FROM PRISTINE TO POLLUTED

HOW CHEMICALS AND POLLUTANTS DRIVE

FISHERY DECLINES AND ECOSYSTEM COLLAPSE

Case Study:
Mekong River
Vietnam

March 2024

FROM PRISTINE TO POLLUTED: HOW CHEMICALS AND POLLUTANTS DRIVE FISHERY DECLINES AND ECOSYSTEM COLLAPSE. CASE STUDY: MEKONG RIVER, VIETNAM

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IPEN is a network of over 600 non-governmental organizations working in more than 125 countries to reduce and eliminate the harm to human health and the environment from toxic chemicals.
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National Toxics Network (NTN) was a not-for-profit civil society network striving for pollution reduction, protection of environmental health and environmental justice for all. NTN was committed to a toxics-free future.

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Cover: Figure 1: Rice and fish cultivation Mekong Delta Vietnam (Source: Tran Xuan Long, 2021)

Author’s Preface

My family have given me tremendous support and opportunity in my life. School holidays were always a chance to escape suburbia and be immersed in nature. Often times we’d go somewhere by the water, be it a river, a lake or the ocean beaches. At every opportunity I had a fishing rod in hand, with high hopes for capturing a big fish, but even small fish were enthralling to me.

My Mum was a radiography nurse with an interest in science and biology that I came to share with her. My Dad was a public servant working in quarantine inspection service with an economics background. Interactions with veterinary scientists at my Dad’s work, were formative in influencing my thinking through high school and direction to University.

My interest in aquatic animals continued to grow, but rather than embark on a marine biology degree I chose to explore my interests through a veterinary degree at University of Sydney. Through the undergraduate degree the science of animal health and food production captured my mind and upon graduation I launched into a rural job that spanned dairy cattle, birds, cats and dogs. It was another five years later with an injured back from pulling out calves and repairing injured hooves that my original visions of becoming a fish veterinarian returned.

I was very lucky to again have good fortune shine on me and I commenced work for the State Government as a fish veterinarian at a regional laboratory. The lab was stacked with immensely skilled veterinary pathologists to whom I owe a great debt for their patience in imparting their knowledge to me. The job involved investigating the causes of fish kills and fish disease all around the State, embracing both field work and laboratory diagnostics. The role also had a biosecurity policy component. It was a slow dawning through this time, that all was not well with the health of the rivers. Expanding knowledge helped me recognize there were multiple threats. It became clear to me that disease in aquatic animals was tightly associated with the health of the environment in which they lived.

In wild capture fisheries the media and conservation group narratives were focused on over-fishing. Fisheries management also focused on catch as the dominant influence on fishery productivity - declines were regularly attributed to too much fish being caught. Correspondingly, management responses sought to reduce catches through implementing a range of measures like size limits, bag limits, closed seasons, marine protected areas, license buy-backs, restocking and quota. The effects of the degrading water quality and habitat were not given the same consideration. This struck me as being inconsistent with the evidence of disease expression and mortality incidents which had nothing to do with fishing activities.

Dr Mariann Lloyd Smith, founder of the National Toxics Network (NTN) and member of International Pollutants Elimination Network (IPEN) and Joanna Immig connected with me to co-author the report, Aquatic Pollutants in Oceans and Fisheries. Following this endeavor, IPEN supported me, through NTN, with a team of co-authors and editors to produce three case studies: Richmond River, NSW, Australia; Mekong River, Vietnam; and Fraser River, British Columbia, Canada. These case studies explore a history water pollution brought by changes to land-use and changes of pollution governance over time. Each case study gives insight to the current day circumstances and offers up pathways for restoration. A synthesis report brings together common themes from 3 cases studies.

I hope that humanity can quickly learn from the global body of science and haphazard pollution governance through time, to achieve restoration of aquatic ecosystems. To do this, relies in no small part, on our ability to control the water pollution we generate.

Matt Landos

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Executive Summary

The Lower Mekong Basin (LMB) supports one of the largest, most rapidly expanding and economically dynamic human populations across the globe. It is also one of the world's most productive and diverse ecosystems. Over 80% of the sixty million people living in this region are significantly impacted by changes to fish availability because of pollution, climate change, degradation of wetland ecosystem services, upstream development activities and population growth. Fish is the main source of dietary protein in both national and international trade. The Mekong Delta is a hotspot of aquaculture and fish biodiversity and a center of agricultural production in Vietnam.

This report summaries the environmental history and major decisions by government that led to changes in land use, aquaculture development and wild capture fisheries. The changes to productivity of wild fisheries and the influence of major pollutants in the Mekong Delta are explored.

The Mekong Delta of Vietnam is facing existential threats from climate change contributing to drought and saltwater intrusion, upstream dam development altering flows of water and sediment, water pollution and environmental degradation from the use of pesticides, chemical fertilizers, antibiotics, and agrochemicals in agriculture/aquaculture farming systems. The environmental changes in the Mekong Delta have been closely associated with human efforts to control the water through canal excavation for land reclamation to support the resettlement process and expand aquaculture and agricultural production.

During the Vietnam War (1954 – 1975), most of the farmers produced only one traditional floating rice crop per year, relying on rainfall and the annual flood in the delta for the necessary water supply. In 1967, the first high-yielding rice varieties (HYV) were introduced in the flood plains, leading to increased rice production during the early 1970s as colonial forces promoted the shift in land use. This drove extensive change in the delta's ecological landscape and changed people's livelihoods, boosting income and food production.

A post-war Government shift to open the country to globalized trade seeking economic growth, set forth massive expansion of irrigation canal networks to fulfil new agricultural policies. It resulted in the conversion of large parts of the Mekong Delta grasslands, wetlands, melaleucas, and mangrove forest into agricultural land. During the 1980's, 700,000 hectares of melaleuca forest in the Plain of Reeds was converted to rice fields, and from 1983 to 1995, half of the mangrove forest area (≈50,000 ha), was converted to shrimp farms. The expansion and intensification of rice production have seen volumes climb 74% from 1995 levels to reach ≈ 43.5 million tonnes/year.

With intensification has come a rapid increase in the amount of pesticides used. Imports of pesticides have grown from 6,500-9,000 tonnes in 1985, to now 70,000-100,000 tonnes of pesticides per year from 2019 to 2021. Although pesticides, herbicides and synthetic fertilizers have played an important role in increasing agriculture production, they have also caused damage to water quality, food safety, aquatic organisms and soil. Pollutant loads of pesticides and fertilizers have risen in line with increasing use with negative health and productivity consequences for wild shrimp, fish and other aquatic creatures due to the deterioration in the health of their ecosystems.

In 2012, Vietnam's costs for imported pesticides were roughly equal to its revenue from fruit and vegetable exports. So, while contributing to expanded economic growth, the food security benefits that are often touted as a justification for expanded intensive pesticide-dependent agriculture fail to consider the externality costs on human and environmental health which are mounting.

Inland fisheries of the Mekong Delta are important for livelihoods, incomes and food protein security but not well-documented or recognized. Development planning legislation generally focuses on protection of freshwater biodiversity, fisheries conservation strategies and better agriculture and aquaculture production practices. This tends to overlook the pollution drivers of the loss of productivity of freshwater wild fisheries.

A striking inverse relationship was identified between annual wild freshwater fisheries catches and intensive HYV rice farming area and production tonnage from 1995-2020. As HYV rice farming increased, fish yield decreased. The deterioration in water quality and habitat from increasing pollution from agriculture and untreated wastewater, as well as the change in land-use leading to exclusion of fish access, are major contributors to the decline in aquatic productivity.

Water quality to support aquatic life is generally better in the Mekong River main channels but less favorable in the Delta's smaller water courses where domestic wastewater, diffuse pollution from intensive rice farming systems and other industrial sources combine to degrade water quality. The surface water pollution in the Mekong Delta is now an urgent threat to human, aquatic animal (fisheries) and ecosystem health. Water quality parameters including pH, turbidity, maximum concentrations of ammonium, arsenic, barium, chromium, mercury, manganese, aluminum, iron, *Escherichia coli* and total coliform counts in canals exceeded Vietnamese water quality guidelines for drinking and domestic purposes.

Within the next 20–30 years agriculture and aquaculture/fisheries sectors and wetland ecosystems of the regional Lower Mekong Basin will not support sustainable growth due to the significant biophysical changes caused by the upstream basin development activities, dams, urban development, industrial aquaculture and agriculture production with the accompanying water and environmental pollution and wetland ecosystem degradation.

The regulatory framework for industrial wastewater in the Mekong Delta is ineffective due to gaps, overlaps and a poor understanding of the environmental regulations by industrial producers creating major surface and groundwater pollution. The use of pollution intensive production technologies and a failure to adopt pollution-minimising technologies coupled with the limited capacity and financial resources of companies and local enforcement agencies, as well as the low level of penalties for violations, contributes to the problem. Due to a lack of wastewater treatment systems, contaminated wastewater enters the canals and river.

To address the many emerging issues and achieve sustainable and climate resilient development of the Mekong Delta after Resolution No.120/NQ-CP dated November 17, 2017, the Government Ministry of Agriculture and Rural Development (MARD) have issued many signed directives, decrees, and decisions. These have included setting objectives for 2050 around the ratio of eco-agriculture and hi-tech agriculture which will account for over 80% of total agricultural production, with forest coverage to reach over 9%. Eco-agriculture methods incorporate agricultural production and biodiversity conservation, as well as livelihood creation to benefit, especially for the poor. Hi-tech agriculture combines latest technologies in farming to enhance effectiveness, efficiency, and farm product quality to meet the market demand. The objectives require food production to shift into more environmentally friendly methods with reduction of fertilizers and pesticides. This in turn is expected to encourage application of high tech and biotechnological methods to aid agricultural production.

The local Government objectives seek to structure agricultural production according to three focuses: fisheries; fruit trees; and rice associated with ecological sub-regions, in which aquatic products from freshwater, brackish water, and salt water are considered as key products. The integrated agriculture and aquaculture systems are considered a good option to protect wild fisheries and provide greater food diversity for local farmers. However, some decisions are quite difficult for local farmers to implement in practice.

Vietnam's economic growth has dramatically altered the national poverty rate from around 50% in 1980 to 9.8% in 2016. Despite the immense agricultural development, the rural area of the Mekong Delta had 10.8% of people under the poverty line in 2016[1]. The people of the Mekong Delta have the lowest percentage of trained employed workers at 9%, compared to 16.6% nationally. This has led to some groups such as AusAid and United Nations Industrial Development Organisation (UNIDO) questioning whether it has been the rural development strategies applied which have led to meaningful livelihood changes, or other local factors. The declines in availability of wild fish associated with the agricultural intensification have been shown to impact the poor most adversely.

The metrics used to assess the success of current economic development appear deficient. They don't appear to capture local ingenuity or the externality costs to human and environmental health. The headlines showing great strides in poverty alleviation in the Mekong Delta do little to explain the costs incurred from the industrial development strategy to create this wealth for some. The negative consequences of the economic development on the health of ecosystems also eventually impacts the health of the community and arguably in the near-term place at risk living standards and social well-being.

With the growing impacts of development increasing pollution, altering climate, water quality and fishery productivity, it seems that more urgent changes to Government development plans and direction of foreign aid, will be needed to support sustainable and happy lives for the millions of inhabitants of the Mekong Delta and to better protect the environment that supports them. The transboundary nature of problems like climate change and dams on the river will require international action to help sustain Vietnam.

[1] https://documents1.worldbank.org/curated/en/206981522843253122/pdf/124916-WP-PULIC-P161323-VietnamPovertyUpdateReportENG.pdf

1. Introduction

Fisheries can be viewed both as essential components of nature and life on earth and as an essential ecosystem service providing important food protein, income and livelihoods for humanity. However, catches from freshwaters are often overlooked when considering fisheries. Hundreds of millions of people around the world benefit from low-cost protein, recreation, and commerce provided by freshwater fisheries, particularly in regions where alternative sources of nutrition and employment are scarce [1]. Consumption of wild-caught freshwater fish is concentrated in low income countries, where it makes a critical contribution to food security and livelihoods [2].

This report provides an overview of the environmental history and key decisions by Government that altered land use. A history of aquaculture and fisheries production development and management as well as the legislation regulating the management of pollutants in the Lower Mekong Basin (LMB) of Vietnam is considered. The role of key impacts from anthropogenic, industrial development, agriculture and aquaculture production and other issues contributing to the apparent decline in the Mekong Delta inland freshwater fishery in Vietnam are explored.

Agriculture and aquaculture are the main occupation. While the wild capture fisheries are a common secondary occupation for many of Mekong Delta's population. The products of LMB wild fisheries are the major essential protein sources for the local people accounting for 47–80% of animal protein in regional diets, with an average consumption of 50.3 kg/person/year [3-5].

The Mekong Delta of Vietnam is a wetland ecosystem formed from the deposit of the sediment carried by the Mekong River as it approaches and empties into the South China Sea through a network of tributaries. The Mekong Delta is the most important region for aquaculture and agricultural production in Vietnam and contributes significantly to the country's export revenue. It produces over 55% of rice production and approximately 60% of total aquaculture including fishery output for Vietnam [6].

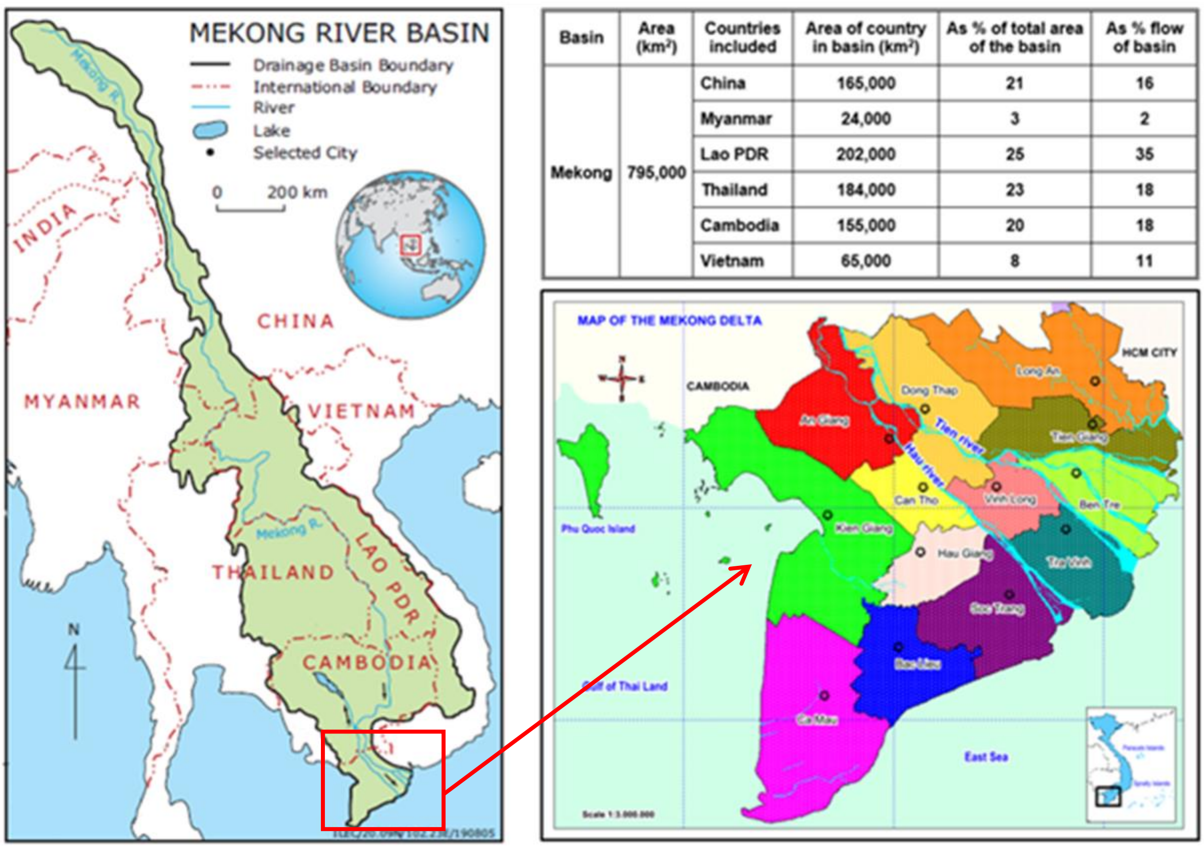
Vietnam is now the world's second largest rice exporter with 6.4 million tonnes and still firmly in the top three largest seafood/aquaculture exporting countries in 2021. More than 50% of these products are produced from the Mekong Delta [7]. Although the industries of aquaculture and intensive agriculture production generate high profit and income, they also risk causing negative environmental impacts, such as landscape modification, pollution, and biodiversity loss [8-10] as detailed in this report.

2. Methodology and data collection

This report reviews and discusses policy and management of natural fisheries production (wild fish catch) and the influence of major pollutants in the Mekong Delta over the last two decades. A brief overview of the small-holder fisheries in the Lower Mekong River basis is presented. Fisheries policies and legislation related to the management of wild capture fisheries, aquaculture, and pollutant management in Vietnam from 1945 to 2020 are reviewed. The recent policy initiatives of the Fisheries Law of 2020 and the Master Plan for Fisheries Development to 2025 will be discussed. Data which was illustrative of fisheries production, environmental management and protection from Vietnamese government, scientific reports and relevant publications at the local, provincial, national-level government and international agencies were also collected, evaluated, and are discussed in this report.

3. Physiography and geomorphology of study area

The Mekong River supports the largest inland fishery in the world accounting for around 25% of global freshwater fish catch. It originates in the Tibetan Plateau at an altitude of 5,000m, travels around 4,800km through six countries, and then flows into the East Sea, sometimes referred to as the South China Sea. The Lower Mekong Basin located in the territory of four countries of Laos, Thailand, Cambodia and Vietnam, covers an area of 606,000 km^2 (accounting for 76% of the basin area) and contributes more than four-fifths of the water for the Mekong River [11, 12] (Figure 1).



Basin	Area (km²)	Countries included	Area of country in basin (km²)	As % of total area of the basin	As % flow of basin
Mekong	795,000	China	165,000	21	16
		Myanmar	24,000	3	2
		Lao PDR	202,000	25	35
		Thailand	184,000	23	18
		Cambodia	155,000	20	18
		Vietnam	65,000	8	11

Figure 2: Map of Mekong River basin and the Vietnamese Mekong Delta. Source: [13-15]

Administratively, the Mekong Delta has 13 provincial-level administrative units, one centrally run city and twelve provinces: Can Tho, Long An, Tien Giang, Ben Tre, Vinh Long, Tra Vinh, An Giang, Dong Thap, Kien Giang, Hau Giang, Soc Trang, Bac Lieu and Ca Mau. This is home to many ethnic communities of Kinh, Khmer, Chinese and Cham who came to conquer and exploit the Delta around 300 years ago.

In the year 2000 the estimated yield of wild freshwater fish in the basin, excluding the aquaculture component, was 1,860,000 tonnes [16]. The Mekong River Commission's expert panel's estimate 71% of the total freshwater fishery resource to be migratory. Around half of the migratory fish are considered highly vulnerable as they are comprised of species that require migrations of up to a thousand kilometers or more for reproduction [17, 18].

Agriculture is responsible for 80–90% of all water extraction from the Mekong River. Water from the Mekong River accounts for about 94% of total country-level water extraction in Cambodia, 82% in Lao PDR, 91% in Thailand, and 86% in Vietnam [19]. Agriculture development of the Mekong Delta is the reason why a country that once suffered from food shortages is now the world's second largest exporter of rice (***see the summary of overview of the Mekong Delta in Box 1***).

BREAKOUT BOX***

Box 1: Overview of the Mekong Delta

- It covers an area of approximately 4 million hectares and is 12% of the Vietnam's territory, 27% of Vietnam's agricultural land.
- Population of 17.2 million people (18% of total national population); 75% of the population live in rural areas and 76 % of the population is engaged in agriculture;
- Economic importance: 40% of the country's agricultural production, more than 50% of agriculture exports, 55% of national rice production, 65% of fruit production, and 60% of its combined fisheries and aquaculture output.
- Third largest industrial region
- Large area of functioning wetlands offering ecosystem services

CLOSE BOX***

Aquaculture in the Mekong Delta is an emerging production sector where black tiger (*Penaeus monodon*) and white shrimp (*Litopenaeus vannamei*) (brackish water) and Pangasius catfish are key production species for export, while other species are for domestic market and household use. The conversion of saline land and areas of mangrove forest to the alternative farming of brackish water shrimp-rice production is expanding rapidly and helping to raise income levels of farmers engaging in rice production.

