A pilot of integrated mangrove-aquaculture as a nature-based solution to mitigate climate change in West Bengal, India

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Mangroves are one of the world's most threatened tropical ecosystems and provide a wide range of services including coastal protection, erosion control and storage of carbon. Although natural processes such as coastal erosion and extreme weather events influence forest vulnerability, mangrove degradation is predominantly linked to human activities. Growing population pressure in coastal belts and rising food demand necessitate land use changes driven by commodities, such as aquaculture, which may impact the mangrove environment. For example, shrimp farming developed significantly worldwide in the 1980s and 1990s, primarily in Asia and South America, spurred by rising international demand and a high market price. Since the 1980s, an estimated 1.5 million ha of mangroves have been lost worldwide due to shrimp aquaculture[1]. In India mangroves covered about 4,975 km^2 accounting for 3.6% of worldwide mangrove vegetation. Although mangroves are protected by legal instruments, the Indian coastline witnessed a rapid extension of shrimp farming. In India's states of West Bengal, Andhra Pradesh and Odisha, about 213 km^2 of mangroves and mudflat were destroyed for shrimp farming between 1988 and 2013[2]. Anticipating the impact, the Supreme Court of India ordered the shutdown of all shrimp farms within 500 meters of the high tide line in December 1996.

The coastal region of West Bengal hosts the world's largest contiguous mangrove forest, the Sundarbans. There, reclamation of mangroves mostly for timber and cropland began in 1770 during the British colonial period and continued until the mid-nineteenth century. Since the 1970s, parts of this coast witnessed a transformation from the paddy cum fish/ shrimp integrated system to extensive shrimp-fish farming. The situation was more prevalent when both the state and central government have intensified their efforts to develop coastal aquaculture and started promoting export-oriented shrimp farming during the late 1980s to early 1990s. At present, West Bengal has nearly 50,000 ha of brackish water areas. This expansion led to further mangrove destruction and soil salinisation, and a slew of socio-economic issues that worsened after outbreaks of white spot shrimp virus (WSSV) disease around 1994-1996 and 2000-2002. Nevertheless, the export of *Penaeus monodon* from West Bengal has increased by about 80% between 2001 and 2013 and reached almost 50,000 tons. Since then, *P. monodon* production in West Bengal has been dropping whilst *P. vannamei* production has risen by 60% from 2013 to 2020 to about 35,000 tons.

The shrimp industry in India seems to thrive but is confronted with the same threats and sustainability challenges as elsewhere. The most common challenges are poor quality and irregular supply of shrimp seed and low survival rate, and general hazards are disease-related production loss and market uncertainty. Minimal value-added processing and a lack of traceability due to many unregulated and unregistered farms exacerbate the market situation, as growing consumer awareness on sustainable seafood, urges India's shrimp producers to shift to traceable and sustainable systems. Moreover, climate change threatens the viability of the shrimp farming systems both directly and indirectly. Therefore, strategies must be developed both to reconcile mangroves and biodiversity conservation, and to solve issues of food safety, water quality and social welfare.

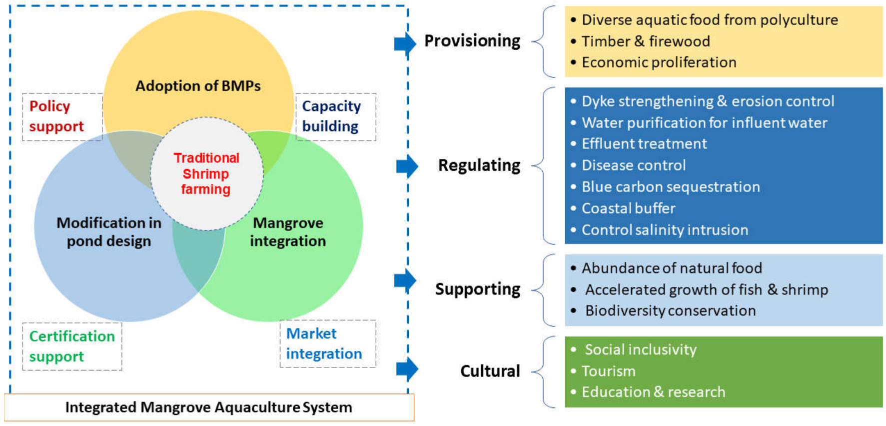
Mangroves are in peril due to shrimp farming across the Sundarban delta. Left and right are northeastern and western parts of Sundarban respectively.

