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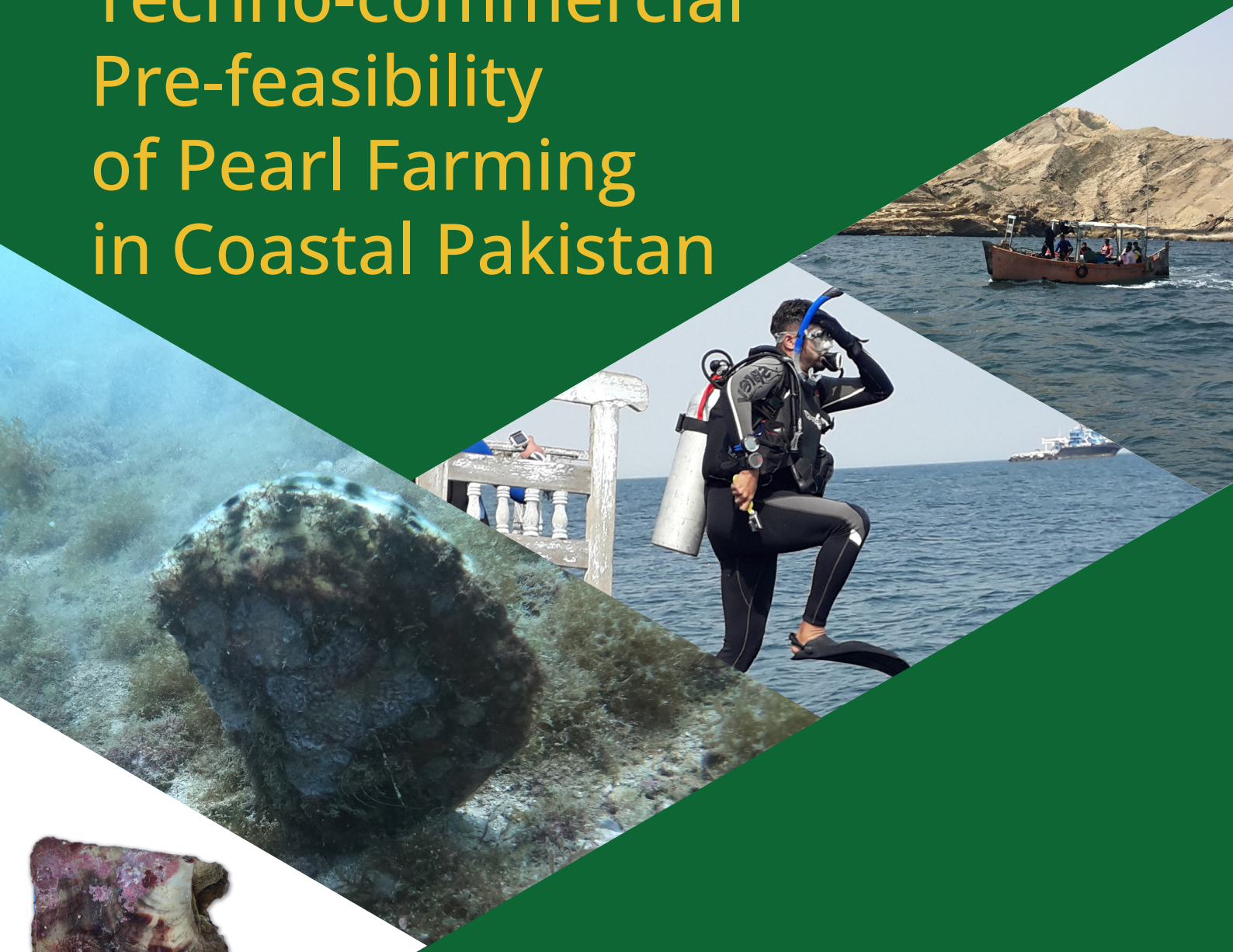
Climate Adaptation and Resilience (CARE) for South Asia Project

Techno-commercial Pre-feasibility of Pearl Farming in Coastal Pakistan



A Pre-feasibility Study

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EXECUTIVE SUMMARY

Climate change is increasing the risk to coastal communities in Pakistan, including more intense storms, floods, coastal erosion, and sea level rise. Due to socioeconomic and political factors people are more vulnerable to these hazards, with disasters causing significant land and livelihood loss, ultimately resulting in displacement.

The present pre-feasibility study on the potential of pearl farming in coastal regions of Pakistan as an alternative livelihood option was carried out as part of the CARE for South Asia project's larger goal of building resilience of communities affected by climate change. As the concept was introduced to the project stakeholders in Pakistan for the first time and there has been no such study carried out prior to this study, detailed information on marine pearl farming is provided where the main product is not edible and unique to the venture.

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, in particular, the history and stories that revolve around the ancient pearl fisheries and of "pearls of renown", these being pearls that have transcended in history due to their beauty, size, and perfection. In case of Pakistan, analysis of both historical accounts and biological data regarding Pakistan's involvement in ancient or recent pearl fisheries have found little to almost no information on the subject.

However, analysis of the biological, environmental and sociological information indicates that the conditions are conducive to pearl farming and evidence of species of pearl oysters from Genus Pinctada have been described as inhabiting the coasts of Pakistan, as are the pearl oysters from Genus Pteria, which are described as inhabiting this coastline. Although the fieldwork to explore pearl beds did not yield any results, individual species were seen and a few suitable sites have been proposed to explore the venture, based on environmental and sociological characteristics. An important consideration for the project is in the area of regulations regarding the use of the nation's ecological reserves and the introduction of pearl oyster species from other countries.

The study proposes a unique strategy towards the success of pearl farming in Pakistan. As the traditional pearl farming strategy will take some time to be established, pearl oysters must be located—either locally or have to be sourced from abroad—and brought to the adapted shrimp larvae labs for the production of laboratory-grown "spat" (juveniles), and then grown in newly established pilot stage pearl farms. This could take anywhere between 2 to 4 years, depending on the celerity of the efforts. On the other hand, a less traditional pearling strategy could be explored in Pakistan, one that will help recover its biological inventory in a sustainable manner: the establishment of new natural pearl beds, by means of repopulation. This strategy would require long-term planning and would have to start in a suitable natural protected area (such as Astola and Charna islands).

The study also highlights an important aspect of the advantage of marine pearl farming over freshwater pearl farming, as the latter is more complex with lower economic return.

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1. Introduction

1.1 Background and Context

Climate change is a reality, and Pakistan is highly vulnerable on this front. According to the Global Climate Risk Index (CRI) 2021, Pakistan has been recurrently affected by climate change-induced hazards and thus has been ranked amongst the most affected countries both in the long-term index as well as in the index for the respective year (Eckstein et al., 2021). Negative impacts of climate change are increasing the risk to coastal communities, including more intense storms, floods, coastal erosion, and sea intrusion. Due to socioeconomic and political factors people are more vulnerable to these hazards, with disasters causing significant land and livelihood loss, ultimately resulting in displacement. Additionally, sea level rise, rise in sea surface temperature and poor river water management affect the marine and riverine environments and the communities' main livelihoods of fishing (Bram, 2021).

The proposed study on the pre-feasibility of pearl farming in coastal regions of Pakistan as an alternate livelihood option is part of the CARE for South Asia project's larger goal of building resilience of communities affected by climate change. Loss of livelihood due to climate change impact has been foreseen in the coastal regions of Pakistan. As part of this effort, the study assessed the techno-commercial feasibility of establishing a saltwater pearl farming operation in the coastal regions of Pakistan to reduce the migration of population in search of alternate livelihood in already overburdened urban areas in the coastal provinces.

1.2 Objectives and Structure:

This document entails the assessment of the techno-commercial feasibility of establishing a saltwater pearl farming operation in the coastal regions of Pakistan.

The information presented in this report is divided into four categories:

i. Background, objectives and evaluation process

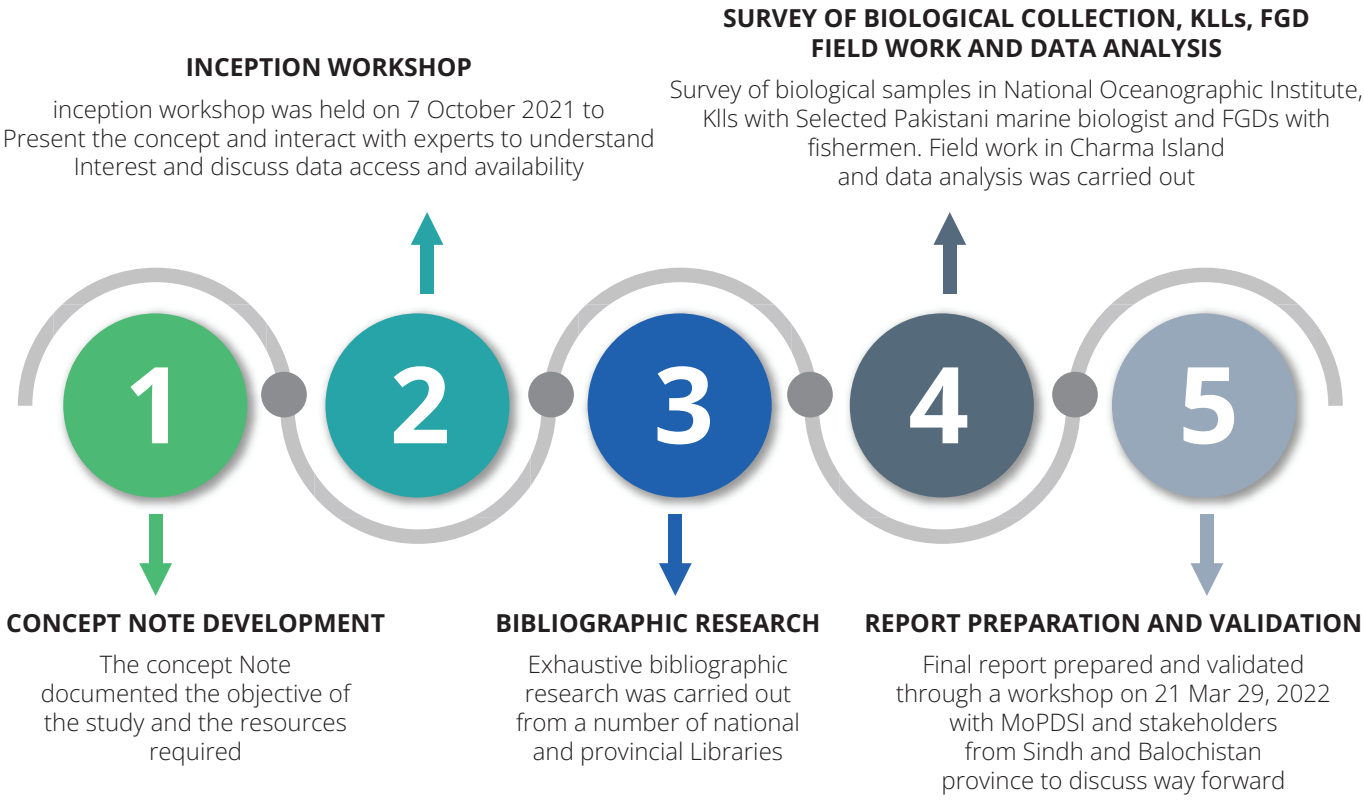
ii. Introduction to marine pearl farming

iii. Pearl culture in Pakistan

iv. Strategies for establishing pearl farming operation in Pakistan

These categories are essential to understand the possibility of establishing any type of pearl farming operation in Pakistani waters. With the data that has been obtained from multiple sources, the analysis has allowed us to consider the long-term possibility of using this form of aquaculture venture as a viable option to minimize coastal population migration and offer a sustainable and viable economic industry for the local communities.

The following process was followed in order to evaluate the possibilities of establishing any pearl farming venture in Pakistan.