Climate change is leading to rising sea levels as well as saltwater intrusion, and according to studies up to 60% of the Mekong Delta could be underwater by the year 2100 [20, 21]. The mangrove forests along the coast and wild fisheries are in dramatic decline [22]. The frequency of flooding and storm surges have increased considerably and lead to saltwater intrusion in the country's interior. The climate change driven melting of glaciers in the Himalayas in the headwaters of the Mekong catchment are anticipated to increase the variation in flow down the river [23].

The fertile delta land was formed more than 10,000 years ago from the deposition of alluvium carried by the Mekong River, along with the gradual accumulation of marine-derived substrates through the ages of sea-level changes [24]. However, the sediment deposition in the Mekong Delta began to change in 2005. It has transitioned from a constructive mode to an erosional mode and on average, the coastline is now eroded about 1.4 m per year [25]. The main cause of this problem is due to the sediment load carried by the Mekong River being reduced through human activities such as excessive sand exploitation, construction of hydroelectric dams, and destruction of coastal mangrove forests.

The Vietnamese Mekong Delta is one of the most low-lying and densely populated areas in the world. It is vulnerable to seawater incursion, flood risk, and shoreline change, all exacerbated as a consequence of sea-level rise related to climate change [26]. Overall, climatic impacts on aquaculture/fisheries in the Mekong Delta are predicted to be highly variable, depending on the current climatic zones of activity. The more negative impacts are likely to be on aquaculture operations in temperate regions. The growth rate of cultured, cold-water species will be impacted by exceedances in the optimal temperature range for body function. Increased thermal stress is likely to contribute to increased disease as pathogens begin to overwhelm them [27].

According to Ministry of Natural Resources and Environment, [28] Vietnam's average temperature has increased about 0.89 °C and sea level has risen about 16.5 cm from 1958 to 2018.

BREAKOUT BOX

Box 2. Climate change forecast for the South, including the Mekong Delta, using the average for 1980–1999 as baseline for future comparison and analysis:

The Mekong Delta's climate is classified as tropical monsoon which is hot year-round and has a seasonal distribution of dry-wet months depending on the operation of the monsoon. The annual mean temperature ranges from 26 to 28°C with only slight variation, the highest temperature normally appears in April (29^{o}C) while the coolest temperature normally occurs in December (25°C) (Figure 3).

Temperature changes linked to greenhouse gas emissions:

- Low emission: the annual average temperature would increase about 1.2 °C by 2050, and 1.8°C by 2100.
- High emission: the annual average temperature would be increase about 2 °C by 2050, and 3.2°C by 2100.

Annual rainfall changes linked to greenhouse gas emissions: *Rainfall in the dry season would decrease under each scenario*.

- Low emission: Annual average rainfall in the rainy season would increase in the South about 10 - 15% by 2030, and 10 - 20% % by 2100.
- High emission: Annual average rainfall in the South would increase about 10 - 15 % by 2030, and 10 - 25% by 2100.

Sea level rise changes linked to greenhouse gas emissions:

- Low emission: sea level is expected to rise 23 and 54 cm by 2050 and 2100, respectively;
- High emission: sea level is expected to rise 28 and 73 cm by 2050 and 2100, respectively.

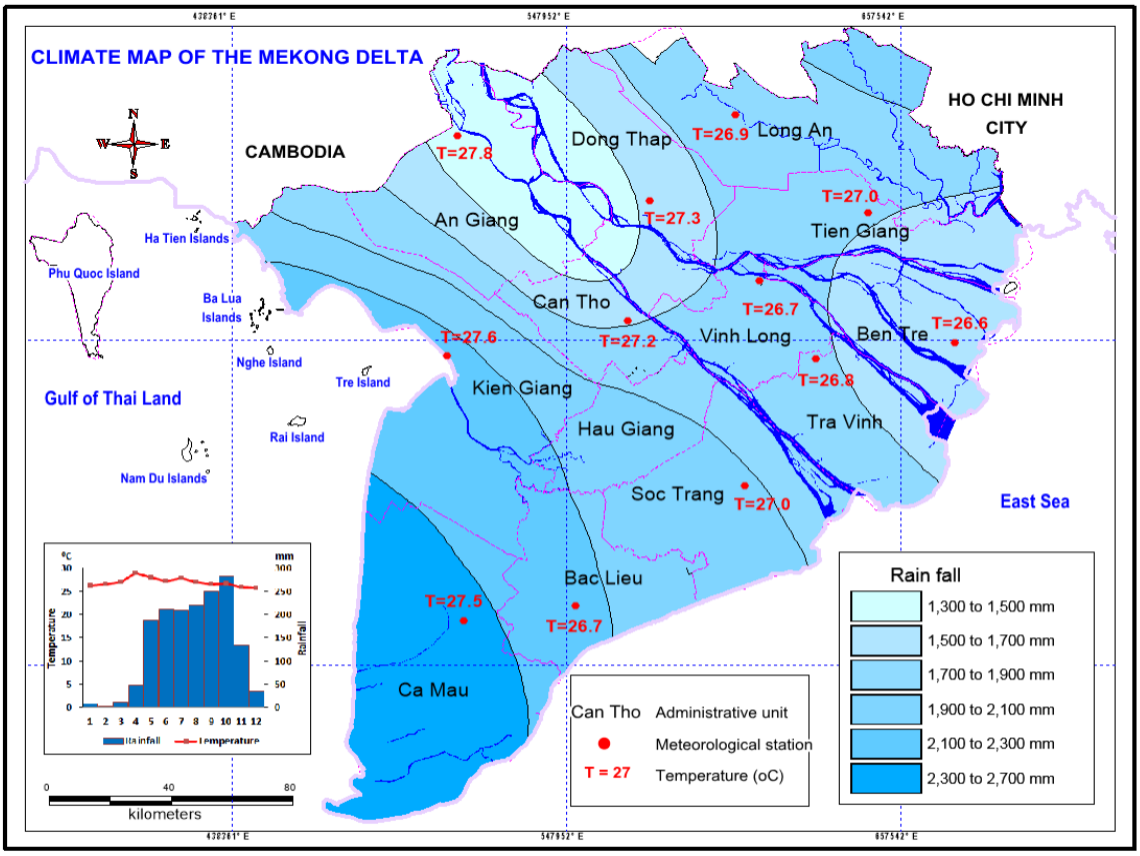


Figure 3: Climate map of the Mekong Delta illustrates temperature and total rainfall. Source: Dinh [15]

CLOSE BOX

The hydrological features and water resources of the Mekong Delta are a dense network of rivers and canals [29]. The natural rivers supply many aquatic resources such as fish, shrimp, and plankton, creating favorable conditions for the development of fishing and aquaculture. The system's canals have developed mainly over the past 100 years in order to supply irrigation water and achieve drainage of water in agricultural development, urban settlement and for water transport [30].

The river flow is characterised by huge mean annual discharge, the amount of water flowing from the Mekong River into Vietnam through the Tien and Hau Rivers is 408 billion m^3 per year (Figure 4).

Figure 4: Map of water distribution of two main branches (Hau and Tien River) of the Mekong Delta. Percentage figures of total water flow. Source [15, 31]

Despite having the large amount of water, the river flow regime is divided into two distinct seasons, monsoonal flood and dry season. The flood season carries around 75% of the total flow beginning in June-July and ending in November-December. In this time, a large area in a the Long Xuyen Quadrangle, the Plain of Reeds, the region between the Tien and Hau River are so inundated that it can reach 2 to 3m deep and remain flooded for 3–5 months [32]. The area flooded depends on the intensity of the annual floods. About 2.0 million ha (half of the Delta's total area) is annually flooded in a big-flood year while about 1.4–1.6 million hectares are inundated in a small-flood year [30]. The flood pulse is the dominant trigger in the Mekong of the annual cycle of sediment flows and ecological processes within the fluvial system, which cause a distinct seasonality in the annual hydrobiological cycle between an aquatic phase and a terrestrial phase [33].

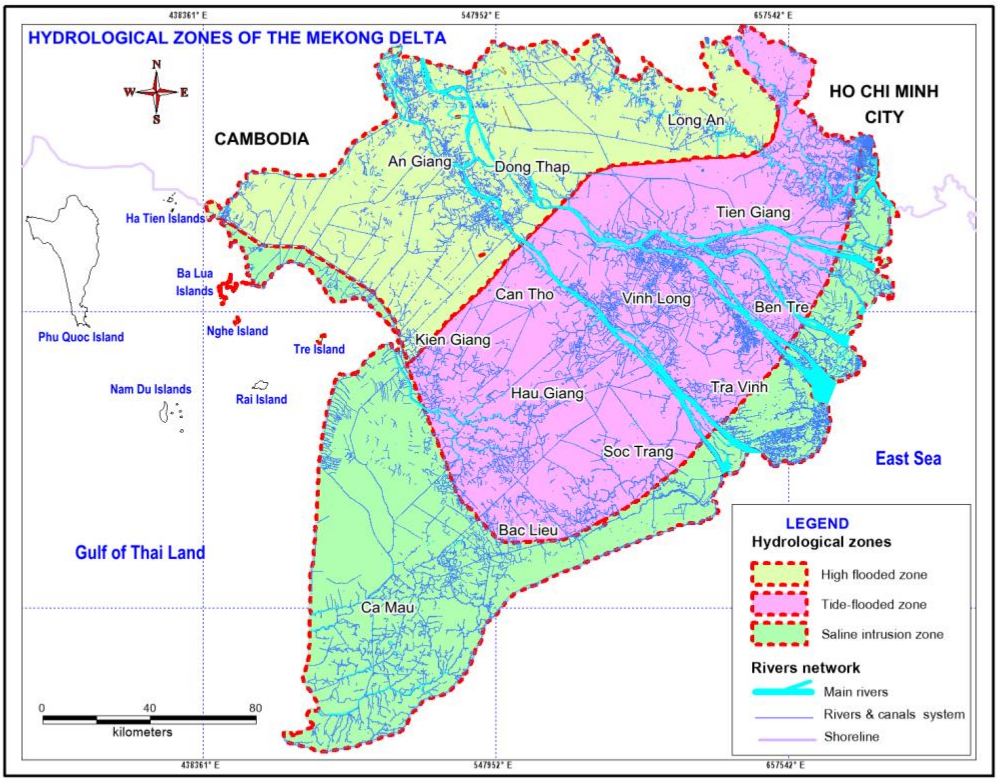


Figure 5: Hydrological zones of the Mekong Delta. Source (Dinh, 2021).

The cause of the inundation is due to the flow from the upstream combined with the rising tide pushing the water into the interior, inundating the lowlands of the Delta. Based on the relationship between the impacts of floods and tides, the Mekong Delta can be divided into three hydrological zones (Figure 5) following [34, 35]:

- The high flooded zone: the northern region of Mekong Delta, includes most of the Long Xuyen Quadrangle and the Plain of Reeds, where local hydrology is dominated by the river floods.
- The tide-flooded zone: the central region of the Mekong Delta, stretches from Can Tho, Vinh Long to Tien Giang, where the floods still predominate however, the tides have a strong impact on the flooding process.
- The saline intrusion zone: the eastern and southern regions of the Mekong Delta, include the estuary of the Mekong River, along the Gulf of Thailand and the Ca Mau peninsula, where the local hydrology is mainly influenced by the tide.

4. Major historical events affecting the Delta's environmental changes

The Vietnamese Mekong Delta is a region where the waters of the Mekong River are always present everywhere and are woven throughout all aspects of peoples' lives. The environmental changes in the Mekong Delta have therefore been closely associated with both natural processes, as well as human efforts to modify the water through canal excavation for land reclamation to support the resettlement process and expand aquaculture and agricultural production. The history of environmental change in the Mekong Delta of Vietnam is presented in Figure 6.

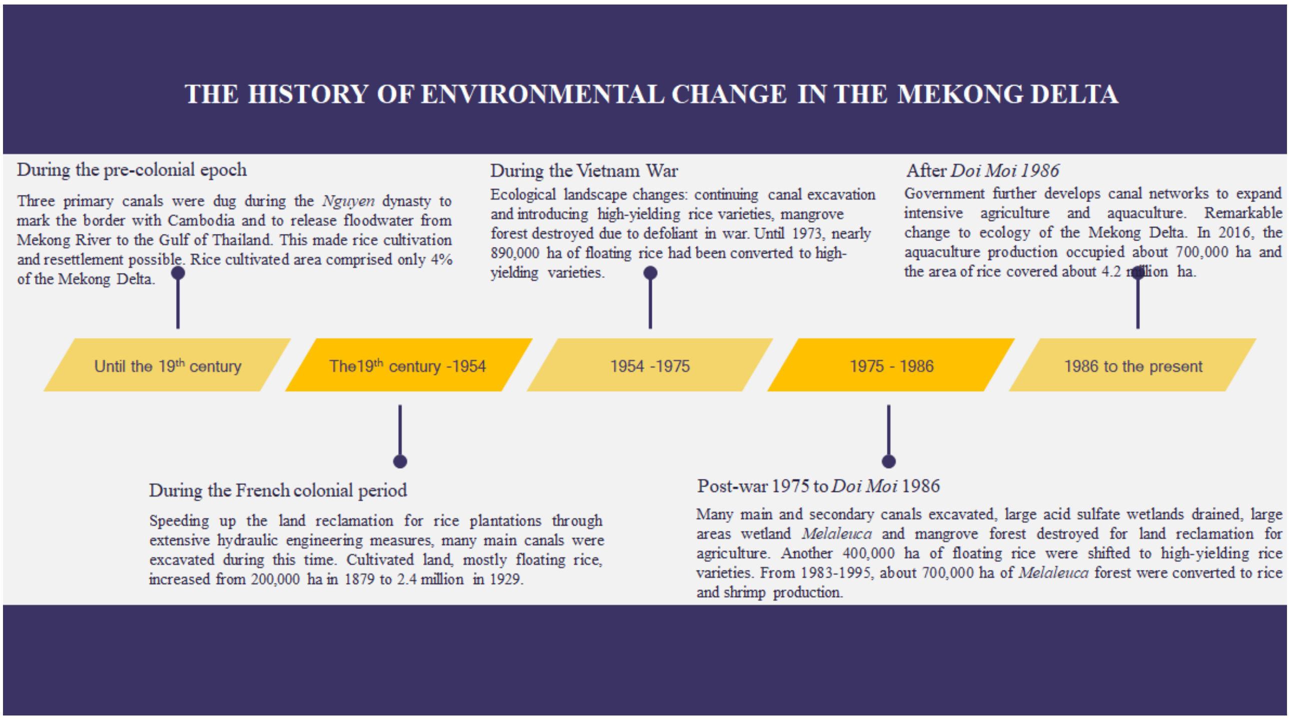


Figure 6: The history of environmental change in the Mekong Delta Vietnam. Source: (Dinh 2021)

4.1. *Canal excavation for land reclamation before and during the French colonial time*

Prior to the French colonization, most of the Vietnamese Mekong Delta was covered with acidic soils and undrained backwater swamps covered in native vegetation. During the *Nguyen* dynasty (1705 – 1858), three strategic canals, namely Bao Dinh, Thoai Ha and Vinh Te, were excavated to mark the border between Vietnam and Cambodia and to facilitate the exploitation of the land for resettlement and rice cultivation [36] (Figure 7). The main land reclamation process began with the Vietnamese colonization of the Mekong Delta during this eighteenth century when a never-ending flow of Vietnamese settlers, mainly from the northern and central regions, entered the Mekong Delta along its rivers and newly dug canals [37]. The rice growing area corresponded to only 4% of the Cochin China region during mid-1800s Henry [38]. The Vietnamese pioneers reclaimed the farmland lying next to the natural river transport routes and practiced traditional *lua mua noi* "floating rice" [36], rain-fed and medium-deep waterlogged traditional rice varieties [39].

As the majority of the Mekong Delta during this period was uncultivated areas of freshwater forest, flooded grasslands and wild fresh-water fish were abundant. Freshwater fish formed an important part of the diet for most people in this region [40]. The principal food was rice supplemented mainly by fish, vegetables and occasional meals of poultry which were the chief sources of animal protein. A staple condiment was *nuoc man*, a pungent sauce made of fish preserved in brine. It was inexpensive but provided a good source of protein [41].

During the French colonization (1858 – 1954), many primary canals (Figure 7) were dug at a high speed to allow drainage of salts and acid so that the land could be used for rice plantations driving rapid agricultural growth and environmental change in the Mekong Delta. From the 1880s to 1930s, the French colonial administration excavated nearly 1,800 km to extend the rice growing area [40]. The new hydraulic network facilitated settlements and land reclamation across most of the uncultivated areas. The process was fueled by large concessions of uncultivated land being granted to French colonists and Vietnamese dignitaries [38]. Cultivated land area rose from 200,000 hectares in 1879 to 2.4 million hectares in 1929, increasing the proportion of total farming area in the Mekong Delta from about 5% to 60% [36]. Cochin China became one of the three major rice-exporting regions, with around one million tonnes of white rice shipped out every year [40].

Figure 7: The excavation of Cho Gao Canal in 1875. Source: www.anhxua.vn

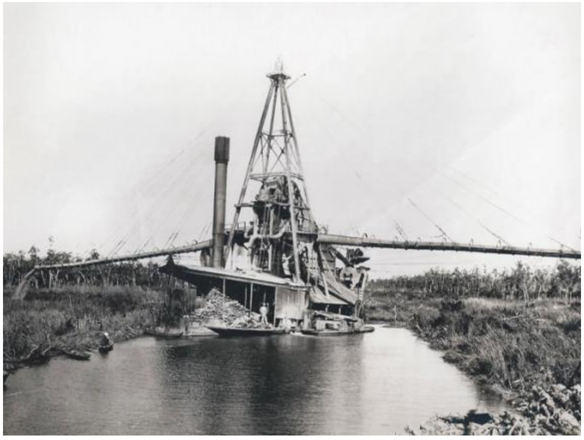


Figure 8: Dredge Loire in Indochina in 1930. Source: www.anhxua.vn

By the 1930s, with the exception of the Plains of Reeds, almost all the present primary canals and secondary canals in the Mekong Delta had been developed, such that most of the land was being cultivated [38, 42] (Figure 8). Historical data could not be identified to explore the extent of aquatic pollution consequences from any importation of synthetic fertilizers and pesticides during the French colonial period. The rapid canal excavation under the French colonial regime led to a vast area of wetland being converted to farmland for rice production. The completion of the Rach Gia-Ha Tien Canal in 1930 opened up coastal lands for freshwater irrigation by flushing more fresh water into formerly brackish water estuaries [43]. However, water in the swamps of the coastal hinterland is still seasonally brackish and acidic such that it is only suitable for drinking and agricultural uses during the rainy season. Disturbance of the soil in swampy depressions can lead to release of acid causing fish kills [44].

4.2. *Ecological landscape changes during the post-colonial period (1954-1975)*

During the Vietnam War (1954 – 1975), many primary and secondary canals were excavated to construct new settlements on the floodplains to control the new land, and especially to provide war services for South Vietnamese government [36]. Navigation in the Mekong Delta was facilitated by the dredging of riverbeds and the constant improvement of the canals, particularly those which connected the principal rivers of the region. Sampans, junks, and other shallow-draft vessels were mostly used, although small steamers were common on the lower reaches of the rivers. The delta's inhabitants lived in villages made up largely of bamboo houses with thatched roofs which were built directly on the ground. During the flood periods, the only dry land was that forming the banks of the canals and rivers. On such pieces of land, often isolated by the floodwater from other communities and neighbors, stood the farmhouses with their small garden plots for growing vegetables, a few fruit trees and a fish pond [41].

The Mekong Delta of Vietnam is the home of traditional rice (TR) with 595 local varieties (Plant Resource Center, online). Most of the farmers produced only one traditional rice crop per year, relying on rainfall and the annual flood in the delta for the necessary water supply. In some areas where drainage was very low, the annual flood covered the areas to a depth up to ten or more feet. Floating rice, a subvariety of a late-maturing type, was grown in these areas. The traditional floating rice system did not rely upon chemical fertilizers or pesticide inputs for cultivation. In December, farmers burned rice straw, applied cow manure fertilizer and ploughed their fields by buffaloes. When the first rains fell in April, farmers began to plough and harrow the land and sowed the seed of floating rice. During the flood, the rice plants elongated. When the water came down in November, the rice plants fell flat on the ground and flowered. Farmers harvested floating rice by sickle between December and January. Using the remaining moisture in the soil and silt deposits some farmers then cultivated upland crops, which were harvested before the flood in June [36]. Particularly in flood low-lying sections of the delta, after harvesting floating rice farmers also made fish ponds on the lowest parts of their rice field to capture wild fish for daily meals [36, 43]. Floating rice was the predominant seasonal rice in the upper the Mekong Delta's provinces, with an area of >500,000 ha before 1975 [45]). The floating rice growing areas belong to two big wetlands known as Long Xuyen quadrilateral (500,000 ha) and Dong Thap Muoi (697,000 ha) and include areas in Kien Giang, An Giang, Dong Thap, Tien Giang and Long An provinces.

