# Feasible practices to enhance the sustainability of shrimp farming in Ecuador

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Rosalie Dudink (5897963)

Writing assignment

Environmental Biology, Ecology and Natural Resource Management, Utrecht University

Supervisor: D. Tolunay MSc

Ecology and Biodiversity, Utrecht University

Examiner: Dr. P.A. Verweij

Energy & Resources, Copernicus Institute of Sustainable Development

Second Reviewer: Dr. M. van Kuijk

Ecology and Biodiversity, Utrecht University

## Abstract

The shrimp farm industry in Ecuador has caused major environmental issues. Pond construction in mangroves has resulted in deforestation, biodiversity loss and has applied pressure on mangrove-dependent communities. Measures to mitigate these issues have been proposed but their effectiveness and success have not yet been clearly analysed. Papers on sustainable solutions for shrimp farming in Ecuador and their effect have been reviewed. Communal custody of specified mangrove areas has proven to be most successful in mangrove conservation, together with protected areas established by the State. Moreover, reforestation of mangroves by local communities have been fundamental in mangrove regeneration. Most promising options for the future include strengthening of management and law enforcement by the government with participation in policy making of coastal communities. Improvements are needed in mangrove and shrimp farm monitoring. In addition, more financial support and training is needed for restoration and conservation of mangroves and for technological solutions mitigating water contamination issues.



## Laymen’s summary

The main shrimp producer of the Western Hemisphere is Ecuador. Along the shore, in the intertidal zone, nutrient levels and water temperatures are suitable to grow shrimp. The intertidal zone is the habitat of mangroves, fish, crustaceans, birds and mammals. Local communities live here and are dependent of the mangroves for their resources. Moreover, mangroves capture carbon, purify water and protect the coast. However, intensification of shrimp farming for an increasing export demand has led to increasing areas being cleared for the construction of shrimp ponds. In addition, wastewater from shrimp ponds contain antibiotics, disinfectants, piscicides and elevated levels of nitrogen, salt and sediment. This wastewater is dumped in nearby waterbodies, affecting water quality. Consequently, shrimp farms in mangroves cause important ecosystem services to be lost, a decrease in biodiversity and local communities to lose their habitat.

In the 1970s the first shrimp farms were established; total shrimp pond area increased, mangrove area decreased, and production numbers rose. However, since the 1990s environmental and social issues related to shrimp farming were noticed. Papers were published about the various effects shrimp farming had. Other papers have been responding with solutions to mitigate these effects. The shrimp farm industry is an important source of income for the government; shrimp farming in itself will not be banned. Therefore, to stop biodiversity from decreasing, to maintain the important mangrove ecosystem and prevent local communities from losing their habitat, sustainable solutions must be investigated. In this paper, proposed sustainable solutions have been reviewed. Effective and successfully proven solutions are combined to propose a sustainable, ecological and governmental (SEG) sustainable shrimp farming approach: Most restoration of mangroves is found in zones with custody agreements with local communities and protected areas by the State. Local communities have replanted and helped natural regeneration of mangroves. They should be supported through training and financial support. Moreover, ecotourism in their habitat could provide for their income. The government should aim at including their opinions in policy making, besides improving enforcement of laws on mangrove use. Shrimp farmers can be supported by training on environmental issues and sustainable shrimp farming. Also, support is needed for the construction of sustainable shrimp farms, preferably recirculation systems with constructed wetlands to reduce wastewater effects. At last, close monitoring of mangroves, both removal and regeneration, are necessary in mangrove restoration.

# 1. Introduction

Shrimp farming in mangroves is known to be practiced for more than 600 years. The first simple shrimp farming was implemented in Indonesia to harvest catching feed for fish (Schuster, 1952). During this time, Inca's in Ecuador performed a similar practice (Twilley, 1989). They closed tidal lagoons to catch penaeid shrimp larvae; short-living shrimp species who migrate to nursery habitats in wetlands (Gowri & Nammalwar, 2015). This type of aquaculture is still done by local communities living along the coast; local communities catch shrimp for their own consumption and safeguard numbers of aquatic species to prevent depletion of coastal waters. In the 1930s, the first experiments on cultivation of shrimp were conducted in Japan, through induced spawning of Kuruma shrimp. This research was followed by experimenting in countries with more favourable conditions for shrimp cultivation than Japan. The first success was that of an intensive culture method for Black Tiger shrimp in Taiwan in the 1970s. This was the start of the intensification of shrimp farming, spreading onwards to other countries in Asia. The Food and Agricultural Organisation reported that the current top five producing countries of coastal and marine crustaceans are: China, Vietnam, India, Indonesia and Ecuador. In 2020 whiteleg shrimp (*Litopenaeus vannamei*) was the top aquatic species produced worldwide with 5.8 million tonnes (FAO, 2022). Currently, Ecuador is responsible for more than half of the shrimp farmed in the Western Hemisphere, exclusively farming whiteleg shrimp (Boyd, Davis & McNevin, 2022).

## 1.1 Shrimp Farming in Ecuador

Ecuador depends on the export of primary commodities, leading to an unstable economy. Before the first intensive culture farms of shrimp, Ecuador has faced crises due to plagues in banana and cacao monocultures. The country was in desperate need of coming out of debts (Veuthey & Gerber, 2012, Vallejo, 2010). Around the 1970s, farmers from Panama decided that Ecuador was suitable for year-round production of shrimp (Cheshire, 2005). This was due to favourable water temperatures and the abundance of tidal coastal zones with a high nutrient richness, needed for the growth of shrimp larvae (Khuong, 2016). The first farms were established in the South-West of Ecuador, in the El Oro province. This expanded northwards to the provinces of Guayas and Manabi and reached Esmeraldas in mid-1980s where mangroves are located. (Figure 1). Because the shrimp industry was increasingly profitable, the government of Ecuador started to grant concessions, allowing farmers to use certain coastal areas for periods of 10 years (Veuthey & Gerber, 2012). However, this governmental support advanced shrimp farming activities, which destructed mangrove ecosystems and affected the livelihood of the local communities. Consequently, local communities started to protest. This forced the government to take actions to mitigate consequences correlated to shrimp farming. Thus, in 1978 a law was enacted to illegalize the construction of ponds for shrimp farming in mangroves. However, 99% of all shrimp farms in mangroves have been established after the enactment of this law (Hamilton, 2020, Chapter 2). This is the reason of a poor enforcement of the law; the government has issued private concessions and mangrove land was illegally enclosed by shrimp farmers (Veuthey & Gerber, 2012).

