Mangrove Friendly Aquaculture

FishAdapt Project




Food and Agriculture
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United Nations

Cover photographs:

Top left to right: Extensive mangrove pond in Myanmar; Shrimp harvested from a pond. Bottom left to right: Algal culture in south Myanmar; mangrove plantation in east Thailand (Photos courtesy Edoardo Pantanella)

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In view of the impacts that climate change is going to have in the world and in particular on food security and vulnerability, the Food and Agriculture Organisation of the United Nations has launched a series of initiatives targeting the awareness, the capacity building of both ministerial officers, development agents and communities on the sustainable management of natural resources.

Climate change adaptation and climate smart approaches are fundamental to reduce the footprint of modern agriculture and aquaculture systems, to improve the food output by restoring natural habitats and to improve the resiliency of all those communities that are at the frontline for the effects of the climate change.

On this regard FAO prepared a comprehensive manual on mangrove friendly aquaculture to propose strategies in forest restoration that prioritize food production, systems integration, and sustainable use of resources also with a focus on greenhouse gases abatement through carbon sinks.

The present manual was prepared by Dr. Edoardo Pantanella aquaculture consultant and climate change specialist, supervised by the FAO FishAdapt Team Leader Mr. Jose Parajua and reviewed by the FAO national aquaculture expert Daw Moe Kyi Phyu and the national climate change adaptation - disaster risk management expert U Aung Tun Oo.

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Abstract

This manual seeks to provide a comprehensive technical knowledge on all the aspects related to mangrove friendly aquaculture, and to showcase strategies that can be used to promote sustainable use of forests combined with aquatic productions.

The manual wants to give to the readers a broad knowledge about the code of conducts for the responsible management of mangrove ecosystems and aquaculture, and to outline the numerous benefits and services that the mangrove ecosystems give.

The successive section addresses aspects of forestry management, and puts particular emphasis on the ecological needs of the different plants that are grouped under the denomination of mangroves. The knowledge is particularly important to avoid common mistakes in zoning and plantation that could bring to rapid degradation of the forests. The successive part provides instead the necessary know-how on plant nursery and plantation that is needed to successfully realize reforestation plans at community level.

The aquaculture part of the manual covers four main production options that can be chosen depending on the local environmental conditions and ecosystems: shrimp farming, crab farming, seaweed, and shellfish culture. The objective is to provide adequate knowledge on the possible farming opportunities in order to improve the socio-economic well-being of local communities and reduce the pressure from unsustainable farming/harvesting practices that have been the major causes of the past forest degradation.

Examples of good aquaculture practices as well as technical information on water management and animal/plant husbandry can help the readers to develop their own farming strategies on a level of sustainability and cost effectiveness.

The success of mangrove restoration plans as well as mangrove friendly aquaculture depends on how well the development programs from central governments are people-oriented and environment-focused. Missing one of these two components would bring to short terms sustainability results. On this regard it is important to develop ecosystem approaches that are community based, since they can give better impact on the sustainable use of natural resources through participatory programs.

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Abbreviations/symbols

ANR	Assisted natural regeneration
BW	Body weight
DO	Dissolved oxygen
DoF	Department of Fisheries
EAAM	Ecosystem approach to aquaculture management
EAFM	Ecosystem approach to fishery management
EIA	Environmental impact assessment
MFA	Mangrove friendly aquaculture
MSL	Mean sea level
MT	metric ton
NGO	Non-governmental organization
NH_3	Ammonia
NO_3	Nitrate
P_2O_5	Phosphorus pentoxide
pH	level of acidity or alkalinity of the water, soil
PL	Post larvae
PPT	Part per thousands
SOP	Standard operating procedure
TSP	Triple super phosphate
TVET	Technical vocational education and training

Glossary

Accumulation	Gradual inclusion in the body of chemicals, such as pesticides
Aerobic	A state of presence of oxygen
Ammonia	Compound of nitrogen, present in fertilizers but also excreted by fish
Anaerobic	A state of absence of oxygen
Anoxic	Anaerobic
Autotrophic	An organism capable to produce its own food by using light and inorganic elements.
Berm	A level strip of ground at the top of a slope.
Bioturbation	Disturbance of sediment materials by living organisms
Buffer zone	An area of land designated for environmental protection
Carnivorous	Animal feeding on other animals
Carrying capacity	The number of living organisms that a pond or water body can support without environmental degradation
Cyanobacteria	A type of bacteria that is capable of photosynthesis
Herbivorous	Animal feeding on grasses
Heterotrophic	An organism not able to produce its own food but needs to procure it from other organisms
Evapotranspiration	Is the sum of evaporation from soil land, water surface and plant transpiration to the atmosphere
Extractive aquaculture	Aquaculture with species able to use nutrients or wastes from water
Fingerling	Juvenile stage of an aquatic animal measuring 2-3 inches in length
Fry	Juvenile stage of an aquatic animal soon after hatching
Macrophyte	An aquatic plant growing in or near water bodies.
Market-size	Desired weight/size by market customers
Morbidity	The proportion of sickness of a certain disease
Moulting	The cast off or shed skin of an animal’s exoskeleton
Nitrate	Oxidized form of nitrogen
Oligotrophic	Environment that offers very low levels of nutrients
Omnivorous	An animal feeding on any source of food
Osmotic pressure	Hydraulic pressure created by the presence of salts
Persistence	The lifetime of a chemical compound before being degraded
Phytoplankton	Microscopic marine algae
Plankton	The sum of microscopic organisms, such as microalgae or phytoplankton, microscopic animals or zooplankton, present in the water that constitutes the base for the nutrition for planktivorous fish.
Planktivorous	Animal feeding on plankton

Pneumatophores	Aerial roots of mangroves
Primary productivity	Production of organic compounds by photosynthetic organisms
Pristine	Uncontaminated
Propargule	A plant material that functions in propagating an organism
Recruitment	The increase in a natural population
Resilience	The ability of an organism to recover quickly after a stress
Spat	The spawn of the shellfish
Stilt root	A root that arises from the lower part of the trunk of the tree and runs obliquely to the ground
Tidal flow	Water current caused by the tides
Trap and hold	A system of capturing aquatic animals in a contained water body for farming purposes without releasing them out
Vivipary	Germination that occurs when the seed or embryo is still attached to the parent
Wilding	A wild plant
Zonation	The distribution of plants or animals in particular zones responding on specific ecosystem characteristics
Zooplankton	Small or microscopic heterotrophic organisms that drift with water currents

1. Introduction

Mangroves are shrubs and trees that grow in tropical and subtropical regions, in intertidal zones along the coasts and estuaries, where saline water meets the shores. These plants grow in areas above the mean sea level where the land is clear from tidal water for not less than 70%. The adaptation to saltwater lets these plants grow green belts between the marine and freshwater ecosystems. These forests provide at least US$1.6 billion each year in ecosystem services (IUCN, 2010).

Mangroves forests are one of the most endangered tropical ecosystems. In the world approximately 35% of mangrove forests have been already disappeared, although numbers raise up to 50-80% in South and Southeast Asia, with at least 16% of endangered species as effect of deforestation (IUCN, 2010; WWF 2019).

Many are the threats that mangroves face worldwide, the first and most common is their clearing due to their valueless outlook, which justifies the shift from forest land towards agriculture, aquaculture, salt production, industry (mining, oil, manufacture), and construction of infrastructures (roads, dikes, tourism). This freedom to act is often justified by the fact that in most of the cases there is not a clear knowledge and economic awareness of the ecosystem services that the mangroves procure nor interest to account for the environmental damages procured by human activities.

In rural and coastal areas another hazard comes from logging and overharvesting. In many countries wood and charcoal still represent the main sources of fuel for cooking and heating. However the increasing population and the high need for energy put unsustainable pressure on these resources, particularly worsened by the severe overexploitation carried out by marginal people who try to get a living out of them.

Besides, natural changes can affect the tree population due to coastal erosion and the negative effects on the filtering capacity of plants caused by suspended sediments, or the changes in the water outflow from rivers as a consequence of dams' closures or droughts, which bring up salinity to uncomfortable limits for the plants. In this climate change plays an important role due to the rising sea levels, or disruption in the optimal low/high salinity ranges of the sea operated by changing rain patterns.

Destruction of submersed habitats such as coral reefs is another important effect of climate change, particularly impacting through acidification of sea/ocean waters as a consequence of carbon dioxide dissolved into the water. Lack of reefs lets stronger waves and faster currents hit the coastline and can dramatically decrease the settle and rooting of young plants due to the re-suspension of the sediments.

More direct impact from human activities are also overfishing with its negative effect on the whole mangrove ecosystem and biodiversity. Moreover pollution plays a significant role in the disruption of mangrove ecosystems by creating toxic conditions to both animals and plants, such as the effects of oil spillage on the smothering of plant roots that bring plants to suffocation.

Mangroves forests are fundamental, they protect coastal communities from extreme weather events, storms, erosion and tsunamis. The rich ecosystem created by the roots and the organic detritus supplied by the plants creates the ideal conditions for the reproduction of aquatic animals and supports other components of the inshore marine habitats, such as seagrass beds and coral reefs. Furthermore the contribution of mangroves is also given by the carbon sequestration, operated by the photosynthesis and the mobilization of organic nutrients upwards the whole food chain constituted by organism chopping, degrading and feeding on detritus, lower carnivorous (small aquatic animals) to end up with bigger carnivorous fish, mammals and humans

The present manual seeks to build knowledge on the sustainable management of mangroves, and conservation of biodiversity by providing useful references on codes of conducts of mangrove areas, as well as technical inputs concerning the forest and aquaculture management with a broad range of management options.

1.1 importance of mangroves

A great deal of ecosystem services are provided by mangroves. Ecosystem services greatly contribute to the human wellbeing and livelihood in many ways: supply of fuel either as wood or charcoal, protection against floods and erosion, prevention of salt water intrusion, procurement of optimal habitats for wild animals, support of animal and vegetal biodiversity, sink of nutrients from eutrophic water, depuration of air, carbon sink and oxygenation. In addition to all these ecosystem related benefits additional societal characteristics are also considered, such as aesthetic and recreational values.

In many cases the above values have never been accounted, firstly because of their characteristics of being accessible to everyone, and secondly for the constant availability of their benefits by any users. Being public goods there has never been any incentive by local communities or administrations to estimate their values. This eventually brought to severe cost-benefit underestimations for every decision to be taken in terms of land use (agriculture, livestock, industry, infrastructures) and environmental conservation (Brander et al., 2012).

Table 1 Benefits from mangrove forests

Direct benefits	**Indirect benefits**
• Availability of timber for construction, shipyard, fishery/aquaculture structures • firewood, charcoal Not timber forest products such as • Honey • Sweetmeats (propargules) • Vegetables (fruits, leaves) • Sap (nipa palm) - sugary syrup, alcohol • Salt production • Animal fodder • Raw materials for constructions, crafts • Non-mangrove plants for the industry • Tannins, Dye • Habitat for herbal plants • Seaweed Animals such as • Aquatic animals (fish, crustacean, shellfish) • Brine shrimp (*Artemia salina*) • Other animal farming	• Spawning ground for fish, shrimp and crabs • Biodiversity • Protection against storms, waves • Reduction of coastal erosion and siltation • Prevention of salt water intrusion into freshwater areas • Carbon sink against global warming • Nutrient sink of eutrophic waters • Support of food chain • Ecotourism and recreational activities • Research and education

1.2 impact of aquaculture and agriculture on mangroves

In many areas of the world mangrove forest destruction is strictly linked with pond construction for aquaculture. However in many cases the expected aquaculture improvement has not produced the expected outcomes due to the characteristics of the highly acidic soil rich in sulphate in certain areas, which is eventually not suitable for aquatic animal farming.

The clearing of large areas and the lack of proper management create problems of erosion that affect the ecosystems: increased turbidity and suspended solids reduce the production of plankton due to the difficulty of the light to penetrate in the water column to promote photosynthesis; the suspended soil particles also increase the risk of pond siltation or accumulation on the surfaces of the mangroves' roots bringing to reduced uptake of air.

The direct effect of aquaculture is also seen in the deterioration of the water quality, particularly where there is no wastewater treatment to control the discharge of organic wastes from animals or chemical products. Sterilizing agents, pesticides and antibiotics are more likely to be used in intensive systems and their release creates problems of toxicity to wild animals. Likewise pond harvest can increase sediment loads in the effluents.

At ecosystem level one of the major impacts affecting the local habitats is the progressive disappearance of native/wild species. In traditional trap and hold systems farmers relied on the natural stocking of ponds with shrimp post larvae and fish fry trapped during the tidal inflows, the incoming stream of water was in fact sufficient to capture enough juveniles for the farming season. However the progressive intensification of the operations has increasingly pushed farmers to collect any juveniles along the shores, which has depressed wild stocks by preventing any immature fish to reach their age of reproduction. Although in many places this practice is banned, there are still such catches of juveniles, or the long-term effects on the limited recruitment of fish.

The depression of the recruitment has been facilitate by the lack of those precious organic nutrients that used to be released by plants into the water. On the contrary the increased uses of pesticides from intensive agriculture in nearby lands have indiscriminately created voids in wild animals.

Recruitment problems have been overridden in many cases by the progressive industrialization of the production that targeted the use of juveniles from hatcheries. However in many cases the native species were substituted by exotic and more profitable ones, which have brought genetic contamination of the local habitats and, in some cases, facilitated the diffusion of diseases in uncontaminated areas due to lack of control and biosecurity procedures.

2. Code of practice for sustainable management of mangroves

Since 1995 FAO started to implement the Code of Conduct of responsible fisheries, which contains a set of principles and standards for the voluntary compliance of the fisheries and aquaculture sectors with reference to responsible practices, conservation and management of living aquatic resources. The chapters 9 and 10 (Annex 1) in particular contain important guidelines specific for aquaculture involving: the sensitive use of aquatic genetic resources with particular focus on native species, farmed species, biosecurity, and endangered species; responsible aquaculture productions involving the improvement of farming systems, participatory approaches of communities, waste management, regulations on use of chemicals and biosafety; national aquaculture plans with reference to the Environmental Impact Assessment (EIA), livelihood, governance, the coordination at transboundary levels, and governance.

Since the year 2000 there has been a focus on the development of principles, guidelines, and best practices for responsible aquaculture in mangrove ecosystems. An example is the Code of Practices for Sustainable Use of Mangrove Ecosystems for Aquaculture in Southeast Asia (Annex 2) implemented by SEAFDEC (Bagarinao and Primavera, 2005).

The code consists in 22 articles covering different aspects of the management of such aquatic ecosystems, more in particular:

1. Recognize that mangroves provide key services and goods, which are not properly accounted, and play an important role in supporting livelihoods.
2. Protect and conserve mangroves to maintain ecological services, goods and livelihoods.
3. Improve governance and sustainable use by rationalizing policies and laws to balance mangrove conservation and other uses, and to guarantee coordination between different government agencies
4. Integration of mangrove with other productive sectors (aquaculture) in specific zones and by taking into account proper planning based on monitoring systems
5. Carry out periodic classification of mangrove areas in terms of ecological quality and present use. Classification under the following criteria:

Ecological quality	Present use and status	Recommended disposition
• Excellent	not yet used, pristine	full protection, non-use, 'no touch'
• Good	slightly	used conservation, sustainable use
• Poor	fully converted	damaged optimum use, rehabilitation

6. Maintain buffer zones of mangroves between land and water by also securing them with law updates. Secure the compliance of aquaculture farms with the maintenance of buffer zones.
7. Locate aquaculture farms outside pristine mangrove ecosystems, coral reefs and seagrass beds. Avoid lands with peat soils or potential acid sulphate that are not suitable for aquaculture. Forbid/minimize large-scale aquaculture in protected environments.
8. Forbid the conversion of pristine mangrove ecosystems into shrimp aquaculture farms and other uses
9. Environmental impact assessment (EIA) requirement for large scale farms in mangrove areas
10. Promote non-destructive and sustainable small-scale integrated mangrove-aquaculture systems that are beneficial to fishing communities.
11. Make available to farmers appropriate technologies and information on the best management practices for different aquaculture systems in mangrove areas
12. States should ensure that aquaculture farmers adopt codes of practice. State should also help farmers to adopt more sustainable farming practices and technologies to comply with the codes of practice.
13. Establish a system of appropriate licenses, permits, and fees for use of land and water, penalties for violations of aquaculture regulations, and other incentives and disincentives to ensure that farms use mangrove-friendly technologies
14. Ensure the optimum production of fish, crustaceans, molluscs, or seaweeds in mangrove areas. No uses of aquaculture lands in mangrove areas for scopes different from aquaculture, penalties with loss of licenses.
15. Establish land and water quality criteria for aquaculture
16. Prevent pollution, disease contamination, and hydrological alterations in mangrove ecosystems by means of appropriate water management and effluent treatment. No impact is allowed in waterways.
17. Strictly regulate the introduction of exotic species for aquaculture to avoid genetic pollution
18. Regulate or prevent the collection from mangrove areas of broodstock for hatcheries, larvae and juveniles for grow-out farms, and juvenile fish and other feedstuff for farmed fishes and crustaceans
19. Promote the rehabilitation of abandoned fish and shrimp ponds back to mangroves with the support and cooperation of local communities

20. Consider product labelling and certification for mangrove-friendly aquaculture and fishery products.
21. Support research, training, and education about mangroves and mangrove friendly aquaculture.
22. Establish mechanisms for conflict resolution among the various stakeholders in mangrove areas, including compensation schemes

3. Mangrove management

Mangrove ecosystems are fundamental for the maintenance of ecological services and to prevent climate change related effects. In general it is more effective to prevent mangroves from being destroyed rather than restore them since ecosystem functions can be maintained without interruptions.