Under travel restrictions due to COVID-19, data and information were collected via literature review, online and onsite discussions with experts from universities, interviews with fishermen, a field visit to Charna island and validation of the findings with local experts and stakeholders. The project team also prepared a Pearl Farming Manual in order to help prospective pearl farmers analyze the possibility of using pearl farming as a way to support their livelihood.

2. Introduction to Marine Pearl Farming

Pearl farming is an aquaculture industry that is well suited for any size of operation (from small family-owned operations to large-scale ventures). What make these aquafarming operations unique is:

- The main product is not edible, but a gem: the Pearl.
- The product does not require any form of refrigeration or processing to keep it “fresh for its use” and transportation is simple and cost effective.
- Since pearls can be kept stored for long periods of time without spoiling, there is no need to rush in for sale and to lower prices.
- Farming operations can be highly modernized (as in Australia) or very simple, as in Venezuela and Ecuador. The farms are in the ocean, very rarely on land. This allows for lowered costs since there are no water pumping costs and no need to purchase or lease land.
- Every-day farming operations are easy to teach to fishermen and their communities.
- Several other by-products can be produced at the same time as the pearl, such as “pearl meat”,
  often considered a delicacy, and mother-of-pearl-shell (MOP) which is used for handcrafts, jewelry production and even for the elaboration of traditional medicine.

The aspects that make pearl farming a uniquely difficult venture are:

- Well-trained Pearl-Seeding technicians are expensive to train or hire, but possible to hire and train if a training program is initiated for this purpose.
- An adequate stock of wild pearl oyster "spat" (juveniles, usually smaller than 3 mm), laboratory-grown spat or adult pearl oysters to supply the pearl farm. This is crucial to establish a successful pearlfarm.
- Grading and sale of the pearl harvest is also a delicate task, best left to highly trained personnel with adequate background though training can be provided in this aspect.

Figure 1 Large, high-quality baroque pearls from Mexico

Pearl farming has taken root since Kokichi Mikimoto began growing pearls commercially in Japan in the 1920s. This industry slowly began expanding all over the globe, becoming a highly profitable industry, valued at several millions of American dollars each year, with at least 30 countries producing these gems in at least 8 different mollusk species. Global marine pearl production in 2004 had an estimated value of $475 million USD according to Golay-Bouchel's estimates (Bondao-Reantaso et al. 2007).

Some producers have attained a great level of quality productions with sustainable pearl farming initiatives that have helped ensure the livelihood of coastal communities and protect the environment. At the same time, two of these producers are in the Asia-Pacific area and are magnificent examples of this ethos: "Jewelmer" from the Philippines and "J. Hunter Pearls" from Fiji Pearl farming has taken root since Kokichi Mikimoto began growing pearls commercially in Japan in the 1920s. This industry slowly began expanding all over the globe, becoming a highly profitable industry, valued at several millions of American dollars each year, with at least 30 countries producing these gems in at least 8 different mollusk species. Global marine pearl production in 2004 had an estimated value of $475 million USD according to Golay-Bouchel's estimates (Bondao-Reantaso et al. 2007). Some producers have attained a great level of quality productions with sustainable pearl farming initiatives that have helped ensure the livelihood of coastal communities and protect the environment. At the same time, two of these producers are in the Asia-Pacific area and are magnificent examples of this ethos: "Jewelmer" from the Philippines and "J. Hunter Pearls" from Fiji.

In particular, the Philippines have been able to use pearl farming to offer a great livelihood to local villagers and offer aid in reconstructing local infrastructure after typhoon damage; also, in stopping cyanide and dynamite fishing, which are greatly damaging to coral reefs. In Mexico, pearl farming (Figure 1) has helped increase biodiversity and biomass in the area, since the pearl farms usually consist of rafts or long-lines, from where the aquaculture cages are suspended, and the oysters are kept for their protection and survival (Figure 2). These structures are anchored to the seafloor, so they do not move with the sea currents or tidal action. The diversity of farming systems is associated with the type of environment where the farm is located.

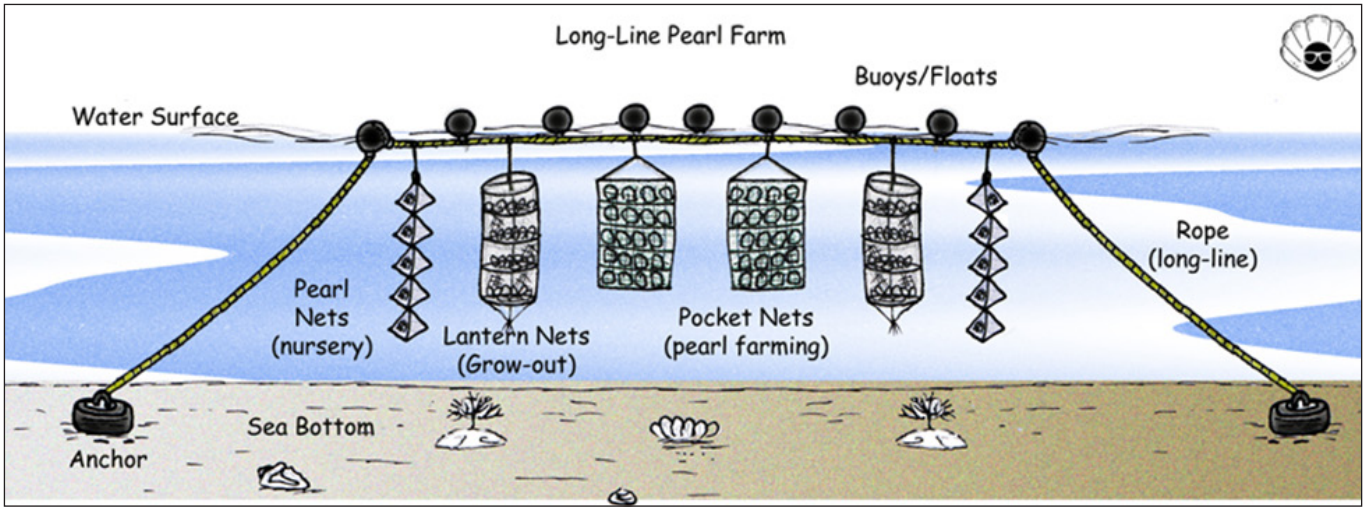


Figure 2 A typical Long-Line Aquaculture system used for pearl farming

However, there are also problems in the pearl farming industry. The main one is fierce competition with Chinese freshwater pearls (Figure 3), with a production that exceeds one thousand metric tons per year. The world's markets have suffered since saltwater pearls are costlier than their freshwater counterparts, and pearl prices have dropped dramatically from the 1990s to present times. Still, there is a consistent belief in the minds of many that pearl farming offers an amazing opportunity: to have a high income and very few problems, when in fact, it can be quite the opposite in many situations.

Figure 3 Low-quality freshwater pearls from China

Pearl farms are also prone to environmental affectations, such as typhoons, tsunamis, chemical and sewage pollution, freshwater discharges from rivers and climate change (Figure 4). Akoya pearl farms in China were destroyed in the 2000's after heavy rainfalls affected the salinity of the pearl grounds and brought in pollutants. Pearl oysters have often been seen as "canaries in the mine" in the environment, where they are considered as "Indicator Species".

There is a saying in the pearl industry: "Beautiful pearls can only be grown in a beautiful environment". Thus it is of the utmost importance to find the perfect location to maximize the opportunity to culture high-quality, high-value pearls. To try and produce only average-quality pearls is simply a waste of time and efforts, unless we consider that pearl farms can offer local coastal communities an opportunity to gain an economic income by means of the sales of pearls via the touristic market and to increase their fishing yields thanks to the positive ecological effects of a pearl farm on fish populations.

Figure 4 Main building of the "Perlas del Mar de Cortez" pearl farm and jewelry store in the touristic island of Cozumel in Mexico's Caribbean riviera. On the left side we see the brand-new building in 2004 and on the right side the complete destruction caused by hurricane "Wilma" in 2005

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 of "pearls of renown", these being pearls that have transcended in history due to their beauty, size, and perfection (i.e., "La Peregrina", "The Big Lemmon", "Hope Pearl", etc.). In most of the "newly" established pearl farming ventures throughout the world this has been a reality: pearl culturing sites have been chosen due to their historical background with a previous pearl fishing effort, such has been the case for countries such as Japan, Philippines, French Polynesia, Australia, Myanmar, Indonesia, and more recently in Mexico and the Persian Gulf (Figure 5).

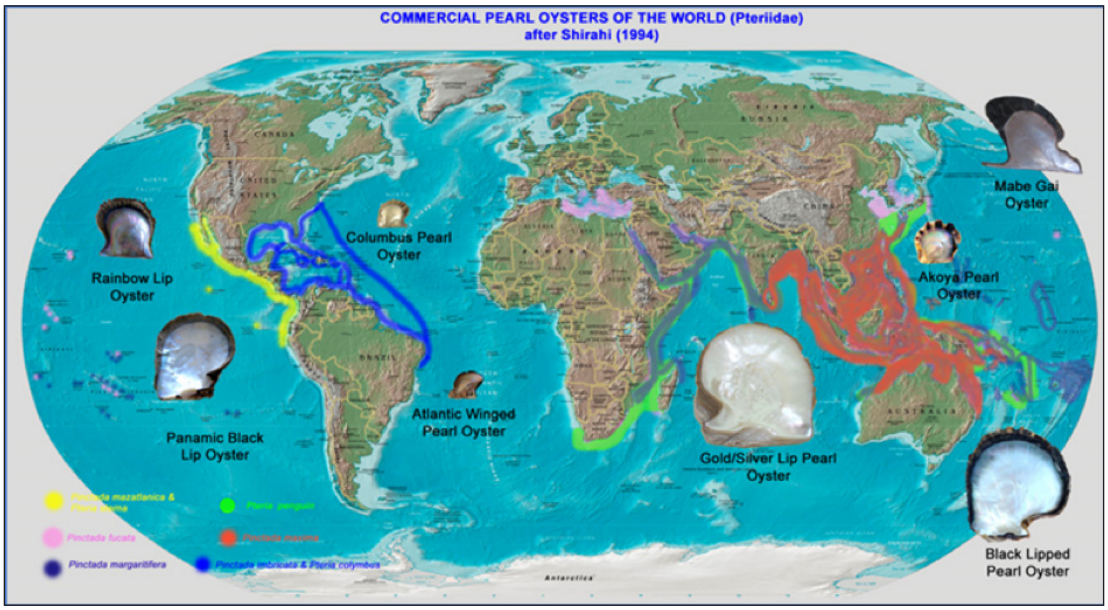


Figure 5 World Map showing the distribution of some of the most commercially used Pearl Oyster species used for pearl fisheries and pearl farming (after Shirahi, 1994)

There also have countries that have attempted to reintroduce the pearl industry to their coasts and that have also had a rich pearling tradition such as Venezuela, Costa Rica and Panama and that have failed at these attempts; and finally we also have a few countries with almost no previous historical background in pearl fisheries but have been successful in establishing such ventures, such as New Zealand and Chile, both of these with Abalone blister (mabé) pearl farming.

Figure 6 Natural Persian Gulf pearls (photo by Dr. Laurent Cartier of SSEF Gem Lab)

Due to this fact we have analyzed both historical accounts and biological data regarding Pakistan´s involvement in ancient or recent pearl fisheries and have found little to almost no information on the subject. For instance, one of the most important published works on pearl fisheries - Kunz & Stevenson's "The Book of the Pearl", published back in 1908 - has absolutely no mention of pearls nor of pearl fisheries in Pakistani waters. Similarly, another modern source that is considered one of the most reputable, Strack's "Pearls", from 2008, does not mention Pakistani pearl farming.

Both sources mention nearby Sri Lanka, Bahrain and the Gulf of Oman as having sustained very important pearl fisheries, the Persian Gulf being considered as "the most important place of origin for pearls" with as many as "70 to 80% of all-natural pearls" originating within this area since thousands of years ago (Figure 6). The same goes for Ceylon (old name for Sri Lanka), which sustained important pearl fisheries in the past. The same sources identify the most important pearl oyster species in the area between the Persian Gulf and Sri Lanka (Figure 7) as the "Lingah" pearl oyster (Pinctada fucata imbricata complex species group) and the "Black lip" pearl oyster (P. margaritifera vars persica and/or erythraensis), but other sources also mention the "Penguin Wing" oyster (Pteria penguin).