The following sections of this article present and discuss an ecosystem-based shrimp farming system embedded in a local traditional method, bheri, that has the potential to reverse coastal ecosystem degradation.

Integrated mangrove-aquaculture: A potential nature-based solution

Nature-based solutions are interventions that aim to protect, restore and sustainably manage natural and modified ecosystems to benefit human well-being and biodiversity and address societal concerns[3]. Integrated mangrove-shrimp farming or simply aquaculture is the coexistence of mangroves and shrimp aquaculture in a tide-fed environment. In comparison to other shrimp farming systems, integrated mangrove-shrimp farming can additionally produce timber and supports biodiversity.

Potential benefits that can be derived from an integrated mangrove aquaculture system.



In several coastal hamlets of Tamil Nadu, the M.S. Swaminathan Research Foundation (MSSRF) has successfully tested an integrated mangrove fishery farming system to restore mangrove-based livelihoods and rehabilitate ponds, since 2006. Local farmers cultured black tiger shrimp (*P. monodon*) along with mud crab (*Scylla* spp.) and fish (flathead grey mullet *Mugil cephalus*, and Asian seabass *L. calcarifer*). Farmers adopting the integrated mangrove fishery farming system on modified outer and inner embankments planted certain mangrove species (*Rhizophora mucronata*,

Coastal halophytes at the brackishwater canal periphery provide excellent opportunities for nutrient source and sediment trapping for the shrimp farm.


Many of the tidal regions of South and North 24 Parganas offer ideal conditions for mangrove-based silvofisheries.

R. apiculata, *Avicennia marina*) and other saltmarshes (*Sesuvium portulacastrum*). The survival and productivity of *L. calcarifer* was 11% and 12.5% greater in the integrated mangrove fishery farming system relative to the open aquaculture system[4].

The choice of mangrove species for an integrated mangrove-shrimp system needs to account for numerous factors such as inundation frequency, tannin content, carbon : nitrogen ratio, half-life and decomposition rate of mangrove leaves. Leaves of mangroves can have either toxic or beneficial impacts on shrimp and other seafood. Other considerations are the societal uses of mangroves products such as honey, fruit, firewood and timber.

Bheri, a traditional shrimp farming system in West Bengal

The *bheri* is a traditional nature-dependent aquatic food production system of West Bengal which is unique in South Asia. Flanked by embankments, the shallow bheri range from 0.5 to 100 ha and are mostly stocked with *P. monodon* at low density. Bheris also provide ecosystem services such as carbon sequestration, floodwater storage and biodiversity. Depending upon distance from the sea, bheris may be high-salinity (> 20 ppt salinity), medium-salinity (10-20 ppt) and low-salinity (< 10 ppt). Bheri aquaculture practices range from traditional to improved extensive farming. All exchange water at neap (outlet) and spring (inlet) tides by means of a sluice gate made of wooden boards and bamboo poles (locally called *goi*). The water is filtered using bamboo screens (*pata*) to prevent loss of stock; some farmers use nylon nets to prevent natural recruitment, including unwanted organisms. The stocking season usually begins in late January and lasts until mid-October. Harvesting begins three to four days before the full moon and new moon and continues for three to four days after the full moon and new moon using traps made of bamboo locally called *atol* and cast netting. Usually, the last harvesting is done in the second week of December. In the improved system, farmers usually dry and desilt the pond bed, apply moderate quantities of lime and cattle dung, provide farm-made feed, repair embankments and sluice gates more regularly, and have a hut for storage and watchmen (locally called *ala*).

Next to *P. monodon* (6-10 PL/m^2) farmers may stock *L. calcarifer*, *Chelon parsia*, *M. cephalus* and *Mystus gulio*. In low saline areas, farmers may stock Indian major carps, tilapia (*Oreochromis niloticus*) and giant freshwater prawn (*Macrobrachium rosenbergii*). The natural recruitment includes, among others, horina shrimp *Metapenaeus monoceros*, Indian white shrimp *Fenneropenaeus indicus*, sea bass and mullet. The total seafood production ranges between 700-750 kg/ha/year of which 300-400 kg/ha/year is shrimp of which 80-90% is exported. In North 24 Parganas District, after harvesting and dewatering, most farms hire tribal people to handpick a substantial volume of freshwater eel (*Anguilla bengalensis*).