Planting mangroves is extensively done by many, but expected objectives are far from being reached. Planting seedlings does not necessarily bring back mangrove forests because many factors stand behind the successful Ecological Mangrove Restoration approach that encompass ecology, hydrology, sociology, economics and multiple stakeholder involvement:

Enabling biophysical conditions – namely water quality, soil, sediments, use of best species adapted to local environments, natural densities and positioning, growth and mortality rate. Eventually unsettled mangrove forests do not bring back the desired ecosystem services nor any socio-economic benefits to local communities.

Enabling socio-economic conditions - The success of restoration plans is largely sustained by favourable socio-economic conditions. Lack of participatory approaches or conflicts on livelihoods opportunities that do not match conservation objectives (e.g. illegal logging for fuel wood/charcoal, clearance for agriculture or aquaculture lands) are common causes of failure. Where possible, economic alternatives should be scoped and opportunities from restored ecosystem services should be targeted. Land ownership or use rights need to be reinstated as well as the possibility to find co-management agreements to secure the sustainable recovery and management of forests.

Table 2 Successful restoration conditions

Successful mangrove restoration

• Planting different species of mangroves improves resilience in the forest/buffer zones
• Planting suitable species for the local conditions guarantees for higher survival rate, growth rate
• Planting in suitable areas:
    • not submerged in water for too much time
    • not too far from the intertidal range
    • not too exposed to water erosion or waves
    • suitable water quality
    • adequate type of soils
• Planting away from water streams to let water and sediments move
• Planting where there is adequate water flow
• Plant away from areas where mangroves grow naturally to avoid any disruption of natural regeneration
• Plant away from areas not previously covered by mangroves to avoid damages to particular habitats such as intertidal mudflats, seagrass beds, sandy beaches

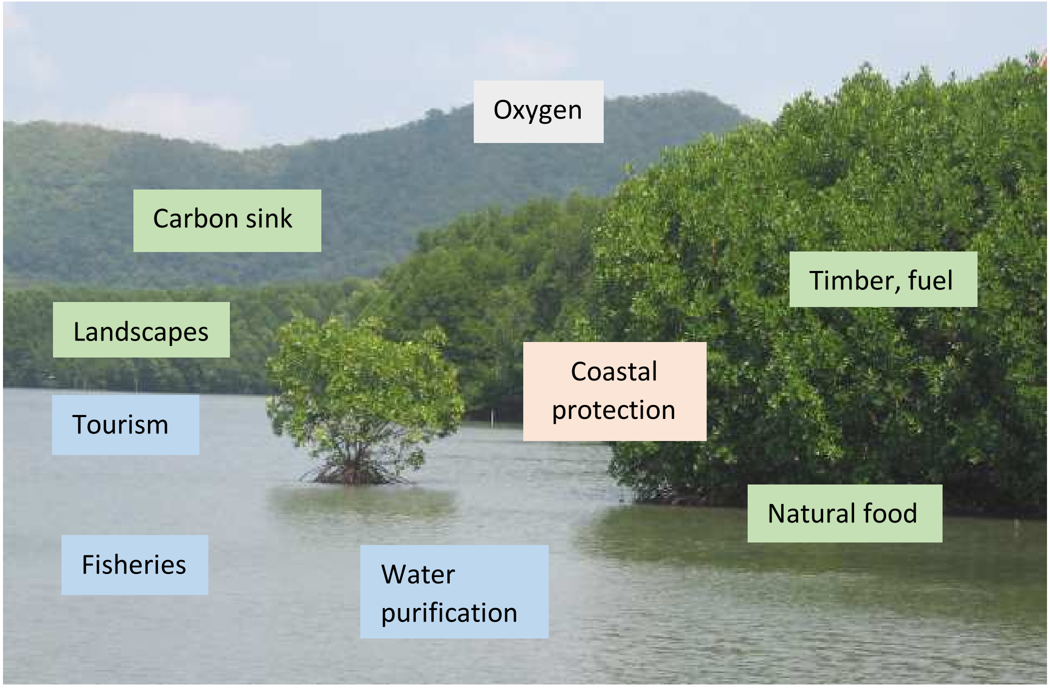

Fig. 01 Ecosystem benefits from mangroves

3.1 Mangrove ecology

Environmental conditions

Mangroves are mainly located in the equatorial and tropical zones, partly subtropical dry zones of the deserts and partly in warm temperate areas with mild winters.

Salinity is strictly variable and depends on the occurrence of rain during the monsoon season. During rainy season in fact water permeates the soil above the saline water tables and pushes down the salts from the root level. On the contrary the presence of dry conditions, particularly during droughts and sunny summers, favours the accumulation of salts in the upper layers of the soil that need to be washed away by tides to avoid hypersaline and crusty conditions that are negative to plants.

However the high tolerance to salinity is derived from the capacity of these plants to separate incoming water from salt that should be successively removed by tidal flows or rains to avoid accumulation. Excessive evapotranspiration and reduced rainfall would in fact increase the accumulation of salt on the soil and the formation of crusts.

Growth is always linked to the availability of water, and fastest shoots' elongation is always seen during the rainy seasons. In favourable sites the growth is observed all year round, while shoot die-back is seen in drought-prone areas during intense heat in summer seasons.

Temperatures in equatorial zones are not a critical factor, but intense evapotranspiration caused by high temperatures and sunlight bring plants to water stress and to the creation of saline crusts on the soil surface, which are dangerous for the plants.

Presence of wind and storms in general reduces the canopy and the size of the trees. Taller mangroves are more likely found in environments protected from extreme weathers. Nevertheless the presence of mangrove belts along the coasts is very effective to reduce the impact of waves and storms, as well as the effect of tidal flooding.

Turbidity is also an important factor linked with water speed. The faster the water flow the more soil particles are transported. This has a series of implications for the mangrove ecosystem due to siltation, since accumulation of suspended soil can create disturbance in the breathing roots (pneumatophores) that could get clogged by mud particles.

The mangrove habitat is characterized by an intense dynamicity. Optimal growth is in fact attained with the alternated presence of freshwater and tidal flows. For these reasons the optimal locations for mangroves are along shorelines and water streams. In addition, the continuous readjustments of sediments create the conditions for each type of mangrove to settle in their ideal location for both depth, stream and salinity, providing that silt deposition does not affect the roots respiration.

In mangrove areas one of the key determinants for the establishment of agriculture and aquaculture is the acidity of the soil. In many areas where mangroves grow the soil results rich in organic matter and iron, but the combination of sulphate from seawater and the oxidation from the air, due to excavation, decreased water level, makes the soil prone to acid sulphating, which brings the acidity down to pH 3 and makes farming economically unsustainable due to the large amount of lime needed to correct the soil acidity.

The movement of water through tides is also important to bring in and out nutrients needed to either plants or living organisms. Dissolved oxygen is carried with incoming water and is used by the roots and living organisms. At the same time water removes the accumulation of salts, carbon dioxide and sulphur from the soil. Therefore the frequency of tides and freshwater flow is important to keep the levels of salinity within optimal ranges.

It is worth to note that not all mangroves have the same tolerance to salt: while some do not settle with freshwater conditions the vast majority thrive for soil salinity reaching the same levels of the sea (35 ppt). Above this level plants become progressively stunted due to the difficulties to take up nutrients from too saline water, which is caused by the osmotic pressure.

This diverse adaptation to salinity by different species is one of the characteristics of the zonation, which determines a typical sequence of species from the shore to the inland areas. In mangrove restoration or management the knowledge of salinity ranges, soil characteristics, elevation/depths, tidal flooding and drainage are important to determine the settlement or displacement of species growing under changing conditions. Flooding is also important for the dispersal of the propagules.

3.2 Zonation

Mangrove species distribution depends on the perfect matching of the optimal growth needs of each species with the physical characteristics of a given site: tidal elevation and flooding regime, salinity ranges across the seasons, soil, freshwater supply and rainfall, hydrology etc.

The distribution of the different species may vary in elevation according to the tidal level, and to the position along the river depending on the influence of the water salinity. Downstream locations in the estuaries has level of salinity closer to the sea during the dry season with brackish water conditions during the rainy periods. Locations upstream are more likely brackish in dry season and slightly saline in the rainy season.

Mangroves in the Southeast Asia are naturally following a natural pattern constituted by a zone of frontliner plants that are more resistant to waves and to deeper flooding, such as *Avicennia marina* and/or *Sonneratia alba* followed by *Rhizophora stylosa* and *R. apiculata* in the back.

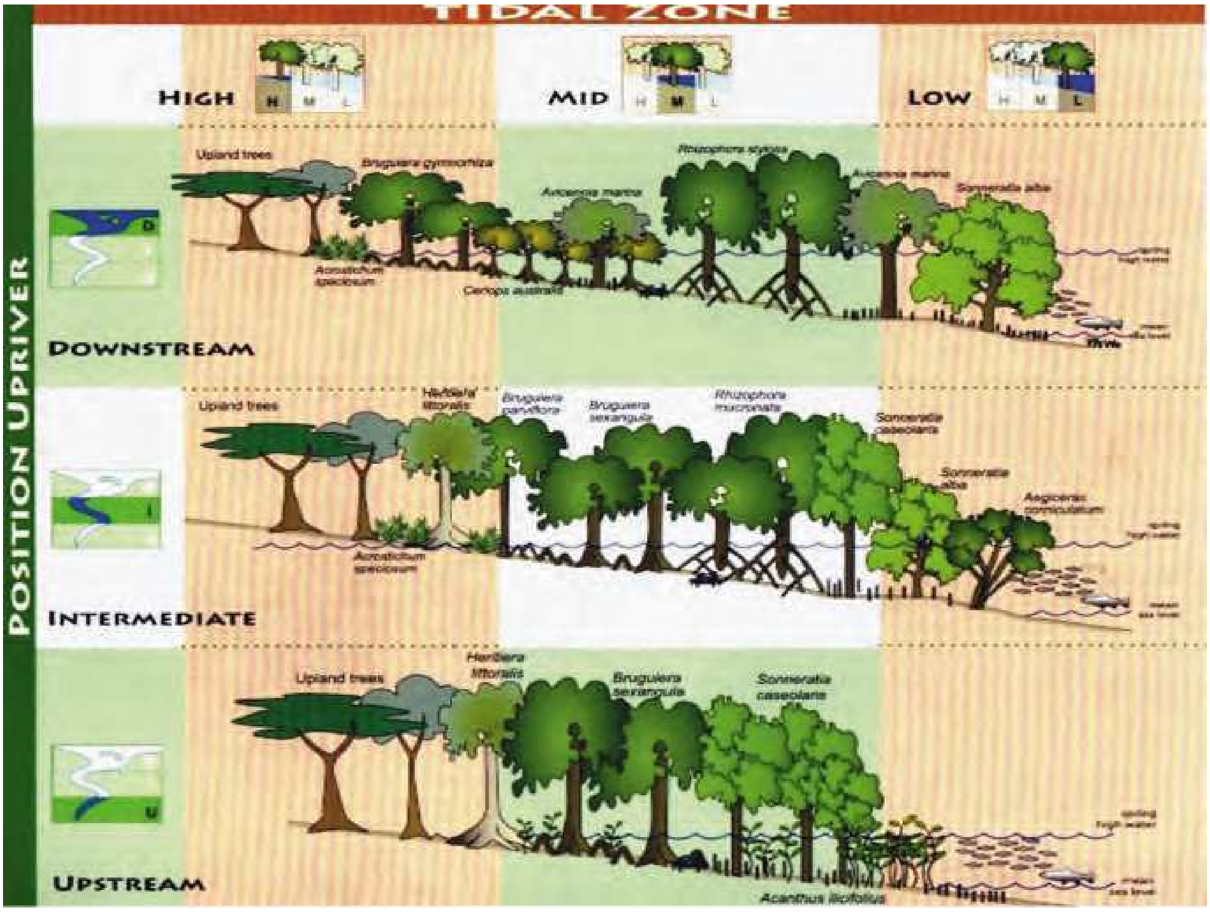

Fig.02 Location of mangroves according to tidal zone and estuarine location (Duke, 2006 - modified)

Table 03 Site characteristics of common mangrove species with local names (Duke, 2006)

Species	**Intertidal zone**	**Estuarine position**	**Salinity**	**Substrate**	**remarks**
Avicennia marina	Lower	Downstream	Wide range	Varied	Front liner
Avicennia alba	Lower	Mid- to downstream	Full salinity	Sandy muddy	Front liner
Sonneratia alba	Lower	Downstream	Full salinity	Sandy muddy	Front liner
Rhizophora stylosa	Lower	Downstream	Full salinity	Sandy	Behind A*. marina-S. alba*
Rhizophora apiculata	Lower	Downstream	Full to brackish	Sandy to muddy	Behind *A. marina-S. alba* zone, along riverbanks, other sheltered sites, e.g., lagoons
Rhizophora mucronata	Lower to middle	Mid- to downstream	Brackish	Muddy	Along tidal creeks and rivers
Bruguiera cylindrica	Middle to upper	Midstream	Brackish	Muddy	Often found along tidal creeks
Ceriops decandra	Middle	Midstream	Brackish	Muddy	Colonizer, invades grassland

A. rumphiana	Middle	Midstream to upstream	Brackish	Muddy	Often landward
A. officinalis	Middle	Midstream to upstream	Brackish	Muddy	Often landward
Xylocarpus granatum, X. moluccensis	Middle to upper	Midstream	Brackish	Muddy	Dioecious, leaves turn brown, orange, red then fall
Heritiera littoralis	Upper	Midstream to upstream	Brackish to fresh	Muddy-clay	Landward, rarely near the sea

3.3 Main mangrove species

Mangroves are plants particularly adapted to waterlogged conditions. The main characteristics is the presence of breathing roots that allow plants to get the required oxygen for the respiration of the roots, particularly in soils where the amount of oxygen is limited if not absent. Air intake is guaranteed by modified roots called pneumatophores, which raise from the ground and have pores for the air to enter. Their shapes are variable, from pencil-like shape for *Avicennia marina*, to conical ones for *Sonneratia alba* or stilt roots for *Rhizophora* spp. Stilt roots in particular diverge from stems and branches and enter the soil further away, these also help the plants to have some stability.

Another characteristic that makes mangroves different from the other plants is their different way to reproduce, vivipary. Seeds in fact germinate and develop in juvenile plants when they are still attached to the trees. These seedlings are called propargules and are already able to carry out photosynthesis while they get the necessary water and nutrients from the parent trees. While detaching the propargules have some buoyant capacity that helps them to stay afloat to colonize other areas and eventually settle away with the help of roots that penetrate the soil.

3.3.1 Avicennia marina

A. marina or grey mangrove belongs to the family Avicenniaceae*.* It is an evergreen plant 2 to 10 m (8-25 ft) tall in shape of shrubs or trees. It has pencil-shaped pneumatophores. The leaves have special glands to eliminate excess of salt in the lower side. Flowers are small, sized up to 0.5 cm (0.2 inches) and fruits are round, heart shaped. Leaves are used as good fodder by livestock, particularly in rainy season when the level of salt is lower.

Fig.03 *Avicennia marina* (Selvam, 2007)

A. marina is highly tolerant to a wide range of salinity in both water and soil. Its preferred soil is clayish and alluvial, but can thrive in sandy and rocky soils. The plant is also tolerant to salinity.

Propagules appear like normal seeds that can stay afloat and disseminate once they reach maturity and fall from the plant, however the plant is viviparous. Propagules can be also collected from plants and be soaked in brakishwater to peel the outer layer off. Once naked the propagules are planted with the small root side pushed gently to the soil. The plant is then transplanted when reaches a height of at least 30 cm (12 inches).

3.3.2 Rhizophora apiculata

Rhizophora apiculata belongs to the large family of Rhizophoraceae. It is a branched evergreen plant that can grow up to 20 mt (80 ft), although its average height is 6-10 mt (24-40 ft). It is characterized by numerous stilt roots that leave the main stems and branches down to the soil to provide aeration and support. The green-brown viviparous propagules are 25-30 cm long (10-12 inches) and buoyant.

The wood is less durable than other mangroves but used for poles.

The plant prefers deep soft mud but could grow in sandy soils. It can easily propagate by propagules that can be collected from the ground, water or directly from the tree. Mature propagules have a red collar in the cotyledon.

Presence of holes created by borer insect should be checked in propagules collected from the ground as they may be damaged. Collected propagules can be kept in buckets for few days but it is important to periodically submerge the whole seedling to avoid drying up. Propagules can be transplanted directly in the soil by one third of their length. Nursed seedlings could be transplanted instead when they have at least 4 leaves.

3.3.3 Rhizophora mucronata

A evergreen plant similar to *R. apiculate* that can achieve taller sizes up to 25-30 m (100-120 ft).

The plant has numerous stilt roots protruding from the stem and branches like all the plants belonging to the same family Rhizophoraceae. The plant has much longer floating propagules than R. apiculata that can reach 40-70 cm (16-28 inches) in length and 2-2.5 cm (0.8-1 inch) in width.

The wood in not resistant like other plants but is used for poles. The bark is used to obtain a very thick dying material.

The plant grows in mud but also in sandy/stoned soils. With high salinity the plant assumes a more prostate conformation. Propagules can be planted directly in soil by 1/3 of their length, those with not external rooting can be nursed.

Fig.04 *Rhizophora mucronata* (Selvam, 2007)

Fig.05 *Rhizophora apiculata* (Selvam, 2007)

3.3.4 Sonneratia sp

The species belonging to the Sonneratiaceae family *are* characterized by small-medium size plants reaching heights of 10-15 m (40-60 ft). Pneumatophores are cone-like and can be 50-90 cm (20-36 inches) tall and up to 7 cm (2.8 inch) wide with a spongy surface. The fruit is round, green.

The wood is very hard and resistant to pests to the extent that it can be used for boats. Fruits is edible, eaten raw or used to make vinegar.