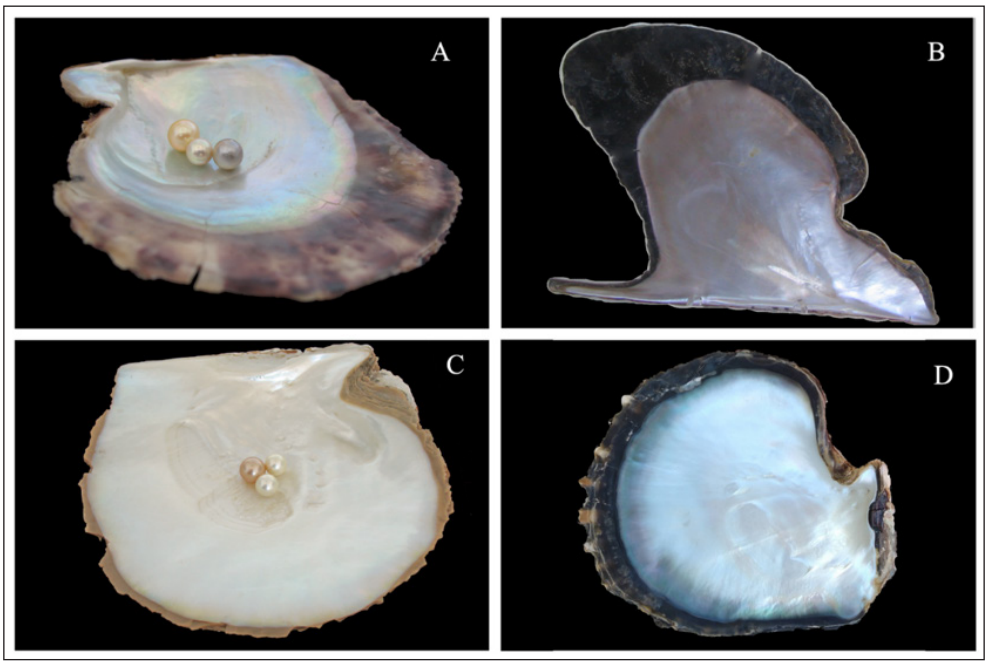


Figure 7 Pearl Oyster species with pearl farming potential for Pakistan, if found in Astola and/or Charna Islands or imported from another nearby country. A. Akoya or Lingah pearl oyster (Pinctada imbricata complex). B. Black Winged pearl oyster (Pteria penguin) C. Silver-lip pearl oyster (P. maxima) and D. Black-lip pearl oyster (P. margaritifera). The only species identified so far has been the Akoya/Lingah pearl oyster

This study focuses on the most viable pearl farming option for any country: 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 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:
  - ✓ Dissolved oxygen levels
  - ✓ Stable pH
  - ✓ Pollutants are more easily diluted
  - ✓ Stable Water Temperatures
- There is far less competition over the sea than over freshwater

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

- Pearly Mussels are 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 8).
- 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 (introduction of an 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 (see this link for more details).

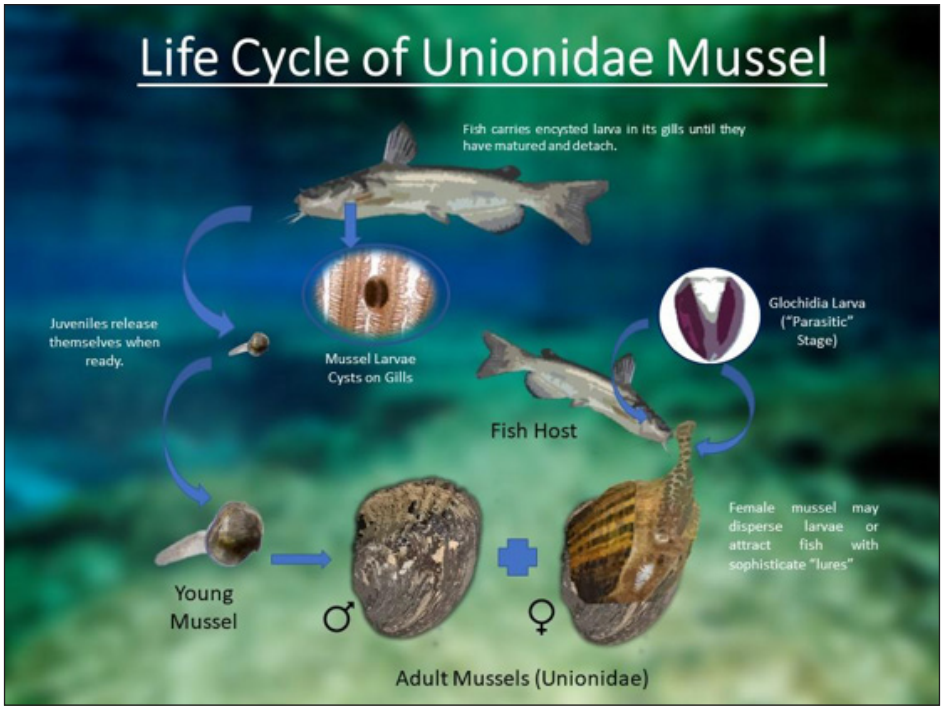


Figure 8: The complicated larval stages of the pearly mussels (family Unionidae), which require a fish host during a period of its larval development. Without this host the larva dies (Tucker and Theiling 1999)

3. Pearl Culture in Pakistan

One of the prerequisites of pearl culture which is applicable for Pakistan too are information on the following aspects:

1. Biological
2. Environmental
3. Sociological
4. Policies and Regulations.

3.1 Biological Information:

This is the most important category, as, without available living organisms, it would be hard to initiate any pearl farming venture. The information that was analyzed to gather biological information included scientific and government reports, university collections, and direct interviews with experts.

The information was gathered from the following sources: 1) Research Library, Centre of Excellence in Marine Biology (CEMB), 2) Dr. Mahmud Hussain Library, 3) Seminar Library, Zoology Department, and 4) Research Library, Marine Reference Collection and Resource Centre (MRCRC), which all are located within the campus of University of Karachi. Discussion was also held with representative of Daily Dawn (Newspaper which published article on pearl farming in Pakistan) and the Directorate of Fisheries, Government of Sindh province.

A. The following pearl oyster species (family Pteriidae) were identified and were found to be present in Pakistan's coastline:

Three species of pearl oysters from Genus Pinctada have been described as inhabiting the coasts of Pakistan: P. margaritifera, P. imbricata and P. maxima. These are the same species distribution that has been described by Shirahi (1994).

Five species of pearl oysters from Genus Pteria are described inhabiting this coastline: Pt. heteroptera, Pt. peasei, Pt. tortirostris, Pt. avicular and the most important species in this group: the larger Pt. penguin.

These species would be the important roster for Pearl Farming in Pakistan: P. margaritifera, P. imbricata and Pt. penguin.

The details of the pearl oyster species are as follows:

Pinctada margaritifera

This species is known world-wide as the "black-lipped pearl oyster" and is famously known for being the producer of famous black pearls from the Atolls of Tahiti and the island nation of Fiji. It has been reported by Moazzam and Ahmed (1994) on the coast of Jiwani, Balochistan where it occurs rarely.

There are several sub-species or varieties of this species, with the most common being var. typica from Fiji, var. cummingi from French Polynesia and var. persica from the Persian Gulf. Due to its proximity, it is likely the local variety would be P. margaritifera var. persica.

Pinctada imbricata complex (P. fucata/P. imbricata/P. radiata/P. vulgaris)

This species complex is commonly known as the "Akoya Pearl Oyster" or "Lingah". It has been reported from Astola Island (Marine Protected Area) near Pasni (Balochistan) by Khan and Dastagir (1975 as P. vulgaris cited in Moazzam and Ahmed 1994, page 46).

This species is the most understood and utilized pearl oyster in the world, being used presently in Japan, China, Australia, Vietnam, and the United Arab Emirates for pearl production. Due to this, it has great potential to produce "white" Akoya pearls.

Pinctada maxima

This species was reported by Moazzam and Ahmed (1994) as Pinctada anomioides from the coastof Jiwani, Balochistan. This species could have been misidentified for P. margaritifera var. persica, s ince their shell shape, color and size are similar between these two species when younger. This species is usually referred to as the "Silver Lip Pearl Oyster", and it produces the most valuable and larger saltwater cultured pearls referred to as "South Sea Pearls".

Pteria species

At least three species of "winged pearl oysters" have been described as inhabiting the coastline of Pakistan: Pt. heteroptera, Pt. peasei, Pt. tortirostris, Pt. avicular, and Pt. penguin (Khan and Dastagir 1972, Kazmi 2018, Shah et al. 2003).

Of these species, the only one that holds immediate commercial interest would be the "Black Penguin Wing Pearl Oyster" or Pt. penguin, due to its larger size and the fact that it has been able to produce beautiful cultured Mabé pearls since the 1960's and it is still being used for small scale pearl production in Tonga, Philippines, China, Indonesia, and Japan. This last species has been reported as having been found on the Sindh coast.

B. A List of vertebrate and invertebrate predators and pests has been compiled for this study. The complete and detailed list can be found in Annexure 1, but suffice it to say that the usual pearl oyster predators and fouling pests are found in Pakistan.

The worst fish offenders are usually deterred by means of pearl farming cages (lantern, pearl, and pocket nets), and the rope hanging method may not be employed if these predators are in the farm's vicinity. Tests will have to be performed. The typical fish predators belong to the families Tetraodontidae (puffers), Balistidae (triggerfishes), Lethrinidae (breams), Sparidae (seabreams). Bottom dwelling sharks, skates and rays would not be of great concern in a pearl farm, since they mostly stay close to the bottom.

Carnivorous snails would not be a concern in a pearl farm, except for members of family Ranellidae (Cymatiidae), which are known to enter the pearl farming cages during their larval stage, then grow and cause massive mortalities as has happened in French Polynesia. The same is true for some species of crabs and stomatopods. Prospective pearl farmers must keep a watchful eye for the appearance of these predators within their midst (Gervis & Sims 1992).

Finally, polychaete worms have long been considered a major nuisance for pearl farming. These organisms drill the shells, weakening them and causing "mud blisters" which render the shells unusable for any commercial operation. If these pests are found in great numbers in any pearl farming site, strategies to minimize their impact must be enforced or risk the unfeasibility of the pearl farming venture due to weakened and sick pearl oysters (Bondad-Reantaso et al. 2007).

In any case, these pests and predators will not be able to stop any pearl farming venture from becoming established if best farming practices are employed.

C. Pearl Oyster species census, in one of the two islands that have been cited as having pearl oysters: Astola and Charna, both in the coastline of Balochistan province. Fieldwork was also conducted in March 2022 around Charna Island to explore pearl oysters and pearl beds (Figure 9). The fieldwork results were important to strategize (Details of fieldwork can be found in Annexure 2) any pearl farming efforts and the following were observed:

- There were no pearl beds found.
- There are at least two other commercially valuable species of bivalves present in this island, due to the quality of their meat: a large orange-shell Scallop (family Pectinidae) and the wedge-shaped "Pen Shells" (family Pinnidae, very likely Pinna sp.). Natural pearls from these two species can also be valuable.
- The native "Lingah" or "Akoya" pearl oyster (Pinctada imbricata complex) was found, but their numbers are in unknow quantity, almost non-existant.
- Images showed no typical predators in the area: starfishes, crabs, octopus, carnivorous snails nor fishes (puffers, parrots, triggers) which are known to devour pearl oysters and other species of bivalves.

