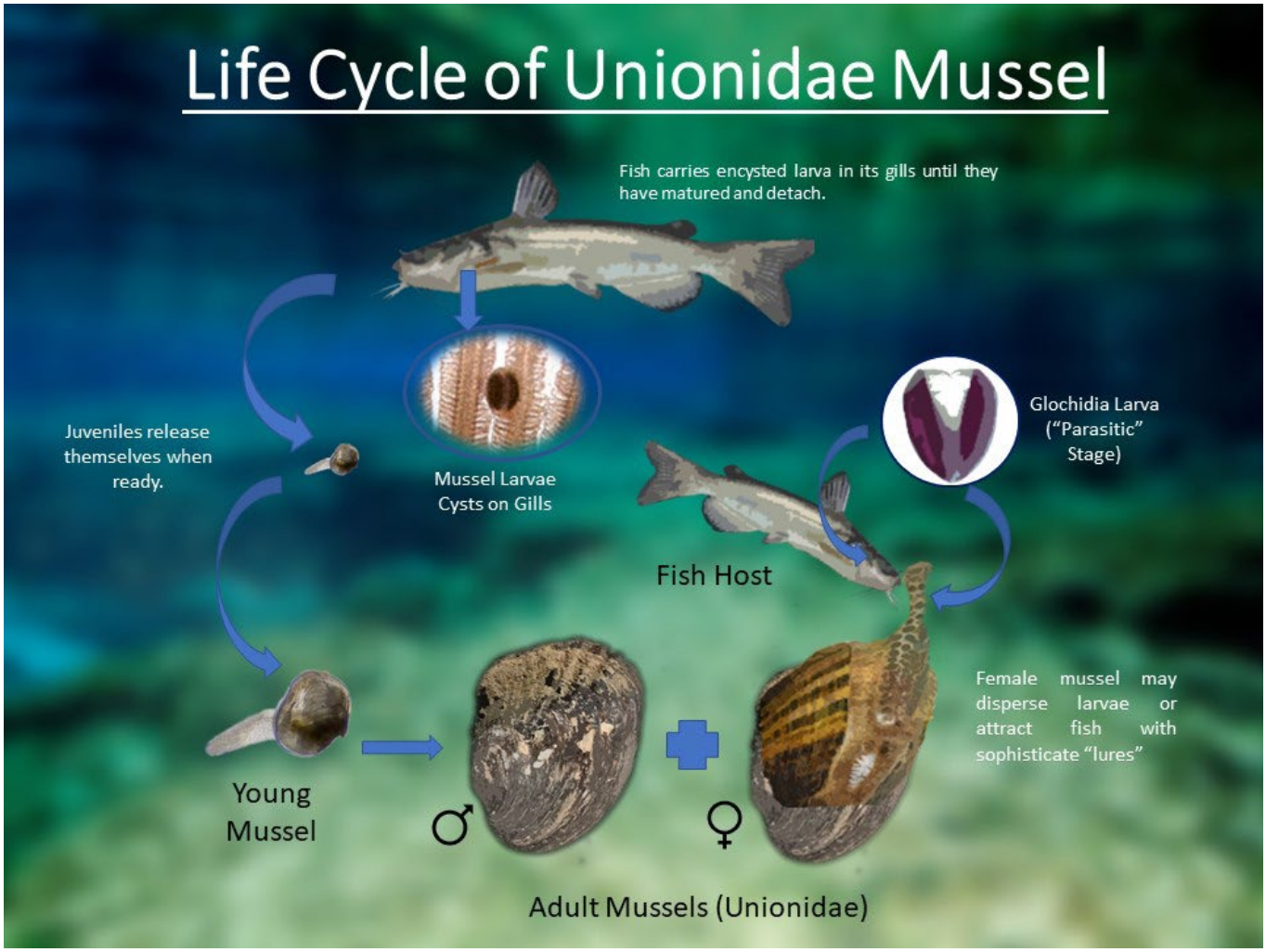

Figure 70: The unique lifecycle of Pearly Mussels (family Unionidae) involves a "parasitic" larval stage referred to as "glochidia", where the larva are either discharged outside of the body of the female or the organism utilizes a "fish lure" to attract fish that will ingest the "larval sac" and thus 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.

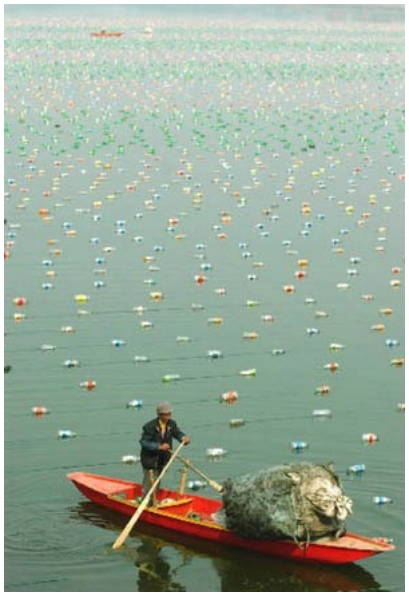

Figure 74: A Chinese freshwater pearl farm that uses plastic bottles as floats. Photo by Xinhua News Agency August 13, 2007.

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.

