SHAMBA CENTRE for food & climate

Nature-based solutions in small-scale aquaculture to improve food security

Stories on early practice

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Contents

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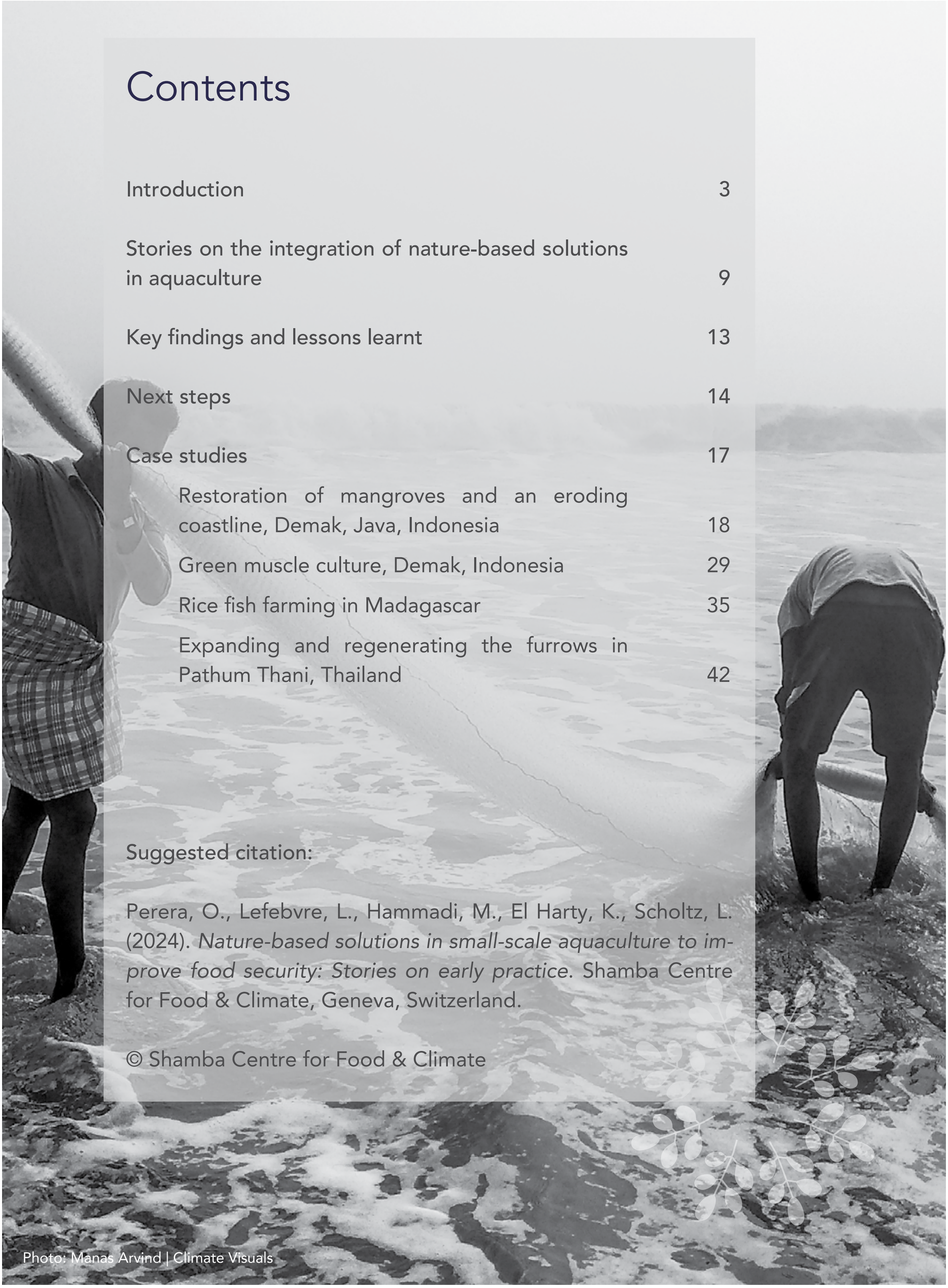


Photo: Manas Arvind | Climate Visuals

Introduction

The growing need for healthier diets to achieve global food security in the face of climate change and biodiversity loss requires new solutions for how we produce and consume food. This is particularly the case for proteins, including aquatic plants and animals. As the natural resource base and ecosystem services are the foundation of all food and agricultural systems, nature-based solutions can be used to deliver on food production while curbing climate change and restoring biodiversity.

Nature-based solutions are designed to optimize the delivery of ecosystem services including food and water; regulate diseases and climates; support the pollination of crops and soil formation, and more (Food and Agriculture Organization of the United Nations (FAO), 2023). Aquatic foods are rich in proteins and, depending on the species, are also rich in iron, zinc, calcium, vitamin A, and omega 3 fatty acids (DHA and EPA). They have the potential to improve food security and nutrition, and to improve the livelihoods of small producers (FAO, 2023).

What is aquaculture?

Aquaculture is the farming of aquatic organisms, including fish, mollusks, crustaceans and aquatic plants. Farming suggests some form of intervention in the rearing process to enhance production. This can be for example, regular stocking, feeding, and protection from predators. Farming also implies individual or corporate ownership of the stock being cultivated. For statistical purposes, aquatic organisms which are harvested by an individual or corporate body which has owned them throughout their rearing period contribute to aquaculture (Edwards & Demaine, 1997).

This research explores how nature-based solutions can contribute to small-scale aquaculture, and in this way increase access and availability of aquatic proteins for food security and nutrition.

Aquaculture includes a highly diverse array of farming practices, and encompasses many different species and systems with varied environmental impacts and nutritional values. It ranges from "marine bivalves, which require minimal input during grow-out, to filter-feeding freshwater finfish species (e.g., silver and bighead carps), to omnivorous finfish and crustaceans that commonly rely on plant-based feed with partial inclusion of fishmeal and fish oil, to carnivorous finfish, including tuna, which can consume up to 20 times their weight in wild fish" (Henriksson et al., 2021).

Aquaculture is one of the fastest growing food subsectors:

- It produces 50% of aquatic foods globally, and this is forecast to increase by 15% by 2030.
- In 2020, global aquaculture production was worth approximately USD 80 billion (FAO, 2022).
- The global aquaculture industry includes 20.5 million small-scale aquaculture producers and 37 million other workers, suppliers, and intermediaries (Pita, 2022).
- As a large proportion of their harvests are consumed by domestic populations, these producers are particularly important in increasing food security and nutrition (Pita, 2022).
- Aquatic foods also provide at least 20% of the average per capita intake of animal proteins for 3.3 billion people.
- While 88% of aquaculture production (excluding algae) takes places in Asia – China, Indonesia, India, Vietnam, and Bangladesh – small-scale producers contribute 80% of this volume (FAOs, 2022).

Photo: Shutterstock

50%
of aquatic foods globally is produced by aquaculture

US$ **80 bn**
global aquaculture production in 2020

3.3 bn people
receive at least 20% of their intake of animal proteins from aquatic foods

80%
of aquaculture production is from small-scale producers

Figure 1: The growing share of aquaculture in blue foods production

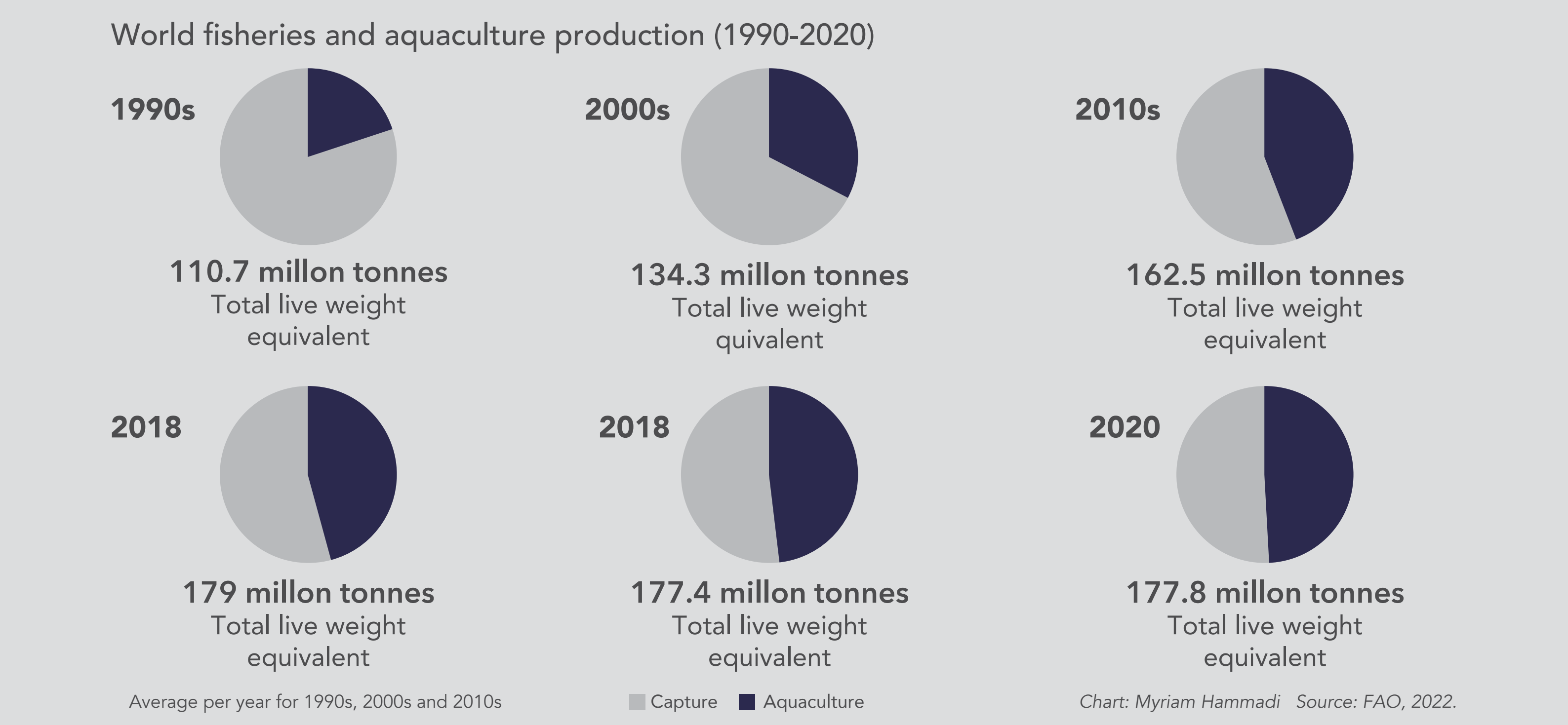
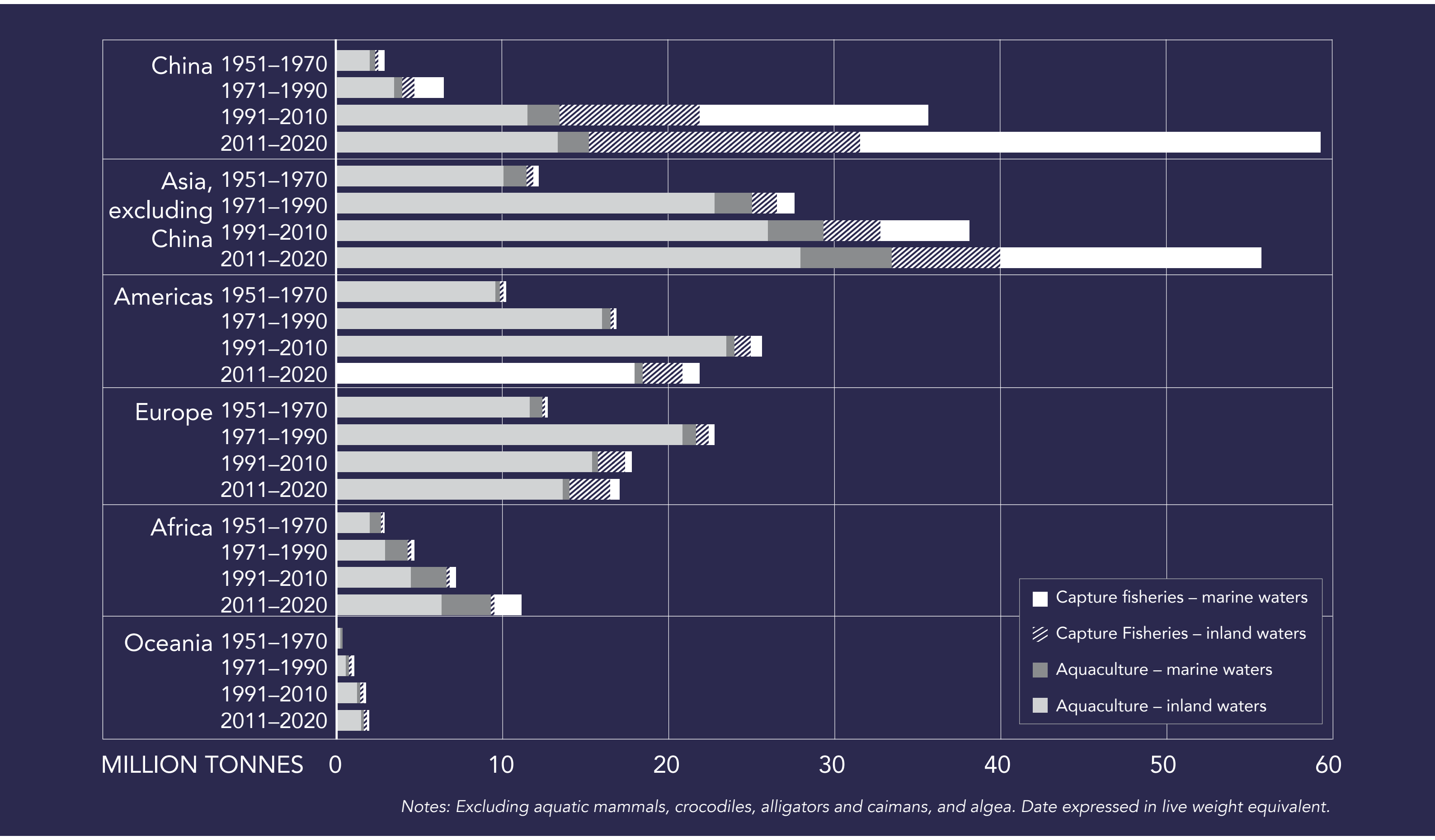


Figure 2: Regional Contribution to World Capture Fisheries and Aquaculture Production



Source: *The State of World Fisheries and Aquaculture 2022. Towards Blue Transformation*, Rome, FAO, 2022.

