IMPACT OF AQUACULTURE FARMS ON THE MARINE ENVIRONMENT:
INTERNATIONAL CASE STUDY

VOLUME 2

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THE PEARL PROTECTORS

Impact of Aquaculture Farms on the Marine Environment: International Case Study

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An Initiative of The Pearl Protectors
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THE PEARL PROTECTORS

The Pearl Protectors is a volunteer-based and non-profit marine conservation organisation in Sri Lanka. Established in 2018, The Pearl Protectors seek to mitigate the impacts of anthropogenic activities on the marine environment, reduce plastic pollution and promote sustainable practices through youth-engagement, volunteerism, awareness and advocacy.

Projects undertaken by The Pearl Protectors over the years entail the launching of the 'Pearl Protector Approved' Accredited Standardisation Certificate to promote a plastic-free dining culture; the annual construction of a Christmas tree out of discarded plastic bottles to highlight single-use plastic pollution; school education programmes; ecobrick workshops; coastal cleanups; and social media campaigns to inspire action towards protecting the marine environment.

The purpose of this advocacy initiative in preparing case studies is to emphasize the impacts of prevailing aquaculture practices and to promote sustainable resource utilization. The authors and contributors of the case studies are volunteer researchers.

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ABBREVIATIONS

FAO - Food and Agriculture Organisation of the United Nations

GDP - Gross Domestic Product

HABs - Harmful Algal Blooms

InSAR - Interferometric Synthetic Aperture Radar

IMTA - Integrated multi-trophic aquaculture

KSA - Kingdom of Saudi Arabia

MBV - Monodon baculovirus

SOC - Soil Organic Carbon

SPF - Specific Pathogens Free

SDGs - Sustainable Development Goals

TSV - Taura Syndrome Virus

WSSV - White Spot Syndrome Virus

ABSTRACT & OBJECTIVES

Aquaculture and shrimp farming have seen considerable growth over the last few decades and although sustainable practices have been employed on a global scale, there have been numerous environmental implications which have been identified in this report through the investigation of aquaculture-related anthropogenic activities. The methodology used in the report was based on relevant and recent peer reviewed scientific journal articles and publications. Case studies and country profiling analysis have been used to examine aquaculture activity in 10 countries across Africa, Asia, the Middle East and South America. A broad range of environmental issues were identified and addressed.

The primary objective of this report is:

- ❖ To investigate the impacts of aquaculture and shrimp farming activity on the marine environment in a global context.

- ❖ The report focuses primarily on coastal aquaculture.

INTRODUCTION

Aquaculture is one of the world's fastest-growing production systems, at an annual rate of 8% and contribution of 44.1% to the world's fish supply of 167.2 million tonnes. (FAO, 2016). An estimated 500 million people in developing countries are directly or indirectly reliant on fisheries and aquaculture (Jayanthi, 2018).

Global trade of prawn and shrimp amounts to approximately USD 28 billion per annum. The majority of shrimp production originates from farms in Latin America (Ecuador) and Asia, producing *Penaeus vannamei.* In a general context, there has been stability in the industry, however widespread disease outbreaks have resulted in significant losses to farms, in particular that of India, Thailand and Vietnam (FAO, 2020).

In recent decades, overwhelming growth in the aquatic resource sector has led to unsustainable practices involving degradation of fish stock, overfishing, and habitats, ecosystem and biodiversity loss. The resultant economic loss was measured at USD $83 billion per annum in the fisheries sector and over USD $6 billion per annum from diseases in aquaculture farms. The serious risk imposed by climate change is perceived to adversely impact fish farming communities, particularly those in coastal low lying areas leading to displacement, loss of livelihood, high intensity weather events and changes to fisheries distribution (FAO, 2020)

The United Nations has developed a blueprint of Sustainable Development Goals (SDGs), of which SDG 14 has been exclusively dedicated to "*the conservation and sustainable use of the oceans, seas and marine resources".* It outlines 10 targets specific to the sustainable management of fisheries, protection of marine and coastal eco-systems, minimisation of ocean acidification and an end to harmful fisheries subsidies (United Nations, 2020).

4 CASE STUDIES

4.1 TAIWAN

The geographic location and topography of Taiwan make it a conducive environment for the establishment of aquaculture farming, with over 35 candidate and major species cultured for commercial purposes. Between 2010 and 2016, the average revenue from the shrimp aquaculture industry amounted to USD $ 3 billion. The Taiwanese government have been supportive of the industry, making shrimp aquaculture notable, since the 1980's. Primary cultured species include the Giant River shrimp *(Macrobrachium rosenbergii)*, White-leg shrimp *(Litopenaeus vannamei)*, Grass shrimp *(Penaeus monodon),* Sand shrimp *(Metapenaeus ensis)* and Kurus shrimp *(Penaeus japonicus)* (Ming-Yang, 2019). Large-scale breeding and intensive aquaculture are the preferred methods in a Taiwanese context as farmers are limited to land use, with the majority situated in close proximity to agricultural and residential areas. Shrimp are cultured extensively in land-based ponds.

Various impacts and issues associated with shrimp farming and aquaculture activities in Taiwan have been identified and summarised as follows:

- **Use of veterinary drugs for the prevention of disease** contaminates shrimp and pollutes soil and water environments. Shrimp samples were examined and found to contain banned compounds: Chloramphenicol, Nitrofuran Metabolites and Leucomalchite green (Ming-Yang, 2019).

- **Regulation of fishery rights and access privileges** and the longstanding issue of 'Black' farms. These farms are ineligible to apply for certification and subsidies and are not required to report their production levels, creating a challenge for government bodies to collate complete information on the aquaculture industry, leading to a management loophole, prohibiting effective and informed policy decision making.

Land use type	1996		2011		Change	
	Area, km²	% of total	Area, km²	% of total	Area, km²	% change (Equation (1))
Agriculture	83.46	44.77	84.96	48.11	1.5	0.8
Aquaculture	61.53	33.0	41.76	23.63	−19.77	−32.25
Industry	8.63	4.62	20.01	11.33	11.38	131.87
Residential area	7.08	3.79	12.18	6.90	5.10	72.03
Sandy coast	3.87	2.08	0.29	0.16	−3.58	−92.51
Vegetation	1.35	0.72	1.89	1.07	0.53	39.26
Abandoned land	0	-	0.54	0.31	0.54	0.31
River	14.79	7.93	11.51	6.52	-	-
Road	-	-	3.47	1.96	-	-
Cloud	5.72	3.06	-	-	-	-
Total area	**186.44**	-	**176.60**	-		

Figure 1: Land Use Changes along the Yunlin coastal zone
(1996 - 2011) (*Source: Lo & Gunasiri 2014)*

