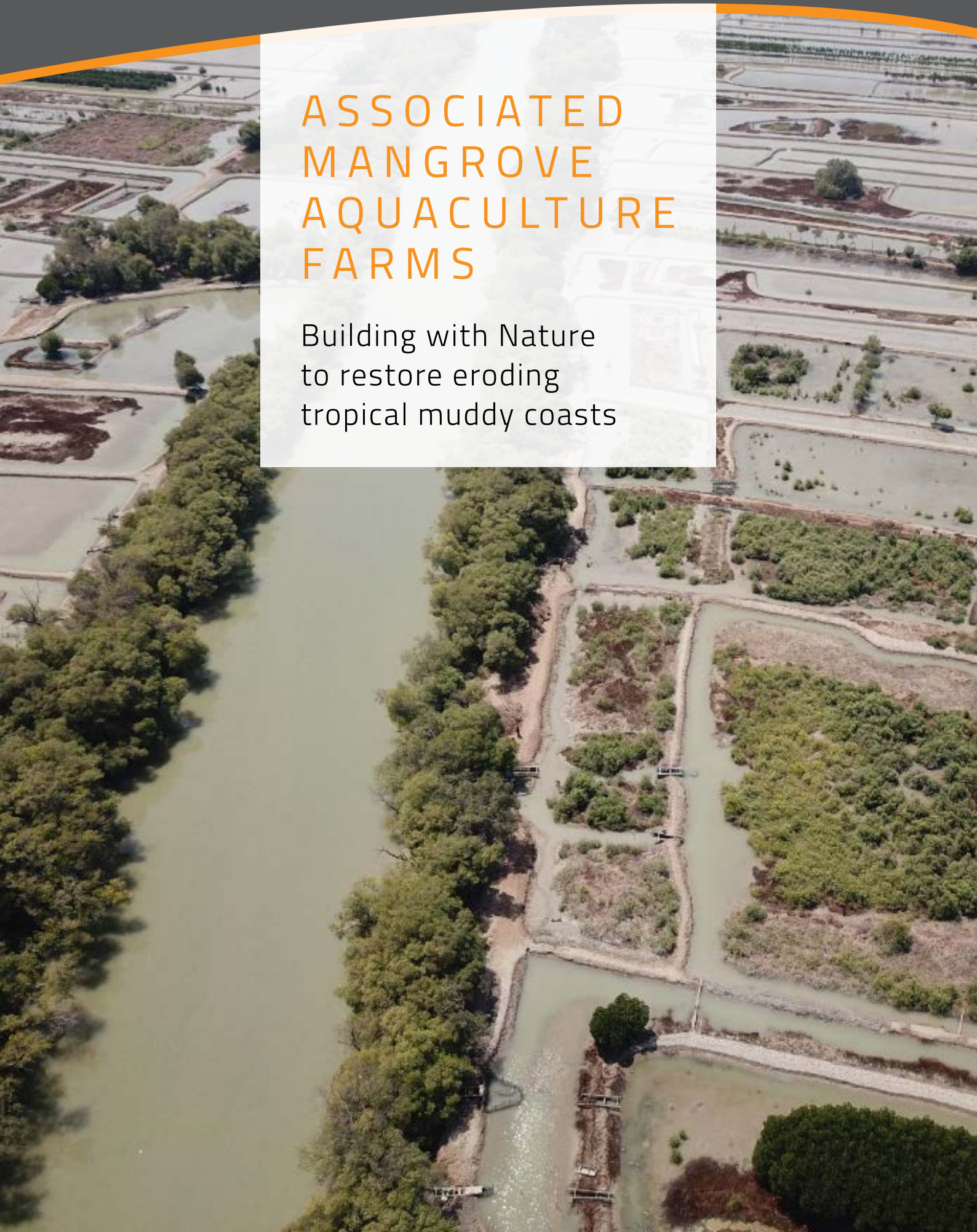


ASSOCIATED MANGROVE AQUACULTURE FARMS

Building with Nature
to restore eroding
tropical muddy coasts



Aerial view of three ponds in Onggajoyo with natural mangrove regeneration (right hand side of the picture) (© Blue Forests)

TECHNICAL GUIDELINES SERIES

This guideline is part of a series of Technical Guidelines on technical and socio-economic Building with Nature measures that, in combination, help to restore eroding tropical muddy coasts. These guidelines are based on insights and lessons learned during the implementation of a district scale pilot in Central Java as part of the Building with Nature Indonesia program. By sharing our lessons learned in these practical guidelines, we aim to enable replication by government agencies, the water and aquaculture sector and NGOs. Building with Nature measures need to be part of integrated coastal zone management and require a thorough problem understanding and system analysis. Stakeholders interested in replicating our approach bear full responsibility for the success and sustainability of the approach.

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EXECUTIVE SUMMARY

Expanding shrimp aquaculture has been one of the main drivers of the worldwide loss of mangrove forests. Consequently, tropical mud coastlines have become vulnerable to severe erosion and catastrophic flooding. The likelihood has increased of the scenario that millions of inhabitants could become displaced from their homes and land, and lose their livelihoods, including income from aquaculture. In tropical muddy coastlines, building hard seawalls and dykes to protect aquaculture and households against erosion and flooding is too costly. A more sustainable and cost-effective alternative is the Building with Nature approach, an integrated and participative way of planning, designing and constructing water infrastructure with the aim to create mutual benefits for both nature and society.

Along tropical mud coastlines, Building with Nature can involve the creation of a mangrove-based economy that integrates revitalisation of aquaculture productivity with mangrove restoration to protect coasts. A mangrove greenbelt dampens waves and builds up sediment, thus protecting traditional earthen seawalls along rivers and ponds, and reducing their maintenance cost, while also enhancing fisheries and water quality.

In Indonesia this approach was implemented at district scale in the Building with Nature Indonesia project in Demak, Central Java. This project introduced innovative Associated Mangrove Aquaculture (AMA) systems, the focus of this guideline, to restore mangrove greenbelts in the estuary along inland waterways and to protect adjoining fishponds. In AMA systems, part of the aquaculture pond is given up to make space for riverine mangroves. Such riparian greenbelts along rivers and creeks perform ecosystem functions (ecosystem services) and enhance biodiversity and increase economic opportunities for the local population. As such, AMA offers a more sustainable alternative to silvo-fishery systems, of which several types are practised in Indonesia, but none that contribute to coastal protection, and some that may have negative effects on aquaculture.

To implement AMA systems, farmers set back the river dyke and adjust the sluice system to create a mangrove greenbelt along the river. Proper pond management is the key to success, for example by allowing natural sedimentation by opening and closing sluice gates at the right moment in time. For the application of AMA systems farmers need to give up a portion of their ponds and invest in building extra dykes and gates. To build their knowledge and confidence, the Building with Nature project in Demak engaged farmers through Coastal Field Schools to demonstrate that applying Low External Input Sustainable Aquaculture (LEISA) and other good aquaculture management practices, can indeed improve their yields and their income in an ecologically sound way. The Building with Nature Indonesia project demonstrated that applying a LEISA allows farmers to triple their income from milkfish and shrimp farming.

The creation of sustainable mangrove aquaculture landscapes, and therefore the practices applied in Demak, are of global relevance given the severe decline in mangrove forests worldwide. Building with Nature solutions are always site specific and require the active engagement of stakeholders, especially local farmers, early in the development of the project. It is also recommended to engage farmers through accompanying measures and post building activities, such as Stakeholder Innovation Platforms (SIP) and Saving Clubs.

1 INTRODUCTION

Nearly half of all the world's mangrove forests have been lost since the mid-twentieth century, along with their valuable functions like coastal protection, carbon sequestration and fisheries enhancement. Loss rates are extremely high in South-East Asia, the Caribbean and the Pacific³¹.

Indonesia is still home to the largest area of mangrove forests in the world. But, since the 1980s, urban expansion, aquaculture farms, oil-palm plantations and timber extraction have caused the loss of about 1.2 million hectares of mangroves. Currently, less than 3,5 million hectares remain³⁰, while many sites are degraded and have limited ecological and economic value. In the last years, mangrove deforestation has contributed to the loss to the sea of 30 thousand hectares of land along its coast²⁹.

The uncontrolled expansion of brackish water aquaculture ponds (tambak) for profit is globally one of the main causes of mangrove loss. Remaining mangroves need protection, including along Indonesia's north Java's coast, where loss of mangrove forest has caused coastal erosion and loss of precious land (Figure 1). Indonesia has a presidential decree (2016-51) supporting the maintenance of a greenbelt of 50 meters along waterways (rivers and creeks) in the estuaries, and 100 meters (counting from the line reached at the highest tide, along the coast. However, once the land has been given over to private property ownership, formal control over actual land use is lost, and the law is difficult to enforce, unless contractually specified. Moreover, the decree applies to the marine area, while the provincial government mandate extends only up to the flood-line at high tide.

In the district of Demak, residents used to make a good living from rice paddies and aquaculture ponds behind a wide mangrove greenbelt. Due to mangrove deforestation and other threats, such as land subsidence, land, villages and infrastructure are all at risk. In several subdistricts of Demak, near Semarang, where the coastline has retreated several kilometres, hundreds of hectares have been lost and the inhabitants of two villages have had to move. In addition to the loss of mangroves and income from forest products and crops, people have also lost their income from mangrove-associated fisheries, as many seafood species rely on mangroves as nursery and feeding grounds.

In rural settings, mangrove and brackish water aquaculture can be complementary land-use systems when managed sustainably. Ecosystem functions of mangroves for aquaculture systems include wave dampening and sedimentation that protect and strengthen the pond dykes. Farmers also collect wild fry from the mangroves to stock their ponds. Mangrove roots absorb heavy metals, while the leaf litter of mangroves enhances biogenic nutrient cycling and diversity of macrobenthos, and limited quantities of litter from some species improve the pond water quality.