What are nature-based solutions?

The Fifth Session of the United Nations Environment Assembly (UNEA-5), in March 2022, made a resolution on adopting a multi-laterally agreed definition of nature-based solutions as,

> *"actions to protect, conserve, restore, sustainably use and manage natural or modified terrestrial, freshwater, coastal and marine ecosystems, which address social, economic and environmental challenges effectively and adaptively, while simultaneously providing human well-being, ecosystem services and resilience and biodiversity benefit"* (United Nations Environment Programme [UNEP], 2022).

The 'Resolution on Nature-based Solutions for Supporting Sustainable Development' also calls on United Nations Environment Programme (UNEP) to support the implementation of nature-based solutions that safeguard the rights of communities and indigenous peoples (UNEP, 2022). The FAO states,

> *"Nature-based Solutions (NbS) are being mainstreamed as an opportunity to guide the current development into a more sustainable path, with eco-friendly technology in line with nature"* (Arnés García & Santivañez, 2021).

The FAO 'Fisheries and Aquaculture Technical Guidelines Supplement on Ecosystem Approaches to Aquaculture' define the approach as,

> *"a strategy for the integration of the activity within the wider ecosystem such that it promotes sustainable development, equity, and resilience of interlinked social-ecological systems. Being a strategy, the ecosystem approach to aquaculture (EAA) is not what is done but rather how it is done. The participation of stakeholders is at the base of the strategy"* (FAO, 2010).

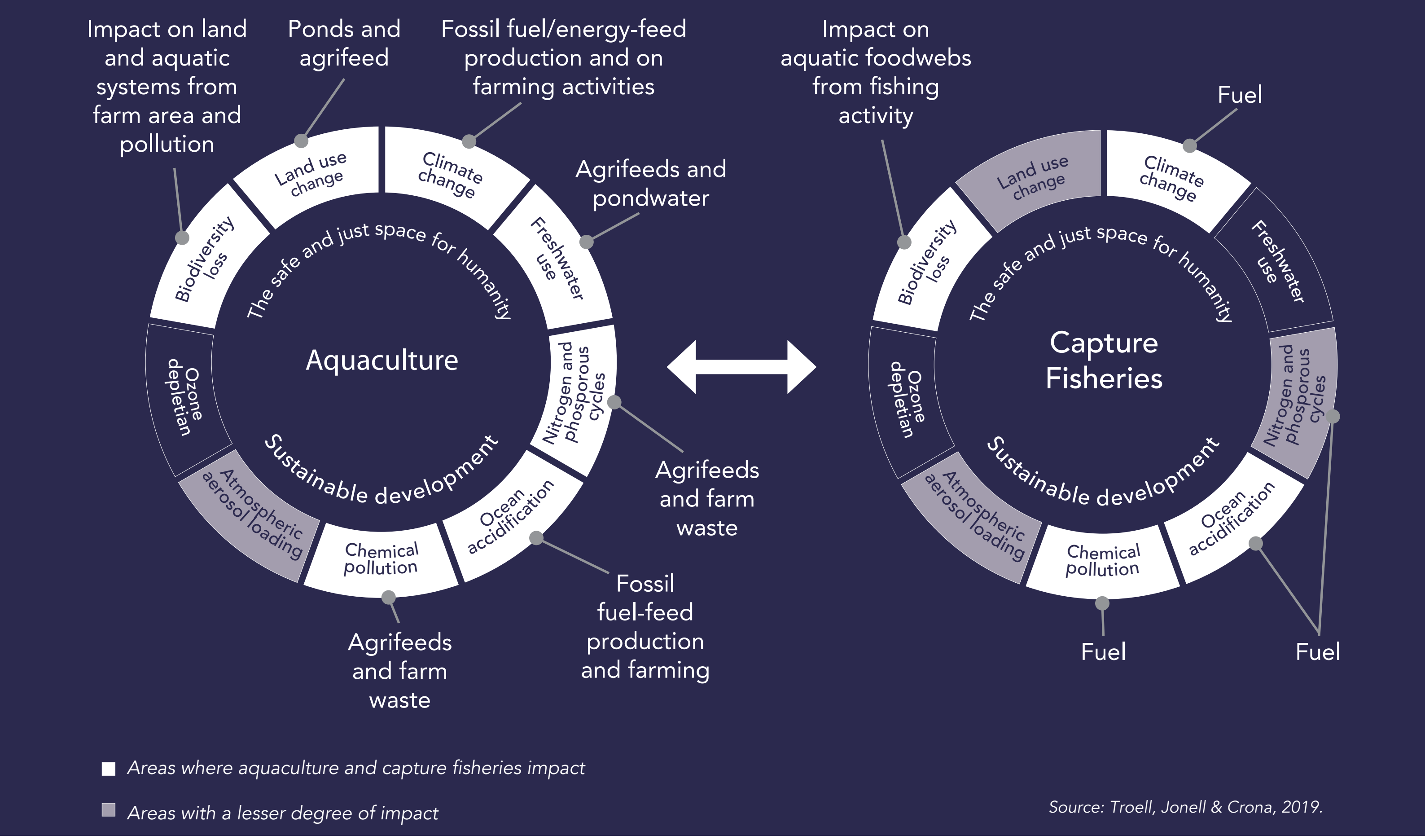
The United Nations (UN) Food Systems Summit 2021: Summary of Action Tracks, highlights the importance of nature-based solutions as part of the overall vision for transforming food systems towards sustainability, resilience, and equity (UN, 2023).

Challenges to the negative externalities of aquaculture

For the aquaculture sector to live up to its forecasted growth, it is increasingly important to reduce its negative environmental externalities.

Troell et al. (2019) point out that the impacts of aquaculture have been under-estimated because its "contribution and relationship to the various [planetary boundaries] have not been described in any coherent way". There is no "detailed estimate of global area of biomes converted to aquaculture, including on land", and "few comprehensive analyses identifying freshwater use for seafood production exist".

Figure 3: Schematic overview of how seafood, capture fisheries, and aquaculture, relate and contribute to impact on key planetary boundaries



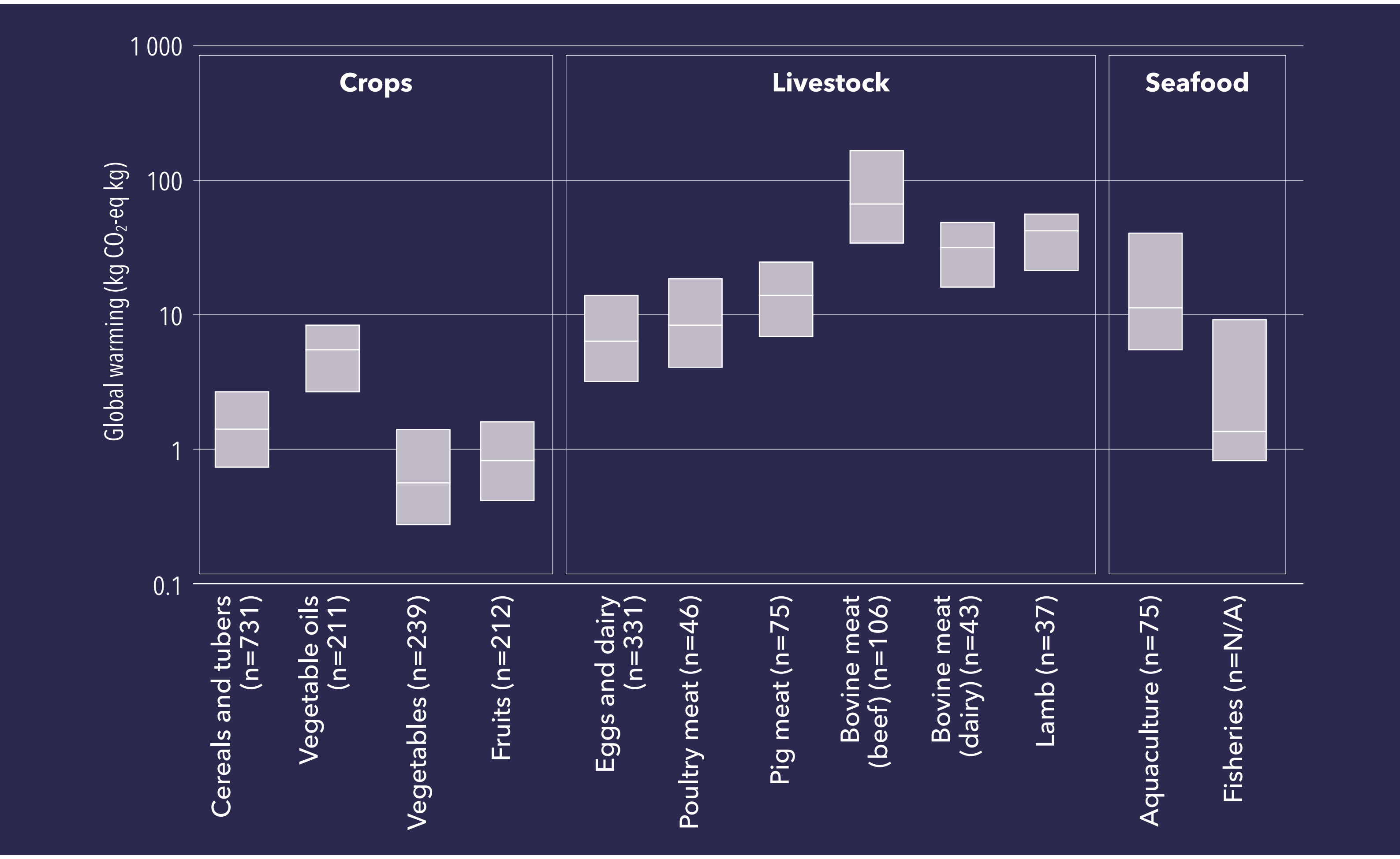
Source: Troell, Jonell & Crona, 2019.

Since 2022, the international press has regularly covered the algae blooms, fish deaths, and the human health impediments of intensive aquaculture all over the world, citing examples from Bangladesh to Scotland, and from Chile and Indonesia to Norway. These reports have included examples of direct greenhouse gas emissions from aquaculture feed and farm emissions, and pollution of natural water bodies from the poorly regulated and managed use of nutrients, synthetic inputs, and antibiotics.

There is also rising concern on the chemical and biological contamination of farmed species. The *EAT-Lancet Seafood Scoping Report* draws attention to the high levels of toxins – heavy metals, persistent organic pollutants, ciguatoxins (toxins from algea blooms), antibiotic residuals, and micro plastics – that can be found in fish. The concentrations of these contaminants can be higher in fish and seafood from enclosed waters (Troell et al., 2019).

Figure 4: Greenhouse gas emissions related to 1 kg of food commodities

Source: Troell, Jonell & Crona, 2019, p. 8.



Meeting future anticipated on demand must include reducing the environmental footprint of aquaculture, which will require changes to how seafood is produced to limit its impact (Troell et al., 2019). "Fulfilling the potential of aquaculture to contribute positively to food system transformation will require better accounting of the environmental performance of different types of production systems, and interventions that facilitate upscaling of aquatic farming to support sustainable diets" (Henriksson et al., 2021).

Stories on the integration of nature-based solutions in aquaculture

This section discusses stories of nature-based solutions in small-scale aquaculture and designs that aim to deliver on a range of ecosystem services, including but not limited to, food security along with improved livelihoods for small producers. These designs seek to mimic nature and build with nature. They are pluri-disciplinary and integrate biological sciences, hydrological and ecological engineering, principles and practices from agroecology and permaculture, aquaculture, and ecosystem restoration to manage natural ecosystems. The common goal of all these stories is to optimize the delivery of aquatic foods and ecosystem services to improve livelihoods, food security, and to protect and restore nature.