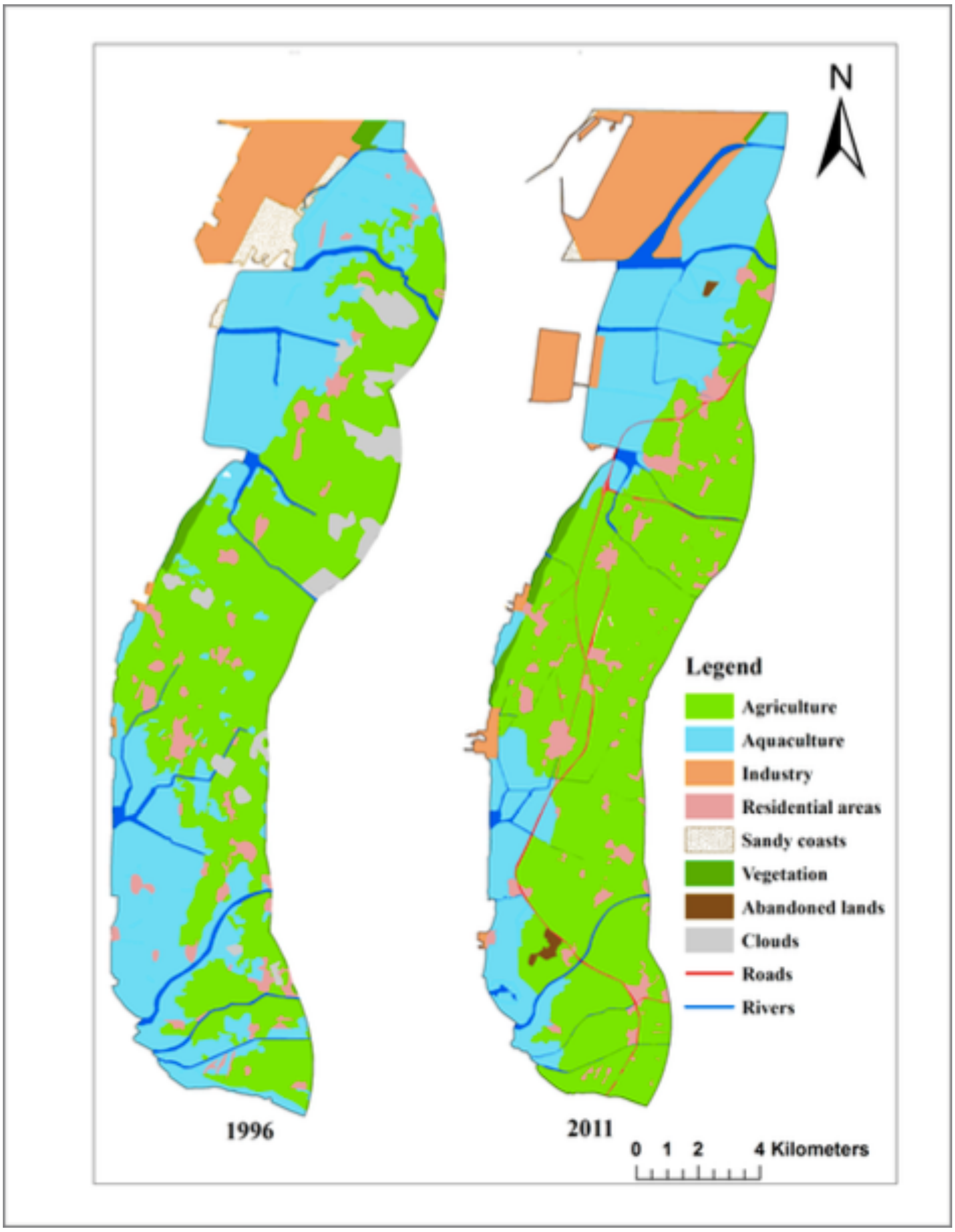

Figure 2: Land Use Maps (1996 - 2011)
(*Source: Lo & Gunasiri 2014)*

The study showed positive correlation between a decrease in aquaculture land area and a corresponding negative impact on shoreline. Between 1996 and 2011, several aquaculture ponds were converted to farmland, causing shoreline to move landward by either decreasing accretion area or increasing area of erosion. This scenario is relevant where an aquaculture farm may be established and over time, abandonment and changes in land use result in detrimental effects to the shoreline.

❖ **Accretion position and erosion changes** to the Yunlin County shoreline of approximately 1.65km, due to changes in agriculture and abandoned aquaculture lands, moving the shoreline landward is shown in Figure 1 and 2 (Lo & Gunasiri, 2014).

❖ **Land subsidence** in Chiayi County which is located on Taiwan's largest alluvial plain. InSar geodetic technology was used to monitor large levels of subsidence along the coastal region of Chiayi stemming from groundwater pumping for the aquaculture industry which has raised an issue around relative sea level rise. The study recorded a maximum coastal subsidence rate of 4.5 cm/year which is an estimated 15 times of global eustatic sea level increase of 2-3 mm/year. Tidal records represented in Figure 3 at the Wegang and Dongshi tide gauges have recorded rates of sea level change of 26 and 43 mm/year, far in excess of global rates (Wei-Chia Hung et al. 2017).

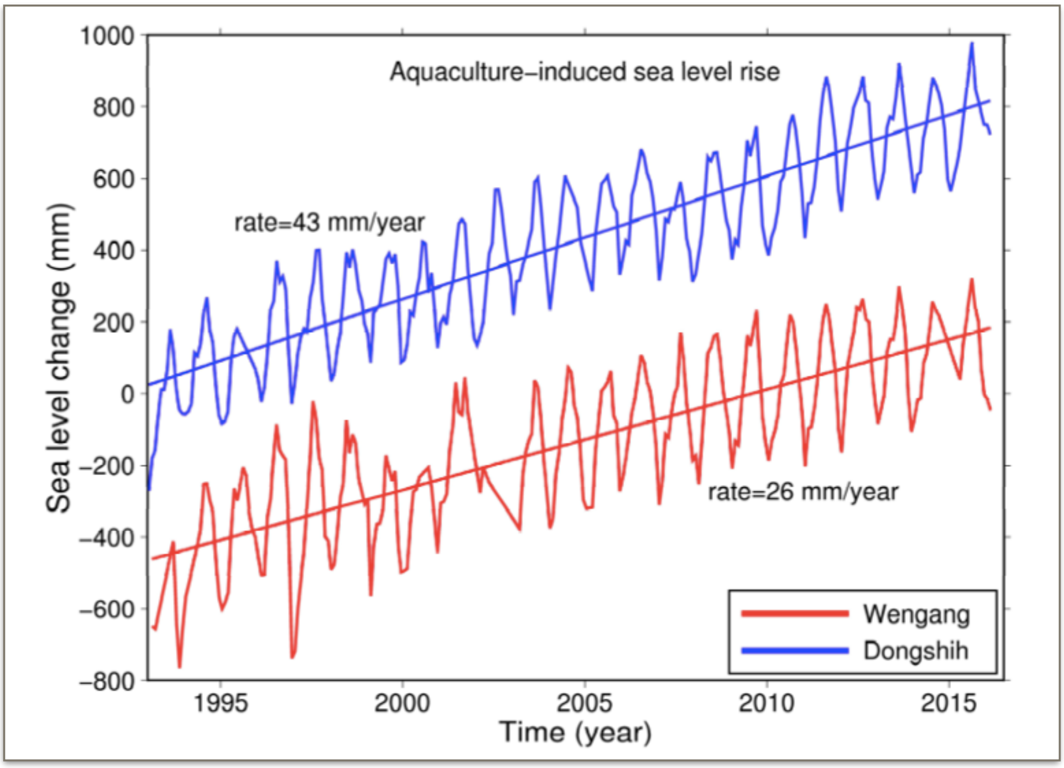

Figure 3: Records of tide gauges in Dongshih & Wengang (Chiayi) showing relative sea level rise due to land subsidence; (*Source: Wei-Chia Hung et al. 2017)*

4.2 REPUBLIC OF CHINA

Between 2000 to 2017, China saw a rise of circa 150% in its aquaculture operations, ranking as the world's largest aquaculture producer generating over 46.8 million tons per annum (FAO, 2019). The country is highly diversified in its farming systems, aquaculture species and finfish culture in freshwater. Fish production forms a large component of freshwater production, with shrimp production dominating brackish water, and the production of seaweed and bivalves primarily a part of marine production (FAO, 2017).

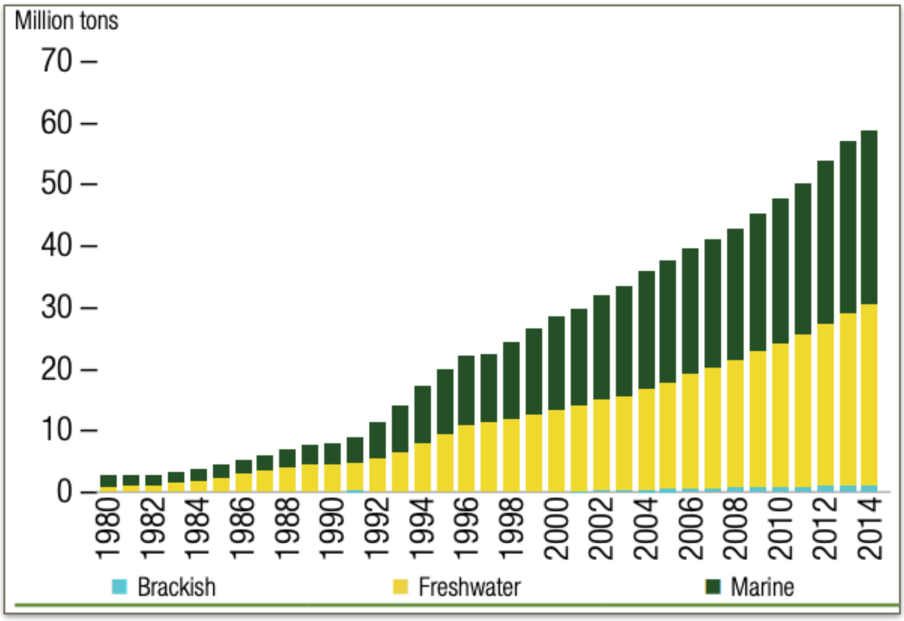

Figure 4: China aquaculture production by environment
(*Source: FAO 2020)*

However, China's immense growth in the shrimp and aquaculture industry has resulted in a wide range of environmental implications, of which some are highlighted below:

❖ **Spread of bacterial disease** in species including *streptococcosis* in tilapia fish species and *red body disease (Taura Syndrome), white spot syndrome (WWSV), Early Mortality syndrome and Vibrio.* (Nielsen et al, 2005)

❖ **Use of antimicrobials, chemicals, disinfectants, and probiotics** to treat pond water in tilapia and shrimp farms, for the prevention and control of disease. Disinfectants were thought to kill pathogen movement between ponds. Chlorine dioxide and lime were used on tilapia farms to kill wild fish. It was found that Chinese aquaculture farmers had a lack of experience and knowledge in the diagnosis and control of aquatic animal disease (Li et al, 2016).

