Extreme Weather Events and Coastal Fisheries: Impacts, Vulnerability and Adaptation Strategies in Vietnam

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Abstract Many studies have shown the impact of Extreme Weather Events (EWEs) on the coastal fishery sector, vulnerability and adaptation measures from the government and coastal households. Food security and fishery-based livelihoods of more than 500 million people currently raise concerns for governments and coastal fishers. The impact of EWEs on the coastal fisheries is considerable, and it may be multidimensional impacts, direct and indirect, and positive and negative; however, losses and damages have been ignored. The coastal fisheries in Vietnam showed to be one of the most vulnerable sectors to EWEs about fishing, fresh and brackish aquaculture. Although the government and coastal fishers have adopted adaptation strategies, it seems not enough with the unpredictable weather change. Also, weak adaptation capacity and shortage of necessary capital resources (human, technology, finance) are becoming significant barriers, threatening the fisheries sector's sustainable development. Drawing upon the available literature, linked with the Sendai Framework for Disaster Risk Reduction, Warsaw International Mechanism of the United Nations Framework Convention on Climate Change, and Sustainable Livelihood Framework, this study assesses the impacts, vulnerability and current adaptation strategies and provides potential adaptations in Vietnam.

Keywords Extreme weather events · Coastal fisheries · Impacts of extreme weather events · Vulnerability and adaptation strategies

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1 Introduction

There have been many studies on the impact of climate change and EWEs on fisheries industry and the vulnerability and adaptation options of coastal fishers (Allison et al., 2009; FAO, 2018; Handisyde et al., 2017; Maulu et al., 2021). EWEs are harming coastal fishing farmers in multi-faceted ways, including direct and indirect impacts (Adhikari et al., 2018; Badjeck et al., 2010; Daw et al., 2009; De Silva & Soto, 2009; Freeman, 2017; Handisyde et al., 2006) negative and positive impacts (FAO, 2014). Studies have shown that the impacts are at global, regional and coastal community levels (Badjeck et al., 2009; Maulu et al., 2021). Meanwhile, the fisheries sector is considered as the most vulnerable sector to EWEs and climate change, especially in coastal areas (FAO, 2018; Soto et al., 2018). The level of exposure and vulnerability of the industry will determine the severity of impacts on the fisheries sector, as well as the hazards associated with the location, type of livelihood and capacity to cope and respond and the existing national and local adaptation strategies (FAO, 2018). Vulnerability is also not a static factor, it depends on other socio-economic factors such as income, age, education and governance.

There has been substantial research on adaptation and livelihood adaptation to climate change and EWEs. A majority of studies consider adaptation and adaptive capacity from the management perspective (Melnychuk et al., 2014) and focus on management tools and their roles in addressing sustainable livelihoods (FAO, 2018). Adaptation and livelihood adaptation practiced by fishers are also shown in several studies. Nagy et al., (2006) found that fishers are self-adaptive to the variability of weather events without the intervention of local government and public managers. Studies of FAO (2018) show micro-adaptations and macro-adaptations implemented by the government, organizations, communities, coastal aquaculture and fishers in response to EWEs inside and outside fishery industry.

Vietnam has a coastline of about 1650 km, passing through 28 provinces from the North to the South and is situated in a tropical monsoon climatic region. The geographical characteristics placed Vietnam into the most vulnerable countries to climate change and natural disasters. In 1997, (Fumihiko & Dang, 1997) pointed out that the central coast in Vietnam is subject to EWEs, which have caused considerable loss of life and construction for coastal areas. Based on the predicted climate change and sea-level rise, Vietnam is one of the top five most affected countries by a 1-M rise in the sea level (Thanh et al., 2004). Climate change also impacts livelihoods and biodiversity in the coastal areas (Neil Adger, 1999). Eckstein et al. (2019) reported that from 2000 to 2019, Vietnam suffered 226 EWEs; about 286 people died annually and damaged about 2018 billion USD.

