Future Scenarios of Climate Change Impacts on Fisheries and Aquaculture in Vietnam

Nhuong Tran¹, Chin Yee Chan¹, Yee Mon Aung¹, Conner Bailey², Michael Akester³, Cao Le Quyen⁴, Trinh Quang Tu⁴, Hoang Van Cuong⁴, Timothy B. Sulser⁵ and Keith Wiebe⁵

¹WorldFish, Penang, Malaysia

²Auburn University, USA

³WorldFish Myanmar, Myanmar

⁴Vietnam Institute for Fisheries Economics and Planning (VIFEP), Vietnam

⁵International Institute for Policy Research Institute (IFPRI), USA

Corresponding author: Nhuong Tran

N.Tran@cgiar.org

ABSTRACT

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 likely impacts of climate change on Vietnam's fisheries sector by exploring plausible future scenarios for four key commodities representing 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. This study uses a foresight scenario analysis using a qualitative scenario approach as the starting point for additional modeling of climate change impacts.

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

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34 INTRODUCTION

35 Vietnam's fisheries sector has emerged as a dynamic engine of economic growth important both for
36 food security and foreign exchange earnings. Climate change poses an array of challenges to this
37 sector. In this article, we report on foresight analysis efforts designed to help public policymakers
38 and private sector entrepreneurs identify risks associated with increasing climate change impacts on
39 Vietnam's fisheries sector, including marine capture fisheries, freshwater aquaculture, and brackish
40 water aquaculture. Important structural change in Vietnam's economy began in 1986 with the
41 introduction of a market-oriented economy within the context of continued state guidance. Since
42 that time, Vietnam has sustained an average GDP growth rate of over 7% per year, advancing from
43 one of the poorest countries to one entering the ranks of middle-income countries while
44 dramatically reducing poverty in the process (Baum, 2020). The fisheries sector of Vietnam mirrors
45 these structural changes, with dramatic increases in both marine capture fisheries and aquaculture.
46 In 2018, Vietnam ranked seventh in the world in marine capture fisheries and fourth in aquaculture
47 (FAO, 2020). Vietnam's 2018 seafood exports earned US\$8.9 billion. Seafood available for
48 consumption totaled 37.7 kg per capita in 2016 and the fisheries sector represented 3.4% of
49 Vietnam's gross domestic product (FAO, 2021). These figures reflect the growing importance of the
50 fisheries sector in Vietnam not only for export earnings but for income, employment, and food
51 security.

52 Until recently, marine capture fisheries played a leading role in seafood production in
53 Vietnam. After 2007, however, aquaculture production surpassed that of the marine sub-sector and
54 has expanded its role ever since (**Figure 1**). Encouraged by international donor agencies, the
55 government of Vietnam has promoted aquaculture as a means of reducing rural poverty while
56 increasing exports (Ha and Bush, 2010). Three species are of particular note in Vietnam's
57 aquacultural development: pangasius catfish, tilapia, and shrimp. Pangasius (*Pangasius*
58 *hypophthalmus*) are primarily grown in the Mekong River Delta (MRD) of southern Vietnam using
59 an intensive freshwater production system. Some pangasius producers have shifted to tilapia
60 (*Oreochromis niloticus*), another freshwater species, which is grown both in the MRD and in the
61 Northern provinces. Shrimp farming in brackishwater coastal mangrove and tidal flats has been
62 centered primarily in the MRD. Initially, shrimp farming involved low-intensity production
63 methods of tiger shrimp (*Penaeus monodon*) but in recent years, there has been a shift to the white-
64 legged shrimp (*Litopenaeus vannamei*) due in part to disease resistance of that species. Low-
65 intensity production systems are still common among small-scale producers in the MRD, but higher
66 intensity production systems (i.e., greater stocking densities and higher feeding rates) have played a
67 role in expanding harvests (Armitage and Marschke, 2013; Gaudreau et al., 2012). Recently, the
68 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 (Government of Vietnam, 2018; Tran et al., 2013).

Figure 1 here in text

Climate change represents a serious challenge to sustaining the growth of Vietnam's fisheries sector. Vietnam is one of the world's most vulnerable countries to global 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, 2021). The Intergovernmental Program on Climate Change (IPCC) predicts a mean eustatic (global) sea level rise between 0.43m and 0.84m by the end of the 21st 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 mangrove (Douglas, 1997). 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 temporary flooding, salinization of soils and groundwater, and permanent submergence of land are foreseen in the MRD (Carew-Reid, 2008; Doyle et al., 2010). The MRD is also the center for Vietnam's pangasius industry (Belton et al., 2011; De Silva and Phuong, 2011). 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 up-river.

