

## Research Article

# NO<sub>x</sub> Elimination and Drainage NP Elimination Should Be Stopped for The Production of Fish and for The Protection of Global Warming

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### Abstract

Contribution of aquaculture to global food security has increased significantly, especially after the realization that the capture fisheries have approached their maximum take and the land-based farming systems are facing serious constraints. Aquaculture should pursue the sustainable development goals to be able to deliver the expected supplies. It can do so by bringing about transformations consistent with the principles of sustainable development. Aquaculture influences the oceans and their ecosystem services negatively as well as positively, depending on the pathways of its development. It is pertinent to highlight the implications of both these impacts and present specific case scenarios that provide evidence of how the ecological aquaculture can benefit the environment, society and economy. Success of such aquaculture models can be measured through sustainability indicators. This paper elaborates these issues while providing an account of the role of aquaculture in food security.

**Keywords:** Aquaculture; Oceans; Sustainability; Working models

### Introduction

The contribution of seafood to global food security is being increasingly realized. At a time when capture fisheries have stabilized around 93.4 million tons and aquaculture production has reached 101.1 million tons [1], the fish farming is accepted as a major solution for food security [2]. With 1.0 billion people suffering from hunger and malnutrition in the developing world, more than 1.0 billion obtaining most of the animal protein from fish and 3.0 billion getting 20% of daily animal protein from fish [3], there can be no doubt about the significance of fish in human nutrition. The world per capita fish consumption that has increased to 20 kg in 2014 [1] is another pointer of the role of seafood, especially that originating from farms. The first sale value of fish from aquaculture is worth US\$160.2 billion [1]. Fish has emerged as the most widely traded segment of the world food economy [3]. Considering that the world's population is increasing by 80 million each year, it is expected to exceed 9.0 billion by 2050. Food and Agricultural Organization of the United Nations (FAO) has predicted that 70% more food must be produced globally by then to meet the increase in demand. Due to scarcity of land for farm-

ing and resources that it takes to yield the harvest, growing food in the ocean is the only viable and attracting option to bridge the gap between supply and demand.

Aquaculture is a cost-effective and efficient system of producing animal protein. When organized in responsible ways it can be the least ecologically impacting of all food production systems. It is evident from the sustainability indicators for animal protein production, namely Food Conversion Ratio (FCR) measured as kg feed/ kg edible weight, and Protein Efficiency (PE) measured in percentage unit. FCR values are 31.7, 4.2 and 2.3 for beef, chicken and fin fish, respectively whereas PE (%) is 5, 25 and 30 for beef, chicken and finfish in that order [4,5]. Other aquatic animals such as bivalve mollusks (mussels, oysters, clams) are non-fed extractor species that are filter feeders, picking plankton and particulate matter. They yield even better outcomes by producing food without human intervention in feeding them. Aquaculture uses space three-dimensionally which maximizes the use of resources while improving the yield per unit volume, unlike land-based food systems. It deserves emphasis that any ecologically sustainable food production (including aquaculture) that maintains the natural capital on which it depends can continue indefinitely [6]. The aquatic farming systems provide an outstanding example of a food system where ecological considerations can make them inherently sus-

tainable because of the inclusiveness of the principles that take into account the diversity of methods and different approaches to impart resilience that is especially needed in a changing climate.

Many issues of the current twenty-first century have placed aquaculture at a crossroads. It must grow rapidly and take the direction of sustainability to be able to produce expected outcomes. Food security is a serious issue and is becoming more so with the passage of time. Ironically, challenges to it have never been greater. Visionary policies, smart strategies and effective means of implementation can help aquaculture expand its contribution to blue growth, food security and human welfare. In addition to improving food supplies, aquaculture is also being looked upon as a sector that can deliver solutions to the problems such as unemployment, community empowerment and many more. For an industry that is so rapidly growing and diversifying, there can be no 'One size fits all' approach, and strategies need to evolve in the context of local ecological, social and economic scenarios [7]. There are some aquaculture designs where a systems approach has been shaped by inspiration from the processes that nature uses to produce seafood using ecosystem services.