- **Sea grass degradation and decline in biodiversity:** Significant differences were found in sea grass parameters observed at 3 sites. Qingge and Changqi had abundant aquaculture ponds in comparison to Yelin (Figure 5). Although reduced light penetration and the high concentrations of ammonium and high sulphide pore water were the main drivers, it was found that aquaculture appeared to have strong impacts on biodiversity of sea grass in particular smaller species. This resulted in a decline in biodiversity where sea meadows were dominated by more robust sea grass species. Original mangrove wetlands serving as important nitrogen sinks, were replaced over time by aquaculture ponds along Hainan's coastal belt. The replacement of the natural buffer along with additional nitrogen was found to aggravate consequences for downstream coastal ecosystems (Herbeck et al, 2014).

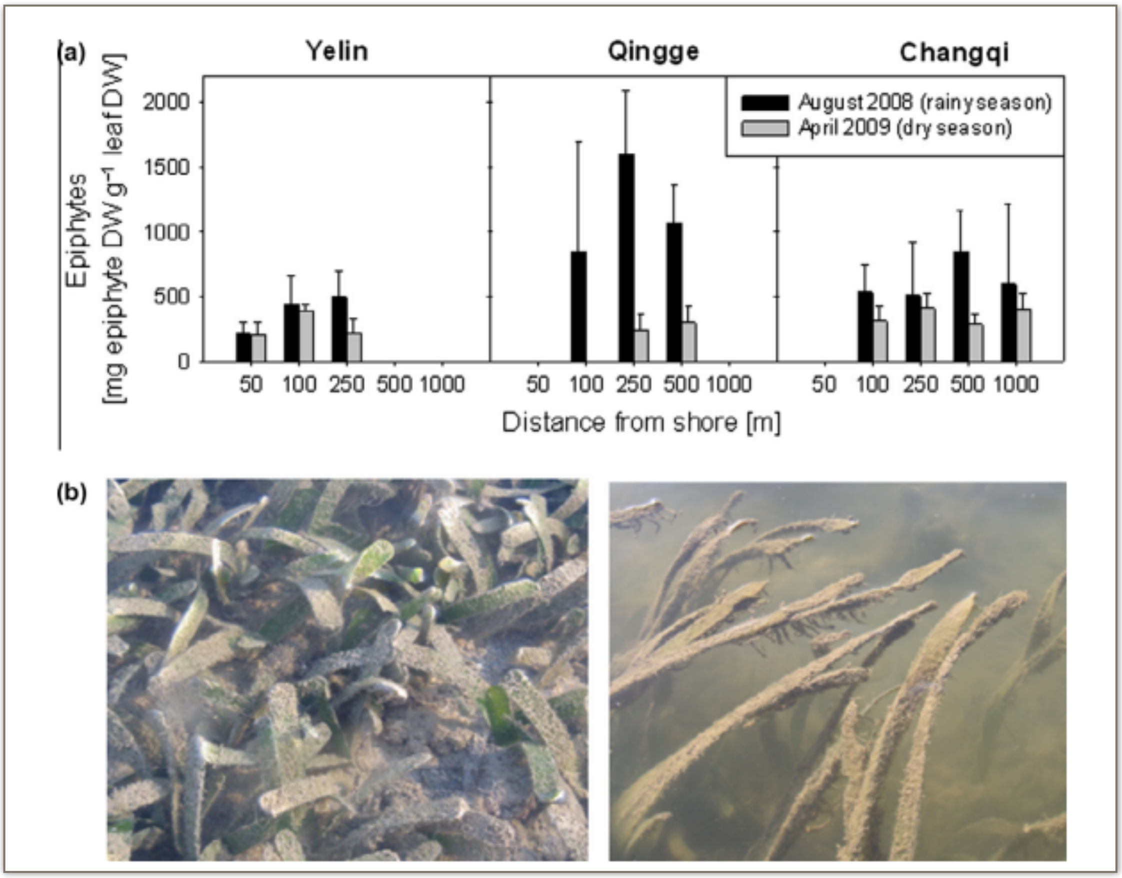

Figure 5: a)Mean (+/- SD) epiphyte load of T. hemprichii at 3 study sites (Aug 2008 - April 2009) b)High amounts of filamentous epiphyte and particulate matter on sea grass

(*Source: Herbeck et al. 2014)*

4.3 VIETNAM

Aquaculture contributes to Vietnam's expanding agricultural economy accounting for an estimated 3.5 % of the country's GDP (World Bank, 2014). In 1995, the approximate total aquaculture area was 453,000 ha, and it was found to have doubled by 2013, and is primarily concentrated around the Mekong River Delta. The *Shrimp* and *Pangasius* are two of the country's dominant species produced on aquaculture farms. For the purpose of this case study, the environmental impacts of the *Shrimp* will be examined. Figure 6 summarises the output of the intensive white-leg shrimp and intensive black tiger shrimp farms in 2014 (Phuong et al., 2015). Generally in the order of 0.5 ha, intensive farms are defined by high stocking densities, whereas extensive farms, commonly associated with the black tiger shrimp are bigger, ranging from 1-3 ha. Shrimp are raised with fish, in polyculture settings, or rotated with rice crops (Phuong et al., 2015).

Species	Cultured area (ha)		Production (tons)	
	Whole country	Mekong	Whole country	Mekong
Black tiger	590,000	537,000	260,000	248,000
White-leg	95,000	67,000	400,000	245,000

Figure 6: Intensive shrimp farming area and output *(Source: Phuong et al. 2015)*

The expansion of this industry has resulted in considerable environmental degradation which threaten the sustainability of aquaculture farming over the longer term. The expansion has resulted in:

- **Conversion of areas of mangrove vegetation** to farms and ponds. Decline in mangroves due to the development of shrimp farms and agriculture leading to ecological degradation and deforestation (Sam et al, 2005)

- **Use of drugs and chemicals** used in intensive and semi-intensive black tiger shrimp farming. 12 chemicals were found to be used in pond treatments with the most common being Calcium hypochlorite (41.7%), closely followed by Trichlorfon (20%) and Formalin/Formaldehyde (16.7%) (Tu et al, 2006). Similarly, drugs are also used in the prevention and treatment of diseases, including antibiotics (norfloxacin, enrofloxacin, and sulphamethoxazole)

❖ **Pollution loads from intensive shrimp farming:** A study of 22 farms in Ho Chi Minh City, estimated the production of 1 tonne of black tiger shrimp generated 30kg of Nitrogen and other outputs, summarised in Figure 7. It was projected at the time of the study, that by 2014, an estimated 75% of the wastewater was found to be discharged into local rivers on the coast along the Mekong River Delta (Anh et al, 2010). Intensive *Pangasius* farming in the delta was also found to generate over 37 million m^3 of sludge and 10 billion m^3 of wastewater.

Indicator	Total (kg/ton)
Total N	30[a]
Total P	3.7[a]
BOD	259[a]
COD	769[a]
TSS	1,170[a]
$N\text{-}NH_3$	4.8[a]
Total N from sediment	8.4 ± 3.3[b]
Total P from sediment	5.9 ± 2.5[b]

Figure 7: Pollution loads from shrimp production
(*Source: Anh et al. 2010)*

❖ **Depletion of groundwater** resulting from aquaculture, in particular shrimp farming activities (Vuong, Lam & Van, 2015) in the Mekong River Delta making unsustainable extractions a growing concern for those reliant on this natural resource.

❖ **Saline intrusion** in some areas of the Mekong Delta resulting in adverse implications on crop yields, production and suitability. Shrimp farms have accelerated the extent of salinity by the drawing of groundwater for the purpose of pond replenishment. Land subsidence caused by the exploitation of groundwater, particularly in coastal areas, pose flood inundation hazards coupled with the threat of sea level rise (Erban, Gorelick & Zebkar, 2014)

Figure 8 summaries the overall environmental impacts of shrimp farming in the context of Vietnam. In addition to the issues highlighted above, other significant implications involve biodiversity loss due to clearing of vegetation and habitat, acidification, and spread of disease.