Coastal fishing villages and major fishing ports in the provinces of Hai Phong, Da Nang, Khanh Hoa, and Ba Ria 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 (Ahmed et al., 2019; Badjeck et al., 2010; Brander, 2007; 2012; Cooley and Doney, 2009; Doney et al., 2012; Savo et al., 2017).

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 efforts. Foresight modeling is designed to be an integral part of development planning and resource allocation for an economic sector such as fisheries. Over the years, the Vietnamese government has developed strategies and produced master plans for the fisheries sector, but these strategies and

104 plans have not benefitted from data and insights based on objective and systematic foresight
105 modeling. Currently, the number of Vietnamese professionals with expertise in strategic forecasting
106 related to the fisheries sector is still limited. The need for foresight modeling today is particularly
107 urgent given that climate change currently is and will continue to affect aquatic resources of all
108 kinds, with serious consequences for the fisheries sector.

109 The qualitative foresight approach we employed here uses expert opinion obtained over the
110 course of two workshops, one conducted in Vung Tau in 2015 and the other in Hanoi in 2019. The
111 workshops were organized by the Vietnam Institute of Fisheries Economics and Planning (VIFEP)
112 and WorldFish and focused on the medium-term future of Vietnam's fisheries sector, including both
113 freshwater aquaculture, brackish water aquaculture and marine capture fisheries. Workshop
114 participants were asked "Under what circumstances and with what policies, could the Vietnamese
115 fishery sector develop sustainably?" This question was explored by examining the factors driving
116 changes in freshwater and brackish water aquaculture and marine capture fisheries, and by
117 evaluating major challenges and opportunities facing the production of key commodities in the
118 Vietnamese fishery sector. The specific contexts required to support sustainable sector development
119 were examined within each scenario. To emphasize the range of pathways that can simultaneously
120 exist, current fishery and aquaculture production systems showing key elements of each scenario
121 trajectory were examined. The scenarios presented in this study were designed to guide discussions
122 that will lead to strategies and policies that support sustainable development within Vietnam's
123 fisheries sector development into the future. The combination of concrete structure, detailed data
124 and fruitful perspectives has significantly contributed to the development of insightful scenarios.
125 One of the essential strengths of scenario exercises rests on the incorporation of creative thinking of
126 participants during the process. During the workshops, participants from diverse institutions with
127 different points of view were encouraged to think creatively and focus on exploring multiple future
128 alternatives beyond a single predicted outcome.

129

130 **REVIEW ON FORESIGHT AND SCENARIO METHODS**

131 Foresight analysis is an approach that has been widely applied in various fields to study future
132 uncertainties (Cook et al., 2014). Several methods exist to study the future, such as (i) extrapolation
133 of existing trends, (ii) historically-based future studies, (iii) and development of scenarios by
134 various tools, involving horizon scanning, participatory consultation, expert panels, and scenario
135 building (Oborn et al., 2013). Maier et al. (2016) and Borjeson et al. (2006) report that there are
136 three types of scenario development methods), namely (a) predictive scenarios - "what will
137 happen"? (b) exploratory scenarios - "what could happen?", and (c) normative scenarios - "how can
138 a specific future be realized?". The first two scenarios are forward-looking and problem-oriented

139 (explorations, projections) while the third is solution-focused with a backward view (backcasting).
140 Foresight scenarios are stories communicated using an interdisciplinary approach and providing a
141 narrative explaining how plausible futures might emerge (Raskin et al., 1995). Unlike prediction,
142 projection or forecasting, foresight scenarios are not descriptions of a single result, but rather an
143 exploration of multiple plausible outcomes (Badjecket et al., 2011). Scenarios systematically
144 consider a range of drivers of change and their complex interactions and do so over time. Climate
145 change qualifies as a critical driver of change having the potential to destabilize production in both
146 the aquaculture and marine capture fisheries sub-sectors. The process of change may not be linear
147 as one change may bring on additional changes, creating the possibility of multiple outcomes over
148 time. Simply predicting the course of change based on historical trends is inadequate. Foresight
149 scenarios alert decision-makers to consider unforeseeable changes, enabling them to deal with and
150 plan strategically for whatever the future could bring (Cook et al., 2014).