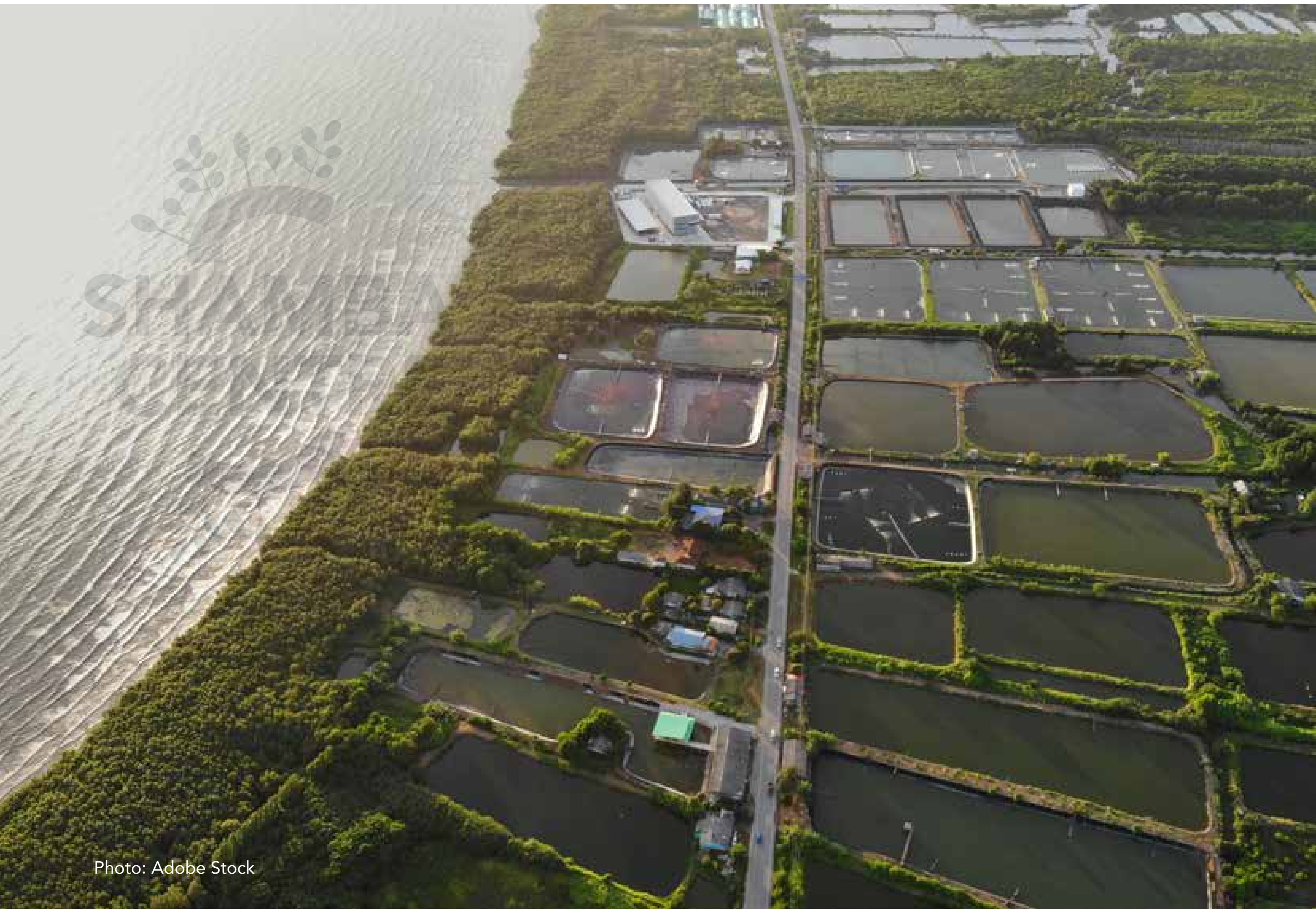


Photo: Adobe Stock

An overview of the different approaches of nature-integrated aquaculture is provided in the tables on pages 10–12. Several of these approaches are available as separate case studies.

Approaches integrating nature-based solutions in aquaculture

Nature-integrated approach	Characteristics	Benefits
A. Mangrove integrated aquaculture	• Farming fish, bivalves (clams, mussels, oysters, and scallops) and algae in ponds or structures that are built to be independent of the surrounding mangrove ecosystem. • Makes the best use of the ecosystem services and biological resilience of the mangrove ecosystem. • Builds on and integrates traditional knowledge. • Greatly reduces dependance on synthetic inputs.	• Improved food security and nutrition for coastal communities. • Improved household income. • Increased resilience to extreme weather, storm surges erosion.

Stories

Building with Nature, Demak, Java, Indonesia

The award-winning project improved food security and livelihoods for hundreds of small aquaculture producers. The design integrated the following:

- restoration of 200 km of mangrove forests
- innovation in the siting of aquaculture ponds adjacent to the mangroves (and not within them)
- practising low external input aquaculture that optimized on the nutrients accumulated by the mangrove forests
- coastal field schools to provide farmers with ongoing learning and innovation
- additional income through *bio rights*, payments for maintaining the mangrove ecosystem.

The cost-benefit analyses are included in the *Building with Nature* case study on page 18.

Green Muscle Culture, Demak, Indonesia

The idea to farm green muscles in the estuary in front of the regenerated mangroves in Demak, originated at the coastal field schools established under the *Building with Nature* project.

Muscle beds, or rather muscle anchors, are constructed in the estuary, in front of the mangrove greenbelt 3–6 kms from the shoreline. These are vertical structures made of bamboo and rope, which are available locally, are inexpensive, and can withstand coastal conditions.

The mangrove integrated estuary is rich in nutrients from the sediment accumulated by the mangrove roots, as well as from the ‘litter’ provided by the leaves. The roots filter toxins and heavy metals which creates a healthy coastal ecosystem.

The cost-benefit analyses are included in the *Green Muscle Culture* case study on page 29.

Nature-integrated approach	Characteristics	Benefits
B. **Reef integrated aquaculture**	• Farming fish, bivalves, and algae adjacent and above regenerated and constructed reefs. • Extremely low or no external inputs. • Can include cages, ropes, and other structures suspended above and around the reef. • Benefits from the nutrients and biological stability of the reef ecosystem.	• Improved food security and nutrition for coastal communities. • Improved household income. • Increased resilience to extreme weather and storm surges.

Nature-integrated approach	Characteristics	Benefits
C. **Integrated multi-tropic aquaculture (IMTA)**	• Mimics the biological interactions of species living in different trophic habitats and occupying different niches in an ecosystem. In natural ecosystems, the waste of finfish is absorbed by heterotrophic species, such as bivalves and sea cucumbers, as well as by autotrophic species, such as algae and plankton. IMTA mimics these interactions in the farming of fish, bivalve, and algae. • Follows a closed looped circular economy design. • Farming can be done in the same pond or cage, or in successive monoculture ponds or cages. For example, fish, bivalves, and algae farmed in different, but successive ponds. • Provides for the integration of recirculating aquaculture systems that use mechanical and biological filters to purify and reuse water in aquaculture. • Reduces water use and the discharge of polluted effluents when compared to intensive aquaculture. • The suspended solids farms can be processed into fertilizer or used for the production of bio-gas. • Reduces dependance of synthetic inputs.	• Can be used in rural and urban settings. • Can be scaled from small back garden installations to larger extensive farms. • Improved food security and nutrition in coastal and inland areas. • Improved household income. • Provides solutions for aquaculture in water-scare regions.

Nature-integrated approach	Characteristics	Benefits
D. **Integrated agriculture and aquaculture**	• Farming of fish and crops in the same field or pond. • Mimics the biological interactions of species living in different trophic habitats and occupying different niches in an ecosystem. • Builds on local knowledge and expertise. • Reduces dependance of synthetic inputs.	• Improved food security and nutrition through diversified yields. • Improved household income.

Stories

Rice-fish farming in Madagascar

By integrating fish farming into rice cultivation, small farmers are producing fish and rice harvests in the same fields. Farming is undertaken with no synthetic chemicals and builds on the high symbiotic relationship between carp and tilapia and the rice paddies. Farmers find that on average, rice-fish farming yields are 10% to 20% higher than when farming rice alone. Household incomes are diversified, and food security and nutrition are improved.

See case study on page 35.

Fish farming in the furrows, Pathum Thani, Thailand

In the 1980s, farmers in the Thai province of Pathum Thani were looking for solutions to improve their food security, access to water, and their livelihoods. Traditionally the main crop grown in Pathum Thani was rice, but the rice fields were becoming increasingly vulnerable to flooding and drought due to extreme weather. The farmers had tried to diversify and grow more climate-resilient crops, but rainfed agriculture was no longer viable and irrigation was inadequate.

The farmers innovated by regenerating and altering the furrows –small, shallow ditches on the rice paddies, as follows:

- They dug the furrows deeper and wider, and expanded their network and connectivity across the fields.
- The farming cooperatives restored the connectivity of the furrows to the main river canals using locks and gates. This helped control the flow of water during rainy and dry seasons.
- As the water flowing though the furrows improved, farmers began to diversify into farming catfish and tilapia which could be harvested twice a year.

See case study on page 42.

Key findings and lessons learnt

There are several common threads that run through the stories presented in section 2:

1. **Nature-based solutions take a whole-of-system approach** and can provide whole-of-systems benefits, including food, ecosystem services, and biological resilience in the longer-term. This is demonstrated in the cost-benefit analyses and anecdotal evidence presented in the stories.
2. **Nature-integrated design requires the careful management of all inputs including feed**. The entire system is designed to optimize the recycling of nutrients and energy with the ecosystem, and increase its biological diversity and resilience. This optimizes the efficiency of natural self-sustaining food webs and reduces the reliance on external feed. Emphasis is placed on natural feed, using local ingredients from agriculture and kitchen waste.
3. **There is neither one standard recipe nor one design that can be scaled to fit all**. Solutions are designed to suit the ecosystem at hand, taking into account the competing and conflicting demands by the different stakeholders that depend upon it.
4. **Nature-integrated aquaculture requires pluri-disciplinary expertise** that ranges from biological and marine sciences to hydrology, engineering, agriculture, aquaculture, and landscape design. Designs can be tailored to meet a landscape, farm, or pond.
5. **People are at the core of the design**. Nature-based solutions are designed to meet the priorities of the stakeholders and communities that stand to gain benefits to their food security and livelihoods.
6. **Nature-integrated design is not a panacea. Implementation takes time and early design can fail**. Continuous trial, error, and adaptation is needed to reach the optimum level of delivery. For example, in the *Building with Nature* project in Demak, Indonesia, early efforts to regenerate mangroves (that could help to subsequently increase aquaculture productivity) were not successful due to land subsidence, caused by the draining of aquifers by nearby cities.

While anecdotal evidence of nature-integrated aquaculture abounds, there is very little recorded data on their results – be it on the harvests of aquatic animals or the increase of wider ecosystem services. Stakeholder consultations on sustainable aquaculture afforded the authors the opportunity to engage with many entrepreneurs, producers, designers, researchers, journalists, and NGOs. They all provided examples of nature-integrated aquaculture projects, but most had few records on costs and benefits.

Many stakeholders also remain sceptical about whether nature-based aquaculture can generate sufficient aquatic animals and plants to feed the world. They argue that while such designs can certainly improve food security and nutrition, and diversify the income of marginalized communities and small-scale producers, more intensive designs are needed to meet rising global demand for sustainable proteins. This is a valid point. There is certainly a need for further experimentation research to compare the whole-life costs of nature-integrated designs with more intensive approaches.

Next steps

International efforts on small-scale aquaculture and nature-based solutions are increasing. Sustainable aquaculture is included in both national food systems' pathways and nationally determined contributions (NDCs) under the Paris Agreement. The FAO reports that, of the 85 new or updated NDCs submitted between 1 January 2020 and 31 July 2021, 62 of 77 with adaptation components included artisanal fisheries, aquaculture, and ocean and coastal zone management (Crumpler et al., 2021).

Similarly, on nature-based solutions, the UNEP reports that by 1 May 2021, 55 Parties to the Paris Agreement had submitted updated or revised NDCs, of which 44 referred to nature-based solutions for mitigation. An increasing number of NDCs had quantifiable targets (Bakhtary et al., 2021), and the number of NDCs that referenced wetlands or coastal ecosystems also increased (UNEP and International Union for Conservation of Nature (IUCN), 2021).

This is good news as it may bring more opportunities for stakeholders working on aquaculture and nature-based solutions to exchange experience and work together. This is good news as it may bring more opportunities for stakeholders working on aquaculture and nature-based solutions to exchange experience and work together. Most nature-based solutions target climate resilience and the restoration of biological diversity, while the production of food is almost an afterthought. Similarly, sustainable aquaculture experts may fail to consider climate and biodiversity gains for nature-integrated 'extensive' designs. This is a missed opportunity.

The FAO's *The State of World Fisheries and Aquaculture 2022, Towards a Blue Transformation* states unequivocally, "In the next ten years, aquaculture must expand sustainably to satisfy the gap in global demand for aquatic foods, especially in food-deficit regions, while generating new or securing existing sources of income and employment. This requires updating aquaculture governance by fostering improved planning, legal and institutional frameworks and policies" (FAO, 2022).

An example of a response to FAO's call for bolder governance on aquaculture is the *EU strategic guidelines for a more sustainable and competitive EU aquaculture for the period from 2021 to 2030*. It makes strong recommendations on how aquaculture can contribute to climate, pollution control, and aquatic biodiversity and sustainable competitiveness (European Commission, 2021).

In addition, following FAO's call for sustainable expansion of aquaculture, the work of the IUCN on synergies between the IUCN Global Standard for Nature-based Solutions and its application to aquaculture may provide an important starting point. In 2022, IUCN published preliminary findings on the application of the IUCN Global Standard to several near-shore and on-shore nature-based aquaculture projects around the world. The results indicate that while there is potential to greatly increase nature-integrated aquaculture (referred to by IUCN as ecosystem approaches to aquaculture), there is a need to recognize parallel solutions that are not 'dependant' on natural ecosystems but mimic natural processes in an artificial setting (le Gouvello et al., 2022).

As extreme weather events become more frequent and global demand for fresh water is set to outpace supply by 2030, aquaculture will be in more demand amongst the industries that are hardest hit. Aquaculture on land will face acute shortages of water, while near-shore and on-shore aquaculture will face more frequent storms and erosion. Moreover, even very small changes in temperature can have a direct impact on the species being farmed, and new pathogens and diseases may emerge which could have serious consequences for yields, incomes, businesses, and livelihoods. This makes innovation on sustainable and nature-integrated aquaculture both important and urgent.