In the North 24 Parganas District the medium and low saline bheries are prevalent and occupy 40% of water bodies. The Bidhyadhari River is the lifeline of shrimp aquaculture and also an outlet for sewage from the Kolkata metropolitan and its factories producing leather, garments, plastic and glass. The Bidyadhari River receives saline water under tidal effect from the sea and discharges into the Bay of Bengal through the Haribhanga estuary.

In recent years, bheri farmers have experienced declining shrimp yields, probably related to poor water quality due to effluent from industrial and urban areas and from semi-intensive P. vannamei farms. Water may have an unusual colour, an unpleasant odour or be foaming. Moreover, due to the clogging of canals and rivers, the sediment burden on farms is growing. Some farmers experienced decreased salinity levels in North 24 Parganas District while it is increasing in the Sundarbans area. Poor knowledge and awareness limit the implementation of simple better management practices (BMPs) such as removing sediment from ponds, applying proper amounts of lime, and biosecurity measures. The large pond areas, complex land ownership and lease system are further hindrances for the adoption of BMPs. Naturally recruited seed are often blamed for the spread of WSSV and other water-borne diseases, but traditional producers choose to stock seeds from natural sources because they find that wild shrimps have superior development, body colouration and survival rates than hatchery-reared shrimp. However, many farmers have switched to *P. vannamei* which has a higher growth rate than *P. monodon*.

Climate change-induced extreme weather events, such as coastal flooding, are becoming common in this part of the Ganges delta. These events result in the breach of pond embankments, escape, stress and mass mortality of stock, the introduction of undesirable species, worsening of water quality, and finally, massive economic loss. Social conflicts due to the salinisation of cropland and labour issues are increasingly common phenomena.

A pilot of integrated mangrove-aquaculture

To understand the possible benefits of mangrove integration in the bheri, our consortium compared three integrated mangrove-aquaculture systems together with three local farmers of Basirhat-II and Haroa blocks in North 24 Parganas (Table 1). The long-term objectives were:

- To improve the shrimp farming environment and establish a mangrove-based organic system.
- To increase shrimp and fish productivity through mangrove-based nutrient recycling in ponds.
- To fortify the carrying capacity of the farm and the adjacent coastal ecosystem.
- Mangrove restoration, carbon sequestration and income generation.

The initial investments in the integrated mangrove-aquaculture system are substantial due to the alteration of pond dykes and other hydrological modifications. All three farms practiced improved extensive shrimp farming and strictly adhere to the internal control system and standard operating protocol of the organic certification standards. For example, all farmers stocked hatchery-reared organic shrimp PL (<10 PL m^2) periodically and only liming was allowed. Usually, no supplementary feed was given, and shrimp grew based on the natural productivity of the farm. The selection of farmers and community willingness are critical steps of this system. Therefore, the farming communities (farm owners, farm-workers, part-time workers) were sensitised and empowered through training and exposure visits that created a consensus about mangrove conservation among local communities.

Before planting mangroves, dykes were redesigned with different slopes to make the plantation easier. Based on the size and topography of the farms, island like platforms were also developed for the planting of mangroves. Mangroves were incorporated into the inner embankments, peripheries, in-pond platform, and outer embankments of the adjacent canal. To provide some immediate benefits, some fruit

About the Consortium

The pilot activities were funded by the German retail chain ALDI SÜD in collaboration with the European shrimp importer Shore and the German Development Bank KfW-DEG in a public-private partnership model. Bluesensus, a German consulting firm, collaborated on the project alongside Indian partners Blue Sea Aquaculture Private Limited (BSA) and Nature Environment & Wildlife Society (NEWS) for implementation in the field. Since 2014, the three farms have been part of the organic shrimp farming clusters of the West Bengal Traditional Black Tiger Project, which was a joint venture between the European retailer Hofer KG and the Austrian Development Agency and supported by Ristic GmbH. As a spin-off from the Hofer KG project, Blue Sea Aquaculture Private Limited was formed in January 2017. In cooperation with hatchery, processing, and exporting partners, BSA has developed three organic shrimp farming clusters of 1532 ha involving 31 farmers with guaranteed traceability and chain of custody. Since 2015, the farms have been certified according to European Union organic regulations and Naturland standards. The BSA project was a pioneer of organic aquaculture standards under the National Program for Organic Production in India.