During this period, freshwater, estuarine and marine fish were plentiful. In coastal areas of the Mekong Delta, sharks, dogfish, rays and shad were obtainable in various seasons of the years. Eels were enormous and a great variety of freshwater fish of the carp and catfish families were commonly found in rivers, canals, lakes and flooded rice fields. Crocodiles thrived in the delta until this time, and some human deaths from attacks were recorded each year. There were snakes of many varieties, including large pythons and cobra. Inshore areas fielded large catches of shrimp, lobster and shellfish. In 1964 there were about 246,000 fishermen and 56,470 fishing boats, of which 9,710 were motorized. Total catch was established at 397,000 metric tonnes. From 50,000 to 60,000 tonnes of fish were used each year in the preparation of *nuoc mam* (fish sauce), a pungent salty sauce that was an important element in the Vietnamese diet.

In 1967, the first high-yielding rice varieties (HYV) such as IR5 and IR8 rice were introduced in the flood plains [36]. To help farmers to adopt these new rice varieties and take advantage of them, the South Vietnamese government, with the help of the United States, began to import chemical fertilizers and pesticides, as well as motorized equipment such as tube pumps, hand-tractors and small motorized threshers [46]. This was the start of the introduction to Vietnam of the Green Revolution, mainly in the central plain of the Mekong Delta. It led increased rice production during the early 1970s. These developments drove remarkable change in the delta's ecological landscape as chemically dependent rice agriculture expanded the farmed area, natural hydrology was changed and substantial nutrient and agricultural chemical loadings enter the ecosystem. From almost zero in 1968, HYV was grown on 890,000 hectares in 1973 (31% of the total rice cultivated area) and provided around three million tonnes of paddy representing 45% of the total rice production of Vietnam [47] (Figure 9).

** Break-out box**

The “Green Revolution”

After the second world war, chemicals which had been designed as weapons of warfare were re-purposed as weapons to control pests on crops. During the 1950’s and 60’s new technologies created high yielding plant varieties, synthetic fertilizers, pesticides, mechanization, and irrigation, which all favored monocultural approaches to agriculture.

The US Government and the corporations developing the new technologies strongly promoted the transfer of this approach to agriculture to the world. Where it was applied it rapidly led to increases in crop yields, which were welcomed in some countries which had food shortages, such as India, Vietnam, and Mexico.

While it has been lauded by its proponents as the revolution which alleviated poverty and starvation, increased incomes, and reduced juvenile mortality, the long-term impacts of the revolution are now being counted.

Some of the negative impacts from the Green Revolution include global declines in biodiversity, soil and water quality, high levels of food waste, patents on staple crops, financial debt for farmers and a move away from staples to cash cropping which is leading to food insecurity in some countries.

Close breakout box

During this Vietnam wartime a vast area of wetland in the Mekong Delta was lost due to the use of chemical herbicide defoliants [48-50]. Between 1962 and 1971, U.S. military forces sprayed nearly 75.8 million liters of herbicides, over approximately 1.46 million hectares in South Vietnam. The preparation known as ‘Agent Orange’ accounted for around 40 million liters of the total amount sprayed. It contained equal parts of the herbicides 2,4 D and 2,4,5 T, the latter of which was contaminated with dioxin 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD). The exposure to TCDD led to harmful health effects in an estimated 3 million Vietnamese people [51-53]. In the Mekong Delta, the first major US defoliation operation to clear Vietnamese army infiltration routes was carried out over the mangrove forests in the Ca Mau Peninsula in September 1962 [54]. Up to 1968, the Ca Mau Peninsula was almost entirely covered with dense mangrove forests which were more significantly affected by herbicide spraying than any other vegetation type in South Vietnam because a single exposure to spray can kill mangrove trees. After heavily spraying in 1967 and 1968, nearly half of the mangrove trees of the peninsula had been destroyed [55].

4.3. *Ecological landscape changes during the 1975-post war context*

Implementation of post-war agricultural development policies was one major driver of wetland degradation in the Mekong Delta as the further development of an extensive network of irrigation canals, resulted in the conversion of large parts of the delta to agricultural land [49, 56]. The introduction of high-yielding varieties led to a significant decline in traditionally floating rice cultivation area. From 1976 - 1980, nearly 400,000 hectares of traditional deep-water rice system in the Long Xuyen Quadrangle and Plain of Reeds were converted to double modern rice system with HYV [36].

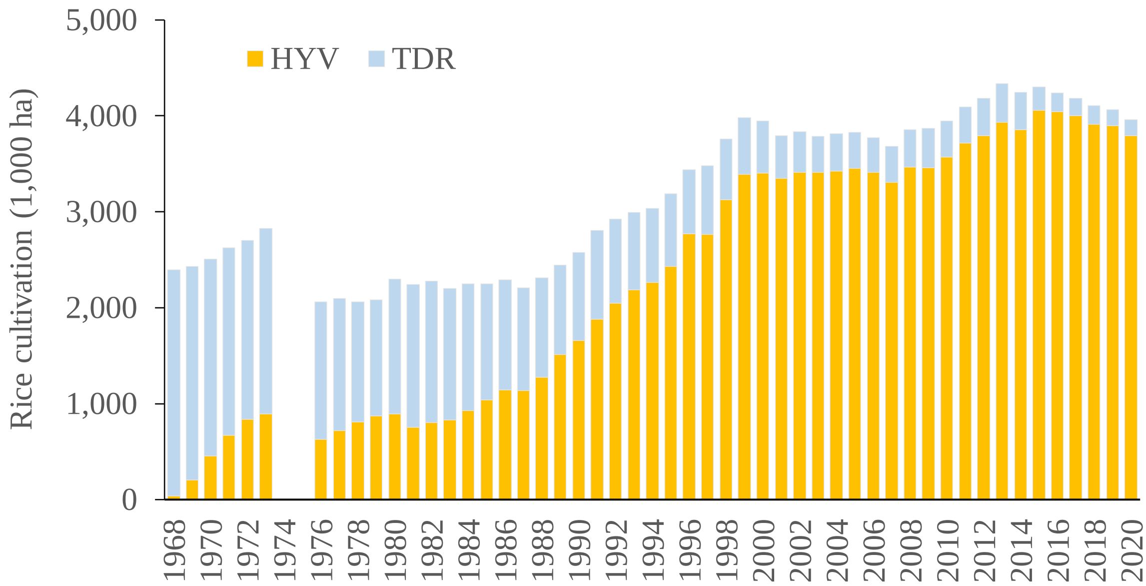


Figure 9: The transformation of rice cultivation in the Mekong Delta from 1968 to 2020. Source: GSO from 1995 to 2020, Vo Tong Xuan (1975) and Nguyen Tri Khiem (2002).

It is said by old farmers that the floating rice cultivation requires no pesticides, and a very small amount of chemical fertiliser would suffice as soil fertility is naturally maintained through the deposition of rice stalks as floods recede[2] (Figure 10, Figure 11). The floating rice fields also provided an important habitat for different kinds of fish. During flooding season, rice farmers could harvest wild fish inside the flooded fields to earn additional income. In contrast, the modern rice system offered advantages in shortening crop cycles such that several crops a year could be grown, however they are heavily reliant upon chemical fertilisers and pesticides. The significant decline of wild fish catches in the fields coincided with the disappearance of their natural habitats in the floating rice system. This resulted in the loss of an income source for farmers.

Figure 10: Remaining floating rice area in Long Xuyen Quadrangle in 2015. Source: Le Thanh Phong

Figure 11: Farmer caught natural fish in the ditch after harvesting floating rice. Source: Le Thanh Phong

[2] Huynh Van Khau, 2014, rice farmers in Cay Gon village, Vinh Phuoc commune, Tri Ton district, An Giang province.

In the same period, new economic zones "*Vung kinh te moi*" were set up by the Vietnamese government in most parts of the Mekong Delta to promote intensive rice production that led to destruction of thousands of hectares of grasslands, wetland *melaleuca* and mangrove forest [36]. For instance, during the 1980's, 700,000 hectares of *melaleuca* forest in the Plain of Reeds were converted to rice fields, and from 1983 to 1995, 50,000 ha which represented half of the mangrove forest area in the coastal zone was converted to shrimp farms [57].

Another concern was that despite substantial modification in the hydraulic regime since 1930, much of the land in the Mekong Delta still suffers from acidification and salt intrusion until this time. When soil with high organic content was exposed to air through such activities as intensively dredging canals, the oxidation of the soil created sulphuric acid. Water runoff leaches this acid from the soil and consequentially lowers the pH of the water to levels that can be unsuitable for rice and harm fish. Intensive flushing of soils with fresh water reduces acidity, but within the Long Xuyen Quadrangle, which is less than one metre above sea-level, such flushing was difficult to control. Water currents in creeks and canals frequently reversed and inadvertently swamped a field instead of draining it [43]. Despite these issues, the percentage of the Mekong Delta which was able to be irrigated rose from 52% in 1990 to 91% by 2002 [58]. The Delta now has over 10,000 km of canals and 20,000 km of dykes, profoundly altering the hydrology and wetland-agricultural ecosystems of the region. About 90% of the cropland is now irrigated [59].

4.4. *The current environmental change in the Mekong Delta*

The increased scale of aquaculture and agriculture production has generated income for local people to improve their lifestyles and reduce poverty, although many crop inputs are supported by taking on debt which is paid off at crop harvest [60]. Synthetic fertiliser application rates in the Mekong Delta are significantly higher than in other parts of the basin. However, such intensification of production brings with it cumulative negative environmental impacts, which can impact the productivity of wild shrimp, fish and other aquatic creatures which are dependent upon a healthy environment [20, 57, 61].

Management of diseases and water quality in aquaculture and rice-fish ponds has given rise to the addition of numerous chemicals to paddies/ponds including: antibiotics like quinolones such as enrofloxacin and ciprofloxacin, cephalosporins; potentiated sulphonimides; tetracycline; disinfectants; and pesticides such as trifluralin, quinalphos and dichlorvos [62]. With the expansion and intensification of aquaculture the volume of feed applied has grown leading to the generation of more nutrient rich organic waste and release of increased suspended solids. Such discharges lead to increases in turbidity in receiving waters in addition to driving oxygen depletion and nutrient loading (eutrophication) [8, 9, 63]. It is anticipated that these pollutants are seriously impacting, directly and indirectly, on wild fisheries and ecosystem function throughout the whole Mekong Delta region.

The Mekong River Commission still considered water quality to be good to very good in the Lower Mekong Basin tributaries and mainstem river in the 2000's, however in the last decade it has clearly deteriorated, with flow alteration, diffuse source wastewater, deforestation, intensive agriculture, plastic pollution, domestic waste and urbanization impacting biodiversity and aquatic ecosystem services [64].

Environmental water quality is very important for aquatic life and ecological systems and is a key factor affecting the health of the Mekong Delta and associated wetlands. Water quality to date, has not restricted agricultural use except in the Mekong Delta where high levels of salinity hinder agriculture. However, in some areas elevated chemical oxygen demand, phosphate and ammonium and potassium levels exceed World Health Organization and Vietnamese standards for drinking water due to untreated discharge from intensive rice agriculture and from urban wastewater [65].

In Vietnam, insecticides form the bulk of pesticides applied to rice. Insecticides are more controlled by government agencies compared to other pesticides due to the perception of their greater human toxicity risks. There are significant data gaps in spatial coverage, frequency and range of pesticide residues in surface water and aquatic sediments in the Mekong Delta [66]. Mekong River Commission sampling failed to identify any residues from its limited sampling program which focused predominantly on older generation organochlorine and organophosphate pesticides [12]. Other research has found elevated mixtures of pesticides and PCB contamination in the surface water, sediments and shellfish of the Mekong Delta. The pesticide sources have been attributed to both agricultural and household use. The levels of some pesticides such as diazinon, DDT, hexacyclochlorohexane, lindane and endosulfan are above the effect levels and often present as complex mixtures that are expected to adversely impact the health of aquatic ecosystems. The PCBs appear to be from industrial uses, old electric transformers and contamination from oils in automotive and marine uses [66-68].

The degraded water quality has already contributed to massive outbreaks of shrimp disease and toxic algal blooms [8, 9, 63, 69, 70]. Agriculture and aquaculture in the Mekong Delta are facing an increasing number of pressures including global warming, salinity level fluctuation due to climate change, demands from retailers and buyers, high investment costs, disease outbreaks, market downturn, high-quality competition, and international standard certification [71, 72].

Under the Government development scenarios, pollutant loads would be expected to increase in response to the expansion and intensification of irrigated agriculture and settlement, producing expanding pesticide and nutrient waste streams. Current fertiliser application rates in the Mekong Delta are significantly higher than in other parts of the basin [12]. Discharge of untreated domestic, agriculture and aquaculture industrial wastes are likely to be further raising nutrient and pollutant concentrations and increasing biological and chemical oxygen demand in receiving waterways.

5. Critical changes in land-use types of the Mekong Delta after the *Doi Moi* renovation policy

In 1986 the Vietnamese government decided to implement a wide-ranging economic liberalization policy, known as *Doi Moi* which recognised free market exchange and the key role of the family-based agricultural economy [73]. With the re-orientation of rice production for export, the imports of mineral fertilisers and pesticides increased dramatically. From 1985 to 1995, mineral fertilisers imports grew by more than 260% from 350,000 to 1,264,000 tonnes. Under this new kind of farming environment, farmers' access to inputs became easier and they immediately used their newly recovered investment capacity to intensify their rice-based production systems and to increase paddy yields [74].

The *Doi Moi* policy has led to a significant ecological change in the Mekong Delta. Large parts of the natural landscape have been converted to agricultural land, aquaculture facilities, and urban environments [75, 76]. Though these significant changes to the delta have brought some groups economic gains, they have also been associated with environmental costs, including the deterioration of water quality because of discharges of untreated urban and industrial wastewater, pollution from agriculture and aquaculture [77-79], changes to the river's sediment regime, which has led to adverse impacts on the overall function and productivity of wetland ecosystems [80].

5.1. *Land-use types change in the Mekong Delta*

Rice cultivation has been the dominant land use type in the delta since post-Vietnam war, and still occupies over 50% of the area [81, 82]. The area of land used for aquaculture and fruit trees increased rapidly while the area of mangroves and uncultivated land decreased. Rice land showed the greatest change.

Many wetlands and acid sulfate soil areas were exploited to produce rice. However, the area under rice cultivation has tended to decrease continuously since 2000 (the average decrease is about 30,000 ha/year in the 2001–2010 period and 14,000 hectare/year in the 2010-2014 period) [83, 84]. This was due to the conversion of rice fields to aquaculture, fruit trees, and other annual crops [85].

This was also due to increased salinity incursion due to climate change driven drought, reduced sediment downstream movement due to dams, upstream dams reducing total flow and reducing peak flow, so that Tonle sap wasn't filling, and then subsequently wasn't sustaining the freshwater persistence of flow which had historically held back saltwater ingress [86]. Increased groundwater extraction for agricultural and other uses is also contributing to subsidence in the delta. The impact of this groundwater over-extraction is reported to be an order of magnitude greater than the effect of the oceanic warming to cause thermosteric sea level rise [87].

Aquaculture became the second-largest land-use type in the Mekong Delta behind rice from 1995, accounting for 13% of the area in 2015 (Figure 11) [88]. Aquaculture began to develop in coastal areas from the 1980s and expanded rapidly from coastal to inland areas. It covered approximately 513,000 hectares in 2015, with the average growth rate of aquaculture reached 20,000ha/year between 1976 and 2015 [81]. The increase in aquaculture area is due to the conversion from rice land, mangrove forests or exploitation from alluvial land, riverside, and nearshore coastal water surface [84].

The planting land has been the dominant land use type in the delta since 1979, and still occupied over 72% of the delta area in 2015. The change to aquaculture is most pronounced in all land use change (LUC) categories, with its percentage of area in the delta increasing to 19% in 2015. With the transformation of large-scale inland planting land into aquaculture ponds, aquaculture has become the second largest land use type following the planting land in the Mekong Delta from the late 20th century. Mangroves generally experienced a significant decrease before 1995, followed by a rise. The total area decreased slightly from 1979 to 2015, but the degree of patch fragmentation increased significantly.

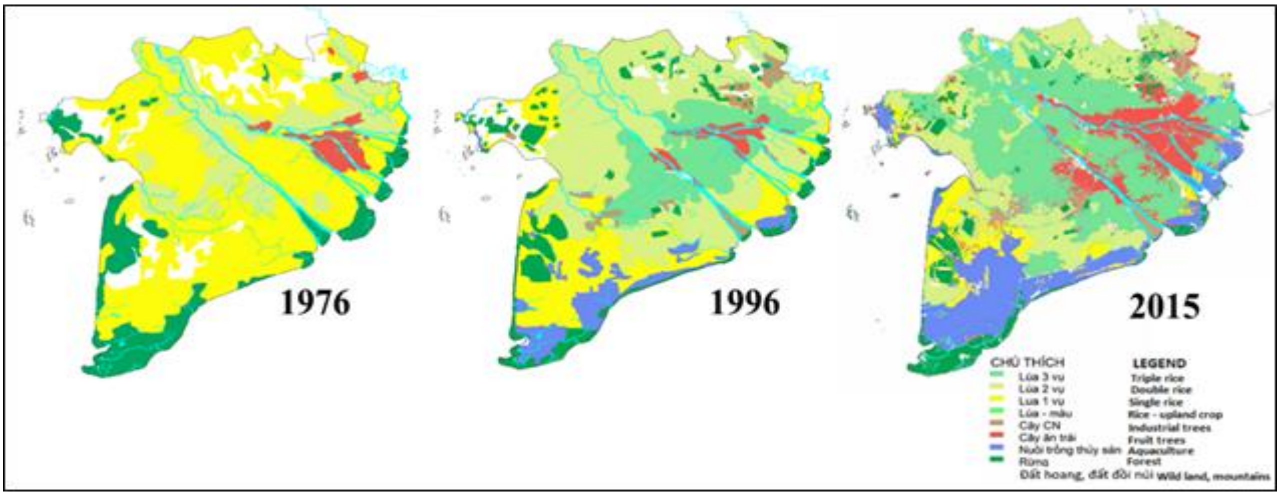


Figure 12: Land use changes in the Mekong Delta in 1976, 1996 and 2015. Source: Loan and Nguyen [89].

Since 1995 more than 190 industrial zones have been established within the Mekong Delta, with more planned for development. Industrial zone activities in the Mekong Delta include shoes and textiles, petrochemical and pharmaceutical products, processed seafood and agricultural products, beer, boiled and pounded steel and cattle feed production [90]. Few had wastewater treatment plants installed when first constructed with discharge of effluent directly to the river reportedly commonplace. While regulatory inspections and at times fines were issued by Government regulators for non-compliance to pollution regulation, this has not necessarily resulted in a change to achieve compliance or eliminate industrial pollution of the Mekong River [90].

5.2. *Recent changes in human intervention of flood prevention in the Mekong Delta*

Figure 13: High dyke systems for additional rice production during flood season in An Giang province. Source: Tran Xuan Long

Since the early 2000s new flood control measures such as high dyke systems have been constructed starting in An Giang province, before spreading more widely into the Mekong Delta [40]. The aim is to reduce the flood inundated areas to extend rice cultivation areas and to allow a third annual HYV rice crop., This development initiative has included a strong belief in human mastery over nature and the waters of the Mekong Delta. These developments have supported economic and agricultural productivity but have underestimated the complexity and integrated nature of the ecology and livelihoods of thousands of inhabitants in the Mekong Delta [91]. An unintended consequence appears to be negative impacts on wild fisheries catches [92, 93] that are a critically important food sources especially for the poor [35].

Most of the sharp increase in rice production from the year 2000 to 2020 was produced in the additional rice crops inside the high dyke systems (Figure 12). This launched Vietnam as the world’s second largest rice exporter with over 90% of exported rice produced in the Mekong Delta [6].

The HYV area reached 90% by 2010 and 97.5% in 2020 spanning 3,794,400 (ha). Meanwhile, Traditional Rice farming areas decreased markedly to just 169,300 (ha) in 2020.

6. The history and present fisheries of the Mekong Delta

Until about 5000 years ago, the Lower Mekong Basin was inhabited by small groups of hunter gatherers who ate many kinds of wild foods, including fish, crustaceans, and molluscs [94].