This paper discusses the multiple dimensions of aquaculture sustainability and highlights the need for transcending disciplinary boundaries to develop resilient seafood production systems.

## **Aquaculture and Ocean Ecosystem-what is The Link?**

No matter how successful aquaculture is, it cannot be projected as a solution to overexploitation of ocean resources. Rather, it is a solution to bridging the gap between seafood supply and demand. Ocean ecosystem deserves to be managed not just for the sake of seafood but the many vitally important services it provides. The rapid growth of aquaculture industry and its expanding stake in the global food security owe to the impacts on the ocean that have undermined its capacity to produce food. Ecologically sustainable aquaculture takes some pressure of exploitation off the oceans but unsustainable aquaculture adds to the pressures that the oceans are already facing directly or indirectly from human actions. In fact, efforts to expand sustainable aquaculture have been triggered by the expansion of unsustainable aquaculture that cared for production of high market value carnivorous fish and shrimp at the cost of ecosystem resources such as prey fish and marine critical habitats. Some of the main unsustainable aquaculture practices are described below:

- Extraction of pelagic prey (forage) fish from ocean disrupts the trophic structure in the sea, leading to pressure on marine biodiversity and functioning of the ecosystem.
- Collection of brood stock from wild population for captive breeding in hatcheries adversely affects the natural population recruitment and thus reduces the population size in the sea.
- Construction of culture ponds in mangrove forests degrades or

destroys the mangrove ecosystem.

- Release of large quantities of nutrients from some forms of aquaculture leads to eutrophication that impairs the quality of marine environment for many species besides contributing to harmful algal blooms.
- Use of exotic species in aquaculture that fetch high price in international market often leads to their escape into the sea environment which results in stress on native populations through competition and exposure to pathogens.
- Release of hatchery-produced juveniles that have narrow genetic base to natural environment leads to their inbreeding with the native species, thereby weakening the genetic variability and resilience of the wild populations in the sea.

The most serious problem linked to the culture of carnivorous fish is use of enormous quantities of many species of small-sized planktivorous fish as feed for high-value farmed fish. These forage fish are a fundamental part of marine food webs. Their overharvesting has disturbed the marine ecosystem. Due to their low price in the market the forage fish are also consumed by low income groups and for them these fish are a matter of food security. According to estimates provided for the year 2014 by FAO (2014) [8], 21.7 million tons of global capture fisheries production were destined for the so-called non-food products, mainly for the manufacture of fish meal and fish oil. Of this, 16.3 million tons (75%) were converted to fish meal and fish oil, and the remaining (5.4) were largely used for direct feeding in aquaculture, fry or fingerling for culture, ornamental purposes, bait or some raw material. While most of the fish meal and oil were diverted to aquaculture but a portion was also used for poultry, cattle and other livestock, and direct human consumption such as medicinal grade fish oil. Aquaculture industry has grown since these data were released, and if the latest estimates are given credence the quantity of wild-caught forage fish used up by the aquaculture has gone up to 30 million tons [9]. Given the complexity of this situation and its implications for seafood security, it is essential to invest in producing new feed products from sustainable sources. Although it takes a long time and a great deal of research to develop new feed alternatives from beginning to scaled commercial production, it is a worthwhile undertaking. It is not just for the sake of marine conservation and sustainability of seafood but also from an economic perspective. If the estimated 200-300 million tonnes of additional aqua feed needed each year by the end of this century is a credible figure, the feed industry itself will be worth a US\$ 100 billion enterprises [10]. To some extent this will also lessen the exploitation of forage fish populations in the sea.

## **Main Elements of Sustainable Aquaculture**

Sustainable aquaculture is and will remain a dynamic concept for the reasons that sustainability of aquaculture systems will vary with species, method of culture, state of knowledge, technology usage, societal perception, location and possibly other factors.