Examples of dispositions from *The strategic guidelines for a more sustainable and competitive EU aquaculture for the period 2021 to 2030* that promote ecological intensification:

- **The need for a new EU strategy for aquaculture:** "This sector can also help: decarbonise the economy; fight climate change and mitigate its impact; reduce pollution; contribute to better preserving ecosystems (in line with the objectives of the Biodiversity strategy and the Zero-pollution ambition for a toxic-free environment); and be part of a more circular management of resources".
- **Climate-change adaptation and mitigation:** "Energy consumption and carbon emissions from production, transport and processing must be reduced as much as possible"; "certain types of aquaculture, such as the cultivation of seaweed and molluscs, can provide climate-mitigation services (such as carbon sequestration)".
- **Access to space and water:** "(Spatial) planning should also take into account the adaptation of aquaculture to climate change, as well as the potential of certain types of aquaculture to mitigate the impact of climate change (e.g. carbon capture or preservation of ecosystems that provide for protection against extreme weather events)".
- **Environmental performance:** "When properly managed, aquaculture can also be a method of protein production with a lower carbon and environmental footprint than other types of farming. Furthermore, certain forms of aquaculture (e.g. mollusc farming, aquaculture in ponds and wetlands, and the farming of algae and other invertebrates), when appropriately managed, can offer many ecosystem services. These services include the absorption of excess nutrients and organic matter from the environment or the conservation and restoration of ecosystems and biodiversity".
- **Access to space and water:** "Special attention should be given to the development of aquaculture with a lower environmental impact (such as combining certain types of farming to further reduce the emissions of nutrients and organic matter into the environment)".
- **Animal health and public health:** "The need to better prevent disease and parasite infestation and thereby reduce the need for veterinary medicines; the need to reduce the use of pharmaceuticals, including antimicrobials and anti-parasitic substances, which may damage the environment or contribute to antimicrobial resistance".

Source: European Commission, 2021.

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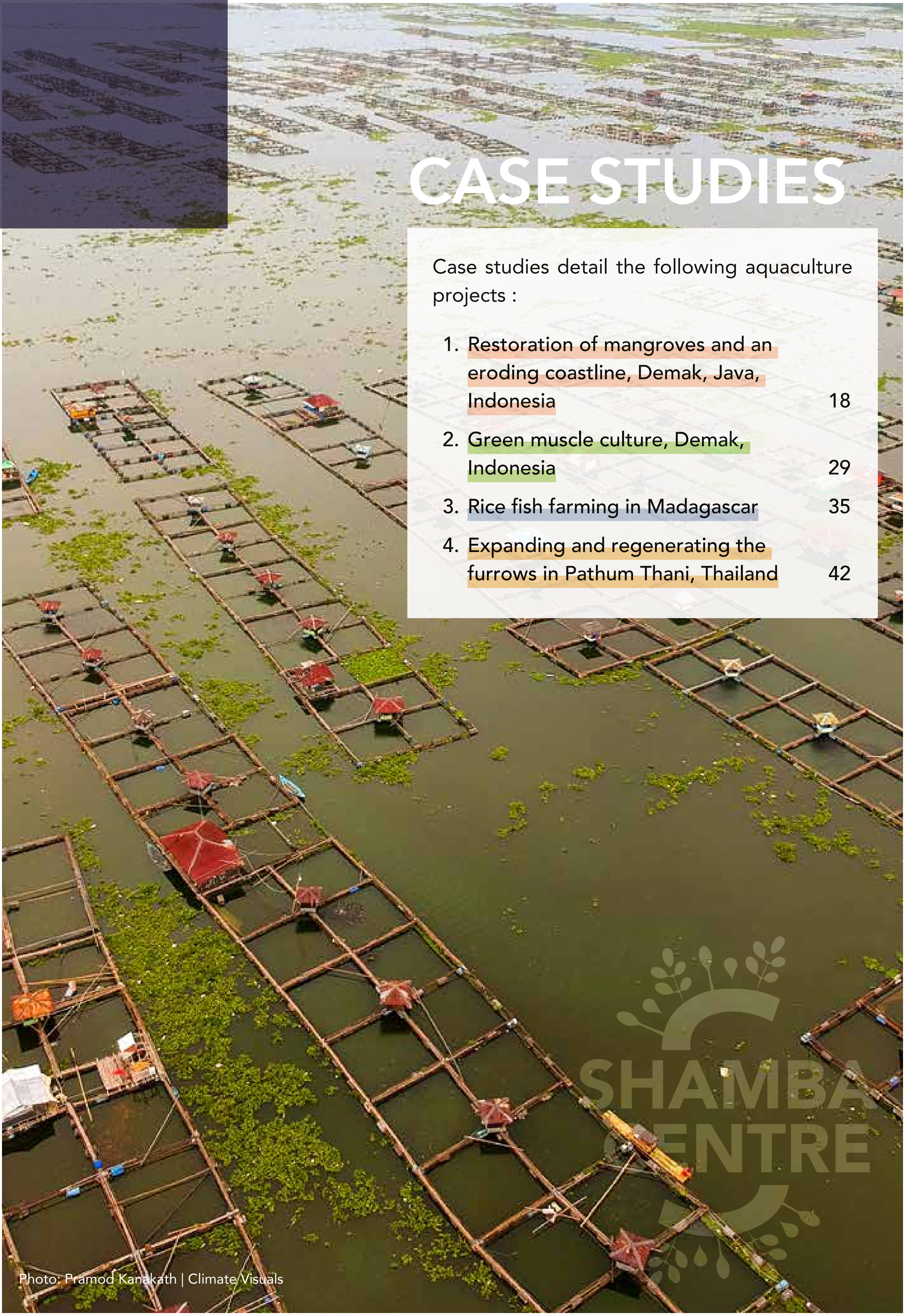


CASE STUDIES

Case studies detail the following aquaculture projects :

Photo: Pramod Kanakath | Climate Visuals

Case study 1

Improving food security, nutrition, and livelihoods through restoring mangroves and an eroding coastline, Demak, Java, Indonesia

/ Dr Roel H. Bosma, Sustainable Agriculture Production System Expert, Nedworc Foundation
Oshani Perera, Co-founder and Director of Programmes, Shamba Centre for Food & Climate
Henk Nieboer, Owner and Consultant, Adelta

In 2023, the Food and Agriculture Organization (FAO) of the United Nations, and the United Nations Environment Programme (UNEP) recognized Building with Nature project as one of the ten best pioneering World Restoration Flagship projects. The award was part of the United Nations Decade on Ecosystem Restoration.

About the project

A collaboration between Wetlands International, Ecoshape, the Indonesian Ministry of Marine Affairs and Fisheries, the Indonesian Ministry of Public Works and Housing, and several NGOs and universities based in the Netherlands and Indonesia implemented the *Building with Nature* project in Demak, Central Java, Indonesia between 2015 and 2021, The Netherlands Sustainable Water Fund provided core funding, with additional contributions provided to the Wageningen University by the Netherlands Ministry of Agriculture, Nature and Food Quality.

The Demak coastal district, located near the Central Java capital Semerang has long endured coastal erosion, floods, and land loss due to heavy storms. This situation has worsened with climate change, sea level rise, and the destruction of natural mangroves across the coastline. The region has also suffered land subsidence due to excessive groundwater extraction in and around Semerang.[1]

1 Land subsidence occurs when ground water is extracted and the deeper layers of the soil dry out and become compacted. This, in turn, lowers the surface of the land, which then increases erosion in coastal areas, as the land surface becomes lower than that of the sea.

To slow down the erosion and to prevent further losses from floods and storms, the provincial government has built canals and sea walls. However, these have resulted in several challenges. The canalisation of rivers has lowered the availability of riverine mud along the coastline while the sea walls have disrupted the sediment and water flows along the coast. Erosion continued along the coast, and near-shore and on-shore aquaculture activities, thus threatening the main livelihood for the fisher communities in Demak.

Between 2000 and 2015, approximately 70 000 people and 6 000 hectares of aquaculture ponds were exposed to the risks of flooding and land subsidence. Income from aquaculture decreased by 60% to 80% when compared to the late 1990s. Simulation studies conducted by Deltares indicated that the high subsidence rates alone would cause the rapid loss of coastal areas over the next ten years. The local communities, the local municipalities, and the Indonesian Government sought an alternative approach and launched the *Building with Nature* project in 2015.

The design – Part 1: Securing the shoreline

According to well-established research, mangroves along shorelines can reduce wave height by 13% to 66% and thus significantly reduce the impacts of storm surges. For this reason, the project selected a mangrove-integrated design.

In 2015, *Building with Nature* began working with local communities to build and maintain semi-permeable structures, such as fences, in the coastal mud 50–100 metres from the shoreline. In the beginning, these fences were made with locally found brushwood and bamboo. Some, destroyed by the tides, needed to be replaced while parts of other fences, damaged by shipworms, needed constant maintenance to increase their resistance and longevity. Ultimately, the project designers placed hollow PVC poles in the coastal mud which were filled with concrete. As such, the structures mimicked the roots of mangroves, and could slow down the currents and trap the sediment transported by the tides.

> Several villages that had suffered substantial losses in food and livelihoods offered nearly 80 hectares of near-shore aquaculture ponds to plant these fences. The entire exercise sensitized the local communities to the interdependence between the mangroves, aquaculture harvests, household income, and food security. For several decades these villages had farmed oysters, crabs, and fish using mangrove-integrated designs, but from the 1990s, they had started to cut down the mangroves to make way for larger ponds.

In 2017, however, the project partners noticed differences between the newly regenerated mangroves. Some grew to about 1 metre in height, while others, especially those closer to Semerang, were washed away by the tides due to accelerated land subsidence caused by industrial and municipal ground water use around Semerang.

Overall, the project team noted with satisfaction that the semi-permeable fences worked. In the first year, some areas accounted for approximately 25 centimetres of accumulated sediments making the difficult work constructing the semi-permeable fences worthwhile. In 2018, the local communities took ownership of these fences, and the municipal governments introduced new regulations to protect the newly planted mangroves and regained shoreline from premature aquaculture usage during the mangrove restoration process.

Permeable structure at Bedono, 2015

Photo: Yus Rusilia Noor | Wetlands International

Monitoring of permeable structures

Photo: Kuswantoro | Wetlands International

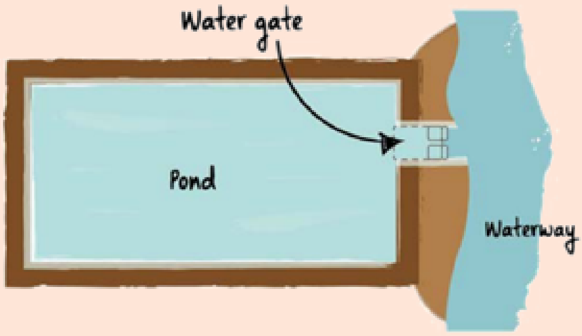
The design – Part 2: Associated mangrove aquaculture

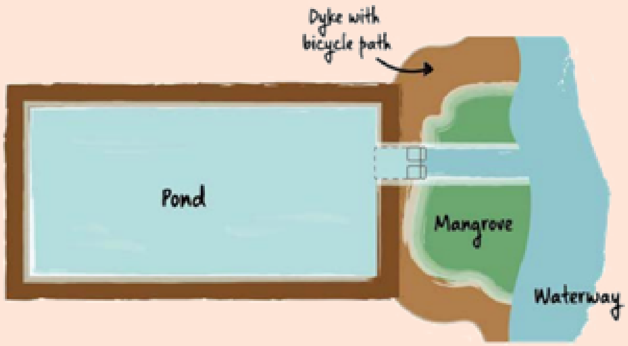
As the replanting and regrowth of the mangroves advanced, coastal field schools introduced farmers to associated mangrove aquaculture. This nature-based solution optimizes the nutrients, purifies water, and uses the shade availed by the mangrove roots, barks, and leaves to farm aquatic animals in ponds that are located alongside, but outside, the mangrove areas.

Traditional designs of mangrove aquaculture – often called silvo-fisheries, focuses on regenerating and maintaining mangroves around and inside the ponds. However, mangrove canopies bring excessive shade and falling leaves generate too much litter. The decomposition of the leaves decreases oxygen and increases toxic nitrogen components in the pond. The latter changes inhibit the optimal growth of the fish and shrimp being farmed. Too much shade reduces the primary production of the pond and the growth of the cultured organisms. In addition, mangroves inside or around the ponds do not contribute to many ecosystem services (see below).

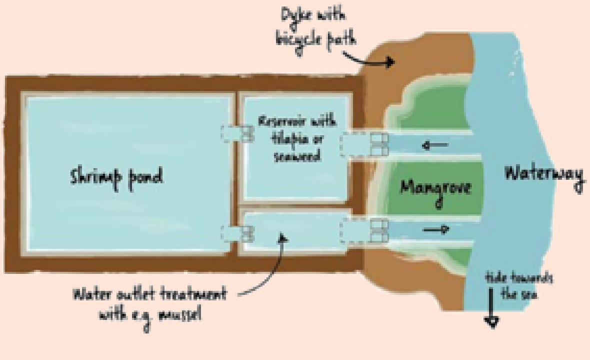
Associated mangrove aquaculture, as practiced in Demak, improved this design by placing the mangroves between the pond and waterway (canal, creek, river, or sea). This allowed the mangroves to act as a buffer between the waterway and the pond and created multiple ecosystem benefits:

- The mangrove roots purified the water in the ponds.
- The mangrove roots and trees accumulated sediment that increased nutrients for the species being farmed in the ponds.
- The surrounding estuary gradually became a nursery ground for fish and increased the resilience of the mangroves.
- The healthy mangroves increased the productivity of the aquaculture ponds.





Above: Overview of a common pool without mangrove and a standard associated mangrove aquaculture pond for a single farm.



Right: A complex associated mangrove aquaculture system for better water management.

