Lessons Learnt from the Past to Mitigate the Negative Aspects of Aquaculture in Developing Countries

A K H Priyashnatha*
Faculty of Technology, Eastern University, Sri Lanka
Corresponding author: E-mail: priyashanthahasith@gmail.com

U Edirisinghe
Postgraduate Institute of Agriculture, University of Peradeniya, Sri Lanka
E-mail: udenied@gmail.com

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Abstract
Aquaculture is considered, understood and identified as the "only way" possible to bridge the growing supply-demand gap of aquatic products in the world. Vast resource availability with higher profitability, growing demand for aquatic biotic resources and limitations of natural fish resources due to overfishing have led to speedy development of aquaculture worldwide. However, especially in developing countries, the sustainable development of aquaculture has been hampered immensely due to a number of reasons. Accordingly, the aim of this paper is to investigate the relevant information, to identify those negative aspects in depth and indicate possible implementations or changes required to mitigate deleterious repercussions. Environmental pollution, destruction of ecologically sensitive habitats (e.g., mangroves, salt marshes, mudflats, lagoons, and estuaries), soil salinization, irrational introduction of invasive aquatic species to sensitive habitats, disease outbreaks, risk to human health, and justifiable social concerns are among the major adverse effects of aquaculture. In a wider aspect, these could be overcome by addressing the shortcomings of knowledge, policies and regulations, adapting better monitoring/management mechanisms, public participation and application of novel rational and advanced technologies along with appropriate strategic plans. Thereby, aquaculture could be recognized as the most environmentally friendly, carbon-neutral, food production and sustainable sector compared to other animal food production sectors in the world.
Keywords: Aquaculture, Aquatic Biotic Resources, Environmental Pollution, Sustainable Development

Introduction
Aquaculture is no longer a young industry and has matured adequately over the past three decades. Because of applying the novel advanced technologies, it has developed species with higher economic benefits, and enhanced trade performance, resulting in a revolution in aquaculture in recent years, bringing the production ten times greater than agriculture production (Primavera, 2006; Li et al., 2011). In 2018, the total world aquaculture production was at an all-time high of 114.5 million tonnes and the first-sale value of production was estimated as US$ 263.6 billion. In addition, global aquaculture contributed 46.0 % to world fish production in 2018, up from 25.7% in 2000 (FAO, 2020). This speedy development of

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aquaculture shows the ability to fulfill one-third of the global protein requirement in 2050 (Froehlich et al., 2018), also reaching half of the world's seafood production for human consumption soon (Primavera, 2006; Li et al., 2011). Today, about 90% of the world's aquaculture production is generated from developing countries (Watts et al., 2017), particularly from China, India, Indonesia, Vietnam, Thailand and Chile as they are the leading producers in the world (FAO, 2020). Owing to the more predictable returns than fishing and tremendous income today, worldwide there are about 23.4 million full-time-equivalent employees in the aquaculture sector and the majority (85%) of them are from Asian countries (Valderrama et al., 2005; FAO, 2020). The aquaculture industry also generates employment in supported industries such as feed manufacturing, hatcheries, fry and fingerling culture, processing and marketing, hence aquaculture shows the importance of generating more and more new employment opportunities and poverty alleviation in local communities and act as an integral element of macroeconomic growth in many developing countries (FAO, 2020). However, despite all these benefits of aquaculture, it poses tremendous pressure on natural resources and local traditional fisheries, especially in developing countries where unorganized, non-scientific aquaculture practices are common (Olesen et al., 2011). Though there is much historical evidence that aquaculture practices in developing countries had been carried out in a manner that is destructive, new aquaculture practices are emerging without having a proper plan and may not be conducted sustainably (Chen, 1989; Harkes et al., 2015). This implies that, yet insufficient attention has been paid in developing countries to address the negative impacts of aquaculture. Under these contexts, a considerable number of research papers were reviewed in order to gain a broad and thorough understanding of aquaculture-related impacts. Accordingly, this paper aims to provide a review of various aquaculture impacts on both socio-economic and ecological aspects by using evidence from past to present, where the consequences of aquaculture had been reported, while emphasizing perspectives on how to mitigate those impacts for future sustainable industry, particularly in the developing countries.