Figure 1. Coastline changes Demak (north-east of Semarang), 1972-2015 (© Wetlands International, based on maps from Aerial photography, WorldView, Landsat, US Army, Peta Rupi Bumi Indonesia).

In Indonesia, mangrove restoration is often done through so-called 'silvo-fisheries', of which several types are practised. In most Indonesian silvo-fishery systems, mangroves are planted on bund dykes and/or on heightened platforms in the middle of the pond surrounded by a deeper ditch. Unfortunately, these systems perform low in terms of aquaculture yield and ecosystem functions^{16, 18} (see Box 1). The latter is because those mangroves are disconnected from the estuarine water and tide. Mangroves inside a pond neither support sedimentation, nor attenuate sea waves and a storm surge, cannot help to filter water, nor provide habitat for fish species^{16, 18}.

Examples from subdistrict Sayung in Demak and subdistrict Kawilingi in Brebes show that planting mangrove on the dykes and in ponds (See Appendix 1) does not help to protect the coast: after some spring tides combined with storms, the trees were left standing but most dykes were destroyed (Figure 2). Moreover, trees shed their leaves and part of the leaves fall into the pond when the tree is planted on the dyke; too many leaves in the pond reduces water quality¹⁸. Thus, such silvo-fishery systems do not contribute to coastal protection¹⁶ and may even have negative effects on aquaculture¹⁸. In contrast, a mangrove greenbelt between the waterway and the pond, as in an AMA system, contributes to dyke protection and marine biodiversity, while simultaneously improving water quality because of tidal flood and ebb¹⁸.



Figure 2: Lost silvo-aquaculture ponds elsewhere in Timbuloko (© Witteveen+Bos)

BOX 1: FINANCIAL BENEFITS OF ASSOCIATED MANGROVE AQUACULTURE

A mono-culture shrimp farm earns between 1,000 to 30,000 USD/ha/yr, and the shrimp yield varies between 40 and 6,000 kg/ha/yr. The Total Economic Value (TEV) of mangroves forest varies according to the contribution to ecosystem services (ESS).

In South Minahassa this TEV was 36,000 USD per ha (Mankay et al, 2012, cited by [16]). The ESS include among others harvested timber and fruits (provision services), the catches of fish that were nursed there (habitat services) and flood protection (regulation services) (Russi et al, 2013, cited by [16]).

THE MINIMA AND MAXIMA OF THE TEV OF MANGROVE'S FOUR ESS (USD/HA/YR).		
	MIN	MAX
Provision services	44	8,300
Habitat services	27	68,800
Regulation services	1,900	135,400
Cultural services	10	2,900

Table 1: The minima and maxima of the TEV of mangrove's four ESS (USD/ha/yr).

While a well managed average tiger shrimp farm produces 6,000 kg/ha/yr, a classical silvo-aquaculture system can yield at maximum about 400 kg/ha/yr.

PRODUCTION FOR FARM OF 12 HA	EXTENSIVE	INTENSIVE	AMA (7 HA MANGROVE)
Appr. shrimp yield (*1,000 kg)	4.8	72	30
Farm revenues	30	432	180
TEV of Ecosystem Services	0	0	252
Total economic values	29	432	432

(Amounts in 1,000 USD/yr)

Table 2: Production for farm of 12 ha

In an AMA system the pond can be managed more intensively, because the water quality is not limited by leaves falling in the pond. Thus, in AMA the shrimp yield can be identical as for the normal intensive farms. Thus, together with the TEV of the ESS (accounting the value found for South Minahassa) the economic value of an AMA is equal to a monoculture intensive shrimp farm if the area of mangrove is about 60%. Moreover, due the lower ecological qualities, the financial risks of the intensive system are higher. The proportion of mangrove in the AMA stimulated by Building with Nature is about 20%, and thus the total economic value is much higher.

To create a sustainable mangrove aquaculture landscape that optimizes both mangrove ecosystem functions and aquaculture systems, mangrove greenbelts along coasts and rivers need to be restored, while aquaculture productivity is enhanced. This requires close collaboration with pond owners because farmers need to give up a fraction of their ponds for the estuarine mangrove greenbelts. For recovering the largely unproductive or eroded ponds along the coast to create the required wide coastal mangrove greenbelts, a juridical approach may be needed. This is because landowners may claim rights while they occupy protected coastal mangrove. For the riparian greenbelt, the Building with Nature Indonesia project proposed to replace with mangroves a section of the pond along the waterways, including canals, creeks and rivers, in each estuary. This guideline focuses on the restoration of riverine mangrove greenbelts through the introduction of 'associated mangrove aquaculture systems' (AMA) (Figure 3).

After introducing AMA-systems and explaining the rationale for practising them, this guideline specifies the principles of this approach and the reasons why farmers would wish to adopt it (chapter 2). The guideline then describes where, when and how AMA systems are to be built (chapter 3), why farmers should build complex AMA (chapter 4), which species of mangrove should be introduced along estuarine waterways to optimise ecosystem functions (chapter 5), how monitoring could be organised (chapter 6), and which activities are advised or needed after the construction of AMA ponds (chapter 7).



Figure 3: Natural regeneration in a mangrove component of an AMA, with measuring sticks to monitor the sedimentation and water height. (© Roel Bosma)

BOX 2: COASTAL FIELD SCHOOLS BOOSTING YIELD AND INCOME WITH LEISA²⁰

The project Building with Nature – Demak trained fish farmers to practice Low External Input Sustainable Aquaculture (LEISA) at Coastal Field Schools (CFS). Alumni were expected to improve their pond management, and learn to apply LEISA (see Box 4 for more information on LEISA practice). As part of the practice, farmers spread home-made liquid compost and manure to the dried pond once a year, and maintain water quality by adding this liquid compost whenever needed in view of the water colour. General monitoring of all 277 alumni allowed us to calculate the adoption rate and yield increases, while closer monitoring of a smaller sample of 17 farmers provided revenue from sales, operational cost and the gross margin. The alumni's results are compared to a baseline measured in 6 villages of Demak in 2015: 192 kg ha⁻¹ yr⁻¹ of milkfish, 43 kg ha⁻¹ yr⁻¹ of shrimp, and a gross margin of 10 million Indonesian rupiah per farm, or 630 USD ha⁻¹ yr⁻¹.

About 85% of the alumni of the CFS applied LEISA to some extent. The farmers who did not apply LEISA, nor stocked shrimp, continued their milkfish production using chemicals, harvested about 700 kg milkfish ha⁻¹ yr⁻¹ and earned little. The milkfish yields of LEISA farmers were more than three times higher than the baseline. Their average shrimp yields were over six times the baseline. The average margins of farmers who applied LEISA were 3 to 10 times higher than those who did not, and 2 to 4 times higher than the baseline, resp., in 2017 and 2018. The yields and incomes of the farmers applying LEISA were higher in the 2nd year (2018) compared to the 1st (2017) which might be explained by (1) stocking more often, (2) more farmers using (more) industrial feed, or (3) other factors such as less flooding, or better application of their learning. The farmers reaching the best results had smaller ponds and applied more manure.

	MILKFISH				SHRIMP			
	2015	2017/18	S-2017	S-2018	2015	2017/18	S-2017	S-2018
CONTROL	234	350	633	854	47	31	-	-
LEISA	-	243	770	1291	-	134	268	434

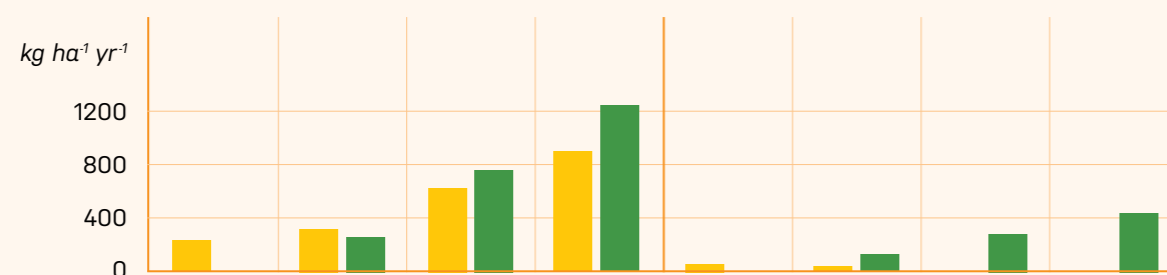


Table 3: Figures for Non-LEISA and LEISA farmers in 2017 and 2018 compared to a baseline in 2015 of the average yields of milkfish and shrimp for all trained farmers (2017/18) and a small sample (S-2017 & S-2018), and farms' operational cost, revenue and gross margin for the small sample.

COASTAL FIELD SCHOOLS (CFS)

At present, most aquaculture farmers in Indonesia achieve low yields or benefits due to insufficient training, poor practices and the use of chemicals and antibiotics that disturb the ecological balance. Therefore, we recommend that farmers receive initial training at Coastal Field Schools (Box 2), to demonstrate that applying low external input sustainable aquaculture (LEISA) and other good aquaculture management practices, can indeed improve their productivity and income (see guideline *Building Sustainable Aquaculture through Coastal Field Schools*). The curriculum of the CFS developed by *Blue Forest Indonesia* and customised for the *Building with Nature Indonesia* programme, includes raising awareness of the importance of mangroves and ways to rehabilitate this type of ecosystem¹⁹. The CFS trains farmers to apply LEISA and triple their income from milkfish and shrimp farming, and results in willingness to plant part of their pond with mangrove (Box 3).