Vietnam's population mainly dwells in urban areas, therein almost 75% of urban population living in coastal and delta zones (Nguyen & Shaw, 2010). A majority of coastal delta residents whose jobs are relevant to the fishery industry, and this sector annually contributes to more than 4–5% of GDP in Vietnam (Nguyen et al., 2017). From 2006 to 2016, the fishery industry helped 4 million laborers into employment, with 1.89 million people specialized in the fishery and the others work in this sector and combining with other professions.

Although the positive contributions from the industry, in a global study about fishery-based livelihood, reported that freshwater and brackish fishery in Vietnam have the highest vulnerability to climate change and EWEs (Soto et al., 2018). With efforts of the government in recent years in planning fishery development, developing programs and projects to improve fishers' livelihoods, the impacts of climate change and EWEs are considerably are reduced, and some benefits have been admitted. Even so, when fishers notice that vulnerability is increasingly severe and transparent, they always have to pre-prepare prompt responses and long-term strategies to cope with unpredictable EWEs without government interventions.

Although the impacts of EWEs and climate change on the fisheries sector, vulnerability and adaptation strategies of coastal fishers have been researched upon, these studies are restricted to specific scales and fields, focusing on various specific content in the fisheries sector. A lack of consistent data and uncertain developments is also a significant barrier to have reliable quantitative results for improved decision-making. Individual studies at individual scales and communities lack the synthesis and connection to form a holistic and oriented guideline. A broader and comprehensive study of positive and negative impacts, vulnerability and the government's and coastal fishers' current adaptation strategies to EWEs will help to infer the appropriate interventions by the government, local authorities and coastal fishers in formulating potential adaptation strategies in Vietnam.

Drawing upon the available literature, linked with the Sendai Framework for Disaster Risk Reduction, Warsaw International Mechanism of the United Nations Framework Convention on Climate Change, and Sustainable Livelihood Framework, the EWEs caused impacts, vulnerability and adaptation strategies are clarified in the following three parts. Part one details the impacts of EWEs on the coastal fisheries sector. Documented direct and indirect and positive and negative impacts of EWEs on coastal aquaculture and fishing activities will be clarified. Part two investigates the fisheries sector's vulnerability to EWEs and current adaptation strategies. Finally, part three provides recommendations for potential adaptation strategies in Vietnam to respond to EWEs at national, regional and household levels. Results from this study will significantly aid the national and sub-national governments and coastal fishers in fully understanding the impact of EWEs and apply adaptation measures in practice for production activities and sustainable development of the fisheries sector in the future.

2 Impact of Extreme Weather Events on Coastal Fisheries

An extreme event occurs when a value of a weather or climate variable is above or below a threshold value near the upper or lower ends of an observed value range of the variable. "*Extreme weather includes unexpected, unusual, unpredictable, severe or unseasonal weather; weather at the extremes of the historical distribution—the* *range that has been seen in the past*" (IPCC, 2007). Types of EWEs can be heatwaves, extreme precipitation, coastal flooding that causes risks (IPCC, 2014), cyclones, typhoons, floods, extreme sea-level rise, droughts and heatwaves (FAO, 2018). This study uses EWEs such as typhoons, floods, heatwaves and extreme rainfall to assess the impact on coastal fisheries production.

2.1 Negative Impacts

Aquaculture and fishing activities are markedly affected by substantial threats from EWEs and other stressors FAO (2018). Communities with fishery-based livelihoods have suffered climate-related extreme events, such as hurricanes, cyclones, sea-level rise, coastal flooding, widespread flooding, ocean acidification, floods and coastal erosion, of its waterfront location.

Table 1 shows a general review of documented impacts of EWEs on aquaculture and fishing. Accordingly, EWEs can impact positively and negatively or directly and indirectly on coastal fisheries and aquaculture. EWEs such as typhoons and floods can wipe out and damage aquaculture systems, including washing away/damaging ponds (cages, fish and livestock species, breeds, equipment and production machines such as aerators, electricity, houses and laboratory equipment, boats, nets and fishing gear and infrastructure (roads, electricity, ports).