Currently, about 40% of mangrove area has been lost in Ecuador due to the conversion of mangroves into shrimp ponds (Hamilton, 2020, Chapter 2). In 2008, the Ecuadorian government has legalized mangrove conversion into shrimp ponds to secure a part of the profit for the state's budget (Veuthey & Gerber, 2012). Consequently, shrimp farming has been increasing the past years, making Ecuador the fifth largest shrimp producer of the world (FAO, 2022). In 2019 the production was estimated to be about 540,000 tonnes (Boyd et al., 2021b). About 230,000 ha is dedicated to shrimp farms (Monsalve & Quiroga, 2022). The shrimp industry provides a substantial contribution to the economy. However, these benefits are overshadowed by the consequences for nature and society (Primavera, 2006).

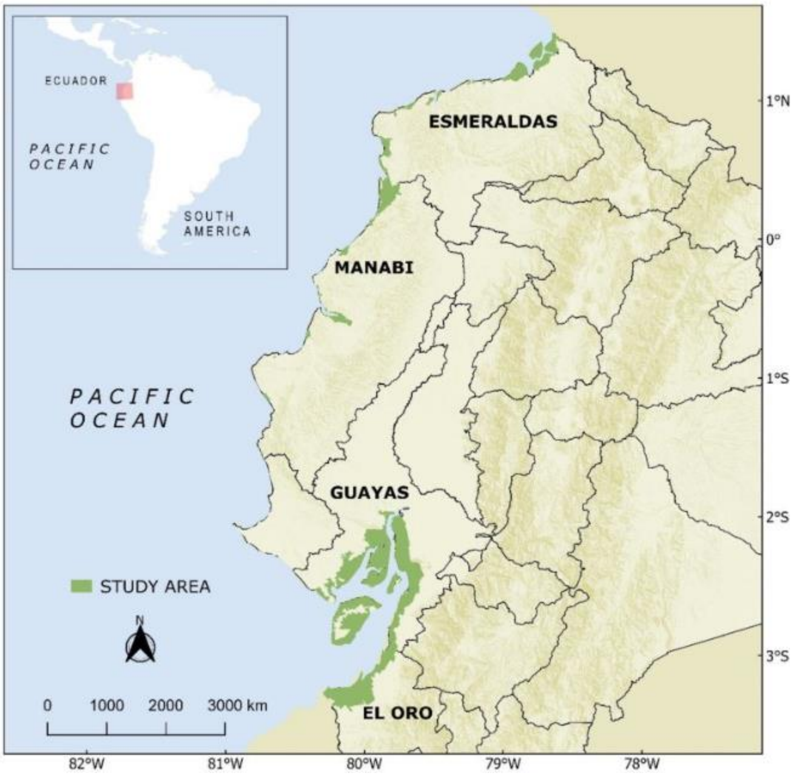


***Figure 1*** *Coastal provinces of Ecuador. In green the locations where mangroves grow, these are the regions where shrimp farms are located (Boyd et al., 2021b, Morocho et al., 2022).*

## 1.2 Ecological issues

Most shrimp ponds are constructed close to river mouths and estuaries. Estuaries have the ideal water, nutrient and feeding conditions for female shrimp, called brood stock, who are collected for their eggs. Furthermore, for the so-called grow out ponds where juvenile shrimp is brought to grow, fresh estuary water is needed daily. Because mangroves grow in most of the areas surrounding estuaries in Ecuador, mangroves are removed for the construction of ponds (Hamilton, 2020, Chapter 2, figure 2). An average shrimp farm has a lifespan of 7-15 years. After those years shrimp farming is known to collapse. Bacterial infections and viruses due to insufficient hygiene are the primary reasons for this collapse (Páez-Osuna, 2001). In Ecuador in 1993, the Taura Syndrome hit and in 1999 the White-spot virus, drastically reducing harvests, (figure 2, Veuthey & Gerber, 2012).

When a virus or bacterial infection hits, shrimp farmers are forced to abandon their farms and move somewhere else. However, when a mangrove area has been cleared for shrimp farming, the habitat has been altered to such extent that mangroves are growing back naturally (Páez-Osuna, 2001, Hamilton, 2020, Chapter 6). As a result, the global mangrove area has been reduced by 30%; 40%-60% of this is caused by shrimp farming (Veuthey & Gerber, 2012). Currently, the mangrove area has been estimated to be 161,835 ha. Mangroves provide ecosystem services such as coastal protection through flood control, sediment trapping, water purification and prevention of soil erosion. It is a nursery ground for larvae of fish, crustacean and mollusc species. Not only is it a nursery habitat, but mangroves are also nesting grounds for certain birds, bees, mammals and reptiles (Mitra, 2020). Consequently, with the exploitation of mangroves, important ecosystem services are lost.

Another loss in ecosystem services of mangroves concerns their role in carbon sequestration. Only 0.3% of the global coastal area is occupied by mangroves, but they store about 14% of coastal organic carbon (Alongi, 2020). A shrimp farm has 80% less mg carbon per ha compared to a ha of extensive mangrove (Hamilton & Lovette, 2015, Merecí Guamán, 2017). Furthermore, the irreversible mangrove loss is linked to a decrease in water quality, soil erosion and higher risks from floods and storms. Additionally, the removal of mangroves leads to habitat loss and thus low biodiversity (Martinez-Alier, 2001). Globally about 40% of vertebrates endemic to mangroves is at the verge of extinction (Luther & Greenberg, 2009).