Illustrations: Roel Bosma | Ecoshape.org

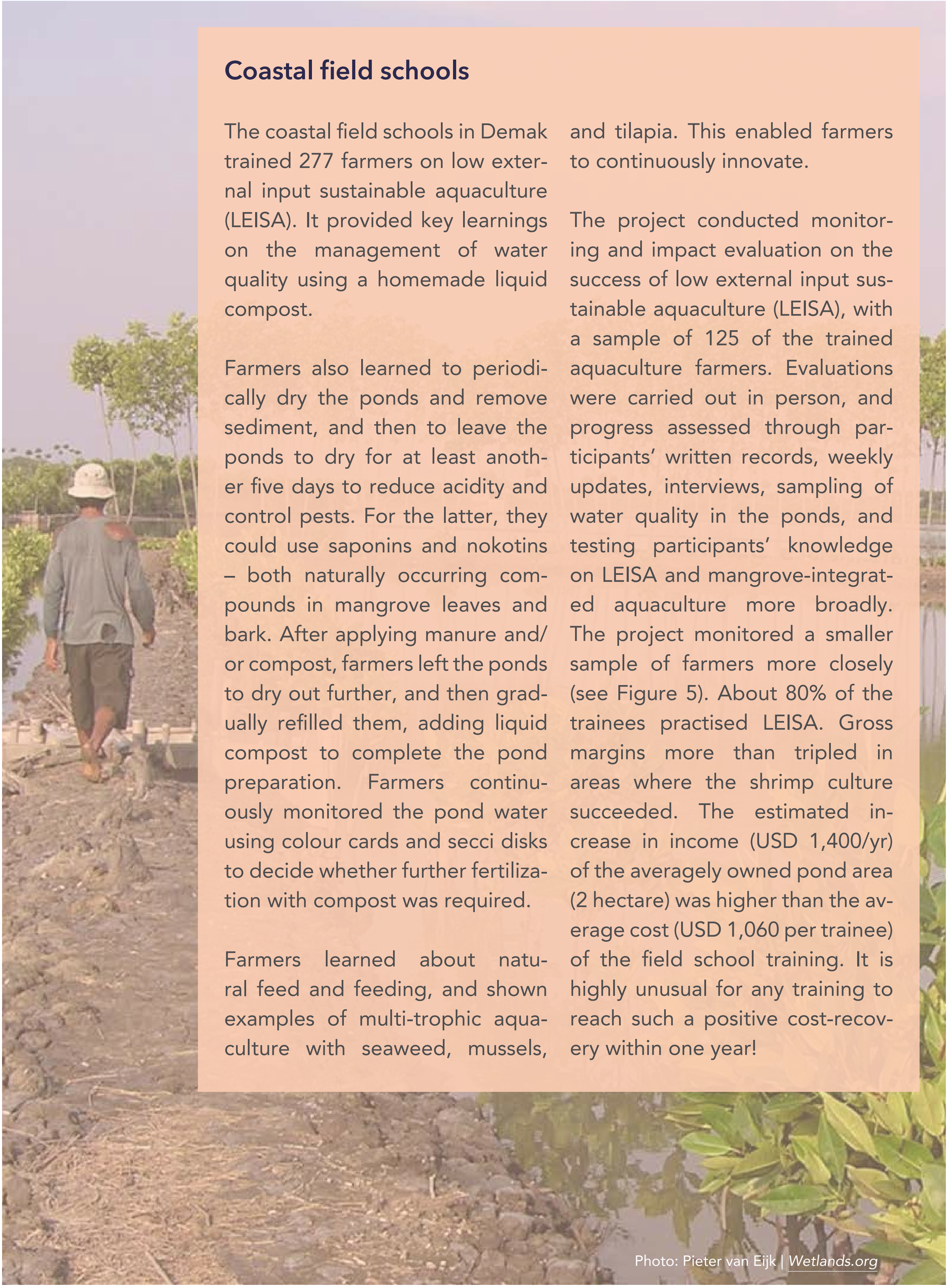
The design – Part 3: Low external input sustainable aquaculture (LEISA)

Building with Nature, together with the NGO Blue Forests, and the Faculty of Fisheries and Marine Science at the Diponegoro University, worked with the aquaculture farmers to introduce and innovate further on 'low external input sustainable aquaculture'.

This design was inspired by agroecology on land, which optimizes the use of the natural ecological processes of energy, water, and nutrients, functioning in circular processes, to enhance productivity with zero waste. The project worked with villages to explore, collect, and use locally available resources, such as leaves, and the waste from fruits and vegetables, to produce a liquid compost to serve as an aquaculture fertilizer. In addition, the local farmers and the project team, incrementally experimented with integrated multi-trophic designs, to farm tiger shrimp or white legged shrimps, milkfish, tilapia, seaweed, and mussels in the same pond or in successive ponds. These designs proved to be a success. Farmers managed to eliminate the use of expensive chemical fertilizers and water purifiers, and thus reduced their costs. They also experienced increases in yields, with subsequent increases in income.

The project suggest that yields and income could have been further increased if land subsidence could be controlled – some ponds continued to be washed away during the worsening storm surges and extreme weather events. Higher bunds or embankments were not sufficient to save some ponds. Farmers could either practise aquaculture in netted ponds or in the tidal lakes created by the power of water and waves, culture seaweed and mussels on lines, or fish.

The project introduced coastal field schools to improve aquaculture practices and to raise awareness about the importance of mangroves and ecology. Farmers attended these schools at least once per fortnight, over five to eight months, learning from experts as well as debating design improvements and alternative ways to produce feed, maintain water quality, protect the mangroves, and increase yields and revenues. It also provided famers with the opportunity to understand that climate change and the ever-increasing pressure for fresh water from nearby industries and cities, would require continuous adaptation to a dynamic and unpredictable environment. The sustainable use of the natural coastal habitat and its mangrove forests offers the best chance to ensure income and food security.



Coastal field schools

The coastal field schools in Demak trained 277 farmers on low external input sustainable aquaculture (LEISA). It provided key learnings on the management of water quality using a homemade liquid compost.

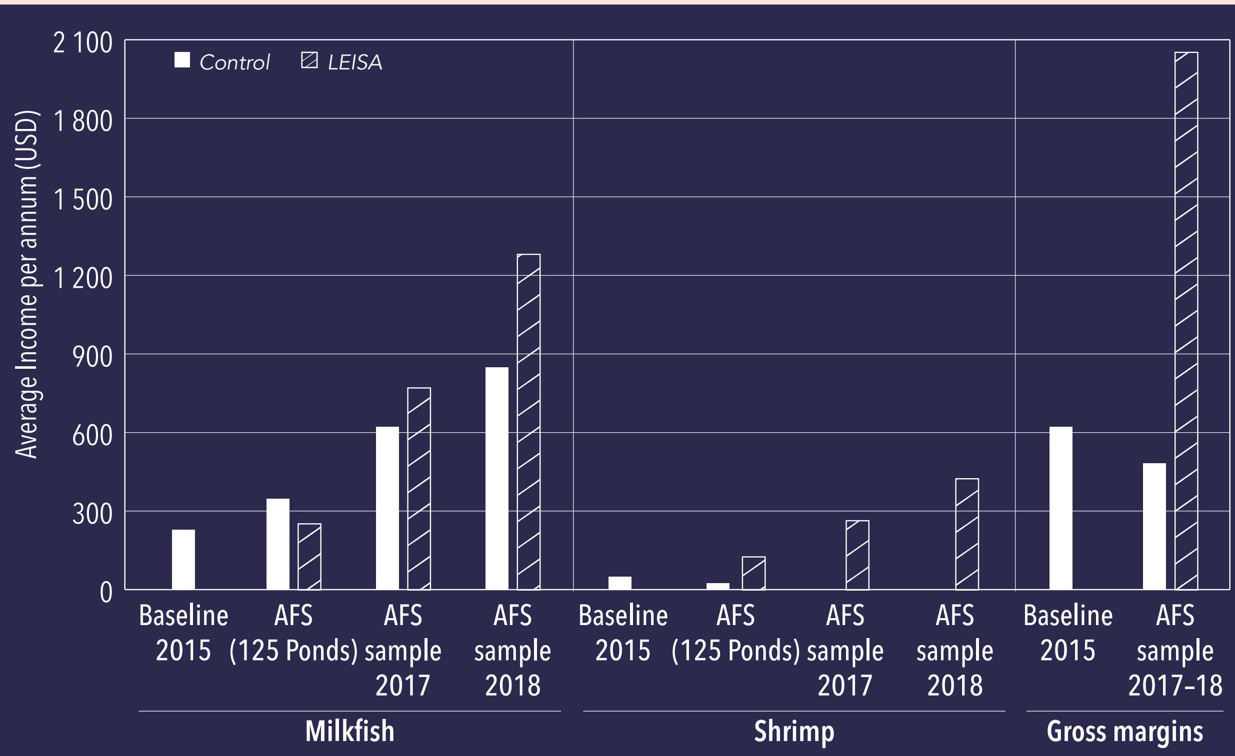
Farmers also learned to periodically dry the ponds and remove sediment, and then to leave the ponds to dry for at least another five days to reduce acidity and control pests. For the latter, they could use saponins and nokotins – both naturally occurring compounds in mangrove leaves and bark. After applying manure and/or compost, farmers left the ponds to dry out further, and then gradually refilled them, adding liquid compost to complete the pond preparation. Farmers continuously monitored the pond water using colour cards and secci disks to decide whether further fertilization with compost was required.

Farmers learned about natural feed and feeding, and shown examples of multi-trophic aquaculture with seaweed, mussels, and tilapia. This enabled farmers to continuously innovate.

The project conducted monitoring and impact evaluation on the success of low external input sustainable aquaculture (LEISA), with a sample of 125 of the trained aquaculture farmers. Evaluations were carried out in person, and progress assessed through participants' written records, weekly updates, interviews, sampling of water quality in the ponds, and testing participants' knowledge on LEISA and mangrove-integrated aquaculture more broadly. The project monitored a smaller sample of farmers more closely (see Figure 5). About 80% of the trainees practised LEISA. Gross margins more than tripled in areas where the shrimp culture succeeded. The estimated increase in income (USD 1,400/yr) of the averagely owned pond area (2 hectare) was higher than the average cost (USD 1,060 per trainee) of the field school training. It is highly unusual for any training to reach such a positive cost-recovery within one year!

Photo: Pieter van Eijk | Wetlands.org

Figure 5: The yields of milkfish and shrimp, and the pond's gross margins of farmers applying LEISA compared to those who did not adopt this innovation



Source: Widowati et al., 2021

Biorights: Pay-for-performance financing

Building with Nature used a unique pay-for-performance scheme to reward farmers who practised associated mangrove aquaculture or reconverted their pond in a mangrove greenbelt. The project gave farmers access to low-cost loans or 'bio-rights' to help fund the transition. However, it cancelled the loans when predetermined levels of performance were attained and the required level of mangrove restoration/maintenance achieved.

As mangrove associated aquaculture and lower external input aquaculture are mutually reinforcing, and productive mangroves are vital for increasing yields of aquaculture and fisheries, farmers valued the additional revenues from the bio-rights as a pay-for-performance revenue. They used the revenue to maintain the permeable fences, convert degraded ponds into greenbelts to further improve aquaculture practices, started to cultivate vegetables, increased the manufacture of liquid compost, cultivated green muscles along the permeable fences, and built boardwalks to increase revenue from tourism.

After the *Building with Nature* project closed in 2021, the bio-rights payments continued and today are funded partly by the local municipality and partly by Wetlands International.

Women entrepreneurs

Women entrepreneurs emerged from the coastal field schools, where women began to make feed pellets using dead fish and cassava floor. The feed, together with the water filtration services, and nutrients provided by the mangrove roots, increased the frequency of harvest from four months to two months.

The project also reallocated ponds on the reclaimed coastline to village women entrepreneurs. Several months later, these women set up a community-owned pond, the profits of which were channelled into a community savings fund.

Gains made

The Building with Nature project greatly increased food security across Demak.

Research conducted by Wageningen University and Diponegoro University in 2022, confirmed a recovery of near-shore fish populations and a marked increase in local wild catch yields when compared to 2014, before the implementation of the Building with Nature project.

The social cost-benefit analysis

The project completed a Social Cost-Benefit Analysis (SCBA) to demonstrate that investing in *Building with Nature* can deliver economic, social, and financial value. Commercial and concessional funders often request such an analysis to assess the non-financial and intangible benefits and costs, such as improvements in food security and human health, an increase in biodiversity and carbon sequestration.

> The discount rate used for the SCBA was 6% over a period of 85 years.

As the project area experienced erosion to different degrees, the SCBA was undertaken for two sections (Figure 6). For each section, the SCBA applied three scenarios. However, for the most affected coast (due to accelerated soil subsidence) only two scenarios are presented here.

The SCBA shows that the business-as-usual scenario, without the *Building with Nature* project, would cause substantial damage, especially in the areas most exposed to erosion. The cost of protection and the value of lost land would be ten times greater than the investment required for prevention. As the sea level rises and the force of storms increases, the areas along the coast that are least affected by erosion would likely suffer similar losses in the future.

