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Role of aquaponics in the sustenance of coastal India – Aquaponics is a solution for modern agriculture in ecologically sensitive Indian mangrove Sundarbans: A review

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Abstract
Providing a concrete global food guarantee has been the vision of scientists, world leaders, and nations. With a constantly growing per capita income in India, the demand for fish is on the rise. Over exploitation of aquaculture in mangrove areas, have resulted in loss of local habitat, and the restricted shrimp exports. This is a critical environmental imbalance as the mangroves are the lungs of our planet. India is the world's second largest food fish producer and newer sustainable technologies must be adopted. Aquaponics is a combination of aquaculture together with growing vegetables and crops without the use of fertilizers. Integrated multi-trophic aquaculture (IMTA) involving aquasilviculture can be employed to integrate food with bio mitigation of the Sundarbans. Its application has potential in the Indian Sundarbans as a method for environment-friendly aquaculture. We investigate the possible use of aquaponics as a means for food production without compromising the mangrove wetlands.

Keywords: Aquaponics, IMTA, mangroves, mitigation, sustainability

1. Introduction

Freshwater and irrigational land is gradually disappearing as result of industrialization and excessive use of chemical fertilizers. This is resulting in the expansion of aquaculture from freshwater to marine and brackish water regions [1]. Nearly 73% of the Indian Sundarbans population is directly or indirectly dependant on aquaculture as a means of livelihood [2]. World Bank mentions that fish comprises 16% of animal protein consumed globally. With per capita income on the rise, this hunger for fish will only go up [3]. Global food fish production has exceeding 66 million tonnes, with India ranking second at 4.2 million [4]. It is evident that aquaculture is constantly expanding hence new sustainable technologies need to be adopted to continue feeding the world.

Intensive monoculture and over-exploitation of the mangrove wetlands for aquaculture production is one drawback of in this sector. Tiger shrimp culture in the Indian Sundarbans has resulted in the loss of wetlands and mangroves [5]. Apart from serving as an ecological niche for a variety of flora and fauna, the mangroves stand to detoxify the anthropogenic and natural wastes released daily. Tiger shrimp and pacific white shrimp have been flagged witha restriction for export to the western buyer as they are produced by un-sustainable practices [6, 7]. This adversely affects the export trade of food fish from the coastal regions of India, which include the Sundarbans.

For improving the environmental stability or biological mitigation of the mangrove regions, mixed species polyculture with a combination of shrimps and fishes is a definite solution. Polyculture is a sustainable option which is a combination of various feeding habits resulting in fishes consuming natural available plankton and insects, followed by application of proper formulated feed for optimum harvest [8-12]. Another method called integrated multi-trophic aquaculture (IMTA) refers to a system of culture where the wastes of a certain species are energy or carbon source for another species. This system includes fin-fishes and shrimp culture along with shellfish and herbivorous fishes and marine algae varieties. Polyculture can be the co-culture of different fishes in the same trophic level; however, IMTA includes maximum utilization of all the various trophic grades [13, 14].

In addition to polyculture and IMTA, the technique of aquaponics may be a probable solution to address the concerns relating to threats to the mangrove ecosystem and water availability. With water conservation being a top priority in modern agricultural processes, aquaponics may improve agricultural sustainability and performance with limited use of nutrients and maximizing land utility [15]. It's a tried and tested method to farm fish in grow-tanks using necessary aqua-feed and additives. The nutrient rich water is pumped out into grow-bedswhere vegetables and crops are grown and harvested. The water which gets filtered by the growing crops then goes back to the fish tanks. For the Sundarbans, brackishwater aquaponics may be adopted for shrimp and fish polyculture along with mangrove sampling production which has been discussed later in the paper. Such programmes can improve aquaculture production along with providing stability to the region.
Aquaponics can be effectively used to treat waste water effluents of the aquaculture ponds. Fish farming discharge water is high in nitrogen, phosphorus and solids which can be utilized by constructed mangrove grow beds. Re-utilizing these nitrogenous compounds is beneficial since this can cause ammonia and nitrite toxicity [16]. In the following sections we will discuss about the types of aquaponics systems and their derivates which can be recommended for protecting our wetlands along with an insight on the efficiency of the technology.