Negative Impacts of Aquaculture Industry

Socio-Economic Impacts

In the recent past, many confrontations have also been taken place against the aquaculture industries due to its negative impacts around the world, including Mexico, Guatemala, Honduras, Ecuador, Brazil, Thailand, Vietnam, Indonesia, Philippines, India, Bangladesh and Sri Lanka (Senarath and Visvanathan, 2001; Allsopp et al., 2008). In a recent study, Priyashantha (2018) found that the majority of residents at East Coast, Sri Lanka opposed the operation of a functioning shrimp farm due to several direct and indirect socio-ecological negative impacts. Those highlighted issues included reduction of yields in the paddy cultivations near to the shrimp farm, depletion/salinization of drinking well water resources, restrictions on the traditional fishing area, reduction of natural fishing resources in the nearby river and destruction of mangroves etc. It was with this in mind, in 2016, a huge protest arose in Vaharai, Batticaloa district, East Coast, Sri Lanka against the proposed Industrial Aquaculture Park (1,110 ha) by the government and ultimately leading to shutting down it temporarily. Job security is one of the social concerns of employers, who engage in aquaculture. The major fact is the emergence of the diseases, leading to investors leaving the farm, finally resulting in losing their investments and laborers who worked losing their jobs. Many disease outbreaks have been reported throughout the world, even at the time aquaculture started to emerge. Sea lice, Caligus elongates caused tremendous economic losses in salmonid aquaculture, particularly during the 1990s. In Canada, the loss was $20 million in 1995, while in Norway it incurred a loss of Nk 500 million in 1997 and in Scotland, it had been f15-30 million in 1998 (Pike and Wadsworth, 1999). Sri Lanka was affected due to the disease epidemic of white spot syndrome virus, particularly during the 1990s, which accounted for the loss of SLR 1,000 million, while about 85% of farms were abandoned (Kumaranayake et al., 2015). Re-emergence of Salmon Anemia viral disease of Atlantic salmon (*Salmo salar*) in Chile during 2007-2009 took significant attention causing US$ 2 billion in losses and making 15,000 people jobless. Thereafter, salmon production costs also increased by 30% due to control measures (Mardones et al., 2011). Risks of food-borne diseases are one of the health impacts that are associated with the consumption of cultured fish. In America, many illnesses were reported with the consumption of shellfish and shrimps, which were contaminated with Salmonella spp. (Hamilton et al., 2018). Unregulated use of antibiotics in the aquaculture industry has created serious human health and food safety concerns, where consumption of cultured fishes treated with an antibiotic daily could create antibiotic resistance in humans due to the accumulation of antibiotic residues (Pham et al., 2015). Such incidents were recorded in Vietnamese aquaculture (4th largest aquaculture producer) products, as antibiotic-resistant genes in bacteria were discovered (Hedberg et al., 2018). With the understanding of those impacts, the use of antibiotics is now restricted in many developed countries including Europe, North America and Japan. However, in developing countries, lack of regulations and enforcement have facilitated the use of antibiotics extensively (Watts et al., 2017).

Ecological impacts

Introduction of invasive alien species (IAS) into natural ecosystems: Negative impacts on local biodiversity due to voluntary and/or accidental introduction of exotic invasive aquatic biota (alien species) reported during the history. In Thailand, there are about 40 exotic species cultured in aquaculture farms, where only two species (*Trachinotus blochii* and *Artemia* spp.) were found to be beneficial for aquaculture, as all the other species had caused threats to marine or freshwater ecosystems (Sampantamit et al., 2020). Other than the food fish aquaculture, the ornamental industry also poses great threats in introducing invasive species with over 5,000 species traded globally (Mendoza et al., 2015). The presence of exotic organisms can also change the trophic relationships in a few different ways, such as decreasing the number of prey available to native predators, reducing natural food resources and breeding grounds for the native fish species. Introduction of Nile perch (*Lates niloticus*) in Lake Victoria (the world's largest tropical lake in East Africa) to boost the fishing resource is one of the most historically experienced lessons, where an explosive increase of Nile perch in the 1980s, whipped out about 65% of the endemic haplochromine cichlids, eradicating approximately 200 vertebrate species in less than a decade and could be the largest extinction event among vertebrates in this century (Goldschmidt et al., 1993). The introduction of a novel apex predator Peacock bass, (*Cichla monoculus*, formerly *C. ocellaris*) into Lake Gatun, Panama in 1969, is another classic example, which led to powerful community-level consequences, where more than 60% of the most common native fish species have been extirpated and the remainder have been significantly reduced in areas colonized by Peacock bass (Sharpe et al., 2017).