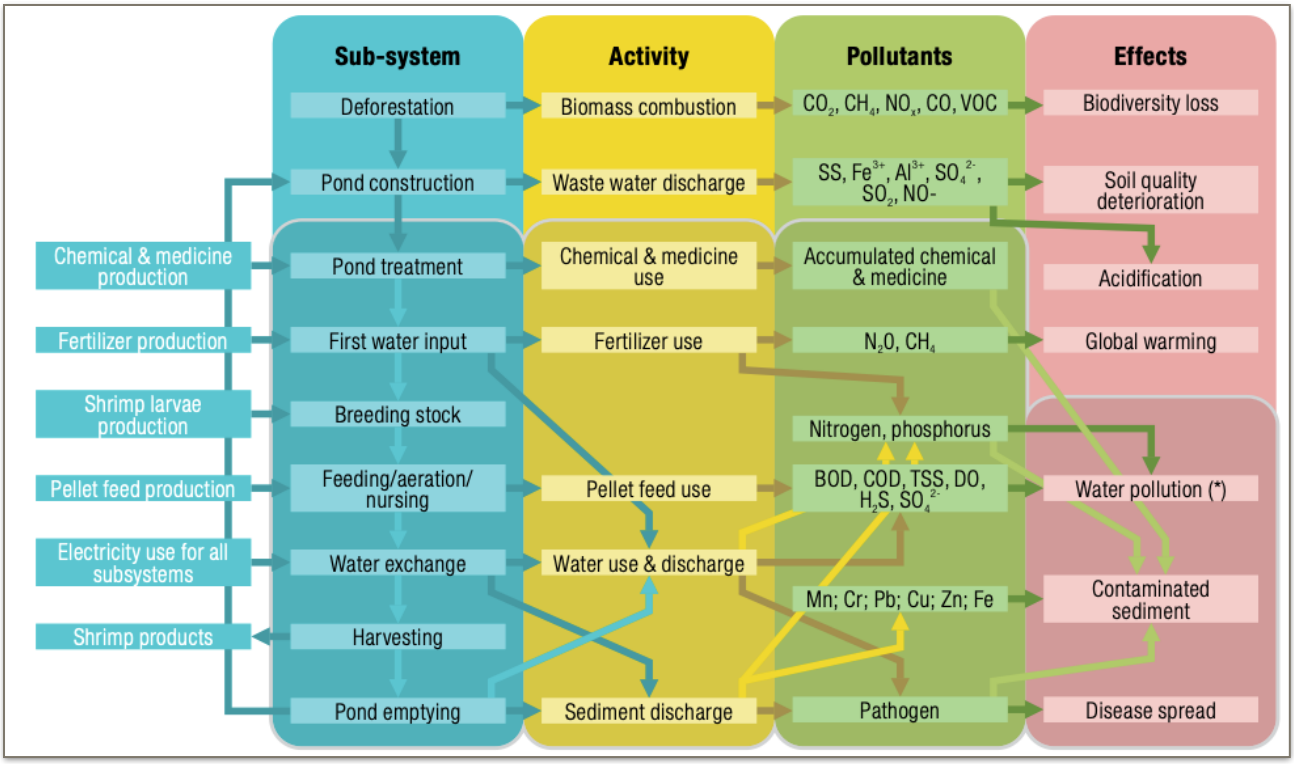

Figure 8: Environmental impact of shrimp farming, Vietnam (*Source: Anh et al. 2010)*

4.4 INDIA

India has become the second largest shrimp producer globally, with an estimated increase of 879% over the last 25 years (FAO, 2016) coupled with the use of 11% of potential available area for coastal aquaculture operations (MPEDA, 2016). Major shrimp producing states in India include Andhra Pradesh, West Bengal, Gujarat, Tamil Nadu and Odisha. Approximately 140,656 ha of coastal salt-affected lands, conducive for brackish water aquaculture in India was utilised, accounting for 6.62% of global aquaculture production (MPEDA, 2016).

	Area under shrimp culture (shown in interval of five years)					
State	1990–1995	1996–2000	2001–2005	2006–2010	2011–2015	2017#
Andhra Pradesh	34500	83930	61429	3418	40445	42462
West Bengal	34400	41980	50215	47488	53947	58285
Kerala	14100	14470	10797	9545	15385.44	12622
Orissa	8500	9000	7030	4769	9297	10778
Karnataka	3500	3635	1528	1484	813.41	2281
Maharashtra	2400	533	524	660	1400.71	1413
Tamil Nadu & Pondicherry	2000	1882	3684	2381	5199.94	8263
Gujarat	700	447	891	1925	4426.18	4552
Goa	600	770	295	272	34	10

#Not applicable five years interval data.

Figure 9: State-wise area under shrimp culture (Ha) (*Source: MPEDA, 2018)*

Despite significant economic gain, adverse environmental impacts from shrimp aquaculture has been widely examined and reported of which primary concern is directed at:

- **Disease breakout:** During 2006-2008, an estimated annual loss of USD $255 million was reported in India attributed to shrimp related diseases (Figure 10). Multiple genotypes of White Spot Syndrome Virus have been recorded in shrimp farms in India, with varied infection potential (John et al., 2010; Waikhom et al., 2006). Recent studies showed the presence of WSSV infection in the white leg shrimp (*L. vannamei)* under semi-intensive cultures conditions (Balakrishnan et al, 2011) The prevalence of MBV was also reported in wild *P. monsoon broodstock*.

Genome	Family	Pathogen/Pathogen group	Year of reported in India
DNA Viruses			
dsDNA	*Nimaviridae*	WSSV – genus *Whispovirus*	1994
dsDNA	*Baculoviridae*	MBV – an occluded enteric Baculovirus	1993
ssDNA	*Parvoviridae*	IHHNV – a systemic Parvovirus	1998
		HPV – enteric parvoviruses	2002
RNA Virus			
ssRNA	*Barnaviridae*	LSNV – Luteovirus-like (unclassified)	2007

Figure 10: Emerging viral pathogens in Indian shrimp aquaculture *(Source: Walker et al, 2010)*

❖ **Overcrowding and pollution:** In a bid to increase profitability, several farms crowded together along the coastal fringe (Escobeda-Bonilla et al. 2005). The enormous input of prophylactics, protein rich food and manure contributed to increased pollutant loads in areas in close proximity to the sea shore (Yang et al. 1999). The farms were exposed to poor hygiene practices and the majority had no drainage possible (Samocha & Lawrence, 2018).

❖ **Illegal importation of seed:** Farmers resorted to illegal importation of seeds from Vietnam, Thailand, Philippines and Thailand which were claimed to promote better rates of growth. Similarly, prophylactics were also imported with nil regulation in place to control this activity (Anon, 2002). This resulted in issues pertaining to surface and ground water pollution in the surrounds of the shrimp culture farms.

❖ **Contamination:** The exaggerated use of hazardous chemicals contaminated creeks, near shore sea waters and drinking water sources with accumulations of heavy metals found in creek sediments and increased fungal and bacterial counts from organic contaminants. An overgrowth of blue-green algae causing eutrophication, was observed due to increased discharges of contaminants via canals and waterways. Changes to soil characteristics were also reported in agricultural lands around aquaculture farms (Pathak et al. 2000; Rico et al. 2020; Srinivas & Venkatraylu 2016).

❖ **Impact on biodiversity:** The Whiteleg shrimp *(L.vannamei)* is an introduced, voracious, nonselective forager with a higher consumption of food than native species of shrimp. When released into waterways, the Whiteleg shrimp may create competition for the native species present (Chavanich et al, 2016). The introduction of alien species into natural bodies of water can increase risk of alteration to biodiversity and natural ecology of the given site (Tiberti et al. 2014). Despite quarantine procedures, there is probability that unknown microbes may enter the waterway in conjunction with exotic species.