2. The Nitrogen Cycle

The nitrogen cycle is well complimented by aquaponics (Fig. 1). Feed is administered to the fish grow-tanks, which is digested to produce waste. Fish excrete ammonia through urine, faeces (approx. 17%) and their gills (approx.. 80%). The nitrification cycle is the process by which the ammonia produced by the fish is converted by *Nitrosomonas* bacteria to nitrite and then by *Nitrobacter* to nitrate which acts as nutrient for the plants [17, 16].
Ammonia (NH_3) in water exists as total ammonia nitrogen (TAN), described by the following equation [15]:

$$NH_4^+ \leftrightarrow NH_3 + H^+ \quad (1)$$

Feeding rate is a crucial factor in generation of ammonia in an aquaculture pond, and this can be described by [18, 15]:

$$P_{TAN} = \text{(Daily Feed in Grams) X (\%age of Protein Content in Feed) X } 0.092 \quad (2)$$

P_{TAN} is the total ammonia production in grams per day.

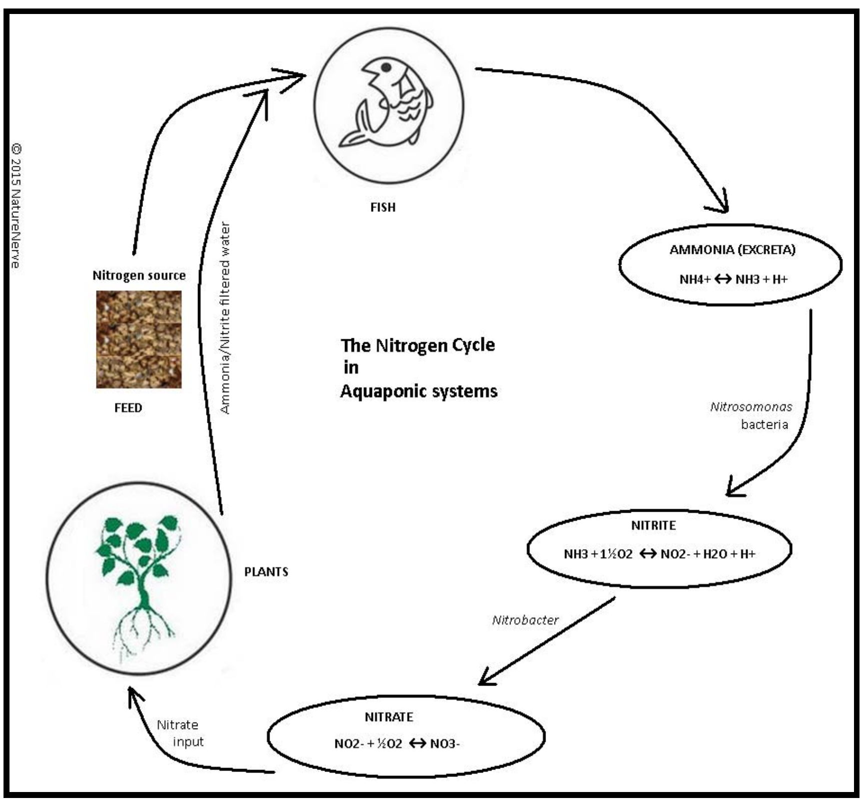

Fig 1: The nitrogen cycle in aquaponics

In aquaponics, the growth of plants from the aquaculture water fed system results in consumption of NH_4^+ which in turn converts NH_3 to NH_4^+ for balance according to equation (1). Nitrifying bacteria present in the plant grow beds/bio filters convert ammonia to $NO_3^-$from which plants take up their nitrogen requirements in aquaponics (Fig. 2) [15, 19 20].
This process is catalyzed first by *Nitrosomonas* bacteria by the following equation:

$$NH_3 + 1½O_2 \leftrightarrow NO_2^- + H_2O + H^+ + 84 \text{ kcal mol}^{-1} \quad (3)$$

Followed by the second step conversion by *Nitrobacter* bacteria:

$$NO_2^- + ½O_2 \leftrightarrow NO_3^- + 17.8 \text{ kcal mol}^{-1} \quad (4)$$

Hence the stocking density of plants is a crucial factor to balance the nutrient requirements for crop production.

Fig 2: A. Beneficial colonies of bacteria as green bio-film on gravel plant grow beds in an aquaponic system. The action of *Nitrosomonas* and *Nitrobacter* species of bacteria in conversion of ammonia from the aquaculture effluent water into NO_3^- for plants to take up nitrogen. B. Planting tomato saplings in the gravel beds.