Knowledge is the most powerful among these factors. An aquaculture system that we consider sustainable based on our current state of knowledge may not measure up to the sustainability standards as we gain a better understanding of the biological or ecological systems in which it operates. Since knowledge has no frontiers, sustainable aquaculture should logically be accepted as a journey, not a final destination. It is a work in progress and requires that we continue to make efforts towards that goal to address the new challenges as they arise, requiring course correction or adaptive modifications. Key elements of sustainable aquaculture are shown in (Figure 1).



**Figure 1:** Essential requirements for Ecological Aquaculture

The main factors considered in accepting whether or not an aquaculture practice meets the above requirements are elaborated here.

### Environmental Factors

Ecosystem compatibility, especially with respect to marine critical habitats; Conservation of freshwater; Efficiency of effluent and sludge management; Water quality control; Control of sediment quality; Minimized use of fish meal and oil; Responsible sourcing of brood stock or closing the breeding cycle in hatcheries; Producing healthy seed in hatcheries rather than mass collection of juvenile fish from wild environment; Using indigenous species rather than exotic ones; Control of escape of fish to natural environment; Stringent control of operations that threaten natural biodiversity.

### Economic Feasibility

Low production cost; Reduced input of resources or externalities; Improved harvest of stocked species; Efficient use of harvest, including recycling of by-products; Generation of value-added products enhances income; Increase in the usage of locally sourced materials in production modules; Founder brood stock

sourced from wild can be maintained for seed production for extended periods of time. Closing the cycle obviates the need to buy expensive brood stock.

### Welfare of Society

High quality food; Harvest free from residues of harmful chemicals through biosecurity measures; No adverse impact on space in community use (sanitation); Supply of fresh fish; Employment opportunities to indigenous people; Empowerment of local communities without gender bias; Entrepreneurship that produces spinoff benefits to communities; Platform for community views in decision-making related to development projects.

### Working Models of Sustainable Aquaculture

Considering the production-demand scenario, aquaculture will be the prime source of seafood by 2030. It offers demand-driven economic opportunities since the seafood industry which is currently worth US\$390 billion is set to steadily grow. This will, however, require periodic review and timely adaptive intervention.

Human intervention leading to conservation and food security can be designed in unique ways depending on ground realities. Linking aquaculture with what is called the 'Culture-based fisheries' is an example of positive outcomes from academia-community joint endeavours. Attempts by Kian et al. (2012) [11] to restore ecosystem of a coastal river considered 'Dead' in terms fish catch through ranching of a hatchery produced shrimp (*Macrobrachium rosenbergii*) that feeds in lower trophic levels provide a good example of working model. This species breeds in brackish water where early larval development takes place before the post-larvae start ascending the river even as they transition from free swimming life and planktivorous diet to a predominantly benthic lifestyle and euryphagic feeding habitat. Their diet comprises items that are easily available (aquatic vegetation, juveniles of bottom-living invertebrates, insect larvae and plankton). While the mass release of hatchery produced post-larvae into the lower reaches of the Petagas River enabled the shrimp to utilize whatever resources were available in the habitat, they themselves become part of the food chain, thereby contributing to revival of ecosystem by restoration of biodiversity and improving the catch. A water body used as a garbage dumping ground can gain respect as a source of fishing for the indigenous community. Unlike past practices where mangrove swamps were converted into shrimp ponds, inflicting a serious loss to biodiversity, this culture-based fisheries model helps in rebuilding the biodiversity whereas silvo-fishery model of aquaculture tends to conserve the biodiversity. There is still a need for caution in organizing aquaculture in healthy coastal-marine ecosystems. Any such attempt should be backed by a comprehensive environmental monitoring program comprising observations on water quality, marine biodiversity and functional links of the ecologically sensitive habitats. Case studies in Malaysia and else-

where in the world where aquaculture has been carried out using ecosystem resources of coastal bays, estuaries and lagoons provide a wealth of information for carefully planning ecological aquaculture (Figure 2).