With this information obtained from the Charna Island, it may be inferred that:

1. saltwater pearl farming is possible in Pakistan, but due to the low numbers of pearl oysters present it would be wise to also perform a census of the biological inventory on Astola Island.
2. It will be necessary to first utilize a pearl aquaculture setting in helping to first repopulate and reestablish this native pearl oyster species -and hopefully identify others- that have disappeared from the coast of Pakistan.
3. The reason for the disappearance of pearl oyster beds from the coastline of Pakistan may be a combination of factors, both natural and human. It could be that pearling vessels from the Indian sub-continent and the Persian Gulf could have been visiting the coastline of Pakistan since early times, and this caused the pearl beds to become depleted over time. Since the pearls were brought to their native ports they could have been considered as "Persian Gulf Pearls" or "Gulf of Manaar Pearls", with never a mention of their original source.

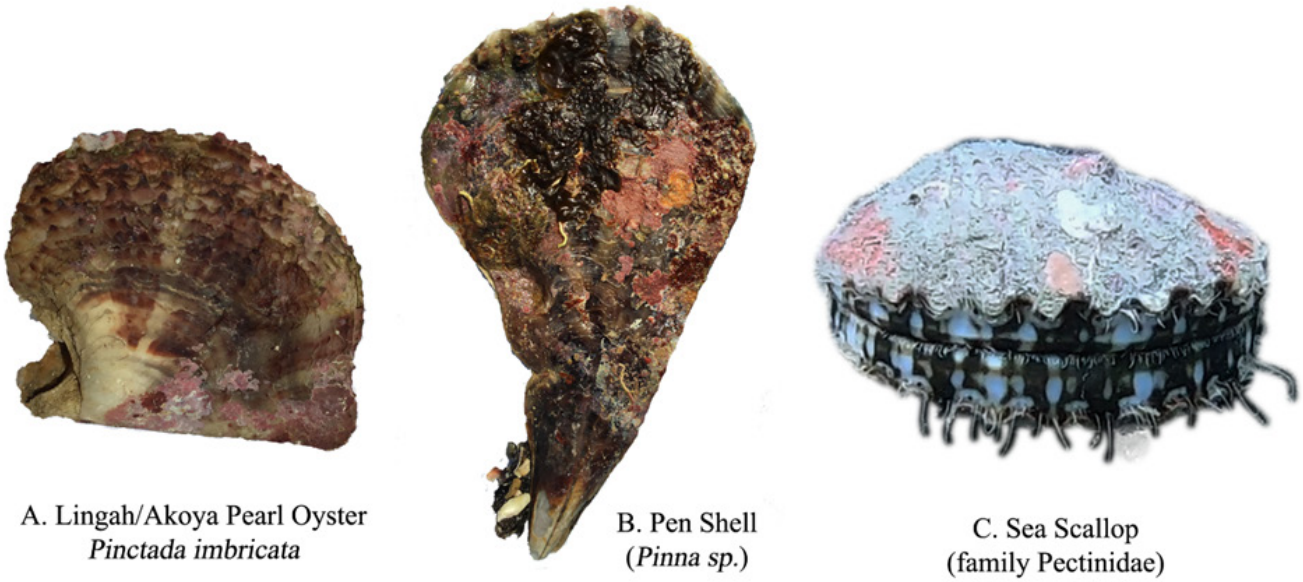


Figure 9: Three species of commercial interest found in Charna Island in March of 2022

3.2 Environmental Information

This category generally would contain the largest amount of information, including oceanographical data, as well as weather information, presence of important biological ecosystems, hydrological data (river discharges) and pollution levels, etc. The list is the following:

1. Oceanographicaldata

   The coastline of Pakistan is part of the Arabian sea and stretches from the eastern edge of the Indus delta and to Gwatar bay, where we find the Dashtr river delta. Several anthropogenic activities have caused ecological imbalances in the coastline. Freshwater effluents during the monsoon season should alter the chemistry and sediments of the waters where these effluents are discharged (Beg 1995).

Figure 10: Map of the coastline of Pakistan. (Source: Atlas of Pakistan, Survey of Pakistan)

a. Salinity levels

Low salinity levels could cause serious affectations and even massive mortalities (Gervis and Sims 1992) on pearl oysters, but according to data, the coastline of Pakistan and the Arabian sea are quite stable in their salinity levels, keeping at a range between 36 and 38 ppt (Rabbani et al. 1986), but there are locations were freshwater discharges can cause a temporary salinity disruption, but due to the construction of barrages and dams, the once great freshwater discharges are not present and the threat of salinity affecting discharges is not there, especially on the Indus river.

b. Sediments and Turbidity

Another possible environmental threat that was considered when the inception workshop took place. Sediments discharged by the rivers were said to be the cause of major turbidity, which do not allow for effective photosynthesis (Gervis and Sims 1992), thus diminish the natural production of phytoplankton and which also affects the feeding mechanism of many bivalve species by overwhelming their branchial filtering system with particulate matter (Southgate and Lucas 2008). River discharges offer an accumulation of sediments at the mouths of rivers where they empty into basins and the ocean. There are several small deltas at the mouths of seasonal rivers in Balochistan. The large Indus Delta covers nearly the entire coast of Sindh. It forms a remarkably uniform landform with large extensive mud flats intervened by narrow creeks, the remnants of former river tributaries. The destruction of mangrove forests would also allow for the increase of sediment flow into the ocean since the absence of these trees -and their unique root system- would allow for these sediments to flow more freely into the ocean (Dr. Guillermo Soberón-Chávez, pers. comm.).

c. Hypoxia and Minimum Oxygen Zones

The National Institute of Oceanography (NIO) informed about hypoxia in world oceans. The minimum oxygen zones do occur in the Arabian Sea but far away from the coastal waters of Pakistan where water depth is 200 meters or more. In Pakistan's coastal waters, the dissolved oxygen reported in various publications do not show hypoxic condition. Hypoxic condition occurs at about 2 mg/L dissolved oxygen in the seawater (Breitburg et al. 2018). Khan et al. (1999) reported 6.83 to 7.73 mg/L dissolved oxygen in the seawater collected from Gwadar east bay in Balochistan.

Thus, this condition, which initially seemed quite dangerous for pearl farming will definitively not impact any possible pearl farm location in Pakistan's coastline.

d. Substrate type

Substrate availability is one of the most limiting factors in the distribution pearl oysters, incareas that would otherwise be good habitats. In French Polynesia, P. margaritifera is scarce or absent in some lagoons due to limited hard substrate availability (corals) since the species is excluded from soft bottoms, on the other hand, P. maxima are found on mud or sandy bottoms, usually in association with seagrass communities. Spat will only settle upon a hard substrate comprised of a seabed with a hard crust that covers a softer substrate is considered ideal for this species. The Akoya -P. fucata- oyster occurs on extensive shoals, or paars, that have rocky or dead coral outcrops often with a dense growth of marine algae (Gervis and Sims 1992).

e. Bathymetrical data

Pearl oysters are found at depths from less than one meter to over 20 meters in depth (Gervis and Sims 1992). Thus, Pakistan has ample opportunities for pearl farming considering this factor.

f. Sea currents

Pearl beds of different species are found thriving in strong water currents, these seemingly inducing or promoting faster growth, but poorer quality pearls may be produced in stronger currents (Gervis and Sims 1992; Southgate and Lucas 2008). Another issue is the ability of pearl farmers to dive under these conditions (Haws 2002).

2. Detailed information on local weather patterns, including historical TYPHOON and flooding data.

3. Natural disasters, such as tsunami-producing earthquakes.

4. Pollution information: all kinds and how prevalent these are.

Information shared during the inception workshop provided the necessary information to understand that at least in an environmental level pearl farming is definitively not a problem in Pakistan's coastline, but each location must be evaluated on a site-by-site basis to select those that offer the best alternatives for pearl oyster growth and survival, as well as to produce beautiful pearls.

3.3 Sociological Information:

Without a community to back this project and as the most important reason behind it as well we do not have a reason for this pre-feasibility study. Populations near areas with these traits will be considered as the most viable targets. If there are touristic areas nearby, this can also be considered as a plus, given the economic opportunity these sites can offer to the local villages.

This is a list of the possible sites (placed to their nearest town, village, or area):

Jiwani Sunset Point

- Ganz
- Emi Island Beach
- Boat Basin, Gwadar
- Australia Beach
- Gonadal Beach
- Gaddani Rocky Beach
- Goth Manjar
- Bhit Khohri
- PN Nathiagali Hut
- French Beach, Karachi.

3.4 Policies and Regulations

This is an important requirement for this project, and are thus considering the following:

a. Federal Government's interest in the Project.

b. The need to find alternative and sustainable economic options for coastal communities.

But, due to the sensitive location of certain strategic sites such as: Military and Commercial ports, nuclear power plants, natural parks or reserves and touristic resorts, these must also be addressed and known to all parties involved in this project.

The next step involves setting up the framework for site selection, considering the information presented in TAPAS deliverable report (Figure 11).

A very important consideration for this project is in the area of Regulations regarding the use of the nation's ecological reserves and the introduction of pearl oyster species from other countries. It is possible that these Ecological reserves will have to be used in order to utilize their biological inventory (native pearl oysters) to "jump-start" a pearl farming initiative, instead of relying on any foreign or imported pearl oysters.

On an important side note, we should ask ourselves why it is crucial for Pakistan to rely on local natural resources over external sources. The questions and, most importantly, the answers are here to help all involved parties evaluate.

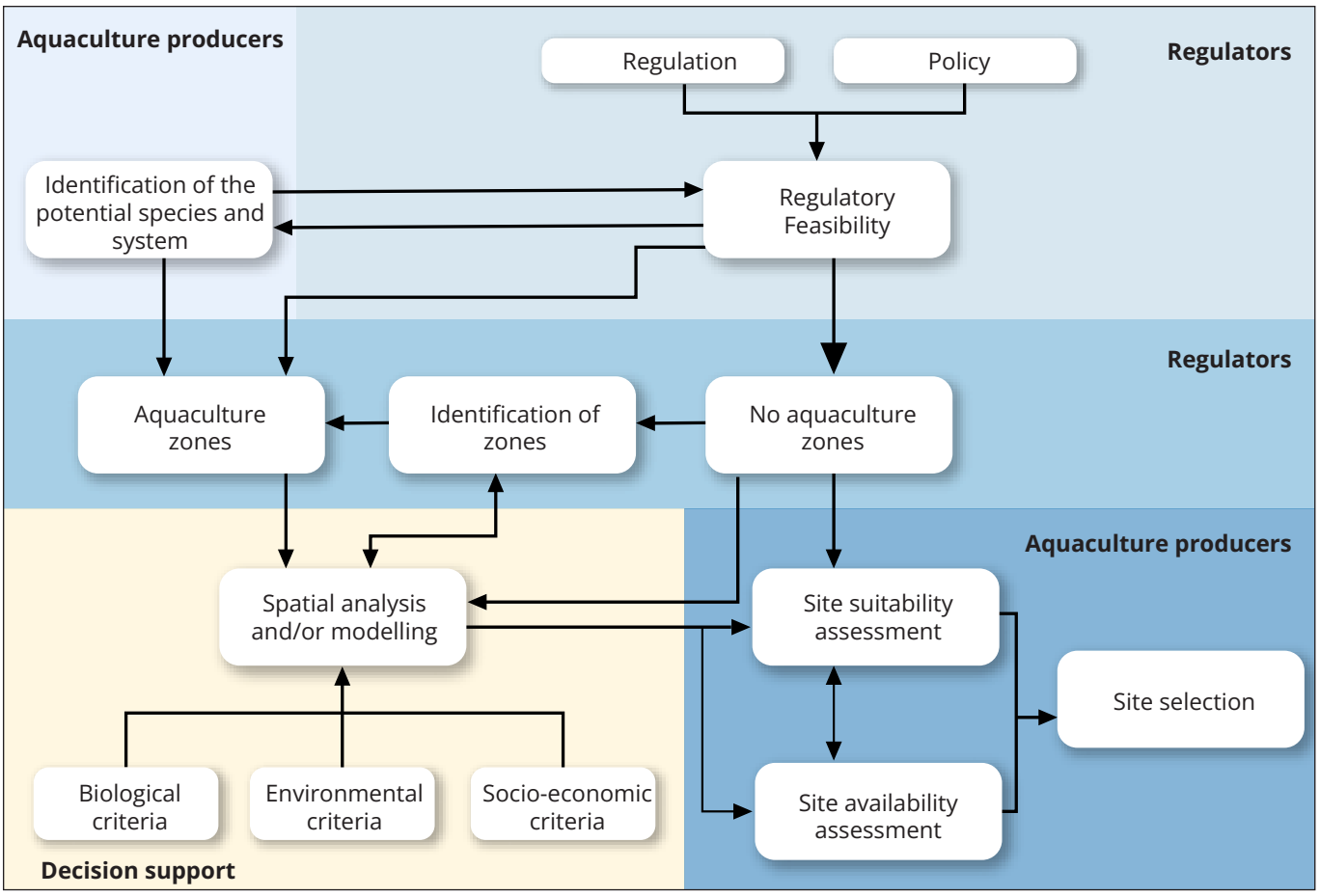


Figure 11 Overview of a spatial framework for site selection and regulation, from Tapas deliverable report

3.5 Why it is Important to Rely on Pakistan's own Biological Inventory?

If healthy pearl oyster beds were found in Pakistan (mainly in Astola and Charna Islands), there will be no need to import nor quarantine the pearl oysters, and it will also be possible to also use "spat collectors" (simple mesh bag, passive juvenile pearl oyster collecting system) to collect tiny (3-5 mm in diameter) pearl oysters that can be transferred to other sites to initiate pearl farming trials.