151 Oborn et al. (2013) highlight the importance of a scenario development method known as
152 morphological analysis that can be used to identify important issues and support policy formulation
153 by taking into account economic, political, technical, and environmental factors. Other foresight
154 methods such as horizon scanning and scenario planning are used by business and governments for
155 capacity building and long-term strategic planning (Cook et al., 2014). An example of one
156 important foresight scenario narrative relates to nutrition-sensitive aquaculture (Gephart et al.,
157 2020). Such scenarios related to the fishery sector help prompt discussions and planning about the
158 kinds of fisheries that are desirable for the future. Forecast scenarios explore knowledge gaps and
159 identify the common problems before suggesting research issues, it can also help to broaden the
160 perspectives and discussions on the future industry. Each scenario developed through various
161 scenario tools holds the potential for contribution to the targeted theme, such as nutrition-sensitive
162 aquaculture (Gephart et al., 2020).

163 Foresight scenarios take three major forms: quantitative, qualitative, and semi-quantitative.
164 Quantitative methods estimate variables and employ statistical analysis (Popper, 2008). Quantitative
165 foresight modeling is relatively helpful in forecasting systems with well-understood variables over a
166 short period of time but works less well for extended periods when uncertainties are significant and
167 unqualifiable (Cook et al., 2014). Foresight modeling based on qualitative information has been
168 employed to evaluate scenarios in the distant future characterized by increasing uncertainties and
169 complexity. As qualitative scenario planning has the potential to facilitate and structure discussions
170 between stakeholders and scientists about the uncertainties, it can contribute to increased
171 legitimacy, collective learning, and advanced scientific understanding (Rockmann et al., 2012).
172 Qualitative scenario approaches aim to bring research findings together about the inquiry topic from

173 a range of experiences, meanings, and perspectives (Barnett-Page and Thomas, 2009). For example,
174 the future of aquaculture in the MRD is not predetermined, but rather exposed to varying forms of
175 natural and human interference the impacts of which are not immediately visible. Qualitative
176 narratives with descriptive richness can effectively illustrate the nature of ambiguity and the
177 variables (quantitative and qualitative) that go into foresight modeling. Efforts to integrate
178 quantitative (e.g., econometric models) and qualitative description are referred to as a semi-
179 quantitative approach to scenario building.

180 Several quantitative models have been developed to support scenario development, including
181 the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT)
182 developed by the International Food Policy Research Institute (IFPRI). IMPACT is a partial-
183 equilibrium economic model representing a competitive agricultural market for crops and livestock
184 that specifies models for countries, regions, and sub-regions. For the fisheries sector, IFPRI,
185 WorldFish, World Bank, Food and Agricultural Organization (FAO), and the University of
186 Arkansas at Pine Bluff improved the IMPACT fish model based on trends in individual countries
187 and groups of countries for the production of capture fisheries and aquaculture, taking into
188 consideration income, population growth, seafood consumption, and international trade to project
189 global fish supply. To date, several comprehensive foresight modeling reports, including (1) Fish to
190 2020: Supply and Demand in Changing Global Markets (Delgado et al., 2003); (2) Fish to 2030:
191 Prospects for Fisheries and Aquaculture (World Bank, 2013); (3) Fish to 2050 in the ASEAN
192 Region (Chan et al., 2017), prospects and challenges of fish for food security in Africa (Chan et al.,
193 2019) (4) the OECD-FAO Agriculture Outlook (OECD/FAO, 2017), (5) the CGIAR research
194 portfolio report (Rosegrant et al., 2017), and (6) Fish to 2030: the role and opportunities for
195 aquaculture (Kobayahshi et al., 2015) have been generated to provide regional and global overviews
196 of future fish supply and demand and to provide input for sustainable aquatic food system policies.

197 Three other models are of importance. The Common Agricultural Policy Regionalized Impact
198 (CAPRI) model and the Global Biosphere Management Model (GLOBIOM) incorporated fish
199 components into their modeling systems (Chang et al., 2018; Latka et al., 2018) and focused on
200 medium or long-term projections at the regional and global levels. A third fish sector model
201 (AsiaFish) developed by Dey et al. (2005, 2016) has been used extensively at the country level to
202 evaluate consequences of changes in incomes, urbanization, technology, fishing effort, export
203 prices, trade policy, and impacts of climate change and related adaptation strategies on fish supply
204 and demand in Indonesia and Zambia (Tran et al., 2017, 2019). This model is solved by a
205 Generalized Algebraic Modeling System (GAMS) program to produce a future picture of the
206 fisheries sector at the country level by projecting dynamics of fish supply and demand and drawing

207 policy implications based on those projections. Most parameters required for calibrating this model
208 must be estimated from real-life data using econometric methods (Dey et al., 2005) which is
209 difficult in many developing countries. To overcome this challenge, Tran et al. (2019) used the
210 primal approach for production and consumption sectors which is less parameter and data
211 demanding, instead of using the dual modeling approach.