3. Types of Aquaponics and related Systems

(a) Floating raft method. In a raft system (also known as float, deep channel and deep flow) the plants are grown on polystyrene boards (rafts) that float on top of water (Fig. 3) [21, 22]. A significant amount of nitrification occurs on the undersides of the polystyrene sheets. The system provides maximum exposure of roots to the culture water and avoids clogging. The sheets shield the water from direct sunlight and maintain lower than ambient water temperature, which is a beneficial feature in tropical systems [23]. Most often, this is in a tank separate from the fish tank. Water flows continuously from the fish tank, through filtration components, through the raft tank where the plants are grown and then back to the fish tank. The beneficial bacteria live in the raft tank and throughout the system. This is one of the greatest benefits of the raft system [17].

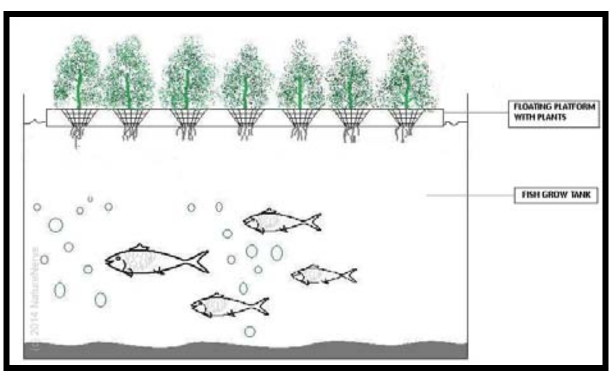

Fig 3: Floating raft methodof aquaponics

(b) Gravel system method. It is a cheap and readily available growing media that is filled in the grow bed (Fig. 4) [24]. To ensure adequate aeration of plant roots, gravel beds have been operated in a reciprocating mode, where the beds are alternately flooded and drained [23]. This method uses the fewest components and no additional filtration, making it simple to operate [25]. Gravel has several negative aspects. The weight of gravel requires strong support structures. It is subject to clogging with suspended solids microbial growth and the roots that remain after harvest [26].

Fig 4: Gravel system methods

(c) Nutrient Film Technique (NFT). This is a method in which the plants are grown in long narrow channels (Fig. 5). A thin film of water continuously flows down each channel, providing the plant roots with water, nutrients and oxygen [27, 28]. Troughs are used in this method which is lightweight, inexpensive and versatile. Troughs can be mounted over rearing tanks to efficiently use vertical greenhouse space [29]. Few drawbacks of NFT method are a separate bio filter is required, because there is not a large amount of water or surface for the beneficial bacteria to live. In addition, the plumbing used in a hydroponic NFT system is usually not large enough to be used in aquaponics because the organic nature of the system [23]. The thin film of water that flows through NFT (nutrient film technique) channels absorbs oxygen by diffusion, but dense plant roots and associated organic matter can block water flow [30].

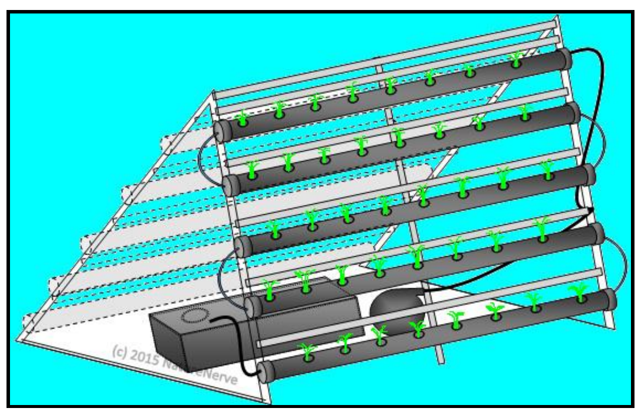

Fig 5: Nutrient film technique.

(d) Recirculating Aquaculture System (RAS). This technique represents a unique way for fish farming (Fig 6). Instead of the traditional method of growing fish outdoors in open ponds this system rears fish at high densities, in indoor "controlled" environment tanks. Recirculating systems filter and clean the water for recycling back through fish culture tanks [31]. In RAS it is possible to combine wastewater treatment in constructed wetlands with the production of crop plants biomass [32]. For each kilogram of fish produced in RAS aquaculture, the nutrients in the resulting wastewater allowed a vegetable biomass production of 7 kg [33].

Fig 6: Tilapia aquaponics by Recirculating Aquaculture System (RAS).

Aquaponics combines RAS with hydroponics (growing plants in a nutrient water source) in a balanced environment. The primary goal of aquaponics is to reuse the nutrients released by fishes to grow crop plants. RAS can be designed to be very environmentally sustainable, using 90-99 percent less water than other aquaculture systems. RAS can reduce the discharge of waste, the need for antibiotics or chemicals used to combat disease, and fish and parasite escapes. One of the key concerns in RAS is relating to the load of suspended solids and in particular to fine particles. The presence and accumulation of particulate wastes in RAS can negatively impact the water quality by affecting the performance efficiency of the water treatment or bio filter units and resulting in total ammonia nitrogen (TAN) spike [34-36].