Besides the destruction of mangroves, the discharge of wastewater from shrimp ponds, containing salt, nutrients, sediments, antibiotics and fish poison, imposes a negative impact on the area surrounding the farms. It is estimated that an average sized shrimp pond replaces 345 $m^3$–600 $m^3$ water a day (Gautier, Amador, & Newmark 2001). Within a shrimp pond, the salinity of the water increases because of higher evaporation rates of standing water. This results in disturbed water balances when this water re-enters the estuary during drainage. Consequently, losses of aquacultural land due to saltwater intrusion of shrimp farms have been reported in Ecuador (Hamilton, 2020, Chapter 2). Poor quality feed for shrimps also effects water quality: nutrient levels increase, pH alters, algae growth is induced. The water which leaves the pond is filtered, but still contains pollutants. This wastewater can cause a reduction in dissolved oxygen, eutrophication, changes in benthic communities and thus death of fish and other species when entering adjacent estuaries (Hossain, Uddin & Fakhruddin, 2013). Moreover, practices in shrimp farming such as aeration and feeding results in suspension and sedimentation of the water. When water with elevated levels of colloids and suspended soils is discharged in adjacent waterbodies, this results in turbidity. In turn, turbidity blocks sunlight and has thereby detrimental consequences for primary production (Dewalt, Vergne & Hardin, 1996). Furthermore, antibiotics and pesticides are dispensed among shrimps to protect them from diseases and prevent infection outbreaks. A consequence is a decreased disease resistance of shrimp, requiring an ongoing supply of antibiotics (Kautsky et al., 2000). Additionally, residues of pesticides and antibiotics in wastewater might be toxic to non-target species (Primavera, 1998). Lastly, in shrimp ponds fish poison is used to kill unwanted fish, killing wild fish when released into estuary waters (Collins, 2010).

A threat imposed by shrimp farms other than wastewater is the escape of shrimp into the river or estuary. This could be a problem when the shrimp is a non-native or exotic species. It might disrupt the food chain, alter the habitat or bring diseases (Hossain et al., 2013). Another concern related to shrimp farming is fish caught for shrimp feed. Paradoxically, growing of shrimp is said to compensate for catching of fish. However, the use of wild fish for shrimp feed causes a decline in fish stock, together with the removal of mangroves (Naylor et al., 2000).

Altogether, shrimp farming imposes detrimental consequences for the biodiversity of coastal areas (Diana, 2009). Beyond a loss in ecosystem functioning and biodiversity, the livelihood from people living directly from the mangroves is also affected (Martinez-Alier, 2001).

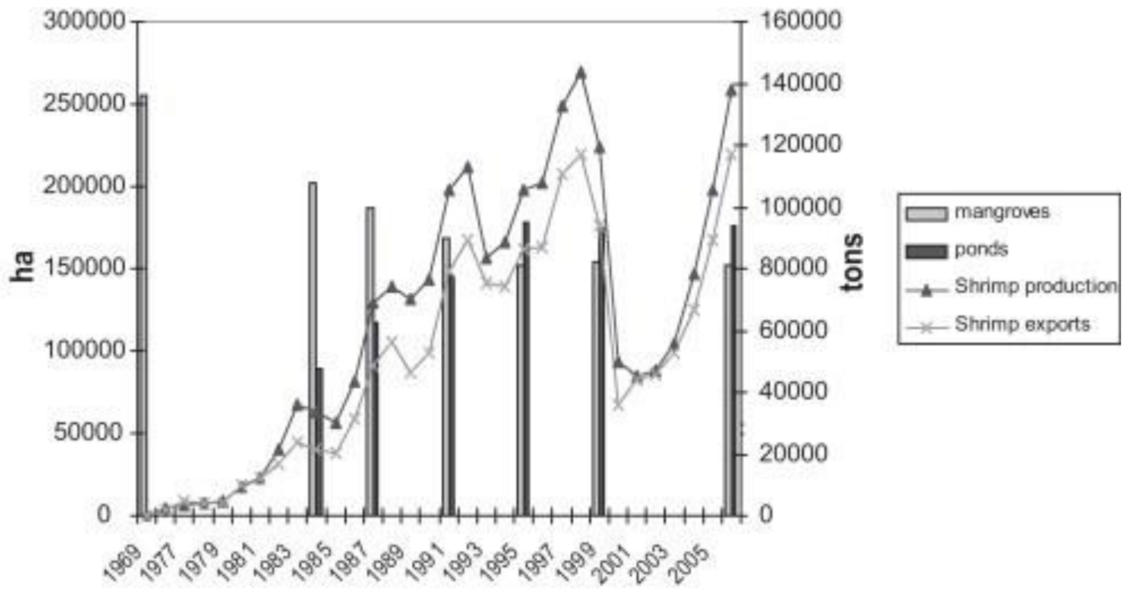


***Figure 2*** *Surface of mangroves (light grey) and area of ponds (dark grey) converted into shrimp farming in ha and shrimp production and export from Ecuador in tons between 1969 and 2005. The four declines in shrimp production and export can be explained by an El Niño event (1985), the Seagull Syndrome (1989), the Taura Syndrome (1993) and the White-spot virus (1999) (Veuthey & Gerber, 2012, FAO, 2020).*

## 1.3 Socio-economic issues

In Ecuador, mangroves are unalienable national goods, managed at local level as common pool resources. Local communities hunt and fish in mangroves and collect food, medicines and construction materials from mangroves. Common pool resource management is based on norms and rights; users have their responsibilities in managing the natural resources. Those who do not follow the rules are sanctioned (Veuthey & Gerber, 2012).