212 **METHODOLOGY**

213 This study has developed future scenarios using a qualitative scenario approach using an
214 exploratory scenario method (Reilly and Willenbockel, 2010). Our scenario activities have
215 progressed through several steps. The scenarios were accepted as the starting ideas to identify
216 knowledge gaps and discuss future demands and emerging research issues (Oborn et al., 2013).
217 Two stakeholder workshops, each consisting of 20-30 invited stakeholders, followed the scenario
218 work.

219 The first step was to engage the core research team in a preliminary literature review, results
220 of which were presented at the beginning of each workshop. The core research team then identified
221 types of stakeholders and stakeholder organizations to participate in the workshops so that diverse
222 experiences and views could be brought together to explore future scenarios on climate change
223 impacts on marine capture fisheries and aquaculture. Two participatory stakeholder consultation
224 workshops were conducted, one in 2015 and the other in 2019. The workshops were organized by
225 WorldFish in collaboration with the International Food Policy Research Institute (IFPRI), and the
226 Vietnam Institute of Fisheries Economics and Planning (VIFEP). Each workshop included 20-30
227 key stakeholders representing the public and private sectors, industry associations, research
228 institutions, national and international non-profit organizations in Vietnam, and academia. The
229 intent was to involve a wide range of actors whose knowledge and experience would allow them to
230 analyze the socio-environmental issues associated with marine capture fisheries, aquaculture,
231 climate change, economics, and international trade.

232 In the first workshop conducted in 2015, an introductory presentation on the importance of
233 the foresight approach and the expected outcomes of this participatory technique to generate
234 qualitative foresight (“scenario”) narratives were given. To start the exercise of suggesting drivers
235 of change, participants were first asked to identify past drivers of change that shaped aquaculture in
236 the MRD over the past 10 years. Two professional researchers (workshop facilitators) monitored the
237 discussions. Participants were then divided into groups to identify drivers of change that will likely
238 affect aquaculture in the MRD in the future. Groups were instructed to assign scores from “1 to 5”
239 to each driver, based on its impact and level of uncertainty. An impact score of “5” represents if a
240 driver of change acts, it would have a significant impact on aquaculture. Similarly, an uncertainty
241 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” scenario development approach, two critical drivers with the highest impact and uncertainty scores were distinguished to develop a four-quadrant scenario logic for future aquaculture in the next 10-20 years. A representative from each group presented the narrative storyline of the quadrant scenarios that were created.

The second workshop in 2019 stretched over three sessions. In the first session, past and current trends of Vietnam’s fishery sector were presented. The second session included a presentation on the scenario development by exploring challenges and opportunities of the Vietnamese fisheries sector, including potential impacts of climate change on the fisheries sector of the future. At this session, participants were asked to identify research priorities for fisheries development by sub-sector (capture fisheries and aquaculture) and by commodities (tuna, pangasius, shrimp, and tilapia). Workshop facilitators monitored workshop 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. Finally, global climate change and its potential impact on fisheries and aquaculture and analysis of the vulnerability of aquaculture to climate change in Vietnam were presented. Participants were then grouped to draw up development scenarios for marine capture fisheries and aquaculture and examine the likely impact of climate change on key commodities.

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.

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

277 harvest coming from inland waters. Data on marine capture fisheries were reported for four regions,
278 including the Gulf of Tonkin, the Central and South-Eastern regions, and the MRD. Even as
279 landings of fish increased, the relative share of landings between these four regions remained
280 remarkably constant (**Figure 2**). Of marine capture fisheries output, tuna harvests (primarily
281 skipjack and yellowfin) were reported at 16,650 MT (Directorate of Fisheries, 2018).

282 **Figure 2 here in text**

283 **Aquaculture Area and Production**

284 Aquaculture has been practiced in Vietnam for centuries using low-intensity "traditional"
285 production methods. A shift towards more intensive systems began in the 1960s but the real change
286 came after the year 2000 when the Vietnamese government encouraged farmers to convert low
287 productivity saline rice fields, uncultivated areas, and salt pans in the coastal zone into brackish
288 water ponds for aquaculture (The Government of Vietnam Resolution No.09/2000/NQ-CP of June
289 15, 2000). This new policy encouraged private sector investment in both production and processing
290 facilities. Public sector infrastructure investments also were made. Between 1995 and 2018,
291 aquaculture production in Vietnam increased by more than 10 times, from 415,000 MT to 4,153,000
292 MT, with most of this gain coming since 2000 (Directorate of Fisheries, 2017; GSO, 2018). Finfish
293 and shrimp accounted for 70% and 19%, respectively, of total production.