Figure 4: Coastal Field Schools (© Boskalis)

BOX 3: MANGROVE RECOVERY IN DEMAK

In 10 coastal villages of Demak regency, farmers who had attended the CFS became aware that they need more mangroves in the form of greenbelts along the coast, estuaries, rivers and canals. More than two dozen farmers gave up their (degraded) pond for coastal greenbelt recovery (~50 ha), and about four dozen allocated portions of their ponds for riparian setback to create associated mangrove aquaculture (~110 ha). The *Building with Nature Indonesia* program provides financial and technical support to community groups for coastal and riverine mangrove recovery combined with aquaculture and livelihood revitalization through the Biorights incentive mechanism. Other projects can propose ways to financially support the farmers with initial investments to adjust the pond layout and sluice system to set up complex associated-mangrove-aquaculture systems.

2 ASSOCIATED MANGROVE AQUACULTURE

2.1 CONCEPT OF ASSOCIATED MANGROVE AQUACULTURE

Associated Mangrove Aquaculture, or AMA, is a concept for associating aquaculture with forestry by means of a greenbelt of mangrove along shorelines of waterways in the estuaries. This contrasts with existing ponds that have too little or no mangrove left on the shorelines (Figure 5). AMA is a type of silvo-aquaculture (see Appendix 1) and is sometimes called mixed-mangrove-aquaculture. However, in contrast to the usual silvo-aquaculture systems where the mangroves are planted on the dykes and in the pond (Appendix 1), in AMA the mangroves are located outside the pond.

The recommended area to be dedicated to mangroves depends on the effluent from adjacent ponds. For intensive shrimp farming, the area of mangrove should be at least as large as the ponds. For LEISA systems this requirement is smaller; the recommended width of the greenbelt depends on many factors, but 10 m seems the least for individual farmers, while a community plan might require twice as much or more to be cost effective.

Mangroves on dykes and in ponds often hamper pond maintenance, and their litter and shade reduce pond productivity. Leaves from these mangroves will decompose in the ponds. This decomposition may provide feed sources to the shrimp and other cultured organisms. But with too many mangroves, or when the pond water is not refreshed regularly, this litter increases ammonia levels in the water, decreases the dissolved oxygen content, and thus reduces pond productivity. Toxins may even cause mortality in the cultured organisms. Many farmers seem to know this and cut branches regularly to keep trees small, but in shallow ponds, shading has a local function to reduce water temperature. The ideal shrimp pond has a depth of 0.9 to 1.4 meters¹.

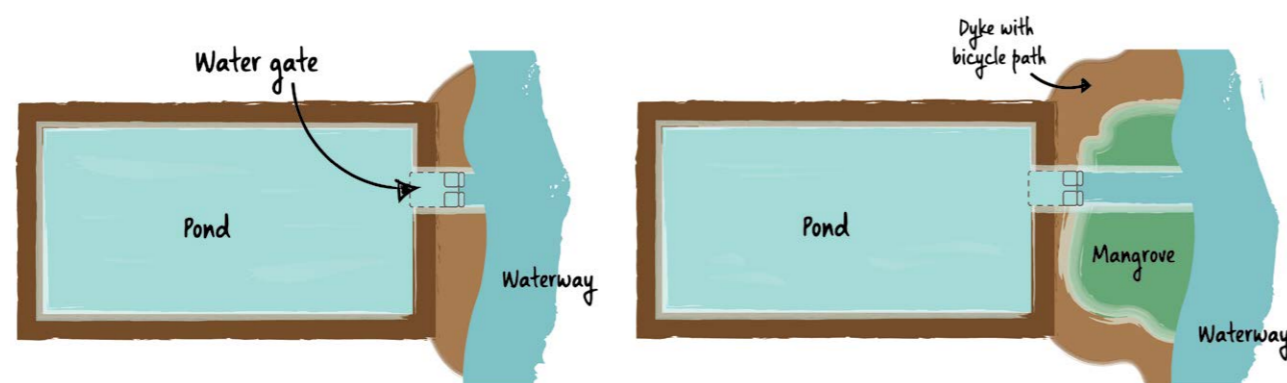


Figure 5: Overview of a common pond without mangrove (left) and a standard AMA for a single farm (right)
(© Roel Bosma)

2.2. WHY PRACTISE ASSOCIATED MANGROVE AQUACULTURE

We recommend AMA for several reasons:

- The mangrove greenbelt protects the pond dyke from the impact of waves as well as from chronic erosion, and can compensate for soil subsidence;
- The mangrove greenbelt acts as a biofilter, reducing the levels of toxic materials, e.g. heavy metals, hydrogen sulphide and shrimp pathogens.
- The mangrove greenbelt provides additional benefits not directly associated with the ponds:
 - Products, such as firewood and timber.
 - Fertiliser made by composting leaf material from some species; after composting, these leaves do not produce ammonia, nor do they reduce oxygen levels.
 - Human food from some *Avicennia*, *Bruguiera* and *Sonneratia* species, which also has market potential.
 - Nursery grounds and feeding grounds for aquatic organisms and thus an increased potential catch for estuarine and offshore fisheries.

The additional products from the mangrove and fishing reduce dependency of the farmer and village on aquaculture. This compensates somewhat for losses due to any predatory birds and snakes, which find refuge in the trees, but are also common in other aquaculture systems. One potential challenge in introducing AMA is for the farmer to maintain ownership of the land and its products. Therefore, border poles or an open fence of branches could be set on the old dyke to delineate ownership.

One single farmer can practise AMA, but to improve the landscape, ideally all farmers along a canal participate in the conversion of their system. However, farmers need to give up part of their pond area which represents production potential. This is compensated with improvements in yield and profits obtained from the smaller pond, after implementing the techniques learned at the Coastal Field Schools²⁰. This profitability can be further improved by practising Complex Associated Mangrove Aquaculture discussed below. In Tanakeke Island (South Sulawesi), fish farmers who gave up all or a portion of their ponds for mangrove rehabilitation could register this area with the Land Office (Badan Pertanahan) for a tax break given for environmental conservation (Conservation easement).



Figure 6a: AMA shortly after construction in Tambakbulusan (© Suhadi, Blue Forests)



Figure 6b: AMA shortly after construction in Tambakbulusan (© Suhadi, Blue Forests)

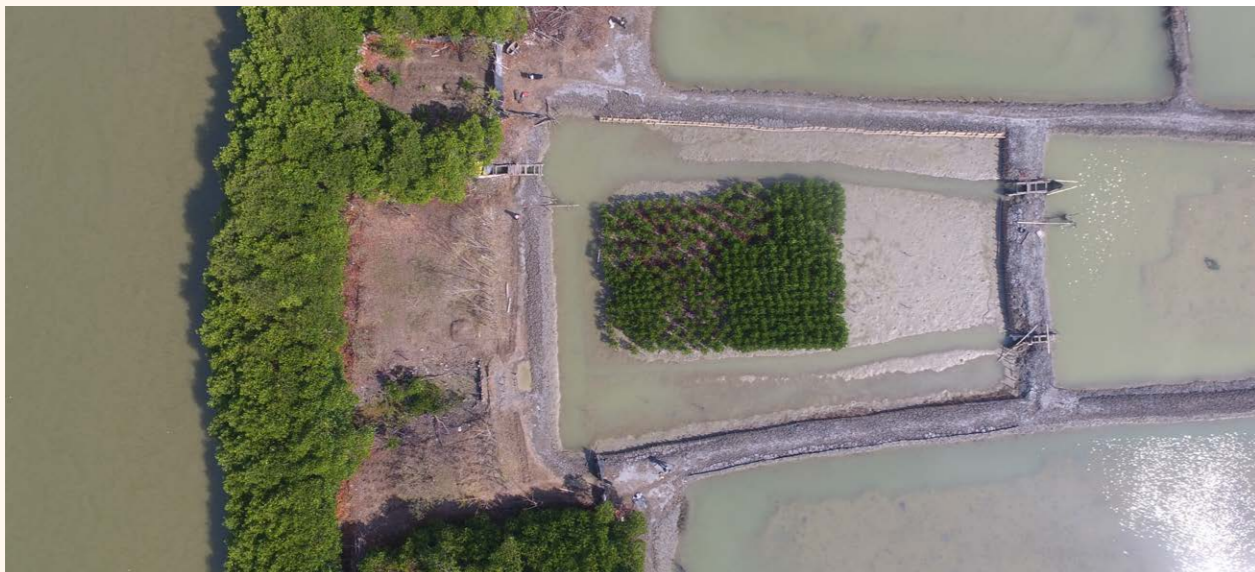


Figure 6c: AMA 6 months after construction in Tambakbulusan (© Suhadi, Blue Forests)



Figure 6d: AMA 6 months after construction in Tambakbulusan (© Suhadi, Blue Forests)

2.3. WHY PRACTISE COMPLEX ASSOCIATED MANGROVE AQUACULTURE

Farmers who are able to invest more in aquaculture to reach higher yields, can create complex AMAs with more ponds for more species. Complex Associated Mangrove Aquaculture farms have additional ponds for storage (water preparation) and sedimentation which allows for better water quality management (Figures 7 and 15). In the storage pond (reservoirs), to improve water quality even further while allowing additional marketable harvest, the farmer stocks Tilapia, seaweed, shellfish and, if available, Seabass (*Lates calciferes*). In this storage pond (reservoir) the salinity level can be kept within the safe range for shrimp or other farmed organisms. From this pond, water is channelled into the pond(s) stocked with shrimp and, if desired, Milkfish. Finally, the sedimentation pond enables the removal of excess waste before water is discharged or returned to the storage pond.

The additional advantages of Complex AMA are at least twofold:

- Improved water quality in the shrimp farm
- Diversified system with more products and sources of income.

Both these advantages reduce the risk of harvest failure for the farmer, and increase the yield per hectare. The system is also less costly than intensive systems for risk, management and yield increase; e.g. bio-flock systems that need feed, aerators, continuous provision of energy and continuous surveillance. Complex AMA is a perfect system to apply LEISA (Box 4). To apply Complex AMA, the farmer must sacrifice additional pond surface and invest more in dykes and water gates or passages made with pipes.