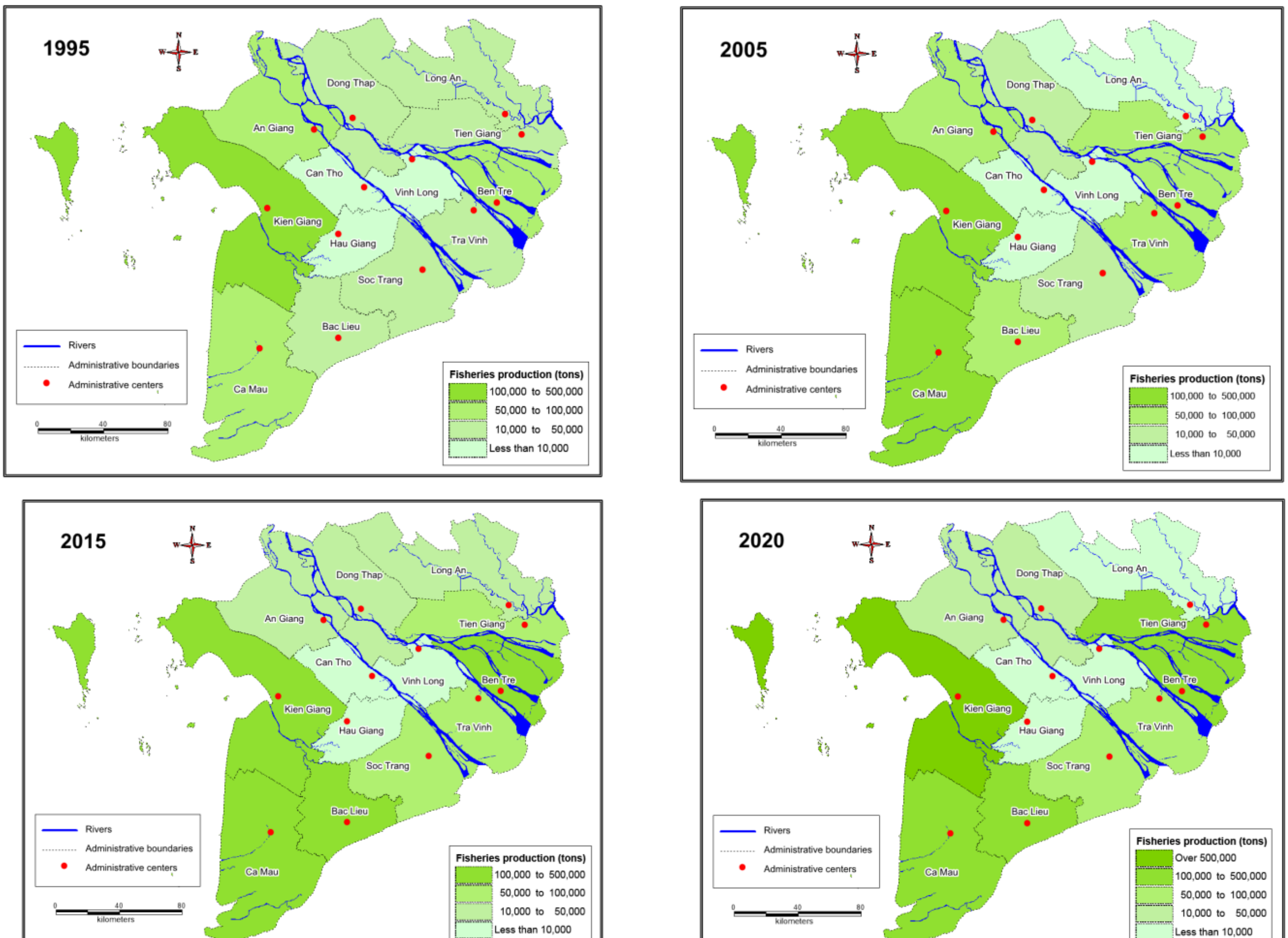


Figure 14: Fisheries production changes in the Mekong Delta in 1995, 2005, 2015 and 2020 (includes catches from sea and catches from naturally produced seafood from rivers, streams, lakes, lagoons, or rice fields, etc). Data Source: GSO from 1995 to 2020

The Lower Mekong Basin (LMB) supports one of the largest, most rapidly expanding and economically dynamic human populations across the globe. After the Amazon and Congo river basins, it is one of the world's most productive and biodiverse ecosystems [93, 95, 96], and one of the world's major freshwater aquatic ecosystems providing significant seafood resources to Vietnam and surrounding countries [97, 98]. There are approximately 800–850 freshwater fishes in this region [99, 100]. When marine and estuarine migratory fish are added to this, the LMB supports an incredible diversity of 1,148 fish species [101]. Total fish catch estimated at 2.3 million tonnes per annum with around 80% coming from freshwater.

The inland wild catch fisheries production are considered an important source of local food security and nutrition, income, and livelihoods for about 40–50 million residents, particularly the rural poor and ethnic groups of farmers and fishers who live near or along natural rivers, streams or seasonally flooded areas in villages and communes of Lao, Cambodia and the Mekong Delta of Vietnam [92, 102].

Although the total area of the Mekong Delta only accounts for approximately 12% of Vietnam's territory, it produces more 60% of inland fisheries production and contributes about one-third of the total fisheries yield of the Lower Mekong Basin [7].

The total fishery catches in all provinces (freshwater and marine) of the Mekong Delta have nearly doubled from 1995 to 2013 to reach more than one million tonnes in 2013, due to substantial increases in marine fishing effort and gear [103]. The direct impacts of local population growth have included increasing catches (overfishing) for local consumption, competition for surface and groundwater by other industries, particularly agriculture, modification of hydrology and water quality by dams, and clearing of forests [104].

Over the last three decades in particular, this delta region has undergone a huge aquaculture expansion of fish and shrimp, employing many people, who no longer need to go fishing. Various other industries have also expanded to offer employment since the 1990s, so a decrease in fisheries participation rates is considered likely [93, 105]. During 2006 to 2016, over 300,000 fishery employees left their jobs, the majority of whom are from remote areas of the Mekong Delta.

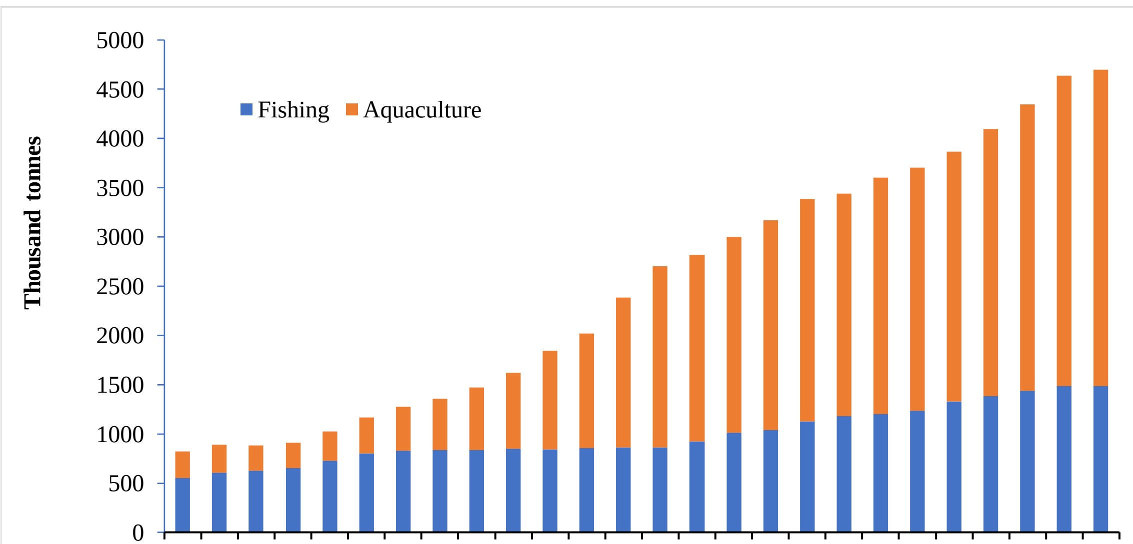


Figure 15: Aquatic production in the Mekong Delta 1995-2020 (includes Fisheries and Aquaculture production in freshwater and adjacent marine fisheries). Source: GSO from 1995 to 2020.

In 1995-2001, the fishery catch from the inland (freshwater-only) provinces (An Giang, Dong Thap, Can Tho, Vinh Long, Long An) of the Mekong Delta increased but the upward trend has been reversed since 2001. In contrast, coastal localities in the Mekong Delta, namely Tra Vinh, Tien Giang, Ben Tre, Kien Giang, Soc Trang, Bac Lieu and Ca Mau provinces all enjoyed positive growth in brackish water fish caught in the 1995–2020 period [106]. Fisheries and aquatic production changes in the Mekong Delta in 1995, 2005, 2015 and 2020 are presented in Figure 14 and

Figure *15*.

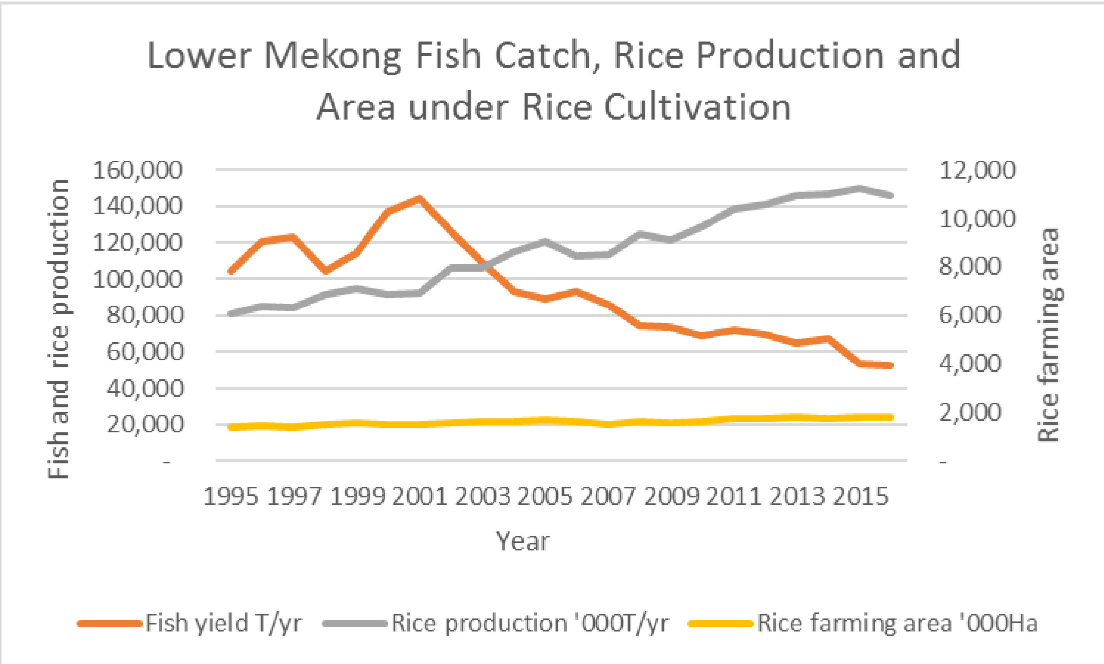


Figure 16: Trends in annual freshwater fish catch, rice production and hectares under cultivation (inland provinces only). Source: K. Hortle

The inverse relationship observed in Figure 16 above between annual fish yield and rice farming area and production tonnage are potentially due to the change in land-use leading to exclusion of fish access, but also importantly changes in volumes and area of pesticides and fertilisers use which could harm aquatic productivity [107].

The height of floods also appears to be inversely correlated to fishery productivity, although from 2003 onwards this explanation alone appears to be insufficient to explain the extent of declines [107]. During years of lower flows and lower flood heights there is likely to be less dilution of the cocktail of pollutants present in the river, which may compound the effect of low flows on fishery productivity further.

Numerus factors are contributing to the decline in freshwater fish catches in Vietnam's Mekong Delta including the impact of exotic species, weak enforcement of fishing and pollution laws, hydropower, catching , catching more fish upstream, habitat loss, flooding regimes, agriculture, pollution, use of illegal fishing equipment and too many fishers [107]. Long-term datasets (1995–2016) of the Mekong Delta showed a general decline in commercial fish catches, which are positively correlated with peak water levels (which indicate flood levels), and negatively correlated with land-use/landscape changes and the intensive of three annual rice crops farming with high dyke protection, especially where flooding has been prevented to facilitate a third annual rice crop [93].

With future proposed dam construction it is estimated that about 550,000 to 880,000 tonnes of wild fish catch and over 103 migratory fish species (including five threatened species) will be lost. Approximately 52–84% of the sediments/nutrients will also be trapped and prevented from reaching the Mekong Delta by the 11 hydropower dams planned on the Mekong River mainstream and 77 other dams in the Mekong Basin as a whole [3, 18, 108].

The mainstream dams on the Mekong River will change the ecosystems of the river and place highly valued fish and commercial fish species, such as the Giant catfish (Pangasianodon gigas), at risk of extinction. Dams obstruct the spawning and refuge migrations of the cyprinids group, such as Cyclocheilichthys enoplos, Cirrhinus microlepis and the many river catfishes of the family Pangasiidae and the survival rates of populations of these so-called whitefish will also be diminished as they can perish when passing through dam turbines and other structures. Many previous studies report that yields of inland fish (mainly whitefish) are predicted to decline in Vietnam and neighboring Cambodia by some 40 to 60 % in the foreseeable future [3, 20, 104, 109]. In addition to the proposed mainstream dam's impacts on fish migration, significant damage to agriculture, aquaculture and other aquatic production are anticipated.

A study based on interviews of 1,020 fishers in the Mekong Delta indicated around 90% reported that their catch volumes had declined over the previous five years [93].

A significant reduction in fish biodiversity and productivity along the length of the whole Mekong River, beyond Vietnam, has been identified by Valbo-Jørgensen, Coates [110], Nakano, Yahara [111], Baran [112], Coates, Poeu [113]. Similar causes to fishery decline are implicated. It is also reported that 40 important fish species in the LMB of which 7 species are endemic and 3 further species are endangered to the point of extinction. *Tenualasa thibaudeaui, Cirrhinus lobatus, Hampala dispar, Pangasianodon gigas, Puntioplitas falcifer, Probarbus jullieni* and *Aaptosyax gypus* are important endemic species requiring protection. The authors also warned of the likely disappearance of 3 species including Laotian shad (*Tenualasa thibaudeaui*), Isok barb (*Probarbus jullieni*) and Giant catfish (*Pangasianodon gigas*) [114]

It has been predicted that there will be a 20% increase in fish demand in the Lower Mekong Basin over the next 10 years. To mitigate the decline in biodiversity will require coordination and integration of management interventions at all levels in the future. The current analyses suggest there is no indication that future increases in fishing effort will lead to decreased catches or reduced diversity for the non-migratory fish species [115].

However, there are major threats to sustaining wild capture fisheries which include [115]:

- Destruction of spawning grounds or dry season refuges by habitat alterations
- Local changes in the quantity and quality of water available for sensitive habitats and the timing of hydrological events,
- Pollution from agriculture and aquaculture and urban development.
- Construction of dams, weirs or diversions which act as physical barriers to fish migrations.
- Increased sediment load due to deforestation.

7. Water quality monitoring in the Mekong Delta

7.1. *Sediments*

The Mekong River Commission (MRC) and Vietnam National Center for Hydrometeorological Forecasting (VNCHF) have analyzed sediment monitoring stations in China, Thailand, Laos and 11 sites along the Tien and Hau rivers in Vietnam from 1961–2015 [116]. The data shows that suspended sediment load in all stations in the lower Mekong River was reduced significantly by 74.1% (123.6Mt/yr) due to sediment trapping mostly in the six mainstream Lancang cascade dams and other upstream hydropower dams. This loss of normal sediment flow down the river meant a sediment deficit was created in the Tien River in the Mekong Delta of -0.5 m per year in 2014–2017. This meant more sediment was being removed from the Mekong Delta than was being deposited. Sand mining was responsible for a maximum of 14.8% of the annual riverbed removal in the Mekong Delta. Methodologies, key findings and study gaps of the related research works are summarised in Appendix 2. Study areas, employed sediment data, methodologies, key findings and shortcomings of sediment monitoring programs in Mekong Delta of Vietnam

The reduction in sediment flow is contributing to the sinking and shrinking of the Mekong Delta altering aquatic habitat and hydrology [87].

7.2. *Nutrients*

Assessment of water quality recorded by the MRC from 2003 to 2005 revealed that total discharge of about 288,231 tonnes per year of total-N (with N discharge rate of ca. 3.63 kg/ha/yr) and 55,475 tonnes of total-P (with P discharge rate of ca. 0.7 kg/ha/yr) in My Thuan (Mekong River) and Can Tho (Bassac River) [117]. 40% of the nutrient discharge comes from agriculture sector [12].

Available information suggests that the major contribution of nutrient discharge from the agriculture sector is likely from the significant increase in the use of fertilisers, rather than just the enlarged areas of cultivation [118]. Fertiliser consumption in Vietnam more than tripled between 1989 (563,000 tonnes per year) and 1999 (1,934,600 tonnes per year) (MRC Report 2008) and grew more than ten-fold up to 2006 (10.8 million tonnes per year), with high levels of use continuing to 2020 (9.7 million tonnes per year) [119]. Annual fertiliser consumption in the Mekong Delta provinces accounts for nearly half of that of the entire country [120]. Little is known about losses of nutrients from agriculture in tropical climates and none about such losses in the Vietnamese Mekong Delta. The composition of fertilisers used in the Vietnamese Mekong Delta is also not known, but it is likely in the order of 10 to 46% N and 5 to 16% P. Using conservative values for losses of 20% N and 10% P which have been enumerated from paddy rice fields in South Korea [118], and an average fertiliser composition of 30% N and 10% P, the estimated loss of N and P from rice production in VMD between 2006 and 2020 would be 1 x 10^5 to 6 x 10^5 tonnes per year.

There is a considerable and direct discharge of nutrient-rich wastes from animal husbandry and cultured fish/shrimp farming into surface waters in the Mekong Delta. These add to the potential run-off of N and P from fertilisers used in rice farming in the Mekong Delta [121]. Estimation of N and P in effluent from the striped catfish (*Pangasianodon hypophthalmus*) farming sector during the period 2007-2008 in the Mekong Delta [121] and from integrated fish and orchard farming sector [122] show that, only 5–6% of total N, organic C or P inputs introduced into ponds were recovered in the harvested fishes. About 29% N, 81% organic C and 51% P accumulated in the sediments. The remaining fractions were lost through pond water discharges into adjacent canals. Production of 1 tonne of frozen *Pangasius* fillets in the Mekong DeltaAnh, Kroeze [123] releases 740 kg biological oxygen demand (BOD), 1020 kg chemical oxygen demand (COD), 2050 kg total suspended sediment (TSS), 106 kg nitrogen (N) and 27 kg phosphorus (P), of which wastewater from fish ponds contributes 60-90% and sludge from fish ponds and wastewater from processing facilities contributes 3-27% of the total emissions [145].

Wild fish diversity in areas of Can Gio District is significantly lower where most intensive aquaculture farms are located and more farming waste is discharged to the water bodies [124]. The rapid industrialization and urbanization have not been matched with development of sufficient wastewater treatment. Development in megacities contributes to high levels of organic and nutrient pollution via releasing untreated domestic discharges and industrial wastewaters released without appropriate treatment into the receiving aquatic environments. Study of spatial and seasonal variability of nutrient concentrations and eutrophication indicators (organic carbon, Chlorophyll-*a* and dissolved oxygen) in Saigon and Dong Nai Rivers during two hydrological cycles from July 2015 to December 2017 revealed that phytoplankton reached its highest value at 110 mg Chl-*a*/L during dry season and the rivers were deoxygenated (DO < 2 mg/L) during wet season [125].