294 A total of 1.1 million hectares are devoted to aquaculture in Vietnam, with brackish water
295 ponds accounting for two-thirds of the total and dedicated almost exclusively to shrimp production
296 (Directorate of Fisheries, 2018). As can be seen in **Figure 3**, between 2000 and 2018, total
297 aquaculture production increased at a far higher rate than the area under production. Eighty percent
298 of shrimp production in Vietnam occurs in the MRD (MARD, 2019) where it has contributed
299 significantly to economic development for hundreds of thousands of small-scale producers (Jo et
300 al., 2019; Tran et al., 2013). Vietnam ranks third in the world for volume of farmed shrimp
301 production (FAO, 2018), generating US\$ 3.7 billion in export value in 2020 (MARD, 2021). The
302 MRD also is the center for aquaculture production of finfish, notably pangasius. The area devoted
303 to pangasius production is relatively small (5,200 hectares) but the methods employed are highly
304 intensive and yield production totaling 1.25 million MT, accounting for nearly half of all finfish
305 production nationwide (Directorate of Fisheries, 2018).

306 **Figure 3 here in text**

307 The concentration of aquaculture production in the MRD creates significant vulnerability to
308 climate change and particularly to the combination of extreme weather events and sea level rise
309 (Hallegatte et al., 2013). On average, Vietnam is hit by typhoons four to six times a year, bringing
310 high winds, heavy rainfall, and storm surges that destroy homes and infrastructure, and frequently

311 lead to human fatalities. Tropical storms that do not reach typhoon intensity may also cause damage
312 to infrastructure and production facilities and flooding of shrimp ponds. Storm surges combined
313 with projected sea level rise of half a meter or more in the decades to come threaten large parts of
314 the MRD. This problem is compounded by the construction of numerous dams along the course of
315 the Mekong Delta, which have the effect of reducing the river's sediment load and starving the delta
316 of new building material (Elyer, 2020). Vietnam's Directorate of Fisheries (2017) has warned that
317 climate change is likely to have an impact on the fisheries sector.

318

319 **Fish Market and Trade**

320 Since 2014, Vietnam has maintained its position as the third largest exporter of seafood in the world
321 by value, followed only by China and Norway (FAO, 2020). In 2018, total export earnings from the
322 fisheries sector reached US\$8.8 billion, nearly twice the value of exports in 2010 (Vietnam
323 Association of Seafood Exporters and Producers, 2018). The main importers included the United
324 States (US\$1.6 billion), the European Union (US\$1.5 billion), Japan (US\$1.4 billion), and China
325 (US\$1.2 billion). South Korea and other nations of Southeast Asia are emerging as promising
326 markets. Shrimp (US\$3.6 billion), pangasius (US\$2.3 billion), cephalopods (US\$672 million), and
327 tuna (US\$653 million) were the main export products.

328 Vietnam's success in seafood exports is based not only on production within the fisheries
329 sector but also on significant improvements in the seafood processing capacity and quality (Do et
330 al., 2019; Kagawa and Bailey, 2006). Strict food safety requirements for export products represent
331 significant obstacles for the hundreds of thousands of small-scale shrimp producers and the small-
332 scale traders who buy shrimp at the farm (Tran et al., 2013). In many if not most cases, neither the
333 producer nor the trader keeps the kind of records necessary for proof of origin tracing used in
334 seafood certification programs. Organizing hundreds of thousands of small-scale producers and
335 traders in a way to meet certification standards is a huge challenge. Access to the most profitable
336 international seafood markets requires that strict food safety standards be met, including the absence
337 of anti-biotic residues. A variety of certification programs (e.g., Marine Stewardship Council and
338 the Aquaculture Stewardship Council) have additional standards that address sustainability and
339 social justice, among other issues. Obtaining certifications provides access to markets that pay price
340 premiums but is not realistic options for individual farmers operating a one-hectare pond. Tran et al.
341 (2013) suggested that organized groups of small-scale producers and processors could work
342 together and gain mutual benefits – small-scale producers could receive a premium price while the
343 processors could promote their product as supporting small-scale farmers. At present, however,
344 most of the benefits from higher prices brought by certification programs have been captured either
345 by processors who operate their own shrimp farms or by a small number of well-capitalized shrimp

346 producers who manage their farms with higher levels of inputs and productivity than is possible
347 among small-scale farmers.