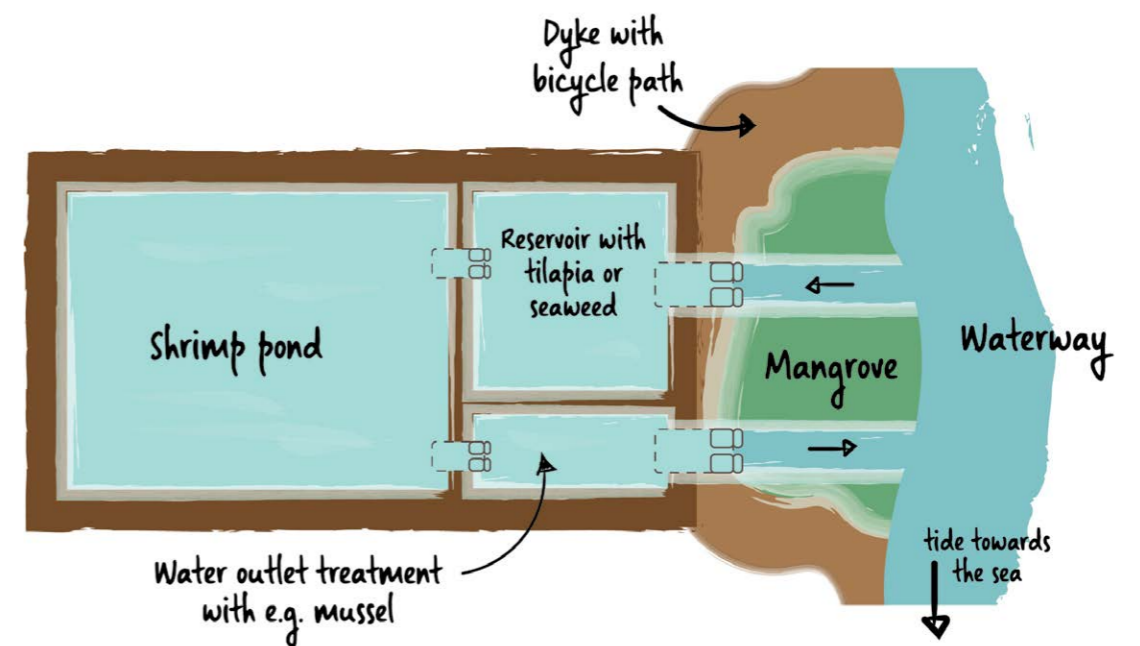


Figure 7: A complex AMA system for better water management (© Roel Bosma)

3 HOW TO ESTABLISH AN ASSOCIATED MANGROVE AQUACULTURE

Figure 8a, b and c give cross sections of the regular pond, a simple AMA and a complex AMA. Researchers recommend complex AMA with two reservoirs and, if the remaining pond is >1 ha, several smaller shrimp ponds. Farmers who nevertheless opt for the simpler, standard design will avoid all separation bunds other than the outside dykes. However, they should be made aware that smaller ponds produce more seafood and income, and are easier to manage.



Figure 8a: Present condition (© Roel Bosma)



Figure 8b: Simple AMA system (© Roel Bosma)

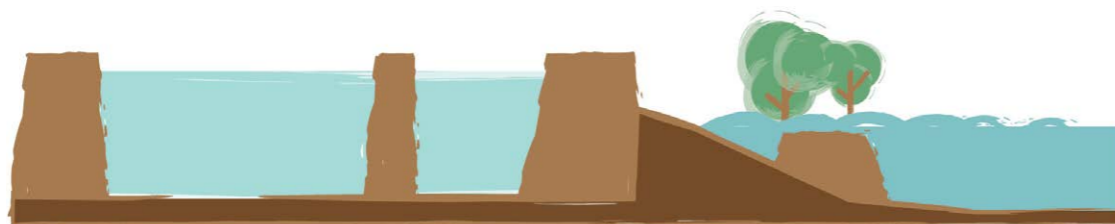


Figure 8c: Complex MMA (© Roel Bosma)

3.1. WHICH PONDS ARE SUITABLE FOR ASSOCIATED MANGROVE AQUACULTURE?

The following sites are not suitable for conversion to AMA:

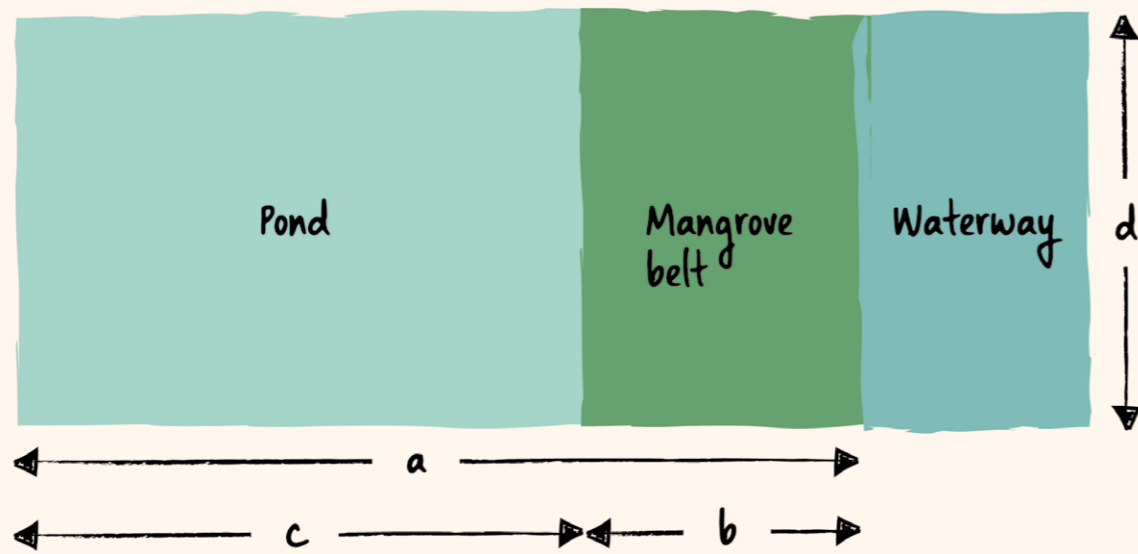
- Ponds with dykes bearing a large road, or heavy protection dykes along larger rivers or canals. When the road is large or the dyke is a heavy protection dyke, moving the dyke needs district planning and major investment.
- Single ponds with dyke(s) carrying paved/non-paved/mud roads suitable for carts.

When several neighbouring ponds with a larger non-paved/mud road, are to be restructured, the dykes can be moved in unison by the owners, even though this requires planning and incurs costs. Dykes with footpaths or bike roads can be moved more easily. However, dykes shared with neighbours who are reluctant to change their system will need structural reinforcement.

The goal is to create an estuary with mangrove greenbelts of at least 20 m wide (ideally 50m). If there already are mangroves present, only a smaller part of the pond may need to be converted. Dimensions depend on the specific circumstances (see Figure 9), and some suggestions are given next.

- If a mangrove greenbelt of at least 5 m is already present, then add 15 to 20 m depending on the length of the pond.
- If a mangrove greenbelt is less than 5 m, then add 20 m if the pond is long enough, otherwise advise to increase the greenbelt to 20 m.
- If 15 m or more are already present, then adding 5 m requires relatively high investment and is too costly. If the farmer wants to add another 10 m or more, then the work will be worthwhile.
- If the longest side is along the waterway, and the pond is less than 30 m wide, then suggest converting all into mangrove. In principle, ponds with a width of less than 30 m from the bank of the waterway should become entirely greenbelt.
- If the longest side is along the waterway but width is between 30 and 40 m, then suggest a mangrove greenbelt of 10 m.
- If the width is more than 40 m away from the waterway, then aim for 20 m of mangrove greenbelt.

The remaining pond should always have a width of 20 m or more. Narrow ponds with their long side adjacent to the waterway are either more costly to transform, or would become economically unviable, so we advise complete transformation to mangrove greenbelt.



DESCRIPTION OF THE POND	LENGTH OF THE SECTIONS ABOVE			RECOMMENDATIONS
	a	b	c	
Narrow pond with long-side at river	< 30 m	-	-	Should not be converted to AMA but entirely to mangrove
Narrow pond with long-side at river	30 m < a < 40 m	10 to 20 m	20 m	Not recommended because pond area becomes too small
Narrow pond with long-side at river	a > 40 m	20 to 25 m	≥ 20 m	Most suitable for conversion

Figure 9. The minimum recommended dimensions of the fish pond after AMA conversion for ponds smaller than 3 ha, as in Demak.

Preferably the ponds selected for intervention are clustered, i.e. located next to each other. Then, work can be shared and the positive impact will be higher. Figure 10 shows what this may look like at landscape level.

