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Foresighting future climate change impacts on fisheries and aquaculture in vietnam

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The Vietnamese fisheries sector, including both marine fisheries and aquaculture, has made spectacular progress in recent years, becoming one of the top seafood producing and exporting countries in the world. Looking forward, development goals of this sector must address challenges associated with climate change, including changing distribution of commercially important marine species such as tuna and disruptions to land-based aquaculture production systems. This study investigates the prospective climate change impacts on Vietnam's fisheries sector, focusing on four key commodities including capture fisheries (tuna), freshwater aquaculture (pangasius catfish and tilapia), and brackish water aquaculture (shrimp). The extent of impact varies, but climate change represents a potentially significant threat to sustainable production in each production system. Producers, policy makers, and other stakeholders need to plan for and adapt to climate change to ensure the sustainable development of Vietnam's fisheries sector.

KEYWORDS

aquaculture, capture fisheries, climate change impacts, foresight, Vietnam

Introduction

Vietnam's fisheries sector has emerged as a dynamic engine of economic growth important both for food security and foreign exchange earnings. In 2018, Vietnam ranked seventh in marine capture fisheries and fourth in aquaculture production in the world, earning US$8.9 billion in seafood exports [FAO (Food and Agriculture Organization), 2020]. Seafood available for consumption totaled 37.7 kg per capita in 2016 and the fisheries sector represented 3.4% of Vietnam's gross domestic product [FAO (Food and Agriculture Organization), 2021]. Until recently, marine capture fisheries played a leading role in seafood production in Vietnam. After 2007, however, aquaculture production surpassed that of the marine sub-sector and has expanded its role ever since (Figure 1).

The government of Vietnam has promoted aquaculture as a means of reducing rural poverty and diversifying rural livelihoods while increasing seafood exports to

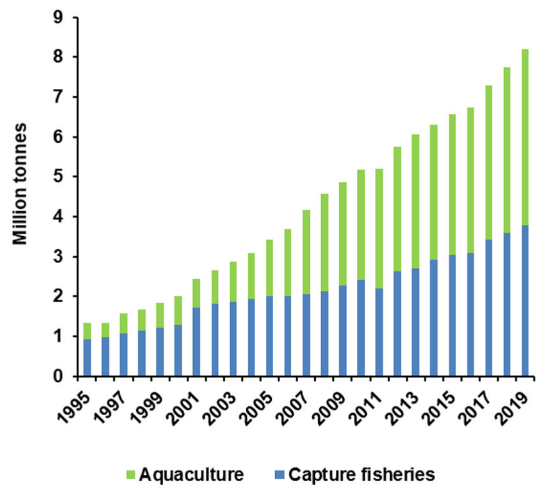

FIGURE 1
Aquaculture and capture fisheries production in Vietnam, 1995–2019. Data source: Directorate of Fisheries (2017, 2018, 2019), and General Statistics Office (2018).

earn foreign exchange earnings to support the country's socio-economic development (Ha and Bush, 2010). Three species are of particular importance in Vietnam's aquacultural development: pangasius catfish, tilapia, and shrimp. Pangasius (Pangasius *hypophthalmus*) are primarily grown in the Mekong River Delta (MRD) of southern Vietnam using an intensive freshwater production system. Some pangasius producers have shifted to tilapia (*Oreochromis niloticus)*, another freshwater species, which is grown both in the MRD and in the Northern provinces. Shrimp farming in brackish water bodies including coastal mangroves, tidal flats, and saline rice fields has been centered primarily in the MRD. Initially, shrimp farming involved low-intensity production methods of tiger shrimp (*Penaeus monodon*) but in recent years, there has been a shift to the white-legged shrimp (Litopenaeus vannamei) with a higher production intensification level. Low-intensity production systems are still common among small-scale producers in the MRD, but higher intensity production systems (i.e., greater stocking densities and higher feeding rates) have played a critical role in expanding Vietnam's shrimp production (Gaudreau et al., 2012; Armitage and Marschke, 2013). Recently, the Vietnamese government passed the National Action Plan for Vietnam's shrimp industry development to encourage shrimp farmers to take part in certification systems for the industry, an increasingly important means of ensuring access to the most lucrative international markets (Tran et al., 2013; Government of Vietnam, 2018). In the Mekong delta region, Resolution No.120/NQ-CP (2017) on climate resilient and sustainable development has highlighted the importance of restructuring and transforming agriculture in three main aspects (aquatic products, fruit trees and rice) in association with agro-ecological zones and, of these, aquatic products (freshwater, brackish water and saltwater) are the main products.

Climate change represents a serious challenge for sustainable development of Vietnam's fisheries sector. Vietnam's long-term development strategy is aligned with the Sustainable Development Goals (SDGs) of the United Nations, which include responsible production practices, protecting coastal, marine, and terrestrial ecosystems, and addressing climate change (Ministry of Planning Investment, 2018). Wilbanks (2003) argues that climate change represents both a challenge to and a catalyst for progress toward sustainable development goals. Mitigating the worst consequences of climate change can help establish a solid foundation for sustainable development of Vietnam's fisheries sector.

Vietnam is one of the world's most vulnerable countries to climate change impacts because of its long coastline (3,260 km) with areas highly susceptible to flooding, and large, densely populated river deltas (Climatelinks, 2017; FAO (Food and Agriculture Organization), 2021). The Intergovernmental Panel on Climate Change (IPCC) predicts a mean eustatic (global) sea level rise between 0.43m and 0.84m by the end of the twenty-first century (Oppenheimer et al., 2019). Local sea level rise in a deltaic environment may differ from eustatic change due to changes in sediment transport caused by upstream dam construction, subsidence due to groundwater withdrawal, changes in ocean currents, or coastal erosion caused by the removal of mangroves (Darby et al., 2020; Tamura et al., 2020). Most importantly, eustatic sea level estimates do not consider the impact of storm surges associated with tropical typhoons. Much of the area currently devoted to shrimp farming in the MRD would be affected by sea level rise and inundation by storm surges. Significant problems of rising sea levels, salinity intrusion, changing salinity gradients in groundwater aquifers, and permanent submergence of land are foreseen in large parts of MRD (Smajgl et al., 2015; Boretti, 2020; Giusto et al., 2021; Xiao et al., 2021). While Vietnam is the world's largest pangasius producer (Vietnam Association of Seafood Exporters and Producers (VASEP), 2016), the MRD is the center of Vietnam's pangasius industry (Halls and Johns, 2013). Pangasius culture is located further from the coast in areas not currently affected by saline intrusion, but sea level rise could change this, causing the industry to move further upriver.