348
349 **Future Scenarios of Climate Change Impacts on Key Fishery Commodities**

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

355 Based on climate change projections published in 2007 by the IPCC and indicators of
356 exposure, sensitivity, and adaptive capacity covering the period 1989-2014, Quyen et al. (2019)
357 developed a vulnerability index (VI) for aquaculture in all 698 districts of 63 provinces in Vietnam.
358 As shown in **Figure 4**, fish farming was at medium or high vulnerability levels throughout the
359 country. Shrimp farming was identified as being even more vulnerable (**Figure 5**). In both cases,
360 parts of the MRD scored highly on the vulnerability index. Kam et al. (2015) reported similar
361 findings of widespread vulnerability, including in the MRD where aquaculture production is
362 concentrated.

363 **Figures 4 and 5 here in text**

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

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

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

382 In addition to sea level rise, climate change may affect maximum temperatures and rainfall
383 patterns. Over the past 50 years, rainfall has increased by 5-20% in the South but decreased by 5-
384 10% in the North (Vietnam Institute of Meteorology, Hydrology and Climate Change, 2010).
385 Climate change could contribute to an increase in extreme weather events, droughts, and changes in
386 salinity affecting estuarine and coastal environments. These changes could affect the reproductive
387 success of crustacean and finfish species. Protecting some coastal areas from sea level rise is
388 technically possible but protecting thousands (or even hundreds) of kilometers of coastline is not a
389 likely scenario. There are engineering solutions to some problems associated with extreme weather,
390 flooding, and other problems, but the broader environmental impacts of climate change will require
391 adaptive management within the fisheries sector designed to mitigate problems forecast to occur
392 decades in the future. In the sections, which follow, we examined the likely impacts of climate
393 change on tuna capture fisheries freshwater aquacultural production of pangasius and tilapia, and
394 brackish water production of shrimp.

395 **Tuna**

396 Vietnam has a long coastline and an Exclusive Economic Zone of more than 1 million km². Tuna
397 species are important to Vietnam's capture fisheries sector, with 2018 landings of skipjack tuna
398 totaling 91,461 MT followed by yellow-fin tuna (25,455 MT) and big eye tuna (3,618 MT) (FAO,
399 2018). Climate change affects water temperature and the distribution of prey species and therefore
400 tuna species (Quyen et al., 2017). Intensified wind and wave action are likely consequences of
401 ocean warming, as are increases in the number and intensity of tropical typhoons that damage both
402 fishing boats and coastal infrastructure important to tuna and other capture fisheries such as cold
403 storage, processing, and transportation facilities (CCSP, 2008). Changes in ocean temperature also
404 can affect dissolved oxygen concentrations, ocean circulation and upwelling that brings nutrients
405 from the seafloor to the surface, thereby increasing primary productivity (e.g., phytoplankton and
406 zooplankton) that supports marine food webs where tuna are apex predators. In addition, rising
407 temperatures are associated with increased ocean acidification, particularly in surface waters (FAO,
408 2009). Acidification has the potential to disrupt primary productivity and adversely affect the
409 reproductive success of both vertebrates (e.g., tuna and prey species) and invertebrates (e.g.,
410 phytoplankton and zooplankton) by harming eggs and larvae at vulnerable life stages.

411 No detailed studies of how climate change affects tuna species in Vietnam's waters are
412 available, but studies in the Pacific Ocean provided a starting point for understanding. Changes in
413 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 (Guidry and Mackenzie, 2013; Lehodey et al., 2010; 2011). Within Vietnam's Exclusive Economic Zone, it is likely that the movement of 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 (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 are landed by wooden-hulled vessels using longlines off the coast of central and northern Vietnam (Urch, 2016). Warming ocean temperatures will tend to drive tuna stocks in a northerly direction towards 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.

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

449 through the MRD. Typhoons that affect the MRD often occur in November and are a source of
450 flooding risk. Other tropical storms and the possibility of increasingly heavy rainfall could lead to
451 frequent flooding, erosion of pond dikes, damage to farm facilities, fish disease problems with
452 higher turbidity levels and lowered PH, and escapes of fish from ponds inundated by flood-waters.
453 Sea level rise and episodic storm surges associated with typhoons and other tropical storms can
454 push saline water from estuaries further into the interior, resulting in the loss of production area.
455 This latter threat can be addressed by moving production facilities further upstream.