Spat collectors are made from rope, plastic mesh bags and/or different organic products such as coconut husks, seashells, palm fronds, and bushes. These are not necessarily harmful to the environment, can be removed from any site in hours and will leave no environmental trace behind them. They are also considered as "passive collectors" and only those creatures that "want to" attach to them will do so, so in every single way this is a very ecological and sustainable method to gather juvenile pearl oysters or "spat".

Figure 12: A cluster of wild-grown Pearl Oysters on a rocky reef in the Gulf of California, Mexico

Another way to utilize the Nation's biological inventory is by using the local pearl beds to supply "breeders" to be used to produced "lab raised spat" (hatchery reared juveniles) to use them to supply to pearl farmers. This strategy would require the actual extraction of between 50 to 100 individuals (of each species that is targeted for production). Depending on the size of the existing pearl beds, this could be quite damaging (small pearl beds with less than 200 individuals) so it may be best to avoid using these and instead focus on using spat collectors or consider importing pearl oysters from nearby countries such as Sri-Lanka or the Arab Emirates.

By having a local resource, a country - such as Pakistan - gains complete independence from the very beginning, avoids the introduction of diseases/pests, and gains time, importantly. This can be better utilized in carrying out pearl farming trials, rather than waiting for paperwork and approvals to come through.

3.6 Why would Pakistan Rely on a Foreign Source of Pearl Oysters?

If native pearl oyster inventories are locally extinct or in such small quantities (and this seems to be the case) the country will not be able to rely on this stock to initiate any pearl farming venture or pilot program. If this is the case or if the pearl oyster beds found in the Ecological Reserves of Astola and/or Charna Islands cannot be used due to Federal regulations, then it will be necessary to consider the next viable option: the introduction of foreign pearl oyster species.

This will involve several instances of government both from the importing country (Pakistan) and the one exporting the pearl oysters. These may hinder or speed up the process.

Very importantly, if pearl oysters are not locally available it may mean that pearl farming is not commercially viable or that the costs of importing the specimens, quarantining, and breeding them in specialized labs will render this effort useless (Figure 13).

Figure 13 Different sources of pearl oysters for a pearl farm

If pearl oysters are introduced from other locations, there are several things to consider:

a. The introduction of unwanted exotic diseases/parasites, alongside the introduced species.

b. The introduction of a species that is not found locally and will require time to adapt to the new environment.

c. The need of a Quarantine period, during which many pearl oysters will die, thus many more oysters will be required initially. This period will depend on local laws & regulations.

d. There are usually many governmental institutions involved in the transfer and importing of live species from one country to another one, making this process time consuming.

e. Pearl oysters will have to be bred inside specialized "hatcheries".

f. It will be up to another Country to decide how many individuals and of which species of pearl oysters will be given to Pakistan.

g. Depending on their survival, these processes (importing, quarantine, use of hatcheries) may have to be repeated several times, until they are no longer required because the pearl oysters have adapted to their new environment and are now thriving in it.

Depending on their survival, these processes (importing, quarantine, use of hatcheries) may have to be repeated several times, until they are no longer required because the pearl oysters have adapted to their new environment and are now thriving in it.

4. Strategies for Pakistan (Way Forward)

4.1 Biological Inventory

If not enough pearl oysters are found on Pakistan's coastline (though it is recommended to carry out a population study on Astola Island), there will be a need to import and quarantine them.

These are the list of nearby countries and species of pearl oysters that could supply pearl oysters to Pakistan:

1) Oman and Yemen – Akoya oyster (P. imbricata) and Persian Black-lip (P. margaritifera var persica)

2) Bahrain and Qatar – Akoya oyster (P. imbricata) and Persian Black-lip (P. margaritifera var persica)

3) Eritrea – Akoya oyster (P. imbricata) and Red Sea Black-lip pearl oyster (P. margaritifera var erythraensis)

4) Sri Lanka – Akoya oyster (P. imbricata)

5) Myanmar – Black Winged Pearl oyster (Pt. penguin) and Silver-lip pear oyster (P. maxima). It will be up to Pakistani authorities to initiate talks with these nearby countries and find those that will be willing to sell or supply enough pearl oysters every 3, 6 or 12 months until there is no longer needed to do so. This will be done with different countries at the same time, because it would be possible to obtain different pearl oyster species in order to find a sustainable and commercial pearl farming strategy.

Of course, many more countries could supply pearl oysters to Pakistan, but the longer distances involved may cause high mortality rates. If required, they can be flown to lessen the impact of time during transportation. Another viable option is to obtain lab-raised spat from these countries, if available. Tens of thousands of spats can be easily transported in a small ice cooler, with far less risk and costs than that of transporting large, adult pearl oysters.

Once the pearl oysters reach Pakistan, they must be rapidly taken to specialized quarantine facilities that will be able to handle, care and feed the pearl oysters until they are considered free of diseases or parasites and can be taken to a pearl farm for bioassays or to hatcheries for breeding.

4.2 Initial Pearl Farming Industry Strategy

To initiate a pearl farming industry, it will be a good idea to have a clear focus or strategy on which the involved parties will become an integral part of the industry if Pakistan has a real intent on supporting and help in establishing this sustainable industry. One of the first questions we must pose is what kind of industry Pakistan wants to promote.

1. 100% Privately funded and operated, with support from the Government (tech support, financing and or subsidies).

2. 50-50 Government and Privately-owned ventures.

3. Community owned ventures initially funded or subsidized by the government or NGOs.

4. Small scale, Family-owned farms. These could be unified under local Social Cooperatives.

The different strategies will pose their unique challenges to the different actors involved in making them possible. Many different combinations will offer greater flexibility to make this industry start and grow, but it may also create confusion. Again, it will be necessary to have a special office (Pearl Farming Initiative Office) under the Aquaculture or Fisheries Ministry, to regulate and promote this industry, avoid the common pitfalls, and disarray that could be faced at the onset or once the industry begins growing.

If we start only with private operations, it will be easier to band them under the Ministry of Economy, but there could be little interest in establishing these operations by private capitalists, since there are not enough economic incentives for the typical entrepreneurs. As an example, Mexico started pearl farming in 1996, and there are only three small privately-owned pearl farms in existence after 26 years. If the Mexican government had decided to help promote small-scale farms for families or communities, there would now be hundreds of small pearl farms. But this is just conjecture on my part.

There needs to be a vision of the industry as a whole to lay down the strategies that will be required to promote its growth under the different stages (nascent, infancy, maturity) that the industry will have over the years. Following are the questions and vision which are required to be addressed before the establishment of the industry.

- Will pearl farming become a tool to help coastline communities make an income and avoid migration unto the cities?

- Will pearl farming become a venture employed by private investors to promote tourism and this -in turn- will help coastal communities by offering employment opportunities?

- Mixed or Hybrid strategies: Coastal communities could raise pearl oysters until maturity (18-24 months) and sell them to private companies or social cooperatives for them to use in pearl production.

- Sales and Marketing: A designated Office of the Ministry of Economy could be in charge of establishing the quality standards and regulations for pearl sales, both in the National and export markets.

- Touristic Promotion: A strategic touristic promotion could be used to promote visiting pearl farms to bring income to the communities that have a pearl farm. Many other sectors would also benefit by this effort.

- Funding or Governmental Spending: Will there be funding for these pearl farming projects? How much and for how long? Pearl farms take a long time to recover their investment (up to 10 years, depending on the project and many other variables). Perhaps economic support to producers will come by means of the supply of lab-raised spat for the farms, the purchase of pearling cages, wages paid to pearl seeding technicians, etc.

These are questions that can only be answered by those in office and engaged in strategic planning. But we first require evaluating if pearl farming will be a commercially viable alternative. If the costs and time involved in making pearl farming possible are too high and time consuming, it might be best to find a better alternative, at least with a traditional pearl farming system.

But the benefits of pearl farming as an ecological restorer and as a fish safe-haven may help round out its benefits to local communities: pearl farms can act as floating reefs, with both pearl oysters and the culture nets helping in nursing and protecting many species of fishes and invertebrates, that in turn can help feed the commercially valuable fish species that sustain the local communities. The pearl oyster's meat - if found unpalatable for the local people - can be used to feed livestock (poultry) or to use in traps to catch crabs or gastropods.

4.3 Technical Opportunities for Pakistan

4.3.1 Shrimp hatcheries in Pakistan

There are three hatcheries, two on the Sindh coast and one on Balochistan coast. All the three hatcheries are non-functional at the moment. Dr. Samina Kidwai, Director General of the National Institute of Oceanography (NIO), Karachi, informed us that the shrimp hatchery of NIO at Sonmiani (Balochistan) has seasonal operations. The Fish and Shrimp Hatchery of Marine Fisheries Department at Hawks Bay (Karachi) is also not in working order. The Shrimp hatchery of Directorate of Fisheries, Government of Sindh at Hawks Bay (Karachi) is maintaining algal culture only and no shrimp larvae are being produced at the present. This means that these installations could become adapted to produce pearl oyster spat if the Government decides to initiate a pilot pearl culture farming operation.

This would involve little investing, the most important being in the area of Human resources: finding a highly trained and knowledgeable mollusk spat producing technician to rapidly produce spat from one or any of the species that will be selected for pearl farming.

4.3.2 Pearl farming workers

There are different personnel required for pearl farming:

1. Field Workers: with skills and abilities related to fishing, including the ability to swim, free-dive, SCUBA diving, and working with ropes, nets, and boats. These are the most important since they are required every single day of operation.

2. Biologists: That will be examining the pearl oysters and monitoring the environment at least weekly. These can be University students that can work at the farms for certain periods of time.

3. Pearl Technicians: Highly specialized personnel that can perform the delicate pearl seeding operation required for the production of cultured pearls.

Pakistan will without a doubt be able to find and supply the necessary personnel, except for point #3. These specialists are trained on site, sometimes for years, at pearl farms. Some countries such as China- usually train their Pearl technicians at one site and then have them travel, from farm to farm, to seed the mollusks. This makes it easier to start an industry. Eventually, established pearl farms will hire their exclusive technicians or train them in-house.