Coastal fishing villages and major fishing ports in the coastal provinces from the northern to southern part of the country (e.g., Hai Phong, Da Nang, Khanh Hoa, and Ba Ria- Vung Tau) are vulnerable to tropical typhoons and other extreme weather events that can damage or destroy fishing boats and port infrastructure. Beyond that, climate change can affect physical and biological conditions in the marine environment including water temperatures, salinity, and acidification of sea water, all of which can affect habitat (coral reefs, mangrove/estuarine ecosystems) and the growth, development, reproductive capacity, and distribution of marine species (Brander, 2007, 2012; Cooley and Doney, 2009; Badjeck et al., 2010; Doney et al., 2012; Savo et al., 2017; Ahmed et al., 2019).

In this paper, we applied a qualitative strategic foresight approach to provide decision makers the analytic ability to recognize threats, opportunities and trends associated with climate change. This qualitative information will also serve as a foundation for continuing quantitative foresight modeling efforts. Foresight is designed to be an integral part of development planning and investment prioritization for an economic sector such as fisheries and aquaculture (World Bank, 2013; Chan et al., 2017, 2019, 2021; Tran et al., 2017, 2019). Over the years, the Vietnamese government has developed strategies and master plans for the fisheries sector, but these strategies and plans have not benefitted from data and insights based on objective and systematic foresight. Currently, the number of Vietnamese professionals with expertise in strategic foresight related to the fisheries sector is still limited. The need for foresight today is particularly urgent given that climate change currently is and will continue to affect aquatic resources of all kinds, with serious consequences for the fisheries sector.

Methodology

Foresight analysis has been widely applied in various fields to study future uncertainties (Cook et al., 2014). It is a creative process to help identify possible, plausible and alternative futures to support decision making under increasing uncertainty. Foresight approaches take three major forms: quantitative, qualitative, and semi-quantitative (Popper, 2008). Quantitative methods estimate variables and employ statistical analysis (Popper, 2008). Quantitative foresight is relatively helpful in forecasting systems with well-understood variables over a short period of time but works less well for extended periods when uncertainties are significant and unqualifiable (Cook et al., 2014). Qualitative foresight has been employed to generate future perspectives in the distant future characterized by increasing uncertainties and complexity. As qualitative foresight planning has the potential to facilitate and structure discussions between stakeholders and scientists about the uncertainties, it can contribute to increased legitimacy, collective learning, and advanced scientific understanding (Rockmann et al., 2012). Qualitative narratives with descriptive richness can effectively illustrate the nature of ambiguity and the variables (quantitative and qualitative) that go into quantitative foresight modeling. Efforts to integrate quantitative (e.g., economic based simulation models) and qualitative description are referred to as a semi-quantitative approach to future prospects building (Cook et al., 2014). Foresight methods allow us to explore knowledge gaps and identify the common drivers/problems before describing plausible alternative futures related to the targeted sector. The methods can also allow testing of how different systems or interventions might help to respond to the challenges that are likely to affect the targeted sector in the future (Prager and Wiebe, 2021).

Using a qualitative and exploratory foresight approach (Reilly and Willenbockel, 2010), this study investigates the prospective climate change impacts on fisheries and aquaculture in Vietnam, drawing insights from two participatory stakeholder consultation workshops conducted in 2015 and 2019 in Vietnam. The two workshops were activities of climate change adaptation projects funded by the CGIAR research programs on Climate Change, Agriculture and Food Security (CCAFS) and Policies, Institutions and Markets (PIM) and were organized by WorldFish in collaboration with the International Food Policy Research Institute (IFPRI) and the Vietnam Institute of Fisheries Economics and Planning (VIFEP). Each workshop included 20–30 key stakeholders representing the public and private sectors, industry associations, research institutions, national and international non-profit organizations in Vietnam, and academia. The intent was to involve a wide range of actors whose knowledge and experience would allow them to analyze the socio-environmental issues associated with marine capture fisheries, aquaculture, climate change, economics, and international trade. The first step was to engage the core research team in a preliminary literature, the results of which were presented at the beginning of each workshop. The core research team then identified types of stakeholders and stakeholder organizations to participate in the workshops so that diverse experiences and views could be brought for creative thinking to explore future scenarios perspectives of climate change impacts on marine capture fisheries and aquaculture.

In the first workshop conducted in Vung Tau in 2015, an introductory presentation on the importance of the foresight approach and the expected outcomes of this participatory technique to generate qualitative foresight narratives were given. To start the exercise of suggesting drivers of change, participants were first asked to identify past drivers of change that shaped aquaculture in the MRD over the past ten years. Two professional researchers (workshop facilitators) monitored the discussions. Participants were then divided into groups to identify drivers of change that will likely affect aquaculture in the MRD in the future. Groups were instructed to assign scores from "1 to 5" to each driver, based on its impact and level of uncertainty. An impact score of "5" represents if a driver of change would have a significant impact on aquaculture. Similarly, an uncertainty score of "5" implies that the likelihood of a driver happening is highly unpredictable. After that, facilitators assembled the groups to categorize identified drivers of change into different themes. Using the "two-axes" foresight development approach, two critical drivers with the highest impact and uncertainty scores were distinguished to develop a four-quadrant foresight logic for the future fishery sector in Vietnam in the next 15–30 years. A representative from each group presented the narrative storyline of the impacts and uncertainty scores of the drivers.

The second workshop in 2019 conducted in Hanoi stretched over three sessions. In the first session, the participants were asked to discuss the past and current trends in Vietnam's fishery sector. In terms of the key drivers identified in the first workshop, the information on what trends are happening and their certainty levels were shared with participants attending the second workshop in the second workshop session. The third session included a presentation on the prospective future of the Vietnamese fisheries sector by exploring the challenges and opportunities faced by four key commodities representing capture fisheries (tuna), freshwater aquaculture (pangasius catfish and tilapia), and brackish water aquaculture (shrimp). In this session, participants were asked to identify the potential impacts and uncertainties of key drivers in the Vietnamese fisheries sector in the future. After completing these sessions, participants were asked to discuss the identified drivers and explore potential impacts and uncertainties of the identified drivers and provide a narrative explaining how plausible futures of the fisheries and aquaculture sub-systems in Vietnam might emerge. In each session of the workshop, facilitators monitored activities to ensure constructive discussion and then encouraged participants to investigate new possibilities, come up with imaginative ideas and promote a broader view of fishery sector development in the context of climate change impacts. In addition to the insights from the two workshops, the study also used data and information collected from the literature review and key informant interviews with the different stakeholders in Vietnam's fishery industry. We believe the viewpoints expressed and reported upon here during the two workshops and literature review and key informant interviews provide an informed basis for our foresight analysis.