456 Based on Global Climate Models (GCM) and Providing Regional Climates for Impacts
457 Studies (PRECIS) climate model by Jones et al. (2003), temperatures in the MRD between Ca Mau
458 Province and Ho Chi Minh City are projected to increase by 1°C in 2050 and between 1.4°C to as
459 much as 2.7°C by the year 2100. Climate change in the MRD also will affect seasonal rainfall
460 patterns, increasing rainfall during the rainy season and reducing rainfall during the dry season.
461 Temperature increases and changes in the hydrological system supporting pangasius production will
462 affect fish growth due to stress, increasing the possibility of viral or bacteriological disease. These
463 changes are likely to have significant economic impacts not only on producer income (Kam et al.,
464 2010) but affect other actors in the value chain, including input suppliers (hatcheries, feed, and
465 equipment), processors, and exporters.

466 Expert workshop participants were optimistic that current levels of pangasius production can
467 be maintained due to existing expertise and the ability to adopt new technologies. Through selective
468 breeding, Vietnam has replaced the original brood-stock established in the 1990s with a third
469 generation of fish adapted to local conditions. This has given experts in Vietnam confidence that the
470 industry will be able to adapt to changing climate conditions over the next several decades. There
471 are external challenges that must be considered. Dam construction on the upper reaches of the
472 Mekong River (i.e., in China and Laos) basin may change hydrological conditions in the MRD. The
473 range of areas suitable for pangasius production is likely to expand northward. In Vietnam, this
474 means the Red River delta may come to play a larger role in Vietnam's pangasius production. China
475 may come to play a more dominant role in pangasius production, increasing competition in
476 international markets.

477 **Tilapia**

478 Tilapia production in Vietnam has grown steadily since 2010 with the success in breeding mono-sex
479 tilapia, reaching 225,000 MT coming from 30,000 hectares of ponds. Currently, tilapia is mostly
480 grown in northern Vietnam and in particular Bac Giang, Bac Ninh, Hai Duong, Quang Ninh, Thai
481 Binh, and Thanh Hoa provinces. Compared to the technological sophistication developed around

482 pangasius production, tilapia producers in Vietnam still have considerable room for improvement.
483 One incentive for doing so is the government's desire to promote tilapia as an export commodity.

484 Like pangasius, which dominates the MRD of Vietnam's south, tilapia production in the
485 north can be affected by climate change. Rising temperatures can slow growth and decrease
486 production (FAO, 2009). Climate models projected temperatures in northern Vietnam to increase
487 more rapidly than in the south. For the north, temperatures are expected to increase by 1.2°C -
488 1.3°C by 2050, with even greater increases (1.4°C-1.5°C) for the north central coast. Similarly, for
489 rainfall, by 2050 northern Vietnam may experience an increase of precipitation between 3.8% to
490 10.1%. A 10% increase spread out over the course of a year would create few problems, but
491 increases may come in short bursts with disruptive potential. As with pangasius production in the
492 south, increased temperatures and rainfall in northern Vietnam can result in damage to ponds and
493 other productive infrastructure and flooding, resulting in fish escapes. Saline intrusion associated
494 with sea level rise will affect tilapia production in coastal areas where pumping groundwater is
495 important to the system.

496 In the near term, climate change is unlikely to have major impacts on tilapia production in
497 Vietnam. To the extent that barriers to trade between China and the United States continue to exist,
498 opportunities for Vietnam to replace China as a source of tilapia to international markets might spur
499 further development. The consensus of workshop participants was that toward the end of the 2020s
500 and beyond, climate change will begin to disrupt tilapia production due to temperature fluctuations,
501 increased rainfall, and coastal inundation. Competition in international seafood markets will remain
502 intensive and may increase as new actors enter the field.

503

504 **Shrimp**

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

511 Research on the impact of climate change on shrimp production has focused on sea level rise,
512 increasingly erratic weather, and higher temperatures and rainfall. Research by Te (2003) and
513 Quyen et al. (2018) has shown that elevated temperatures adversely affect shrimp growth due to
514 stress and increase mortality due to problems of water quality and disease. Weather fluctuations will
515 contribute to stress on the shrimp themselves, heavy rainfall could lead to salinity in ponds to drop

516 to sub-optimal levels. As with all other species raised in ponds, the threat of flooding and mass
517 escapes is a serious concern. Many shrimp ponds in the MRD are barely above sea level so flooding
518 from storm surges from tropical storms and typhoons is a serious risk in many areas. Sea level rise
519 in the decades to come will force some shrimp farmers to abandon their ponds. In the MRD, much
520 of the transportation network is on waterways, so flooding, storm surges, and sea level rise is not so
521 disruptive as are these phenomena on roads and other land-based infrastructure. Where roads and
522 bridges are found, these will be increasingly vulnerable to flooding and may need elevation. Many
523 shrimp processing plants are as little as 0.5m above sea level and most are under 1.5m. These
524 facilities are critical to the shrimp industry and are vulnerable to sea level rise and storm surges.
525 Parts of Ho Chi Minh City routinely flood when heavy rain and high tides coincide.