The indirect impacts of EWEs on the fisheries sector are in production, interaction, distribution and even the abundance of species (Brander et al., 2017) or changes in the salinity (Johnson & Pham, 2020). Disease is one of the widespread indirect impacts caused mainly by heatwave and extreme rainfall. Also, disease outbreaks are increasing and more frequent, which can cause fish death or slow growth in fish (Table 1). It has previously been observed that some new diseases emerged (Easterling et al., 2007), the virulence of pathogens increased (Sae-Lim et al., 2017), or the immune system of species was weakened (Gubbins et al., 2013) by EWEs. For example, temperature stress can affect the neuroregulatory and endocrine systems, cardiovascular and aerobic ranges and the immune response of several species (Adhikari et al., 2018; Sae-Lim et al., 2017).

Many attempts have been made to show changes in the water environment caused by climate factors and EWEs, which indirectly affect fish growth, mortality and reproduction (Table 1). Data from these studies suggested that temperature, precipitation and droughts significantly influence water composition and quality and negatively impact aquaculture. Water composition has also been shown to decrease when the temperature increases beyond the ecosystem tolerance; this impacts the organic pollution level of water caused by suspended solids. For example, organic pollution or concentrations of TDS and COD increased in Hoa Vang after the flood in Phu Vang, Thua Thien Hue, Vietnam (Mac et al., 2016). Extensive research has shown that water pollution also occurs more frequently by heatwaves and floods, or hydrology and water systems are considerably changed by temperature variability (Cochrane et al., 2009; Seggel et al., 2016). Also, temperature alters thermal stratification in

Table 1 Impacts of EWEs on aquaculture and fishing

Ways of impact	Documented by previous studies
1. Aquaculture	
• *Negative impacts*	
Swept away/do damages to a production system	Bell et al. (2011); FAO (2018); Johnson & Pham (2020); Rutkayová et al., (2018)
Swept away/do damages to infrastructure	FAO (2018); Hobday et al., (2015); Johnson & Pham (2020); Mills et al., (2013)
Variability in production, interaction and contribution of fish	Brander et al., (2017)
Changes in the salty rate	Johnson & Pham (2020)
Fish death and reproduction rate	Johnson & Pham (2020); FAO (2018); Brander et al., (2017); Mac et al., (2016); Hobday et al., (2015); Kirtman et al. (2013); Mills et al., (2013); Doney et al. (2012); Diersing (2009)
Productivity and quantity decreased	Adhikari et al. (2018); Badjeck et al., (2010); Freeman (2017); Mac et al., (2016); Rutkayová et al., (2018)
The low growth	Adhikari et al. (2018); Akegbejo-Samsons (2009); Brander et al., (2017); FAO (2018); Gubbins et al. (2013); Hobday et al., (2015); Mac et al., (2016); Marcogliese (2008); Mills et al., (2013); Sae-Lim et al., (2017)
Diseases	Easterling et al. (2007); FAO (2018); Gubbins et al. (2013); Handisyde et al. (2006); Hobday et al., (2015); Johnson & Pham (2020); Mac et al., (2016); Mills et al., (2013); Sae-Lim et al., (2017)
Water resources and environment	Badjeck et al., (2010); Brander et al., (2017); Cochrane et al., (2009); Daw et al., (2009); FAO (2018); Hobday et al., (2015); IPCC (2007); Johnson & Pham (2020); Mac et al., (2016); Mills et al., (2013); Ngoan (2010); Rutkayová et al., (2018); Seggel et al., (2016)
Invasion of unwanted invasive species	Rutkayová et al., (2018)
Structure and diversity of ecosystems	Adhikari et al. (2018); Beare et al., (2004); De Silva and Soto (2009); FAO (2018); Freeman (2017); Hobday et al., (2015); Mac et al., (2016); Mills et al., (2013)
Changes in biodiversity	Mac et al., (2016)
Farming areas decreased	Mac et al., (2016)
Changes in land use	FAO (2018)
Abandon and stop cultivating certain species in regions	FAO (2018)

(continued)