Soil salinization/acidification*:* Aquaculture farms are sometimes abandoned for a variety of reasons, including operational, economic and hygienic concerns, leaving the soil hyper-saline, acidic and deteriorated. Owing to these, farmlands are unable to be used for other intended purposes such as agriculture without following a costlier restoration. In addition, dolomite and other chemicals used in aquaculture to remediate the soil can alter its physicochemical properties, therefore exacerbating the problem (Martinez-Porchas and Martinez-Cordova, 2012). For example, in Sri Lanka, 1,140 ha of coastal lands in Puttalam District, were dedicated to shrimp farming, 90% of farmlands left without functioning (Harkes et al., 2015).

Destruction of natural habitats*:* The development of extensive and semi-intensive shrimp farming tremendously accelerates mangrove deforestation than intensive shrimp farming. Malik et al. (2015) reported that in Indonesia, more than 75% of mangrove coverage (> 1.1 million ha) has been removed since the 1980s, due to the expansion of unplanned and unregulated commercial aquaculture. According to Paez-osuna (2001), in the world, about 1-1.5 million ha of coastal lowlands comprising mainly salt flats, mangrove areas, marshes and agricultural lands have been converted into shrimp ponds. In the Philippines, mangrove coverage has been reduced from an original area of about 500,000 ha to approximately 288,000 ha in 1970 and 261,400 ha were converted into brackish water fish ponds during 1993 (Janssen and Padilla, 1999). Today, the overall area of mangrove forests in the Philippines has dropped by nearly half, due to this rapidly growing aquaculture industry (Long and Giri, 2011). As reported by Harkes et al. (2015), Sri Lanka is also among the countries, where 50% of the mangrove areas in the Puttalam district had been cleared between 1992 and 1998, for the establishment of shrimp aquaculture.

Pollution of the natural aquatic bodies due to organic wastes and nutrients*:* Uneaten feed, excreta, used pesticides, herbicides and antibiotics are among the major pollutants released by the aquaculture industry. A comprehensive literature review conducted by Buschmann et al. (2006) have emphasized the negative impacts of salmonid farming on the Chilean coastal environment. They have highlighted the destruction of benthic biodiversity at least by 50% due to excess loading of organic matter, deposition of copper and higher Biochemical Oxygen Demand (BOD) i.e. lowering of the dissolved oxygen content. Negative effects of aquaculture industries due to the excess release of surplus nutrients (nitrogen and phosphorus) into aquatic resources have caused eutrophication. It causes the development of harmful algal blooms (HAB), which contribute to biodiversity losses and is now becoming a global concern. The formation of HAB with the mass accumulation of cyanobacteria leads to the release of cyanotoxins, which are extremely toxic to the environment and aquatic biota. HAB contamination can cause the death of aquatic macro-micro flora and fauna, eventually threatening aquaculture and fisheries practices. Though exposure to HAB is not fatal to humans, it has been associated with complications including pneumonia, liver damage, hepatic failure, gastrointestinal illnesses and cancer (Serrà et al., 2021). A review of studies undertaken by Tsikoti and Genitsaris (2021) have shown such development of HAB, particularly due to the intensive aquaculture systems in numerous coastal areas of the Mediterranean Sea belonging to France, Greece, Morocco, Spain and Tunisia etc.

Disease introduction to the native organisms*:* Historical evidence indicates the introduction of diseases and parasites through aquaculture operations. In the early 1900s, Japanese oyster drills and a predatory flatworm were introduced along with the Pacific oyster to the West coast and at that time this affected native oyster stocks, which eventually led to the decline of their population (Goldburg et al., 2001). Infection of Salmon sea-lice (a parasite on skin and blood), is one of the widespread problems for wild salmon and trout, in countries where extensive farming (creating a better place for the parasite to grow faster and transmit) is practiced. The introduction of the sea-lice to the natural environments happens through the infested water released by the salmon aquaculture farms. (Torrissen et al., 2013). Similarly, the introduction of nematode parasites of the genus *Anguillicola* to Europe from Asia with eels (*Anguilla* spp.) had led to the decline of the European native eel population significantly (Dangel et al., 2015).