526

527 **DISCUSSION**

528 Through two stakeholder consultation workshops, national and international experts were brought
529 together to discuss a range of different adaptations to climate change within Vietnam's fisheries
530 sector, explicitly including both marine capture fisheries and aquaculture. This consultation
531 provided the basis for this preliminary foresight modeling and scenario planning effort designed to
532 identify alternative pathways and options to inform resource management and development
533 planning. The ability to project future scenarios will increase the ability of policy makers and
534 private sector investors to prepare in advance and mitigate disruptions caused by rising
535 temperatures, increasing precipitation, rising sea levels, and increasingly severe weather events
536 including tropical storms, typhoons, and attendant flooding. On a daily basis in the future, climate
537 change is likely to have dramatic impacts on hydrologic conditions, including storm surges,
538 salinization of coastal aquifers, intrusion of saline water further upstream, and coastal erosion.
539 These impacts are likely to have profound impacts on aquacultural production systems vulnerable to
540 changes in water quality, pH, and salinity, and to near total loss of fish or shrimp in the event of
541 inundation. The marine capture fisheries sub-sector is vulnerable to storm damage affecting boats,
542 harbors, and other infrastructure, and to spatial shifts of commercially important species associated
543 with increasing ocean temperatures.

544 Vietnam's fisheries sector has experienced dramatic production increases, improving both
545 national food security and generating significant foreign exchange earnings. As described here,
546 climate change represents a serious challenge to the fisheries sector in the future. These challenges
547 are best met through advanced preparation, projecting future scenarios and planning strategies to
548 mitigate or overcome the challenges. Modeling the impact of multiple factors associated with
549 climate change on development within the fisheries sector can provide policy makers the
550 information necessary to set policies to manage resources for long-term sustainability, and to

551 balance food and nutrition security for poor and vulnerable populations with international trade
552 goals. This information is also of importance to private sector investors in infrastructure,
553 production, and processing facilities.

554 The Government of Vietnam has recognized the importance of improving forecasting and
555 scenario development capacity. Scientists and fisheries managers in Vietnam have reached out to
556 international partners, notably WorldFish and IFPRI to support capacity building in this arena. As
557 the research highlights the importance and usefulness of the quantitative foresight modeling tools as
558 mentioned above, these modeling tools would be a useful tool to support the Vietnamese fisheries
559 sector's planning and revision. Successful adoption of the IMPACT model and fish sector model for
560 foresight modeling and scenario planning will require technical and financial support from donors,
561 CGIAR research centers (IFPRI and WorldFish), universities, and other partners with the requisite
562 technical skills.

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

576 **CONCLUSION**

577 Vietnam's fisheries sector currently makes an important contribution to employment, livelihoods,
578 food security, and export earnings. The multi-faceted challenges of climate change for marine
579 fisheries, freshwater aquaculture, and brackish water aquaculture required well-designed policies
580 and sector development planning. Despite these challenges, we believe it fair to say that adaptation
581 to climate change has not yet achieved the level of policy primacy as has increased production and
582 export earnings. Given the increasing challenges that climate change will pose for Vietnam's
583 fisheries sector in the years ahead, foresight modeling and analysis will provide critically important
584 information to policymakers and private sector investors. Investments in strengthening data

585 collection and both quantitative and qualitative foresight modeling capacity will pay dividends for
586 decades to come.

587

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596

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842 **FIGURE 1:** Aquaculture and capture fisheries production in Vietnam, 1995-2019

843 Data source: General Statistics Office (GSO), 2018; Directorate of Fisheries, 2017, 2018 and 2019.

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846 **FIGURE 2:** Proportion of regional marine landings in Vietnam, 2013-2019

847 Data source: General Statistics Office (GSO), 2018; Directorate of Fisheries, 2017, 2018 and 2019

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FIGURE 3: Areas of aquaculture farms and aquaculture production in Vietnam, 2000-2019

Data source: General Statistics Office (GSO), 2018; Directorate of Fisheries, 2017, 2018 and 2019

855

856 **FIGURE 4:** Vulnerable level of fish farming to climate change

857 Source: Quyen et al. (2018)