Table 1 (continued)

Ways of impact	Documented by previous studies
Caused damages to coral reefs, red tides, algal blooms and reduced dissolved oxygen	Badjeck et al., (2010); Cochrane et al., (2009); Diersing (2009); FAO (2014)
Increasing cost and changing input supply	Adhikari et al. (2018); Badjeck et al., (2010); Cochrane et al., (2009); Daw et al., (2009); De Silva and Soto (2009); Freeman (2017)
• *Positive influence*	
New environment and farming area created	Bell et al. (2011); Chan et al. (2019); Easterling et al. (2007)
New fisheries emerge, leading to increased productivity, improving heredity	Badjeck et al., (2010); Bueno and Soto (2017); Gubbins et al. (2013)
Promoting longer growing seasons for some species	Collins et al., (2020); Gubbins et al. (2013); Troell et al., (2017)
Nutritional diversify	Collins et al., (2020); Seggel et al., (2016)
Increasing productivity of algae	Gubbins et al. (2013)
Minimizing temperature increase	Seggel et al., (2016)
Promoting wastewater management	Beveridge et al. (2018)
Further development of transgenic varieties	Gubbins et al. (2013)
2. Fishing	
• *Negative impacts*	
Causing chaos in fishing grounds and oceans	Brander et al., (2017); Daw et al., (2009); FAO (2018); Hobday et al., (2015); Mills et al., (2013)
Degrading and reducing availability of species	Doney et al. (2012); FAO (2018); Hobday et al., (2015); Mills et al., (2013)
Damaging to corals and occurrence of red tides, algal blooms and reducing dissolved oxygen	Badjeck et al., (2010); Cochrane et al., (2009); Diersing (2009); FAO (2014)
Depleting water and natural resources	Cochrane et al., (2009); FAO (2018); Hobday et al., (2015); Mills et al., (2013); Seggel et al., (2016)
Destroying ships and infrastructure	FAO (2018); Hobday et al., (2015); Johnson & Pham (2020); Mills et al., (2013)
Increasing fishing and management costs and input supply disturbance	Adhikari et al. (2018); Badjeck et al., (2010); Cochrane et al., (2009); Daw et al., (2009); De Silva and Soto (2009); Freeman (2017)
• *Positive influence*	
Appearing new fishing and fishing environment	Badjeck et al., (2010); Easterling et al. (2007)
Prolonging the growth period of some species	Collins et al., (2020); Gubbins et al. (2013); Troell et al., (2017)

Source Authors

deep water; and floods change the heat in the open aquifer (Seggel et al., 2016), which adjusts to the distribution and nutrient abundance in water (FAO, 2018; Hobday et al., 2015; Mills et al., 2013). Droughts also cause deterioration of water resources quality and water scarcity and conflicts between sectors (Barange et al., 2018; Handisyde et al., 2006), which are indirectly affecting to fishery production.

Lowland areas have been shown to face many risks when experiencing extreme rainfall (Bell et al., 2011), including unwanted species entry (Rutkayová et al., 2018). In addition, EWEs also decrease biodiversity (Mac et al., 2016) or changes in ecosystem characteristics; these changes lead to a decrease in the cultivated area and changes in land use in several places (FAO, 2018). It is now well established that EWEs also contribute significantly to abandoning and stopping chasing certain species in regions, causing damage to coral reefs, red tides, algal blooms and reducing dissolved oxygen (Table 1). In all the studies reviewed here, these impacts seem to cause losses and damage to fish varieties and production systems; they also increase mortality, decrease reproduction rates, productivity and production volume and slow growth. Also, it is shown that opportunity costs increase by production disruptions, affecting aquaculture activities and the sustainable livelihood development of fishermen (Cochrane et al., 2009).