Due to the increase of N and P nutrients together with the decrease of suspended solids in the water bodies, the Vietnam Mekong Delta with large systems such as the Mekong River, Dong Nai River, Tri An reservoir, Dau Tieng reservoir, Bung Binh Thieng reservoir and numerous smaller canals, streams and aquaculture ponds are now experiencing seriously harmful algal blooms. Strong blooms were observed in discharge water of Mekong river throughout the year [126]. Indicative of such blooms, high concentrations of Chlorophyll-*a* (> 4 mg/m^3) at near-shore water (within 30-40 km from the coast), and especially high (> 5 mg/m^3) during rainy seasons occur. High concentration of dissolved cyanotoxins (e.g. microcystin) from cyanobacterial blooms have been found in small water bodies and canals in the vicinity of urban settlements throughout the Mekong Delta [127]. Methodologies, key findings and study gaps of these research works are summarised in Appendix 3. Study areas, employed nutrient discharge data from cultured fish farms and integrated orchard-fish farms in VMD, methodologies, key findings and shortcomings

7.3. *Industrial pollution*

In the Mekong River Delta, there are approximately 190 industrial zones. Only 7% of industrial zones in Mekong Delta have installed sewage treatment plants and only 15% have solid waste handling systems in place [128], with an estimated 27% of total wastewater volume treated [129]. Therefore, industrial wastewater contamination appears almost everywhere. The discharges can have significant impacts to the region's rice and fisheries production. For example, up to 13,458 m^3/day of wastewater was discharged untreated from operations in Tra Noc Industrial Zone (Can Tho Province) to Sang Trang Canal, Cai Chom Canal and the Hau River (Vietnam Environmental Agency of the Ministry of Natural Resources and Environment, 2010).

The regular discharge of high-volume wastewater flows exceeding TSS, COD and NH_3-N standards by 10-fold into the neighboring water bodies caused the local farmers to suffer reduced crop yields, contamination of drinking water and increased incidence of human diseases and deaths [130]. Dam Doi District, Ca Mau Province had experienced unusual, massive fish deaths due to excessive levels of ammonia, which was attributed to untreated wastewater from seafood processing factories in Hoa Trung Industrial Zone and industrial parks in Ca Mau City. An incident occurred in June 2017, where locals reported a massive number of dead fish in branches of the Ganh Hao, Muong Dieu and Bay Hap rivers [106].

The barriers to effective regulation of industrial wastewater include an ineffective regulatory framework due to gaps and overlaps, poor understanding of environmental regulations by the industrial producers, use of pollution intensive production technologies, the limited capacity and financial resources of local enforcement agencies, the lack of financial resources of the industrial producers for constructing wastewater treatment plants and adopting pollution-minimising technologies, and low fines for violations [128].

Due to a lack of wastewater treatment systems, wastewater enters the canals and river untreated such that chemical and microbiological contamination is high, and surface and groundwater pollution are major environmental problems [131, 132]. There is no detailed study on how these industrial activities will affect water volume and quality Delta-wide. The flat landscape of the Mekong Delta, annual flooding and a lack of investment pose significant design and operation challenges to achieve effective wastewater management. Low cost options such as constructed wetlands may offer the best opportunities [129]. Where adequate control of pollutants cannot be achieved, a focus will need to shift to prevention at the point of manufacture and use, rather than end-of-pipe capture solutions. This will be required for PBDEs as Asia has not stopped production. High emissions of PBDEs from e-waste recycling sites are demonstrated to be accumulating in fish in ponds below facilities [194]. It is also expected to be necessary to address PFAS and other persistent chemicals at the point of manufacture.

7.4. *Agricultural chemicals (pesticides)*

Public concern in Vietnam over pesticide pollution of the environment and drinking water resources is increasing. In Vietnam, both the variety and quantity of pesticides applied increased rapidly from the end of the 1980s (20,300 tonnes) to 2010s (72,560 tonnes) [133]. Rice farmers applied on average 0.3 kg of pesticide active ingredients per hectare per year (ai/ha/year) during 1981-1986. This increased to 2.54 kg ai/ha/year through 2001-2017 [134].

In 2021, highly hazardous pesticides (HHPs) approved for use in Vietnam represent 5.7% of the 104 active ingredients in use [135]. Due to a desire for faster responses, around 60 to

80% of farmers overdosed their pesticide applications by up to five times higher than recommended application rates [136]. Around 60-70% of households in the major rice growing areas owned spray applicators [137]. Recent comprehensive monitoring of pesticides in different water sources used for drinking (surface water, groundwater, water at public pumping stations, surface water chemically treated at household level, harvested rainwater, and bottled water) has been done in rural areas of An Giang Provinces and Can Tho City [136]. The results show that despite the local differences in the amount and frequency of pesticides applied, pesticide pollution was ubiquitous (Appendix 4. Study areas, employed pesticides data from intensive paddy rice cultivation and orchard farms with key findings. WHO Class II (moderately hazardous pesticides) including the fungicides isoprothiolane and propiconazole, the insecticides fenobucarb and fipronil were found in almost all water samples exceeding national quality standard threshold levels for drinking, irrigation and domestic purposes.

High persistence in water and long transport distance pesticides including quinalphos and tebuconazole (long hydrolysis half-lives), thiamethoxam (high stability in water), and butachlor (low soil sorption) were detected in canal water. Considering ecosystem health, propiconazole, fipronil, fenoxaprop-p-ethyl, cypermethrin, and tebuconazole are listed in US EPA's "Aquatic life benchmarks" (US EPA, last update 2021). In 2018, an evaluation of direct toxicological effects of pesticides on aquatic organisms living in the rice fields was performed using screening model tool Pesticide Risks in the Tropics to Man, Environment and Trade (PRIMET) in combination with species sensitivity distribution (SSD) model with a focus on fish [138]. According to the reported exposure toxicity ratio (ETR), all the above-mentioned fungicides, insecticides and pesticides detected in different water sources in rural areas of An Giang and Can Tho are classified as "possible risk" and "definite risk" in acute- and chronic-toxicity. Fipronil was considered to cause acute- and chronic toxicity to fish and invertebrates, exceeded 50.3 % of guideline value in 83% of the studied samples [155].

Pesticides were applied generally 3 times per crop in both integrated rice–fish farming systems (2 rice crops and 1 fish crop per year) and three rice crop farming. Pymetrozine, fenobucarb, quinalphos, trifluralin and dichlorvos are reported to be commonly used commercial pesticides in these rice-fish farms in the Mekong Delta. About 9% of the total water samples analyzed contained residues of quinalphos from rice-fish systems [139].

Another study detected quinalphos and trifluralin in water and in farmed and wild fish tissue [140] in addition to antibiotics in association with the intensification of aquaculture enterprises, such as catfish, tilapia and shrimp culture.

Quinalphos, like other organophosphate pesticides, is a neurotoxin and inhibits the neurotransmitter breakdown enzyme, acetyl cholinesterase (AChE). There is evidence of quinalphos decreasing AChE activity in brain, muscle, gill and liver of freshwater fishes, e.g. carp (*Cyprinus carpio*) [141], and affecting testicular function of air-breathing catfish (*Clarias batrachus*) [142].

In 2012, Vietnam's costs for imported pesticides were roughly equal to its revenue from fruit and vegetable exports [143]. So, while underpinning expanded volumes of production and expanded economic growth, this has not always translated into wider direct economic benefits. The food security benefits that are often touted as a justification for expanded intensive pesticide-dependent agriculture, fail to consider the externality costs on human and environmental health which are mounting.

7.5. *Pharmaceuticals and personal care products*

Between 2008 and 2018, Vietnam was the highest user of antibiotics (39 out of the 67 antibiotic compounds reviewed) and in the top 15 antibiotic pharmaceutical using countries in the world [144]. All antibiotics used for livestock and aquaculture in Vietnam are imported as raw materials and finished products. According to Department of Animal Health, approximately 2,000 tonnes of raw antimicrobials was imported each year. Up to January 2019, there were 13,000 veterinary medicine products licensed for used in Vietnam, of which the majority were antimicrobial products, leading to increased antimicrobial resistance (AMR) in the region [145]. Buying and selling antibiotics without prescription was identified as a major factor for high level of antibiotic use contributing to the increased AMR in Vietnam [146].

Intensive fish farming systems (*Pangasius* catfish and tilapia species) have also been reported to use 7 types of antibiotics and many different types of disinfectants. Enrofloxacin, sulfamethoxazole and trimethoprim were reported to be the most used antibiotics to treat bacterial diseases in catfish [139].

Starting from January 2018, 24 chemicals and antibiotics, including Enrofloxacin and Ciprofloxacin were prohibited to add in animal feed for growth stimulation[3] .

Following the prohibition of specific uses of antibiotics, no study has explored compliance with the law [147, 148]. Despite the widespread use of antibiotics in aquaculture and livestock production, limited data are available on concentrations of antibiotics residues occurring in environment, livestock, aquatic and terrestrial animal tissues, animal products, wastewater and soil in Vietnam [149].

Antibiotics promote the development of anti-microbial resistance in exposed bacteria. This can make treatment and control of bacterial diseases in farmed fish and shrimp more difficult and create food safety risks from residues in seafood [150, 151]. The impacts on wild fish and aquatic ecosystems are not well researched. It is expected that these compounds will act as a xenobiotic stressor. Effects on the gut biome may also have consequences for exposed organisms.

There appears to be very limited measurement data of PCPP apart from antibiotics residues for Vietnam. Data from other Asian countries [152] suggests that there are signs of significant contamination from PCPP in the Mekong Delta Basin. Appendix 5. Study areas, employed antibiotics data from fish and shrimp farms in Vietnam with key findingssummarises key findings in short-term monitoring antibiotic usage and antibiotic residues in aquatic products in Vietnam urban and rural areas.

In 2019 within the area of the Mekong Delta around 52% of households are connected to sewers, mostly within urban areas. Households in rural areas tend to discharge directly into irrigation canals. There were only 8 wastewater treatment plants meeting the treatment demand, with five of these still under construction, hence capacity was only at 6.9% of the demand level. Around 58% of the 103 district hospitals have wastewater treatment systems [129]. This leaves considerable scope for medical waste to be released to waterways without treatment.

[3] Circular No. 06/2016 / TT-BNNPTNT dated May 31, 2016

7.6. *Plastic and Microplastics*

Vietnam is ranked seventh of the top country generators of plastic waste in the world, with over 1.8 Mt/year. In 2018, production output of the plastic industry increased by 7%, reaching 8.3 million tonnes, of which packaging plastic production accounted for the largest proportion (Ministry of Natural Resources and Environment, 2019). The per capita consumption and use of plastic in Vietnam increased rapidly from 1990-2018, from 3.8kg to 41.3 kg/person [28]. This trend is consistent with the proportion of plastic in domestic solid waste which increased from 5.5% in 2009 to 13.9% in 2017 [84].

In Vietnam, the sorting and collection of plastic wastes is voluntary and there are no government programs for plastics collection and recycling. Plastic wastes which have no or low value such as foam boxes, plastic straws and thin plastic bags, are disposed of into the environment, incinerators or landfills. Available information showed that unmanaged plastic wastes accounts for 1.83 million tonnes/year, including 0.28–0.73 million tonnes of plastics discharged into the sea per year [153]. Up to 80% of Vietnam plastic wastes comes from the mainland production and human activities, with the remainder from fishing aquaculture and shipping (MONRE, 2020).

Significant quantities of macroplastics (average 33.4g/100m^2) are accumulating on the bottom of the Mekong River Delta, particularly during periods of lower flow when plastic loads were 2.5 times higher. Much higher loads up to 923.2g/100m^2 were accruing near large cities. Both fish and decapod crustacean appear to be attracted to this material [154].

Data on the status of microplastic pollution in Vietnam is limited to a few baseline assessments of the distribution and concentration of microplastics in sediments and water samples. The density of fibrous microplastics in Saigon River in 2016 varied from 172,000 MPs/m^3 to 519,000 MPs/m^3 [155]. Microplastic pollution was evident in Asian green mussels (*Perna viridis*) in brackish water in Thanh Hoa Province with 0.29±0.14 microplastics per gram of soft tissues and 2.60±1.14 microplastics per individual in wet basis. In wild shrimp and fish species, microplastics were present in all samples of *Metapenaeus ensis, Metapenaeus brevicornis, Cynoglossus puncticeps, Scianidae, Polynemus melanochir, Pseudapocryptes elongatus*, *Clupeoides borneensis* and *Glossogobius sp.*, in Long Tau River, downstream of Sai Gon-Dong Nai River. The average density of microplastics in fish and shrimp is in the range from 0.33 to 1.41 fibers per gram of organism in wet weight basis [156].

The impact of such loadings of plastic on the health and reproduction of aquatic animals is the subject of ongoing international research which is highlighting problems such as nutritional losses and transport of toxic chemicals into aquatic food webs, causing degradation of their productivity and posing risks for human consumption. Wastewater sludge is currently not well captured in the Mekong Delta [129], so release of microplastics and their associated contaminants in the wastewater stream is highly likely.

7.7. *Acid sulfate soil drainage*

Acid sulfate soils (ASS) are highly acidic and have low fertility, covering around 41% of the Mekong Delta [157], particularly in the older soils [158]. The process of wetland drainage and reclamation of these soils in raised bed configuration has triggered the generation of acids and mobilization of metals.

Leaching toxic substances out of the rootzone is an effective measure for improving soil quality and up-land crop yield in ASS, however it results in discharges of metals such as iron, aluminium and sulphuric acid to surrounding water and land [159]. This acidic runoff can be harmful to aquatic ecosystems [160] and to the productivity of aquaculture enterprises.

A floodplain fisheries survey at Binh Long (in Long Xuyen Quadrangle) and Phu Thanh (in the Plain of Reeds) during the 1992 monsoon showed that lower yield of fisheries (42 kg/ha/year) at Phu Thanh site in comparison to the yield of 80 kg/ha/year at Binh Long. The authors stated that it could be the result of low water pH, as Phu Thanh is located on area defined by the moderate-to-severe ASS [161]. Higher elevation of raised beds of ASS leads to fivefold increased mobilization of aluminium compared to lower elevation raised beds [160]. More than 60% of area of Ca Mau peninsula, which is coastal low plain estuary, broad and relatively shallow (rarely deeper than 30 m) with gently sloping bottoms and depths increasing uniformly toward the mouth and with extensive areas of deposited sediment, is classified as an ASS area [162]. The coastal low plain estuary area of Ca Mau became severely acidic at end of the dry season, with typical pH value (with soil:water = 1:5) from 3 to 3.5. The promotion of acids and soluble metal release from acid sulphate soils after seasonal drought, resulting to further acidification was found [158].

8. General legislation and management framework for the Mekong Delta

The legal framework of development and management policies for wild capture fisheries are a body of legislative texts that has evolved over the last four decades. Government policy towards the small-scale fisheries has changed significantly since the ''*doi moi*'' (renewal) policy launched in 1986 [163]. Fishery policies in general aimed to regulate fishing to ensure the sustainable management of fishing resources, to limit overfishing and ensure the sustainability of the livelihoods of fishers [164]. The sector policies were aimed at increasing production, exports, and national economic development. The period of 1986 to the early 2000s is characterised by a rapid increase in production and an even larger increase in fishing effort, both inshore and offshore. However, the management of the fishery was given limited attention in the market-driven environment.

To protect near-shore fisheries and restore coastal marine resources the Vietnamese government encouraged offshore fishing from the mid-1990s, by supporting the construction of large vessels at subsidised interest rates[4]. A priority was to be given to offshore fishing and a 5-year tax relief for all offshore vessels (e.g. the 3% natural resources tax) was established[5]. In 1998 an extension of the marine product export program to year 2005 was approved [6] [165].

Following, the ordinance on the Conservation and Management of Living Aquatic Resources promulgated in 1989 [166], the Fishery Law was approved in 2003 comprising 10 chapters and 62 articles of which many are relevant to small-scale fishery[7] [8][163, 167].

[4] Decision No. 393/TTg: promulgated in July 1997, the Decision supports the construction by the government of fishing vessels to be sold to fishers at subsidised (reduced) prices
[5] Decision No. 358/TTg dated May 29, 1997 of the Prime Minister on preferential taxation of off-shore fishing
[6] Decision No. 251/1998/QD-TTg on the ratification of the Program for Developing the Export of Aquatic Products up to 2005. Date of text: 25 December 1999
[7] For example: article 6 bans specific fishing activities such as using destructive fishing gear. Under article 8, the Ministry periodically issues lists of prohibited species for capture; closed seasons and areas, banned fishing gear, and measures or information on the rehabilitation and conservation of aquatic resources and their habitat.
[8] https://vanbanphapluat.co/law-no-17-2003-qh11-of-november-26-2003-on-fisheries

Despite the enhanced regulatory protections in recent years, several factors have led to the over-exploitation of inshore and freshwater wild fisheries. A lack of Government enforcement of laws meant that fishing net mesh sizes were often smaller than the mesh sizes allowed by national regulation. There is a high level of by-catch and incidental catch of small-size/juvenile fish. Harmful fishing gear such as push nets, stow nets, and fixed nets are still commonly used in some places. Trawlers have caused damage to seabeds. Historic destructive fishing techniques, such as explosives, and poison [163], have largely been eliminated. Some use of electricity through fishing nets is still practiced in some areas. Local managers may overlook it, as it is viewed as something which poor farmers may need to use to feed themselves.

The 2003 *Fisheries Law* provides for a stronger and more comprehensive legal basis for management of fisheries and aquaculture. This Law attempts to regulate for more sustainable and responsible fisheries management through ecosystem approaches and integrated management. The relevant capture fisheries and small-scale fisheries chapters are tabulated in Appendix 9.

The new *Fisheries Law* (2003) provides for co-management under Article 9. Article 15 states that ‘‘The provincial People's Committees shall have responsibility to issue rules of fishing grounds in rivers, lakes, lagoons, and other natural waters under its jurisdiction in accordance with guidance of Ministry of fisheries (MOFI). In 2004 the Government approved the Aquatic Resource Protection and Development Program until 2010[9]. The decision provides for the protection, development and management of aquatic resources in inland and territorial waters with the aim to protect, rehabilitate and develop social community awareness relating to the resources and the wetlands and their possible environmental, economic, social and biodiversity potential, also with the education of the fisher community [168]. The laws have worked well particularly when their implementation is supported as part of a dedicated program which involves training of local people to understand the changes. However, when such supported programs end it is difficult to maintain the same level of compliance. Low levels of pay for Government Fisheries officers may force them to work second jobs reducing their ability to support the implementation of the new law.

A Master Plan for Fisheries Development to 2010 and Orientations toward 2020 was introduced in 2006 [10] [169, 170]. The overall objective of the Master Plan to 2010 is ‘‘To develop fisheries sector to become a mass production with highly competitive capacity and export turnover, and high capacity of self-investment for its development, significantly contribute to socio-economic development of the country, particularly in coastal and inland areas.’’ The Government of Vietnam has recognised the problem of excess fishing boat capacity. The Master Plan for Fisheries Development to 2010 and Orientations to 2020 (January 2006) states that, all inshore areas are over-exploited, making life hard for coastal communities relying on fishing.’’

[9] Decision No. 131/2004/QD-TTg dated July 16, 2004 of the Prime Minister approving the aquatic resource protection and development program till 2010

[10] Decision No. 10/2006/QD-TTg: based on the new Master Plan for Fisheries Development 2010 and Orientations Toward 2020, the Decision calls for the fisheries sector to reduce the number of fishing vessels down to one-half by 2010 and the number of vessels with engines less than 45 Hp from 64,000 to 30,000 vessels by 2010. However, fishers have the option to upgrade their small vessels to larger vessels/larger-scale to be able to fish offshore or stop fishing and seek other jobs

The Plan is enjoying some success with reforesting activities in their early stages of fishery habitat restoration. Where catches had declined, fishery incomes became no longer enough to support people. This has seen the departure of fishers from the industry and regions with a drift towards jobs in cities. Some fishing remains in the upper Mekong by larger operators, and some subsistence fishing for home consumption. It is hoped with time the fishery will recover and once again support more fishers.

The Government focus on short-term economic development as an overriding priority has not afforded strong protection of the aquatic environment. Researchers have noted that "Vietnamese development priorities that constrain the integration of environmental objectives, since the development philosophy emphasises economic growth, and environmental protection is seen as something that can only be afforded after wealth accumulation or the attainment of middle-income status (Bass et al. 2010)".

9. Legislative framework for the management of pollutants

Pesticides have been used in Vietnam for more than six decades since the "green revolution" in the 1960s. Before the 1980s, pesticides were only managed by the state. In 1989 the Vietnam government transferred management from the Ministry of Agriculture and Rural Development (Vietnam Government)[11] and in 1993, Vietnam Government permitted the private sector to participate in the distribution and trading of pesticides[12].

Figure 17 illustrates the change in values of pesticide imported, pesticide product and active ingredient registrations from 1986-2020. Continuous growth of registered products and active ingredients is evident from 1996 to 2017. Around 2017 the government found that pesticides were being overused and were causing adverse impacts on environmental, agricultural and human health.