**Figure 2:** Feasibility Studies Being Carried Out in The Sea.

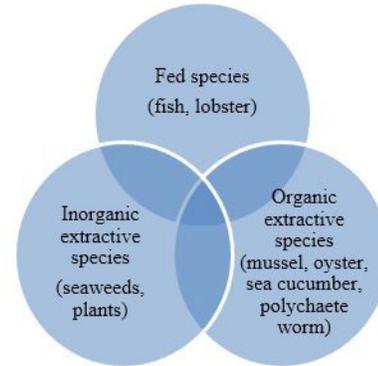
Brummett (2013) [5] has emphasized that ecosystem sustainability of aquaculture should consider sustaining diversity and abundance of indigenous species at desirable levels, and this requires a zoning program to designate areas over which monitoring programs should be established to measure indicators of sustainability of aquaculture, water quality, biodiversity and ecological carrying capacity. Institutionalizing this effort that would bring educational institutions (Figure 3) on board with their accredited analytical facilities will ensure success of these aquaculture projects.



**Figure 3:** Fish Hatchery with Modern Facilities at Borneo Marine Research Institute.

Integrated Multi-Trophic Aquaculture (IMTA) presents yet another model of ecological aquaculture that meets the sustainability criteria. Fundamentally, it mimics the processes that operate in natural ecosystem and serves to demonstrate how a responsible stewardship of an aquaculture system can ensure that the vital aquatic production is ecologically compatible, economically

feasible and beneficial to the community. It benefits the growers as well as the consumers. Key components of IMTA are recycling and integration of multiple species from different trophic levels (Figure 4).



**Figure 4:** Integration of Three Types of Trophic Level Species.

The water used in the system is recycled for reuse even as it serves as a vehicle for nutrient cascading. The system comprises fed species which are supplied feed from outside. The uneaten feed and metabolic waste from the fed species flow into holding space for organic extractive species that include filter feeders (e.g., mussel, sea urchin) and deposit feeders (Polychaete worm) which pick up organic particulate matter (uneaten feed and faeces) for nourishment. The water flow continues into a chamber or open area containing plants or seaweeds that extract dissolved inorganic nutrients such as nitrogen and phosphorus produced by fed species as well as organic extractive species. The water so filtered and cleared by the extractive species is available to fed species for their use. This is how wastes are assimilated into biomass and energy rather than being drained into natural environment as pollutants. The living biological filters (extractive species) are marketable biomass that brings additional income to farmers. These complementary species in IMTA work the same way in a natural ecosystem that they share albeit in a more diversified form.

IMTA has opened up challenging areas for research and development that extends far beyond the selection of species to be integrated into a production module. Currently, most of the IMTA models select one species from each trophic level, while leaving the possibility of increasing the number of species at various levels. This will be possible if the system design can be engineered to optimize the capture of waste products since stocking rates of fed and extractive species would depend on efficient nutrient cascading. IMTA would fail when waste from fed species is beyond the capacity of extractive species to assimilate, leading to poor quality of water returning to the fed species tank or entering the environment. IMTA also includes substrates for nitrifying bacteria. Innovative substrate that can concentrate these bacteria in higher density will contribute to reducing the residence time of nitrite and

ammonia in the water by hastening their conversion into nitrate. Experimental trials carried out at our aquaculture facilities [12-16] have used grouper, seabass, tilapia, spiny lobster as fed species, mussels and sea cucumber as organic extractives and seaweed and plants as inorganic extractive. Substrate for nitrifying bacteria used included gravel, coral rubble, Crystal-Bio and geotextiles. Growth of IMTA will depend on continued research to improve the environmental performance, diversification of species and production efficiency of the engineered modules. There are many indicators that leave no doubt about the sustainability inherent in IMTA modules. These are described in (Table 1).