In fisheries, a wide range of previous studies have shown that EWEs and climate change cause disturbances in fishing ground stocks and oceanic regime variability (Table 1); this forces fishing fishers to give up or stop pursuing certain species in some regions (FAO, 2018). It has also been explained that warming temperatures may cause fish to migrate from warm to cold waters (Beare et al., 2004), changing species distribution and catch potential (Brander et al., 2017). Some species were predicted to be degraded (FAO, 2018; Hobday et al., 2015; Mills et al., 2013), reducing the availability and quality of species, which may reduce the potential and sustainability in the future (Doney et al., 2012).

Coastal areas and coral reefs are considerably vulnerable to EWEs. Temperatures can affect dissolved oxygen availability, metabolic rates, eutrophication in water supplies and toxicity of pollutants (Badjeck et al., 2010). This variability leads to reduced feed intake, slow growth or increased fish mortality and the risk of disease spread (Mac et al., 2016). Another indirect effect of EWEs on fisheries is the alteration and degradation of natural resource flows (FAO, 2018; Hobday et al., 2015; Mills et al., 2013) including coral reefs, water quality and temperature (Seggel et al., 2016). In addition, ships and infrastructure systems such as ports can be severely damaged by typhoons, floods and heatwaves (FAO, 2018); these impact increase production and management costs.

The impacts of climate change and EWEs are recognized and long lasting and can cause severe consequences for fishermen with aquaculture-based livelihoods. This trend may lead to the livelihood and economic instability of coastal fishers (Badjeck et al., 2009; Barange et al., 2014; FAO, 2018) and potentially impact the future sustainable development (Cochrane et al., 2009; FAO, 2018).

It needs to be perceived profoundly that the impact of EWEs, and their damages are clear in some cases. However, in other circumstances, there will be barriers to identifying whether such losses and damages are caused by EWEs or other environmental factors (FAO, 2018). The impact levels by each EWEs also differ (Seggel et al., 2016), and they are not always static because of the influence of other socio-economic factors (Badjeck et al., 2010).

2.2 Positive Impacts

In addition to the negative impacts, significant positive changes in species, farming areas, heredity, nutrients and even wastewater management can be created by some certain EWEs. New fishing and aquaculture areas can be created; such as low-lying areas caused by extreme rainfall (Bell et al., 2011) mangrove expansion by floods (Easterling et al., 2007) or cold waters by increased temperatures (Chan et al., 2019). This new environment can ensure the socio-economic sustainability of fishers. Rising temperatures may promote longer growing seasons for some species, such as black tiger shrimp, tilapia, oysters and mussels, especially in temperate regions (Collins et al., 2020; Troell et al., 2017). Several new species may improve heredity, which increases production output and creates job opportunities and momentum for sustainable development in society (Bueno & Soto, 2017; Gubbins et al., 2013). It has been observed that near-coastal environments may have nutritional diversity by changes in kelp yield after extreme rainfall (Collins et al., 2020). In addition, new fisheries may emerge as fish populations change geographical distribution, and some marine areas may increase productivity, which may increase the catch potential of some fisheries (Badjeck et al., 2010).

3 Vulnerability of Coastal Fisheries and Adaptation Strategies in Vietnam

3.1 Vulnerability of Coastal Fisheries Sector to EWEs

The severity of impacts of climate change and EWEs on humans will vary depending on the exposure and vulnerability of coastal fisheries communities (FAO, 2018). The hazard intensity is relevant to the position, types of livelihood and existing adaptive capacities of a nation and locality. Thus, drawing upon exposure indices of the frequency and mortality, the dependence on fisheries and adaptability, the fisheries sector of many African and Southeast Asian countries is highly vulnerable to natural disasters (Badjeck et al., 2010). Exposure and vulnerability to natural disasters are not static due to the influence of socio-economic factors such as income, education, age and governance and season or the concurrency degree of other EWEs (Banholzer et al., 2014). Therefore, planning and introducing adaptation strategies in fisheries is fraught with difficulties. The individual impacts of EWEs also make it challenging to synthesize scientific knowledge about their impacts (Seggel et al., 2016).

The fisheries sector is not a particular industry but a part of the value chain and is closely linked to many other industries. Therefore, the vulnerability of this sector needs to be assessed in a dynamic environment and involving all stakeholders. Identifying all factors contributing to vulnerability is fundamental for implementing responses, recovery and promoting the adaptive capacity of the communities and ecosystems on which they depend (Soto et al., 2018).