Since pearl farms require at least 3 or 4 years until pearl oysters attain "seeding size" (6 to 10 cm, depending on species used), there will be more than enough time to find or train these technicians, but it will be necessary to find personnel with the good hand-eye coordination and with empathy towards the mollusk's well-being, as to be able to reduce mortality rates and increase high-quality pearl production. It has been stated that an aspiring pearl technician requires to operate around 9 thousand oysters before he can be considered a properly trained technician and then his results (production of cultured pearls) must be evaluated to consider if he/she is considered adequate for the job. In my most recent experience in training personnel, I believe that 1 to 2 thousand operated pearl oysters per technician will be able to suffice.

Figure 14 People involved in Pearl Farming: A. Field workers; B. Seeding Technicians; C. Pearl oyster ready for seeding operation; D. Biologists

Thus, if Pakistan wants to have at least 6 trained technicians, a population of at least 12 thousand ready to operate pearl oysters are required, since selection of the best mollusks removes between 30 to 50% of the oysters in a farm. When pearl farms have experience growing their oysters and environmental conditions have been good, most pearl oysters will be ready to usebut, in some instances, we will require more time to help the unselected animals regain their health to be able to be used in 1-3 months' time after their rejection. Some are never used due to their weakened state and are discarded (sacrificed).

If only three technicians are to be trained, there will be a need for about 6000 mollusks. If we only have 3000individuals, only one technician can be trained.

A good farm size (manageable with just 4-6 full-time field workers) can have between 5 to 10 thousand pearl oysters.

Pakistan has excellent Universities with Marine Research departments that could oversee the education, training and managing of the specialists that will oversee the monitoring of the pearl farms and seeding of the pearl oysters. Finally, the knowledge to grade and value/appraise pearls can also be managed by one of the same Universities, after hiring a person knowledgeable in the area that will be able to train the University's personnel.

4.4 Marketing and Value-Added Production

Pakistan may decide to produce "raw pearls" (unset pearls for the local or export market), but a much better income can be made by including a value-added proposition. This can be done under different strategies:

1. Setting the pearls on silver and/or gold settings, to sell to the local and export markets.
2. Using pearls and shell (mother-of-pearl) to produce specialty goods, such as clothing, purses, sculptures, inlayed items, etc.
3. Establishing touristic pearl farms where visitors can harvest their own pearls and have them mounted on jewelry.
4. Online pearl jewelry sales.

It is quite possible to make a good enough income for a pearl farm with these strategies, although it is highly dependent on the local economic growth or on foreign tourism. A mixed strategy can be utilized as well.

Figure 15 Different marketing strategies for selling pearls: Wholesale, Touristic Retail and Online Sales

4.5 An Unusual Pearl Farming Strategy

It seems to me that a "traditional" pearl farming strategy will take some time to become established in Pakistan, as pearl oysters are located -either locally or from abroad- and brought to the adapted shrimp larvae labs for the production of laboratory grown "spat" (juveniles), then grown in newly established pilot stage pearl farms. This could take anywhere between 2 to 4 years, depending on the celerity of the efforts.

But another, less traditional pearling strategy could be developed in Pakistan, one that will help it recover its biological inventory in a sustainable manner: the establishment of new natural pearl beds, by means of repopulation. The United Arab Emirates are already working on a similar strategy: the use of natural -protected- pearl beds and their fishery under a sustainable strategy.

This strategy would require long-term planning and would have to start in a suitable natural protected area (such as Astola and Charna islands). There would be several stages to this strategy, which will be listed below:

1. Identification of endemic pearl oyster individuals and their sites.

2. Relocation of these individuals to form "clusters" of at least 10 individuals per square meter. This is considered as the minimum population of oysters required to promote efficient natural breeding.

3. If not, enough oysters are found, produce lab-raised "spat" and grow them in protective cages until they grow to become 3-4 cm tall (shell diameter) and place these in prepared areas at densities of up to 150 individuals/m2.

4. Note: Both strategies can be placed into effect at the same time, to produce better results.

5. Constant Monitoring (weekly or monthly) is necessary to find problems with predators and reduce mortalities.

6. After 6 months, place spat collectors near the area to gauge reproductive effectiveness.

7. If pearl beds are not growing with new cohorts (newly settled oysters) it will be necessary to add more lab-raised pearl oysters until this happens.

8. Once we have a sizeable population of pearl oysters (over 100,000 pearl oysters at different stages of growth) some of the pearl oysters (larger ones at around 7-8 cm) can be used to provide breeding stock for hatcheries and/or spat collectors can be placed to capture wild-spat that can then be used at chosen pilot pearl farming sites.

9. As the pearl beds grow, these can also be sustainably harvested for natural pearls (15% of the population can be harvested), with the funds being used to improve the Marine Protected Site.

10. This strategy can also be used with other marine bivalves that have been identified as having a commercial potential, such as "Pen Shells" and "Sea Scallops". These organisms can be used to produce unusual natural pearls and high-quality seafood.

Figure 16 Natural pearls from Mexican species of "Pen Shells" (Atrina maura and A. texta) and "Sea Scallops" (Nodipecten subnudosus) that may sometimes achieve good value in the international markets. Similar looking pearls could be produced in Pakistani waters using local species

The Mexican Experience

As additional context to this subject: back in 1990 a pearl oyster census was carried out inside Bacochibampo Bay, Guaymas, Sonora, Mexico. The result of this census showed that in the entire Bay (roughly 282 Hectares) there were just 88 individuals of the "Panamic Black Lip Oyster" (Pinctada mazatlanica) and fewer than 300 individuals of the "Rainbow Lip Oyster" (Pteria sterna) within the aforementioned area. Pearl oyster recruitment via "spat collectors" also offered dismal results:

- Pteria sterna: 7 - 14 spat/m2
- Pinctada mazatlanica: 0 - 2 spat/m2

In simple terms, there was little to no recruitment of new cohorts of both species and the pearl beds would never recover.

The first recovery efforts undertaken involved fishing all available pearl oysters within Bacochibampo Bay and the surrounding areas, especially on the small islands and rocky reefs. After some time, some 100 large black-lip adults had been recovered and placed under culture conditions inside the experimental pearl farm at stocking densities of 30 to 75/m2. Wild Spat collected experimentally yielded the rainbow-lips required for the reproductive recovery of the species (the collected adult specimens died of stress during handling). By 1996, wild spat recruitment increased dramatically:

- Pteria sterna: 300 spat/m2
- Pinctada mazatlanica: 36 spat/m2

By the year 2010, with an established population of 150,000 rainbow-lip pearl oysters and just 120 black-lips, wild spat collection had increased with one of the species:

- Pteria sterna: 8,000 spat/m2
- Pinctada mazatlanica: 27 spat/m2

Figure 17 A view of Bacochibampo Bay in Guaymas, Sonora, Mexico. This is the site of that country's first commercial pearl farm

The pearl farm acted as a "reproductive station" and had been replenishing the local environment and furnishing the pearl farm with all of its pearl oyster needs. At about the same time, the Fisheries Department of the State of Sonora found what appeared to be a new pearl bed, located about 90 Km away from the pearl farm. The pearl bed had millions of pearl oysters and it was something that had not been recorded - and never before evaluated using scientific methods - in the Gulf of California since the 18th Century. After this find and the subsequent scientific analysis, this species of pearl oyster (Pteria sterna) was taken out of Mexico's Protected list, which barred its use in fisheries since 1950, meaning that fisheries experts deemed that this species does not require any special protection from the Federal government.

Figure 18 Photo of a small portion of a natural pearl bed of "Rainbow Lip Pear Oysters" (Pteria sterna) that was found inside the Gulf of California, Mexico, near Guaymas back in 2010

Unfortunately, the new pearl beds were fished into oblivion shortly after since fishermen took all the pearl oysters at once; instead of harvesting them sustainably.

4.6 Benefits of Pearl Establishing Marine Pearl Farms

Figure 19 Underwater view of a pearl farm. The cages act as "floating reefs" offering food and shelter to a myriad of small organisms (plants and both vertebrates and invertebrates) which in turn become an important food source for larger fishes, thus pearl farms can become quite interesting to fishing communities

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 Pearl farms may have the ability to help recover the local fisheries, under proper fisheries management.

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. Every other person, even children, could manufacture mother of pearl handcrafts, buttons, and jewelry, which they can sell to the larger cities and to the touristic industry.

   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.

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

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

5. Conclusion

There are many strategies that can be employed in Pakistan. The easiest, most sustainable and most cost-effective would be to start with the recovery of pearl beds, first in Astola & Charna Islands and then into other sites. This can be followed by establishing small pilot-scale pearl farms in small coastal/fishing communities and medium- to larger-sized pearl farms.

The first stage would take between 2-4 years, the second stage starting once the first one is "completed" (which really means that the newly reestablished pearl beds are large enough to supply "spat" for any number of pearl farms).

Pearl farming is always a long-term investment. Therefore, it would be easier and less time-consuming for the country to set up a pearling industry that has a sizeable biological inventory (several species of suitable pearl oysters and large pearl beds).

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ANNEXURE 1

POTENTIAL PEARL OYSTERS' PREDATORS AND PESTS IN THE COASTAL WATERS OF PAKISTAN

Note: The note has been prepared by Ms. Sumaira Khatoon (Marine Biologist), Intern ADPC

Pearl oysters, especially spats and juveniles, are vulnerable to predation. A number of fish species and other marine animals such as gastropods, cephalopods, and crabs etc. feed on pearl oysters (Pit and Southgate, 2003). Since no work has been done on the biology of pearl oysters in Pakistan, nothing is available in the literature regarding pearl oysters' predation in country's coastal waters. However, a number of marine animals that feed on pearl oysters are reported in the literature published from countries other than Pakistan. An account of such predatory marine animals (Predators and Pests) that occur in Pakistani waters is detailed below.

1. PREDATORS

1.1. FISHES

The most important families of predatory fish are Lithernidae, Balistidae, Tetraodontidae, and Sparidae (Gervis and Sims, 1992; Humphrey, 2008). It has been reported that in the Persian Gulf mortality rate of pearl oysters, due to fish predation, may go up to 35% (Humphrey, 2008). Crossland (1957) reported several species of fish from the Red Sea, like Lethrinus karwa, Acanthopagrus bifasciatus (as Chrysophrys bifasciatus), and Pagrus sp, which prey upon pearl oyster Pinctada margaritifera. Crossland (1957) also pointed out that larger fish, like Pseudobalistes flavimarginatus (as Balistes flavimarginatus), could break open even the older shell of pearl oysters up to 6 mm thick and that ray could also prey upon the oyster shells.

The members of the four fish families found in the coastal waters of Pakistan are given hereunder.

1.1.1. Family Lethrinidae

Lethrinids are moderate to large-size fishes commonly known as emperors, emperor breams, and pigface breams. They inhabit coral reef and rocky areas in coastal waters. Most species of this family have molariform teeth, with which they crushed hard shelled invertebrates including bivalve molluscs. Lithrinid fish of Pakistan that feed on molluscs are listed in Table 1.

Table 1. Species of Lithrinidae fish found in the coastal waters of Pakistan

S. No.	Species	English name	Local name	Reference
1	Lethrinus elongatus	Long face emperor	Mullah	Bianchi, 1985; Psomadakis et al. 2015
2	L. nebulosus	Spangled emperor		
3	L. harak	Thumbprint emperor		Psomadakis et al. 2015
4	L. lentjan*	Pink ear emperor		
5	L. microdon**	Small tooth emperor		
6	L. obsoletus	Orange striped emperor		
7	L. olivaceus	Long face emperor		
8	L. ornatus	Ornate emperor		
9	Monotaxis grandoculis	Hump nose big-eye bream		

***Feeds on Pinctada sp.** (Toor, 1964)
*This species probably does not feed on molluscs

1.1.2. Family Balistidae

Members of this family are commonly known as triggerfish. These fish use their powerful jaws for feeding on various hard animals such as molluscs, crustaceans and sea urchins etc. Some species are also known to seek softer prey such as small fish, while others are vegetarian, feeding primarily on algae or plankton.