Table 1. Different integrated mangrove aquaculture systems (IMA) developed in North 24 Parganas, West Bengal.

Parameters	IMA-1	IMA-2	IMA-3
Planting year	2018	2019	2020
Block	Basirhat-II	Haora	Basirhat-II
Village	Andulpota	Bireswar-Gopalpur	Sadiknagar
Geo-coordinates	22°37'25.45"N 88°48'21.51"E	22°36'15.58"N 88°43'49.89"E	22°40'11.13"N 88°44'55.53"E
Area (ha)	5.89	1.45	2.0
Maximum salinity (ppt)	10-12	10-12	10-12
Water pH	7.5-8.5	7.5-8.5	7.5-8.5
Mangrove species introduced / tested	*Avicennia officinalis* *Bruguiera gymnorhiza* *Rhizophora apiculata* *Ceriops decandra* *Heritiera fomes* *Sonneratia apetala* *Nypa fruticans* *Xylocarpus moluccensis*	*Avicennia officinalis* *Bruguiera gymnorhiza,* *Rhizophora apiculata* *Ceriops decandra* *Heritiera fomes* *Sonneratia apetala*	*Avicennia officinalis* *Avicennia marina* *Sonneratia apetala* *Bruguiera gymnorhiza* *Rhizophora apiculata* *Nypa fruticans* *Heritiera fomes* *Xylocarpus moluccensis*
Type of planting	Dyke, platform, peripheral planting	Dyke, platform, peripheral planting, outer canal bank planting	Dyke, platform, peripheral planting
Mangroves (n)	2,510	1,576	3,118
Mangrove coverage	10%	20%	15%

Different modes of integrated mangrove-aquaculture ponds.

trees were also given to farmers who planted these in the periphery of the rest house. The mangroves were collected from a nursery located at Sundarbans. Mangrove species were selected based on salinity and soil profile and varieties of freshwater-loving to salt-tolerant mangrove species were tested in this intervention. Based on the seasonal availability, mangroves were planted at the beginning and end of the monsoon season. The protection against free-roaming livestock was ensured through bamboo fences around the farm. Regular monitoring was conducted to observe the survival and growth of mangrove species. Dead mangroves were continuously replaced.

Observations and lessons

Planting of the mangrove is recent, and a minimum of five years is required to recognise and interpret the effects on ponds, environment and income. The current average shrimp production from these ponds ranges 300-320 kg/ha/year while the average fish production ranged 400-450 kg/ha/year.

In low saline areas across the three sites, the growth of *A. officinalis* (*bain*), *Sonneratia apetala* (*keora*), *Heritiera fomes* (*sundari*) and *Nypa fruticans* (*golpata*) was slightly better than that of *Bruguiera gymnorhiza* (*kankra*) and *R. apiculata* (*garjan*). However, *Ceriops decandra* (*goran*) showed a poor growth rate in farm conditions. It is interesting to note that, flowers were already observed in *A. officinalis* and *S. apetala* within two years of planting. Natural recruitment of mangroves was observed on two farms where the canal is in very close proximity to the farms. In that case, the fastest growth rates were observed for naturally settled *S. caseolaris* (*ora*), *A. officinalis* and *E. agallocha* (*genwa*).

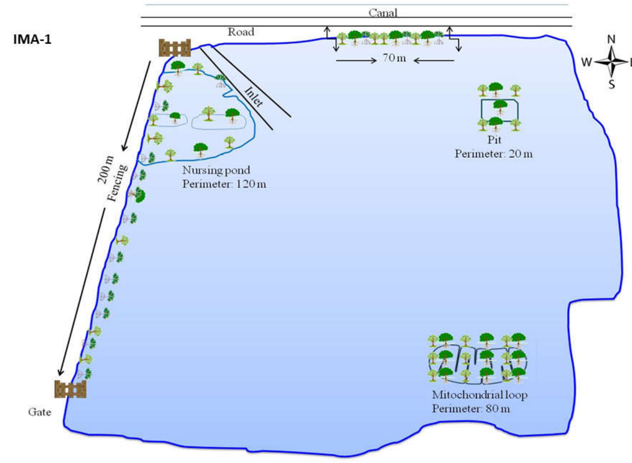
Regular monitoring of plant health is essential in the integrated mangrove-aquaculture system for at least few years after plantation. Small ponds can be maintained better (in case of integrated mangrove-aquaculture system 2), and the impact may be felt sooner. We observed that watering of the plants during December to February as well as in summer seasons reduced mortality. Furthermore, the use of organic amendments enhanced mangrove growth.