During the past 20 years, information about the vulnerability of the fisheries sector to climate change and EWEs has become available at global and local levels (FAO, 2017). The indicators (Allison et al., 2009) and geographic information systems (GIS) (Handisyde et al., 2006) are used to rank and assess vulnerable degrees of the aquaculture sector on a global scale. Accordingly, a model structure was developed to synthesize indicators of exposure, susceptibility and adaptive capacity (Handisyde et al., 2017; Soto et al., 2018). However, limited data and uncertain developments lead to current research findings just stopping at comparing vulnerability levels across geographic regions rather than attempting to quantify these results (Soto et al., 2018). Also broader studies at national and global scales have still been helpful for decision-making and policy solutions for individual countries. It is also a meaningful direction for more profound studies at the local and household levels.

The literature on local-scale vulnerability assessment of the fisheries sector to EWEs focuses mainly on individual communities and species, for example shrimp farming-associated threats in Bangladesh (Kais & Islam, 2017), the exposure of aquaculture in southeast Australia (Doubleday et al., 2013), tilapia fish production under climate variability in Thailand (Pimolrat et al., 2013), the vulnerability of Chile's aquaculture industry (González et al., 2013), shrimp farming vulnerability to climate change in Vietnam (Quach, 2018). Research at the local level is critical since it considers production practices, environmental conditions and stakeholder and community interactions. Besides, it also investigates negative impacts and positive benefits from weather change and EWEs. These aspects are essential for guiding adaptation strategies and future development at local and household scales.

Vietnam is one of the most severe climate change-affected ten countries (Eckstein et al., 2019). This classification is based on aggregated socio-economic data and the observation of EWEs over approximately 20 years. The data also provides a country's vulnerability and exposure to EWEs (Eckstein et al., 2019; Kreft et al., 2017). In addition, about 20% of the total area of Vietnam is in low-altitude coastal areas and 55% of the country's population dwells in these areas (Neumann et al., 2015). It is predicted that low-lying areas affected by flooding and saltwater intrusion as sea levels rise. Vietnam is also a low-income country with limited adaptive capacity and natural resources depended livelihoods (Johnson & Pham, 2020). All of these make Vietnam vulnerable to climate change and EWEs.

Vietnam is the fourth largest seafood production in the world, after China, India and Indonesia (FAO, 2016). Fisheries play an important role in Vietnam's economy and are considered a resource for economic development, poverty alleviation and food security (FAO, 2011). At the national level, EWEs can affect GDP, exports, trade balance and employment. At the sectoral and local levels, EWEs impact fishers' income and sustainable livelihoods, industry input and output market participants. Currently, fish is considered the primary protein source in the Vietnamese diet, accounting for 40% of food consumption (FAO, 2011).

Vietnam's fisheries sector is predominantly small scale, particularly vulnerable to unpredictable weather patterns and climate change-caused changes (Johnson & Pham, 2020). Data conducted by Phillips et al. (2016) showed that Vietnam had about 2.4 million households engaged in aquaculture and 90% of them have farms with an area of fewer than three hectares; about 80% of ships have a capacity of less than 70 kW in 2011 (DF, 2022). Fish and shrimp farms are often located offshore and in bay areas, which are more likely to be affected by typhoons. Also, shrimp, fish, oyster and other aquaculture farms are in low-lying areas, estuaries, lagoons and mangroves. It has also shown that tidal flats, ideal areas for clams, are often greatly affected by sea-level rise and flooding (Johnson & Pham, 2020).

EWEs are causing significant damage to the seafood industry in Vietnam. The annual losses and damages to the economy due to EWEs form about 5% of GDP (equivalent to 15 billion USD) (MONRE, 2007) of which fishing loses about 1.5 billion USD per year and aquaculture and livestock are 650 million USD per year. Typhoon Damrey in 2017 is an outstanding example causing more than 30 billion USD damage in Khanh Hoa province, Vietnam. The storm sank and destroyed 1141 boats, fishing gear, 44,320 cages and 3,270 rafts and infrastructure (Johnson & Pham, 2020).