With the arrival of intensive, shrimp farm companies, fish, mollusc and crustacean species abundancies have decreased in mangrove areas. Agricultural land is affected, and local people cannot access mangroves due to illegal shrimp farm enclosures. Local inhabitants do not only rely on mangroves for aquatic animals, but mangrove wood also provides them with charcoal, fuel, and construction materials for boats, homes, bridges, piers, and traditional fishing gear and traps. Subsequently, inhabitants are deprived of their food, resources for important materials and income (Beitl, 2012). Thousands of ethnic minority families of the 450,000 African people have been displaced from their coastal regions of the Esmeraldas Province. Inhabitants and local fishermen who have been living from sustainable farming between mangroves are either forced to move to cities or work for shrimp farms for their basic needs and income. However, the quality of working conditions on the farms are poor; wages are low, working day are long and sexual abuse of women and child labour are frequently reported (EJF, 2003). The shrimp farm elites deprive and marginalize local people, often with violence. Guards with dogs and guns prohibit access to shrimp farm enclosures (Beitl, 2012, Martinez-Alier, 2001, Veuthey & Gerber, 2012).

Moreover, shrimp farms impose other risks to livelihoods; deforestation of mangroves decreases flood and cyclone protection (EJF, 2003). Additionally, fish poison, antibiotics and pesticides in wastewater cause (skin) diseases to people working in contaminated waters (Veuthey & Gerber, 2012). The government does not act as the shrimp farming sector supports the economy (EJF, 2003). In society, tension and resistance increased: first, protests were passive, but they turned into being increasingly violent (Stonich & Bailey, 2000). Nonetheless, there has been a shift in some regions to improve the communication between the shrimp industry and local people. Local people started to get support from organisations such as FUNDECOL, Greenpeace, Mangrove Action Project and smaller NGOs within the International Shrimp Action Network (ISANet).

The problems were noticed by the academic world. As a result, in the period between 1997 and 2020 an increasing number of papers have been published about the environmental issues regarding shrimp farms in Ecuador. Measures to mitigate issues related to shrimp farming have been proposed by a number of these papers. However, there is a need for discussion whether these measures are successful to improve conditions in the future (Monsalve & Quiroga, 2022). Therefore, we address the following research question: '*What proposed measures for mitigating environmental issues related to shrimp farming are effective?.'* We discuss sustainable solutions and examine whether they have been adapted and implemented in e.g., management strategies, set-up of shrimp farms and collaborations with local inhabitants. Through an evaluation of and reflection on the current situation in Ecuador regarding shrimp farming we aim to understand what the prospects for the future are.

# 2. Towards sustainable shrimp farming

Since the start of shrimp farms practices, it has become increasingly clear that the shrimp farm industry is causing structural problems. Both in an ecological and a socio-economic perspective. It is a fact that improvements must been made regarding sustainability. Researchers and organisations have responded with recommendations and options for creating a sustainable shrimp farm industry, which are evaluated in this review. The list includes measurements to reduce mangrove deforestation and to improve regeneration; measurements to reduce the environmental impact of shrimp farms practices; certification standards to promote sustainable shrimp farming; changes in governance and local management and measurements to improve the situation of local communities.

## 2.1 Shrimp pond construction

Tobey, Clay, & Vergne (1998) were one of the first to propose practices to improve the shrimp farm industry. To protect mangroves, they proposed to prohibit farmers from constructing ponds in biodiverse areas such as mangroves and wetlands.
In agreement with this, Ashton (2008) proposed to situate new farms behind the intertidal zone which is based on NGO statements to the 26th Session of the Committee on Fisheries in March 2005. During this session, NGOs all agreed that prohibiting pond construction in intertidal zones is one of the best ways to reduce impacts of shrimp farming on mangroves. After 1999, there was a sharp decline in ponds constructed in mangroves in Ecuador; 2 out of 14 ponds were constructed in mangroves between 2000-2019. Since 1999, when mangroves are cleared for the construction of ponds, they are not eligible for seeking certification by the Global Aquaculture Alliance (GAA) and the ASC (Boyd, Davis & McNevin, 2021). However, according to Morocho et al. (2022) the destruction of mangroves in Ecuador reached its maximum between 1998 and 2010, when 194,56 ha (4.6%) of mangrove cover was lost, due to farm expansion. Boyd et al. (2021b) estimated that currently, 31% of shrimp farm area in Ecuador is in the intertidal zone.

Besides social and ecological problems linked with shrimp farms in mangroves, Bagarinao & Primavera (2005) and Páez-Osuna (2001) argument that deforested mangrove soil in Asia is not suitable for shrimp ponds. These authors elaborated that when mangrove areas are excavated, elevated levels of iron sulphide are exposed leading to a decreased pH. Consequently, to keep shrimp alive, water exchange rates must be raised to lower the acidity. This article focussed on the situation in Asia, nonetheless, Sonnenholzer et al. (2002) also described this process in Ecuador. Boyd et al. (2021b) added that due to the always wet earth in wetlands, earth pond constructions are difficult and drying out of ponds between crops for sanitation measures is impossible. Furthermore, dense mangroves stems and roots are difficult to remove. Crabs and other organisms in the high biodiverse mangrove ecosystem can easily enter ponds, bringing diseases and lowering yield and thus profitability of the shrimp ponds.

To clarify in what regions aquacultural practices are allowed, Bagarinao & Primavera (2005) and Bodero & Robadue (1977) described and proposed the zoning of coastal land as part of a coastal management plan. Subsequently, a list of the different zones and its uses must be created and enforced by a governmental body. This would need a regulatory framework with policies and procedures on how permits are issued, and people are sanctioned. However, the Integrated Coastal Zone Management, which was implemented to specify and protect natural areas, lost importance after 2017 on the political agenda. This resulted from an absence in specific regulations, coordination and resources and a missing collaborating between institutions (Manrique, Barragán, & Sanabria, 2018).