The plants can be found in wetlands with decreasing salinity, but the plant can tolerate soil salinities up to marine strength. It prefers muddy, sandy and rocky soils. It prefers tides of at least 1 m (3.3 feet) of extension.

The plant is propagate by seedlings grown in nurseries. Fruits can float and outer skin can be peeled off by rotting fruits in a heap and squeezing out the seeds that should be floating to be vital. Seeds, if kept in brackish water for a few days, sink during germination to float back again after the rooted sprouts develop. Sprouted seeds can be sowed in containers. Transplant occurs when seedling reach 30-40 cm (12-16 inches) in height in six months.

Fig.06 *Sonneratia caseolaris* (Selvam, 2007)

3.3.5 Bruguiera sp.

Brugheria belongs to the family of the Rhyzophoracee. It can be either a dominant or co-dominant species thriving in brackish water conditions. The tree size is about 6-10 m (20-32 ft) but can arrive up to 30-35 m (98-115 ft).

It has breathing roots consisting in an outer layer of sponge-like structure that trap air during submersion. Propagules are variable depending on the species but on average 10-25 cm (4-10 inch) long and 0.5-2 cm (0.2-0.8 inch) wide.

Timber is hard and strong but only some species are long-lasting enough for boat building.

The plant prefers silty clay soil and high- and mid- tidal zone, optimal salinity is 8-34ppt. *Bruguiera gymnorrhiza* is also very shade tolerant and can grow under forest canopy. Propagules can be either planted directly in soil by inserting 1/3 of their length into the dirt. Seedlings are transplanted when they are 20-35 cm (8-14 inch) tall.


Fig.07 *Bruguiera cylindrica* (Selvam, 2007)


Fig.08 *Bruguiera gymnorrhiza* (Selvam, 2007)

3.3.6 *Ceriops sp.*

Ceriops sp. belong to the family Rhizophoraceae. The plant can grow up to 40 m (130 ft.) in favourable conditions, more commonly 4-15 m (13-50 ft.). It has stilt roots. Like members of the same family the floating propagules are viviparous and 25 cm (10 in) in length.

The plants prefer mid to high tidal zones with soft sandy soil. Best salinity range is 0-15 ppt but can tolerate up to 45 ppt. Propagation is made through propagules collected or harvested and inserted into the soil or grown in nursery bags to be successively transplanted when seedling reach at least 20 cm (8 in) height


Fig.09 *Ceriops tagal* (Selvam, 2007)

3.3.6 *Xylocarpus* sp.

The genus, belonging to the family of Meliaceae, gathers three closely related species *X. granatum*, *X. moluccensis* and *X. rumphii*. The plants are in shapes of shrubs or trees and can reach heights of 5-15 m (2-6 in.). The breathing roots are variably present, less developed in *X. Rumphii*, more present in *X. moluccensis*. Fruits are round, about 15 to 20 cm (6-8 in.) wide, holding 4-10 floating seeds.

The trees procure one of the most important timbers with durable wood used for shipyard or construction. Barks are used for tannins. Some medicinal uses are also known.

The plants grow in deep rich soil but also in rocky shores in the upper tidal range. Plants grows best in a sunny position, and tolerate light shade when young. Propagation is through seeds that are germinated in nurseries. Seeds are collected from mature fruits that are buoyant, only mature fruits are capable to float while immature not. Fruits are left in water until they break up and release the floating seeds that are successively collected. Germination in general occurs within 3 days up to 12 weeks, with germination rates of 60-65%. Seedlings can reach 80-120 cm (32-48 in.) in less than one year and can be transplanted thereafter.

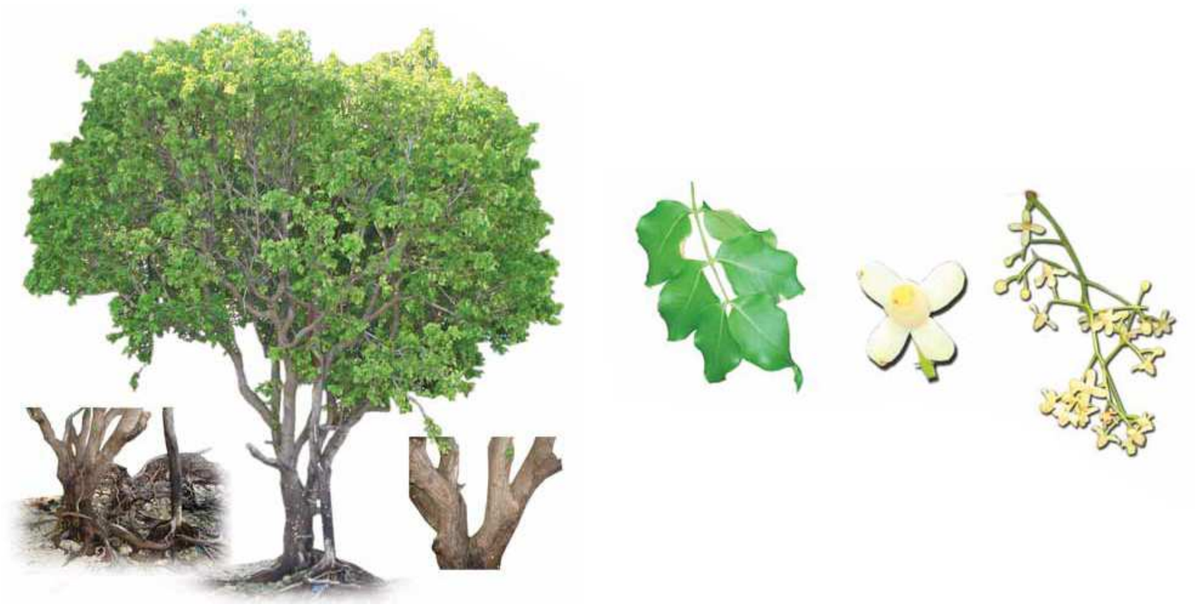

Fig.10 *Xylocarpus rumphii* (Selvam, 2007)

3.3.7 Heritiera littoralis

A branched tree belonging to the Malvacee family that can achieve heights of 30 m (100 ft.). The plant has buttress roots that have also breathing function. Fruits are large, buoyant and are dispersed by currents.

It is one of the most important timber trees for its strength, although not durable. Roots are used as a fish poison, but the active ingredients contained are also effective against boll weevil. Bark contains tannins.

The plant grows well toward the edge of mangrove belts in the upper tidal zone close to freshwater swamps. It prefers low salinity in fertile, moisture-retentive, sandy loamy soil and a sunny position. The method of propagation is through seeds that are collected from mature fruits.

Germination occurs in the fruits since germination rates of naked seeds is very poor. Germination starts after 8 days and terminates within 50 days with a 75% of success. The rate of growth is a bit slower, with 50-60 cm (20-24 in.) of height attained in 10 months.

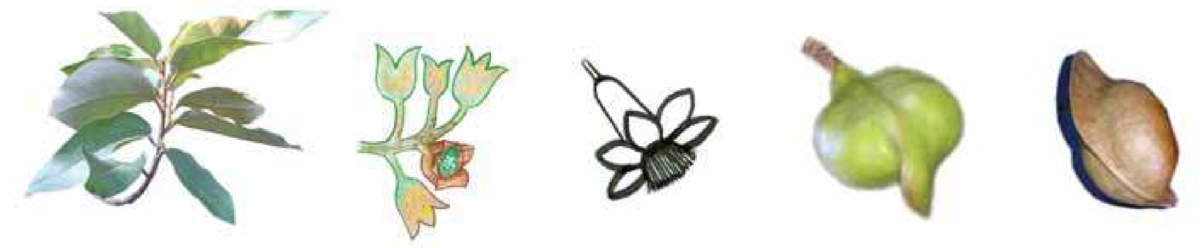

Fig.11 *Heritiera littoralis* (Selvam, 2007)

3.4 Companion plants

3.4.1 Nypa fruticans – Nypa palm

Nipa palm is a large, evergreen palm belonging to the family of Arecaceae. The palm form clumps of erected leaves that can become 6 m tall (18 ft.).

Nipa palm is a valued food and source of materials. Immature seeds can in fact give a jelly-like food, the sap of the palm is used to make syrup, sugar, alcoholic drink and vinegar. The plant is also used for traditional medicines. The leaves are used for thatching and construction material (walls, roods) as well as tools. The leaves contain also up to 10% of tannins. The palms are very useful to contain erosion along mudflats.

The plant like sunny expositions and thrive in areas with 1500-3500 mm rain annually. Germination seems to occur after fresh seeds are kept for a long period of immersion in seawater.

Fig.12 Nipa palm along the shores in company of mangroves

3.5 Restoration

The restoration aims to recover biodiversity and important ecological processes and services to degree similar at the original natural conditions.

Reforestation of mangroves should target those coastal and riverine areas at or above the mean sea level (MSL), which also includes the upper intertidal level. Upper intertidal level is the range in height between the highest tide occurring during new or full moon and the milder high tides occurring during the first or last quarter of the moon.

Locations in the lower intertidal and subtidal zones that include tidal flats and seagrass areas are indeed more available for the lack of ownerships and land conflicts, but are not suitable because their settling levels are too low from the optimal one.

Green belts made with sequences of different mangrove species suited for each depth but also beach forests with shrubs and trees such as Pandanus, Terminalia, Acacia, and Cocos, can efficiently control erosion, waves and storms and attenuate the effect of tsunamis. Earthen sea dikes protected by rock will only last 5 years, but if a green belt is established on its front it can last for 50 years (Bagarinao et al., 2005).

Fig.13 A mangrove green belt

Fig. 14 Dense root system of mangroves

Rhizophora are the favored mangrove species for reforestation, however other species like *Avicennia* or *Sonneratia* are used for the commodity to have large propagules that can be easily planted and can bypass the nursery stage. These species are well suitable for abandoned ponds, muddy tidal creeks and rivers dominated by *Rhizophora* or other plants that can withstand brackishwater conditions. Rehabilitation of ponds could restore back forests within 3-5 years with planting or assisted natural regeneration (ANR) instead of the 15-20 years required by natural regeneration, providing that natural hydrology is recovered and propagules are available.

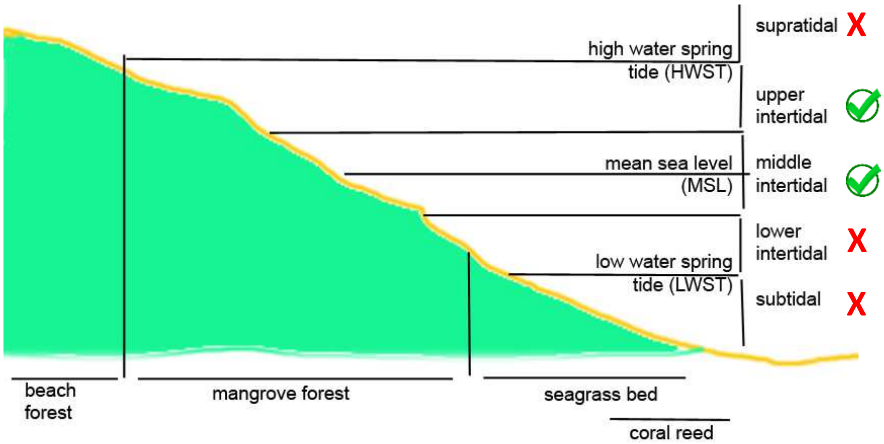

Fig. 15 Optimal location for mangroves in relation of tides and other habitats

On the other hand seafront reforestation may have some more difficulties if erosion has modified the elevation of the intertidal zone thus making less suitable areas for the plants to settle due to the prolongued flooded conditions.

Fig. 16 Effect of erosion on sea front where mangroves are absent. Reforestation may be more difficult because of the much lower level for mangroves and stronger streams (Wiafe, 2010)

Settling of propagules is limited by the high flow of the streams or waves that make it more difficult the reforestation in sea-front or riverine areas than pond regenerations. Natural areas of germination with seed or propagules reaching densities up to 300,000/ha (120,000/acre) are possible (Primavera et al, 2012) where the flood is slowed down from existing roots (pneumatophores) or artificial barriers. Larger seeds are easier to settle in seafront than small seeds that are more susceptible to be washed away by the flow before germination and rooting. When roots and leaves emerge, the small plantlets need to be protected against the waves, a type of protection that is guaranteed by pneumatophores and ponds' dikes.

Such spontaneous growth of new plantlets in favourable conditions (wildings) can be removed and transplanted nearby with limited stress. Removal of part of the wildings in highly populated grounds is acceptable, as the intense competition occurring among all these new seedlings would end up to their death. However, it is important to leave a good percentage of seedlings on the ground so that they will support natural recruitment. If wildings are big enough they can be directly transplanted in the ground, but small ones could be left growing in plant nurseries until they reach an adequate size for transplant (30-50 cm/12-20 inches), thus saving 6-12 months.

The success in the establishment of successful plantations is mainly based on the correct choice of the location based on the tidal exposition, waves, soil, and drainage. A quick reference can help practitioners to identify the correct areas for nursery and grow out is available below.

3.6 Choosing the nursery area

There are a series of criteria to consider when planning a nursery. First and most important is the location that needs to meet the following requirements:

- Use low tidal flooding to reduce the tasks of irrigating the plants
- protection against waves, particularly during bad weather.
- develop the nursery on a plain land with no slopes
- Have a partial shading from other plant canopies, but avoid the presence of pests
- develop the nursery not far from the transplanting area to avoid additional work and costs.
- have some sort of freshwater supply
- proximity to source of seed/propagules

The extension of the nursery depends on the quantity of plants: few square meters for small units, hundreds of square meters for large nurseries.

Fig.17 A plant nursery on a flat bed in a pond under daily flood. Plants are ready for transplant

A nursery is constituted by the following components:

1) a soil preparation zone for the potting mix preparation
2) a seedbed for seedlings consisting of canals for irrigation with the tidal water
3) storage area for equipment and seeding material to be used for large scale operations
4) a fence to protect the seedling against animals and flowing material
5) shading for juvenile plants, created by nets or other existing plants

3.7 Seedling collection

It is important to consider that the best time for collection is early morning and late afternoon, avoid the hottest hours of the day as the scorching sun rays can create damages to the already stressed plants. The ideal tide for collection is towards 40 cm (1.5 ft.) above the minimum level of the spring tide.

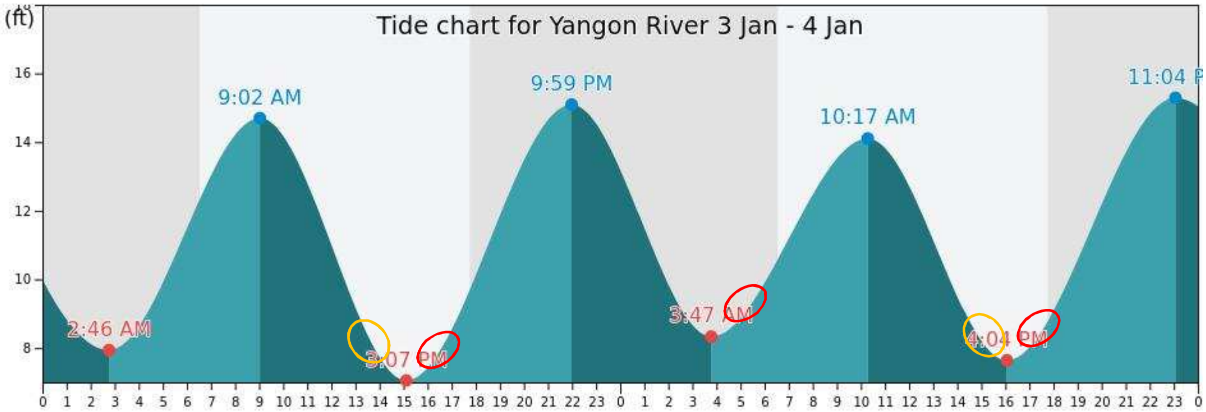

Fig. 18 Tidal chart and best tidal height to operate seedling collection/transplant, ideally early morning or late afternoon (source: https://www.tideschart.com/)

Wildings are in general positioned nearby the mother tree, as they germinate where the seeds or propargules fall. Plantlets retained by the roots of the plants are more resistant because their growth have been sustained by a holding structure and the stem has not been prone to stream damages.

Fig. 19 Wildings collection with their panicle of soil. Small plantlets are bagged and then left grown in nursery for 6-12 months until they reach 30-40 cm (12-16 inches) (Primavera, 2007)

The ideal size of the wildings is up to 40 cm (16 inches), but better size is 10-30 cm (4-12 in.) with at least 6 leaves due to its easier effort to extract plants with roots. Bigger plants are more prone to have their roots damaged by the pulling. Use a shovel or digging blade to dig the soil around the plants in order to avoid to take out a bare-root plant that is eventually going to die. Taking plants from a sandy substrate is more likely to fail due to the tendency of the sand to fall apart, thus exposing the root to air and damage.

Big wildings (up to 40 cm) can be directly transplanted on site, while small size wilding of 10-20 cm (4-8 in) should be bagged (20 x 30.5 cm) and left grown in the nursery for a period of 6-12 months until their reach a size of 30-40 cm (12-16 in.).

3.8 Seeds and Propagules collection

This task should be carried out when the fruits are ripe, which occurs 2-3 months after flowering. Fruits can be directly harvested from the plants or by collecting the newly fallen fruits on the ground that appear with no evident damages from impact or pests. Fruits containing seeds are left soaked and macerated to remove the seeds that are left germinated directly on a polybag in case of large seeds (*Avicennia*), or on a bed and then moved to a polybag in case of small seeds (*Sonneratia*). Bag size cab be 10 x 15 cm (4 x 6 inches).

During the nursery stage normal fertilization, and pest control should be observed to maintain a healthy stock for transplant. Maintenance should be done 2-3 times a week to keep the plants upright, fertilized, regularly irrigated by the tides and under an efficient pest protection, which is also done by seawater covering the plants for their length.