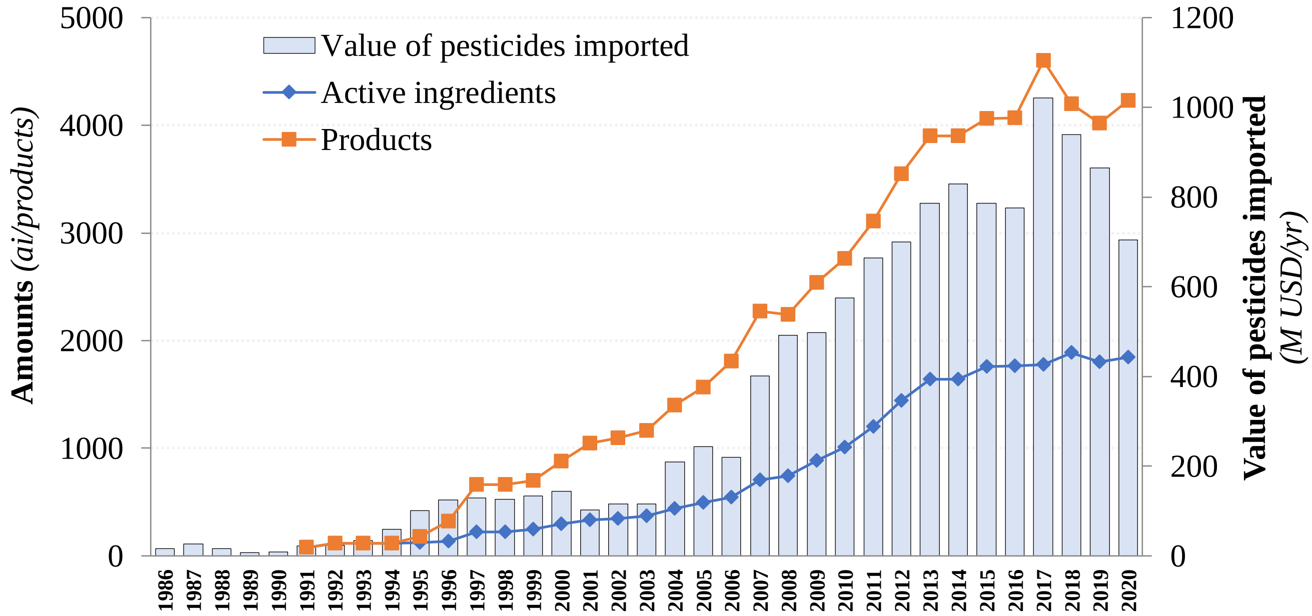


Figure 17: Active ingredients, products of pesticide registration and import value of pesticides from 1986-2020 in Vietnam. Source: MARD from 1991-2021 & GSO from 1986-2021

[11] Decision 9-CT_HDBT in 1989

[12] Ordinance 8-L/CTN in 1993

In 2017 the Government introduced a Resolution on the sustainable and climate-resilient development of the Mekong River delta, called "resolution of natural base" [13]. The Resolution sought to change Mekong agriculture to become more environmentally friendly and based-on the natural development. This involved building the structure of agricultural production according to three focuses: fisheries/aquaculture – fruit trees – rice associated with ecological sub-regions, in which aquatic products (fresh water, brackish water, salt water) are considered as key products. In 2020 a Decision[14] approved the mission for planning the Mekong delta stage 2021-2030. The vision to 2050 showed that the master plan of Mekong delta and the planning of each province must be consistent with the vision, goals and views of 2017 Resolution[11]. In addition, in 2018, a Decree about organic agriculture was signed by the Government. This Decree regulates the production, certification, labeling, logos, traceability, trading, and state inspection of organic agricultural products in the fields of cultivation, animal husbandry, forestry and animal husbandry, aquaculture and policies to encourage the development of organic agricultural production[15]. All these measures have become the legal basis to gradually reduce dependence on chemicals in agricultural production. Following on from these legal changes a series of decisions were made by the Ministry of Agriculture and Rural Development (MARD) to remove numerous pesticides from use [16,17,18,19,20,21].

Break-out box

Since 2017, at least 14 chemicals with 414 ai and 782 products have been banned in Vietnam. The banned active ingredients include Carbendazim, Benomyl, Thiophanate Methyl, 2.4 D, Paraquat, Trichlorfon, Acephate, Diazinon, Malathion, Zinc Phosphide, Chlorpyrifos Ethyl, Fipronil, and Glyphosate.

In 2021, the Plant Protection Department of Vietnam announced it will be implementing the procedures to permanently ban 20 active pesticide ingredients including carbosulfan, benfuracarb, group of dithiocarbamate (mancozeb, propined, zineb, maneb, ziram), group of herbicides (atrazine and acetochlor), chlorothalonil, carbaryl, thiodicarb and group of antibiotics (erythromycin, gentamicin sulfate, kanamycin sulfate, oxytetracycline (oxytetracycline hydrochloride), streptomycin (streptomycin sulfate), and tetramycin) in 2022 and 2023 [171].

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[13] Resolution No.120/NQ-CP dated November 17, 2017, of the Government on sustainable and climate-resilient development of the Mekong River delta

[14] Decision 1163/QD-TTG dated July 31, 2020 approving the mission for planning the Mekong delta stage 2021-2030, vision to 2050

[15] Decree No. 109/2018/ND-CP dated August 29, 2018 about organic agriculture

[16] Decision No. 03/QD-BNN-BVTV dated January 03, 2017 removal of agrochemicals containing Carbendazim, Benomyl and Thiophanate-methyl from Vietnam's list of permissible agrochemicals.

[17] Decision No. 278/QD-BNN-BVTV dated February 08, 2017 of the Ministry of Agriculture and Rural Development on removal of agrochemicals containing 2.4 D and Paraquat from Vietnam's List of Permissible Agrochemicals.

[18] Decision No 4154/QD-BNN-BVTV (16/10/2017), Decision of the Vietnamese Government ... Government decisions related to organic agriculture in Vietnam, 2006-2020. ... 10 4154/QD-BNN-BVTV (16/10/2017)

[19] Decision of the Vietnamese Government ... Government decisions related to organic agriculture in Vietnam, 2006-2020. ... 15 3435/QD-BNN-BVTV (28/08/2018)

[20] Decision No. 501/QD-BNN-BVTV dated February 12, 2019 removal of agrochemicals containing chlorpyrifos ethyl and fipronil are removed from the list of permissible agrochemicals in Vietnam

[21] Decision No 1186/QD-BNN-BVTV dated April 10, 2019 removal of agrochemicals containing glyphosate

Close break-out box

In 2020, the list of pesticides allowed in Vietnam are 1,847 active ingredients and 4,229 products, in which biologicals such as probiotics are 221 (12%) active ingredients and represent 974 (23%) products (Phong, Thanh and Long, 2020)

Table **1: Categories of active ingredients and trade names of pesticides allowed for use in agriculture in Vietnam in 2020**. Source: MARD 2020

Appendix 6. List of active ingredients and products of highly hazardous pesticides banned in Vietnam from 2017-2020.) can be found in Appendix 6.

Table 1: Categories of active ingredients and trade names of pesticides allowed for use in agriculture in Vietnam in 2020. Source: MARD 2020

Pesticides used in agriculture	Active ingredients		Trade names	
	Number	**(%)**	**Number**	**(%)**
Insecticides	861	46.6	1821	43.1
Fungicides	587	31.8	1282	30.3
Herbicides	241	13.0	702	16.6
Rodenticide	8	0.4	26	0.6
Molluscicide	31	1.7	151	3.6
Growth regulators	54	2.9	157	3.7
Pheromon	8	0.4	8	0.2
Enhancers/wetting agents (eg alkylphenols)	5	0.3	6	0.1
Other	52	2.8	76	1.8
Total	**1847**	**100**	**4229**	**100**

10. Governance framework for maintaining fisheries productivity of the Mekong Delta

It should be noted that policies of the Government of Vietnam are defined in terms of Laws, Decrees, Decisions, Ordinances, Circulars, and Regulations, with the latter enforced at provincial level. The provinces are the lowest authorities at which policies and regulations are drafted consistent with corresponding national legislations. The country's fisheries sector is therefore in general, managed in a top-down manner from national level (Ministry of Agriculture & Rural Development) to provincial (Department of Agriculture & Rural Development), district and commune/village levels [172].

Vietnam Institute of Fisheries Economics and Planning (VIFEP) [173] reported the policies to reduce fishing pressure in coastal and inland areas of wild catfish fisheries in

Vietnam and for sustainable development of fisheries productivity, the policies focus on the enforcement of laws in a bid to reduce fishing pressure in coastal areas. Policies issued include: 1) Vietnam Agenda 21 [22], the sustainable development strategy specifies protection of the marine environment, coastal area (mangrove forest and swamp areas), islands (freshwater and brackish water) and developing marine resources. To protect the environment the following actions are specified:

1) Establishment and management of marine protected areas (MPA's) and coastal areas; the application of national, provincial and sectoral environmental standards; improved research, and the application of environmental protection technologies.

2) Promotion of large vessel and credit loan[23] .

3) Protection of natural resources and biodiversity to improve the management of fishing operations, the protection of fisheries resources and their habitat; harmonise the law and policies; identify the authorities and duties of organizations and individuals in the management, control and use of aquatic living resources.

4) Protection of endangered and rare species for setting minimum catch size of aquatic species, to ensure fish breed before being caught, is an important method of ensuring sustainable management of aquatic populations.

5) Control of destructive fishing gear and fishing methods.

6) Control of destructive fishing gear and fishing methods.

7) Protection of aquatic habitat,

8) Rehabilitation and protection of fisheries resources and

9) Co-management for the sustainable utilization of fisheries resources.

The following activities are to be implemented to protect natural fisheries resources and biodiversity including: fishing licensing, control of productivity in specific marine areas, protection of rare and precious species that are in danger of extinction, restocking to enhance breeding population size and density, protection of aquatic habitats, and rehabilitation and protection of fisheries resources.

There is a lack of technical understanding, a lack of regulation and compliance, and a failure to fully implement the environmental protections which are within the regulations. Core to this problem is the lack of planning, technical support and financial capacity at provincial and national levels of government institutions to manage the development of the coastal ecosystems of the Mekong Delta in a manner that is resilient to climate change.

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[22] Decision No. 153/2004/QD-TTg dated August 17, 2004 of the Prime Minister promulgating the oriented strategy for sustainable development in Vietnam (Vietnam's Agenda 21). https://english.luatvietnam.vn/decision-no-153-2004-qd-ttg-dated-august-17-2004-of-the-prime-minister-promulgating-the-oriented-strategy-for-sustainable-development-in-vietnam-vi-16425-Doc1.html

[23] decision No. 393/TTg, 159/1998/QĐ-TTg on the regulation on management and use of credit loans invested according to State plans for projects dealing with building, upgrading of fishing vessels and offshore fishing services

11. Initiatives and innovations for improving fishery productivities in the Mekong Delta

Government intervention in preventing flooding upstream and building high dykes for flood control to project rice crops were indeed successful in their primary aim of increasing rice production through maintaining cultivation of two–three crops of intensive HYV rice [182]. However, it has also caused environmental pollution and the degradation of soil fertility, with accompanying reduction in wild fisheries production due to loss of fish access to habitat and increased exposure to water polluted with pesticides and fertilisers [77, 123, 174].

In recognition of the concerning trends in fish production in 2016-2017, some increased Traditional Rice (floating rice) cultivation took place in Bac Lieu, Kien Giang, An Giang, Dong Thap and Long An provinces (Figure 20). The Government decision to expand sustainable and climate-based farming supported this transition[24]. This recovery occurred because Traditional Rice is suitable for the Rice-shrimp model of agriculture when growing and fish farming in the coastal area. Pesticides and fertilisers are not used in Traditional Rice. The re-discovery of floating rice's suitability to naturally combine with fish and freshwater shrimp has been gaining interest in the upper Mekong provinces of An Giang, Dong Thap and Long An, from 2011 to the present (Figure 21 and Figure 22). The World Bank have supported the integrated rice and natural fish farming system.

The existing rice-shrimp system in the coastal areas and rice–fish inland of freshwater areas provided almost twice the income compared with the most intensive rice system that the government intervention had induced in the Mekong Delta. To reduce pesticide use, important changes have taken place in strategic approaches to plant protection. The Integrated Pest Management (IPM) wild fish–rice methods have brought ecological principles and social science perspectives into traditional crop management. The integrated aquaculture and agriculture farming systems provide more profits for farmers as they produce more diversity of food for people to consume, improving environmental water quality, improved investment outcomes, with reduced pesticide and synthetic fertiliser costs [63, 175].

Figure 18 shows the expansion of HYV farming and the decline in wild fishery production in five provinces that are not bordered by the sea including An Giang, Dong Thap, Can Tho, Vinh Long and Hau Giang from 1995 to 2020.

[24] Resolution No.120/NQ-CP dated November 17, 2017, of the Government on sustainable and climate-resilient development of the Mekong River delta

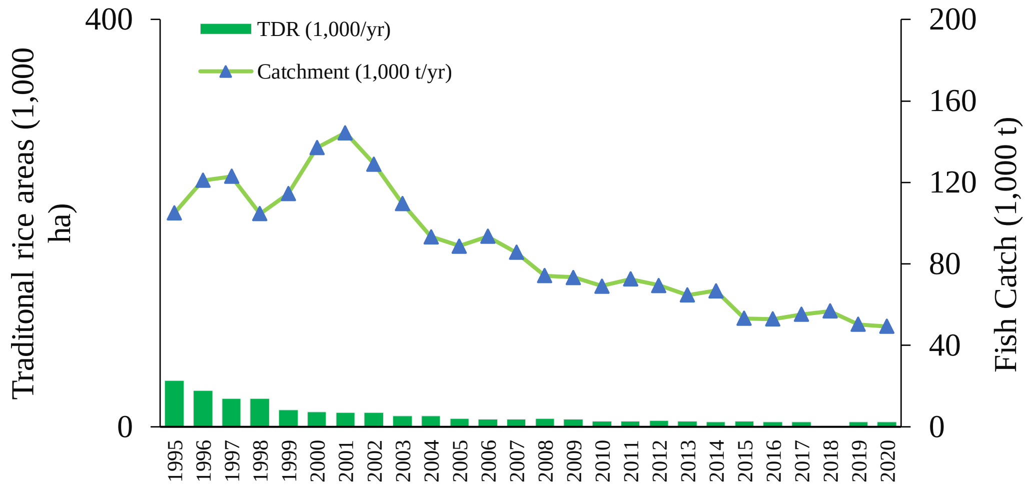

Figure 18: Correlation between Traditional rice (TDR) area and quantity of wild fish catch in five provinces in the Mekong Delta of Vietnam from 1995-2020. Source: GSO from 1995 to 2020.

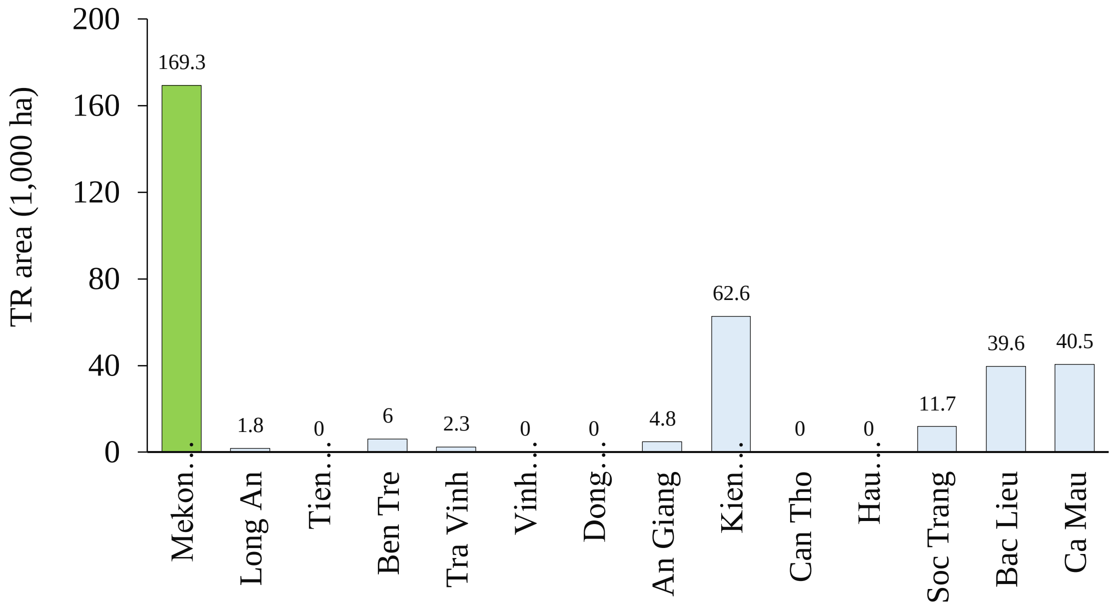

Figure 19: Current status of traditional rice cultivation in Mekong Delta in 2020.

Floating rice is being applied in combination with flood discharge to bring high economic efficiency. In 2021, a farmer in Dong Thap, has applied floating rice in combination with culturing Linh fish and Giant freshwater shrimp with very high economic efficiency, estimated profit of 7,700 USD/ha. In general, the signals are good for a recovery and near-term development of Traditional Rice combinations with aquaculture. The provinces currently implementing the most are Kien Giang, Bac Lieu and Ca Mau (Figure 20).

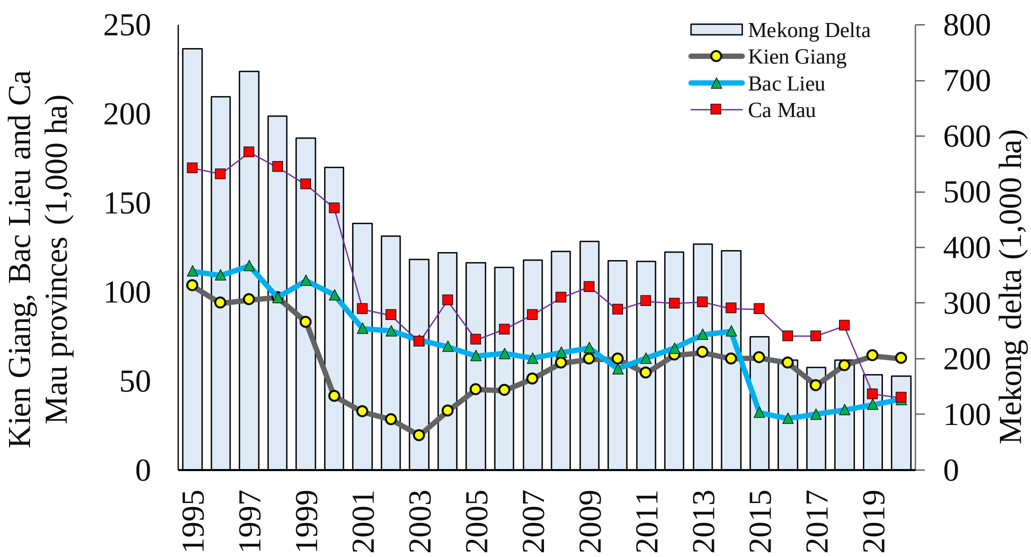

Figure 20: Signs of recovery of seasonal rice growing areas in Mekong Delta

Rice-fish farmers will therefore be more reluctant to use pesticides than rice farmers as they stand to benefit from not only increased income due to less pesticide purchase costs, but also from increased yields of fish.

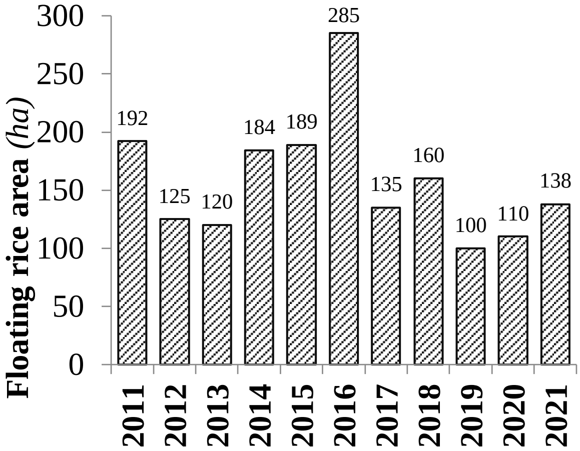

Figure 21: Floating rice cultivation area in An Giang province and Mekong Delta 2011-2020.

Figure 22: Floating rice field in flooding season in Long An province

One potential response to increased salinity intrusion in the coastal Mekong Delta is to shift to alternating rice-shrimp crops, rather than continuous shrimp, or continuous rice cultivation. Such systems encourage greater awareness of the risks from agricultural chemical use due to the sensitivity of shrimp, resulting in reduced volumes of use compared to rice-only land use areas. Not only are there food safety benefits to this low input system approach [176], but they may also support better effluent water quality, thereby supporting a more productive wild fishery also.