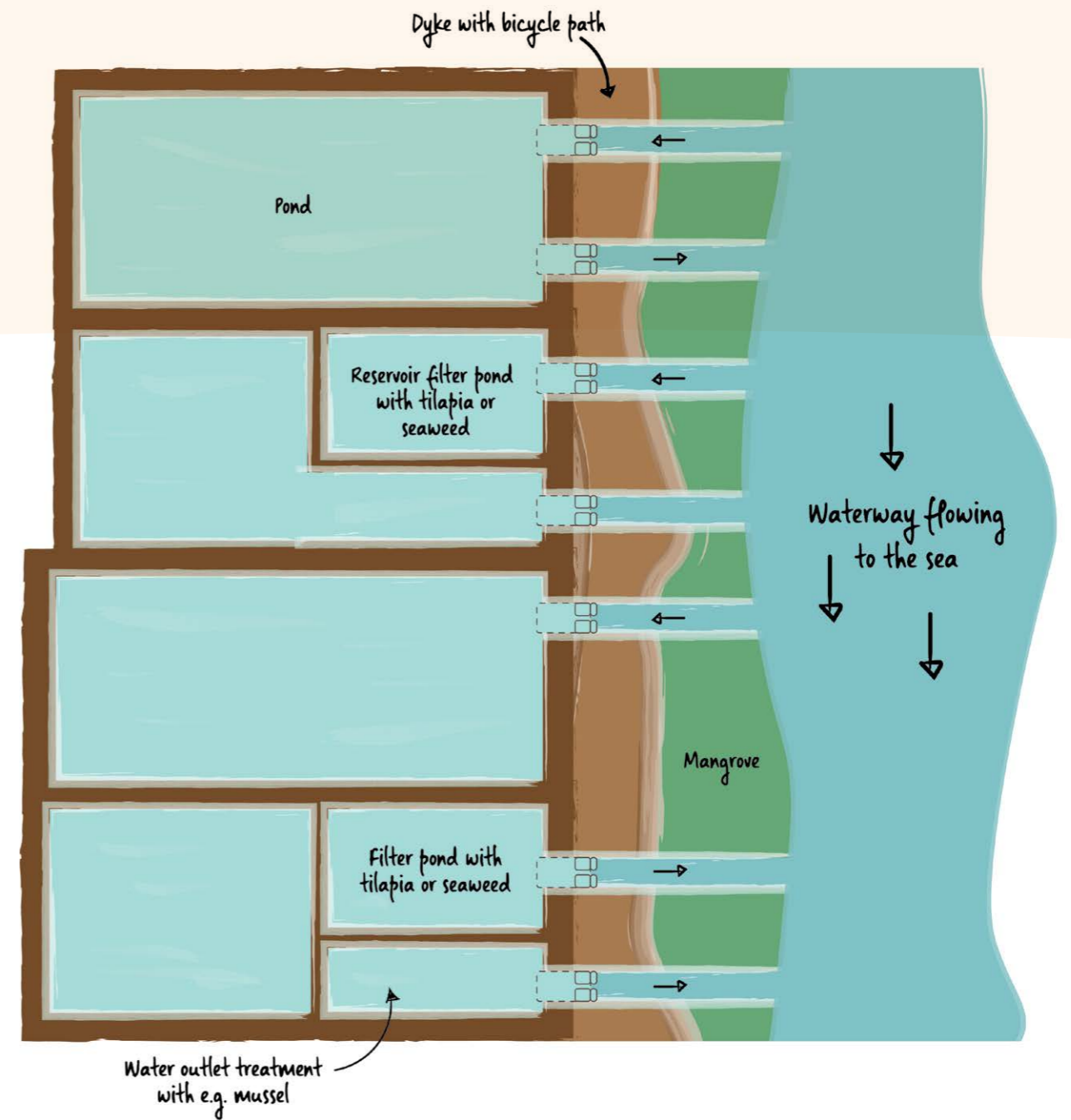


Figure 10: Landscape level view with river (© Roel Bosma)

3.2. DESIGN AND BUILDING OF THE DYKE

The construction stages for building the dyke of an Associated Mangrove Aquaculture system as described below, are illustrated in figure 13. The reference for calculating the height of the dykes is the Lowest Astronomical Tide (LAT). Other points considered in designing and building are HAT = Highest Astronomical Tide, HHWS = Highest High Water Spring, MHWS = Mean High Water Spring, MSL = Mean Sea Level, MLWS = Mean Low Water Spring, and LLWS = Lowest Low Water Spring.

The stages of the building:

- Start the construction of the new dyke by draining the pond, measuring the site and building the water gate(s) in the desired location(s).
- Place bamboo screens (see Figure 10) to maintain soil material in the shape of a dyke; keep the opening at the top wide enough to make a dyke with a crest of 2 m width.
- The dyke and the enforced pond-bund need heavy clay that can be taken from the pond bottom or from the river bed (not dredged near the bank but from the centre!).
- During construction, it is best to drain the pond regularly; then the base of the dyke dries and layers can be added sooner, allowing faster completion.
- The crest of the new dykes is heightened up to $LAT^A + 2.0$ m. The crest is determined as summation of HHWS¹ (LAT +1.1 m), land subsidence (0.3 m), sea level rise (0.1 m) and freeboard of 0.5 m to accommodate other uncertainties for at least a 2 years design lifetime. The first summation of 3 items are called Design Water Level (DWL) at LAT +1.5 m, which thus considers adaptation measures including to climate change and might be different according to the locally and globally expected impacts.
- Reinforce the sections of the dykes, next to the new mangrove habitat that joins with neighbouring ponds.
- Bunds separating filter and sedimentation pond(s) from the production pond(s) are preferably at least 0.2 m higher than normal pond level, but may be less.
- The mangrove greenbelt needs mud that can be taken from the old dyke and from the pond bed if this is not too deep already (ideal water depth in the pond is 0.9 to 1.1 m). The mangrove greenbelt will need a substrate height of at least Mean Sea Level or higher to account for landscape subsidence and sea level rise.
- To be safe, one might leave the old dyke at the level of mean sea level (MSL). This way, water and sediment will come into the new habitat through the water inlet and outlet canals, and with the waves.

^A HAT = Highest Astronomical Tide;
HHWS = Highest High Water Spring;
MHWS = Mean High Water Spring;
MSL = Mean Sea Level;
MLWS = Mean Low Water Spring;
LLWS = Lowest Low Water Spring;
LAT = Lowest Astronomical Tide.

Most ponds accumulate sediment from the river, sometimes several centimetres per year. Thus, ponds need regular dredging, which is an opportunity for a win-win: i.e. deeper ponds and enough soil nearby for the new dyke. Preferably the pond bed remains higher than the low tide level in the river during the season that the farmers dry and dredge the pond. By making secondary canals with water-gates and pumps, the water level in these canals can be lowered to enable emptying. This needs involvement of all or the majority of concerned farmers, as well as planning and investment at both community and district level.

The intention with mangrove greenbelts is also to create a habitat for a wide range of mangrove species and therefore this habitat needs a gradient between the old dyke at the waterway and the new dyke, from dry at mean low tide (MLWS) to submerged/flooded at highest tide (HHWS).



Figure 11: Shovel and raft used to dredge the pond and collect sediment to build the dyke (© Roel Bosma)



Figure 12: An image of the new dyke with the bamboo screens, attached to each other with iron wire, still in place, and the old river dyke in the background (© Roel Bosma)

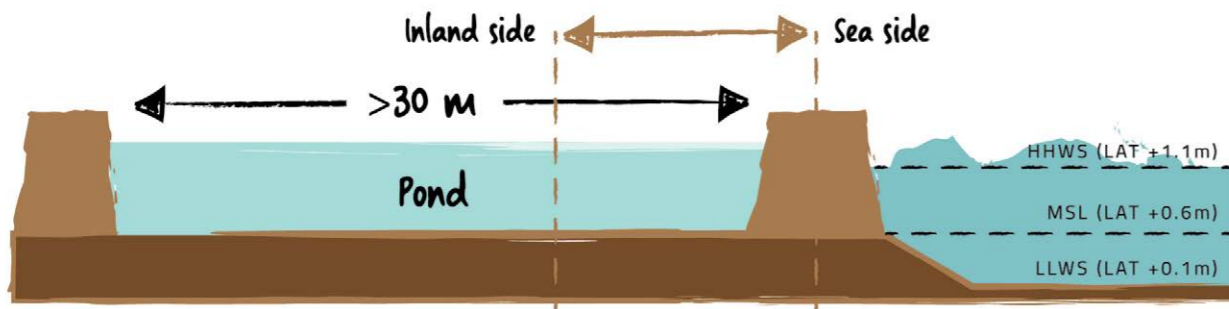


Figure 13a: Original condition of the pond.

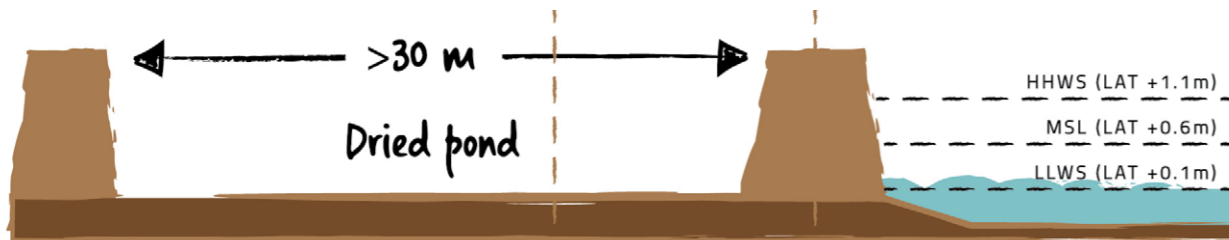


Figure 13b: Before starting the construction, the pond should be dried during LLWS.

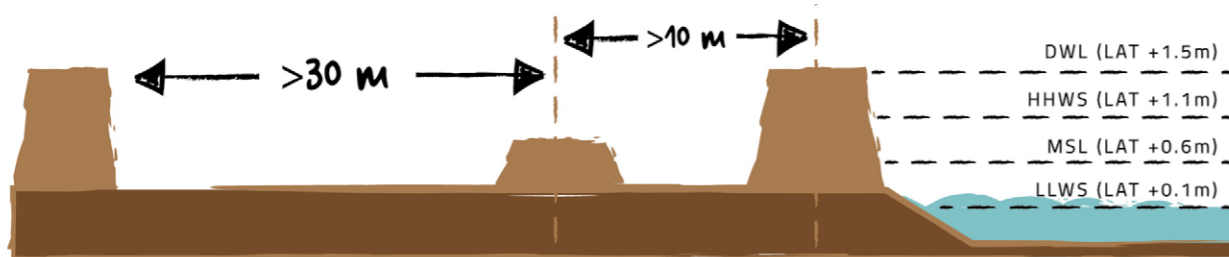


Figure 13c: The dyke is shifted 10m or more inland. The new dyke will be constructed in stages to allow the soil to dry and compact. Its crest is designed at LAT +2.0 m; this is 0.5 m above Design water level (DWL). DWL is summation of HHWS, land subsidence and sea level rise for 2 years design life time.