Nursery periods longer than 6 months need the seedling be separated by the soil below to avoid roots penetrating it, thus making it difficult the transplant. Provide always sufficient room for the roots, this also means that plants should be transplanted in bigger bags to let the root grow sufficiently for the transplant. Stunted plants due to lack of transplant handling have more difficulties to produce good plants.

3.9 Transplant of nursery seedlings

Each mangrove species is adapted to a particular tidal height that must be considered to avoid future risks of die off. Ideally the planting should be preceded by an assessment of the tide by comparing the heights to the charts and the elevation of the terrain. Good methods make use of poles positioned vertically and theodolite to determine the exact slopes, but also levels to calculate the elevations above the mean tide level, minimum or maximum.

A simple strategy is to delimit the areas during neap tides (half-moon) that is not exposed to the water and is aligned to existing pneumatophores that can give guidance to the elevation where the establishment of the plantation is more likely to succeed.

If the area is a sea-front it should be not exposed to strong waves, in this case wave breakers made of bamboo or other material creating an area where the water flow is slowed down help the plants to establish the natural seeds floating on the coastline to settle. The substrate should be firm, with the leg not sinking above the ankle and possibly plantation should be carried along with existing mangroves.


Fig. 20 Wood or bamboo fencings protect against waves and favour natural regeneration (source: vietnamnews.vn 2015 , Schmidt and Duke, 2016)

In the case of pond banks the same rules apply for the planting on the sea-front with protection against waves and firm soil. In the case of pond interior the area interested by plantations should not be waterlogged.

Planting at seafront can use bigger plants (from 50 cm/20 inches) to 1-1.5 m (3-6 ft), while smaller plants of 30-60 cm (1-2 ft.) can be used in the inner sectors. Transplanting should be done during low tide events, and time allowed for the whole operation should be about two hours.

Fig.21 Planting seedlings and securing to bamboo sticks (source: Manila bulletin, 2017)

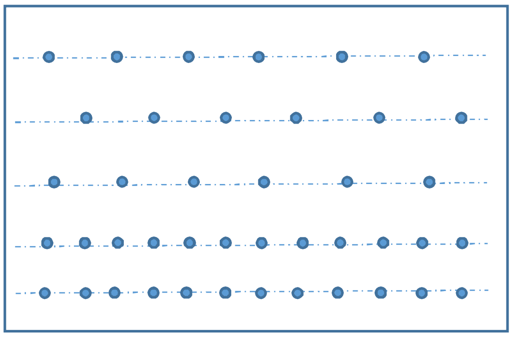

Fig.22 Planting densities between front and rear line

The spacing between plants can be 1.5-2 m (5-7 ft.) for inner lines and 0.5-1m (2-4 ft.) for front-lines where the presence of debris and waves could determine some mortalities.

For planting the procedure is as follows:

1. select the plants to be planted according to their ecological characteristics and the transplanting area
2. transport the plant carefully
3. Define with ropes parallel lines that may have same elevation
4. mark the desired distance between plants for either inner or front-line rows, but keep at least a zig-zag pattern between the rows to avoid the creation of channelization.
5. Dig a hole for each plant with a shovel
6. Remove the plant from its bag by putting lot of attention in not breaking the soil and damaging the root system
7. Put the plant in the hole, the depth should be such that the plant's soil is at the same height of the surrounding soil
8. Fill the void parts of the hole with the remaining soil and compact gently.
9. Put a bamboo stick parallel to the plant and tie it loosely. The stick will give some support and resistance against the waves and streams.
10. Collect the plastic bag and dispose properly if broken or recycle if is still intact.

While transplanting it is a good rule to check if the root goes down vertically, this indicates that once transplanted the root system will go straight downward instead of remaining at the surface, which weakens the plant stability. Also there is no need to put any fertilizer or amendment into the hole, since the presence of nutrients would discourage the plants to search for the nutrients by themselves.

In zonation the degree of flooding affects the sequence of the species under the criteria listed in the table below (Chapman, 1976 modified).

Fig. 23 Planting operations (source, Primavera et al, 2012)

Table 04 selection of plants according to the transplanting areas characteristics

Type of flooding	Salinity/flooding frequency	Type of mangroves
	10-30ppt salinity at high tide	
All high tides	1-2 times/day	*Rhizophora*
Medium/ high tides	10-19 times a month	*Avicennia*
Normal high tides	9 times a month	
Spring tides only	Only a few days/month	*Laguncularia*
	Fresh to brackishwater salinity 0-10 ppt	
Storm high tides only	More or less under tidal influence	*Salina* or *Laguncularia*

3.10 Plantation maintenance

In the first two years the plantation is more vulnerable to possible damages, therefore it is necessary to maintain the trees and help them to grow healthy.

Siltation is particularly heavy where there is constant sedimentation of the water, in this case the planning of the plantation should consider this type of variable. Taller seedling can instead be planted to avoid that the plants get suffocated by the sediments.

Filamentous algae are recurrent infestations that in particularly severe cases could clog and break the young seedlings. They should be regularly removed by means of scissors. It is important to remember that transplanting in the rainy season makes the incidence of algal blooms minimal.

Barnacle infestation can affect plants for their weight and their physical interference to respirations by the roots. Their presence is more accentuated during the youngest stages of the plants but reduces with maturity. The position of the plants also determines their number, since sea-front plants are less affected due to the waves/stream impacts or by the peeling off of the root bark, particularly present in *Sonneratia*. Rhizophora is particularly affected by barnacles nstead. If the barnacle presence is noted remove them gently by using pliers by putting attention not to damage the roots.

Presence of pest could be also relevant with some moths and beetles mostly represented. However moth larvae could be easily controlled with biological insecticides that are not harmful for fish. Use of neem oil on the young seedlings is also an antifeedant of the tender leaves and stems.

Human damages could be limited by regularly removing the garbage accumulating on the young plants, particularly fishing nets getting trapped onto the branches. Boat traffic can be prevented to access the transplanted areas that may not visible during high tide by delimiting the zones with floating buoys and long lines.

Protect the plantation by maintaining a fence in the front-line to avoid strong waves and in the back line restrict the access to herbivores animals.

Fig.24 Barnacles and other shells

Fig.25 Enteromorpha, a filamentous algae

4. Mangrove friendly shrimp aquaculture

Intensive shrimp culture has been characterized by heavy environmental deterioration due to:

- the destruction of mangrove areas to open land for aquaculture operations,
- the intense pollution caused by the massive use of chemicals and drugs,
- the eutrophication procured by loads of animal wastes,
- the deterioration of sensitive soil becoming highly acidic.

Besides, the indiscriminate harvest of shrimp larvae from the wild and the negative interaction of chemicals discharged from the agriculture side have deeply impacted the productivity of the mangrove ecosystems and to the socio-economic sustainability of the poor coastal communities because of the progressive losses of ecosystem services and livelihood.

Mangrove areas can be considered a wetland that support an important food web, but at the same time are a sink for carbon and nutrients associated with eutrophication. Communities have realized that environmental friendly management, and in particular mangroves can sensitively support the industry because of the associated benefits they bring:

- The growth and survival of farmed animals is strictly related to the quality of water and healthy environments
- There is more concern about sustainable practices and current market demand is increasingly focusing on environmental and social ethics;
- Drug-intensive farming is not appreciated by the markets

The mangrove reforestation, in parallel with the conversion of farms to more sustainable and integrated management, would help to maintain the long term productivity of the farms and reinstate existing ecosystem services and food webs to the benefit of the shrimp farms and neighbouring communities.

The presence of plants helps in fact to protect the dikes against erosion, winds and storms; operates as a natural sink for nutrients, conditions the water for aquatic animals, procure an ideal habitat for reproduction for many aquatic species.

While traditional extensive aquaculture creates very little wastes that is mainly consumed within the ponds by other organisms, the role of mangroves becomes more important with farm intensification as the natural absorption of excess of nutrients reduces the impact of farm organic pollutants consisting of uneaten feeds, faeces, dead animals, and moulting residues.

The accumulation of wastes beyond the carrying capacity of the ponds brings nutrients and soluble wastes to be discharged into the outer waters, this creates the conditions for bacteria to grow and to spread beyond farm boundaries. The use of outer water, if other neighbouring farms are farming at high intensity brings in contamination and risks of cross-infections and diseases.

More consistently the presence of wastes accumulating at the pond bottoms favours the exponential grow of micro-organism and the shift to more favourable condition for pathogens to thrive. Deterioration of water quality procures additional stress to animals that become more prone to diseases, which eventually triggers for an immediate series of events that results in the use of heavy chemicals and drugs to control the problems.

Mangrove friendly aquaculture relies on:

- Smaller densities than those observed in intensive aquaculture
- Production within the carrying capacity of the pond
- Large mangrove forest coverage (equal or above 50%) to operate as nutrient sink

- prevent degradation of the water quality
- can make use of supporting fish that help to control the vegetable litter and detritus at the bottom of the ponds

The presence of mangrove is therefore essential to support the food webs according to the following sequence:

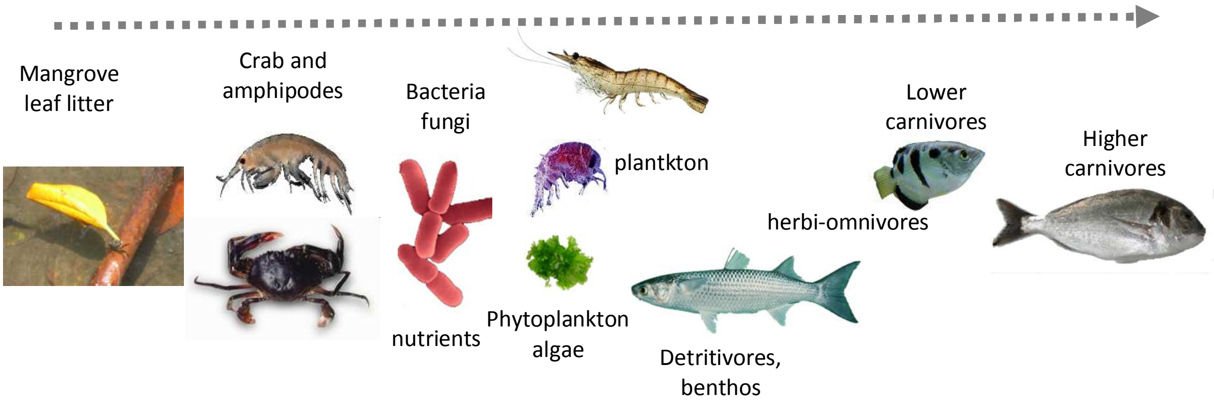

Fig.26 The food web in a mangrove ecosystem

It is however important to consider that the presence of fish species depends on the degree of intensification of the pond management:

- In extensive ponds with no supplementary feeds the presence of herbivorous fish can help to free nutrients from the mangrove leaves and litter into the water to promote plankton growth.
- in semi-intensive ponds the beneficial effect of macro-algae to control the excess of nutrients created by the feed supplied to the shrimp could be destroyed if herbivorous fish are left free to graze and are not compartmented. This grazing activity would eventually deteriorate the water.

In any case the presence of bottom feeders would help to bioturbate the sediment, mobilize organic matter and keep water cleaner. Instead the presence of carnivorous or omnivorous fishes may create problems of predation of the shrimps.

The constant water flow to compensate to the loss/increase of salinity inside the ponds favours the apprehension of nutrients from outer waters, which would benefit the farmed shrimps, however there may be the need to avoid the entrance of predatory fishes into the ponds by using excluding devices (e.g. nets).

4.1 Sustainable Farming

To achieve sustainability there are conditions to follow that consider not only the environment and production, but also the social and economic aspects of farming.

4.1.1 Maintaining and Enhancing Production

Select sites that can guarantee suitable conditions for shrimps, such as no acid-sulphate soils that become unbearable for farming of aquatic animals. However, moderately acidic soils can be mitigated with lime.

Select a site at which water and soil have not previously been contaminated by previous uses or subject to urban, industrial or agricultural drainage influence.

Plan farms with appropriate designs to allow tidal water to reach the ponds with no risk of siltation.

The farm dimension must be proportional to the available water, based on the estimated capacity of the receiving water body to dilute, transport and assimilate effluent water.

Ponds must drain completely by using proper drainage systems.

Design the farm and ponds layouts in such manner to optimize the interaction with the existing mangroves planted inside the farm. This would maximize the intake of nutrients by the plants.

Fig.27 MFA only in not acid soils

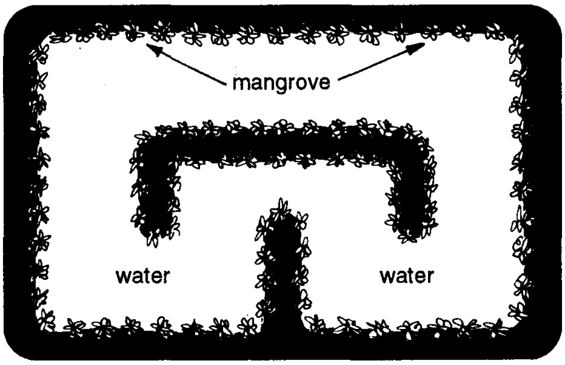

Fig.28 A pond with mangroves (source: Tanan et al, 2000)

Consider that the planting of mangroves could involve the coverage of at least 50% of the farm area. Although this may be limiting for the reduced production area, the presence of trees increases the survival rates due to better water quality, lower water temperatures and lower and moderate support of the food chain through the release of litter for decomposers and herbivorous animals present in polyculture in the ponds.

Plant the mangroves on the dikes, both externally and internally and plan the establishment of plants inside the existing pond on terrains or berms that could be built in parallel or delimit a water path to increase the contact of the plants with the outgoing water flow.

Fig.29 Mangrove growing in parallel and on berms (Macintosh, no date)

Maintain a tidal effect in extensive ponds in order to avoid stunted growth in mangroves that do not like constant water levels. Constant levels of water in ponds make in fact mangrove trees prone to small growth with reduced root systems.

Water should be of good quality with no presence of pollutants and chemical residues that could harm the survival rate of the aquatic animals farmed. Avoid the use of water with contamination from human activities.

Water coming into the farm during the water exchange periods should be allowed to settle in a treatment pond and should not be directly distributed to the ponds. The treatment of the incoming water is in fact important to reduce the risk of pond siltation, which is extensively affecting ponds worldwide. The use of sedimentation ponds would avoid the quick need to carry out maintenance in the ponds to remove the excess of sediments. The sedimentation area or sediment trap, must be calculated and incorporated into the design by an experienced technician who can estimate the water residence time to remove a significant amount of sediments.

Fig.30 Allow tidal water to fluctuate

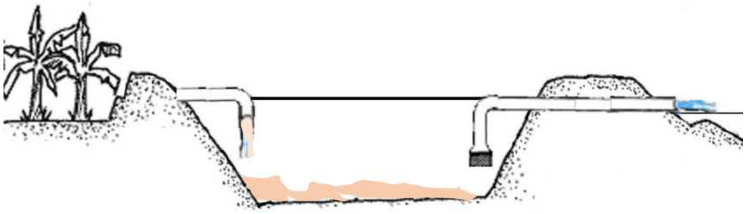

Fig. 31 Sedimentation pond to avoid siltation

Dig the ponds adequately deep to let the shrimp thrive with no negative effects from the heat during summer times. In the forecasting of climate changes it is likely that farms have to cope with higher water temperatures that would ease the diffusion of diseases if no contingent measures are taken. Increase of water depths and improvement of shading through plant canopies both outside and inside the farm/ponds is therefore advisable

Develop the ponds in such ways that animals can be easily harvested.

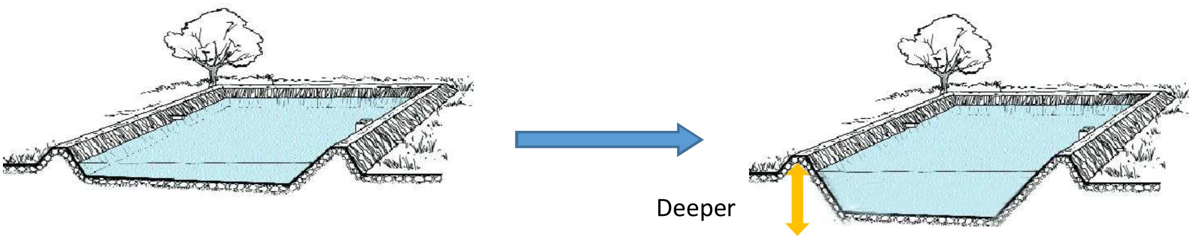

Fig.32 Deeper ponds wherever the temperatures are high and affect water quality

Avoid taking shrimp PLs from the wild to reduce the risks of overexploitation of natural recruitment, and bycatch of juvenile fish that are simply disposed with no possibility to grow and reach maturity. Source shrimp juveniles from nearby hatcheries that guarantee for disease-free larvae.

Plan the stocking of larvae in a timely manner according to tidal and weather conditions. Avoid unnecessary stress to the juveniles by reducing the transport time to the farm. Organize the shipment in coordination with other farmers to reduce the costs.

Stock the ponds according to the carrying capacity of the ponds, overstocking creates in fact accumulation of wastes at the pond bottom and thus deterioration of the water quality, and build-up of bacteria and dangerous microorganisms.

Use good quality inputs to guarantee good growth rates, link with the local Department of Aquaculture to secure reliable juveniles.

Fig.33 Avoid catching PL from the wild

Fig.34 Use good quality disease-free larvae

Source good feed inputs if the pond management is done in semi-intensive way. Keep the feed in a protected, dry and cold ambient to avoid rancidity. Bags should be elevated from the ground, ideally positioned on a pallet to facilitate the inspection. Feed should be consumed on a first in first out basis.