Results

Past and current trends of vietnamese capture fisheries and aquaculture sector

Vietnam's fisheries sector plays an important role in rural and agricultural development and is of increasing significance for the country's economy in general. Over the past 20 years, Vietnam's fisheries sector has experienced rapid production growth, increasing from 1.34 million MT in 1995 to 7.74 million MT in 2018, a nearly six–fold increase in 23 years (Figure 1). By 2007, aquaculture production had surpassed harvests from capture fisheries in total production, accounting for 54 percent of the total by 2018. The fisheries sector has made substantial contributions to rural restructuring through poverty reduction and job creation—nearly five million workers are employed in different segments of the fisheries and aquaculture value chains (Phuong and Minh, 2005; Duijn et al., 2012; Entzian, 2015).

Capture fisheries production

On a global basis, harvests from marine capture fisheries have been stagnant, but this is not so for Southeast Asia in general or Vietnam. According to the General Statistics Office (GSO) and the Directorate of Fisheries (2018), Vietnam's capture fisheries output tripled from 929,000 MT in 1995 to 3,590,000 MT in 2018. Of this total, 94% came from marine fisheries with the remaining harvest coming from inland waters. Data on marine capture fisheries were reported for four regions, including the Gulf of Tonkin, the Central and South-Eastern regions, and the MRD. Even as landings of fish increased, the relative share of landings between these four regions remained remarkably constant (Figure 2). Of marine capture fisheries output, tuna harvests (primarily skipjack and yellowfin) were reported at 16,650 MT (Directorate of Fisheries, 2018).

Aquaculture area and production

Aquaculture has been practiced in Vietnam for centuries using low-intensity "traditional" production methods. A shift toward more intensive systems began in the 1960s but the real change came after the year 2000 when the Vietnamese government encouraged farmers to convert low productivity saline rice fields, uncultivated areas, and salt pans in the coastal zone into brackish water ponds for aquaculture (The Government of Vietnam, Resolution No.09/2000/NQ-CP of June 15, 2000). This new policy encouraged private sector investment in both production and processing facilities. Public sector infrastructure investments also were made. Between 1995 and 2018, aquaculture production in Vietnam increased by more than 10 times, from 415,000 MT to 4,153,000 MT, with most of this gain coming since 2000 (Directorate of Fisheries, 2017; General Statistics Office, 2018). Finfish and shrimp accounted for 70% and 19%, respectively, of total production.

A total of 1.1 million hectares are devoted to aquaculture in Vietnam, with brackish water ponds accounting for two-thirds of the total and dedicated almost exclusively to shrimp production (Directorate of Fisheries, 2018). As can be seen in Figure 3, between 2000 and 2018, total aquaculture production increased at a far higher rate than the area under production. Eighty percent of shrimp production in Vietnam occurs in the MRD (Ministry of Agriculture and Rural Development (MARD), 2019) where it has contributed significantly to economic development for hundreds of thousands of small-scale producers (Tran et al., 2013; Jo et al., 2019). Vietnam ranks third in the world for volume of farmed shrimp production (FAO (Food and Agriculture Organization), 2018), generating US$ 3.7 billion in export value in 2020 (Ministry of Agriculture and Rural Development (MARD), 2021). The MRD also is the center for aquaculture production of finfish, notably pangasius. The area devoted to pangasius production is relatively small

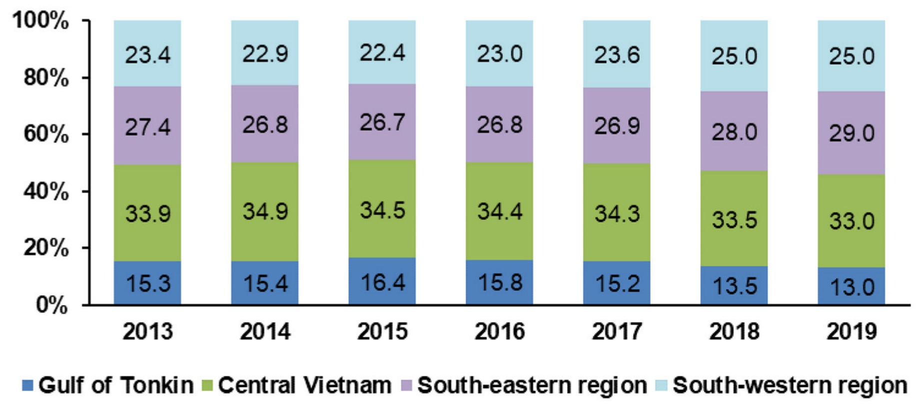

FIGURE 2
Proportion of regional marine landings in Vietnam, 2013–2019. Data source: Directorate of Fisheries (2017, 2018, 2019), and General Statistics Office (2018).

(5,200 hectares) but the methods employed are highly intensive and yield production totaling 1.25 million MT, accounting for nearly half of all finfish production nationwide (Directorate of Fisheries, 2018).

The concentration of aquaculture production in the MRD creates significant vulnerability to climate change and particularly to the combination of extreme weather events and sea level rise (Hallegatte et al., 2013). On average, Vietnam is hit by typhoons four to six times a year, bringing high winds, heavy rainfall, and storm surges that destroy homes and infrastructure, and frequently lead to human fatalities. Tropical storms that do not reach typhoon intensity may also cause damage to infrastructure and production facilities and flooding of shrimp ponds. Storm surges combined with projected sea level rise of half a meter or more in the decades to come threaten large parts of the MRD. This problem is compounded by the construction of numerous dams along the course of the Mekong Delta, which have the effect of reducing the river's sediment load and starving the delta of new building material (Eyler, 2020). Vietnam's Directorate of Fisheries (2017) has warned that climate change is likely to have an impact on the fisheries sector.

Fish market and trade

Since 2014, Vietnam has maintained its position as the third largest exporter of seafood in the world by value, following China (the largest exporter) and Norway (the second largest exporter) [FAO (Food and Agriculture Organization), 2020]. In 2018, total export earnings from the fisheries sector reached US$ 8.8 million, nearly four times the value of exports in 2004 (Vietnam Association of Seafood Exporters Producers, 2019). The main importers included the United States (US$1.6 billion), the European Union (US$1.5 billion), Japan (US$1.4 billion), and China (US$1.2 billion). South Korea and other nations of Southeast Asia are emerging as promising markets. Shrimp (US$3.6 billion), pangasius (US$2.3 billion), cephalopods (US$672 million), and tuna (US$653 million) were the main export products.