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Appendix 1: Chronology of Mekong Delta agrarian transformation and environment related events

Timeline	Major Events/Features
> 300 years ago	- Pioneer Vietnamese settlements in highland areas - Rice collection and rice cultivation for food - Most of the Delta was covered by forest
1705-1858	- The early stages of exploitation of the Mekong Delta under the *Nguyen* dynasty - Three main canals were excavated for land reclamation - Deep-water rice cultivation developed
1858 - 1 954	- Under French colonial regime - Many primary canals were excavated - People moved following the canal systems for settlement - Land reclamation and an extended cultivated area for rice production

Timeline	Major Events/Features
1954 - 1975	- Vietnam/American wars - Many canals excavated in acid sulphate soil in the floodplain area, mainly useful for war services
1966	- Introduction of HYR varieties to the Mekong Delta (IR5 and IR8 rice varieties)
1968	- A shift from single-rice cropping to double-rice cropping per year on the alluvial soil and high elevation topographical areas. - Farmers used agricultural machines for land preparation and irrigation - Some rural areas were not cultivated because of war; villagers move to the town
1975	- National unification
1976-1977	- Farmers came back to the village and rural areas for land reclamation purposes - Rice growing and home gardens were reintroduced
1977-1980	- Brown Plant-Hopper (BPH) destroyed rice fields - Big floods damaged crop production in 1978
1979	- Start shifting from BPH sensitive rice varieties to BPH tolerant rice varieties
1979-1985	- Collectivization established - Many primary and secondary canals were dug - Double-rice cropping area increased - Redistribution of lands to farmers - Many areas exploited (forest area and serious acid sulphate soil) for rice production
1984	- Contract systems introduced
1986-1988	- Policy reform in Vietnam (*Doi Moi*) - De-collectivization and land redistribution to farmers - A shift from central planning- to market-oriented economics

Timeline	Major Events/Features
1988	- Resolution No. 10 dismantled; agricultural collectives open up with a market system based on input-supply and output-sell - Vietnam becomes the third largest rice exporter
1998	- Small dyke systems being built in some places to protect paddy fields (August/low dyke system)
2000	- Historically big flood damaged humans, infrastructure and agricultural production in the Mekong Delta - Permanent dyke (High dyke) system constructed to prevent flood damage in many sub-regions of the Mekong Delta
2003	- Vietnam becomes the world's second largest rice exporter

Sources: Data and information gathered from [74], [177]; [178]; [179]; [180]; [181]

Appendix 2. Study areas, employed sediment data, methodologies, key findings and shortcomings of sediment monitoring programs in Mekong Delta of Vietnam

References	Stations/ study area	Range of data	Methodologies	Key findings	Shortcomings (study gaps)
Binh D.V. et al. 2019 [116]	Tan Chau, An Giang	1980 to 2015; August 2017	Water Quality Monitoring Network dataset of the Mekong River Commission (MRC) and Vietnam National Center for Hydrometeorological Forecasting (VNCHF) dataset of the daily/annual discharges, suspended sediment load (SSL) and concentration (SSC) at numbers of stations in the MRB (Licang, Simao, Lancang, Jinghong in China; Chiang Saen , Nong Khai in Thailand, and Pakse in Laos) and 11 stations along the Tien and Hau rivers (Tan Chau, Vam Nao, Cao Lanh, My Thuan, Tra Vinh, Ben Trai, Chau Doc, Long Xuyen, Can Tho, Dai Ngai, and My Thanh in Vietnam) All stations use depth -integrated methods to measure the SSCs at several vertical profiles in a cross section.	- The daily discharge was unchanged during the 1980-2015, ca. 10,000 m^3/s; - Daily SSC at Tan Chau remained nearly unchanged (mean values of ca. 400 mg/L) during 1980-1992, but decreased significantly to mean values of ~ 100 mg/L since 1993, when the Manwan dam (Lancang River, China) was completed. Instantaneous SSC reduction as a response to dam building likely shows buffering effect of the trapped sediment in the channel downstream of the dam sites; - Similarly, daily SSL at Tan Chau decreased significantly from 401,960 t/day during 1980-1992 to 165,300 t/days in 1993-2001 (-58.9%), 129,780 t/day in 2002-2011 (-67.7%) and 104,290 t/day in 2012-2015 (-74.1%). Significant decrease in the sediment load during 2012-2015, of which 40% was caused by 6 mainstream dams in the Lancang cascade and 32% was caused by the Manwan and Dachaoshan dams, indicated that the impacts of hydropower dams have exceeded those caused by irrigation expansion and land-use change. ; -Approx. 95% of the suspended sediment sample was composed of silt and clay; approx. 90% of the riverbed sediment was composed of sand. Field survey in August 2017 recorded exceptionally high SSC (mean cross-sectional 1,132 mg/L) in 83-km downstream of the sand mining area (Mang Thit, My Thuan), whereas only SSC of 356 mg/L was measured upstream. The flow was seaward during the survey time; -Between 2014 and 2017, mean riverbed incision was equivalent to -1.24 m/yr, which was 4-fold than that of 1998-2014.	-
Hung NN et al. 2013 [182]	Tam Nong District, Dong Thap Province,	2008, 2009, 2010	4 stations installed on the floodplains with low dyke ring, high dyke ring, permanently ponding water, and close to sluice gate (low dyke ring); 3 stations set up in channels. All stations established in an area of 165 km^2. SSC monitored by optical backscatter using calibrated turbidity sensor probe in 30-min intervals. Sampling point representation for cross section ensured by evaluation of spatial heterogeneity via acoustic Doppler currency profiler (ADCP)	- Low-flow season (January to July): mean SSC ~ 50mg/L and varies at~ 20 mg/L due to tidal backwater effect; - High-flow season (July to December): mean SSC ~ 90 mg/L and reaches maximum more or less than 200 mg/L between September and October in all years covered; SSC variation of ~ 50 mg/L due to tides; -Tidal backwater affects SSC with higher frequency, mostly by a vertical redistribution of SSC in the water column through a change in flow velocity, particle settlement and remobilization; -Flood waves from upstream contribute mainly to the annual sediment budget of the whole Delta; -The anthropogenic activities (during the opening of the sluice gates, i.e. the start of the floodplain inundation, and the pumping activities at the end of the flood season) increase SSC up to 250 mg/L. SSC reduced and stabilized at ~ 20 mg/L after a few days; - An exponential decrease occurs within 10 km distance from the Mekong River; beyond this distance, the concentration tends to stabilize at about 40 mg/L; - Background concentration wash load of SSC in the floodplain was about 20 mg/L.	SSC predictions using a sediment rating curve are of very low quality due to a number of effects, including the general load from the upstream Mekong basin, the reduction of the sediment concentration with distance from the main river, the tidal influence, and anthropogenic disturbances. Suggestion: discharge and SSC have to be recorded at high temporal resolution over a longer time period, and sediment rating curves considering the aforementioned effects have to be developed.

Appendix 3. Study areas, employed nutrient discharge data from cultured fish farms and integrated orchard-fish farms in VMD, methodologies, key findings and shortcomings

References	Stations/ study area	Range of data	Methodologies	Key findings	Shortcomings (study gaps)
De Silva SS et al. [121]	Stripped catfish (*Pangasianodon hypophthalmus*) farming sector in the Vietnam Mekong Delta (8°33¢ – 10°55¢N, 104°30¢-106°50¢E; approximately 3.9 x 10^6 ha);	2007-2008	Dataset on fish feeding practices and average FCR (amount of food dispensed as fed/increase in biomass of stock in wet weight) obtained by the Collaboration for Agriculture and Rural Development (CARD) survey program, funded through the Australian Agency for International Development (AusAID); Proximate analysis of N and P of commercial and farm-made feeds, N and P retention in fish body; Nutrient-balance model use nutrient inputs (feed added) and nutrient remove (harvested fish) to estimate gross N and P discharge levels from the VMD farms.	-The sector accounted for 687,000 t production in 2007 and 1,094,879 t in 2008, with over 95% of the produce destined for export to over 100 countries. Commercial and farm-made feeds are used in catfish farming, currently the former being more predominant; -Nitrogen discharge levels were similar for commercial feeds (median 46.0 kg/t fish) and farm-made feeds (median 46.8 kg/t fish); -Phosphorus discharge levels for commercial feeds (median 14.4 kg/t fish) were considerably lower than for farm-made feeds (median 18.4 kg/t fish); -Based on the sector production of 687,000 t in 2007 and 1,094,879 t in 2008 (Department of Aquaculture 2008), the median nutrient discharge levels for commercial feed-striped catfish production in the Mekong Delta were estimated to be 31,602 t N and 9,893 t P in 2007, and 50,364 t N and 15,766 t P in 2008. In case only farm-made feeds, the median nutrient discharge levels for striped catfish production in the Mekong Delta were approx. 32,152 t N and 12,641 t P in 2007, and 51,240 t N and 20,146 t P in 2008; -Because of relatively high feed efficiency, lower protein and higher carbohydrate content in the striped catfish, other cultured fish sector would discharge higher levels of N and P.	-Amounts on nutrients loss to sediments or removed by pond cleaning were not taken into account; -More accurate estimations taking into consideration many variable factors in use and discharge of water from catfish farming practices are needed to obtain total discharge of nutrients directly into the Mekong Delta.
Nhan DK et al. [122]	Three sites in Can Tho, including areas with intensive irrigated fruit production and fertile alluvial soil, and areas with irrigated rice-dominated production and less fertile soils	2002-2003	Monitoring 10 integrated agriculture-aquaculture (IAA) farms (stocked with various fish species) until fish harvesting, among which 6 farms were low water-exchanged with orchard dykes (low ratio of pond:orchard area); and 4 farms were located in flood-prone areas and high water-exchanged with orchard dykes. Ponds sizes varied from 222 to 1584 m^2. Estimation of water inflows and outflows by monitored fluctuations in water depth. Estimation of nutrient input and output in consideration of on-farm vs. off-farm, harvest vs. loss.	-Major sources of nutrient accumulation in sediments comes from on-farm food inputs, particularly on-farm livestock manure (accounted for 32% total-N, 65% organic C (OC) and P inputs) and inflow water (accounted for 61% total-N, 13% OC and 18% P inputs). Off-farm feed inputs were major source of OC only, accounting for 21% of total inputs; -Major sources of nutrient loss comes from outflow water. About 30% of total N, 81% of OC and 51% of P accumulated in the pond sediments. About 4-6% of the nutrients were retained in the harvested fishes. The remaining portions of the nutrients were flushed out with the outflow. -To produce 1 kg of fish, the same amounts of nutrients in food are required in both low- and high- water exchanged ponds, while the latter discharged about twice as much nutrient than the former.	-Due to more frequent measurement of nutrients in the outputs (harvests and losses) rather than in the inputs (on-farm and off-farm sources), quantities of nutrient loss via outflow water could be over-estimated, particularly N. -N fixation was smaller than the N surplus, so the N surplus increased with the amount of nutrients discharged, therefore the amounts of discharged nutrients are easily miscalculated; - Assumption of thoroughly mixed pond water before discharge for the estimation was questionable in ponds using the same pipes for inflow and outflow.

Appendix 4. Study areas, employed pesticides data from intensive paddy rice cultivation and orchard farms with key findings

References	Stations/ study area	Range of data	Methodologies	Key findings
Chau NDG et al. [136]	Four sampling sites in An Giang Province (Hau River, Thoai Son primary canal and Thoai Son District – intensive paddy rice cultivation on acid sulfate soil) and thirteen sampling sites in Can Tho City (O Mon River, Sang Trang and Thom Rom primary canal and O Mon District - rice/orchard system on alluvial soils without irrigation dyke system; Thoi Lai District – year round paddy rice monoculture e on slightly acid sulfate soil)	2011-2012	Questionaire-based surveys of 104 households, covering the water sources used for drinking, and general water consumption patterns; pesticide use and farm characteristics, irrigation management at the study sites. Collection of total 26 grab surface water samples monthly at 3-m distance from the canal bank during high tide; at household-stored surface water tanks; total 22 groundwater samples at private drilled wells. Mult-residue pesticide analytical method was used. Method detection limit of each target compound was determined by conducting 7 replicated experiments, spiking with pesticides (propiconazole, triflorxystrobin, cypermethrin, difenoconazole and azoxystrobin, fenoxaprop-p-ethyl, butachlor, pretilachlor, tebuconazole, hexaconazole, isoprothiolane, fenobucarb, quinalphos, thiamethoxam, and fipronil.	- There were nearly 80 pesticide brands corresponding to almost 60 active ingredients under use at the four study sites (of which herbicides accounted for 22.7 %, fungicides for 39.4 %, and insecticides for 37.9 %); - More than 60 % in Co Do and Thoai Son, and nearly 80 % of the respondents in O Mon and Thoi Lai reported to apply pesticide amounts higher than the recommendation on the label (overdose up to five-fold). Half of these total amounts of pesticides were used in O Mon where fungicides were dominant; -Pesticide use of 1.8 kg active ingredient/ha/crop; - Only a minority of farmers (maximum share of 16 % recorded in Thoi Lai) considered potential health effects, i.e., toxicity of pesticides in their decisions; Empty/used pesticide containers were simply discarded in the field (Thoai Son 93 %) or collected and handed to collectors (Co Do 80 %) or even simply thrown into canals (O Mon 6 %, Thoi Lai 16 %); - WHO Class II (moderately harzadous pesticides): the fungicide isoprothiolane was the most frequently quantified compound (in 97.8 % of all surface water samples), followed by the insecticides fenobucarb (91.2 %) and fipronil (83.4 %): median concentration of isoprothiolane was 0.55 µg/L while fipronil and fenobucarb were quantified at median concentrations of 0.17 and 0.15 µg/L, respectively. One of the most used fungicides, propiconazole (64.3 %), was also found in 39.2 % of the analyzed samples with maximum concentration of 4.76 µg/L. - High persistence in water and long transport distance pesticides: quinalphos and tebuconazole (long hydrolysis half-lives), thiamethoxam (high stability in water), and butachlor (low soil sorption) were detected in canal water; - More than 90% of samples contained Isoprothiclane higher than 0.1 µg/L threshold; about two-third of the analyzed samples contained fenobucarb, pretilachlor, and quinalphos exceeding the 0.1 µg/L threshold. More than 50% of samples contained exceeded Fipronil concentrations causing acute toxicity to invertebrates, while nearly 80% of samples exceeded chronic toxicity; -Pesticides were found in 5 out of 22 collected groundwater samples, and the EC concentration threshold for individual pesticide (0.1 µg/L) in drinking water was exceeded in all these samples.

Appendix 5. Study areas, employed antibiotics data from fish and shrimp farms in Vietnam with key findings

References	Stations/ study area	Range of data	Methodologies	Key findings
Luu QH et al. [145]	North (Hai Phong, Nam Dinh, Vinh Phuc), Central (Binh Dinh, Daklak) and South (Dong Nai, Dong Thap) of Vietnam	June – October 2018	Cross-sectional study population included fish and shrimp farmers in extensive cultivation (natural open water with natural feed in pond) and intensive cultivation (controlled water and animal feed); 60 farms in each province, total 720 farms. Questionaires (open, semi-open, closed) for direct interviews, collecting farmers' educational background, animal husbandry practices and use of antibiotics on their farms for prevention of disease and/or treatment of disease. Descriptive analysis and risk factor identification were conducted using Chi-square test and logistic regression. Statistical analysis was performed using STATA 14 (College Station, TX)	- Antibiotics are widely used in fish farms (64 %, 232/360), but less common in shrimp farms (24 %, 86/360); - In fish farms, there were 11 antibiotic classes (23 different antibiotics), in which Phenicol was the most common (11 %), following by Tetracycline (10 %) and Sulfonamide (7%). In shrimp farms, there were six antibiotic classes (10 different antibiotics) used, in which Tetracycline was the most common (21%). Oxytetracycline is the most common antibiotic of Tetracycline class, which used in both shrimp and fish farms. Florphenicol is the most common antibiotics in Phenicol class, used in fish production. - 88% fish farms and 83% shrimp farms used antibiotics for treatment purpose; 17% fish farms and 12% shrimp farms used antibiotics for prevention. Intervals of antibiotics are between 3 to 5 days. - Antibiotic application in fish production is more widespread (64 %) compared to shrimp production (24%). The farmers stated that "change of weather" or "neighbour's animals are sick" were main reasons to start prophylactic antibiotic treatment of own animals
Uchida K et al. [183]	Local urban and rural markets in Thai Binh, Nha Trang, and Ho Chi Minh City	July 2013 to October 2015	Target 4 classes of antibiotics: quinolones (12 compounds), sulfonamides (14 compounds), β-lactam (5 compounds), and trimethoprim; Sampling products supplied from household aquaculture ponds and nature fishes. LC-MS/MS Analysis with one-step cleanup for sample preparation and matrix-matched calibration.	- 53/362 HCMC samples contained antibiotic residues, including 5 quinolones (ciprofloxacin, enrofloxacin, norfloxacin, ofloxacin, and oxolinic acid), 2 sulfonamides (sulfamethazine, sulfamethoxazole) and trimethoprim; - 39/362 HCMC samples contained Enrofloxacin, even it has been banned for use since March 2012 (Circular 03/2012/TT-BNN). Ciprofloxacin was often detected with enrofloxacin (15/19 = 78.9%) because of Enrofloxacin metabolism; -Several months storing samples may be the cause of undetectable β-lactams in the present study; - Residues were detected more frequently in HCMC (53/362 = 14.6%), where samples were raised on a commercial basis, than in TB (1/118 = 0.9%, $p < 0.001$), where samples were raised on household basis;
Pham DK et al. [184]	Thoi Lai District (Can Tho City) and Tam Nong District (Dong Thap City) in the Mekong River Delta (MRD), southern Vietnam; Cam Giang District (Hai Duong City) and Thanh Tri District (Hanoi) in the Red River Delta (RRD), northern Vietnam	July to August 2011	Cross-sectional study, 94 farms in each area; survey questionaires piloted before use for face validation; 50 shrimp samples and 50 fish samples (any species) from local markets in the study areas (at least 300 g per sample required), bones and offal removal, milled the remaining sample, and stored in sealed plastic boxes at -20°C until analysis. Microbiological inhibition test (New Two Plate test) first, positive samples were then post-screened for further identification of tetracycline and (fluoro)quinolone.	-28/104 (26.9%) of the samples returned positive results by microbiological inhibition tests; -Postscreening tests by Tetrasensor (for tetracyclines) and ELISA (for quinolones) indicated that 7 samples (1 shrimp and 6 fish) contained quinolone residues and that 18 samples (13 shrimp and 5 fish) contained tetracycline residues. Quinolones (enrofloxacin, ciprofloxacin, and norfloxacin) (6/ 51 = 11.8%) and oxytetracycline (4/51 = 7.8%) were identified in fish samples by LC-MS/MS analysis. The detection rate by microbial inhibition tests (28/104 = 26.9%).

Appendix 6. List of active ingredients and products of highly hazardous pesticides banned in Vietnam from 2017-2020.

No	Name of active ingredients	Pesticides	Products	No. of active ingredients	Date decisions	Date of ban	Government's decisions
1	Carbendazim	Fungicide	109	68	3/01/2017	3/01/2019	No.03/QD-BNN-BVTV
2	Benomyl	Fungicide	16	6	3/01/2017	3/01/2019	No.03/QD-BNN-BVTV
3	Thiophanate-methyl	Fungicide	48	48	3/01/2017	3/01/2019	No.03/Qd-BNN-BVTV
4	2.4 D	Herbicide	36	4	8/02/2017	8/02/2019	No.278/QD-BNN-BVTV
5	Paraquat	Herbicide	46	2	8/02/2017	8/02/2019	No.278/QD-BNN-BVTV
6	Trichlorfon	Insecticide	10	5	16/10/2017	16/10/2017	No.4154/QD-BNN-BVTV
7	Carbofuran	Insecticide	4	2	16/10/2017	16/10/2017	No.4154/QD-BNN-BVTV
8	Acephate	Insecticide	16	3	28/08/2018	28/10/2019	No. 3435/QĐ-BNN-BVTV
9	Diazinon	Insecticide	16	2	28/08/2018	28/10/2019	No. 3435/QĐ-BNN-BVTV
10	Malathion	Insecticide	2	2	28/08/2018	28/10/2019	No. 3435/QĐ-BNN-BVTV
11	Zinc Phosphide	Rodenticide	2	1	28/08/2018	28/10/2019	No. 3435/QĐ-BNN-BVTV
12	Chlorpyrifos ethyl	Insecticide	228	173	12/02/2019	12/02/2021	No.501/QD-BNN-BVTV
13	Fipronil	Insecticide	141	91	12/02/2019	12/02/2021	No.501/QĐ-BNN-BVTV
14	Glyphosate	Herbicide	104	9	10/04/2019	10/04/2020	No.1186/QD-BNN-BVTV
	Total: 14		**778**	**416**			

Source: MARD, 2017, 2018, 2019, 2020 and 2021.