3.2 Current Adaptation Strategies and Existing Challenges

National and Regional Adaptation Strategies and Policies

Understanding the risk and vulnerability of the fisheries sector to the impacts of EWEs, Vietnam has made many efforts to respond to EWEs related impacts over the past ten years. Adaptation strategies are specified in fisheries sector development policies and climate change adaptation and risk management policies, shown in Fig. 1. The introduction of a system for monitoring and evaluating climate change adaptation activities in 2022 shows Vietnam's most significant effort.

Spatial planning with the integration of climate change and EWEs has received little attention from countries in the past (Soto et al., 2018). However, countries emphasis recently integrating aquaculture spatial planning with climate factors (FAO, 2017). Vietnam implemented early spatial planning for the fisheries industry (NASRV, 2003; VG, 2014). Although there are mentions of climate change impacts in this planning, integrating adaptation strategies into fisheries spatial planning has not been introduced yet. Spatial plans currently emphasize avoidance of fishing seasons, seasonal locations in fishing and the dominance of factors such as access to land, water resources and available farming space in aquaculture, FAO also indicated in 2018.

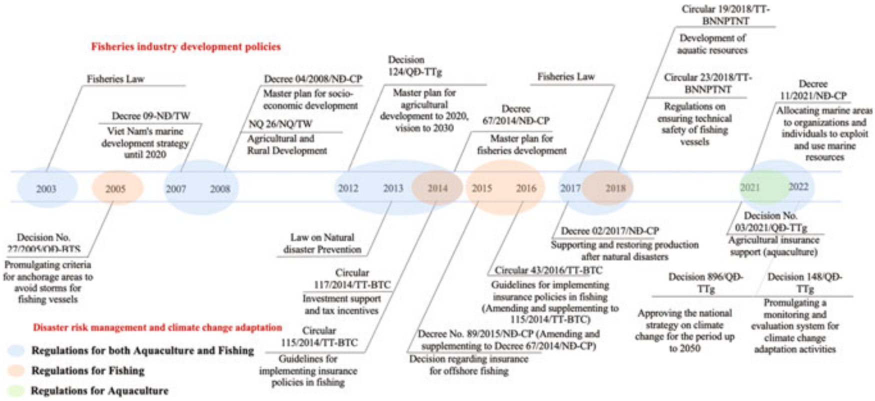

Fig. 1 Policies for fisheries development and natural disaster risk management and climate change adaptations (*Source* authors)

Mangroves are considered "green wall" against sea-level rise and EWEs (Badjeck et al., 2009) and protect the aquatic environment. Mangrove-based adaptation to EWEs has been successfully implemented in Vietnam and is regulated through the Law on Natural Disaster Prevention (NASRV, 2013) and promoted in a system for monitoring and evaluating climate change adaptation activities, 2022. Between 2015 and 2017, Vietnam had nearly 90 projects with 25 thousand hectares of mangroves newly planted, restored and replenished, to successfully act as natural barriers against EWEs (DF, 2022).

Physical exposure becomes a vital factor for assessing fisheries industry vulnerability (Soto et al., 2018). Coastal fisheries sector is the most exposed to EWEs because of its geographical location and production characteristics. Improving infrastructure and physical capital is essential for mitigating physical exposure-caused impacts. In Vietnam, concentrated planning has been carried out on storm shelters and infrastructure for concentrated aquaculture areas and large coastal fish hatcheries, where risks can be controlled (DF, 2005; MARD, 2018; NASRV, 2003). In addition, the locals adopt other adaptation strategies, such as regularly dredging channels and building docks and breakwaters to ensure safe anchoring and sheltering of boats.

Policies regarding leasing and allocating land, water resources and sea surface areas for the fisheries sector have been introduced, allowing fishers to take proactive and appropriate solutions in responding to EWEs (VG, 2021). Access to natural resources also has a significant implication in investing to mitigate the impact of EWEs and using them as a collateral resource in loans.