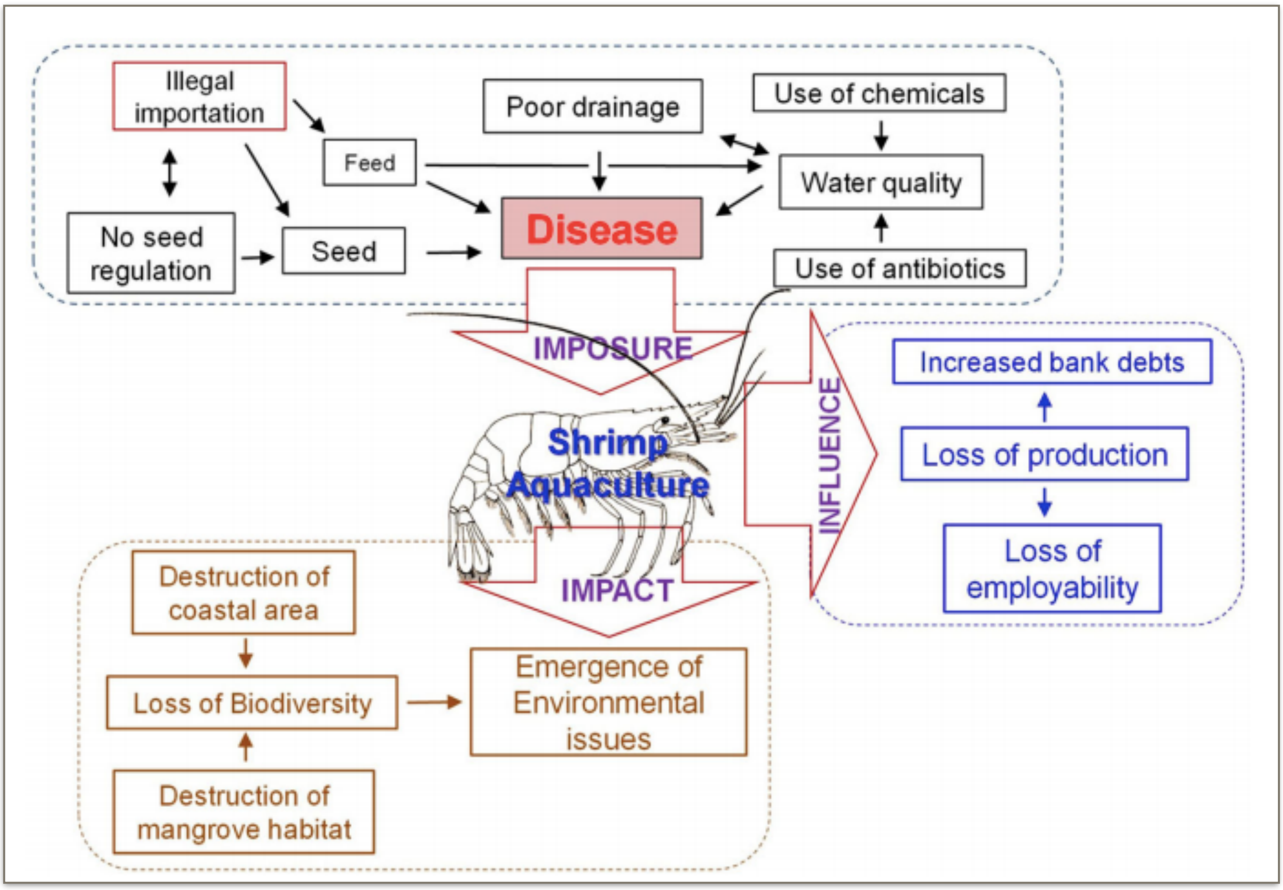

Figure 11: Summary of issues and prospects associated with *L.Vannamei* aquaculture in India *(Source: Salunke et al. 2020)*

4.5 MYANMAR

Aquaculture and fisheries make a significant contribution to the economy of Myanmar amounting to 2% of the country's GDP, 6% of employment and over 50% of animal protein consumption with an estimated overall production of 3 million tonnes (The World Bank, 2019). Two primary species dominate production: Rohu fish (*Labeo rohita*) and Tiger Shrimp (*Penaeus mondon*). Three subsectors of aquaculture are evident in Myanmar, including inland, marine and coastal farming. Two-thirds of shrimp ponds are located in the Rakhine State and the remainder in the region of Ayeyarwady. The farms operate under a '*trap and hold'* system, where shrimp post larvae are trapped during high tide within shallow coastal ponds, and grown without reliance on feed inputs, but the pond's natural productivity (The World Bank, 2019). There has been a reported decline in the productivity of shrimp farms since the mid-2000s. Factors which contributed to this decline included the occurrence of three severe cyclones between 2004 and 2010 which extensively damaged ponds, the imposition of sanctions on Myanmar's exports in 2007, an abundance of wild post larvae possibly related to overfishing of brood shrimp and clearance of mangroves and the increasing prevalence of shrimp disease (Joffre and Aung 2012).

Species	Export volume (t)	Export value (US$ million)	Rank
Rohu	64,017	60.3	1
Live mud crab	16,471	48.9	2
Live swamp eel	7,497	26.1	3
Pink shrimp	10,322	22.9	4
Tiger prawn	4,203	20.3	5
Hilsa	6,107	15.5	6
Ribbon fish	9,265	15.0	7
Soft shell crab	2,835	14.7	8
Fishmeal	21,158	12.8	9
White prawn	2,554	11.5	10

Figure 12: Top 10 species of exported fish, crustaceans & fisheries products, Myanmar (S*ource: ACIAR, 2020*)

Some of the identified issues in shrimp and aquaculture farms in Myanmar include:

- **Limited regulatory enforcement** monitoring and management of stock resulted in considerable declines in marine fish resources (Krakstad et al, 2015)

- **Illegal fishing** in offshore and onshore marine fisheries of Myanmar with illegal fleets of fishing vessels including gear (push nets, baby trawls, and pair trawls) non-conforming with regulatory requirements. Direct, illegal exportation to other surrounding countries with insufficient control and surveillance (Hosch, 2015).

- **Open access** has led to overfishing and depletion of resources. The tender process currently used to allocate rights on an annual basis is shown to create incentives to maximise extraction rather than implementing proper management processes.

- **Poor enforcement of regulation and laws** including lack of accountability in decision making and responsibility, inadequate expertise and management capacity, corruption and the unequal distribution of power.

- **Significant declines in freshwater fish species** recorded in the Ayeyarwady Basin, including commercially valuable freshwater shrimp, Wallago catfish, eel, hilsa, barramundi and smaller endemic fish species (Baran et al, 2018)

- **Loss of wetlands** due to aquaculture ponds resulting in the disruption of annual spawning migrations of wildfish between the floodplain and river. Loss of breeding habitat for the endangered Sarus Crane.

- **Harmful fishing practices** including electrofishing and poisoning

Aquaculture has not been a leading cause of mangrove loss in Myanmar. Giri et al. (2008) find that mangrove deforestation in Myanmar over 1975–2005 occurred mainly due to overexploitation of mangrove forests for fuel wood collection, charcoal production, and illegal logging, followed by encroachment for paddy cultivation.

4.6 MADAGASCAR

The Aquaculture sector of Madagascar contributes to the country's GDP through exportation of farmed shrimps and seaweed and sustains food security, nutrition and population incomes (FAO, 2008). Finfish farming is considered the dominant practice among smaller farmers however it's production is marginal in comparison with inland fisheries and marine aquaculture. The Malagasy aquaculture industry produced 17,407 tonnes of algae, 5,438 tonnes of shrimp and 35,993 tonnes in inland fisheries (FAO, 2019). Over the years, farmers have championed integrated aquaculture - agriculture systems. In Madagascar, rice-fish farming has been the oldest and most common practice. The process involves raising fish and rice in the the same irrigated field to obtain yields from both. The country supports 2% of the world's mangrove vegetation with approximately 213,000 ha of remaining in 2016.

❖ **Emerging pathogens:** The *Enterocytozoon hepatopenaei* (EHP) is an microsporidian parasite. EHP infections have been detected in the Pacific white shrimp *Penaeus vannamei* and Black Tiger Prawns *Penaeus monodon.* Economic losses associated with EHP infections have been rapidly increasing and the pathogen is now considered a critical threat to shrimp farms. Additionally, farms in Madagascar were also subject to severe mortalities caused by acute hepatopancreatic necrosis disease (AHPND), a highly virulent bacterial disease (Tang et al, 2015). Clinical signs of the EHP infection found in farmed shrimp can generally be associated with increased mortality and stunted growth.

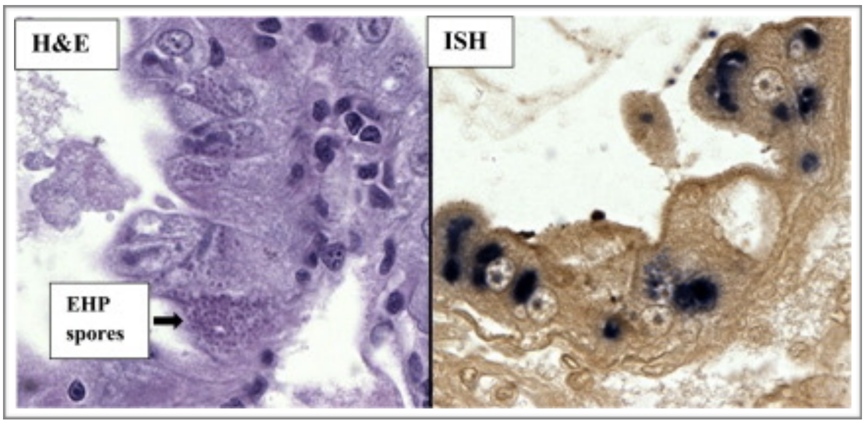

Figure 13: H&E (Mayer–Bennet haematoxylin and eosin-phloxine) histology and in situ hybridization of Enterocytozoon hepatopenaei (EHP) in the infected shrimp *(Source: Tang el al, 2015)*

- **Increased waste:** Levels of waste are correlated to increased feed. Approximately 80% of feed is generally consumed and 10-20% discharged as faeces which are then flushed back into the production system. Water is a carrier of disease in the shrimp culture system. Spread of disease can impact wild species and the environment (WWF, 2020). Coupled with shrimp faeces, antibiotics and chemical products are also discharged into waterways contributing to marine pollution. Intensive fertilisation in the production areas can artificially increase production of phytoplankton.