Figure 6: Three zones of the project area

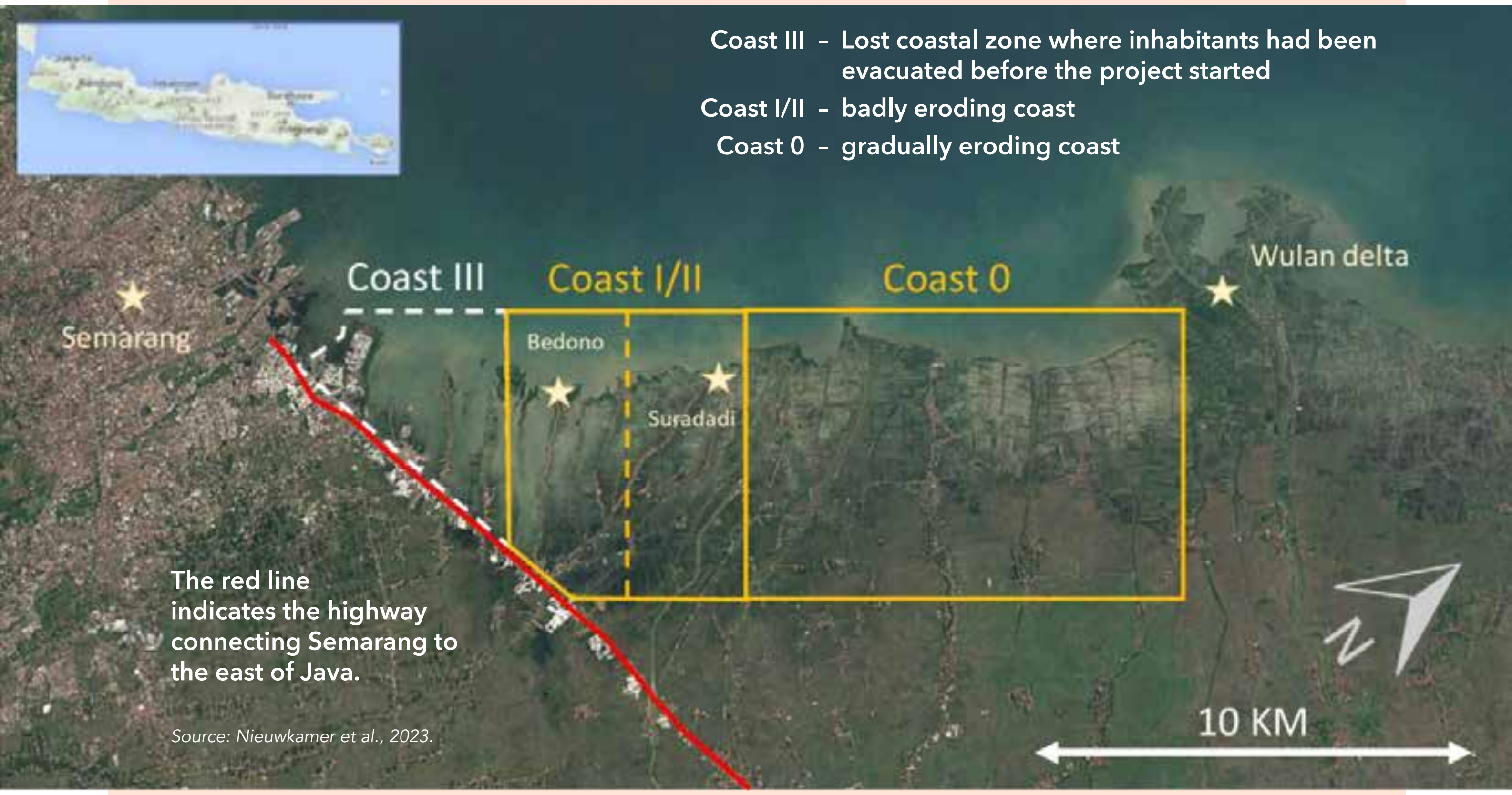


Table 1: Costs and benefits of *Building with Nature* for two degrees of erosion with scenarios

		Least-eroding coast			Badly eroded coast (peri-urban)	
		Business-as-usual	Temporary mangrove aqua-culture landscape	Transition to a mangrove-based economy	Business-as-usual	Transition to a mangrove and fisheries park
COSTS	Staff and socio-economic measures	0	2.3	5.4		2.5
	Permeable structures	-	-	-	0	3.5
	Cost of mangrove & fisheries park					33.1
	Total costs	**0**	**2.3**	**5.4**	**0**	**39.1**
BENEFITS	Tourism and recreation	-	-	-	0	41.4
	Prevented loss of built-up areas	-4.5	-4.5	-1.8	-25.2	0
	Avoided cost revetment of resurfacing highway	-	-	-	-54.6	0
	Aquaculture	35.2	41.4	98.8	10.2	7.2
	Fisheries	4.8	10.8	28.0	0.6	19.5
	Biodiversity	2.3	5.2	13.4	0.3	9.4
	Timber and non-timber products	0.3	0.6	1.5	0.03	1.0
	Carbon sequestration	12.5	31.3	120.5	1.6	107.0
	Total benefits	**50.6**	**84.8**	**260.5**	**-67.1**	**185.5**
	Balance	**50.6**	**82.5**	**255.0**	**-67.0**	**152.4**
	B/C-ratio	**-**	**36.7**	**47.8**	**-**	**4.7**

Source: Nieuwkamer et al., 2023.

On badly erode and least eroding coasts, carbon sequestration offers the greatest benefits, assuming that the sale of carbon credits has been successfully organized. But even without these payments, the restored coast would have regeneration positive returns due to the high income from tourism, recreation and aquaculture.

In the least-affected coast, the cumulated income from aquaculture and fisheries are higher than the value of carbon sequestration, and the balance remains positivein both scenarios even if no payment is received.

All scenarios for investing in nature-based solutions for building a mangrove-based economy have a positive benefit-cost ratio.

A sensitivity analysis confirmed that these remained positive even when the outcomes were only half or quarter of the considered values. When the discount rate is higher, the cost becomes higher and benefits become lower, but the balance remains positive. This balance improves when the discount rate becomes lower.

Thus, investing in a mangrove-based economy is worthwhile and the benefits are higher for the least-affected coast. This demonstrates the need for prevention (mitigation) now, rather than adaptation after destruction, i.e. for maintenance or rehabilitation of mangroves along tropical coasts.

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Case study 2

Improving food security and household income through green muscle culture in Demak, Indonesia

/ Contributed by Professor Sri Rejeki, Aquaculture Department Faculty of Fisheries and Marine Science, University of Diponegoro, Indonesia

About this project

The cultivation of green mussels in Demak, Indonesia builds on the work commenced by the Building with Nature project, which introduced and implemented associated mangrove aquaculture across the district of Demak, between 2015 to 2020. (See the *Building with Nature* case study.)

The Building with Nature project successfully restored over 200 km of coastal mangroves across the shorelines of Demak. These mangroves form a 'greenbelt' which provides many benefits, including:

- coastal protection from severe storms that are increasing in intensity due to climate change
- water filtration and absorption of pollutants, including heavy metals
- trapping sediment that increases nutrients for farming fish and other aquatic plants and animals
- reducing erosion
- serving as a feeding ground and nursery ground of marine organisms.

These benefits and 'services' are of high economic value and critical to the ecological intensification of near-shore and on-shore aquaculture.

Perna viridis

The green mussels cultivated are *Perna viridis*, a species of mussel that does not require a hatchery (Andreu 1958; Hickman 1992), and are able to survive and reproduce without being fed. They are an excellent source of amino acids, omega 3 fatty acids, zinc, foliate, selenium, iodine, and iron.

The idea to farm green mussels in front of the mangrove greenbelt developed at the costal field school, was initiated during the Building with Nature project. Aquaculture farmers, local government officials, and the Building with Nature project experts were seeking additional ways to increase household income, food security, and nutrition, while also providing incentives for the continued protection of the mangrove greenbelts. Discussions on green mussel culture concluded that they offered a viable business proposition. As coastal communities and inland residents began to appreciate the nutritional value, and taste of green mussels from Demak, their price and demand increased.

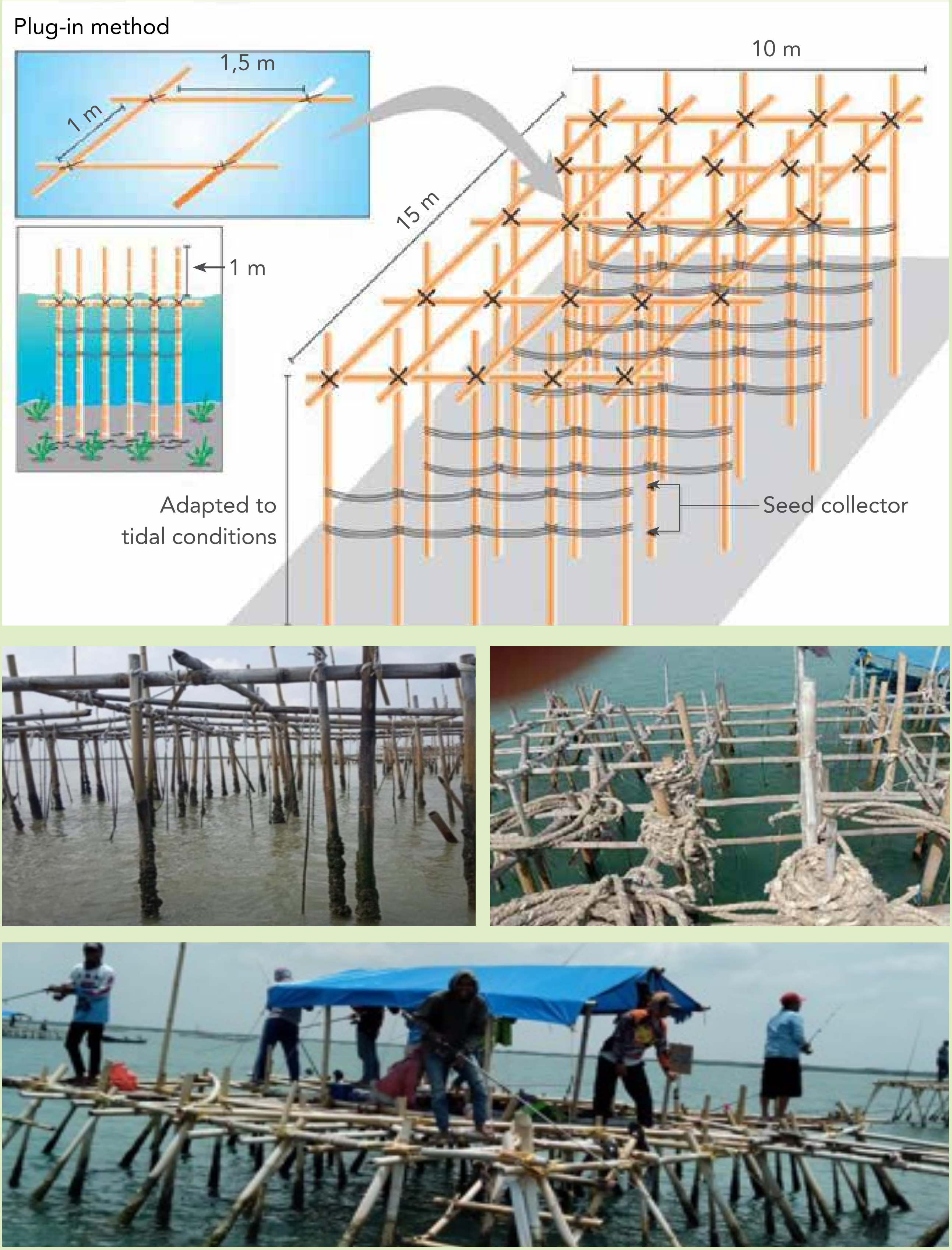
The design

Mussel beds or rather, mussel anchors, are constructed in the estuary, in front of the mangrove greenbelt, 3–6 kms from the shoreline. These are vertical structures made of bamboo and rope, which are available locally and are inexpensive. These materials also withstand coastal conditions.

The mangrove integrated estuary is rich in nutrients from the sediment accumulated by the mangrove roots, as well as by the 'litter' provided by the leaves. The mangrove roots filter toxins and heavy metals, which makes the entire costal ecosystem a healthy nursery and feeding ground for aquatic plants and animals. Green mussel spats attach naturally to the constructed mussel beds. The peak spat settlement occurs between April and June each year.

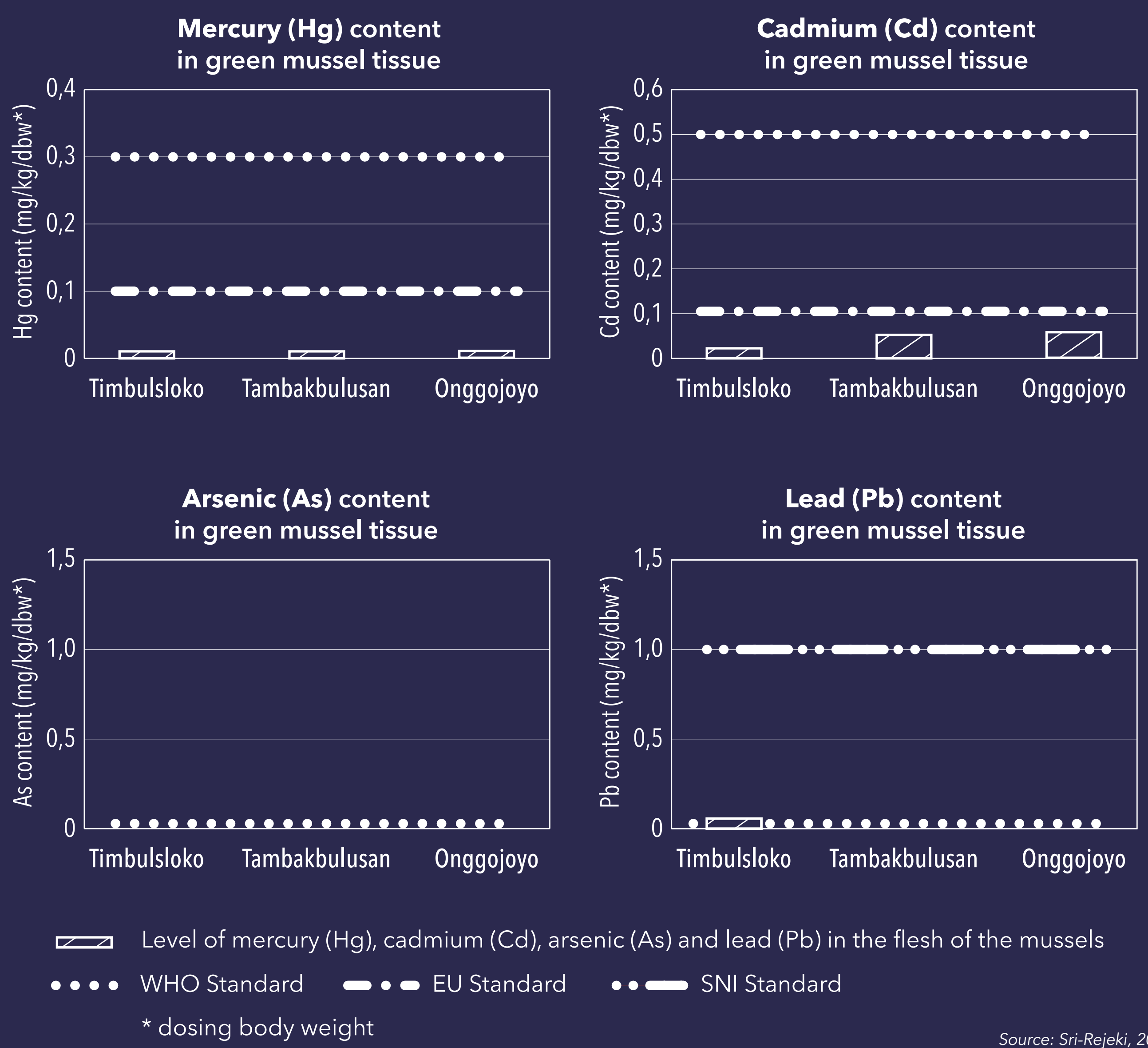
From July to December, green mussels can be harvested on a weekly basis. Mussels are sold in the local markets, and the mussel shell is crushed and used to make broths or fertilizer.