These drawbacks can be negated in modified RAS and aquaponic technology which involves growing plants (preferably raft method) for the filtration and nitrogen removal process [37, 16].

(e) Integrated Multi-Trophic Aquaculture (IMTA). This technique involves cultivating fed species with other varieties of species at various trophic levels that utilise wastes from aquaculture for their growth [16, 38]. IMTA systems not only produce valuable biomass, but also provide waste reduction services. Presently, the most advanced IMTA systems in open marine waters and land based operations have three components – fish, suspension feeders or grazers such as shellfish, and seaweed, in cages, rafts or floating lines – but they are admittedly simplified systems. More advanced systems will have several other components (e.g., crustacean such as sea cucumbers, sea urchins and polychaetes in bottom cages or suspended trays and bottom-dwelling fish in bottom cages) to perform either different or similar functions, but for various size ranges of particles, or selected for their presence at different times of the year [13, 39]. Integrated marine aquaculture can cover a diverse range of co-culture/ farming practices with specialized forms of integration such as mangrove planting with aquaculture (Fig. 7), called aquasilviculture [40, 41]. Aquaponics, fractionated aquaculture, integrated agriculture-aquaculture systems (IAAS), integrated fisheries-aquaculture systems (IFAS) and integrated peri-urban aquaculture systems (IPUAS) are all different forms of IMTA [12]. With options for land and water combinations in both freshwater and marine environments, IMTA is a versatile and powerful food production tool that can be utilized in the Sundarbans for ecological stability; the technique has many benefits, among which bioremediation and bio mitigation with balanced fish production being the most relevant [13, 40, 42].

Fig 7: Aquasilviculture programme at Kakdwip, Indian Sundarbans

4. Biological mitigation of the Indian Sundarbans

The River Ganges flows out into the Bay of Bengal and at this confluence have formed the Indian Sundarban Mangrove ecosystem (Fig. 8), which is the UNESCO World Heritage site for its rich biodiversity and productivity. It spans an area of 9630 sq. km and comprises of 102 islands [43]. Importance of mangrove habitats ranges from economic and ecological protection to the coastal communities [44], shoreline stabilization against cyclones [45], and breeding ground for a variety of fauna. Intensive shrimp aquaculture (Fig. 9) and agriculture, together with timber requirements have lead to a steady loss of these precious forests [46]. Marshland habitats or, intertidal wetlands are the lungs of our planet; annually they absorb 25.5 million tonnes of carbon at the global level. Wetlands act as a filtration and purification system. It is estimated that the daily CO_2 absorption rate in the Indian Sundarbans is over 41 million tonnes with a valuation of USD 75 billion [47]. There have been government projects on mangrove replanting community programmes, yet only with a mangrove long-time survival rate of nearly a low 15% [48].

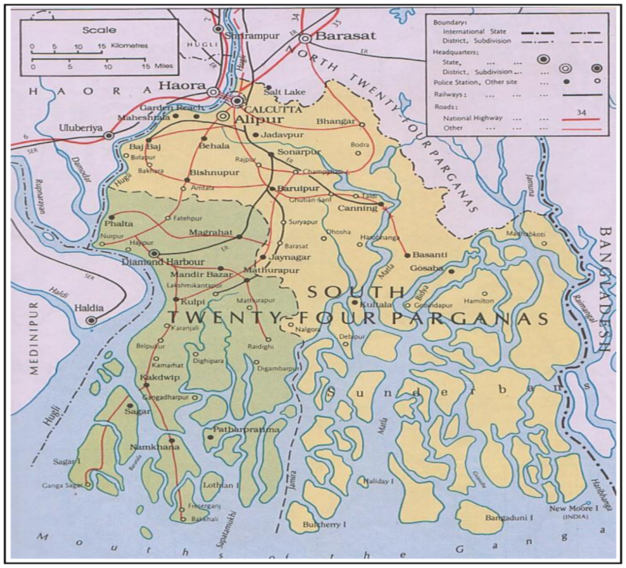

Fig 8: Map of the Indian Sundarbans with the major towns.