- **Deforestation and loss of mangrove habitat:** Major causes include, conversion of land to agriculture, aquaculture, urban development, and logging. Conversion of mangrove vegetation into shrimp farms has become a recent phenomenon, particularly in the northwestern section of Madagascar. Approximately 600 hectares of shrimp farm has been established, since 1998 in the Bali Bay region. In recent times, some mangrove areas of Mahajamba Bay have also been converted for aquaculture. Coastal sedimentation due to over farming upstream and heavy deforestation poses a serious issue on the western coast of Madagascar, as excessive sediment loads can suffocate and kill mangrove species.

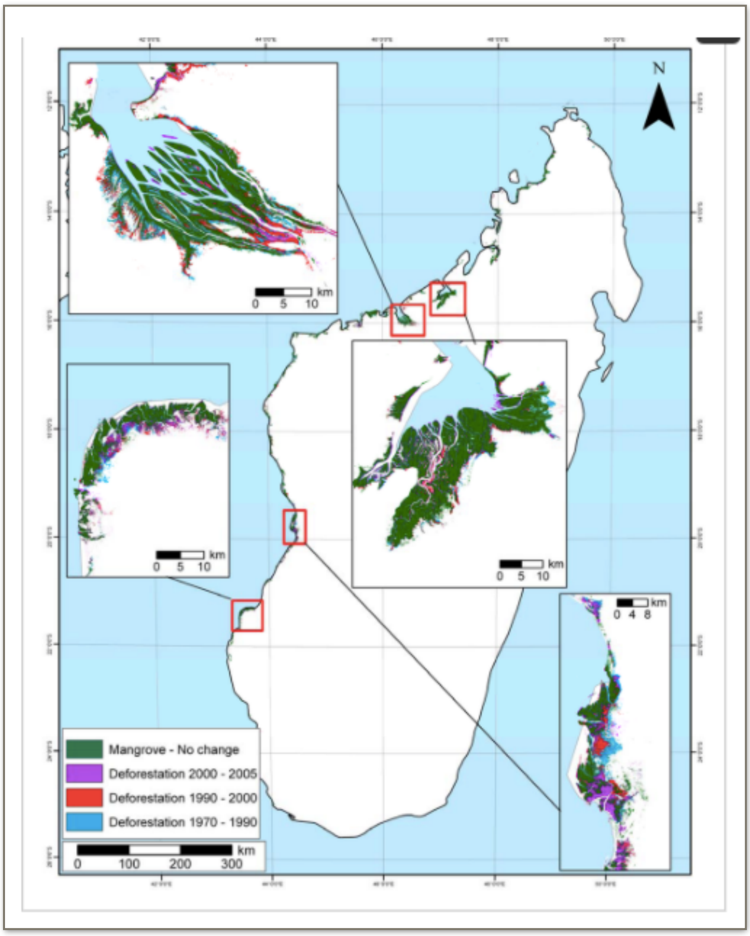

Figure 14: Mangrove forest cover change map, Madagascar (1975 - 2005) *(Source: Giri & Muhlhausen, 2008)*

4.7 SAUDI ARABIA

The shrimp farming industry in the Kingdom of Saudi Arabia (KSA) commenced in 1995 with the culture of the Indian white shrimp grown under semi-intensive production conditions (Aranguren,2016). The primary areas focused on production in KSA are Sea shore, Jizan in the south and in Al-lith in the north. Both regions are characteristic of excellent water quality and environmental conditions conducive for aquaculture.

Figure 15: Location of shrimp farming and aquaculture facilities, Saudi Arabia
(Source: Aquaculture Alliance, 2015)

Rapid growth in the shrimp aquaculture industry in KSA have provided opportunities for economic and social uplift of rural communities and new culture strategies are being framed to develop innovative technologies for the production of quality shrimp. Changes to land use and land cover have various negative environmental consequences on the hyper-saline, hyper-arid Red Sea Coastal Waters of Saudi Arabia.

- **Significant decreases to Soil Organic Carbon (SOC):** One of the key ecosystem services provided by mangrove vegetation is increased efficiency of soil carbon sequestration as the species are considered appropriate organic matter sources. Findings of a recent study in the region, have highlighted that SOC stock of mangroves were 147% higher than in shrimp farms and that anthropogenic activity had a significant contribution to SOC stock decrease. Mean cumulative potential carbon dioxide (CO^2) emissions from loss SOC stock from the conversion of mangroves to shrimp ponds was projected at 34.9 kg CO^2 m^2. Mangrove sediment (0 -10cm depth), had organic matter content of 8g more C kg^{-1} than in shrimp farms. This indicated the mangrove layer can be carbon sink and reflected that mangroves improve SOC content in the sediment (Eid et al, 2019).

- **Fluctuations in mangrove health:** A study conducted in Jezan in the Jazan province examined the impact of an abandoned shrimp farm on mangrove health. Landsat technology was used to capture imagery which initially reflects a prominent boom in mangrove forest during the operation of the shrimp farm. During the period 2010- 2015, post-closure of the shrimp farm, there was an observed negative trend in mangrove land cover highlighted through the change detection algorithm. Organic effluent from the shrimp farm ceased due to its closure and there was a notable decrease in photosynthetic activity of mangroves (Arshad et al., 2020)

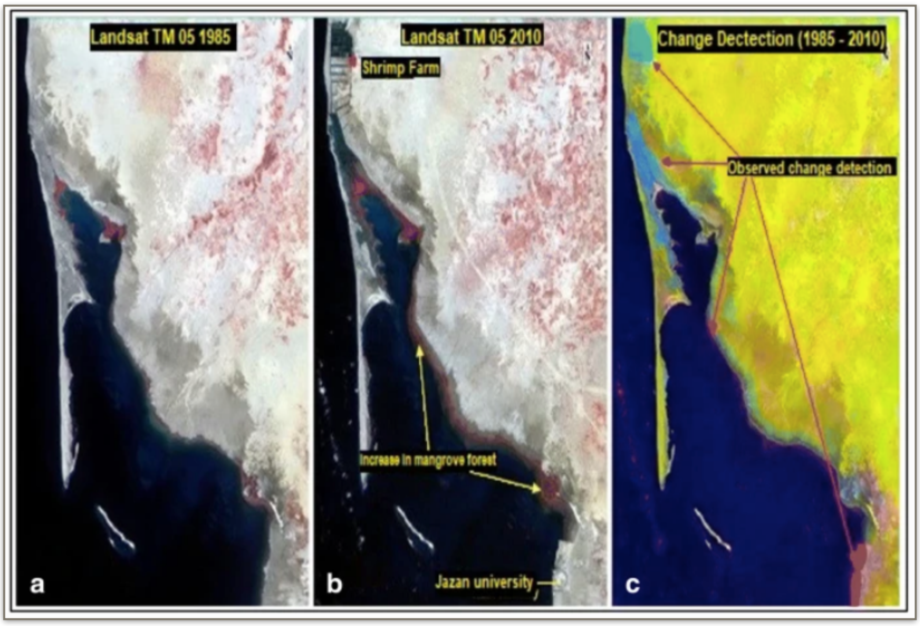

Figure 16: Change detection image (Landsat TM 5) showing increment in vegetation biomass due to released organic material from shrimp farm (BEFORE) *(Source: Arshad et al. 2020)*

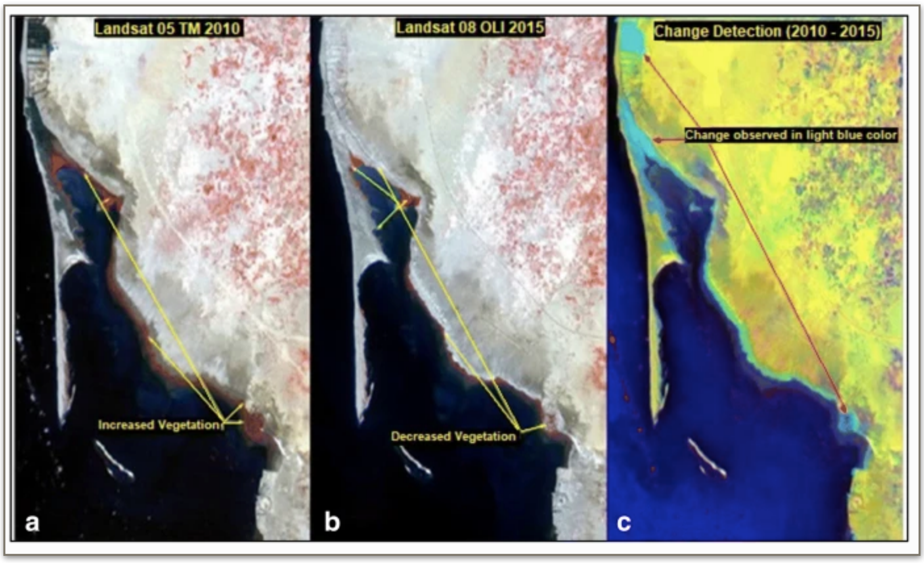

Figure 17: Change detection image (Landsat TM 5) showing a decrease in vegetation biomass due to stoppage of organic material from abandoned shrimp farm (AFTER) *(Source: Arshad et al. 2020)*