## 2.2 Mangrove restoration

On locations where shrimp farms have been abandoned, mangroves rarely back again naturally. This is due to altered water flow properties and water qualities and the presence of potential invasive vegetation. It is possible however, to clear former shrimp farm areas from ponds and replant mangroves or rehabilitate abandoned shrimp farms. After rehabilitation, the former pond area is repurposed as a fish farm, salt plain or natural area with new plants (Ashton, 2008). The government has tried to enforce rules obliging farmers to convert their ponds into mangrove forest after abandonment, however this is not yet occurring in Ecuador. Nonetheless, there are successful reports from programs where volunteers or locals have successfully replanted mangroves (Hamilton, 2020, Chapter 6). Natural regeneration of mangroves is a slow process and can take about 15-20 years. However, assisted regeneration can cause mangroves to be fully grown in 3 years (Primavera et al., 2019). Hamilton described that after 2000, mangrove loss has stabilized to close to zero in all estuaries investigated in Ecuador. These estuaries are in Chone, Cojimies, Muisne, Guayas and Isla Puná. After 2000, mangrove forests were still removed with a constant rate, up to today, due to existing farm expansion. Between 1970 and 2014, 56,000 ha of mangroves have been lost. However, a recovery of 17,371 ha has also been observed. 89% of this recovery is the conversion of 'other LULC than shrimp farms' to mangroves, 11% make up the conversion of former shrimp farms to mangroves. The conversion of shrimp farms to mangroves was only detected in the Guayas estuary and El Oro province. Morocho et al. (2022) also described a recovery of mangroves, of a total of 2.9% between 1998 and 2018. The recovery is due to action taken by local people; the observed decline in wild catch fish and other species was an incentive to replant mangroves. The replanting of mangroves is supported by a representative of the government in Quito, the MAE (Ministry of the environment of Ecuador) and NGOs from the US. To have reliable and exact data about mangrove loss or recovery, authors have highlighted the importance of close mangrove monitoring (Biao & Kaijin, 2007, Hamilton, 2020, Chapter 6, Hossain et al., 2013, Morocho et al., 2022, Tobey et al., 1998).

## 2.3 Shrimp farm practices

According to Biao & Kaijin (2007) and Tobey et al. (1998), shrimp farms should be more in tune with the surrounding ecosystem and the production should not exceed the local carrying capacity. Ashton (2008) and Biao & Kaijin (2007) reported that in making shrimp farms more sustainable, the first step should be to lower the intensity of the shrimp farm. Moreover, nutrient inputs in ponds should be lowered. As described, an efficient approach would be to find the balance between lower nutrient contents in feed and fertilizer while still being beneficiary for the growth of shrimp. Monsalve & Quiroga (2022) concluded that, besides mangrove loss, water quality problems related to shrimp farms are most frequently reported in literature. Ashton and Biao & Kaijin proposed that wastewater must be cleaned by buffer zones before entering water outside the pond. Wastewater could also be reused in mollusc farming; it could serve as feed for certain oyster species. Ashton added to use pond liners to make sure pond water does not contaminate water and soil outside ponds.

According to Kadlec & Wallace (2008), a constructed wetland could serve as a natural marsh and thus a buffer zone, improving wastewater and reducing the impact on the surrounding ecosystem. In figure 3, a free water surface (FWS) wetland system is shown, suitable for livestock wastewater. This system, composed of three basins with pond liners, starts with purification of wastewater through trapping of sedimentation. In the biological treatment, microbes absorb nutrients. Furthermore, an appropriate plant composition of the wetland, including saline tolerant plants, can reduce pollution and salinity. In addition, Zalewski, Wagner-Lotkowska & Robarts (2004) reported that constructed wetlands can remove pathogens, toxics and aid in the decomposition of organic matter. Primavera et al. (2000) also proposed zero-discharge recirculating shrimp ponds with fish, molluscs or seaweed as biological agents and constructed mangroves as biofilters in Thailand, Vietnam and the Philippines. Lin, Jing & Lee (2003) and Shi et al. (2011) concluded that constructed wetlands improve water quality in recirculating *L. vannamei* shrimp farms in Taiwan and China, respectively. Moreover, Pham et al. (2021) highlight the importance of recirculation systems composed of constructed wetlands in sustainable inland aquaculture. In their test system with *L. vannamei* in the Mekong delta, they observed complete removal of nitrite, 78% removal of nitrate and 76% reduction of the chemical oxygen demand (COD) level. Furthermore, comparing the constructed wetland influent and effluent after 18 days showed a 99.8% reduction of anaerobic bacteria.

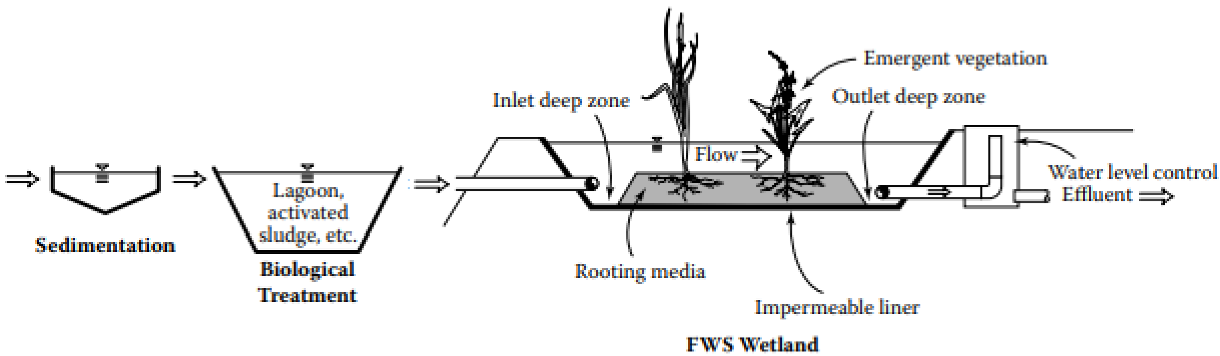


***Figure 3*** *Water purification system with sedimentation pond, biological treatment and FWS wetland (Kadlec & Wallace, 2008).*