Table 2. Species of Balistidae fish found in the coastal waters of Pakistan

S. No.	Species	English name	Local name	Reference
1	Abalistes stellatus*	Starry triggerfish	Kookh	Psomadakis et al. 2015
2	Pseudobalistes fuscus**	Yellow-spotted triggerfish		
3	Sufflamen fraenatum**	Masked triggerfish		

*Feeds on molluscs (Western Australian Museum Collections, 2021)
**Feeds on molluscs (Kulbicki et al. 2005)

1.1.3. Family Tetraodontidae

Tetradontids or pufferfish feed mostly on invertebrates and algae. Large specimens of pufferfish can crack open bivalve molluscs such as clams and mussels with their hard beaks where their four sharp teeth converge (hence the family name, 'tetra' meaning four and 'odous' meaning tooth in Greek).

Table 3. Species of Tetraodontidae fish found in the coastal waters of Pakistan

S#	Species	English name	Local name	Reference
1	Arothron stellatus*	Stellate puffer	Kookh	Psomadakis et al. 2015
2	Chelonodontops patoca	Milk spotted puffer		
3	Lagocephalus incermis	Smooth blaasop		
4	L. lagocephalus	Oceanic piffer		
5	L. lunaris	Lunar tail puffer		
6	L. guentheri	Diamond back piffer		
7	L. spadicus	Half-smooth golden puffer		
8	Takifugu oblongus	Lattice blaasop		

***Feeds on Pinctada margaritifera** (Doroudi, 1996 – as Tetraodon stellatus – cited in Humphrey, 2008).

1.1.4. Family Sparidae

This family includes seabreams that are demersal fishes. Most sparids are carnivorous feeding on molluscs, crustaceans and small fish, but some feed on algae and seagrass.

Table 4. Species of Sparidae fish found in the coastal waters of Pakistan

S#	Species	English name	Local name	Reference
1	Acanthopagrus bifasciatus*	Two-bar seabream	Dandia	Bianchi, 1985
2	A. arabicus	Arabian yellowfin seabream		Psomadakis et al. 2015
3	A. berda	Gildsilk seabream		
4	Catenula	Bridled seabream	Daleri	
5	Sheim	Spotted yellowfin seabream	Dandia	
6	Argyrops spinifer	King soldier bream		
7	Diplodus capensis	White seabream	Kukkidia	
8	D. omanensis	Oman seabream	Taikairi	
9	Pagellus affinis	Arabuan pandora	Dandia	
10	Rhabdosargus haffara	Haffara seabream	Chan	
11	R. sarba	Goldlined seabream		
12	Cheimerius nufar**	Santer seabream	Dandia	
13	Crenidens indicus**	None		
14	Sparidentex hasta**	Sobaity seabream	Dathi	
15	S. jamalensis**	Fanged seabream		

***Predator of Pinctada margaritifera** (Crossland, 1957 – as Chrysohrys bifasciatus)
**Molariform teeth absent and probably do not prey on molluscs / oysters.

1.2. SHARKS AND RAYS

Despite the protection of their hard shells, pearl oysters are vulnerable to predation by sharks and rays (Gamez, 2014). Psomadakis et al. (2015) described 15 families and 47 species of shark from Pakistan. Some species of shark are filter feeders, like whale shark (Rhincodon typus – found in Pakistan) and basking shark Cetorhinus maximus – not found in Pakistan). Others are carnivorous feeding on variety of marine animals. Zebra shark (Stegostoma fasciatus), which is found in Pakistan, feeds mainly on molluscs (Bianchi, 1985).

Following is a list of sharks that feed on invertebrates including molluscs and are found in the coastal waters of Pakistan;

Table 5. Species of Shark found in the coastal waters of Pakistan

S#	Species	English name	Local name	Reference
1	Stegostoma fasciatus[1]	Zebra shark	Billi	Psomadakis et al. 2015
2	Iago omanensis[2]	Bigeye hound shark	Chua	
3	Carcharhinus melanopterus[3]	Blacktip reef shark	Mangra	
4	Carcharhinus dussumieri[4]	White cheek shark	Gussi	
5	Galeocerdo cuvieri[5]	Tiger shark	Mohr	

[1]Feeds mainly on molluscs (Bianchi, 1985).
[2]Diet includes molluscs (Bonfil and Abdallah, 2004).
[3]Feeds on crustaceans, cephalopods and other molluscs (Last and Stevens, 2009).
[4]Feeds on bony fishes and invertebrates including molluscs (Psomadakis et al. 2015).
[5]Feeds on various animals including molluscs (Aines et al. 2018).

Most species of rays possess heavy, rounded teeth for crushing the shells of bottom-dwelling species such as snails, clams, oysters, crustaceans, and some fish, depending on the species. Manta rays (Manta birostris and M. alfredi) feed on plankton. A total of 32 species of rays are known to occur in the coastal waters of Pakistan (Psomadakis et al., 2015).

Rhinoptera javanica (cownose rays), which is found in the coastal waters of Pakistan, is known to **destroy pearl oyster beds** in the Indian Ocean (Shipley and Hornell, 1906).

1.3. GASTROPODS

Several species of gastropods prey on pearl oysters, especially spats and juveniles, and are major source of pearl oyster mortality in the oyster farm and in the oyster beds (Humphrey, 2008). There are three families of predatory gastropods: 1) Cymatiidae, 2) Muricidae, and 3) Bursidae.

1.3.1 Family Cymatiidae

Three species of this family that are known predators of oysters and pearls oysters are found in Pakistan. Linatella caudata and Monoplex pilearis reported from edible oyster beds in Hub River Delta by Aslam et al. (2020) are well known predators of pearl oysters (Humphrey, 2008 – who mentioned Monoplex pilearis as Cymatium pileare). Another species of predatory gastropods of the family Cymatiidae, Gyrineum natator, is reported from Jiwani, Balochistan by Ghani et al. (2019). Humphrey (2008) described G. natator as pearl oyster predator, but he placed this species in family Bullidae.

1.3.2. Family Muricidae:

This family contains some important pearl oyster's predator such as Ocinevrellus inornatus (Japanese oyster drill), Urosalpinx cinerca (American oyster drill), Chicoreus ramosus (ramose murex), Stramonita haemastoma (oyster drill), Eupleura caudata, and Chicoreus virgineus (= Murex virgineus) (Humphrey, 2008; Kennedy et al. 2009; Randoph and Maccarone, 2018). However, none of these species have been reported from Pakistan.

In Pakistan ***Murex carbonnieri*** is reported from edible oysters beds along with ***Indothais scalaris, I. lacera,*** and ***I. saccullum*** (Aslam et al., 2020).

1.4. CEPHALOPODS

All cephalopods are predators and feed on fish, crustacea, worms and other molluscs including oysters. Fifty-seven species of cephalopods have been reported from the coastal waters of Pakistan (Kazmi, 2018). ***Octopus vulgaris*** is known to ***prey on pearl oyster*** Pinctada (Fujita, 1916) and this species ***is found in Pakistani*** waters.

Hiemstra (2015) documented 11 species of Octopodoidea that can drill hole in oysters. These include species of Octopus, *Amphioctopus* etc. From Pakistan ***Octopus cyanea, O. vulgaris, Amphioctopus aegina*** and ***A. marginatus*** have been reported (Psomadakis et al. 2015; Kazmi, 2018).

1.5. CRABS

Crabs ar e amongst the worst predators of pearl oysters' spats and juveniles (CMFRI, 1991). Pilumnid crab ***Pilumnis cursor,*** Xanthid crabs ***Leptodius exaratus, Atergatis integerrimus,*** and portunid crabs ***Charybdis lucifera, C. feriata, Portunus*** spp. and ***Thalamita*** spp., prey on oysters by crushing shell (CMFRI, 1991; Humphrey, 2008). All these crabs are found in the coastal waters of Pakistan (Mustaquim and Rabbani, 1976; Khan, 1977; Tirmizi and Ghani, 1996; Tirmizi and Kazmi, 1996).

1.6. SEA STAR / STAR FISH

Sea star or star fish prey on variety of animals including oysters and pearl oysters (Kennedy *et al.,* 2009; Chelladurai *et al.,* 2015). Asterias forbesi pulls pearl oysters' shell apart and eat flesh (Kennedy *et al.* 2009). From India (Tuticorin coast) *Protoreaster lincki* has been reported as "an **enemy of pearl oysters** along the coast of Gulf of Mannar" (Chelladurai *et al.,* 2015).

From Pakistan, Tahera (1996; 2006; 2007) reported six species of star fish: **1) Luidia maculate, 2) Astropecten indicus, 3) A. polyacanthus, 4) Asterina lorioli, 5) Asterina** sp. and **6) Aquilonastra burtoni** (as **Asterina burtoni**).

Species of the genera Luidia and Astropecten do not feed extra orally (Sloan, 1980), hence it is unlikely that these species prey on adult pearl oysters. However, they can pull apart the shells of pearl oysters' spat and ingest the flesh.

1.7. STOMATOPOD / MANTIS SHRIMP

In northern Australia, stomatopod ***(Gonodactylus falcatus)*** **is the most destructive predator of** ***Pinctada margaritifera*** with individuals consuming in excess of 20 juvenile pearl oysters per week (Pit and Southgate, 2003). Humphrey (2008) also stated that *Gonodactylus falcatus* prey on pearl oysters by smashing.

2. PESTS

2.1 POLYCHAETES

Polychaete worms belonging to the families Spionidae and Cirratulidae have been found to bore pearl oyster shells. The spionids *Polydora ciliata and P. flava, P. webstri* and the cirratulid *Cirratulus cirratus* are the most common shell borers. *Polydora* spp. caused blisters on the inner side of the oyster shells (mud blisters disease). In a few cases, the blisters erupted as tumour-like protrusions, mostly near the adductor impression. The cirratulid C. *cirratus* is found in furrows between the layers of periostracum of the pearl oyster shell. As a result, the furrow eventually becomes deeper and wider causing the peeling of the periostracal layer thus weakening the shell and making the oysters vulnerable to predation (Humphrey, 2008).

Mustaquim (1997) reported nine (9) species of spionid worms from the coastal waters of Pakistan. Of these, following six (6) species were found to bore rock oysters (Crassostrea sp.) and / or spiny oysters (Spondylus sp.): ***1) Boccardia polybranchia, 2) Polydora armata, 3) P. ciliata, 4) P. giardi, 5) P. hoplura,*** and ***6) P. spondylana.*** These species of spionid worms can also bore pearl oysters.

Jawed and Khan (1974) reported *Cirratulus cirratus* from the mud flat of Baba Island, Karachi. This species has not been reported, so far, to bore oysters occurring in the coastal waters of Pakistan.

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ANNEXURE 2

REPORT ON FIELD WORK AT CHARNA ISLAND FOR EXPLORATION OF PEARL OYSTER BEDS ON 10TH MARCH, 2022

Note: The field report has been documented by Dr. Javed Mustaquim, Retd. Prof and Director, Centre of Excellence for Marine Biology, University of Karachi, Karachi, Pakistan

ITINERARY
Date: 10th March 2022 (Thursday)

7.30 to 8.0 am	Gathered at Mauripur, Karachi, Pakistan
8.0 am	Left Mauripur for Goth Manjar beach near Mubarik village by car
8.45 am	Arrived at Manjar beach
9.15 am	Left Manjar beach for Charna Island by boat
10.30 am	Reached at charna island
10.50 am	Briefed the divers about the mission
11.15 am	First dive at station 1 for about 35 minutes
12.20 pm	Second dive at station 2 for about 40 minutes
2.0 pm	Third dive at station 1 for about 40 minutes
3.15 pm	Left charna island for Manjar beach
4.40 pm	Arrived at Manjar beach
5.15 pm	Left Manjar beach for Karachi city

PREAMBLE

A one-day field trip was arranged on 10th March, 2022 to explore the potential of pearl oyster's beds at Charna Island as part of the study on "Techno-Commercial pre-feasibility of pearl farming as an alternate livelihood in coastal belt of Pakistan." The field work was organized by Asian Disaster Preparedness Center as part of the CARE for South Asia Project funded by the World Bank. (Figure 1)

Figure 1 Fieldwork team from ADPC, PCRWR and CEMB, Karachi, Pakistan

CHARNA ISLAND

Charna Island (also spelled Churna Island) is a small uninhibited rocky island without any sandy beach. It is about 9 km west of Manjar beach (also called Sunhera beach) (Fig. 2). The island is about 1.2 km long and average width is about 0.5 km (the widest part measures about 0.85 km). The terrain of the Charna Island rises abruptly from the sea surface and the highest point is about 143 metre (Fig. 3).