4.8 ECUADOR

In 1970, the production of *P.vannamei* in Ecuador, was approximately 50 tonnes per annum. By 2016, there was enormous growth in production levels, to 422,000 tonnes per annum with an annual value of $2.2 billion (UN FAO Fisheries and Aquaculture Department, 2017). Shrimp production accounts for 2.3% of the Ecuadorian economy with an export value of $2.6 million in 2016 (The World Bank, 2017). The shrimp farm's growout ponds are mostly situated in inter-tidal settings in the mouths of coastal rivers or sheltered estuaries. Extensive systems which are reliant on natural tidal flows for free input nutrients, input feed, aeration and water exchange of the growout pond, are mostly established near the mouth of the estuary. However the majority of ponds are located on land in close proximity to the estuary, mouth of the river, or within rivers (Hamilton, 2020).

- **Altered geochemistry of the estuary:** From 1989, impacts of shrimp aquaculture on the ecological environment of Guayas Estuary have been recorded and examined (Twilley, 1989). The process of pumping and draining estuarine waters in and out of the shrimp ponds was of major concern. Over three decades ago, when observations first commenced, it was recorded that the approximate amount of estuarine water pumped in to the pond was 4 x 107 m^3. The volume of water was considered one third of freshwater input in the wet season. It was agreed that the entire geochemistry of the estuary was at risk of alternation due to such substantial movements of water. Due to higher rates of evaporation of standing water on shrimp farms in comparison with the wider estuary, hyper saline waters flow from the ponds into the lower salinity estuary. This overall increase to salinity levels in in the estuary change the balance of the ecosystem, flora and fauna which are inhabitants in it. Growout ponds have the potential to seep larger amounts of saltwater into terrestrial ground and is likely to result in increased salinity in the ground water (Hamilton, 2020).

- **Increased volumes of effluent loads** discharged from shrimp farms located in Chone Estuary was found to be the equivalent of domestic waste loads in the range of 1.5-2.5 million people (Arriaga et al. 1999). Shrimp farm inputs include shrimp waste and faeces, external feed and shrimp farm nutrient outflow. Shrimp waste, being the primary output discharged into the estuary at concentrated levels create rapid deterioration to water quality. The waste can contain organic soil, chemicals, nutrients and bacteria. In transitioning from one shrimp crop to another the discharge of waste water is likely comprise of one tonne of organic waste to every hectare of pond (Flaherty and Karnjanakersorn, 1995).

- **Short life span & abandoned ponds:** The productivity period of shrimp ponds depends on the practices and the location of the shrimp pond. The lifespan of a shrimp pond is usually short, with intensive systems given 5-10 years (Naylor et al. 1998) and 7-15 years in a less intensive system. The main drivers for shrimp pond abandonment and collapse are viral disease and bacterial contamination of sediment at the pond base. After a collapse, the farms are rarely regained and regenerated. Many authors have contended that abandoned shrimp farms are very rarely rehabilitated back into its original state as a mangrove forest ecosystem or used as agricultural land (Paez-Osuna 2001; Naylor et al. 1998). Several abandoned farms, along the coastal fringe are evident on the landscape, several years after abandonment. In some circumstances, farmers may grow Tilapia in ponds when they have become too contaminated for shrimp production, however this is not a common practice.

Figure 18: Abandoned shrimp ponds on the Fringe of Chone Estuary, Ecuador
(Source: Hamilton, 2020)

- **Risk to human health:** In response to human health concerns, inputs in shrimp aquaculture have been studied to understand any negative consequences. The categories identified included issues surrounding, agrochemicals, organohalogens, antibiotics, wastewater, metal and transgenes (Sapkota et al. 2008). The use of antibiotics have been a widely recognised and long term trend in Ecuadorian shrimp aquaculture as a response to curtailing the spread of vibriosis.

- **Breakout of bacterial and viral disease:** Shrimp culture farms in Ecuador mirror the global trend, in that it is also subject to the White spot syndrome virus and Taura syndrome virus (McClennen 2005, Rodriguez et al. 2003) and since the 1990's the viruses have periodically devastated the farmed shrimp industry (Figure 19). Other infectious viruses such as haematopoietic necrosis (HNV) and baculoviral midgut gland necrosis (BMN) were also contributory to shutting down the estuary's commercial shrimp farms (FAO, 2014).

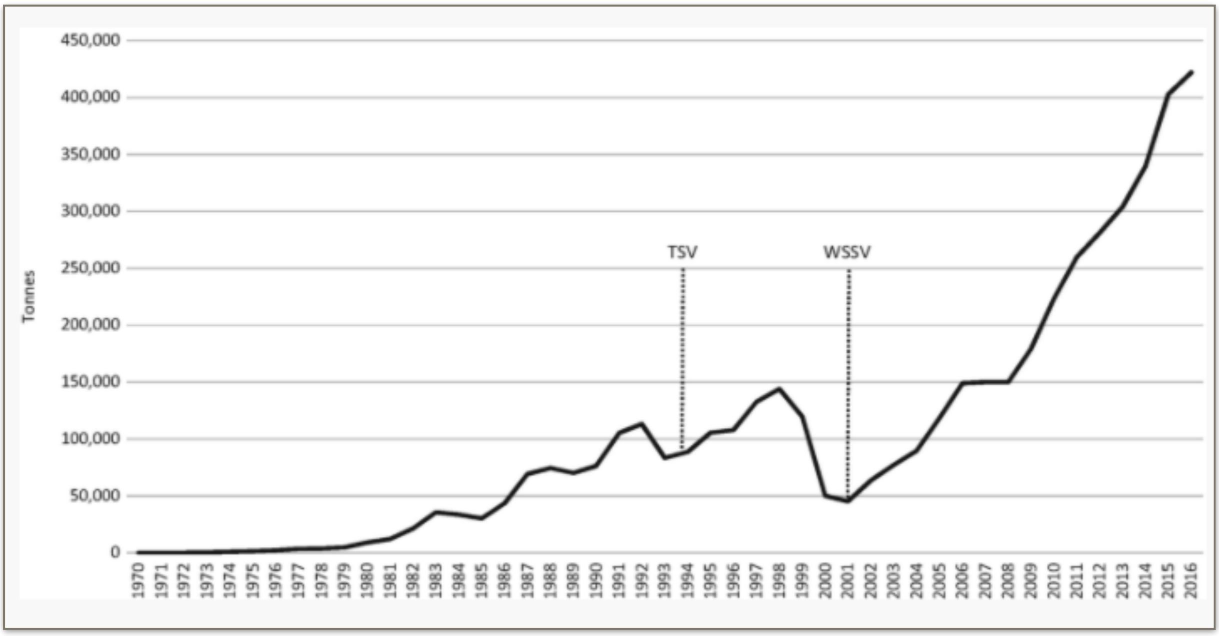

Figure 19: Ecuador aquaculture output and disease outbreak *(Source: Hamilton. 2020)*

4.9 MEXICO

Mexico vastly supports the shrimp farming industry and produced 114,000 tons of farmed shrimp from 66,000 hectares of ponds in 2007. An estimated 90% of this production came from two North Western states bordering the Gulf of California: Sonora and Sinaloa (Figure 20). The production is exclusive to the Pacific white shrimp (*L. vannamei)* and is rapidly increasing. The quantity of shrimp produced in Sonora has more than doubled in the five-year period from 2003 to 2008 and the total pond area has nearly doubled in the same time. Data from 2008 show that Sonora alone, now produces over 80,000 tons from 22,000 hectares of ponds. In keeping with the dominance of these two states and their significance among U.S. imports, this report focuses only on production in Sonora and Sinaloa (FAO, 2010).