Mitigating the Negative Impacts of Aquaculture Industry

Policies and regulations

A comprehensive report submitted by Barg (1992) to FAO highlighted the necessity of strengthening some of the policies and regulations, particularly in the developing countries, while designing aquaculture industries for sound utilization of the ecological capacity of the coastal area to produce aquatic products, providing higher income to reduce the conflicts of the aquaculture industry with other coastal activities, preventing or reducing the adverse environmental impacts and ensuring that the adverse impacts remain within acceptable limits and to reduce the health effects of consumption of aquaculture products. Nevertheless, today many countries and international institutions have begun to strengthen policies on trade-off, land-use, and farm input and output in response to the consequences of the aquaculture industry, though the expectations have not been met due to gaps and weak implementation of policies and management strategies (Gimpel et al., 2018; Belton et al., 2020).

Environmental Impact Assessment (EIA)

EIA often analyzes the impact of proposed project/development on wild fish stocks, public health, drinking water and fish consumption and other inter-related socio-economic benefits and adverse effects. Therefore, EIA ensures that high-quality environmental information is visible to the public officials and citizens before decisions are made and before the government makes any significant commitment to environmental resources. Hence, carrying out a proper EIA should be mandatory, wherever future aquaculture practices are to commence (Priyashantha, 2018). In contrast, various scholars have also shown that EIA has become a political tool, whereas proper judgment could be neglected (Ho et al., 2020).

Monitoring and Management Mechanisms

Water being a limiting resource, irrational use of water could lead to deleterious environmental impacts, necessitating careful handling to conserve these resources. Therefore, rational management of aquaculture mechanisms is essential, since it ultimately leads to the sustainable development of aquaculture, while protecting the consumers, environment and the economic sector. In addition, the management mechanism also needs to be in conformity with the prevailing international policies and regulations, the best available science and technology and the use of best available experiences and expertise (Read and Fernandes, 2003). Reutilizing aquaculture wastes through modifications in the culture system is one of the best methods to reduce aquaculture pollutants and reduce the addition of feeds for cultured aquatic organisms. Moreover, it conserves 90-99% of water, particularly in intensive fish farming practices by the reuse of effluents after treatment (Badiola et al., 2012). A comprehensive literature review conducted by Martínez Cruz et al. (2012) have highlighted the number of benefits of probiotics as it has the ability to replace most of the synthetic chemicals, enhance the growth and reproduction of cultivated species by maximizing the appetite and the digestibility, inhibition of pathogens and improving the immune response of cultured organisms and thereby disease control (e.g., the resistance of *Oreochromis niloticus* against *Edwardsiella tarda*). improvement in nutrient digestion when the feed is supplemented with probiotics, enhance the water quality of ponds *via* minimizing the accumulation of dissolved and particulate organic carbon and balancing the phytoplankton population and finally enhancing the stress tolerance due to the balanced hormone activity of cultured organisms. Wang and Lu (2016) highlighted the importance of polyculture, which supports the sustainable development of aquaculture, since it enhances feed utilization, increases total farm yield and profit along with improving water quality by minimizing the pollutants, reducing diseases and use of chemicals. Integrated Aquaculture-Agriculture (IAA) systems are also an ideal strategy to reduce the negative effects of aquaculture together with economic benefits and thus defined as one of the sustainable aquaculture practices. IAA is described as a concomitant or sequential connection between two or more aquaculture and agriculture activities, including the integration of fish, fruits, vegetables and livestock such as pigs, chicken, ducks, goats and cattle. Animal manure is used as a feed for cultured fish species, which will minimize the administrative quantity of different feeds, making it lucrative for farmers and valuable for the environment. (Debnath et al., 2013). Shifting into

Integrated Multi-Trophic Aquaculture (IMTA) is also important for the recycling of aquaculture by-products. IMTA includes the integrated cultivation of different finfish species coupled with extractive species such as marine invertebrates that feed on detritus and/or algae (Guerra-García et al., 2016). Best water management practices are important for fish health and to reduce the contaminants in water used. Bio-filtration is another technology that has recently been used in aquaculture for wastewater treatment. The basic idea of this technology is the formation of a filter bed *via* the attachment and growth of beneficial microorganisms (e.g., *Nitrosomonas* and *Nitrobacter* spp.) that extract dissolved chemicals from water and turn them into particulate biomass or harmless dissolved compounds (Siddiqui, 2003).