Vietnam's success in seafood exports is based not only on production within the fisheries sector but also on significant improvements in seafood processing capacity and quality (Kagawa and Bailey, 2006; Do et al., 2019). Strict food safety requirements for export products represent significant obstacles for the hundreds of thousands of small-scale shrimp producers and the small-scale traders who buy shrimp at the farm (Tran et al., 2013). In many if not most cases, neither the producer nor the trader keeps the kind of records necessary for proof of origin tracing used in seafood certification programs. Organizing hundreds of thousands of small-scale producers and traders in a way to meet certification standards is a huge challenge. Access to the most profitable international seafood markets requires that strict food safety standards be met, including the absence of antibiotic residues. A variety of certification programs (e.g., Marine Stewardship Council and the Aquaculture Stewardship Council) have additional standards that address sustainability and social justice, among other issues. Obtaining certifications provides access to markets that pay price premiums but are not realistic options for an individual farmer operating a one-hectare pond. Tran et al. (2013) suggested that organized groups of small-scale producers and processors could work together and gain mutual benefits—small-scale producers could receive a premium price while the processors could promote their products as supporting small-scale farmers. At present, however, most of the benefits from higher prices brought by certification programs have been captured either by processors who operate their own

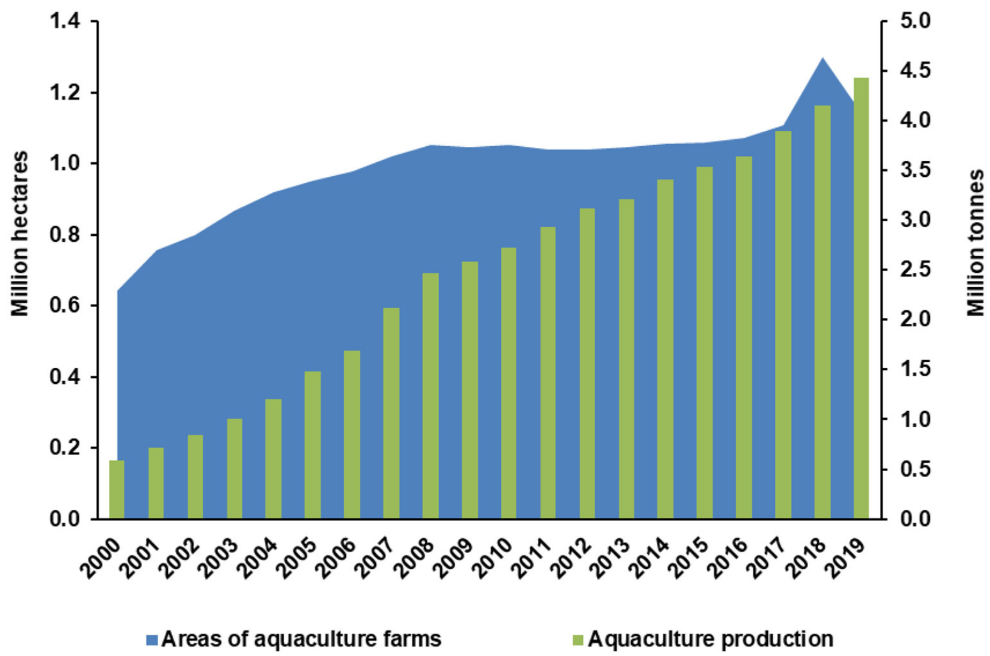

FIGURE 3
Areas of aquaculture farms and aquaculture production in Vietnam, 2000–2019. Data source: Directorate of Fisheries (2017, 2018, 2019), and General Statistics Office (2018).

shrimp farms or by a small number of well-capitalized shrimp producers who manage their farms with higher levels of inputs and productivity than is possible among small-scale farmers.

Prospective of climate change impacts on key fishery commodities

This section starts by describing the various ways Vietnam's fisheries and aquaculture sector is vulnerable to climate change. We then forecasted the likely effect of climate change on the production of four key commodities. In this discussion, marine capture fisheries were represented by tuna while pangasius catfish, tilapia, and shrimp represented freshwater and brackish water aquaculture.

Based on climate change projections published by the IPCC and indicators of exposure, sensitivity, and adaptive capacity covering the period 1989–2014, Cao et al. (2019) developed a vulnerability index (VI) for aquaculture in all 698 districts of 63 provinces in Vietnam. As shown in Figure 4, fish farming was at medium or high vulnerability levels throughout the country. Shrimp farming was identified as being even more vulnerable (Figure 5). In both cases, parts of the MRD scored highly on the vulnerability index. Kam et al. (2015) reported similar findings of widespread vulnerability, including in the MRD where aquaculture production is concentrated.

The studies by Kam et al. (2015) and Cao et al. (2018) used both social and physical indicators to estimate vulnerability to climate change. In these studies, vulnerability estimates of the aquaculture sector in the MRD have been reduced due to investments in local infrastructure as well as poverty alleviation programs supported by both local government and international/national agencies. These studies also relied on data for current levels of vulnerability and do not project into the future. Foresight modeling requires looking into the future, and for our purposes, this involves estimates of temperature, rainfall, and sea level rise from now to the end of the current century.

Minderhoud et al. (2019) examined elevations in meters above mean sea level for the MRD. Their findings showed 29% of the MRD would be inundated by a sea level rise of 50 cm, and this figure would increase to 54% with a rise of 80 cm. Sea level rise of one meter would submerge lands currently occupied by 12 million people, 70% of the MRD's population. The western MRD facing the Gulf of Thailand is the area that will first experience inundation due both to eustatic sea level rise and to land subsidence caused by sedimentation and withdrawal of freshwater for domestic purposes (IPCC, 2007; Thuc et al., 2016). Sea level rise of 80 cm could inundate a substantial area of shrimp farming and a one-meter rise would threaten pangasius production areas along the various courses of the Mekong River (Kam et al., 2012). Previous studies indicated the Red River Delta