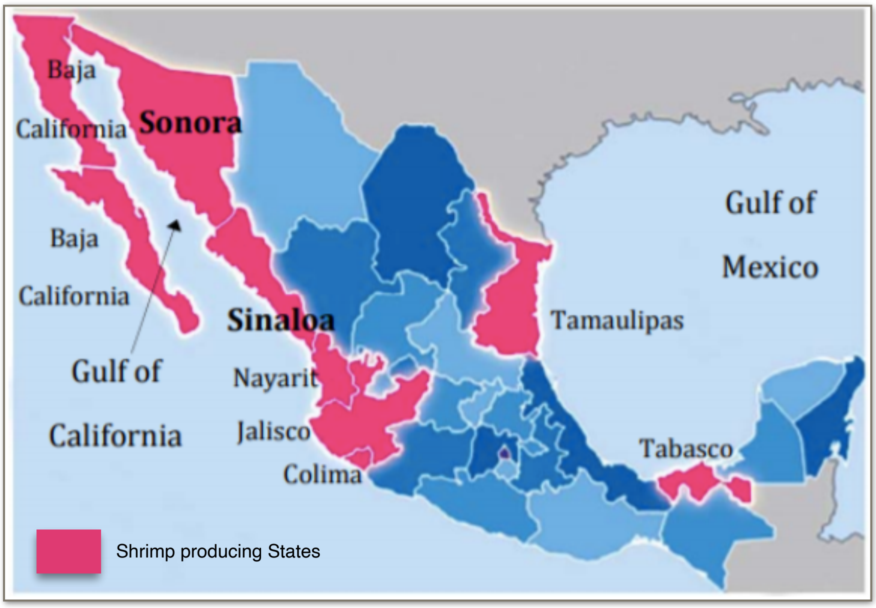

Figure 20: Primary shrimp producing States, Mexico *(Source: Miranda, 2010)*

In the State of Mexico, the most common type of farmed shrimp is *L. vannamei.* The growth and survival of *L. vannamei* postlarvae are strongly dependent on temperature and salinity. When reared at temperatures of 20˚, 25˚, 30˚ and 35˚C and salinity of 20, 30, 35, 40 and 50 ppt, the highest survival and growth coincide at around 28–30˚C and 33–40 ppt. Survival of juveniles is severely compromised at low salinity levels and high temperatures. As such, it is identified that most of the farms are based in Mexican coastal states.

Figure 21: Native geographic range of wild *Litopenaeus Vannamei (Source: Miranda,2010)*

The extensive rate of growth in the aquaculture industry has contributed to detrimental environmental impacts over time including:

❖ **Clearance of mangroves vegetation:** Although mangrove areas have been used and cleared for aquaculture, most ponds have been destroyed or impacted adjacent wetlands, salt marsh and tides habitats that threatened biodiversity and habitat loss.

❖ **High volumes of effluent discharge:** Agriculture and other anthropological untreated nutrient inputs to the Gulf of California are substantial, and significant nutrient discharges from Mexican shrimp farms further contribute to these regional impacts (Miranda, 2010). Nutrient input to this semi-enclosed sea has been generally increasing and is associated with various environmental concerns including Harmful Algal Blooms (HABs).

❖ **Transmission of Pathogens:** Due to the direct impacts of wild shrimp, it has been challenging to detect retransmission of pathogens and it has been widespread among shrimp farms. Currently major 6 diseases have been identified by Specific Pathogens Free (SPF) (Chavez-Sanchez et al, 2002). In 2008, White Spot disease was identified in a farm in Sorona. A study undertaken in the region, identified the *V.parahaemolyticus (Vibrio)* as a potential problem for shrimp farms in parts of north western Mexico, due to its prevalence in hatcheries and ponds (Enriquez-Espinoza et al, 2016)

4.10 HONDURAS

Freshwater aquaculture began in 1936 in Honduras. In 1970, brackish water shrimp cultivation commenced near the Gulf of Fonseca. The main species cultured were *Penaeus vannamei* and *L. stylirostris* where post-larvae were abundantly found in estuary waters. A combination of intensive, extensive and semi-intensive cultures were practised (FAO,2007). Extensive shrimp culture practices are undertaken by low-income fishermen who construct their own tidal ponds. Larvae enter the pond with incoming water at high tides, but no control is exerted over the shrimps that are stocked. In semi-intensive shrimp culture, the hatchery-reared larvae are stocked in ponds and shrimps are also fed with concentrated feeds or balanced rations where production may reach between 1300 - 1500 pounds per hectare per cycle. (FAO, 2007).

In recent times, Honduras has been subject to considerable environmental impacts stemming from aquaculture and shrimp culture operations.

- **Impact on water quality standards:** Estuarine water quality limits shrimp production during the dry season as it becomes limited due to low levels of assimilative capacities, resulting in poor water quality due to municipal discharge, runoff from agricultural fields, organic matter from fringe mangroves and shrimp discharge. This discharges and weather conditions limit the survival of healthy shrimps and decrease the breeding process.

- **Effluents:** Production systems and management methods vary in the process of producing and discharging waste per unit of production. Some farms need to improve in terms of lowering their impacts of pollution. Loss in the tracking of waste management data has worsened the issue.

- **Use of uncertified chemicals:** Improper or overuse of chemicals which can have detrimental impacts on species and human health. The development of unknown species can become chemical resistant organisms. These foreign species may cause issues on both shrimps and environment-friendly organisms active in the pond.

- **Diseases:** The amplification of pathogens and parasite interactions have become a significant issue on shrimp farms as wild species share the same water body. The frequent direct water change has become a strong route for transmission of populations of pathogens to wild shrimps. A high possibility for spread is presented where diseases can be passed from one farm to another from wild shrimps. (Gee,2015)

5 SUMMARY OF KEY FINDINGS

SALINE INTRUSION

LOSS OF WETLANDS

GROUND WATER DEPLETION

CLEARANCE OF MANGROVE VEGETATION

DRUGS AND ANTIBIOTICS IN MAINTAINING HEALTH

AQUACULTURE INDUCED SEA LEVEL RISE

ABANDONED PONDS

DISCHARGE OF WASTE WATER & SLUDGE

DECREASE IN SOIL ORGANIC CARBON

ALTERED GEOCHEMISTRY OF ESTUARY

HARMFUL FISHING PRACTICES

DISCUSSION

The assessment of the international case studies examined in this report is a reflection of the extensive damage caused by the establishment of aquaculture and shrimp farms on the marine and terrestrial environment. Major identified impacts include, loss of wetlands and mangrove vegetation, saline intrusion, alterations to the geochemistry of estuaries, ground water depletion, spread of bacterial and viral disease, use of drugs and antibiotics in the treatment of disease, discharge of nutrients, waste water and sludge, eutrophication, decrease in soil organic carbon, abandoned ponds with short life spans, and aquaculture induced sea level rise.

In response to an increasing trend in global demand in the fisheries and shrimp industries, farmers are striving to increase the profitability of their operations with limited consideration to their environmental footprint. It is evident that in order to increase yield, unsustainable practices such as introduction of anti biotics and other non certified drugs and chemicals are being used in the treatment of disease, untreated waste being discharged into estuaries and clearance of mangrove forests are occurring, to make space for expansions of the farms. A common theme is the occurrence of widespread shrimp diseases and pathogens across the majority of countries analysed. Myanmar and Taiwan have been prime examples where a lack of regulation and law enforcement in the industry have resulted in poor fishing practices and unsustainable outcomes.

However, an examination of the above countries and their aquaculture farming processes have highlighted sustainable practices and emerging aquaculture technologies adopted by governments, farm-level and community-level across these regions, and a few of these practices are outlined as follows:

- **The use of (multi-trophic aquaculture (IMTA))** to optimise and diversify aquaculture products and reduce water pollution in coastal South Taiwan. The system showed a reduction in nutrient levels, turbidity, and phytoplankton (Yeh et al. 2017). The concept of IMTA was developed to further improve the sustainability of intensive aquaculture systems through the adoption of an ‘ecosystem based approach’.

- **‘*Chan Myaung*’ (garden irrigation)** systems introduced in a rural context in Myanmar were recognised as a viable option for fish culture. Pond farmers were found to yield higher harvests from these systems in comparison to other pond mechanisms. Increased production levels were positively correlated with survival rates of stocked fish. The ponds were found to have lower capital investment in comparison to earthen ponds (Karim et al, 2020)

- **Integrated rotational farming system:** The method was introduced in the tidal flat ponds of Hangzhou Bay, China where the Shrimp (*L.vannamei)* was rotated with three species of vegetable - cole (*Brassica. napus),* broccoli (*Brassica oleracea)* and potherb mustard (*Brassica juncea).* Results showed a decrease in the concentrations of soil total nitrogen in the three vegetable rotational farming systems (Ni et al, 2020).

Although some of these practices have been adopted across these regions, it is noted that further extensive research and investigation is required into the long term viability and implications of these practices, of which some technologies and methods are yet in their infancy. Additionally, given the impeding threat of climate change it is critical that substantial research and environmental impact assessments, with ongoing monitoring and assessment and mitigation strategies are established, well in advance of the establishment of farms to ensure suitability and sustainability of projects in the long term.

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