Key issues	IMTA principles of operation	Indicators
Aquaculture waste of fed species	Used up by extractor species, not released outside the system	No discharge (Indicator 1).
Renewal of large volumes of freshwater	Uses water recirculation technique	No wastage of precious water (Indicator 2).
Genetic implications for wild population by escape of fish	Uses indigenous species. Even if hatchery-produced stock is used, it is held in captivity and entire stock is harvested. There could be a possibility of escape in sea-based modules.	No genetic impact on wild populations (Indicator 3a). Work in progress to secure fed species stock in sea-based modules (Indicator 3b).
Disease transmission risk	Health of the stock held in land-based facilities is regularly monitored. Fish showing signs of sickness are removed.	Disease transmission risk in controlled in the case of land-based IMTA (Indicator 4). There are no documented cases on such problem in sea-based IMTA modules.
Prey fish supply	Most of the species used in IMTA are not provided with prey fish. However, pellet feed provided to captive stocks may contain fish meal and oil.	Prey fish substitutes in pellet (Indicator 5a). For pellets where there is still large proportion of prey fish ingredients, sustainability is a work in progress (Indicator 5b).
Ecological footprint of species integrated with fed species	Organic extractive and inorganic extractive species are not supplied food from outside. They depend on waste from fed species. Furthermore, both these stocks are low in trophic level.	Non-fed species at the bottom of trophic levels produce no significant carbon footprint (Indicator 6).

Supply of wild brood stock	IMTA does not include captive breeding that requires sourcing of brood stock from the wild for seed production in the hatcheries. It is a grow-out system to raise young fish to harvestable size.	No direct effect on brood stock in the natural population (Indicator 7).
Stocking of juveniles of fed species	Generally, stocking of fed species depends on supply from hatchery, rather than natural populations. This is considered dependable, more practical in terms of size selection, and a measure of biosecurity.	No pressure on juveniles produced in the wild for population recruitment (Indicator 8).
Environmental resilience	IMTA is implemented under certain controlled conditions that boost the resilience of captive stocks and reduce vulnerability to environmental variables.	More adaptable to changing climate (Indicator 9).
Ecological compatibility	IMTA mimics processes that nature uses to produce food. Land-based modules are not located in ecologically sensitive habitats, so they have no adverse implications for ecosystem. Modules that are in close proximity to natural habitats use ecosystem resources which are viewed as supporting the production.	No threat to marine biodiversity or natural processes in the sea (Indicator 10).

**Table 1:** Sustainability Indicators of IMTA.

While IMTA creates a sustainable ecosystem mimicking nature, there is another form of aquaculture that can be established in natural ecosystems. It is an example of the coexistence of sustainable farming and sustainable natural ecosystem. Worth mentioning in this context are the mangrove-friendly shrimp farming (Silvofishery), pond polyculture, paddy-cum-fish culture and sea farming in large pens installed in coastal marine areas. The sea pens are particularly suitable for species such as sea cucumber which are sedentary. While their brood stock is protected in sea pens, the breeding contributes to population replenishment. Spats set-

tling in or around pens provide stocking material for aquaculture. When all these systems are compared, it is obviously the IMTA that provides a more controlled multiple species farming system. Others mentioned above are more open systems, requiring much larger areas to grow the same quantity of fish and are exposed to a lot more variable factors compared to IMTA. However, this does not exclude such aquatic farming methods from the ambit of ecological aquaculture. A silvo-fishery model uses mangrove ecosystem services to grow fish on a sustainable basis and this commits the grower to conserve this coastal-marine critical habitat which is now also receiving attention for blue carbon storage as a strategy to combat climate change. This topic has been reviewed by Mustafa and Shapawi (2015) [17]. Probably, successful models of aquaculture scientifically integrated with seagrass beds will benefit fish production as well as seagrasses that too provide vital marine ecosystem services besides being important in sequestering and storing blue carbon from atmosphere and oceans. Carbon sequestration contributes a great deal to sustainability of marine aquaculture by offsetting the acidification of seawater [18,19] Data provided by Conservation International for the Blue Carbon Initiative suggests that the mangroves and seagrasses cover 13.8-15.2 million hectares and 17.7-60 million hectares, respectively. In the last 50 years 50% of the mangroves have been lost. Loss of global coverage of seagrasses is 30%. Despite just 0.7% of the land coverage, the carbon emissions from mangrove loss account for up to 10% of emissions from deforestation globally. Seagrasses cover merely 0.2% of the ocean floor but store 10% of the carbon buried in the oceans each year. Ecological aquaculture that promotes conservation of these critical habitats can have multiplier effect-increase in fish production, climate change mitigation and protection of marine ecosystem services generally.