In Ecuador, no records of constructed wetlands were found. However, Brun (2017) reported that yield reduction due to low hygiene in shrimp farms has been an incentive for shrimp farmers, unclear how many, to improve water conditions. Consequently, before entering the ponds, sea water is filtered and UV sterilised. Due to cleaner workways, less antibiotics and pesticides are needed. Additionally, most antibiotic treatments have been replaced with microbial agents and probiotics. Moreover, farmers have been selectively breeding shrimps to culture shrimp with high survival. Shrimps are routinely exposed to viruses and other diseases to create disease resistant larvae. Next to an improved diseases and pests' control, a pre-growing step in shrimp cultivation is included with greenhouse covered, high aeration recirculation systems. This reduces the need for replacement of water, it controls nitrogen levels, and it decreases the amount of organic matter accumulation. Furthermore, feeding strategies have been improved, reducing the FCR. All improvements have been the initiative of farmers and were self-funded (Brun, 2017). However, compared to other major producers of shrimp (Indonesia, Thailand, Vietnam and India), Ecuador still has the highest FCR. 22% of the shrimp farms in Ecuador have an FCR exceeding the maximum FCR as required by certification programs. In terms of energy use, Ecuador is the most sustainable of the five major shrimp producing counties (Boyd et al., 2021). Pond stocking densities have not been increasing but shrimp yield has intensified (Boyd et al., 2022, Brun, 2017). Lower stock densities are compensated with larger shrimp.

Problematic is direct wastewater discharge still being allowed. Furthermore, shrimp farmers continue to use harmful chemicals e.g., antibiotics, fish poison and disinfectants for pond equipment (Monsalve & Quiroga, 2022). Where there is an increasing knowledge on how to reduce negative impacts from shrimp farming, there is urgent need on information of how to put this to practice. According to Tobey et al. (1998) and Primavera et al. (2000) stakeholders on all levels, not only farmers, should be educated about the ecosystem services of mangroves and the role mangroves have in providing local people. Moreover, stakeholders should be taught about the negative impacts shrimp farming has and how shrimp farming can both be a profitable business without impeding the surrounding ecosystem and negatively impacting mangrove-dependent people. According to a survey of Ordoñez (2021), conducted in the El Oro region among shrimp farmers, there is still a need for training and technology improvements.

## 2.4 Certification

Incentives could motivate farmers in farming more sustainable. One of those is certification schemes (Tobey et al., 1998). It rewards farmers for aspects like efficiency, ecological friendliness and social responsibility, by improving farmer's shrimp sales. In 2014, the Aquaculture Stewardship Council (ASC) certified the first farms: the most prominent and transparent certification standard in aquaculture. The ASC tests farms on their environmental responsibility, community engagement, resource use efficiency and worker's welfare. Davis & Boyd (2021) evaluated the difference between ASC certified and non-ASC certified *L. vannamei* shrimp farms. They compared size of shrimp farms, type of production system, shrimp production numbers, water exchange rate, wild fish used in feed, nutrient load, direct energy use and chemical use. Of all *L. vannamei* shrimp farms being ASC certified, Ecuador has a coverage if certification of 22,000 ha, about 10% of its total farms area.

Davis & Boyd (2021) found that ASC certified farms in Latin America, compared to non-certified farms, were significantly larger, had a higher annual production and had a significant higher FCR. Moreover, no significant difference in production intensity, direct energy use and water exchange rate was found. Use of disinfectants were significantly higher in ASC certified farms in Latin America. However, ASC farms were more likely to report its use. Moreover, the use of disinfectants led to a lowered need and use of piscicides. For this certification scheme to be an aid in improving shrimp farms, more consideration should be given to how and when shrimp farms are certified. For example, in quality measurements, such as FCR and direct energy use, no specified quantities are required to obtain the certification, but farmers only need to show correct calculations. Furthermore, the authors discussed that a point of improvement includes that only the larger shrimp companies are able of getting certified.

According to Ashton (2008), in 2007, FAO and NACA initiated the development of guidelines on how certification standards of shrimp farming should be established for governments, NGO's and private companies. However, in the same year, NGO's have called to abolish certification schemes because they might be misleading and mask problems such as human rights violation. In line with these constraints, Vandergeest (2007) compared community-based regulation of shrimp farming with certification networks in Southern Thailand. He noticed that in certification networks, environmental standards are all technical and do not include community input. He proposes to improve certification networks by creating standards that approach community based natural resource management.

## 2.5 Governance and management of mangrove use

All types of mitigating measures can be thought of; however, an adequate management approach is also needed to put them into practice. According to Hossain et al. (2013), structural governance problems are the reason for why it is difficult to deal with issues regarding the shrimp industry. The communication between researchers and policy makers should be improved, institutional structures must be strengthened and there is a need of capable workforce. Furthermore, there is a lack of a structural approach to environmental management. Veuthey & Gerber (2012) describe that there are three ministries, existing of multiple units, in Ecuador within the government who have a voice in environmental matter. Each ministry has different rights and functions and due to constant restructuring, responsibilities change. This has led to difficulty in illegalizing destruction of mangroves. Enforcement of laws regarding shrimp farming is weak and illegal concessions have been granted, in disapproval of local communities, see figure 4.

Within a stronger governmental management of mangroves, an emphasize should be put on the prevention of mangrove deforestation. Satria, Matsuda & Ono (2006) proposed, based on a successful management in pearl fisheries in Japan, to decentralize governance on mangrove rights, creating local authorities to manage coastal and marine resources in the different territories. Hossain et al. (2013) report that continuous monitoring of ecosystem traits should be included in this management to formulate needs and actions. In agreement with Vandergeest (2007), the authors also state that cooperation between public and private sectors is lacking, emphasizing marginalized local communities. Local communities must be involved in policymaking on mangrove use and their needs must be heard to achieve a social and ecological sustainable shrimp farm industry (Ashton, 2008).