Figure 13: Staging the Dyke Construction of an Associated Mangrove Aquaculture system (© Weny Sihombing)

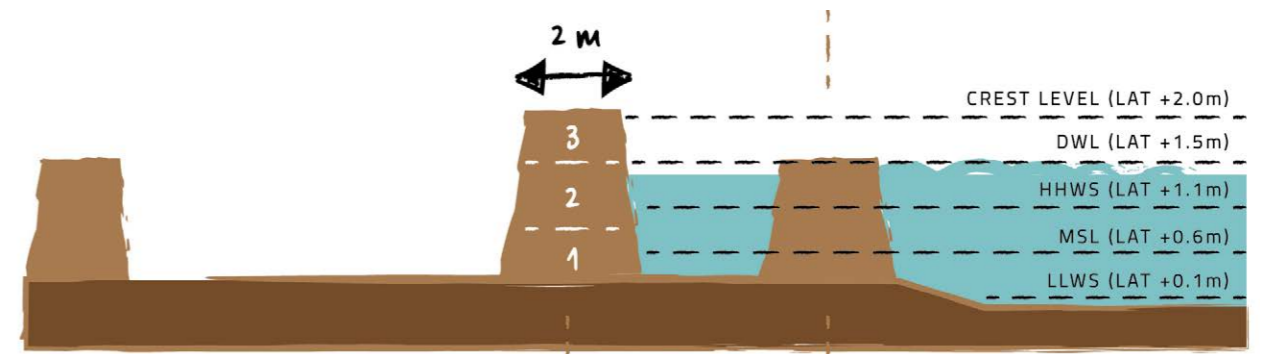


Figure 13d: The slope of the dyke can be the same as the pond-owners experience, if unknown use 1:1.5 (V:H) for 1 m height of dyke. The higher the dyke, the milder the slope.

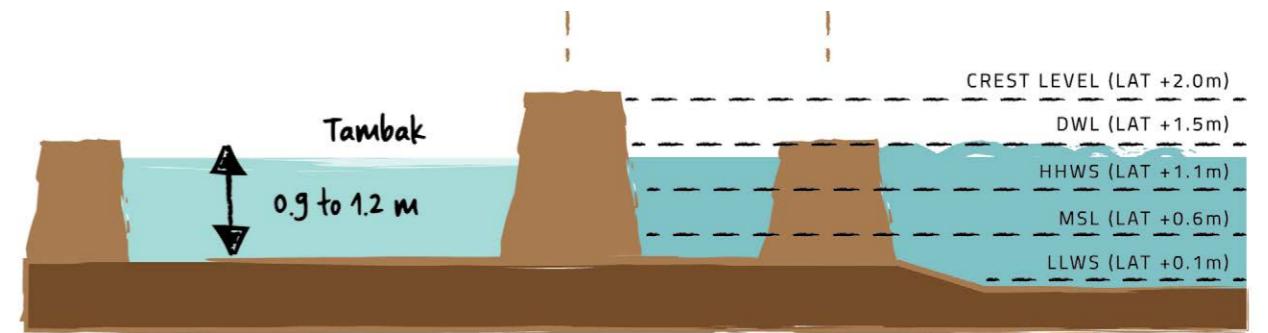


Figure 13e: Filling the pond with water.



Figure 13f: After the new dyke is constructed and the pond is filled with water, the old dyke can be adapted as a mangrove habitat, with moderate amount of fill material needed. The new habitat starts at HHWS, with length of minimum 10 m.

Figure 13: Staging the Dyke Construction of an Associated Mangrove Aquaculture system (© Weny Sihombing)

4 COMPLEX AQUACULTURE SYSTEMS AND OTHER INNOVATIONS

The pond farm at the bottom of figure 10 shows a complex AMA system with two extra reservoirs. The larger one is intended to filter, improve and store water before this water is transferred to the shrimp pond. In regions with many shrimp ponds or other sources polluting the water, farmers may also consider adding a separate sedimentation and recycling pond where water is cleaned before being reused either directly or through the filter pond.

Improving water quality helps to reduce disease outbreaks and improve shrimp growth. These improvements are based on ecological principles, just like LEISA. They use a mix of certain species to maintain optimum water quality⁴. For example, seabass or other carnivorous species in the filter pond reduce disease-transmitting crabs, and can also be harvested. *Tilapia* in the filter pond or in cages in the shrimp pond, help create a good balance between zooplankton and phytoplankton, while excreting a mucus that impedes the growth of disease-causing bacteria and viruses^{5, 20}. These systems are often called "green-water" systems. Appropriate numbers of Green mussel and *Gracilaria* in the filter pond can be used to remove excessive nutrients and organic matter²⁰. The seaweed *Colerpa* can also be used to purify the water.



Figure 14: Water hyacinth that has been shredded and will be used as compost for LEISA practice (© Cynthia Boll)

BOX 4: LOW EXTERNAL INPUT AND SUSTAINABLE AQUACULTURE (LEISA)

Low External Input Sustainable Aquaculture (LEISA) is based on a farming principle developed for agriculture. Inappropriate or excessive use of external inputs, particularly from synthetic chemicals, is avoided, to minimise pest resistance and destruction of the soil ecosystem. LEISA for brackish water farming aims to optimise the use of locally available natural resources (soil, water, plants) and inputs (e.g., animals, organic wastes) to complement and provide the greatest synergy in the agro-ecosystem of the farm. LEISA envisions to be a sustainable farming strategy that enables resource-poor farmers to reduce production costs, maintain a healthy agro-ecosystem, and obtain good yields of healthy produce. The LEISA principles for aquaculture are to:

- Maintain and enhance soil fertility using solid and liquid compost.
- Stimulate recycling of organic matter in the pond with liquid compost.
- Conduct pest and disease management through prevention and safe treatment.

The common input for a LEISA brackish water pond is organic fertiliser, either solid compost or liquid fermented waste (the latter called MOL in Indonesia). The decomposed organic matter of the compost maintains and enhances fertility on the bottom of the pond by improving the soil's physical and structural properties, and chemical and biological composition. The liquid MOL adds energy, minerals and micro-organisms to the pond water to stimulate the growth of natural feed for the cultured organisms by enhancing the recycling of both deposited and suspended organic matter, and favouring the growth of beneficial bacteria⁷.

Specific manuals on this type of Integrated Multi-Trophic Aquaculture are in preparation⁶. Some of these technologies are also useful for ponds outside the mangrove estuary.

Figure 15 shows farms with several small ponds. Experience and research show that farmers can better manage ponds smaller than 1 ha, if these are tambaks with a shallow central plateau and deep enough ditches along the dykes. The harvest and income generated from ponds of less than 1 ha may be double compared to ponds covering several ha, even when farmers apply LEISA (Box 4).

Farmers may think that the space is lost for production, but the final harvest and income will be higher because complex systems reduce the risk of harvest failure due to diseases. Investing time and money in dividing a pond into several smaller ponds seems a huge effort. However, it is simply the first step towards a more efficient use of a farmer's time and resources. Further training at a field school is another step towards improving productivity of aquaculture in Indonesia.