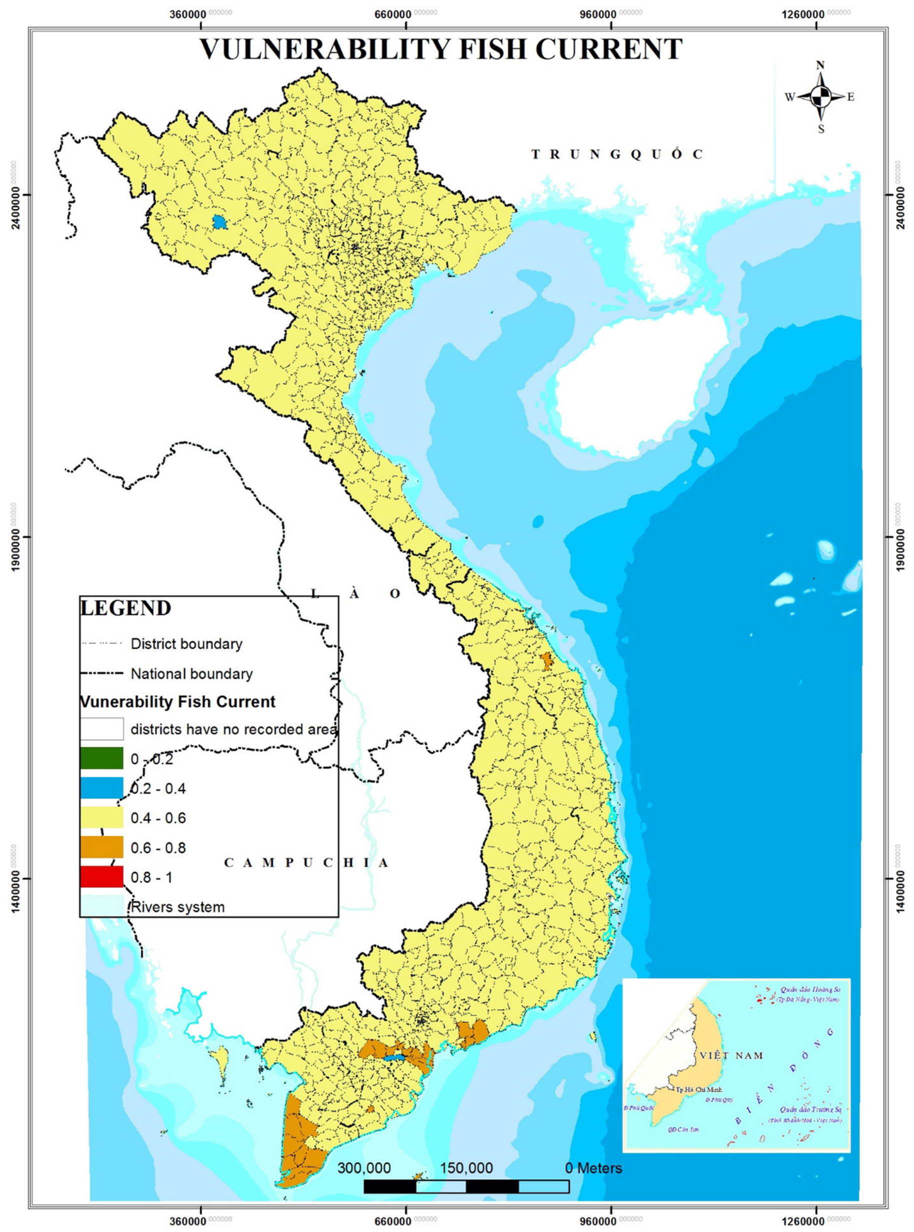

FIGURE 4
Vulnerable level of fish farming to climate change. Source: Cao et al. (2018).

in northern Vietnam also is vulnerable to inundation due to sea level rise (Carew-Reid, 2008).

In addition to sea level rise, climate change may affect maximum temperatures and rainfall patterns. Over the past 50 years, rainfall has increased by 5–20% in the South but decreased by 5–10% in the North. Climate change could contribute to an increase in extreme weather events, droughts, and changes in salinity affecting estuarine and coastal environments. These changes could affect the reproductive success of crustacean and finfish species. Protecting some coastal areas from sea level rise is technically possible but protecting thousands (or even hundreds) of kilometers of coastline is not a likely scenario. There are engineering solutions to issues associated with extreme weather, flooding, and other problems, but the broader environmental impacts of climate change will require adaptive management within the fisheries sector designed to mitigate challenges forecast to occur decades in the future. In the sections, which follow, we examined the likely impacts of climate change on tuna capture fisheries freshwater aquacultural production of pangasius and tilapia, and brackish water production of shrimp.

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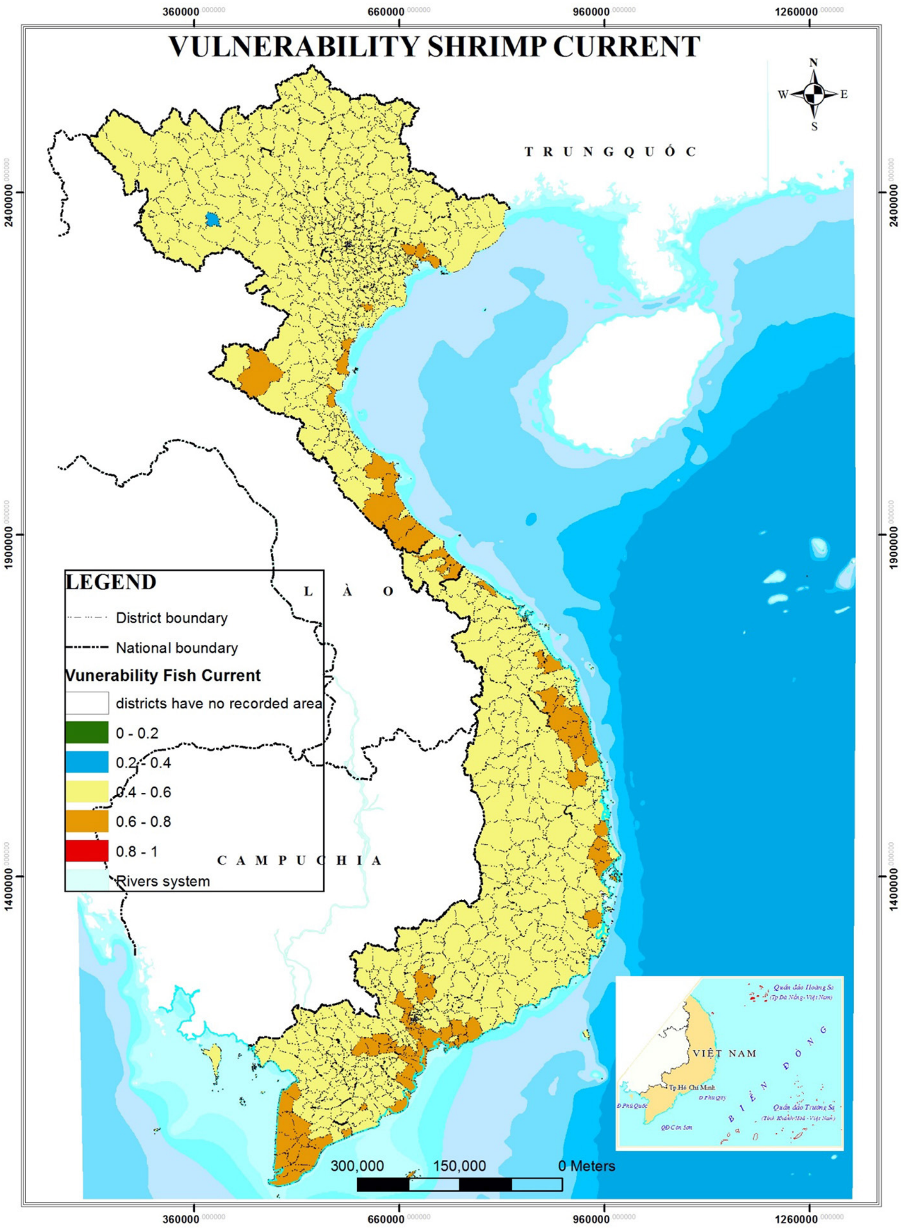

FIGURE 5
Vulnerable level of shrimp farming to climate change. Source: Cao et al. (2018).