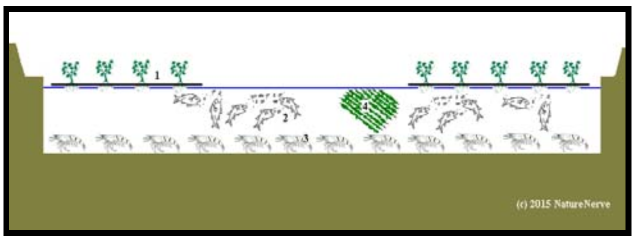

Fig 9: Brackish water aquaponics and aquasilviculture with IMTA. 1: Mangrove saplings by floating raft method on ammonia conversion; 2: Mullets and milkfish on fed culture; 3: Tiger shrimp on particulate organic matter and fed culture; 4: Marine algae in rope culture on dissolved inorganic nutrients.

Mangrove-associated aquaculture, a form of modified aquaponics under IMTA called aquasilviculture has incredible potential in building economic stability in the region together with celebrating the Sundarbans rich biodiversity. Combining water based IMTA technology it is possible to construct a system for mullets, milkfish and tiger shrimp production along with marine algae on rope [49] and mangrove sapling production by raft method. The fishes and algae can be harvested, while the samplings after reaching certain maturity can be transplanted to affected regions of the Sundarbans [50, 51] as part of various community programmes (Fig. 10).

Fig 10: Vast expanses of intensive brackishwater shrimp farms in Sagar Delta, Indian Sundarbans – notice the loss of mangrove vegetation.

Azolla microphylla, an aquatic fern is a popular natural protein source used as fish feed due to its endosymbiotic blue algae *Anabaena azollae* which helps the fern to fix atmospheric nitrogen [52] and it is regularly been grown by aquaponics farmers as aqua-feed to maintain sustainability. Similar process of using low cost protein sources need to be adopted as bio-mitigation technology for the Sundarbans. Mangrove associates like salt marsh grass, *Porteresia coarctata* and marine algae *Enteromorpha intestinalis*, have shown immense potential as successful aqua-feed [2, 53, 54] (Fig. 11). Intergrated IMTA based aquaponics structure may provide a platform to harness a self sufficient system of producing such high quality feed from native species of the Sundarbans and enhance its ecological balance, in addition to herbal neutraceutical therapeutic aqua-feed additives which can bring about a positive change in fisheries productivity in the Sundarbans [55]. In recent years, West Bengal is gradually witnessing new age agricultural transformations with large scale installations of aquaponic systems for food production (Fig. 12).

Fig 11: Natural alternative protein sources in aqua feed for aquaponics and IMTA

a. *Azolla microphyla* been grown and harvested as fish feed for tilapia aquaponics.
b. *Entermorpha intestinalis* growing in brackish water aquaculture ponds in Kakdwip, Indian Sundarbans.
c. *Porteresia coarctata* (salt marsh grass) growing in inter-tidal wetland areas near the banks of the Island of Namkhana, India Sundarbans. *Porteresia*, apart from being a food source,is an important mangrove associate as it stabilizes newly forming islands in the Sundarbans and protects the shore from coast-line shifting. It is also considered a pioneer species in ecological succession. Sustainable agriculture of *Porteresia coarctata* with IMTA may provide economic and ecological security to the mangrove zones.

There is a need for conservation of the mangrove ecosystem and yet it continues to decline because of over-exploited agricultural and industrial expansions, which leads to a prediction of a mangrove extinct world by 2100 [56]. There are strong issues on insufficient governance, gaps in implementation of environmental regulations and intense expansion of tourism which also result in mangrove loss [57]. Coastal fringe communities' are dependent on the Sundarbans mangrove forests, with nearly 3/4th of the population dependant on aquaculture and capture fishing [2, 58].

Fig 12: Aquaponic project installation in Uttar-Para, near Kolkata, West Bengal, India.

5. Conclusion

With an impressive fish culture potential in the Sundarbans, it is imperative to incorporate mangrove friendly aquaponics related systems in the region. This can improve the alternate sources of livelihood for the people of the Sundarbans, along with increase in mangrove cover with proper management of water. A comparison on the annual seaweed yield from various parts of the Indian coastline, Gujarat tops the list with production figures of nearly over 100,000 tonnes and next in line is Tamil Nadu, about 60,000 tonnes. West Bengal has no production data available, in spite of the coastal aquaculture potential. As technology for cultivation of extractive species of marine algae and oysters in the Sundarbans needs to be developed keeping in mind weather conditions, and evaluate the risks of cultivating these species along with fish with a potential for bioremediation. It is established that aquaponics technology can be effectively used to provide locally grown food for our communities. Ecological technologies with integrated aquaculture can herald a welcome change in the mangrove belt, andwith the demand for a steady food guarantee being continuously on high tide, we should rise together to build a sustainable future for our wetlands.

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