Provide constant water exchange during tidal events to the ponds that are managed in extensive ways in order to increase the food intake of the farmed aquatic animals.

Water coming out of the farm in the course of water exchange and during harvest should be allowed to settle in a treatment pond to avoid wastes to be contaminating the outer waters, bringing the risk of disease outbreaks.

Fig.35 Use good quality feed

Fig.36 Use good feed strategies to avoid wastes

Plan polyculture to increase the productivity of the pond with other aquatic animals occupying different food niches. Use detritivores/benthic fishes to favour bioturbation and removal of organic sediments from the bottom. Use of herbivorous fishes to favour the mobilization of nutrients from vegetable litter into the pond water.

Use of shellfish and seaweeds is also encouraged to control the suspended solids into the pond water and the peaks of nutrients that may arise with increasing stocking densities.

Fig. 37 Use shellfish to uptake suspended wastes

Fig. 38 Use seaweed to absorb nutrients

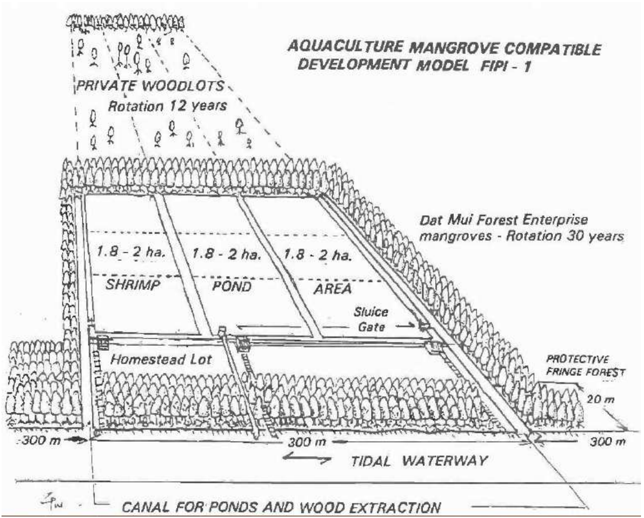

Fig. 39 A shrimp-tree farming model, plants can also be grown on berms in the pond (Source: FAO 1994)

4.1.2 Improving resilience

The setup of the farms should be in appropriate locations that are not prone to extensive flooding that would result in losses of production. Also the dikes and the farm area should be secured against storms, high waves and winds. The presence of green buffer zones of mangroves at the sea-front would increase the protection against weather elements and prevent erosion.

Fig.40 Green belt of mangrove trees protecting the sea front of the ponds

Build strong dikes that are wider and taller, this in accordance to the historical extreme events recorded, which are likely to occur with more intensity and frequency in the future.

Canals should be deep enough for the water to access during low neap tides. Canals can be accompanied by mangroves

Consider seasonal climate variations and hydrology for the design of farm structures and water channels, to avoid costly mistakes and negative effect to the environment.

Don´t locate shrimp farms in areas that have already reached their carrying capacity for aquaculture

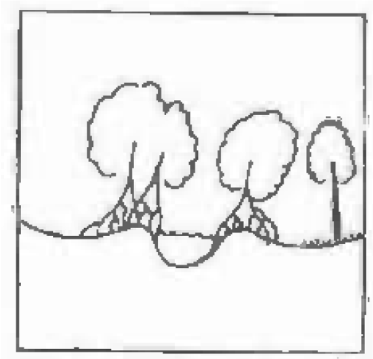

Fig.41 Build stronger/taller dikes against waves/floods Fig.42 Surround irrigation canals with trees

Improve the biosecurity by avoiding the use of uncertain seeds and animals of suspected origins. Manage your farm responsibly and avoid to take risks that can either damage your own and the neighbouring farms. Verify the origin of the larvae/broodstock and claim for a health certificate that can clear issues about diseases.

Avoid stress to aquatic animals by favouring optimal water quality and temperatures. Provide good water exchanges to the ponds depending on the levels of nutrients present and/or the salinity levels during dry/rainy seasons.

Invest in skilled operators in the farm that could improve the growth efficiency, reduce mortalities and risks of diseases by putting in practice good farming managements

Follow the Code of Practices for aquaculture and coordinate with communities to implement good aquaculture practices (GAqPs) to improve productivity and resiliency and to achieve certifiable standards required by the market.

Wastes, which also includes the residues of the moulting and dead animals should be disposed in properly manner and not be washed away outside the farm. Accumulation of organic matter from culture of fish/shrimp creates in fact the conditions for the pathogens to thrive and multiply.

Improve the sustainability and resiliency of forest ecosystems against logging by differentiating and improving the sources of livelihood in local communities. Support of off-farm alternative aquaculture productions such as seaweed and shellfish in lagoons and creeks, bee keeping, non-timber forest products should be encouraged.

Aquaculture management plans must be respected in order to balance the use of the environmental capacity in accordance with other surrounding industries

4.1.3 Protecting Natural Resource Potentials

Avoid ecologically sensitive areas where mangroves forests are located, especially where reserves are established to avoid interferences and disturbance of the habitats.

Farm construction must not impact the flora and fauna

Plan the farm and the reforestation in accordance to the government/local administration plans. Comply with the necessary regulations and benefit from incentives to support the mangrove plantations.

Shrimp farm locations must not affect the water resources of other users by producing effluents, contamination, etc. Avoid the re-use of already drained wastewater (effluents) due to their organic loads.

Fig. 43 Develop farming without affecting natural forests

Fig.44 Avoid the use of chemical contaminants

Avoid use of harmful chemicals, antibiotics and other inputs which might affect the environment. The most important management should be carried out at preventive level by avoiding the possible introduction of pathogens and pests. The second line of defence should be based on the modulation of the local environment to match the animals' needs, and/or the use of biological controls through antagonist species of the pests/pathogens.

Treat water discharged from the shrimp farms before releasing into the environment. Use multi-trophic strategies to improve the control on wastes and favour the recovery of nutrients supplied to the animals with alternative productions.

Fig.45 Treat water with shellfish

Fig.46 Seaweeds to reduce the impact of nutrients

4.1.4 Economic Viability

Develop mangrove reforestation in shrimp farm within a program of environmental restoration supported by the government, local administration, and international projects

Favour credit access to farmers through the institution of microcredit systems or revolving funds organized at community level.

Institute the creation of emergency relief funds to support farmers in case of disasters or crop failures. Funds can be either supported by international projects, government plans or developed on voluntary basis at community level to promote responsible and resilient communities.

Coordinate the resource and input procurement according to cost-effectiveness, proximity. Group with other farmers for farm operations, harvest and procurement of inputs to benefit from scale economies and price negotiation with wholesale suppliers/buyers.

Employ efficient production methods that minimize costs, increase productivity differentiate incomes with alternative productions.

Group with other farmers and develop strategies for direct marketing in order to shorten the value chain and increase the incomes

Invest in quality, also with the support of the concerned institutions (Department of Aquaculture) to improve the harvest and post-harvest management and handling of the products in compliance with the food quality standards (e.g. maintaining the cold chain, SOPs for hygiene).

Secure that farmers can have access of market prices and develop intelligence to coordinate their harvest, handling and selling strategies.

Develop market channels differentiated into local, district, regional and national levels. Favour the direct access of farmers to the markets.

Favour the access of farmers/farmers' cooperatives to international markets by liaising with certification agencies and retail chains interested in ethical products.

Promote the processing of the aquatic commodities at local level to increase the value of the products, improve employment for women, and increase income opportunities.

4.1.5 Social Acceptability

Farms should have minimal to zero impact on the environment

Comply with national regulations for land use, planning laws and coastal management plans

Farms should have minimal to zero conflict with other users of common resources. Development of EAAM/EAFM is essential to coordinate plans of development for the sustainable management of aquaculture/fisheries

Use local human resources where advanced technical skills are not required.

Seek projects, DoF, TVET, NGOs to promote local capacity building in management and technical skills in fish farming/processing.

Develop fair retributions, this would be a compliance factor with many international certification schemes that would add premium prices for social inclusiveness.

Be a good neighbour by avoiding conflicts and developing risk management strategies that can put in harm other farmers or other sector in your own community.

4.1.6 Governance sustainability

The development of mangrove friendly aquaculture (MFA) and mangrove reforestation should be coordinated among different ministries and departments that have competencies for water management, environment, aquaculture/fisheries, agriculture, and forestry. The coordination is important in order to properly plan interventions and to avoid risks of depriving large parts of the local communities of the necessary livelihood. This would allow to steer alternative solutions that can guarantee for the long term sustainability of the forests.

Proper policies should be developed in a synergic way to avoid conflicts different sectors or voids in terms of sustainable use of resources.

The community co-management should be favoured as one of the only strategies to guarantee compliance and control on the regenerated ecosystems.

Incentive schemes for replanting should be considered as part of cross-compliance: easier access to credit, discounts/waiver of aquaculture license fee or taxes redutioons for farmers compliant with ecological management, carbon credits, or penalties (e.g. increase of aquaculture license fee) for those who prefer to run aquaculture in traditional ways.

Ministries should favour the development of credit systems targeting farmers who want to comply with MFA, particularly by instituting a fund of guarantee for loans to purchase PL from hatcheries or inputs in MFA compliant farmers.

GOs, NGOs and international organizations should work to promote the creation of farmers' cooperatives and to liaise them to certification entities for the eco-labelling of their products.

Alternative livelihood strategies should be favoured to discourage poor households to access forest resources for illegal logging.

4.2 Best management practices in MFA

4.2.1 Farm layout

In sustainable aquaculture water quality and pollution are at the highest concern. Good water quality and low organic waste discharges help to avoid risks of eutrophication or pathogens proliferation. Therefore a better control of wastes and water would help to limit the risks of diseases and chemical treatments.

However integrated mangrove-shrimp aquaculture layouts need to be designed according to the degree of intensification of the production. More intensive systems need in fact higher levels water treatment to control pollutants.

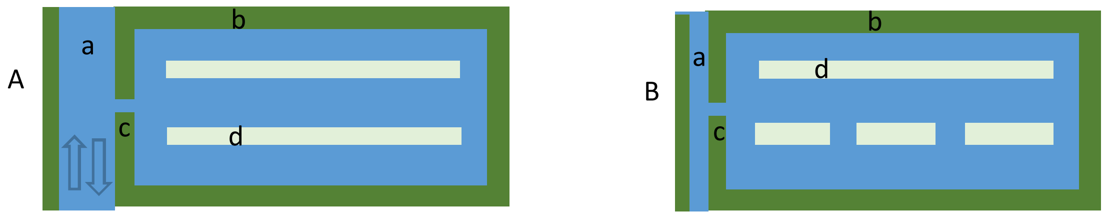

Fig.47 An extensive pond with a serving canal (a), banks covered by mangroves (b) a sluice gate (c) to let tidal water to get in/out and scattered berms (d) in the pond area (variable patterns are possible).

In traditional extensive systems incoming and outgoing water could pass through the same sluice gate, and incoming-outgoing tidal water has almost no effect to the environment due to the scarce load of organic wastes.

Berms with mangroves, as seen in figure 29, help not only to absorb nutrients, but also to sustain the food web inside the pond and to provide some shadow, which is important to keep water temperatures down. The wider canal (a) in the figure 47 in the left (A) is designed to provide sedimentation by reducing the speed of the incoming water, this would avoid the siltation of the ponds that occurs in B where the water speed in the canal (a) is too high to settle the solids before the pond.

On the other hand semi-intensive systems should have a treatment pond or canals serving for the purposes of controlling wastes from spreading outside. This could be a build-in structure inside the pond where seaweed, shellfish can be cultivated for the purpose of absorbing excess of nutrients and provide additional product to the farmers

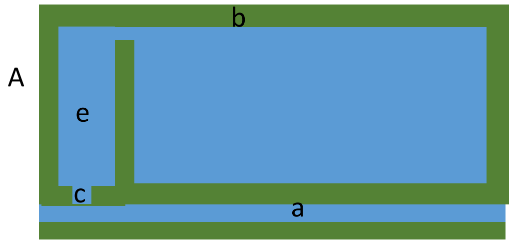

Fig.48 A semi intensive pond with a canal (a) covered by mangroves/plants serving a pond with banks covered by supratidal vegetation (b), a sluice gate (c) lets tidal water to get in/out and pass through a sedimentation-treatment pond (d)

Whenever possible, in semi-intensive systems water input and output from ponds and canals should be separated so incoming and effluent water never get mixed. Its design should include erosion controls. This type of solution can be particularly used in systems that recirculate the water within the farm. Water treatment areas could integrate for example carnivorous or detritivorous fish that consume the wastes and other small aquatic animals, while another sector of the farm can be stocked with seaweed (e.g. *Gracilaria*) to absorb nutrients.

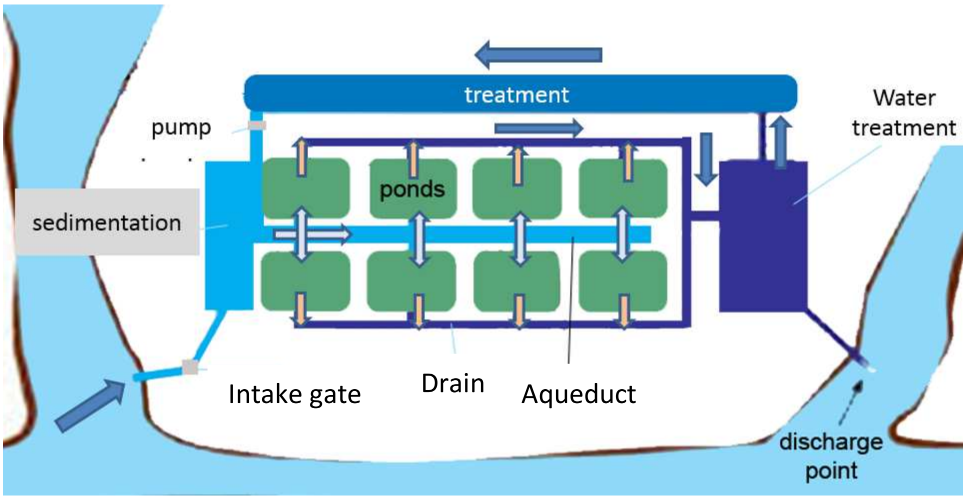

Fig.49 A more intensive farm that has separated inlet and outlet. The inlet is supplied with a sedimentation tank. The inlet and outlet of each pond is separated. The ponds' outlet water converges to a treatment pond where polyculture with macrophites, algae and carnivorous fishes can be established. Abducting and discharging canals and treatment areas are all covered by mangroves.

Given the use of seaweeds and/or shellfish it is also important to choose the correct species that are tolerant to lower salinity, particularly affecting production during the rainy season when the ponds receive large amount of rain water. In this case farmers should exchange pond water in a much larger extent and more frequently to keep the salinity within optimal levels for the farmed animals.

Effluent water discharge must be located in places where transport and effluent dispersion is maximized, and where the impact on environment and vegetation is minimized

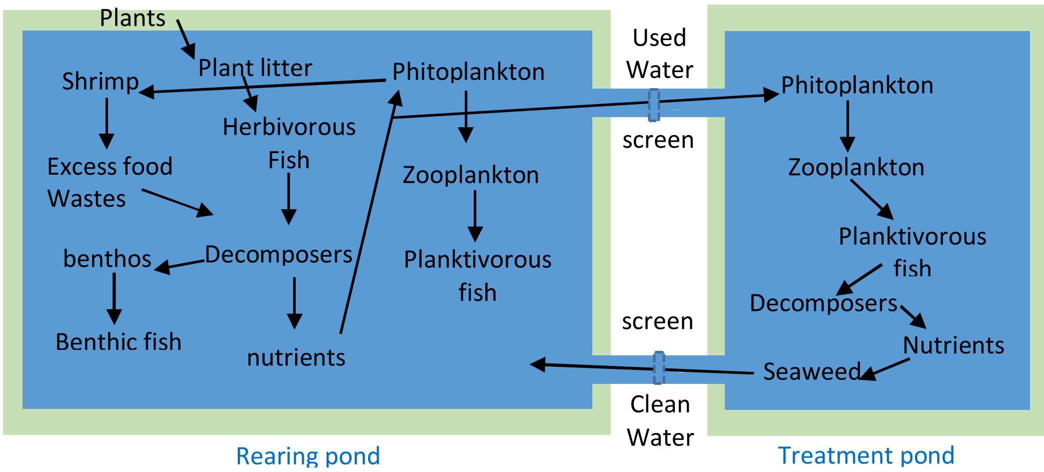

Fig.50 Water treatment cycle and food web network in an integrated shrimp-mangrove system. Screens can be optionally positioned to separate two communities of fish between rearing and treatment ponds.

Many farmers tend to kill any type of animals in their ponds, particularly fish as they do not want animals competing with their shrimp for food and space. The traditional practice uses tea seed powder or chemical products. However in ecological aquaculture the presence of certain fish is encouraged because they promote the food web rather than disrupting it. If no planktonic fish are present it happens that zooplankton (rotifers/copepods) start to grow until they die after running out of phytoplankton food. This would eventually spoil water quality with reduction of oxygen and increase ammonia due to the decomposition of plankton, with consequent stress in shrimps.

Other fish like herbivorous in the main pond can control the vegetation growing on the bank, and eat plant litter, while benthivorous can bioturbate the sediments, thus helping to oxygenate the bottom and avoid the growth of dangerous bacteria or anaerobic zones.

In treatment ponds the control of nutrients can be done by seaweeds (*Gracilaria, Caulerpa*) and sea grass (*Ruppia*). Presence of bigger planktivorous fish may have the same effect to control excess of zooplankton of the main pond. The addition of carnivorous fish can also control undesired herbivorous fish that would graze on seaweeds (Tanan and Tansutapanich, 2000).