In the period of 2005-2009, plans for *custodias* were drafted. Custodias are concessions for mangrove areas granted to organized ancestral communities who practice sustainable activities such as controlled logging, artisanal fishing, culturing of fish, molluscs, crustaceans, and conservation, research and reforestation of mangroves (Beitl, 2012). The extension of custodias have increased up to almost 43% of mangrove area in Ecuador in 2022. These areas fall under the Custody and Sustainable Use of Mangrove Agreements (AUSCM), recognizing rights and uses of communities living these zones. The same areas are protected under the National System of Protected Areas (SNAP). This overlap complements governmental effort and community conservation activities (Rodríguez, 2021, 2022). Custodias receive an economic incentive for the conservation and restoration of their mangrove areas. Furthermore, fines for deforestation of mangroves are established. The earlier described recovery of mangroves  mostly happened in the areas falling under AUSCM or SNAP. In these areas the halt of shrimp farm expansion, the development of mangrove forest on sediment deposits and natural and aided mangrove recovery have attributed to mangrove restoration.

Consequently, based on an IUCN and WWF approved framework, Rodríquez (2021) evaluated the AUSCM and concluded that custodias are 'satisfactory' in mangrove management; they are important and effective for the economy and conservation of traditional users and mangroves. However, overexploitation and contamination of waters is still happening, which indicates a need for greater support. Furthermore, ponds in both the custodias and the State's protected SNAP areas are still illegally constructed, showing that monitoring is lagging and that there is a weakness in the management. Moreover, not all custodias receive an economic incentive, therefore, it is necessary to seek new financing sources. Beitl (2012, 2016) reported that custodias were implemented to overcome the tragedy of the commons, however, they are causing division and conflict between owners of custodias and local people formerly using these areas. Nevertheless, Beitl (2012) concludes that custodias are a way to improve sustainability of the mangroves in Ecuador. However, the government must think of policies to facilitate access to mangroves to fishermen not included in custodia associations. An improvement would be to include all local coastal communities in custodia associations to overcome the tragedy of enclosures.


***Figure 4*** *"Community Territory. Our Mangrove, Our life!" Image of protest to concessions granted to shrimp farmers by C-Condem activists. Retrieved from: https://www.wrm.org.uy, 2022*

### 2.7 Local communities

Local communities suffer mostly from the destruction and enclosing of mangrove areas and the harmful effect on the environmental from shrimp farms. The custodias and protected areas have proven to be successful in reducing these issues. Moreover, rehabilitation and regeneration by local communities have also proven to be helpful. Primavera et al. (2019) stress that restoration of mangroves is more effective when local communities are engaged. They highlight the importance of capacity building through strengthening partnerships with the government, collaborating with other local communities and shrimp farmers and training to improve environmental knowledge and knowledge on resource management. FUNDECOL is an example of an NGO who has been helping local communities in the Muisne region in Ecuador. It has successfully aided community-based afforestation, education and organization of demonstrations. FUNDECOL has also helped in setting up cultural activities, enlarging and improving the local social network (Veuthey & Gerber, 2012).

Moreover, export-driven shrimp farms in mangroves have affected the financial situation of local communities. To provide income, communal tourism and ecotourism have proven to be successful (Primavera, 2019, Veuthey & Gerber, 2012). The definition of ecotourism is "responsible travel to natural areas that conserves the environment, sustains the well-being of the local people, and involves interpretation and education" (as cited in Primavera, 2019). It includes recreational activities such as canoe tours, birdwatching, snorkelling and visiting of local communities and it includes the sale of local natural products. Ecotourism provides local communities with money and enables them to keep living in their original habitat.

## 3. Discussion

Since the start of shrimp farming in the 1970s, mangrove area has been decreasing due to shrimp pond construction in estuaries along the coast; wastewater from shrimp ponds has been polluting water bodies at the cost of biodiversity. Moreover, mangrove-dependent communities have been kept away from their mangroves with violence. In the late 1990s, awareness for these issues has been increasing and an increasing number of papers have been published. Within these papers environmental issues were addressed, as were solutions proposed. Since the shrimp farm industry is vital for the economy of Ecuador, improving its sustainability is necessary. Therefore, about 50 years after the start of the shrimp aquaculture, we aim to find effective and successful measures to enhance the sustainability of the shrimp farm industry. This is guided by the following research question: '*What proposed measures for mitigating environmental issues related to shrimp farming are effective?'* In figure 5 an overview of a proposed approach for sustainable shrimp farming in Ecuador is given.

To start with, to reduce mangrove deforestation, ponds should be prevented from being constructed in the intertidal zone. It should be clearly communicated to shrimp farmers that an unmissable ecosystem must be preserved, and that mangrove soil has technical downsides for shrimp farming. Key would be to provide training for shrimp farmers. Moreover, better enforcement is needed to prevent destruction of mangroves. Appointing zones and thereby showing where to and where not to build shrimp farms has proven to be unsuccessful.

Water contamination is still a major issue in mangrove areas. Consequently, recirculation systems with constructed wetlands are fundamental in improving sustainability of shrimp farms. They can significantly improve water quality. However, constructed wetland systems are costly. Therefore, financial support is needed from the government. Moreover, the sustainability of feed used in shrimp ponds could be improved. Shrimp farms in Ecuador, compared to other countries, have a high FCR on average. Lower FCR numbers of other countries in the shrimp farm industry show that this could be reduced. In addition, Asian countries use significant fewer wild fish because they only use leftovers in their feed (Davis & Boyd, 2021). Again, training for shrimp farmers on sustainable shrimp farming is needed and helpful.

Mangrove rehabilitation and regeneration has proven to be successful when being part of custodias or protected areas. These areas should be extended, and financial support should be given to all custodias. Moreover, to prevent violence and conflict, investigation in a structure to include all local communities in custodias is needed.
Together with the aid of NGO’s and the government, local communities should be supported in restoring mangroves. They have turned out to be the effective factors in mangrove restoration. Financial aid and support in terms of enlarging social networks and improving community-based resource management would improve their capacity. Besides aid in mangrove restoration, local communities should also be aided in setting up ecotourism. This is an effective measurement to generate income while maintaining their original way of living. It improves environmental awareness of tourists as a supplementary benefit.