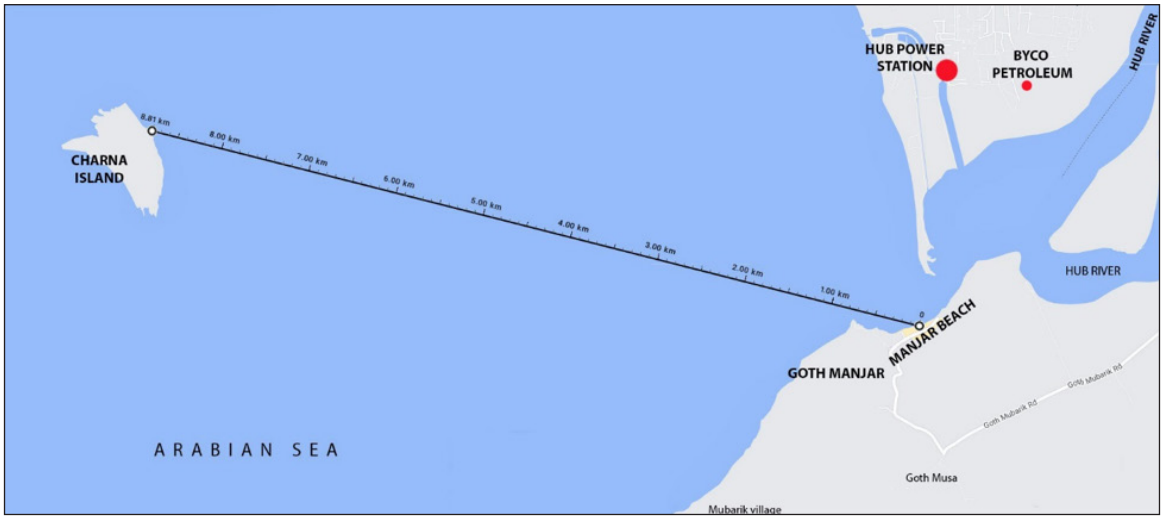

Figure 2. Map showing distance from Manjar beach to Charna Island (8.7 km) (Modified from Google Earth)

The water around the island is clear and average depth is about 8 metre. It is a famous place for SCUBA diving, snorkeling and fishing. Charan Island is a major biodiversity hotspot. Poisonous sea snakes, fishes (cobia, barracuda, angel fish, ray fish etc.), sea-urchins, sea-fan, sea-pen (Pinna spp and Atrina spp.), oysters, scallops (Pectin sp.), corals, sponges, and seaweed are found in this area. Whale sharks have also been reported from the area. Sea-grasses and pearl oyster's beds have not been reported from this area. There is no freshwater source on the island.

Charna Island comes under the jurisdiction of Environmental Protection Agency of Balochistan (BEPA). This island is under consideration for the status of a Marine Protected Area (MPA) and would be the second MPA in Pakistan (the first one is Astola Island). The Hub Power Station (1320 MW coal-fired power plant) and Byco Petroleum refinery are about 8 to 9 km away from the Charna Island.

Figure 3. Photographs showing Charna Island. These photographs were taken from the boat on 10th March 2022 (Photo courtesy of Dr. J. Mustaquim)

DIVING AND PEARL OYSTER FINDS

Figure 4 shows the two diving sites, station 1 and station 2, where SCUBA diving was performed by a group of three divers (Fig. 5). The first dive was performed at station 1, from 11.15 am for 35 minutes. One intact shell (without animal) of akoya pearl oyster, Pinctada fucata, was found by the divers (Fig. 6). This pearl oyster measured 58 mm in length, 50 mm in breadth, and 52 mm hinge length. The divers told us that there were some more dead shells of akoya pearl oysters. We took only one dead specimen as reference material. This specimen is at present with Mr. Zamir Somroo, ADPC.

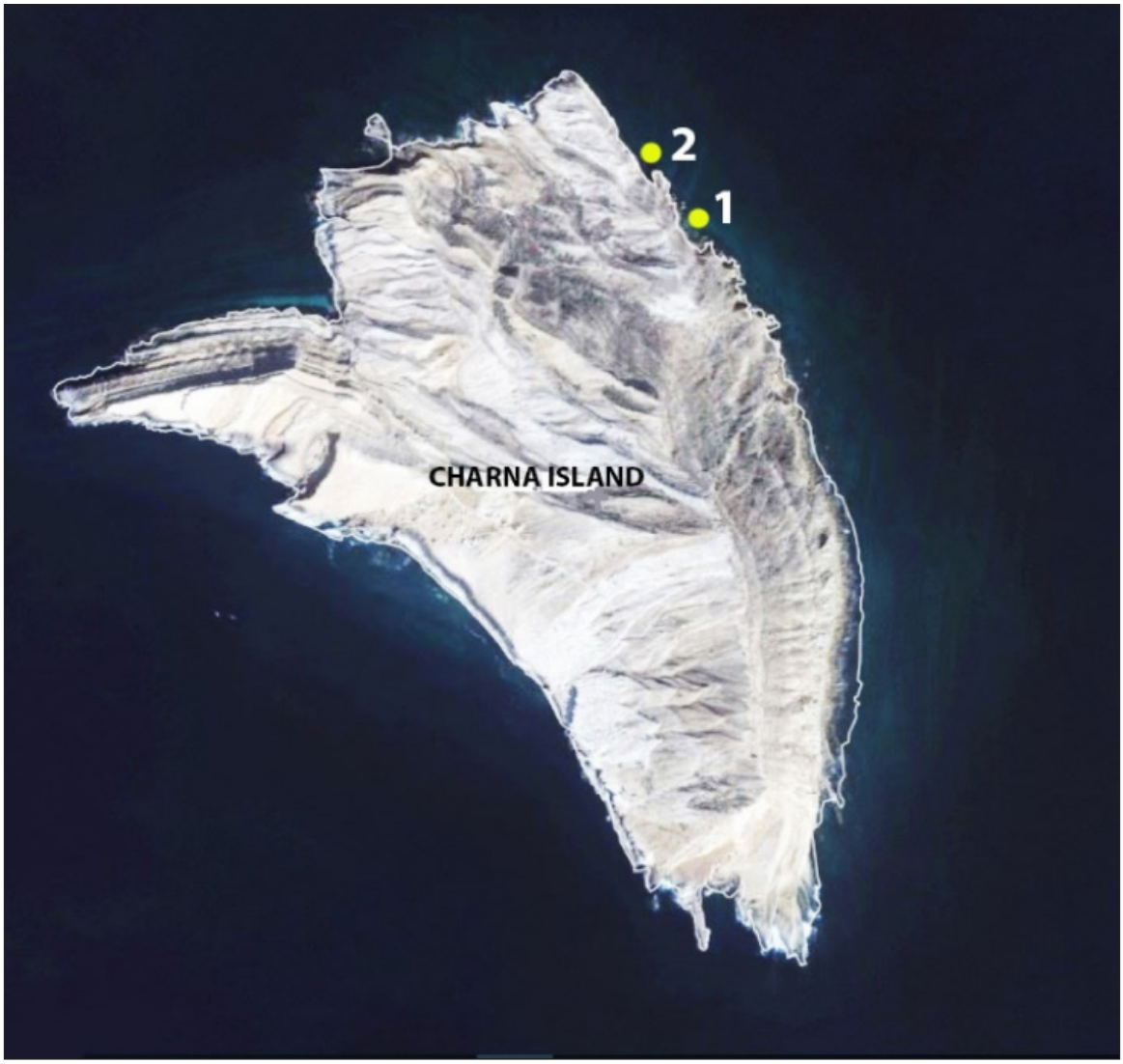

Figure 4. Charna Island. Number 1 and 2 indicate diving stations / sites

Figure 5. Photographs showing divers in action (Photo courtesy of Dr. J. Mustaquim)

Figure 6. Akoya pearl oyster, Pinctada fucata, intact shell (without animal) collected by divers from Charna Island station 1. Measurement: length 58 mm, breadth 50 mm, hinge length 52 mm. (Photo courtesy of Dr. J. Mustaquim)

The second dive was performed at station 2 from 12.20 pm for a period of 40 minutes. At this site no pearl oyster was found. Other molluscs like Pinna, Pectin, and oysters were common at this site.

The third dive was performed again at station 1from 2.0 pm for about 40 minutes. One alive pearl oyster, Pinctada imbricata complex (?) (Fig. 7), with a spat (most probably of the same species of pearl oyster) on upper shell surface was found by the divers. The specimen measured 80 mm in length, 75 mm in breadth, and 65 mm hinge length. The specimen was taken as reference material and preserved in 8% formalin. This specimen is currently with Dr. Javed Mustaquim.

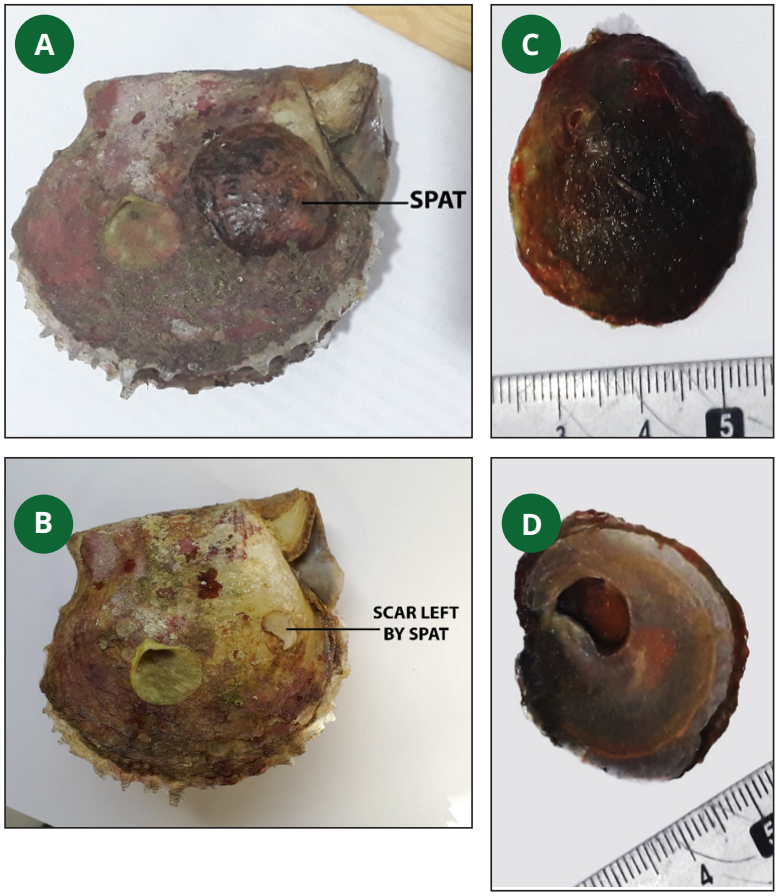

Figure 7. Pinctada imbricata complex (?): A- uncleaned shell with spat, B- cleaned shell (dirt removed by soft brush) with scar of removed spat, C- spat (upper view) and D- spat (lower view). Measurement of A and B: length 80 mm, breadth 75 mm and hinge length 65 mm (Photo courtesy of Dr. J. Mustaquim)

CONCLUSION

Pearl oysters, Pinctada spp., are present around Charna Island, though in small number. Pearl oyster bed was not observed during the present field work but extensive survey covering all sides of the island may reveal its presence.

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