4.2.2 Semi-intensive management

Semi intensive farm management should more likely follow traditional pond management that includes the best practices below. The management of higher densities of shrimp should in fact be more flexible, as there is the need to operate cleaning and disinfection tasks of the ponds in order to maintain good productivity across the years, and to avoid risks of diseases that are more likely to occur in not well maintained ponds

4.2.2.1 Pond disinfection

Following the harvest ponds should be dried to control possible predators, disease agents, promote mineralization of the wastes accumulated at the bottom and release nutrients back to the water. This contributes to healthy shrimp growth, as it encourages good chemical, physical and biological balance in the pond. Sediment management also includes cleaning the pond from wastes (organic, plastic, etc), exposition to solar radiation (UV light) and liming. The drying process should last 2 or more weeks, during that time the gates should be closed to avoid tidal water to enter.

Assess the pH of the soil with very simple meters (fig.27) and correct the acidity with calcium carbonate in the measure of 3000 kg/ha (1200 kg/acre) for soil pH below 5; 2000 kg/ha (800 kg/acre) for soil pH 5-6; 1000 kg/ha (400 kg/acre) for pH 6-7. Liming, particularly with calcium carbonate, helps to have better alkalinity in the water, which avoids big changes in pH between the day and the night, this eventually prevents shrimps from getting stressed.

Carry out maintenance of sedimentation ponds/canals to reinstall the proper depths to favour the water flow during tides.

4.2.2.2 Refilling water and improving its quality

Refill the ponds with tidal water by putting a filtering net to avoid accidental contamination of predatory species in the pond (carnivorous fish, frogs, snakes)

When necessary, ponds should be fertilized once new water is stocked to let the pond mature before the arrival of the shrimp larvae. Measure the transparency with a secchi disk whose reading should be in the 30 to 40 cm range. Fertilization should be done with urea and TSP. Initial fertilization could be applied at least one week before stocking the larvae. Application of 25 kg/ha (10 kg/acre) of Nitrogen and 6-15 kg/ha (2.5-6 kg/acre) of Phosphorus. Control with secchi disk after 4-5 days, if not too green repeat the action.

Fig.51 Liming of a pond

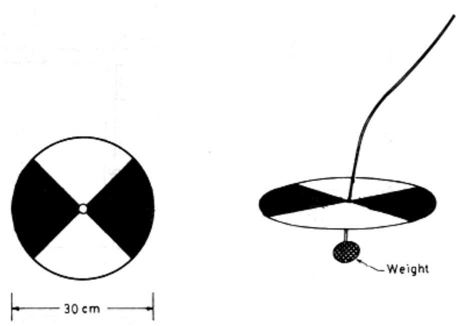

Fig.52 Secchi disk

Target water parameters at the end of the preparation should be:

pH 7.0 – 8.0   alkalinity > 80 mg/L   ammonia < 0.1 mg/L   DO > 4.0 mg/L

4.2.2.3 Use or probiotics

Probiotics may be necessary to improve the treatment of the pond wastes and to indirectly control the proliferation of the pathogens. Probiotics are microorganisms and/or enzymes that are naturally present in nature that have a positive effect on both pond and fish. Probiotics are normally commercialized in almost any country, although their price may be high depending on the distribution system. In many cases the micro-organism involved are also used in agriculture to treat fungal or bacterial diseases in plants.

4.2.3 Extensive management

Extensive management should follow good management practices in aquaculture described in the semi-intensive section above. The degree of treatment of the bottoms depends on how intensively the ponds have supported the natural regeneration of mangroves, which may limit deep interventions on the soil or prolonged drying. Given the very limited impact of organic wastes and the presence of natural decomposition the drainage of ponds is more linked to the control of pests and predators that may have found their way in during the previous crop cycle. Nevertheless plants growing on berms, dikes or directly on the bottom can tolerate conditions of dryness over limited period of time, which could be enough to expose the soil to the air

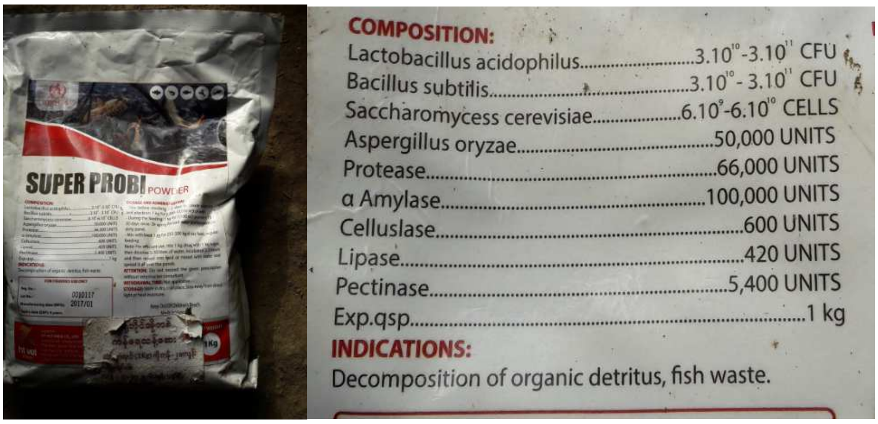

Fig. 53 The composition of a commercial probiotic product used in aquaculture. It contains strains of *Bacillus subtilis*, *Lactobacillus acidophilus* a probiotic found in yoghurt and *Saccharomyces cerevisiae* commonly known as baker's yeast

4.2.4 Stocking larvae

It is important to stock the pond only with the farmed species and to avoid possible risks of introducing predators. Ideal condition would consist in stocking post larvae from hatcheries that should be certified disease-free. This makes sure that the shrimps farmed are of high quality and fast growing.

In many cases the stocking with larvae coming with the tides through the gates (trap and hold) may not be effective by the scarce number of individuals. Although cost-effective, this type of stocking brings in the risk of predators being pulled into the ponds by the same tidal water. Ideally a trap net should be positioned at the pond inlet during the tide in order to successively pick the desired larvae and exclude carnivorous animals.

The stocking densities should not exceed the pond carrying capacity in order to avoid problems of water quality and waste management. Shrimp stress in stocking and handling should also be avoided as a preventive strategy to avoid diseases, or mortality.

Shrimp nutrition is based on either natural feed from the mangrove ecosystem or the artificial feed supplied by the farmer. In both cases part of the nutrition of the crustaceans is supported by important pond organisms such as plankton, small benthic invertebrates and organic debris that are part of the natural food web of the coastal and marine ecosystem.

Stocking densities depend on the intensity of the farm management and on the type of the shrimps:

Species (pcs/m^2)	Extensive	Semi intensive	Intensive
P. monodon	0.5–1	2–5	5-30
P. indicus/vannameii	1-5	8-10	10-50
P. merguiensis	1–5	8–10	10-50
P. japonicus	3–10	10–30	30-250

Fig.54 Bagged shrimps

Fig.55 Stocking shrimp larvae (source: Macintosh)

4.2.5 Pond management

Natural feed should be promoted in extensive ponds that make use only of the primary productivity of the pond and mangrove areas. In semi intensive ponds the promotion of plankton is also accompanied by the distribution of feeds to the shrimps. The size and the ration of feeds should take into account the growth stage of the animals. A monitoring of eaten/uneaten feed can be simply done by observing the feeding trays after feed has been distributed throughout the pond. The combination of broadcasting and feeding tray monitoring is encouraged as it avoids dominant shrimps to prevent any other animals to access the eating area.

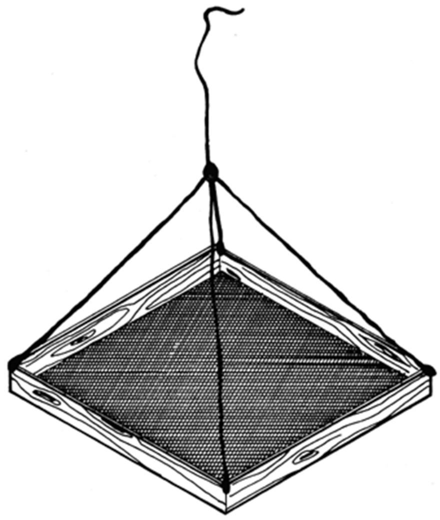

Fig. 56 Different size of feed for different ages

Fig.57 Feeding tray to monitor uneaten feed

The waste produced in semi-intensive systems are not abundant and the assimilative capacity of the pond can handle all the wastes. In case of higher densities or overload of feed the nutrients dissolved in the water may reach some key limits that need to be monitored.

Always measure the plankton in the water with the secchi disk (Fig. 52) in order to maintain good levels of natural food into the pond. Do not exceed with the plankton concentrations in order to avoid problems of oxygen depletion in the water during the night.

Feed should be given when there are optimal temperatures in the pond (26°C). If the temperatures go below or above this value the amount of feed should be progressively reduced. At lower temperatures in fact shrimps do not eat, while at too high temperatures the oxygen get depleted and the animal may enter into acute stress if there is too much organic load into the water caused by uneaten feed.

Be aware to keep the feed always in good storage conditions, elevated from the soil, in a cold, ventilated, shadowed and dry environment. The feed storage room should be protected against the entrance of rodents, have ideally a concrete floor for easy cleaning. Bags of feed should be used on a first in first out basis.

4.2.6 Water quality monitoring

Have good water quality is essential to maintain healthy animals, particularly if the pond management becomes more intensive due to a higher number of shrimps or higher feeding regimes. The water quality parameters should be monitored regularly (weekly basis for semi-intensive farms) and measurements should be written on a table to track growing/decreasing trends that suggest the farmer to use appropriate counter measures to improve water quality.

	01-Jul	08-Jul	15-Jul	22-Jul	29-Jul	05-Aug	12-Aug	19-Aug	26-Aug	02-Sep	09-Sep	16-Sep
amonia												
nitrite												
nitrate												

	01-Jul	04-Jul	07-Jul	10-Jul	13-Jul	16-Jul	19-Jul	22-Jul	25-Jul	28-Jul	31-Jul	03-Aug
pH												
temperature												
EC												

Fig. 58 A table where to write water quality measurement during the weeks.

Salinity – should be maintained in the optimal range for the cultured species.

- 10-20 ppt for *P. monodon* shrimp;
- 10-25 ppt for *P. vannamei*
- 25-28 ppt for *P. indicus* shrimp

The management is particularly important during the monsoon season when the big volumes of rain tend to reduce the salinity, on the contrary the intense evaporation of the water in the pond during the dry season brings up the salinity.

- If the salinity is too low procure water exchange with seawater to raise its concentrations
- if the salinity is too high procure water exchange with seawater as well.

The measurement can be done with a simple refractometer by putting one drop of the water to be tested on to the screen.

Temperatures – must be in the optimal range of 25-30˚C for shrimp *Penaeus monodon* culture. Too low temperatures slow down the growth, while too high temperatures stress the animals, also in view of the much lower dissolved oxygen in the water. In areas where temperature are high it is recommended to have deeper pond, so that shrimp could stay at the bottom, where water is cooler, and/or increase the areas of mangroves into the pond to favour shadow that protect the water from the sun. A simple thermometer can be used to measure the temperatures of the water

pH – is another parameter that is critical as it amplifies the toxicity of ammonia. As written in the previous paragraphs the optimal pH for shrimp is pH 7.0 – 8.0. its value can be measured with simple test kits or paper strips.

Fig.59 Refractometer

Fig.60 pH test kit, liquid type

Fig.61 pH test kit, paper type

Alkalinity – can be measured with test kits. Good concentrations prevent the pond water to variate too much the pH between day and night due to the presence/absence of carbon dioxide at night that makes the water more acid. Good values of alkalinity are > 80 mg/L

If the pH and alkalinity are lower than the optimal level, carbonated lime should be added into the pond at 25 kg/ha (10 kg/acre) on a daily basis until the pH is raised to the desired range.

If the pH and alkalinity in the pond is much higher than the optimal ranges stop liming and start water exchange.

Ammonia is the waste product of the protein degradation by animals. In extensive conditions it is never present, but concentrations increase with farm intensification. The higher the shrimp density or the feed used the higher is the ammonia. Normal ammonia concentrations should be below 0.1 mg/L, however its degree of toxicity depends also on the water temperatures (lower temperatures are better to have ammonia in its less toxic state) and the pH (below 7 ammonia is less/no toxic). If ammonia start to be high a sudden stop of feeding is suggested, followed by a partial water exchange in the pond.

Fig. 62 Test kits to measure different water elements

Fig.63 Test kits are simple and practical to use

Nitrite – it is another subcomponent of the degradation of ammonia and is equally toxic to the animals. The ideal and normal measurement of nitrite is zero in any aquatic system. Values of 0.02-

1.0 mg/L are lethal to many fish species, >1.0 mg/L is lethal for many warm water fishes and <0.02 mg/L is acceptable.

Nitrate - Generally non-toxic. It is the final product of the degradation of the ammonia and is an optimal fertilizer. The sum of ammonia, nitrite and nitrate gives total ammonia nitrogen, whose value in a semi-intensive pond ranges between 0 to 1 mg/L. The monitoring of the nitrogen, together with phosphorus helps to determine the fertilization needs.

Phosphorus - 0.05-0.07 mg/L is optimum and productive; 1.0 mg/L is good for plankton / shrimp production.

Dissolved oxygen (DO) is essential for aquatic life. Good DO in shrimp pond should be 4 mg/L. A low DO (less than 2mg/l) would indicate poor water quality and thus would make it difficult to sustain many sensitive aquatic species that eventually get stressed. Aerators should be used if oxygen readings are 3.5 mg/L or below. From 2 mg/L also feeding must be interrupted. Oxygen can be tested with test kits, or with portable meters

Fig. 64 A DO meter

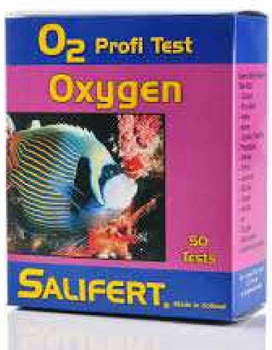

Fig. 65 DO test kit

Fig. 66 pH and salinity meter

Fig.67 Aerator to oxygenate pond water

Fig.68 Transparent water in extensive pond with berms

Transparency - If the transparency measured with the secchi disk (Fig. 52) is lower than 25 cm, the rate of water exchange should be increased to a level higher than in normal conditions.

If the transparency is higher than 40 cm and the phosphate level is low, 0-46-0 formulated fertilizer should be added at 6.25 kg/ha (2.5 kg/acre).

Summary of optimal parameters

- Ratio N:P = 8:1 (e.g. N =0.56 mg/l, P=0.07 mg/l)
- Ca:Mg:K = 1:3:1 (e.g. Ca = 400 mg/l, Mg = 1.200 mg/l and K = 400 mg/l)
- silica should be maintained at 1.0 mg/l and alkalinity > 80.0 mg/l

5. Culture of crabs in MFA

Crabs of large dimensions have gained a great percentage of the markets in recent years due to the high demand and their good prices. In many countries of south and South East Asia crab culture has become an important asset in the rural economies, particularly after the introduction of crab fattening. The reasons for its success stand in the fact that farmers have found this type of culture very cheap, fast in terms of turnover and less risky than shrimp farming, which has created many problems in the recent past due to diseases.

Crabs are common animals of the mangrove ecosystems, most of the time they burrow holes in the muddy soils. Depending on the species they are almost omnivorous and feed on either animals or vegetables (Hill, 1976).

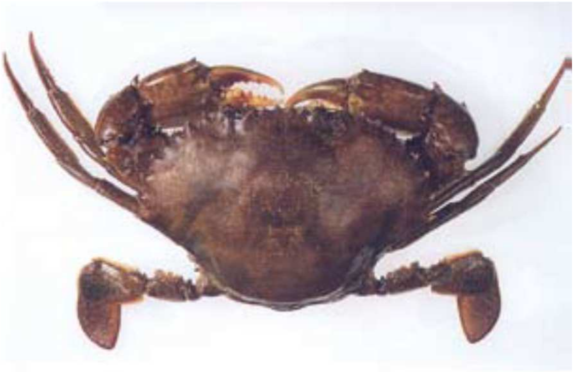

Fig.69 *Scylla serrata* (FAO, 2011)

Fig.70 *Scylla olevacea* (FAO, 2011)

Fig. 71 Mangrove and crab, separation with plastic fences (FAO 2011)

Fig.72 Crab enclosure in Indonesia (Shelley, 2008)

In S.E. Asia mud crab is one of the many species farmed in integrated mangrove aquaculture, for which guidelines for sustainable farming have been produced. The species are actively captured in coastal areas. The techniques for catching vary depending of the skills of the collectors and their experience: by hand, by net, using baited traps or lift nets. In the Philippines a small mesh mounted on a v-shaped frame sieves the ground to capture young individuals. On the other hand traps with baits are used to capture larger animals. In Viet Nam a bottom seine net is used in canals and watered areas (Johnston and Keenan, 1999).

In recent years, collectors have been practicing unsustainable harvesting practices that have brought to the sensitive decline of the natural stocks. It is very common in fact that collectors capture very young individuals despite the legal bans. In other cases the high demand of eggs to be consumed as specialty by some Asian countries has led to the systematic harvest of gravid females, thus preventing spawning and hatching.

Fig.73 A crab trap

Although the hatching technology has been developed and is currently substituting captures particularly in Viet Nam, China, Australia and the Philippines, the degree of diffusion of reproductive facilities is mainly limited in production districts. Crab hatcheries are sub-optimally developed, particularly for the quality of the water, land or infrastructures. Nevertheless techniques for hatching and nursing crab larvae are not difficult and there is currently the FAO technical paper 567 (*Mud crab aquaculture A practical manual*, year 2011) that describes the technology and the management steps in good details.