### Priority Topics for Problem-Solving Research

- Management of knowledge- by using traditional and modern tools of information and communication technology to ensure knowledge flow to researchers, helping them shape their efforts and to the industry to find solutions to the problems.
- Nurturing innovations- so as not to waste resources in repeating failed solutions but consider out-of-the-box approaches that appear to promise drastic increase in production efficiency without breaching environmental thresholds.
- Investing in smart aquaculture- by application of modern marvels such as artificial intelligence and robotics. Initiative taken at our institute in this area by Mustafa et al. (2016) [20] serve as an example.
- Going beyond pond, tank and cage culture- by organizing culture-based fisheries, and low-carbon marine farming systems such as those using sea pens.

- Boosting resilience of farming systems- through biosecurity, nutrition, genetic controls, and modulating farming systems to meet the organic aquaculture requirements.
- Advancing sustainable seafood solutions- through a large-scale farming of low-food chain species or species that can grow on feeds made up of ingredients from sustainable sources. Research is beginning to show that even carnivorous species have physiological systems to make use of plant-based diets and grow fast enough for a profitable aquaculture. This brings choice of food more under human control without imposing dietary restrictions on consumers.

Undoubtedly, past experience helps but modern-day and anticipated challenges are of different scales, requiring blending of traditional knowledge with scientific achievements. Science provides an evidence-based understanding of current issues and some future scenarios through analysis of trends. It will augur well for development of aquaculture if policy makers use science as a tool to convince the communities to accept what is good for them. The approach taken by the World Fish Centre to identify target countries with low and medium Human Development Indicators and high dependence on fish for food, and where aquaculture is either in early stages of expansion or has been established but needs to develop more rapidly to meet the demand is worth mentioning here [21].

Generally, aquaculture research moves fast enough in examining the evolving scenarios but probably more efforts should be invested in presenting information in a form that can motivate the informed decision-making. Policy-making agencies and managers act within their budgetary controls and mandates to fulfil the aspirations of the society, so for them the basis of action is not limited to scientific inputs alone. Through interdisciplinary efforts the scientific information can be packaged with social science, economics and monetary policies which would be easily appreciated and may even expedite decisions to support sustainable aquaculture. The fact that situations evolve over time, the management system for aquaculture industry will have to be adaptable to be able to respond to changes and maintain the growth trajectory.

### Conclusions

Ecological aquaculture can contribute a great deal to creating a sustainable food future. By promoting policies and practices for farming marine fish, shellfish and seaweeds that serve as human food in responsible ways, it has the potential of addressing the dilemma of food security for the human population likely to exceed 9.0 billion by 2050. Ecological aquaculture is highly diverse, adaptable and open to innovations in all the links of its production cycle and, therefore, has more horizons for making progress than any other food system. Ecological aquaculture tends to bring many

species in the farming systems, some of which synergistically utilize ecosystem resources to grow. Another feature of aquaculture is its compatibility of stocking multiple species in a limited space to multiply yield per unit area. New models of integrated aquaculture systems have enormous potential that can be tapped by way of targeted research into their designs and operating principles. Continued focus on every aspect of sustainability will enable aquaculture to help in building resilience in world food supplies. Decision-making in favour of aquaculture can help this sector to drastically increase its contribution to blue growth and societal welfare.

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