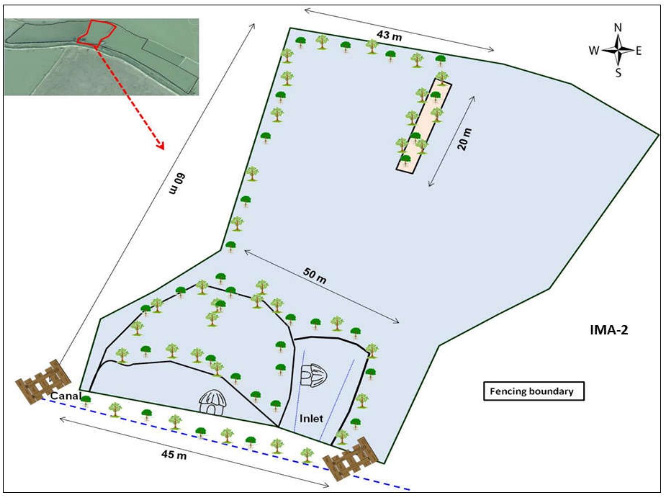
Future outlook and conclusion

Despite the potential benefits of mangrove-shrimp integrated farming in terms of climate change mitigation, its large-scale implementation and adoption may confront social, economic and ecological hurdles. Implementing an integrated mangrove-aquaculture system can be technologically tough for farmers at times, and the platform restricts the pond area available for shrimp farming.

The integrated mangrove-shrimp farming system has the potential for an organic certificate. According to the standard of Naturland[6], farms can acquire organic certification if the former mangrove area in parts of the shrimp farm is refor-ested to at least 50% within five years. For small individual farmers, the certification cost is too high to gain the premium prices for organically certified products, and farmers need to unite in clusters or cooperatives[7]. The same is valid for farmers wanting to capitalise on the carbon credits of their

Three IMA models implemented in North 24 Parganas District.





mangroves. Some governments provide more accessible rewards for mangrove ecosystem services, eg., land tax reduction or subventions.

To maximise the ecosystems services of the mangroves, experts recommended an associated design in which the mangroves are separated from the pond along the canal to create a natural habitat[8]. If such a design were to be implemented farmers would have to give up part of their pond and might feel that they were losing their land; they should either be compensated, or the design should somehow delimit their propriety. Such a design should guarantee regular mangrove flooding and increased interaction between the farm forest and its surrounding aquatic system.

To achieve sustainable mangrove management, local communities must be involved, and interested shrimp farmers trained, also to educate other farmers about the benefits of mangroves for the environment and shrimp. At present, many brackish water ponds in West Bengal's coastal region, particularly in the Sundarbans, are underutilised and underproductive due to inadequate management and other issues. Improving awareness can help to revert part of these ponds to mangroves; this gives scope for long-term storage of carbon and related payments to farming communities. Integrated mangrove-aquaculture systems can be part of such a strategy. However, institutional, technical, and financial support is required for the reversion to be successful.

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Important factors to consider before deploying integrated mangrove-aquaculture

- Farmer communities' willingness and active participation.
- Land ownership.
- Training.
- Tidal amplitude and suitable biophysical conditions of soil and water.
- Modification of pond dykes and hydrological correction.
- Selection of locally available mangrove species.
- Continuous supply of seedlings from mangrove nurseries.
- Tannin content of mangrove leaves.
- Frequent water exchange and inundation level.
- Protection from livestock grazing and constant monitoring.
- Periodic pruning or thinning of mangroves.
- Initial high investment costs.
- Opportunities for organic certification.

Different views of IMA-2 in 2021.