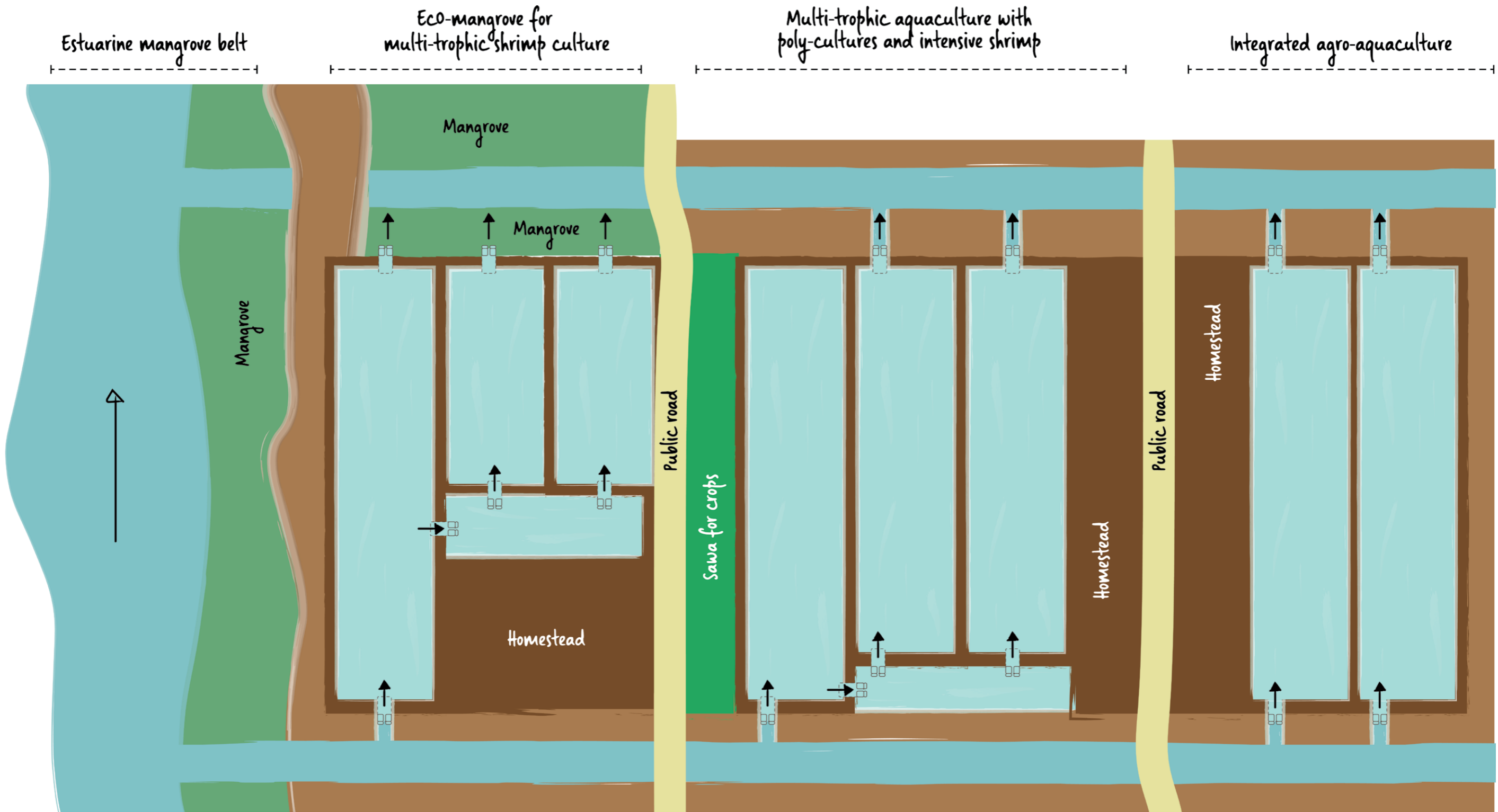


Figure 15: Landscape diagram of three farms sharing the mangrove greenbelt at the left, the inlet canal at the bottom, the outlet canal at the top and the sedimentation pond in the upper left corner. At low tide, the current of the waterway goes from bottom to top towards the sea. (© Roel Bosma)

5 MANGROVE RECRUITMENT OR PLANTING

The estuarine waters of the north coast of Java transport sufficient numbers of mangrove propagules, meaning that mangroves should establish without intervention. If the mangroves fail to establish naturally, this may be for one of several reasons: not enough propagules flow in, water level remains too high at low tide for mangrove re-establishment, or recruitment of propagules of inappropriate species. In our AMA design, the canal to the sluice gate will normally allow enough water in, but if not, a second opening in the old pond-dyke may be needed. If the water level is too high, moving soil from the pond and river will be necessary. Some species may be sufficiently abundant to recover based on natural recruitment without the need for costly planting. However, if water circulation is sufficient, the substrate is not too low, and the soil type is suitable, but propagules still cannot be seen, then planting might be a solution. For planting, propagules are preferred, as this method yields stronger plants.

The selection of mangrove tree species for planting should consider several factors (Figure 16). For example, most *Rhizophora* spp need fewer inundation days, while some species can even do with rainwater only. However, *Rhizophora* propagules generally do not grow well in seafront zones and need to be planted near the new pond dyke. Seafront planting is more successful using adapted seafront species, particularly *Sonneratia alba*, and by using taller, nursery reared saplings of at least 0.5 - 1 m height. Finally, *Avicennia* and *Sonneratia* spp can withstand daily inundation, making them appropriate for the waterfront, and their pneumatophores are excellent for entrapping sediment. *Bruguiera* spp are appropriate for the sloped part of the dyke, as they can do with very few inundation days.

Species of *Avicennia* and *Sonneratia* can be planted with low risk to aquatic production (Table 4). Leaves of most mangrove species provide a substrate for the growth of periphytic biofilms, and those of some *Ceriops*, *Rhizophora* and *Sonneratia* spp. have anti-viral effects. The decomposition of leaves of *Rhizophora apiculata* and *R. mucronata* is slower than in other species; decomposition demands oxygen while these species also contain high amounts of tannin and other toxic substances, making them less suitable. Several species can be pruned for fodder or used for other household and livelihood purposes. For use as fodder, species with a low C/N ratio are recommended.

SPECIES	LEAVES USED FOR			DR (%)	C (%)	N (%)	C:N	ROOT TYPES
	FEED	POND	HUMAN					
<i>Avicennia alba</i>	+	+	+	33	43	2.5	17	PE
<i>Avicennia officinalis</i>	+	+	+	34	47	1.9	25	PE
<i>Avicennia marina</i>	+	-	+	30	44	2.0	22	PE
<i>Kandelia candel</i>	+	+	+	23	47	1.5	31	-
<i>Sonneratia apetala</i>	+	-	+	29	44	1.8	24	PE
<i>Sonneratia caseolaris</i>	+	-	+	20	52	2.6	20	PE
<i>Xylocarpus mekongensis</i>	0	+	0	34	48	3.0	16	PE, B
<i>Lumnitzera racemosa</i>	0	-	0	23	44	2.0	22	-

Legends:

b = buttress k = knee pe = pencil
 pl = plank s = stilt - = non-pneumatophore

Table 4: Characteristics of mangroves that can be used in AMA, including known use of leaves (+ = confirmed; - = no information; 0 = not appropriate), leaf decomposition rate (DR) after six weeks, and approximate C/N ratio (Data source: Chanda et al., 2016), and the type of pneumatophore roots (Adapted from K-S Rahman, Md N Islam, M Uddin Ahmed, R H Bosma, A O Debrot & Md. N Ahsan, selection of mangrove species for shrimp based silvo-aquaculture in the coastal areas of Bangladesh. *Journal of Coastal Conservation* 24:59 <https://doi.org/10.1007/s11852-020-00770-8>).

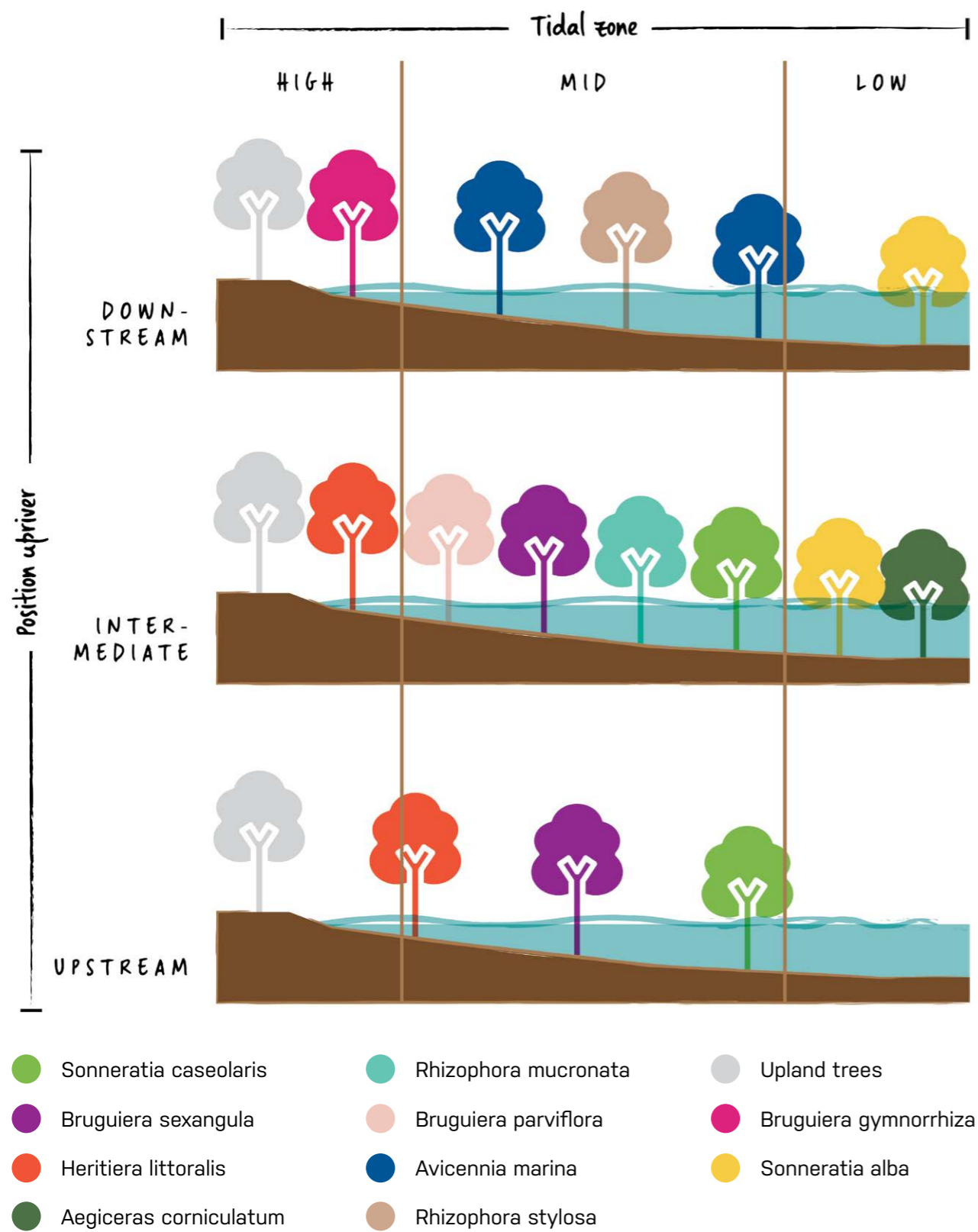


Figure 16: Location of mangrove species in the high, mid and low tidal zone, and the distance from the seafront, for Australia¹⁰. Most, if not all mentioned species also grow in Indonesia (adapted from: Duke, 2006).