The crabs are sold for many specialty foods, such as soft shell produce, eggs, meat extraction, cooked in different fashions, fermented. Crabs close to marketable sizes are captured and fattened, particularly those who have moulted recently and have not filled the space with the new carapace (empty crabs). Wild captures in fact account that at least 7–10 % of the captured animals are empty crabs, which were discarded up to a few years ago. However if the crab are fattened for 3-4 weeks the value of a mature crab can be at least double than the original crab (Shelley, 2008).

On the other hand crabs matching the requirement of the industry are used for soft shell productions by keeping each crab in a box under constant monitoring until they moult. Once moult occurs the crabs are immediately killed and put in ice or frozen before they can harden their new shells. Hard shell crabs are fattened until they reach the marketed size and then sold alive through tightening their claws.

Mud crabs are quite adaptable to many different farm conditions. Their feeding characteristics, mainly omnivorous, make them suitable for different type of feeds ranging from trash fish, pellets, or other by products.

Farming in any cases should consider the growing of individual of similar sizes, due to the tendency of cannibalism in particularly dense enclosures where bigger size animals predate smaller ones, causing significant losses in production. Whereas the dominant crabs do not kill the small ones it can always cause damages by severing their limbs, which result in lower market values. Some strategies to reduce this problem consist in keeping the density relatively low, provide refuges for the smaller crabs escaping from the dominant ones, and, above all, conduct partial harvest of the bigger individuals, which eventually disrupts hierarchies and reduces the stocking densities and competition for food (Say and Ikhwanuddin, 1999; Christensen, Macintosh and Phuong, 2004).

There are two main production types that are used for grow-out:

- Open systems, which consist in ponds, pens in mangrove areas. In such systems crab are reared at different densities
- Closed systems, which consists in individuals contained in single containers or in fattening facilities.

The stocking densities in fattening enclosures varies from 1–1.5 crabs/m^2 (1-1.5 crabs/10 ft^2) of intensive systems down to 1 crab/5–10 m^2 (1 crab/50-100 ft^2) for low densities systems (Thach, 2003). In the case of cage culture mid-sized crabs of 200-400 g are kept fattening at densities of 35 crabs/m^2 (3.5 crabs/ft^2) up to their marketable size. Intensive systems in Viet Nam with supply of feed can reach 1–2 tonnes/ha/crop (400-800 kg/acre) (Lindner, 2005).

The type of feed given for fattening depends on availability, but mainly consists in trash fish, molluscs, animal hide, entrails, and small crustaceans.

5.1 Crab fattening in ponds

Mud crab is a good alternative to shrimp culture due to the high turnover and the lower level of risks due to the higher resistance against diseases of the crabs.

In Bangladesh crab fattening occurs in earthen ponds 1.2 m deep (4 feet) served by tidal streams. In the ponds net fencings delimit chambers of 150-180 m^2 (1600-1800 ft^2) are established with split bamboo sticks planted deep into the mud.

Fig.74 Crab chambers in a pond (Ghosh, 2019)

The stocking of the chambers keep separated the females (weighting 150-250g) and males (200-500g) under a weight of 100 kg/chamber

Crab are fed daily with trash fish at a feeding regime of 10% of body weight for a period varying between two weeks in the warm season and 25 days during the cold season.

The harvest size of males and females is respectively 500-700 g and 250-300 g. According to (Ghosh, 2019) the income is higher during winter and production is done all year round with the exception of the months with the highest temperatures.

At the end of each two cycles the chambers are completely drained and 12 kg of calcium carbonate ($CaCO_3$) and 4 kg of zeolite is applied in each chambers. Earthwork is also done to aerate the soil rich or organic wastes to avoid production of gas or hydrogen sulphide.

Management also consider the aeration of the chambers if crab tend to cling on the net fences. Water exchange involves a depth of 45 cm (takes place in each daily at depth of 0.45 m (18 inches) equivalent to 30% of the volume.

5.2 Crab fattening in containers

Fattening in single boxes, according to the Vietnamese technique, would avoid cannibalism. involves immature females with soft shells and empty males, which are refused from exporters. In general each crab is singularly put in a box floating in 1.2 m deep ponds with tidal water exchange of 20% at every full and new moon. Female crabs 150-180 g size are fattened for 4-6 weeks, depending on their size and biology, with trash fish, snails, mussel meat at 10% body weight. One of the advantages of the boxes is that there is better feed utilization. Females during this period can increase of 25-30 g and can be sold. Pond management requires the addition of dolomite at a quantity of 100 kg/ha (40 kg/acre) every 2 weeks.

Fig. 75 Soft shell crab farm

Fig. 76 Moulted crab and its empty shell

A good management should entail the sustainable harvest of juveniles from the wild. This could be achieved by improving the compliance of local communities, also under co-management structures and by promoting alternative livelihood strategies that would disincentive unsustainable harvesting practices.

Management plans should for example entail the restriction of the number of catchers and traps used. At the same time catchers should record their preys on logbooks to keep record of the degree of exploitation of each areas. In addition there should be limitations on the size of crab to be catch, namely prohibition to capture undersized animals. In Australia for example female crabs are protected leaving thus entitling fishermen to catch only males (Shelley, 2008).

6. Alternative productions for improving resilience in mangrove areas

Alternative livelihoods strategies are an essential component to support the communities living in mangrove areas. One of the main issues from poor households living in areas with scarce employment opportunities is in fact the sourcing of means of income by exploiting natural resources. It is very common the practice of illegal logging of mangroves for timber or charcoal productions, or the clearances of mangrove areas for low-productive shrimp ponds or salinity-affected agriculture lands. At the same time lack of cash and income diversification forces worse-off people to source their shrimp juveniles in the wild as well as crab catchers to collect young crablets indiscriminately. All these unsustainable practices have an impact on the existing mangrove ecosystems and on their ecosystem services. Wise planning should always consider the socio-economic implications of every rehabilitation program through cost-benefits analysis. Simple livelihood strategies can therefore provide economic relief to local communities, thus reducing the impact on mangroves and local ecosystems.

Two extractive aquaculture productions can give support to local communities: seaweed and shellfish. Their characteristics of being cheap to set up and to operate, the low skill requirements make them an ideal alternative for worse-off households or communities. On an ecological level the presence of seaweeds can help to reduce the impact of nutrients dissolved in the water, which also limits the risks of eutrophication. Shellfish on the other hand can help capturing suspended particles (e.g. shrimp/fish aquaculture wastes, but also organic loads from human origin). The benefits of seaweed and shellfish cultivation would help to reduce the impact of human activities in local ecosystems, contribute to the economic development of coastal communities and support the restoration of the mangrove waters and ecosystems.

6.1 Seaweed

Seaweed cultivation could be considered a type of agriculture. The dedication of the seaweed farmer is determinant for the success of the production because attentive eyes would help the growth of the aquatic plants in the best way possible. Numerous are the tasks that require presence, even though not on a daily basis: shaking off silt and other settled materials from the algae, repairing broken lines, fix uprooted stakes, and picking up drifting branches of seaweeds.

The success of the cultivation depends also on three other factors:

(i) Type of seaweeds used – the seaweeds must be healthy and resistant to diseases and breakages. Plants need to increase their biomass quickly and produce high yields.

(ii) Ecological Conditions of the Farm – the farm must be set-up in an ideal location. The observation of native algae can be an indicator of the characteristics of the site. The site must meet the ecological needs of the plants being cultivated.

(iii) Access to Sunlight - seaweeds like any other photosynthetic plants requires sun to carry out photosynthesis.

The algae can provide a wide range of products:

- Food for humans, with high levels of polyunsaturated fatty acids, such as salads, nori, food ingredients.
- Foor for livestock (e.g. fodder for ruminants)
- Products for the chemical/food industry (e.g. agar, carrageenan)
- Fertilizers for agriculture (e.g. algal hydrosilate)

6.1.1 Seaweed choices
The choice of seaweeds depends on the climatic characteristics of the area, the most important factors are the following ones:

- Unpolluted seawater supply
- Optimal salinity for the cultivated algae
- Warm temperatures, 27-30° C
- Moderate water movement of 20-50 m/min
- Water depth of 0.5-1 m at low tides and not more than 2-3 m at high tides
- Firm bottom protected from strong waves

Cultivation of mangroves in bays and creeks is compatible with lines of seaweeds that can get also protected from waves by the plants.

One important factor in the choice of the seaweeds is the salinity of the water. Although during summer/dry season the salinity of the seas is always constant, the level of salt in the water can fall sensitively due to the rainy periods, particularly in monsoonal areas.

Not all the algae are tolerant to low salinity, therefore the choice depends on the direct observation of the salinity ranges across a whole year, or on the environmental monitoring carried out by environmental agencies, universities, and research centres. The most common types of algae are:

- Eucheuma and Caulerpa (optimal salinity 30-35 ppt)
- Gracilaria and sea lettuce (optimal salinity 8-25 ppt)


Fig.77 *Eucheuma* on a long line


Fig. 78 *Gracilaria* (eattheweeds.com)


Fig.79 *Ulva*

A particular aspect of these types of algae is that their reproduction occur through cuttings, this would make it easy to set-up cultivation lines that can be managed by people with low levels of skills.

6.1.2 Eucheuma
Eucheuma is in general cultivated in open water bodies protected from the waves. Creeks or bays are ideal locations, providing that they have high salinity in water all year round even during the rainy season. They type of cultivation is the monoline, which can be either developed at the bottom or be floating. The process to set up a crop is simple and consists on the following steps:

1. Secure the lease for using a specific water body from the local Aquaculture Department or concerned Land and Water Department
2. Prepare the materials used for the setup of the cultivation
3. If using monolines with ropes positioned at the bottom choose an area where the minimal tide covers the seaweeds for at least 0.5-1.0 m (1.5-3 ft.)
4. Clear the bottom from obstacles, stones, other seaweeds
5. For each line fix the wooden stakes into the bottom at 2-3 m (7-10 ft.) distance or more depending on the strength of the current. Push them into the ground with the help of

hammers. Follow a pattern where the monolines are separate by at least 1 m (3 ft.) each other. The length of the monoline can be variable.

6. Stretch the nylon rope at a position of at least 50 cm above the bottom (20 inches) and tie securely to the poles.

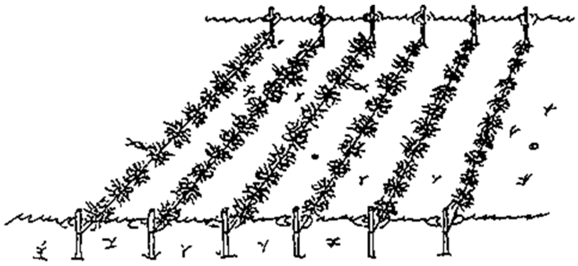

Fig.80 Monoline method (Alih, 1989)

Fig.81 Longline with floaters along the main rope

1. Collect propagation material from a nearby source and transport them immediately. The seedling must be protected against sun, wind, temperatures and rain. Keep the seaweed wet during the transport and submerge immediately in seawater upon arrival.
2. Prepare the seedling and tie them onto the monoline nylon rope at a distance of 20-25 cm (8-10 inches) each. Seedlings should be made of bunches of 50-100g. The tying string should be approximately 25 cm (10 inches). The plant can grow up to 1 kg up to harvest
3. Build a shed if there are plans to dry/store the produce. Plan to have the shed at a reasonable distance to save in transport time. Build some racks where to hang the seaweeds for drying
4. Inspect the crop regularly when growing to remove unwanted seaweeds, remove dirt, remove damaged/diseased seaweeds, and replant missing ones.
5. Harvest seaweed by leaving part of the algae in situ for self-regeneration.
6. Sun dry the harvest onto the racks or on suspended platforms made with nylon net.
7. In dry season the drying of the produce takes about 3-4 days to achieve a moisture content of 30%. Once dried keep the produce in plastic bags and then deliver to the merchant.

Fig.82 Harvested seaweed

Fig.83 Drying seaweeds onto racks

6.1.3 Gracilaria

Gracilaria looks an interesting candidate for production due to its environmental characteristics and the possibility to be grown also in ponds, like in Taiwan.

The salinity ranges of the algae of 15 to 24 ppt match particularly well areas where the length of the rainy season tend to dilute the salinity in the seawater, particularly in creeks or bays where rivers and canals open into the sea. Like Eucheuma the water depth should be 0.5-1m at low tides if the plants are cultivated in monolines to the bottom. The bottoms where the plant thrives are in general clayish loam, silty loam or sandy loam and firm to resist to the force of the waves.

Gracilaria is cultivated for the production of Agar, fodder, human food. The seaweed is only sold dry to the agar industry.

The monoline method is very common and very simple to realize with local materials as already described for Eucheuma. The monoline rope can be suspended in the central part by floaters that keep the culture at an even height.

An alternative method is also the rafts system, used wherever spaces are not suitable for the monoline to be fixed at the bottom (rocky shores) or where there is an intense grazing activity at the bottom.

The advantages of the rafts are:

1) grazing by animals located at the bottom is minimized

2) the algae, stay at a constant distance from the surface, therefore the sun exposition is optimized.

This method however is not recommended in sites exposed to strong waves.

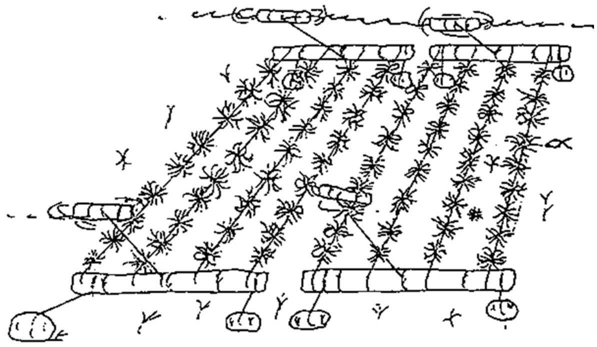

Fig.84 A floating method (Alih, 1989)

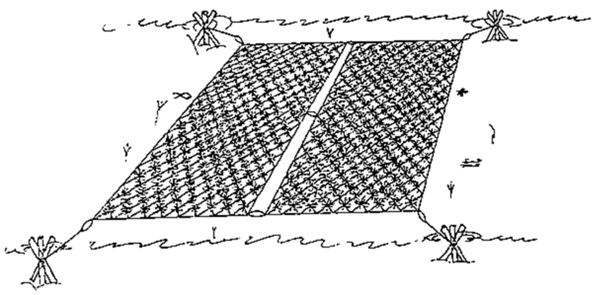

Fig.85 The net methods (Alih, 1989)

6.1.4 Ulva

There are currently many types of sea lettuces growing spontaneously, which can be used as propagation material. Ulva can be used to produce drugs, for human consumption, animal fodder or as organic fertilizer. Like for the previous algae it is reasonable to try to propagate the seaweed in vegetative ways by preparing cuttings that are tied to the monoline.

The type of system can be either the monoline used for gracilaria or by nets that can be stretched by poles at the corner. The same type of management apply.

Polyculture with shrimp (*Penaeus monodon*) and/or mud crab (*Scylla serrata*) has been done in Taiwan. The stocking densities used were 4-5 MT/ha of Gracilaria, 5,000 to 10,000 crab and 10,000 to 20,000 shrimp. Feeding of the crab consists in trash fish and snails. The survival rates are as high as 80% for crabs and 80 to 90% for shrimp has been documented (Trono, 1990)

6.2 Shellfish

Molluscs are widely cultured around the world, in Asia and Pacific they represent a good percentage of the global production. The main species cultivated are the oysters (mainly *Crassostrea* spp.), mussels (mainly *Perna* spp.), clams, cockles, and scallops.

The diffusion of these species in almost linked to the environmental conditions, in particular:

(i) Seawater salinity range of 15-35 ppt.

(ii) Water depth of 1-10 m,

(iii) Muddy bottom for mussels and hard rocky or coralline substrates for oysters.

Shellfish thrive well in areas not affected by strong currents (up to 5-6 km/h). The production area should be a suitable source of seeds, accessible for transport, linked to the markets. The choice of shellfish farming should be also based on the presence of natural stocks, which is a good indicator for suitable production areas.

The culture cycle of oyster and mussel is 1-2 years from spat collection to harvest. The length depends on the characteristics of the water (euthrophic), salinity and temperatures. The culture can be divided into two different steps: collection of spats and grow-out.

Spat collection is the most critical part of the operations because good numbers of juveniles need to be captured from the wild. For this purpose substrates such as empty oyster shells, stones, bamboo poles or tree branches, plastic/nylon straps, nets impregnated with cement are used to naturally let the spats settle. For mussel collection natural ropes, coco wood or husks can be also used.

At ecological level spat occurrence is linked to salinity. The reduction of temperatures and salinity are in in fact a signal for the mature shellfish to release their spats. For tropical oysters a drop from 28 to 24°C triggers the release of juveniles.

At local level farmers know when the main release of spats can occur, this is in general preceded by the presence of barnacles on the collectors (Surtida, 1988).

Spats can be left growing on their collectors or removed to concentrate the cultivation. In the case of mussels the spats harvested from the collectors, are hanged in “socks” made of nylon nets. Periodical maintenance should be done and socks can be rearranged and cleaned following the growth of the shellfish. In the case of oysters more artisanal methods consist in hanging the shells on a rope by making a small hole in the shell.

Fig.86 Hanging system for oyster

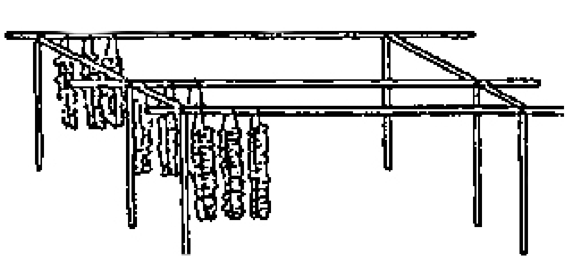

Fig. 87 Vertical hanging

Three principal grow out methods for shellfish culture are in use:

- hanging method including floating rafts, traditional longlines supported by buoys, simple hanging to structures planted onto the bottom
- stake or stick method, normally consisting on poles planted on to a soft bottom

- broadcast or sowing method, done in shallow bays with firm bottoms to support the materials used as collectors and for growing oysters

In the case of mussel farming the floating rafts have some advantages due to their mobility, higher productivity, the possibility to variate the densities of the strings and to avoid siltation.