Monitoring of mangrove regeneration and degradation is needed for successful restoration. An example from mangrove rehabilitation in the Philippines showed its necessity. Namely, in 2012 one million mangrove propagules were planted in the Philippines. However, this was rushed with the consequence of a survival rate of not more than 1.9% after 4 years (Primavera, 2019). Monitoring is also needed for better enforcement of the government to prevent mangrove loss. As a note on the data: for the period of 1969-2006, data on shrimp farming and mangrove expansion in Ecuador is universally used from Centro de Levantamientos Integrados de Recursos por Sensores Remotos (CLIRSEN). However, after 2006, CLIRSEN has not reported data. Consequently, different authors have presented their own data which does not resemble (Hamilton, 2020, Morocho et al. 2022). Furthermore, for the initial mangrove area in 1969, prior to export driven shrimp farms, Veuthy & Gerber (2012) report over 250,000 ha of mangroves; CLIRSEN reports 203,624 ha.

Moreover, a better, structural approach to prevent mangrove loss and enhance sustainability of the shrimp farms industry from the government is needed. Decentralization of authorities could be helpful as it is currently unclear who has control over what. However, this needs further investigation if this would prove to be successful in Ecuador. In addition, local communities should be included in policy decisions about mangrove uses and rights because of their importance in mangrove restoration.
Lastly, certification standards have potential to improve sustainability of the shrimp industry and created awareness with the customer. However, they are not yet effective. More consideration should be given to how and when shrimp farms receive certification. This is achieved through clear, globally established guidelines. Moreover, smaller farms should be included in certification to involve and influence the whole industry. More attention should be put in how farms treat local communities and its employees.

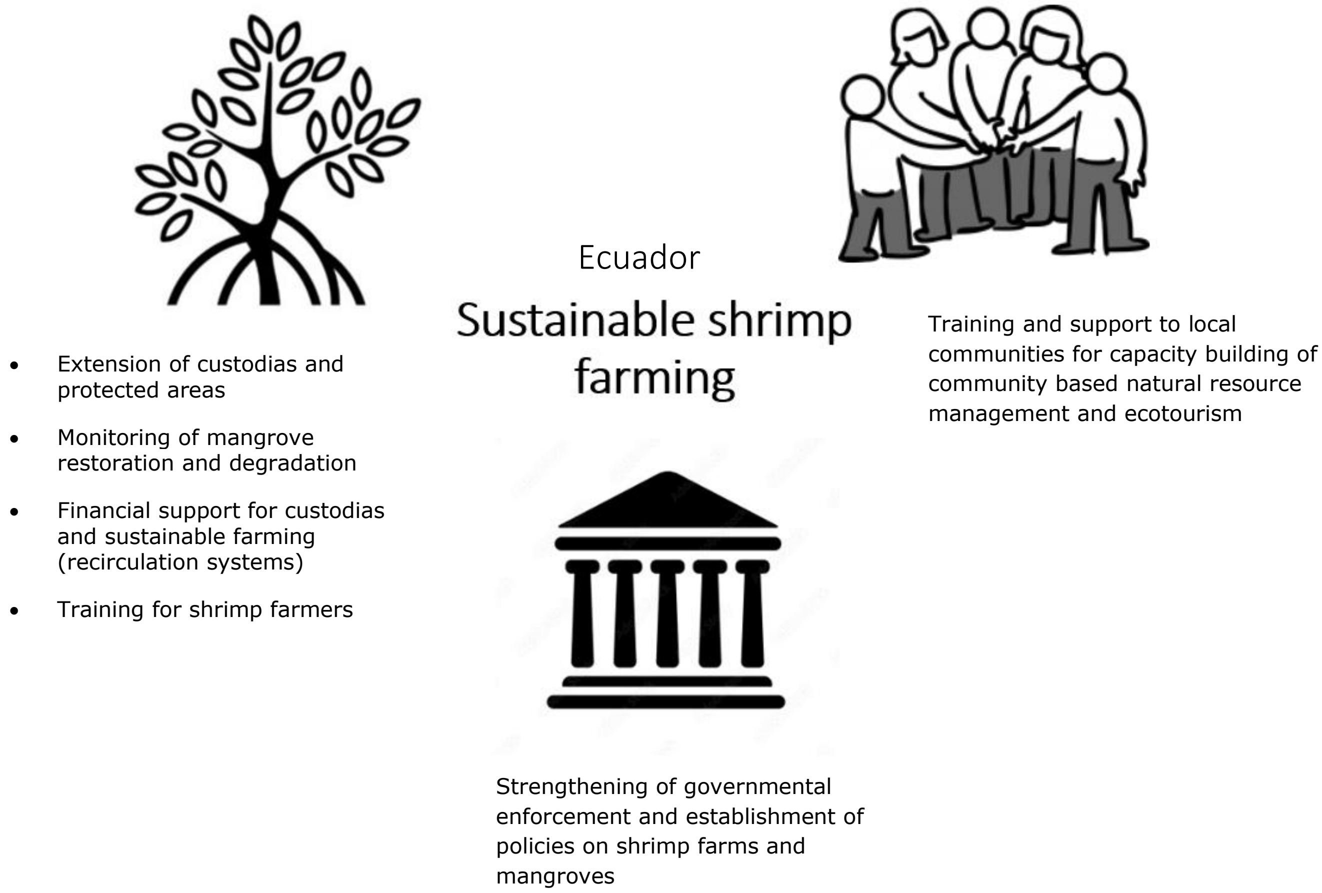


***Figure 5*** *SEG sustainable shrimp farming approach. Social, ecological and governmental measures to enhance sustainable shrimp farming in Ecuador.*

## 4. Conclusion

To conclude, effective measures for mitigating both ecological and social issues related to shrimp farming in Ecuador have been deduced from proposed sustainable solutions and research to their effectiveness and success. Custodias and protected areas with restoration of mangroves by local communities have proven to be successful in mangrove regeneration. In the future, attention must be given to a strengthened legislation and enforcement on prohibiting destruction of mangroves. Monitoring of mangroves has proven to be necessary. Moreover, financial support and training must be given to both shrimp farmers and local communities to achieve a shrimp farm industry in harmony with its environment.

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