Appendix 7. Law on Fisheries (18/2017/QH14), Viet Nam – Fisheries (Sources: FAOLEX Database accessed on: 24 March, 2022)

https://www.fao.org/faolex/country-profiles/general-profile/see-more/en/?iso3=VNM&countryname=Viet%20Nam&area=Fisheries&link=aHR0cDovL2Zhb2xleC5mYW8ub3JnL2NnaS1iaW4veG1sLmV4ZT9kYXRhYmFzZT1mYW9sZXgmc2VhcmNoX3R5cGU9cXVlcnkmdGFibGU9YWxsJnF1ZXJ5PUFSRUE6RkkgQU5EIElTTzpWTk0gQU5EIFQ6QUxMIE5PVCBSTzpZIEFORCBSRVBFQUxFRDpOIEFORCBTVVBFUlM6TiBBTkQgWjooTCBSIE0pIE5PVCBaOlAmc29ydF9uYW1lPUBzcHJmRkkmbGFuZz14bWxmJmZvcm1hdF9uYW1lPUBYU0hPUlQmcGFnZV9oZWFkZXI9RVhNTEgmcGFnZV9mb290ZXI9RVhNTEY%3D

Law on Fisheries (18/2017/QH14). Date of text: 21 November 2017

Decree No. 26/2019/ND-CP of the Government Regulating a number of articles and measures to implement the Fisheries Law. Date of text: 08 March 2019

Decree No. 42/2019/ND-CP regulating the Sanctioning Administrative Offences in the Field of Fisheries. Date of text: 16 May 2019

Decree No. 80/2012/ND-CP on management of fishing ports and storm shelter zones for fishing ships. Date of text: 08 October 2012

Decree No. 59/2005/ND-CP on conditions for a number of aquatic resources production and business lines. Date of text: 04 May 2005

Decision No. 103/2000/QD-TTg on a number of policies to encourage aquatic breeds development. Date of text: 05 August 2001

Decree No. 55/2019/ND-CP on providing legal assistance for small and medium -sized enterprises. Date of text: 24 June 2019

Circular No. 21/2018/TT-BNNPTNT regulating the recording, submission of reports and logbooks of aquatic resources; publication of designated fishing ports confirming the origin of fisheries from exploitation; list of illegal fishing vessels; certification of raw materials, certification of exploited aquatic resources issued by the Minister of Agriculture and Rural Development. Date of text: 15 November 2018

Decree No. 39/2018/ND-CP on guidelines for Law on support for small and medium -sized enterprises. Date of text: 11 March 2018

Circular No. 105/2010/TT-BTC guiding a number of articles of the Law on Royalties and guiding Government's Decree No. 50/2010/ND-CP of 14 May 2010 which details and guides a number of articles of the Law on Royalties. Date of text: 23 July 2010

Decree No. 32/2010/ND-CP on the management of fishery activities of foreign ships in Viet Nam's sea areas. Date of text: 29 March 2010

Decree of the Government No 27/2005/ND-CP regulating and guiding the implementation of certain articles in the Fisheries Law. Date of text: 08 March 2005

Decree No. 99/1998/ND-CP on management of sea-going vessel purchase and sale. Date of text: 28 November 1998

Directive No. 1/1998/CT-TTg to strictly ban the use of explosives, electric impulses and toxic substances to exploit aquatic resources. Date of text: 02 January 1998

Decision No. 596/QD-TTg establishing the National Steering Committee for combating Illegal, Unreported and Unregulated Fishing. Date of text: 20 May 2019

Decree No. 67/2014/ND-CP on a number of fisheries development policies. Date of text: 07 July 2014

Decree No. 51/2014/ND-CP providing the assignment of given sea areas to organizations and individuals for marine resource exploitation and use. Date of text: 21 May 2014

Decree No. 161/2013/ND-CP on registration, purchase, sale and building of seagoing ships. Date of text: 12 November 2013
Decision No. 375/QD-TTg approving the Scheme on reorganization of production in marine resource exploitation. Date of text: 01 March 2013
Decree No. 102/2012/ND-CP on the organization and operation of the fisheries resources surveillance force. Date of text: 29 November 2012
Decree No. 53/2012/ND-CP amending and supplementing a number of articles of the Decrees on fisheries. Date of text: 20 June 2012
Decision No. 635/QD-TTg approving the Project on yield and quality improvement of products and goods of the agricultural sector to 2020 under the national program on yield and quality improvement of products and goods of Vietnamese enterprises. Date of text: 30 May 2012
Decision No. 279/QD-TTg approving the program on aquatic product export development through 2015 and orientations to 2020. Date of text: 07 March 2012
Decision No. 188/QD-TTg approving the Program on protection and development of aquatic resources through 2020. Date of text: 13 February 2012
Circular No. 01/2012/TT-BTC guiding the customs clearance of imports and exports subject to quarantine. Date of text: 03 January 2012
Circular No. 124/2011/TT-BTC guiding registration fee. Date of text: 31 August 2011
Circular No. 28/2011/TT-BNNPTNT providing the validation of catch certificates and statements for exportation into the European market. Date of text: 15 April 2011
Decision No. 332/QD-TTg approving the Scheme on development of aquaculture through 2020. Date of text: 03 March 2011
Decision No. 1690/QD-TTg approving Vietnam’s fisheries development strategy through 2020. Date of text: 16 September 2010
Decree No. 52/2010/ND-CP on import of fishing vessels. Date of text: 17 May 2010
Regulation of the Maritime and Fisheries Minister No. PER.12/MEN/2010 on minapolitan. Date of text: 14 May 2010
Decree No. 33/2010/ND-CP on the management of fishing activities in sea areas by Vietnamese organizations and individuals. Date of text: 31 March 2010
Decision No. 2194/QD-TTg approving the Scheme on development of agricultural plant and forest tree varieties, livestock breeds and aquatic strains up to 2020. Date of text: 25 December 2009
Decision No. 2033/QD-TTg approving the Scheme to develop production and sale of “tra” catfish in the Mekong river delta up to 2020. Date of text: 04 December 2009
Decision No. 34/2009/QD-TTg approving the Master Plan on Development of the Tonkin Gulf Coastal Economic Belt up to 2020. Date of text: 02 March 2009
Decision No. 18/2009/QD-TTg approving the master plan on socio-economic development of Vietnam’s sea and coastal areas in the Gulf of Thailand up to 2020. Date of text: 03 February 2009
Decision No. 102/2008/QD-BNN approving the planning on development of the production and sale of “tra catfish” in the Mekong River delta region up to 2010, and orientations towards 2020. Date of text: 17 October 2008
Decision No. 85/2008/QD-BNN promulgating the Regulation on management of aquatic breed production and trading. Date of text: 06 August 2008
Decision No. 97/2007/QD-TTg approving the scheme on biotechnology development and application in the fisheries domain up to 2020. Date of text: 29 June 2007

Decision No. 01/2007/QD-BTS on the inspection of aquatic products exported to the US and Canada. Date of text: 13 February 2007

Decision No. 242/2006/QD-TTg approving the program on development of aquatic product export up to 2010 and orientations to 2020. Date of text: 25 October 2006

Decision No. 15/2006/QD-BTS promulgating the Regulation on management of import and export of fishery goods. Date of text: 08 September 2006

Decree No. 66/2006/ND-CP on Development of Rural Trades. Date of text: 20 July 2006

Decision No. 10/2006/QD-TTg approving the master plan on development of the fisheries sector till 2010 and orientations toward 2020. Date of text: 11 January 2006

Decision No. 51/2005/QD-BGTVT promulgating the Regulation on registration of Vietnamese seagoing ships. Date of text: 12 October 2005

Decree No. 128/2005/ND-CP providing for sanctioning of administrative violations in the fisheries domain. Date of text: 11 October 2005

Decision No.126/2005/QD-TTg on a number of policies to encourage development of aquaculture on sea and islands. Date of text: 01 June 2005

Decree No. 66/2005/ND-CP on ensuring safety for people and ships engaged in fisheries activities. Date of text: 19 May 2005

Decision No. 07/2005/QD-BTS promulgating the lists of chemicals and antibiotics, which are banned or restricted from use in fisheries production and business. Date of text: 24 February 2005

Decision No. 112/2004/QD-TTg approving the Program on the development of aquatic seeds till 2010. Date of text: 23 June 2004

Decision No. 11/2003/QD-BTC promulgating the rates of charges for inspection of the technical safety and quality of inland waterways means. Date of text: 24 January 2003

Decree No. 73/2002/ND-CP adding goods and trade services to List 1 of goods banned from circulation and trade services banned from provisions; and List 3 on goods and trade services subject to conditional business, issued together with the Government Decree No. 11/1999/ND-CP of March 3, 1999. Date of text: 20 August 2002

Regulation on management of aquatic veterinary drugs. Date of text: 23 January 2002

Circular No. 03/2002/TTBTC guiding the Tax Collection Management Regime applicable to aquatic resource-exploiting establishments. Date of text: 14 January 2002

Decision No. 148/2000/QD-TTg on continuing to grant certificate of origin of bivalve molluscs. Date of text: 19 December 2001

Regulation on the Fishing Ship Registry and the Fishing Ship and Crew Registration. Date of text: 15 June 2001

Decision No. 20/2000/QD-BTC issuing the table of charge and fee rates for aquatic resources protection. Date of text: 21 February 2000

Decision No. 251/1998/QD-TTg on the ratification of the Program for Developing the Export of Aquatic Products up to 2005. Date of text: 25 December 1999

Decision No. 224/1999/QD-TTg approving the Aquaculture Development Program for the 1999-2010 period. Date of text: 08 December 1999

Decision No. 640/1999/QD-BTS on the Regulation on hygiene and safety control of bivalve molluscs harvest. Date of text: 22 September 1999

Circular No. 05/1998/TT-BTS guiding the implementation of Decree No. 72/1998/ND-CP of 15 September 1998, of the Government on Ensuring safety for Fishermen and Fishing Means at Sea. Date of text: 29 December 1998

Ordinance on natural resources tax. Date of text: 1993

Decree of the Council of Ministers on Fishery Activities applicable to foreigners and their fishing equipment in the waters of the Socialist Republic of Vietnam. Date of text: 22 December 1990

Decision No 3919/QD-BNN-TCTS of the Minister of Agriculture and Rural Development on designation and announcement of List of sea ports for seafood - carrying foreign ships to land (Phase I). Date of text: 11 October 2019

Decision No. 3246/QĐ-BNN-TCCB regarding the task of controlling import, temporary import, re-export, temporary export, re-import, border-gate transfer and transit activities across the Vietnamese territory of fisheries, and fisheries products that are derived from illegal, unreported and unregulated fishing practices. Date of text: 20 August 2019

Circular No. 02/2006/TT-BTS Guiding the Implementation of the Government's Decree No. 59/2005/ND-CP on Production and Business Conditions of a Number of Fisheries Trades. Date of text: 20 March 2006

Circular No. 44/2010/TT-BNNPTNT providing for conditions on food safety and hygiene-guaranteed intensive Asian catfish-rearing establishments and zones. Date of text: 22 July 2010

Circular No. 45/2010/TT-BNNPTNT providing for conditions on food safety and hygiene-guaranteed intensive tiger shrimp- and white-leg shrimp-rearing establishments and zones. Date of text: 22 July 2010

Circular No. 41/2010/TT-BNNPTNT providing for veterinary hygiene inspection and certification for fishery production and trading establishments. Date of text: 05 July 2010

Circular No. 06/2010/TT-BNNPTNT stipulating the order of and procedures for quarantining aquatic animals and aquatic products. Date of text: 02 February 2010

Circular No. 09/2010/TT-BNNPTNT promulgating requirements on assurance of food quality, hygiene and safety in processing “tra” and “basa” catfish products for export. Date of text: 26 January 2010

Circular No. 53/2009/TT-BNNPTNT on management of alien aquatic species in Viet Nam. Date of text: 21 August 2009

Circular No. 02/2004/TT-BTS guiding the implementation of Goverment's Decree No. 70/ND-CP stipulating the sanctioning of administrative violations in the aquatic resource domain. Date of text: 22 March 2004

Joint Circular No. 27/2003/TTLT/BQP-BTS guiding the coordination between the Ministry of Defence and the Ministry of Aquatic Resources in performing State Management over the Coast Guard’s activities and the coordination of activities between the Coast Guard and concerned Forces of the sea areas and continental shelf of Vietnam. Date of text: 31 March 2003

Circular No. 10/2001/TT-BGTVT guiding the use of copies of the certificates of registration of the sea-going ships and copies of the certificates of registration of inland waterway transport means for circulation of such means when they are pledged or mortgaged for capital borrowing at credit institutions. Date of text: 11 June 2001

Circular No. 05/2000/TT-BTS guiding the implementation of the government Resolution No. 09/2000/NQ-CP on a number of policies for economic restructuring and consumption of agricultural products. Date of text: 03 November 2000

Circular No. 04/2000/TT-BTS guiding the implementation of a number of articles of the Prime Ministers Decision No. 103/1999/QD-TTg on a number of policies to encourage aquatic breeds development. Date of text: 03 November 2000

Circular No. 03/2000/TT-BTS guiding the implementation of the Prime Ministers Decision No. 178/1999/QD-TTg issuing the Regulation on the labelling of domestically-circulated goods as well as export and import with regard to aquatic goods. Date of text: 22 September 2000

Joint Circular No. 6000/1999/TTLT-BGTVT-BTS guiding the implementation of the Government Decree No. 72/1998/ND-CP ensuring safety for fishermen and fishing means operating on the sea. Date of text: 09 December 1999

Joint Circular No. 04/1998/TTLT-TS-KHDT-NHNNVN guiding the management and use of investment credit capital under the State Plan for projects of building and mofification of offshore fishing ships and fishing service ships. Date of text: 17 December 1998

Circular of the Minister of Aquatic Resources No. 2/1998/TT-BTS implementing Decree No. 15-CP/1996 on animal feed. Date of text: 14 March 1998

Decree No. 80/2021/ND-CP on elaboration of some articles of the Law on Provision of Assistance for Small and Medium Enterprises. Date of text: 26 August 2021

Decision No. 172/2002/QD-TTg amending Clause 2, Article 2 of the Prime Minister’s Decision No. 144/2002/QD-TTg on a number of measures to handle debts incurred due to borrowing capital for repairing and building ships and boats as well as procuring fishing gear with preferential credit capital source under the Prime Minister’s Decision No. 985/TTg. Date of text: 28 November 2002

Circular No. 43/2010/TT-BNNPTNT amending and supplementing articles 16 and 17 of the Agriculture and Rural Development Ministry’s Circular No. 06/2010/TT-BNNPTNT of 2 February 2010 stipulating the order and procedures for quarantine of aquatic animals and aquatic products. Date of text: 14 July 2010.

Appendix 8. List of revolution and decision

Resolution No.120/NQ-CP dated November 17, 2017, of the Government on “Sustainable and climate-resilient development of the Mekong River delta”. Link: https://english.luatvietnam.vn/resolution-no120-nq-cp-dated-november-17-2017-of-the-government-on-sustainable-and-climate-resilient-development-of-the-mekong-river-delta-118378-Doc1.html#:~:text=At%20the%20Resolution%20No.,coverage%20will%20reach%20over%209%25.

Decision No. 9/CT dated 17/01/1989 on Import and supply of pesticide services for agriculture production. Link: https://thuvienphapluat.vn/van-ban/Thuong-mai/Quyet-dinh-9-CT-nhap-va-cung-ung-thuoc-tru-sau-phuc-vu-san-xuat-nong-nghiep-37706.aspx

Decision No. 03/QD-BNN-BVTV (03/01/2017). Decision on the removal of pesticides containing Carbendazim, Benomyl and Thiophanate-Methyl from the List of pesticides permitted for use in Vietnam. Link: https://www.ppd.gov.vn/uploads/news/2017_01/QD03%20-%20ngay%2003.01.2016%20loai%20bo%20thuoc%20BVTV%20chua%20Carbendazim%20Benomyl.pdf

Ordinance No. 08/L/CTN dated 15/2/1993 on Ordinance on Plant Protection and Quarantine. Link: https://thuvienphapluat.vn/van-ban/The-thao-Y-te/Phap-lenh-bao-ve-kiem-dich-thuc-vat-1993-8-L-CTN-38464.aspx.

Decision 1163/QD-TTG dated July 31, 2020 approving the mission for planning the Mekong delta stage 2021-2030, vision to 2050. Link: https://thuvienphapluat.vn/van-ban/xay-dung-do-thi/quyet-dinh-1163-qd-ttg-2020-phe-duyet-nhiem-vu-lap-quy-hoach-vung-dong-bang-song-cuu-long-448844.aspx

Decree No. 109/2018/ND-CP dated August 29, 2018 about organic agriculture. Link: https://thuvienphapluat.vn/van-ban/Linh-vuc-khac/Nghi-dinh-109-2018-ND-CP-chung-nhan-ghi-nhan-san-pham-nong-nghiep-huu-co-358653.aspx

Decision No. 278/QD-BNN-BVTV (08/02/2017). Decision on the removal of pesticides containing 2.4 D and Paraquat from the List of pesticides permitted for use in Vietnam. Link: https://www.ppd.gov.vn/uploads/news/2017_02/QD_278_08.02.2017_%20loai%20bo%20thuoc%20BVTV%20chua%20chat%202.4D.pdf

Decision No. 4154/QD-BNN-BVTV (16/10/2017). Decision on the removal of pesticides containing Trichlorfon from the List of pesticides permitted for use in Vietnam. Link: https://www.mard.gov.vn/VanBan/VanBan/QD-%20%204154%20lo%E1%BA%A1i%20b%E1%BB%8F%20c%C3%A1c%20thu%E1%BB%91c%20BVTV%20ch%E1%BB%A9a%20ho%E1%BA%A1t%20ch%E1%BA%A5t%20Trichlorfon%20.pdf

Decision No. 3435/QD-BNN-BVTV (28/08/2018). Decision on the removal of pesticides containing Acephate, Diazinon, Malathion, Zinc Phosphide from the List of pesticides permitted for use in Vietnam. Link: https://luatvietnam.vn/nong-nghiep/quyet-dinh-3435-qd-bnn-bvtv-2018-loai-bo-thuoc-bao-ve-thuc-vat-chua-hoat-chat-acephate-166683-d1.html

Decision No. 501/QD-BNN-BVTV (12/02/2019). Decision on the removal of pesticide containing Chlorpyrifos Ethyl and Fipronil chemicals from the List of pesticides permitted for use in Vietnam. Link: https://www.ppd.gov.vn/FileUpload/Documents/Thuoc%20BVTV/2019_02_12_Quyet%20dinh%20so%20501.QD.BNN.BVTV.pdf

Decision No.1186/QD-BNN-BVTV (10/04/2019). Decision on the removal of pesticide containing Glyphosate chemicals from the List of pesticides permitted for use in Vietnam. Link: https://www.ppd.gov.vn/FileUpload/Documents/Thuoc%20BVTV/2019.04.10%20qd%201186%20loai%20bo%20glyphosate.pdf

Appendix 9: Relevant capture fisheries and small-scale fisheries chapters of the fisheries law of 2003

Chapter of law	Description of chapter
Chapter II	Protection and development of fisheries resources regulates the protection of aquatic habitats, the protection, conservation, enhancement and development of fisheries resources, protected inland areas and marine parks, financial sources for rehabilitation of fish stocks
Chapter III	Fishing regulates fishing operations conducted at sea, in rivers and lagoons. It lays down the fishing rights of organizations and individuals, as well as the granting and withdrawal of fishing licenses
Chapter V	Fishing vessels and services of fisheries activities lays down the management of fishing vessels, fishing ports, fish landing places and fish wholesale markets
Chapter VIII	State management of fisheries activities regulates the state management contents on fisheries activities, competence of state management on fisheries activities and clearly sets out the duties of the Ministry to cooperate with other relevant Ministries and sectors, and People's Committees at all its levels
Chapter IX	Rewards and sanctions for enforcement

Source: Pomeroy, Thi Nguyen [163].

[page]

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