Fig.88 Floating system for oyster

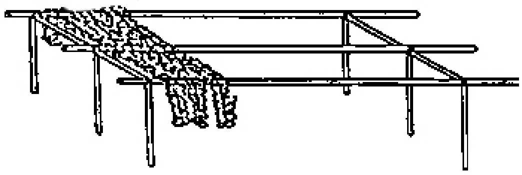

Fig. 89 Horizontal hanging

7. Conclusions

A good management of mangrove forests, also linked with aquaculture, should consider rule of law, and enforcement of regulations. A key factor in success in environmental programs is the co-management, developed through self-regulatory agreements between coastal communities and central-local governments. Sense of ownership reduces the idea that mangroves are a public good that do not deserve care and are susceptible to unlimited exploitation. The progressive understanding of the ecosystem services procured by these habitats has indeed built awareness in local communities on the importance to preserve these natural assets to secure livelihood, but pro-active actions to support full restoration should consider alternative livelihood strategies to guarantee sustainable livelihood in both local communities and natural ecosystems.

Regulatory agreements should be part of coastal development management plans where a wide coordination between productive sectors (fisheries, aquaculture, forestry, agriculture, livestock, and environment conservation) are put in act to sustain both socio-economic development and environmental conservation. Planning should therefore propose alternative and synergic economic alternatives to farmers to differentiate their incomes and give to natural resource sufficient relief to self-regenerate. At the same time building awareness and capacity in local communities would help people to build their livelihoods in more sustainable ways.

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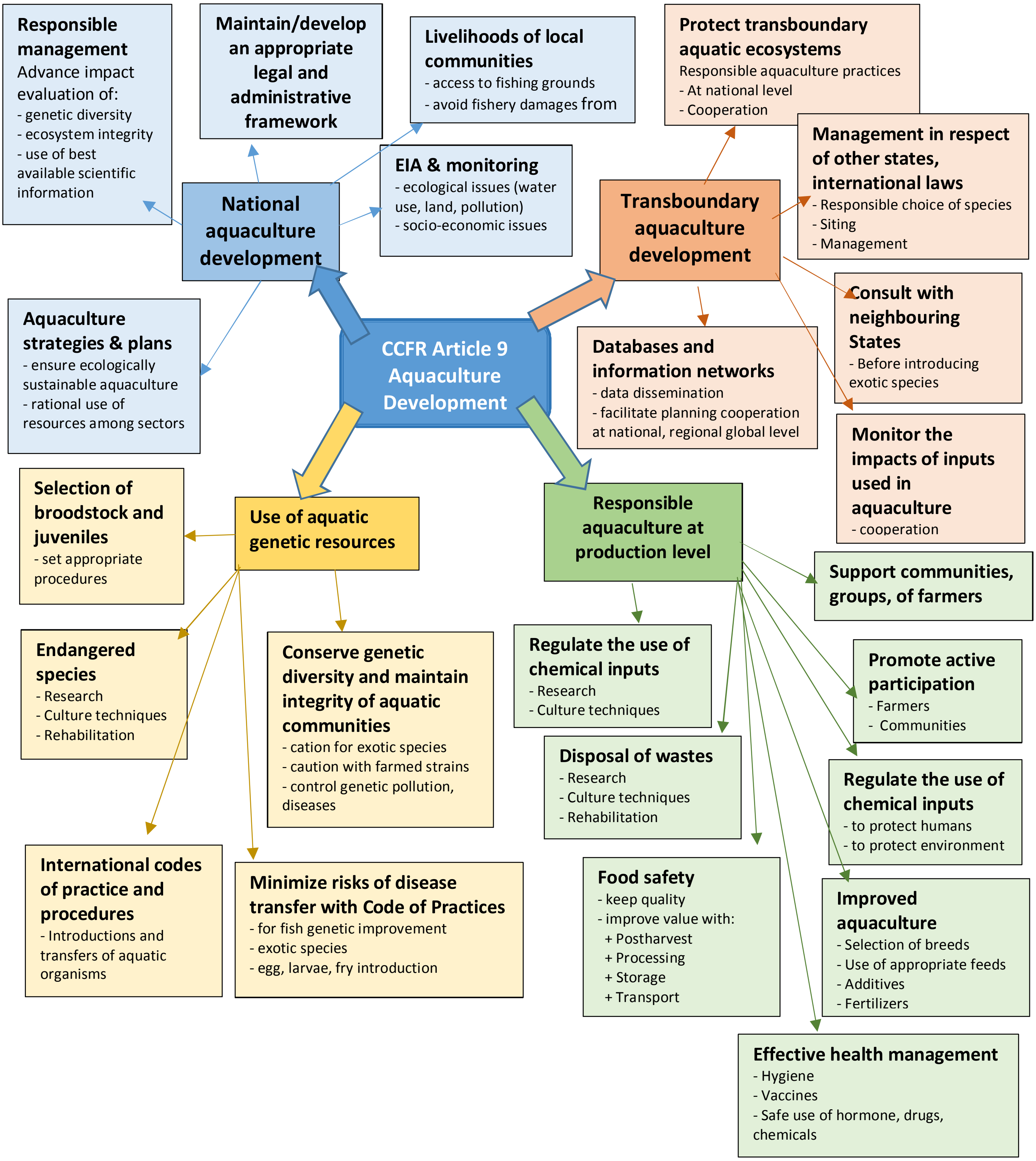
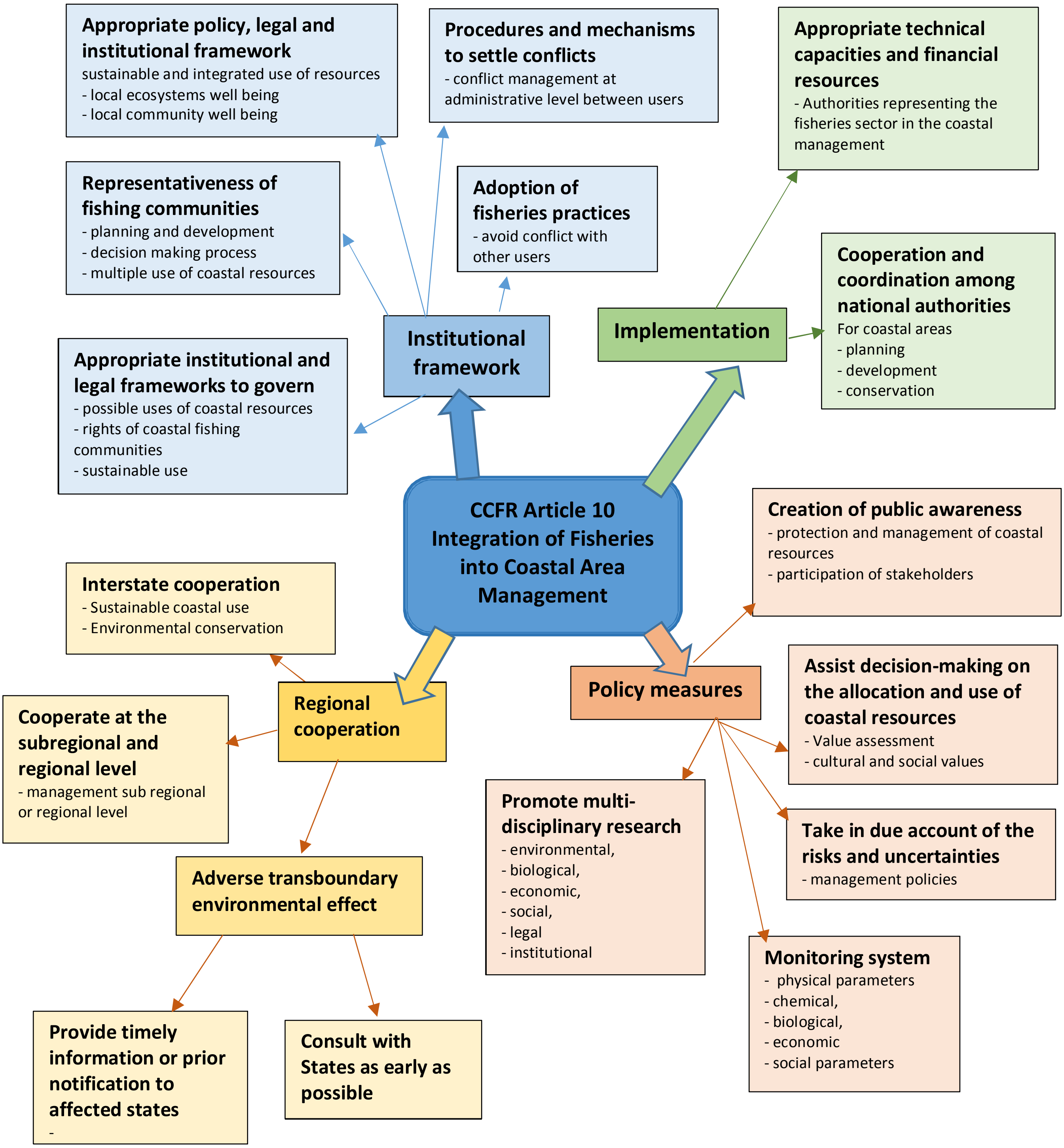
Annex 1
FAO Code of Conduct for Responsible Fisheries
Article 9 – Aquaculture development



Article 10 – Integration of fisheries into coastal area management



Annex 2
Code of Practice for Sustainable Use of Mangrove Ecosystems for Aquaculture in Southeast Asia

Article 1. Recognize mangrove ecosystems as provider of vital ecological services and valuable goods to coastal areas and communities.

1.1. States should recognize, and promote public awareness of, the fact that mangrove ecosystems provide a variety of goods (fuel wood, timber, fish, molluscs, crustaceans, and other products that can be priced in the market), and also vital ecological services that are not usually 'priced' or accounted for, such as coastal protection, nutrient cycling, erosion control, silt entrapment, and provision of habitats for biodiversity, and nursery and feeding grounds for fishery species.

1.2. States should recognize that many forms of subsistence fishing and fish farming in mangrove areas provide vital economic support to coastal communities worldwide.

Article 2. Protect and conserve mangroves to sustain vital ecological services and goods.

2.1. States should protect and conserve large areas of mangroves to safeguard their ecological functions and to ensure that goods and products can continue to be harvested from them indefinitely.

2.2. States should recognize that loss of mangrove areas means the loss of these ecological services and goods, all to the detriment of coastal areas, human communities, and economic enterprises including aquaculture, fisheries, agriculture, and forestry.

Article 3. Improve governance over mangrove conservation and sustainable use, such as for aquaculture.

3.1. States should review and rationalize inconsistent policies and legislation pertaining to mangrove conservation and sustainable use, such as for aquaculture.

3.2. States should improve enforcement of existing laws and regulations related to mangrove conservation and sustainable use.

3.3. States should ensure effective coordination and linkages among the various government agencies involved in mangrove conservation and sustainable use.

Article 4. Integrate aquaculture and mangrove conservation in coastal zone management.

4.1. States should work towards integrated coastal zone and watershed management, where the needs of local communities and the various economic sectors (aquaculture, fisheries, forestry, agriculture, industry, transportation, tourism) are coordinated and harmonized.

4.2. States should establish appropriate zones for use of aquaculture and the various other economic sectors, in agreement with local communities and other stakeholders.

4.3. States should base planning and management decisions on biophysical and ecological data on mangroves and aquatic ecosystems (inventories, maps), their current uses and users, economic costs and benefits, appropriate technologies, and local requirements for education, recreation, and aesthetics.

4.4. States should establish systems for monitoring of mangrove ecosystems, evaluation of economic enterprises, and early detection of adverse effects.

Article 5. Assess and classify existing mangrove ecosystems for proper disposition.

5.1. States should conduct periodic inventory and ecological assessment of the mangrove areas within their territory. Ecological quality of mangrove areas may be defined based on geomorphology, water flows, mangrove cover, forest structure, sediment quality, and plant and animal biodiversity.

5.2. States may classify mangrove areas in terms of ecological quality and present use, and allocate or use them as recommended below:

Ecological quality	Present use and status	Recommended disposition
• Excellent	not yet used, pristine	full protection, non-use, ‘no touch’
• Good	slightly used	conservation, sustainable use
• Poor	fully converted, damaged	optimum use, rehabilitation

Article 6. Retain a mangrove greenbelt or buffer zone along coasts and rivers where mangroves naturally occur, and where replanting is technically feasible.

6.1. States should retain or replant a mangrove greenbelt or buffer zone along the coasts and rivers for protection from erosion, waves, and storms.

6.2. States should enact the necessary greenbelt laws, or enforce existing greenbelt laws.

6.3. States should ensure that aquaculture farms in mangrove areas maintain a greenbelt for protection of the dikes and for treatment of farm effluents.

Article 7. Locate aquaculture farms outside of pristine mangroves, coral reefs, and seagrass beds.

7.1. States should encourage aquafarmers to find suitable farm sites outside of pristine mangrove ecosystems, and also outside of coral reefs and seagrass beds. Mangrove areas often have peat soils or potential acid sulfate soils not good for farms. Coral reefs and seagrass beds are damaged by siltation from farm effluents or sediments.

7.2. States should prohibit or minimize large-scale aquaculture in UNESCO Biosphere Reserves and other marine protected areas.

Article 8. Prohibit conversion of pristine mangrove ecosystems into shrimp aquaculture farms and other uses.

States should prohibit conversion of pristine mangrove ecosystems and associated tidal flats for shrimp farming and other uses that require clear-felling of forests and draining of swamps.

Article 9. If large-scale aquaculture farms must be built in mangroves, then require a full environmental impact assessment.

States should develop and implement procedures for a full, independent, and public Environmental Impact Assessment (EIA), or an equivalent procedure, for large-scale aquaculture farms to be located in mangroves. The EIA includes determination of the impact of the farm on the mangrove ecosystem and on the food supply and livelihoods of local communities. The EIA also provides for a management plan, mitigating measures, and periodic monitoring and evaluation of farm operations.

Article 10. Promote small-scale integrated aquaculture in sustainable-use mangrove areas.

States should promote small-scale integrated mangrove-aquaculture systems that are non-destructive, sustainable, and beneficial to fishing communities.

Article 11. Make available to aquafarmers appropriate technologies and information on best management practices for aquaculture in mangrove ecosystems.

States should make available to farmers appropriate technologies and information on the best management practices for different aquaculture systems in mangrove areas.

Article 12. Follow national and regional guidelines and codes of conduct for responsible aquaculture.

12.1. States should ensure that aquaculture farmers adopt codes of practice based on the Regional Guidelines for Responsible Fisheries in Southeast Asia – Responsible Aquaculture drawn up by the SEAFDEC and ASEAN Member Countries.

12.2. States should also help farmers adopt more sustainable farming practices and technologies so they can comply with the codes of conduct.

Article 13. Apply appropriate incentives and disincentives to encourage good farming practices.

States should establish a system of appropriate licenses, permits, and fees for use of land and water, penalties for violations of aquaculture regulations, and other incentives and disincentives to ensure that farms use mangrove-friendly technologies and management practices.

Article 14. Require optimum production in aquaculture farms located in mangrove areas.

14.1. States should ensure that aquaculture farms in mangrove areas are fully developed for the optimum production of fish, crustaceans, mollusks, or seaweeds.

14.2. States should not allow farmers to use the aquaculture permit to hold lease on the mangrove land for other purposes. Underutilized aquaculture farms must be brought to full use or have their permits or lease revoked.

Article 15. Establish land and water quality criteria for aquaculture.

States should establish land and water quality criteria for allowing farming operations in mangrove ecosystems and other aquaculture sites.

Article 16. Prevent pollution, disease contamination, and hydrological alterations in mangrove ecosystems.

States should establish regulations to prevent severe pollution and disease contamination of mangrove areas from aquaculture effluents, by means of appropriate water management and effluent treatment. Construction of the farms must also not adversely alter the waterways and water flows in mangrove areas.

Article 17. Regulate introduction of exotic species for aquaculture.

States should strictly regulate the introduction of exotic species for aquaculture as these exotics may escape from farms into and through mangrove waterways, often with adverse effects. Mangrove ecosystems are open systems with extensive water exchange and animal movements between adjacent freshwater and marine habitats.

Article 18. Minimize collection from mangrove ecosystems of wild broodstock, seedstock, and feedstuff for aquaculture.

States should conserve animal biodiversity in the mangrove waterways. Thus, States should regulate or prevent the collection from mangrove areas of broodstock for hatcheries, larvae and juveniles for grow-out farms, and juvenile fish and other feedstuff for farmed fishes and crustaceans.

Article 19. Rehabilitate abandoned aquaculture ponds back to mangroves.

States should promote the rehabilitation of abandoned fish and shrimp ponds back to mangroves with the support and cooperation of local communities. Rehabilitation can be achieved by breaking the dikes to restore the water flow and recolonization, or by planting propagules or seedlings from the wild or from the nursery.

Article 20. Consider product labelling and certification for mangrove-friendly aquaculture and fishery products.

States should consider product labelling and certification for mangrove-friendly aquaculture and fishery products to raise consumer awareness about mangrove friendly aquaculture and fishery technologies and practices.

Article 21. Support research, training, and education about mangroves and mangrove friendly aquaculture.

States should actively support research, technology transfer, training, information dissemination, communication, and widespread public education about mangrove conservation and mangrove-friendly aquaculture.

Article 22. Resolve conflicts between aquaculture and other users of mangrove ecosystems.

States should establish mechanisms for conflict resolution among the various stakeholders in mangrove areas, including compensation schemes for the adverse effects of aquaculture on local communities