Public Participation

Consideration of the general public opinions is important while planning/introducing a new aquaculture industry to the area and in making aquaculture policies and regulations in individual countries. Public participation is a key tool in resolving conflicts, supporting implementations and improving quality of decisions (Coffey, 2005). The introduction of public participation could lead to minimizing or avoiding problems such as biological over-exploitation, over-capitalization, monopoly in commercialization, failures in loan payments, failures in controlling effort, use of obsolete vessels and equipment, social conflicts for the resources etc. Scientific advice is also very critical to the public for decision making, management and planning (Hernandez and Kempton, 2003).

Application of Novel/Advanced Technologies

Lebel et al. (2016) have stated that in countries like Thailand and Mexico, where extremely rapid aquaculture development was observed, it is crucial to implement the Geographic Information System (GIS) based databases. Accordingly, a GIS-based system can be used to identify aquaculture pollution and disease spread and these arrangements can be effectively used to mitigate the negative impacts of aquaculture. Mapping of the spatial distribution of aquaculture ponds/lands enables monitoring and management of aquaculture efficiently. Biofloc technology is considered a healthy method to control the nutrient wastes of aquaculture. This method works by adding carbohydrate sources like molasses into the polluted water body to maintain the carbon-to-nitrogen ratio (C/N) at a higher level (10-20:1), with the help of heterotrophic bacteria. Here, generated energy from carbohydrates is used to produce proteins and ammonia, which can be converted into microbial flocs. Therefore, biofloc technology helps to convert the wastes to nutrients and can save 24% of the costs of commercial feed (Binalshikh-Abubkr et al., 2021). Biotechnological (Genetically Modified Organisms/GMO) applications can be used to produce new aquatic technologies for the industry, which are having favorable characteristics such as disease resistance and will reduce the application of chemicals to cure diseases. However, this is still controversial and research studies have yet to be performed (Houston and Macqueen, 2019). Modern biotechnological applications also could be used to develop the ‘Recombinant vaccines’ to control bacterial diseases in fish and also could reduce the use of antibiotics (Mzula et al., 2019). Production of specific pathogen-free (SPF) aquatic organisms such as shrimps is ideal for sustainable aquaculture, since the produced organism may show better mating and reproductive success, minimize the application of chemotherapy and ensure the availability of disease-free broodstock throughout the year *etc* (Barman et al., 2012). Practicing Specific Pathogen Resistant (SPR) and Specific Pathogen Tolerant (SPT) approaches will allow to produce aquatic organisms with higher resistance to specific diseases (e.g., White-Spot Syndrome Virus disease of shrimp) and increase the survivability of the organisms (Alday-Sanz, 2019).

Conclusions and Recommendations

Being a rapidly developing industry, aquaculture is responsible for delivering many negative impacts to social-economic settings and environment/ecosystem, which thereby tends to affect the industry's positive nature. Sustainable practices are heavily questionable in developing countries with poor legal enforcement and poor surveillance. It is urgently needed to fill the gaps of prevailing policies in developing countries. Solving the uneven distribution of novel/advanced knowledge and technologies such as feed management recycling systems, water reuse practices, reclaimed water and releasing wastewater after pre-treatment, new sanitary actions and improvements in biosecurity measures are ideal solutions. In addition, the requirement of EIA, proper land use management plans and public participation are important while implementing new aquaculture projects. Moreover, the economic valuation of the conversion of mangrove forests into aquaculture must be made mandatory. Finally, the entire activity should be coordinated and monitored by an authorized organization, instead of the present system of having multiple organizations for the same subject area without rational coordination among them, which is the main cause for most of the indicated situations.

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