Tuna—capture fisheries

Vietnam has a long coastline and an Exclusive Economic Zone of more than 1 million km². Tuna species are important to Vietnam's capture fisheries sector, with 2018 landings of skipjack tuna totaling 91,461 MT followed by yellow-fin tuna (25,455 MT) and big eye tuna (3,618 MT) [FAO (Food and Agriculture Organization), 2018]. Climate change affects water temperature and the distribution of prey species and therefore tuna species (Cao et al., 2017). Intensified wind and wave action are likely consequences of ocean warming, as are increases in the number and intensity of tropical typhoons that damage both fishing boats and coastal infrastructure important to tuna and other capture fisheries such as cold storage, processing, and transportation facilities (CCSP, 2008). Changes in ocean temperature also can affect dissolved oxygen concentrations, ocean circulation and upwelling that brings nutrients from the seafloor to the surface, thereby increasing primary productivity (e.g., phytoplankton and zooplankton) that supports marine food webs where tuna are apex predators. In addition, rising temperatures are associated with increased ocean acidification, particularly in surface waters (FAO (Food and Agriculture Organization), 2009). Acidification has the potential to disrupt primary productivity and adversely affect the reproductive success of both vertebrates (e.g., tuna and prey species) and invertebrates (e.g., phytoplankton and zooplankton) by harming eggs and larvae at vulnerable life stages.

No detailed studies of how climate change affects tuna species in Vietnam's waters are available, but studies in the Pacific Ocean provided a starting point for understanding. Changes in ocean temperature drive atmospheric and hydrological cycles. The El Niño-Southern Oscillation (ENSO) phenomenon is a recurring climate pattern involving the warming and cooling of tropical waters in the central and eastern Pacific Ocean and has been shown to impact the location and stock sizes of Pacific tuna fisheries. Warmer El Niño conditions favor an increase in skipjack abundance, with a spatial shift in an easterly direction while the cooler La Niña phase results in a shift of skipjack tuna populations to the west (Lehodey et al., 2010, 2011; Guidry and Mackenzie, 2012). Within Vietnam's Exclusive Economic Zone, it is likely that skipjack and other tuna species will gradually move away from the equator (i.e., to the north). Dueri et al. (2014) projected a deterioration of skipjack habitat in most tropical waters and an improvement of habitat at higher latitudes. The primary driver of habitat changes is ocean warming, followed by food density (prey species) changes. Globally, the model used by Dueri et al. (2014) showed an increase in global skipjack biomass between 2010 and 2050 followed by a marked decrease between 2050 and 2095. A more recent study published by Senina et al. (2018) confirmed these results and extends them to include yellowfin tuna.

Climate change is likely to lead to changes in tuna distribution and abundance, though the changes will be gradual rather than abrupt. Most of the available research has focused on skipjack tuna, but there is no reason to expect fundamental predator/prey relationships would be different for other tuna species. Currently, tuna is landed by wooden-hulled vessels using longlines off the coast of central and northern Vietnam (Urch, 2016). According to the workshop discussion among experts, as water temperatures increase, this change will affect water circulation, will change availability of prey species tuna depend on, and may change the ocean floor. Higher ocean water temperatures will tend to drive tuna stocks in a northerly direction toward China, a movement that may reduce access to these stocks by Vietnamese fishers. Increased rainfall will change the pH at the ocean surface and affect salinity, particularly near major river deltas. These changes could affect the reproductive success of prey species tuna depend upon. Climate change also can lead to increased frequency and severity of typhoons and tropical storms, affecting the ability of fishermen to operate in heavy seas or travel greater distances in search of tuna. All these factors may adversely affect the fortunes of Vietnam's tuna fisheries. The growth and increasing sophistication of Vietnam's seafood processing industry may result in tuna caught by fleets from other countries being landed in Vietnam for processing and re-export. Given these possible changes, fishermen and other stakeholders will need to adapt to maintain high levels of production.

Pangasius aquaculture

The total production of pangasius catfish in 2018 was 1.42 million MT from ponds with a total area of 5,200 hectares (Directorate of Fisheries, 2018). Between 2014 and 2018, the total area devoted to pangasius production has remained relatively constant while overall productivity has shown a gradual increase, achieving a level of 273 MT/ha in 2018. As noted above, pangasius production is an important source of foreign exchange earnings.

Climate change may adversely affect pangasius production due to flooding and degraded water quality. Pangasius ponds are located adjacent to the various Mekong River channels that run through the MRD. Typhoons that affect the MRD often occur in November and are a source of flooding risk. Other tropical storms and the possibility of increasingly heavy rainfall could lead to frequent flooding, erosion of pond dikes, damage to farm facilities, fish disease problems with higher turbidity levels and lowered PH, and escapes of fish from ponds inundated by flood-waters. Sea level rise and episodic storm surges associated with typhoons and other tropical storms can push saline water from estuaries further into the interior, resulting in the loss of production area. This latter threat can be addressed by moving production facilities further upstream.

Based on Global Climate Models (GCM) and Providing Regional Climates for Impacts Studies (PRECIS) climate model by Jones et al. (2003), temperatures in the MRD between Ca Mau Province and Ho Chi Minh City are projected to increase by 1°C in 2050 and between 1.4°C to as much as 2.7°C by the year 2100. Climate change in the MRD also will affect seasonal rainfall patterns, increasing rainfall during the rainy season and reducing rainfall during the dry season. Temperature increases and changes in the hydrological system supporting pangasius production will affect fish growth due to stress, increasing the possibility of viral or bacteriological disease. According to the high emission scenario in Vietnam, the sea level will rise by 31 com in 2050 and by 103 com in 2100. Scenario B1 (low emission) shows the lowest rise in sea level, by 27 cim in 2050 and by 70 cm in 2100. These changes are likely to have significant economic impacts not only on producer income (Kam et al., 2010) but also for other actors in the value chain, including input suppliers (hatcheries, feed, and equipment), processors, and exporters. However, there are currently not any solutions for climate change adaptation in Mekong River Delta, therefore, the pangasius industry will surely face many challenges.

Expert workshop participants were optimistic that current levels of pangasius production can be maintained due to existing expertise and the ability to adopt new technologies. Through selective breeding, Vietnam has replaced the original brood-stock established in the 1990s with a third generation of fish adapted to local conditions. This has given experts in Vietnam confidence that the industry will be able to adapt to changing climate conditions over the next several decades.