6 BASELINE AND MONITORING

Establishing a baseline for productivity of aquaculture, fisheries, mangrove, and incomes, and subsequent monitoring of developments can be done through surveys of farmers, fishermen and their households. With proper training and support, farmers can learn to do most of this themselves (see next chapter, and Box 5).

Monitoring the sedimentation rate and soil level is easy to do by periodically measuring sediment height in relation to reference poles. The recovery of mangroves can be followed by regular counting of individuals per species and estimation of plant height by the farmers themselves or a representative of the community.

BOX 5: EVALUATION OF AQUACULTURE CROP AFTER HARVEST.

1. After harvest, the farmer can calculate feed use efficiency better known as Feed Conversion Ratio (FCR). As for intensive farming of tilapia and shrimp, feed is the highest cost factor, and FCR gives a quick indication of the efficiency.
2. The FCR is calculated as: *Total Feed Distributed* divided by *Total Harvested Weight*.
3. For tilapia and shrimp in ponds the FCR should be below 1.2, when using a factory pellet. FCR from home-made feed is mostly higher, while the feed is cheaper.
4. The farmer can also calculate financial results, considering all factors of cost, such as land and taxes, income, and harvest used by the household. Dividing the benefit by the estimated number of labour days, allows comparison of the profit margin with industrial wages.

In each pond, farmers should monitor water quality parameters, such as pH, salinity, temperature and water colour, as they are normally advised to do. The intake water quality can be expected to improve gradually as the mangrove forest grows and starts fulfilling its bio-filtering role. However, this concerns mainly chemical parameters, such as alkalinity and hydrogen sulphide (H₂S), that farmers are not able to measure. These can be monitored in the river or canal and at the intake point of the ponds by scientists or fisheries extension officers.

7 ACCOMPANYING MEASURES AND POST-BUILDING ACTIVITIES

The Building with Nature project in Demak used the Bio-Rights financial incentive mechanism to provide the larger investments required to enable AMA construction. Bio-Rights is an innovative financing mechanism for linking poverty alleviation and environmental conservation¹¹. The mechanism provides micro-credits along with technical support to implement sustainable development measures while stimulating nature conservation and restoration. Upon successful implementation of measures these micro-credits are converted into definitive payments (grants). The Bio-Rights financing mechanism is dependent on central management and external funding sources. In the case of Demak, the bio-rights mechanism involved the creation of 10 formalized community groups in 9 villages. These community groups received training and advice on group management, engagement with policies and planning, as well as in sustainable aquaculture, alternative livelihoods and mangrove restoration.

Once their AMA system is completed, farmers are advised to participate in Stakeholder Innovation Platforms (SIP) and Saving Clubs (See chapter 8 and the Guidelines on CFS). The SIPs can organise learning sessions on using LEISA for other species, or on improving pond infrastructure, for instance, through a separate green-water pond. Farmers can use the money from a saving club to improve their ponds e.g. by making a complex AMA system. A group saving club approach is generally only suitable for more limited capital expenditures.

In Indonesia, an additional benefit of community groups or savings clubs is that formal groups can apply for government assistance through a variety of programs. Indeed, several of the community groups in Demak have already been able to access government funding.

8 SOURCES FOR MORE INFORMATION AND SUPPORT

This guideline touches on many topics relevant to aquaculture and the mangrove coastline. Background information can be found in other guidelines of this series and in the following documents:

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COASTAL AQUACULTURE FIELD SCHOOLS

18. Blue Forest: www.blue-forests.org; info@blue-forests.org; +61 411 440443. For the complete curriculum guidelines and the questionnaires.
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Coverphoto credits: @Eko Budi Prianto, Wetlands International



APPENDICES

X APPENDIX 1

Some of the usual silvo-aquaculture systems in Indonesia that do not provide sufficient ecosystems services and are therefore not advised for effective and sustainable Building with Nature.

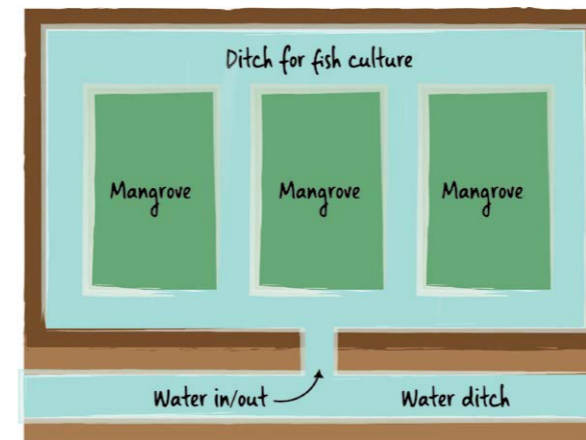


Figure 17a: Regular fishpond with ditch and one-gate water inlet system and three mangrove platforms, called Model Empang Parit Tradisional (Sofiawan, 2000). Officially recognised by the Ministry of Forestry (2004) as the third of four silvo-fishery options (Illustration adapted from: Audrie Siahainenia).

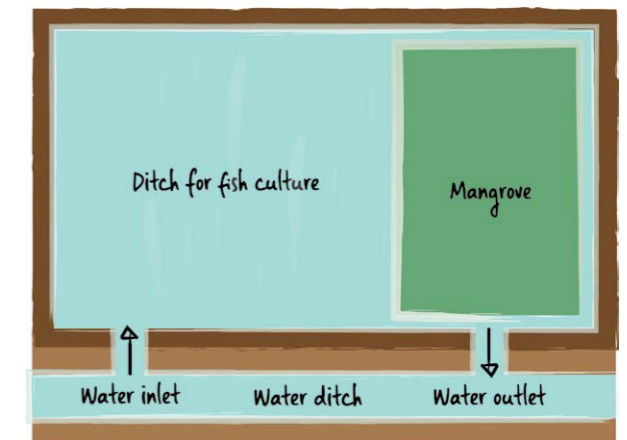


Figure 17b: Modification from regular ditch fishpond without central dyke, called Model Komplangan (Sofiawan, 2000). Officially recognised by the Ministry of Forestry (2004) as the second of four silvo-fishery options (Illustration adapted from: Audrie Siahainenia).

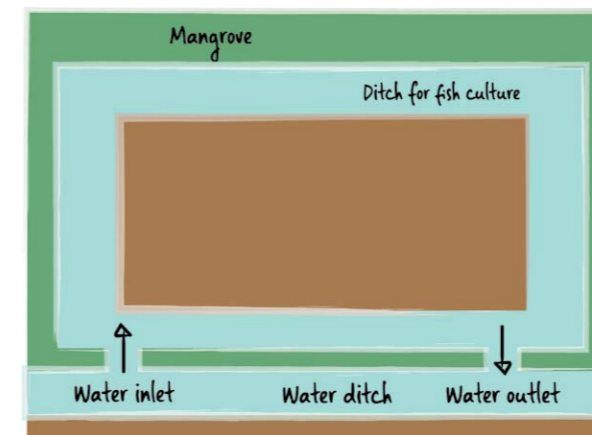


Figure 17c: Open fishpond type (Model Empang Terbuka) with two-gate water inlet system, elevated bank (Sofiawan, 2000). Officially recognised by the Ministry of Forestry (2004) as the fourth of four silvo-fishery options. Local communities tend to use this option, some also without the elevation. It is then known as the tanggul model (Illustration adapted from: Audrie Siahainenia).

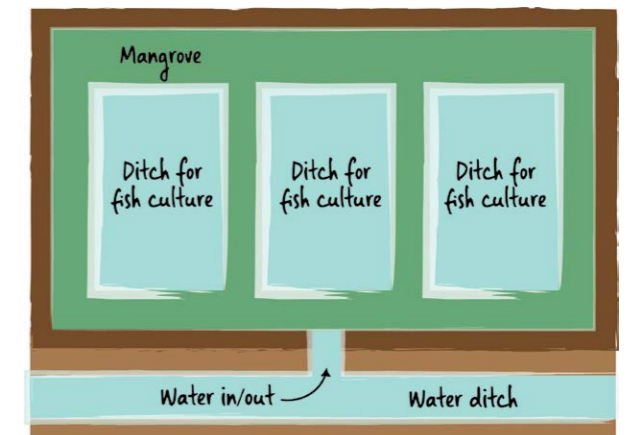


Figure 17d: Kao-Kao model with three separate ditches one-gate water inlet system. The water can flow from ditch to ditch, depending on tide (Sofiawan, 2000). Note that the lighter coloured areas are channels, not dykes (Illustration adapted from: Audrie Siahainenia).

Source: Effects of different management regimes on mangrove ecosystem services in Java, Indonesia. Van Oudenhoven, A.P.E., A.J. Siahainenia, I. Sualia, F.H. Tonneijck, S. Van der Ploeg and R.S. de Groot Technical paper for the 'Mangrove Capital' project. December 2014



Tiger shrimp produced from a revitalization pond belonging to Pak Syafa'adi, one of the Ongojoyo Jaya community group members in Gojoyo Hamlet, Wedung Village (© Pak Maksur)

X APPENDIX 2

LIST OF ABBREVIATIONS

Abbreviation	Description
AMA	Associated Mangrove Aquaculture
CFS	Coast Field Schools
cm ²	Centimeter/square meter
DWL	Design Water Level
ESS	Ecosystem Services
EUR	Euro
FCR	Feed Conversion Ratio
ha	Hectare
HAT	Highest Astronomical Tide
HHWS	Highest High Water Spring
IDR	Indonesian Rupiah
kg	kilogram (weight)
LAT	Lowest Astronomical Tide
LEISA	Low External Input Sustainable Aquaculture
LLWS	Lowest Low Water Spring
m	meter (distance)
MHWS	Mean High Water Spring
MLWS	Mean Low Water Spring
mm	millimeter (distance)
MSL	Mean Sea Level
SIP	Stakeholder Innovation Platforms
TEV	Total Economic Value
USD	US Dollar
yr	Year

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