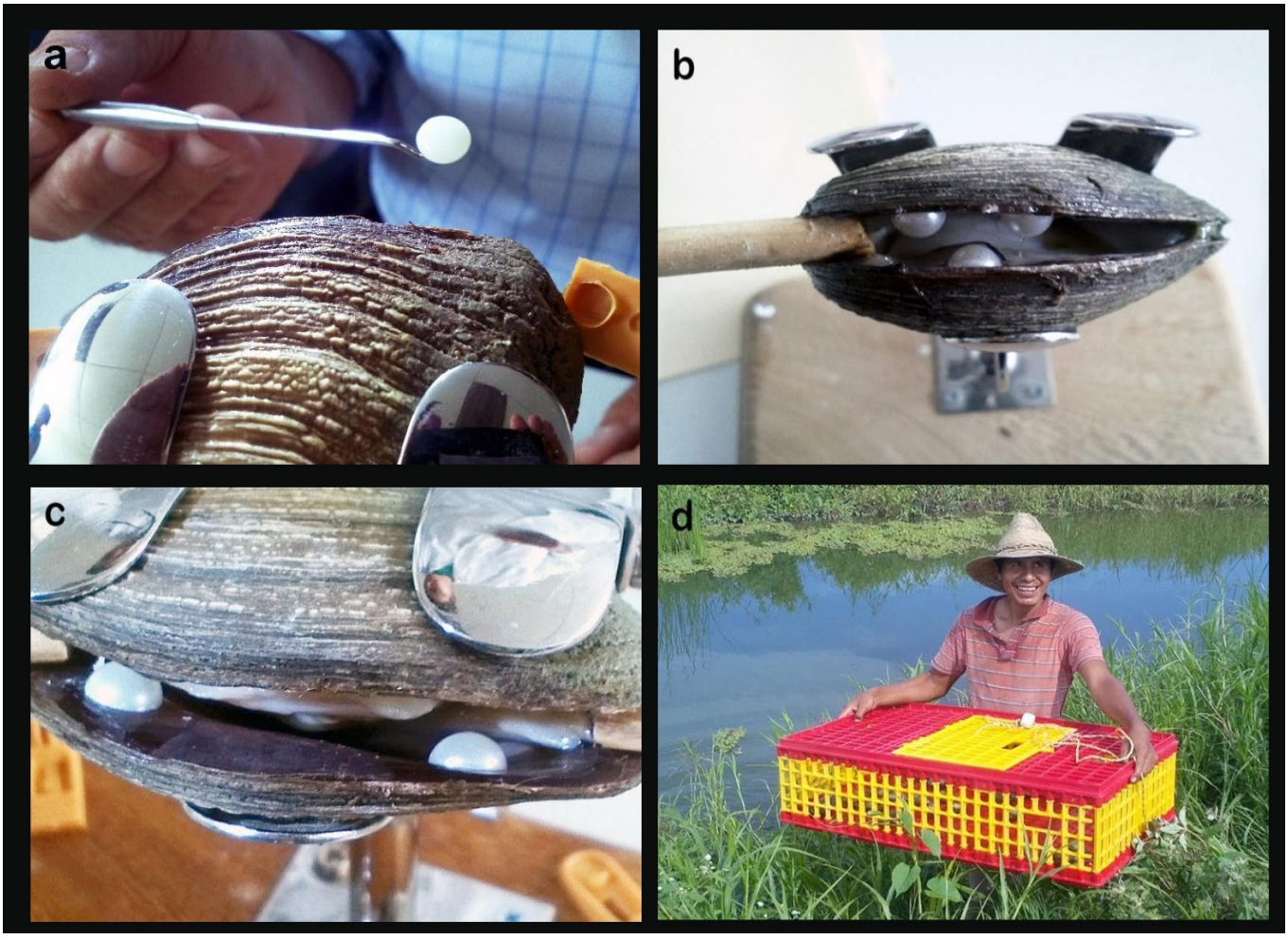

Figure 76: Techniques to produce cultured and Mabé pearls in Mexico, utilizing native pearly mussel species in the State of Tabasco, where vast freshwater sources are still available. Photos by P. Saucedo (Saucedo et al. 2020)

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.

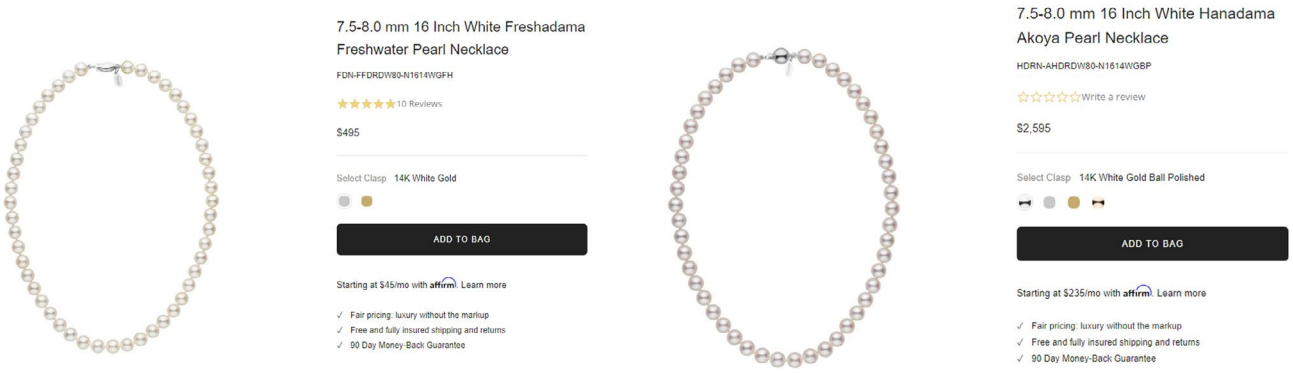

Figure 80. Two similar pearl strands, both 16 inches in length and of equal quality, but one is freshwater (left) and the other one is saltwater (Japanese Akoya). The price differential is enormous, with the saltwater strand being worth over $2000 USD more than the Chinese product. Products on display 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 (CaCO3) 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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