Based on the scenarios of climate change together with other factors being discussed, participants have come up with the following future prospective of Pangasius aquaculture:

Development prospective up to 2025: impacts of climate change on pangasius are not as clear as other subjects. By 2025, pangasius production will continue to maintain its current performance and output. The fingerlings technology will be developed in the direction of circulating pangasius farming and fingerlings production. By 2025 Vietnam will maintain their market share based on the quality of products for international certifications. Production linkages and policies will be improved, production costs will be reduced due to more developed technology being applied. Development prospective in the period 2025–2030: climate change becoming more of concern, especially in the context increasing temperature as well as the accumulation of dam construction upstream in four countries along the course of the Mekong River. However, even if the area of farming decreases, the production of pangasius can still increase thanks to the application of better technology. The range of areas suitable for pangasius production is likely to expand northward. In Vietnam, this means the Red River delta may come to play a larger role in Vietnam's pangasius production.

Tilapia aquaculture

Tilapia production in Vietnam has grown steadily since 2010 with the success in breading mono-sex tilapia, reaching 225,000 MT coming from 30,000 hectares of ponds. Currently, tilapia is mostly grown in northern Vietnam and in particular Bac Giang, Bac Ninh, Hai Duong, Quang Ninh, Thai Binh, and Thanh Hoa provinces. Compared to the technological sophistication developed around pangasius production, tilapia producers in Vietnam still have considerable room for improvement. One incentive for doing so is the government's desire to promote tilapia as an export commodity.

Like pangasius, which dominates the MRD of Vietnam's south, tilapia production in the north can be affected by climate change. Rising temperatures can slow growth and decrease production [FAO (Food and Agriculture Organization), 2009].

Climate models projected temperatures in northern Vietnam to increase more rapidly than in the south. For the north, temperatures are expected to increase by 1.2–1.3°C by 2050, with even greater increases (1.4–1.5°C) for the north central coast. With the faster increase in temperature, tilapia and its production will be affected negatively if there is no measure to cope with climate change. Similarly for rainfall, by 2050 northern Vietnam may experience an increase of precipitation between 4% to 10%. A 10% increase spread out over the course of a year would create few problems, but increases may come in short bursts with disruptive potential. As with pangasius production in the south, increased temperatures and rainfall in northern Vietnam can result in damage to ponds and other productive infrastructure and flooding, resulting in fish escapes. Saline intrusion associated with sea level rise will affect tilapia production in coastal areas where pumping groundwater is important. All scenarios show an increase in temperature, rainfall and sea level. Depending on each scenario, the extent of the impact is different, but generally, with those negative impacts, stakeholders have to take initiative in responding to climate change in order to ensure sustainable development of tilapia—an increasingly important part of Vietnam's aquaculture industry. Development prospective in next 5 years (2020–2025): During this period, the impact of climate change will not be very remarkable. Tilapia production will continue to expand due to enormous investment in terms of capital and technology. This is because of the current trade disputes between China and the United States will make tilapia from Vietnam more attractive than tilapia from China, a major competitor in this market. Entrepreneurs in Vietnam will recognize this opportunity and invest accordingly. The production of tilapia will increase due to high market demand. As supply and demand balance out, the tilapia market will become increasingly competitive. Development prospective for 2025–2050: the growth rate in production of tilapia will gradually stabilize by or shortly after 2025. In the decades which follow, climate change is likely to constrain production increases due to temperature increases and irregular rainfall. Rising sea levels may have a direct impact on production, affecting Vietnam's export goals. In the years 2020–2025, the impact is expected to be small but will increase during the period2025–2050. The tilapia industry will need to adapt by improving production chains, and creating policies to support and develop Vietnam's tilapia industry. Expanding into new markets for tilapia (e.g., Africa) may be beneficial.

Shrimp aquaculture

Two species of shrimp account for most production in Vietnam: the white-leg shrimp (Litopenaeus vannamei, 475,000 MT in 2018) and black tiger shrimp [*Penaeus monodon*, 270,000 MT in 2018; FAO (Food and Agriculture Organization), 2021]. A total of 700,000 hectares are devoted to shrimp farming, mostly in the MRD. Shrimp from Vietnam are exported around the world. In 2018, the Government of Vietnam announced plans to expand shrimp exports to US$10 billion by 2025 by the promulgation of Decision No. 79/QD-TTg of the Government on January 18, 2018 (Government of Vietnam, 2018).

Research on the impact of climate change on shrimp production has focused on sea level rise, increasingly erratic weather, and higher temperatures and rainfall. Research by Te (2003) and Cao et al. (2018) has shown that elevated temperatures adversely affect shrimp growth due to stress and increase mortality due to problems of water quality and disease. Weather fluctuations will contribute to stress on the shrimp themselves, heavy rainfall could lead to salinity in ponds to drop to sub-optimal levels. As with all other species raised in ponds, the threat of flooding and mass escapes is a serious concern. Many shrimp ponds in the MRD are barely above sea level so flooding from storm surges from tropical storms and typhoons is a serious risk in many areas. Sea level rise in the decades to come will force some shrimp farmers to abandon their ponds. In the MRD, much of the transportation network is on waterways, so flooding, storm surges, and sea level rise is not so disruptive as are these phenomena on roads and other land-based infrastructure. Where roads and bridges are found, these will be increasingly vulnerable to flooding and may need elevation. Many shrimp processing plants are as little as 0.5m above sea level and most are under 1.5m. These facilities are critical to the shrimp industry and are vulnerable to sea level rise and storm surges. Parts of Ho Chi Minh City routinely flood when heavy rain and high tides coincide.

Based on climate change scenarios and other factors discussed during the workshops, experts who participated in the workshops described both short-term and long-term prospects for shrimp production. The government of Vietnam issued Decision 79 calling for exports of 10 billion US dollars by 2025. The effects of climate change are unlikely to affect Vietnam's ability to achieve this goal. The possibility of a trade war between China and the United States may create marketing opportunities for Vietnamese shrimp in the United States, positively affecting revenue. However, in the decades to come, increases in temperature, sea level rise, and fluctuations in rainfall will affect shrimp culture directly. In order to ensure sustainable development of the industry, authorities and stakeholders have to take into consideration of the climate change impacts from the early stage, to come up with climate change adaptation strategies and policies for industry development.

Discussion

As Vietnam is one of the world's most vulnerable countries to climate change impacts, climate change represents a potentially significant treat to sustaining the growth of the fisheries sector in Vietnam. Through two stakeholder consultation workshops, 20–30 participants representing the government, research institutions, private sector, industry associations, academia, international partners, and non-governmental organizations were brought together to discuss a range of different adaptation strategies to climate change within Vietnam's fisheries sector. The various stakeholders involved in the interactive process discussed the past and present trends as a starting point for understanding future challenges and opportunities for the fisheries and aquaculture sector and then identifying related research questions and issues. Alternative futures are envisioned from a broader perspective (involving socio-economic and political aspects), where humans play a more important role in the program (Oborn et al., 2013). The consultation workshops provided the basis for follow-up foresight modeling and scenario development to support identifying alternative pathways and options to inform future fisheries and aquaculture management and development planning in Vietnam.