Figure 7: Materials and method: bamboo pole and vertical rope



As the green mussels from Demak are farmed as part of the healthy mangrove ecosystem, with the roots of mangroves filtering the water and absorbing toxins and heavy metals, they are extremely safe for human consumption. The results of a preliminary survey across four villages in Demak completed in 2021, indicated that the concentration of mercury (Hg), cadmium (Cd), arsenic (As) and lead (Pb) in the flesh of the mussels was well below the World Health Organization (WHO) and European Union (EU) permittable limits for consumption.

Figure 8: Heavy metals (Hg, Cd, As, Pb) in the green mussel tissue from four villages in Demak district



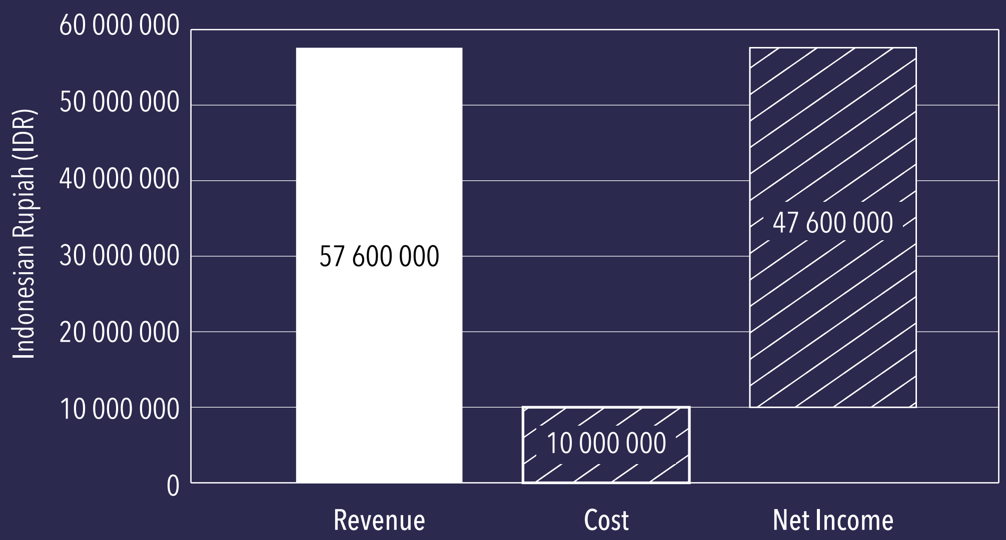
Source: Sri-Rejeki, 2023

Costs and revenue

A simple green mussel bed structure made of 100 sticks of bamboo and 400 metres of re-usable rope costs about 10 million Indonesian Rupiah (IDR). Green mussels reach a marketable size of 6–8 cm shell length after four months. From July to December in 2022, each mussel bed/anchor yielded around 9,600 kg of green mussels, averaging 400 kg per week. With an average selling price of 6,000 IDR/kg, each mussel bed/anchor generated 57.6 million IDR in revenue, and 47.6 million IDR in net income in the same period.

Figure 9 shows the revenue and cost of green mussel culture from one mussel bed/anchor in IDR.

Figure 9: Revenue and cost of green mussel bed structure in Demak, Central Java, Indonesia



Source: Sri-Rejeki, 2023

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Case study 3

Increasing food security and nutrition through integrated rice fish farming in Madagascar

/Kamal El Harty, Advisor, Sustainable Finance, Shamba Centre for Food and Climate

/Expert review and input provided by Olivier Joffre, Team Leader and Linda Weber, Technical Advisor, Sustainable Aquaculture Program Madagascar (PADM), Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ); Dr Jens Kahle, Advisor, Global Program Sustainable Fisheries and Aquaculture, Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ)

About the project

In Madagascar, 80% of the population lives in rural areas with limited access to fish products especially in the highlands (GIZ 2022). In 2021, the average annual consumption of fish per person was 4.2 kg; in comparison, the average annual consumption was 10 kg per person in Africa, 20.2 kg in low- and middle-income countries (LMIC) and 20.5 kg globally (OECD/FAO, 2022).

The two main types of freshwater aquaculture in Madagascar are farming of carp and tilapia in ponds and rice-fish culture, where fish are grown in rice paddy fields. However, the fish farming sector is developing at a very slow rate as it is largely under-exploited and only 20% of suitable rice fields are used for rice-fish farming (GIZ, 2022).

To promote the aquaculture sector, in 2017, the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) initiated the Sustainable Aquaculture Project in Madagascar (PADM), under its Global Program for Sustainable Fisheries and Aquaculture. The PADM project aims to enable small holders in the greater Antananarivo area and in the east coast of

Madagascar, to sustainably increase local fish production so as to:

- help small holders to increase and diversify their income
- improve accessibility to fish products for people in the areas, who are often affected by food insecurity.

On 23 August 2022, with the support of PADM, the Madagascar Ministry of Fisheries and Blue Economy, officially launched the PDACM, the Development Plan for Continental Aquaculture in Madagascar (FAO 2022).

The PADM project is composed of three components (GIZ, 2021):

- Component A: Promoting the production of rice-fish culture in the highlands of Madagascar. This is implemented by the non-governmental organization (NGO), APDRA Pisciculture Paysanne.
- Component B: Promoting pond fish farming with support from the consultancy COFAD in the Analamanga region and the Norwegian Society for Development, Norges Vel, on the eastern coast of the country.
- Component C: Supporting the development of national aquaculture regulatory framework and strategic planning. This is implemented by GIZ in close collaboration with the government.

Integrating fish farming and rice cultivation

In the highlands of Madagascar, Component A of the PADM project focuses on expanding rice-fish culture and improving the technical and financial capacities of rice-fish farmers, with a special focus on women. The project ensures gender equality by reaching out to and empowering women farmers who grow and process rice (GIZ, 2022). Rice-fish farmers are trained to produce high quality fingerlings and to identify and make optimal use of suitable rice fields.

By integrating fish farming into rice cultivation, farmers in the highlands of Madagascar can produce both fish and rice at the same time, in the same area, thereby optimizing resources and diversifying and increasing their income and diets.

There is an important ecological compatibility between fish, particularly carp and tilapia, and rice fields. In rice-fish farming, the use of chemical fertilizers and pesticides is discouraged and even prohibited to prevent damaging the ecosystem and killing the fish (GIZ, 2022).

Alternative, organic, home-made fertilizers are applied to increase the yield of both fish and rice. A study conducted by Mortillaro et al. (2022), showed that applying organic fertilizer in a rice-fish culture can significantly increase the natural productivity and enhance the ecological intensification of both rice and fish.

The rice fields provide a healthy nursery and feeding ground for the fish to grow:

- While scavenging for food, the fish act as a biological control agent, restricting aquatic algae, weeds, and insects, thereby increasing aeration in the rice fields (Ainun Nur Jyoti et al, 2020).
- Additionally, the fish release vital nutrients through excreta that are recycled back into the rice crops (Khumairoh, 2021).
- The movement of the fish enhances soil organic matter and dissolved oxygen levels (Ahmed et al, 2022). This increases the rice crop yields by 10% to 20% (Ahmed et al, 2022; GIZ, 2022).
- Therefore, when carp are introduced in the rice field and act as bioengineers, the reduction of rice production due to the construction of ditches in rice-fish culture is compensated by an increase of rice yield.

This mutually beneficial ecological relationship between rice crops and fish allows farmers to both increase their rice crop yields and harvest between 200 and 300 kg/ha/year of fish (GIZ, 2023), and in this way increase both their income and access to fish in the region.

Steps in rice-fish farming

Rice-fish farming has a short cycle of 6 months and can be implemented in the following steps (APDRA, 2004):

1. Site selection: The site should have abundant water resources and have suitable soil conditions, with a levelled field for rice cultivation.
2. Field preparation: Farmers prepare rice fields by constructing a ditch along the dike or in the middle of the field, to provide a space with deeper water to protect the fish from heat and predators. This also facilitates fish catch during harvest.
3. Flooding and weeding of paddy: After planting, the paddy fields are flooded. The water level is kept at a depth of 30 cm to 50 cm until the rice is matured. Then it is kept at a minimum of 5 cm to facilitate adequate filtration. Weeds are manually uprooted on both sides of cultivated rice plots. Chemical weed control methods are avoided to prevent polluting rice fields or causing fish death.
4. Fertilization of rice fields: Farmers use organic fertilizers, which include a variety of livestock manure, plant waste, and compost fertilizers, such as decomposed straw weeds and rice stalks. Ammonia-based chemical fertilizers are avoided because of their price and toxicity to the fish.
5. Rearing of fish seed: Fingerlings are produced by rearing fry in small rice fields for about one to two months prior to stocking. The fingerlings weigh on average 20 grams to 35 grams and are stocked in the paddy after flooding.
6. Stocking of fish seeds: In April, prior to the release of fingerlings into paddy fields, paddy is transplanted from rice seed beds to major paddy fields. The paddy is left for two weeks to strengthen the paddy roots before stocking. The paddy rearing period is five to seven months, while fish

take about six months to grow (APDRA, 2004).

7. Water quality monitoring: The water level in the rice fields is well managed and water quality is monitored to ensure an adequate level of acidity, turbidity, conductivity, and dissolved oxygen in the water.
8. Feeding of fish: The carp rely on their natural feed found in the rice fields, which can be supplemented with additional locally available feed and agricultural by-products.
9. Harvesting: After six months, fish production yields an average of 330 kgs per hectare (APDRA, 2004). Harvesting is done with a simple bamboo basket, known as canon bamboo. Initially the water is drained through an outlet pipe allowing fish and water to accumulate in the ditches along the dike or in the middle of the field, where the fishes are captured and transferred to large plastic buckets.

Benefits of rice-fish farming in the highlands of Madagascar

The adoption of rice-fish farming in the highlands of Madagascar has provided several benefits to a large number of farmers:

- Rice-fish farmers benefit from an additional revenue stream and an essential source of nutrition from harvesting carp.
- They are able to increase their rice yields by 10% to 20% (APDRA, 2004).
- They benefit from cost savings on pesticides and chemical fertilizers. Carp act as natural biological control agents as they feed on insects and algae. They also release vital nutrients through excreta that are recycled back into the rice crops.
- Fingerling producers who specialize in raising fish from eggs to fingerlings, generate an average yearly revenue of MGA 112,200 to MGA 200,000 in a four-months cycle (GIZ, 2023).
- Carp farmers who specialize in raising fingerling carps to market size carp in rice fields, generate an average yearly revenue of MGA 24,200 to MGA 29,410 in a six-month cycle (GIZ, 2023).

Since 2018, the GIZ sustainable aquaculture project in Madagascar (PADM) has supported more than 14,800 rice-fish farmers to diversify and increase their income. The production of more than 125 tonnes of fish has made fish more accessible to consumers who are often affected by food insecurity in the highlands of Madagascar.

Challenges of rice-fish farming in the highlands of Madagascar

Despite the abovementioned benefits, there are also challenges for rice-fish farmers in the highlands of Madagascar. Some of these challenges include:

- Site selection: The success of rice-fish culture depends to a large degree on the proper selection of the site. Multiple criteria are considered including soil fertility, water retention capacity of the soil, flood-prone locations, adequate water supply, etc. This poses a challenge for many farmers who do not possess a suitable field for rice-fish farming.
- Expertise: Many farmers do not have the knowledge and expertise to identify and manage suitable rice fields for rice-fish farming. In Madagascar, only about 20% of suitable fields are used for rice-fish farming.
- Labour cost: The construction of ditches in the rice-field poses the major investment hurdle for many farmers who wish to adopt rice-fish culture.
- Access to inputs: Access to quality fingerlings and their high costs, as well as the limited availability of feeds and fertilizers, is a challenge for many farmers (FAO, 2019).
- Security: Theft of broodfish, fry, and grown fish is a major concern for many farmers in the highlands of Madagascar.

Cost and profit of fingerling production and carp farming

There are striking differences and trade-offs between cost, return, and risk of fingerling production and carp farming, in rice-fish culture in the highlands of Madagascar.