Future climate change is likely to have dramatic impacts on hydrologic conditions, including storm surges, salinization of coastal aquifers, intrusion of saline water further upstream, and coastal erosion. These impacts are likely to have profound effects on aquacultural production systems vulnerable to changes in water quality, pH, and salinity, and to near total loss of fish or shrimp in the event of inundation. The marine capture fisheries sub-sector is vulnerable to storm damage affecting boats, harbors, and other infrastructure, and to spatial shifts of commercially important species associated with increasing ocean temperatures. Therefore, the impact of climate change on four key commodities (Tilapia, Pangasius, Tuna and Shrimp) in Vietnam varies depending on their habitats. At the national and global level, the extent of impact is likely to be heterogeneous across the various fish production system and species/groups (Barange et al., 2018; Froehlich et al., 2018; Gephart et al., 2020). Climate change, particularly floods and droughts, is increasingly recognized as a potentially significant threat to current and future fisheries sector (Lebel et al., 2015; Limuwa et al., 2018).

Vietnam's fisheries sector has experienced dramatic production increases, improving both national food security and generating significant foreign exchange earnings. As described here, climate change represents a serious challenge to the fisheries sector in the future. These challenges are best met through advanced preparation, assessment of vulnerability to climate change for fisheries at the national level, projecting future scenarios, and planning effective strategies to mitigate or overcome the challenges (Suh and Pomeroy, 2020). The ability to foresee and project alternative futures will assist policy makers and private sector investors to prepare in advance and mitigate disruptions caused by rising temperatures, increasing precipitation, rising sea levels, and increasingly severe weather events including tropical storms, typhoons, and attendant flooding. Modeling the impact of multiple factors associated with climate change on development within the fisheries sector can provide policy makers the information necessary to set policies to manage resources for long-term sustainability, and to balance food and nutrition security for poor and vulnerable populations with international trade goals. This information is also of importance to private sector investors in infrastructure, production, and processing facilities. As the fishery sector's contribution in Vietnam to regional economic growth has been recognized, the challenges of climate change will provoke tensions between the efforts for sustainable ecosystem protection and economic growth. Moreover, various stakeholders including government, private sectors, non-government organizations and consumers need to foster cooperation to promote climate-smart technologies and innovations for mitigating climate change impacts. There is also a need to enhance knowledge of the environmental constraints and opportunities for growth under various climate change scenarios. The elaborated prospective of fisheries and aquaculture sub-systems (commodities) through a qualitative foresight approach can help prompt discussions about which futures are desirable for the current fishery sector (Nakicenovic and Intergovernmental Panel on Climate Change, 2000; Gephart et al., 2020).

The Government of Vietnam has recognized the importance of improving forecasting and scenario development capacity. Research highlights the importance and usefulness of quantitative foresight modeling tools for supporting the Vietnamese fisheries sector's planning and revision. Previous studies investigating futures of the fishery sector using a partial equilibrium foresight modeling approach has generated important insights for understanding how changes in explanatory drivers (variables) such as trading environment, production and consumption patterns, and climate conditions affect fisheries and aquaculture sectors' outcome domains (e.g., Chan et al., 2019; Tran et al., 2019). Successful adoption of the IMPACT model and fish sector foresight modeling will require technical and financial support from donors, CGIAR research centers (IFPRI and WorldFish), universities, and other partners with the requisite technical skills.

One challenge to effective modeling is the quality and availability of statistical data to modelers. Such challenges cannot be overcome overnight, and commitment to this goal from top levels of the national government will be necessary. A second challenge for effective quantitative foresight is understanding the highly dynamic nature of international markets for seafood. Vietnam has become a major seafood exporter, particularly of shrimp and pangasius catfish. These markets are highly competitive, and while climate change poses many challenges, competition in the marketplace adds a new dimension with significant implications for the economic health of the fisheries sector. Recognizing the need for adopting quantitative foresight models, as demonstrated here, a qualitative foresight approach has added value through incorporating data that are not easily quantifiable, drawing on expert opinions in a setting of open discussion, and bringing to the discussions a wide range of stakeholders. This paper is the product of such discussions and provides a basis both for decision makers to set policy and make investment decisions, and for building a foresight modeling effort that combines both qualitative and quantitative models.

Conclusion

Vietnam's fisheries sector currently makes an important contribution to employment, livelihoods, food security, and export earnings. The multi-faceted challenges of climate change for marine fisheries, freshwater aquaculture, and brackish water aquaculture required well-designed policies and sector development planning. Despite these challenges, we believe it fair to say that adaptation to climate change has not yet achieved the level of policy primacy as has increased production and export earnings. Given the increasing challenges that climate change will pose for Vietnam's fisheries sector in the years ahead, foresight modeling and analysis will provide critically important information to policy makers and private sector investors. Investments in strengthening data collection and both quantitative and qualitative foresight modeling capacity will pay dividends for decades to come. The extent of climate change impact on four key commodities representing capture fisheries (tuna), freshwater aquaculture (pangasius catfish and tilapia), and brackish water aquaculture (shrimp) varies, but it represents a potentially significant threat to sustainable aquatic food production in each production system. Foresight modeling can help fisheries managers make policies and decisions to improve the fisheries sector's contribution to sustainable development goals, significantly enhancing food and nutrition security for poor and vulnerable populations. Such modeling also will be of value to entrepreneurs in making investment decisions.

Climate-smart technologies and innovations that build sustainability and resilience in aquatic food systems need to be developed to tackle climate change impacts. Prioritizing inclusive, sustainable and climate-resilient aquatic food systems, consumption patterns and supply chains can contribute to improved environmental performance toward achieving United Nations Sustainable Development Goals. Developing climate information services for aquaculture can assist farmers to manage risks associated with climate variability and extreme weather conditions experienced in food production (Hossain et al., 2021). According to the experiences of climate-smart innovations introduced in Bangladesh, an integrated aquatic food-production system using coastal land and saltwater, introduction of salt-tolerant seaweed crops in coastal wetland systems, training dialogues for new technologies, and designing locally-led climate-smart adaptation techniques can open new frontiers for climate-resilient aquatic food production (WorldFish, 2021).

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

NT: funding acquisition, conceptualization, methodology, data curation and analysis, writing—original draft preparation—review & editing, and project administration. CC and KW: funding acquisition, writing—review & editing, and project administration. YA and HC: data curation and analysis and writing—review & editing. CB, MA, TS, and TT: writing—review & editing. CQ: writing—review & editing and project administration. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2022.829157/full#supplementary-material

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