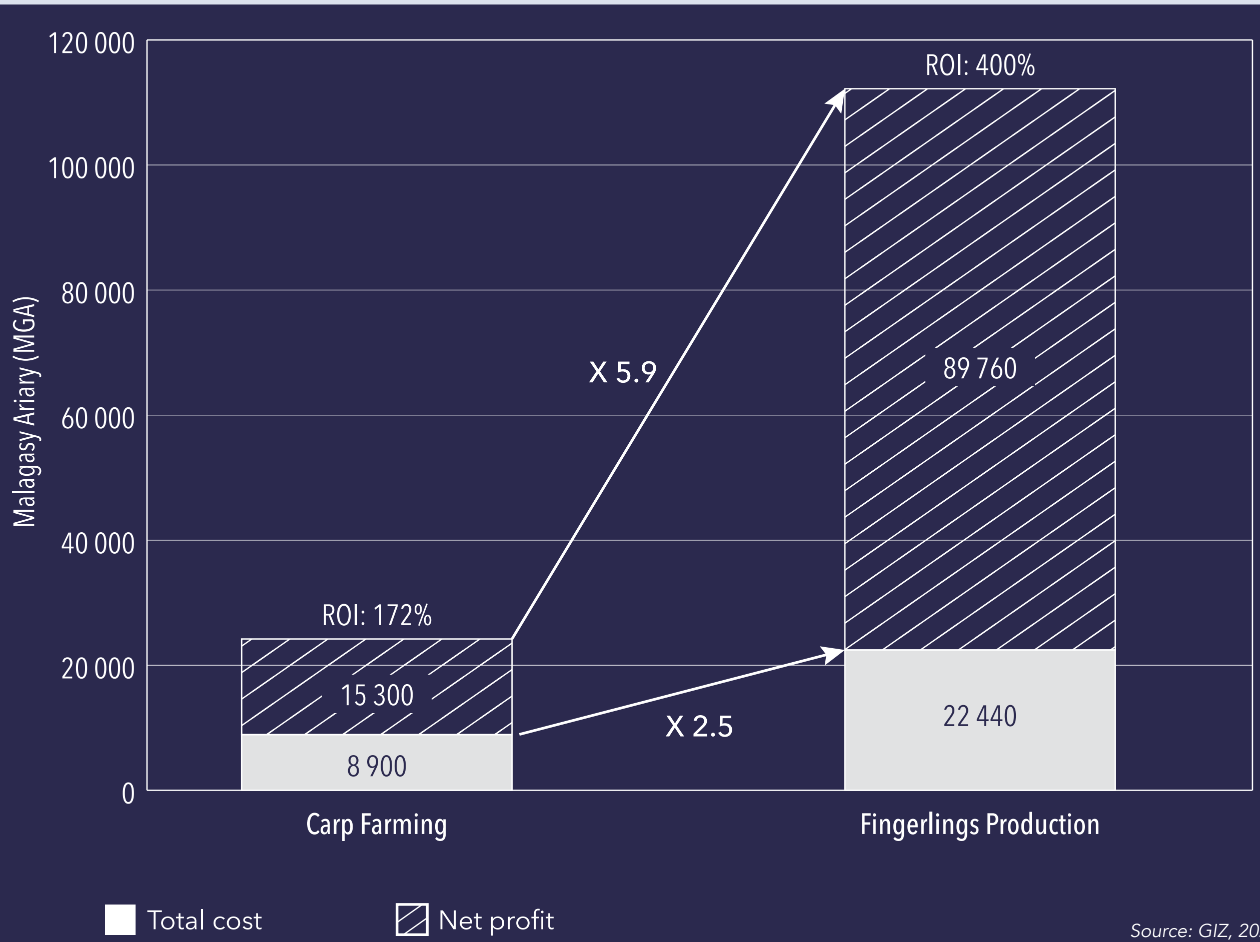
Figure 10 shows a comparison between average total costs and net profits of fingerling production and carp farming per acre per cycle in rice-fish culture in the highlands of Madagascar. It is based on a survey of 10 fingerling producers and 15 carp farmers (GIZ, 2023).

In rice-fish farming in the highlands of Madagascar, fingerling producers generate an average net profit of MGA 89,760 per acre per cycle, which is 5.9 times higher than that of carp farmers (MGA 15,300 per acre per cycle). This translates into a return on investment of 400% for fingerling producers and only 172% for carp farmers.

The high profitability of fingering production attracts many farmers to pursue this segment. However, there are significant risks that need to be considered and higher investments to be made. Although the cycle of fingerling production continues for only four months as opposed to the six months in carp farming, the broodstock must be maintained year-round. Male and female broodstock must be kept separate for several month to avoid uncontrolled spawning. This requires the maintenance of two separate ponds. Broodstock must be fed well to achieve a high number of good quality fry. This requires additional and regular feeding over several months, during the development of the eggs. Fish selected as broodstock are two to five years old. According to the size and quality of the fish, the purchase of broodstock is an investment in a living animal, which must be protected from flooding, predation, and theft.

These risks are amplified by the high investment costs in fingerling production which are 2.5 times higher than that of carp farming. Accordingly, farmers who decide to venture into fingerling production are required to have a high level of technical expertise, while farmers with limited financial capacity and knowledge often opt for carp faming due to the relatively lower risk and investment costs.

Figure 10: Comparison between profit and cost of fingerling production and carp farming per acre per cycle in rice-fish culture in the highlands of Madagascar.



Source: GIZ, 2023

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Case study 4 Expanding and regenerating the furrows in Pathum Thani, Thailand

/ Contributed by Linda Watkin

During the 1980s in the Thai province of Pathum Thani, farmers developed a nature-based solution (NbS) called 'The Furrow'. They needed to find alternatives to conventional rice production, which was becoming increasingly vulnerable to floods and droughts.

When market prices for rice declined, some farmers tried to grow other crops. However, irrigation infrastructure and water supply were inadequate. So they decided to innovate by altering the furrows – deepening and widening the small, shallow ditches on the rice paddies to approximately 2 m x 2.5 m, and expanding the furrow network. These furrows were then connected to the main river canals using locks and gates which allowed them to control flow and water levels. The furrows provided farmers with an irrigation system with sufficient water all year round. This enabled them to grow a variety of crops, and to farm fish in the furrows – most common were catfish and tilapia.

This case study briefly highlights the improvements adopted on a few farms. The author interviewed six farmers with furrows and two farmers without furrows.

The furrows behind the lock system which connected them to the main river canals.

The Flower Farm

Up until 2010, the Flower Farm primarily grew rice on its 800 m^2 land. Between 2010 to 2014, the farm switched to oranges and limes, but was unsuccessful due to citrus disease. Income was very low and, in 2015, the family transformed the farm into an ecotourism business.

With furrows and a year-round water supply, crops included decorative flowers, fish, and mulberries to sell in the markets. Tourists could spend the night in furrow-side huts, fish for catfish and tilapia in the furrows, and take boat rides to enjoy the flowers. The family's 2016 income was THB 450,000 (approximately USD 12,860).

Tourists can take boat rides to see the flowers.

The Corn Farm

Until 2008, the Corn Farm also primarily grew rice on its 800 m^2 land. From 2008 to 2016, the farm focused on growing oranges. However, when citrus disease destroyed this crop, the farmer changed to growing a variety of products, including corn, bananas, peanuts, and melons. Tilapia and catfish were farmed in the furrows. The fish helped control weeds and were harvested for food and to sell in the markets. Harvesting of crops and fish could take place throughout the year. In 2017, the farm produced bananas as its main crop, which resulted in an income of THB 500,000 (approximately USD 15,150). Corn was the maincrop in 2018, which resulted in an income of THB 300,000 (approximately USD 9,375).

In 2018 the main crop grown was corn, with fish in the furrows controlling weeds.

Fruit Farm

Furrows have made it possible to farm fish as well as rice, banana, mango, and palm oil trees since 2016 on this 800 m^2 farm. The farm's 2017 income was THB 475,000 (approximately USD 14,390).

Fruit trees are grown alongside the furrow.

Increases in revenue

The table below shows the increases in farm revenue in Thai Baht from 2015–2019. The farms with furrows recorded a 70% increase in income compared to farms which had no access to furrows.

Table 2: Increases in farm revenue (2015–2019)

Farm	Revenues (Baht/Yr/km²)	Expenses (Baht/Yr/km²)	Increased Net revenues (income/ expenses)
Furrows	25,000	3,611	6.9
No furrows	5,835	2,848	2.0

Increases in farm income

The annual income of farmers with and without furrows were compared on a per area basis over a four-year period. Furrow farms had incomes 77% higher than those without furrows. This was because the farmers could grow crops year-round, had increased access to water, could farm more varied crops, and could adapt to changing markets and prices.

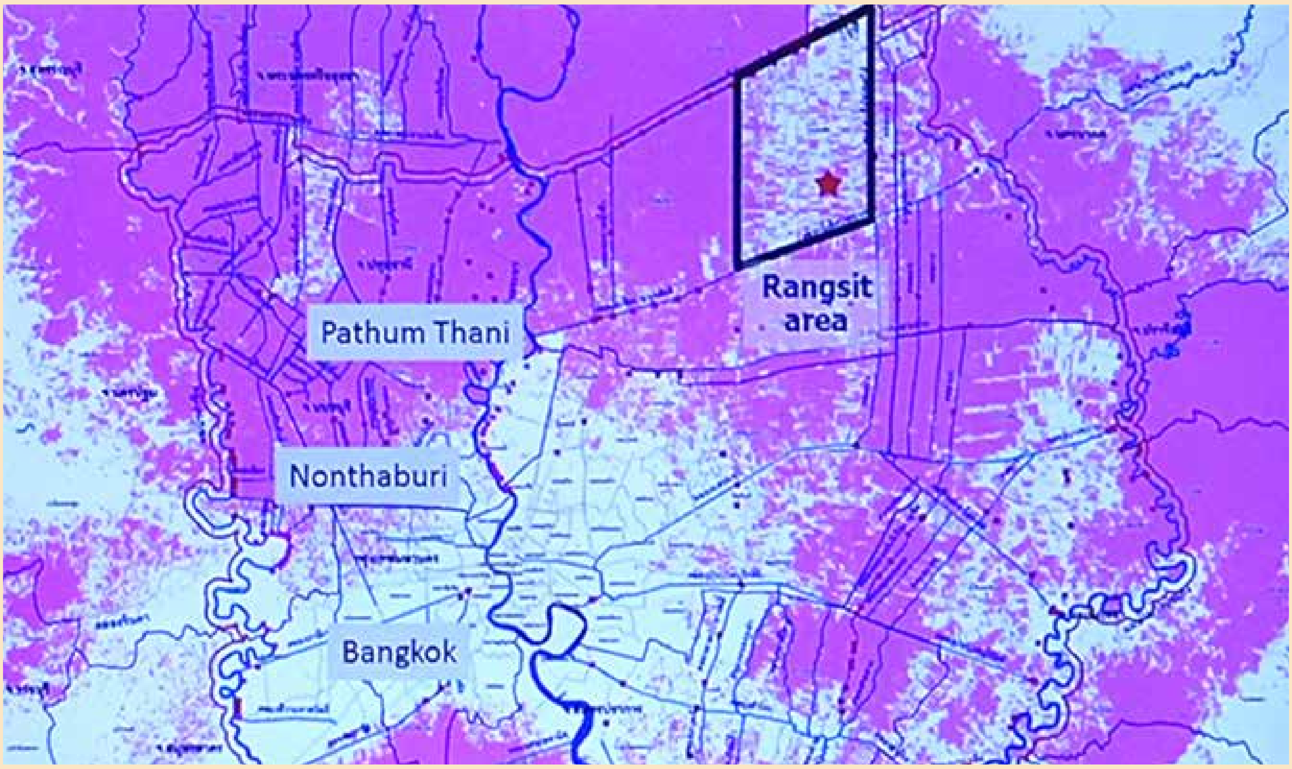
Local flood mitigation

Furrow storage is estimated at over one million cubic metres. Because flooding can result in agricultural damage, farmers work with the local water authority to manage peak flows in the main canals by storing excess water in the furrows. Areas with furrows have the potential to reduce agricultural loss due to flooding by an estimated 43%, compared with areas without furrows.

Historical flood mitigation

The 2011 flood map of central Thailand illustrates how the area with furrows (outlined in black) were approximately 44% less flooded than neighbouring areas without furrows. Excess flows were diverted to the furrows and helped to reduce flood water reaching the major commercial centres of Bangkok.

Figure 11: 2011 flood map of central Thailand



Flooded *Not flooded*

Water storage and reuse potential

Furrows provide farmers with irrigation water in times of low or absent rainfall. It is estimated that furrows provide 4,600 m^3/ha of water storage. Farmers with furrow storage have adequate irrigation water 85% of the year. Before furrows were developed, farmers had to pump water from canals, drill water wells, or do without water during the 6-month dry season.

Connectivity

Connectivity is the flow and distribution of sediment, organisms, and nutrients in the water system. It is vital for food security as it allows pollinators access to crops, and it supports fish and other aquatic species to locate appropriate habitat, spawning areas, and to find mates. Many of the rivers in Thailand have been forced to flow into concrete-lined canals, creating a fragmented water system. By connecting the expansive furrow network to the canals, the Rangsit area has improved connectivity by 72%.

Groundwater recharge

Land subsidence, the settling of the ground surface due to over pumping of groundwater, is a growing problem in many areas of Thailand. Lining rivers with concrete adds to this problem because infiltration can no longer occur. The furrows increase the water surface area and potential infiltration. This has the potential to improve groundwater recharge by up to 79%.

Water quality

When water is directed from the main canals into the furrows, the water quality improves. Sediment and nutrients entering the furrows accumulate and are dredged using muir suction boats. The sludge is directly applied to field surfaces, replenishing soils, and reducing solids in the water. Plants require nutrients such as nitrogen phosphorus, and potassium for growth – components in fertilizer. Samples taken from the main canal and furrows showed that water quality had improved by 45%.

Dredging the furrows using muir suction boats.

Biodiversity

When comparing a monoculture field, such as rice, and one with several types of crops, trees, flowers, and even fish, the biodiversity difference is apparent. Areas with furrows provide up to 75% more biodiversity than those without.

Furrows have made a positive impact on the community of Pathum Thani. Several social benefits that have resulted include:

- education and research opportunities
- increased community involvement
- participatory planning and governance
- empowered local communities
- recreation and tourism opportunities.

Proud of their success, farmers and the local water authority have joined forces to conduct research, produce brochures and educational information, and distribute knowledge to neighbouring communities. They hope to continue the expansion of the furrow network and to spread the potential benefits to a wider community.

The research presented here does not include the calculation of all benefits into monetary terms. By translating the indicator values into economic benefits, stakeholders are more likely to see the value and incorporate nature-based solutions in their projects. The next step is to assign monetary values to the benefits of nature-based solutions.

Research was conducted in Pathum Thani's furrows from 2017 to 2019 and published in the *Sustainability Journal*.

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For more information, please refer to:

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