Research and development of science and technology in fisheries are one of the priorities in Vietnam's policies to respond to climate change and EWEs. This includes digital technology, remote sensing image technology, satellite tracking and managing fleets. Also, technical safety for fishing vessels and supports for facilities/gears/apparatus are adopted (MARD, 2018; VG, 2013). Biotechnology to respond to weather and environmental changes is encouraged in aquaculture through seed production technology, yield-enhancing gene storage, aquatic species resistant to the environment, climate change and disease. One of the climate change-adapted technologies developed in Vietnam successfully carries out a water quality monitoring system. Sensors consist of pH sensors, temperature and salinity sensors and dissolved oxygen sensors, which allow for adjustment or warn if adverse factors in the water environment can be potentially detrimental to aquatic life (DF, 2022).

One determinant of vulnerability is the adaptive capacity (Soto et al., 2018), including financial capacity, education and health. Vietnam has been assessed as a country with a low-adaptive capacity by a lack of financial resources and low qualifications of fishers. It has made efforts to reduce vulnerability and increase resilience for fishers through insurance policies, financial support (production loan policies and damage assistance after natural disasters) and investment and tax initiatives. Natural disaster insurance is one of the successful strategies in responding to EWEs, stipulated in fisheries law, 2003, 2017 and Decree 89/2015/ND-CP (NASRV, 2003, 2017; VG, 2015b) (insurance for the offshore fishing industry). Insurance policies for the offshore fishing industry and pilot aquaculture insurance schemes provide promising examples of policy and practice to strengthen national resilience and provide valuable guidance (FAO, 2016, 2017). Vietnam has introduced natural disaster insurance for the agricultural sector, including aquaculture (Table 2). However, the implementation process faces many institutional barriers and challenges, including the participation of insurance organizations and finance capacity. Although there have been certain efforts to regulate this insurance policy, it has not worked effectively.

A solution that helps fishers to recover from natural disasters was regulated in Decree No 02/2017/ND-CP (VG, 2017). Although it does not consider a long-term adaptation strategy, the government's supports allow coastal fishers to recover quickly. The tax exemptions for imported technologies to respond to EWEs and climate change have reduced the financial burden on fishers. The government has policies to mobilize capital and encourage investment in agriculture by private enterprises (including the fisheries industry) (VG, 2013b) or credit policies serving agricultural and rural development (VG, 2015a). The role of groups in financial support (NASRV, 2003, 2017) has also been done.

Strengthening adaptive capacity through human resource is critical to reducing vulnerability and the impact of EWEs. Despite the introduction of policies for training human resources in fisheries, these strategies and policies still lack solutions and integration into adaptation measures for climate change and EWEs. Human resources in technology are still weak and lacking in Vietnam. Besides, low financial capacity and unavailable technologies are significant challenges and barriers to training strategies. The total demand for fishery workers by 2020 is about five million people, including about 0.6 million fishing fishers, about 3.5 million aquaculture fishers, 0.7 million managers and 0.2 million supporters in the fisheries sector (DF, 2022).

Adaptations occur locally because national adaptation initiatives are constrained by human and financial resources in most developing countries (Hervey & Blythe, 2013). In Vietnam, the local adaptation efforts to EWEs and climate change have

Table 2 Policies to support fisheries insurance to natural disasters in Vietnam

Applied stakeholders	Sources of finance	% of insurance fee supported	Policies
Fishing			
All offshore fishing fishers	–	–	Fisheries Law 2003, 2017
All offshore fishing fishers (labors) and vessels with CV > = 90	Government budgets	100%	Decree 89/2015/NĐ-CP (related to insurance for offshore fishing)
Aquaculture			
1. Poor and near-poor households (According to Decision No. 59/2015/QĐ-TTg dated 19/11/2015)	Government budgets (depending on the budget balance in each period)	90%	Decision No. 03/2021/QĐ-TTg dated 25/03/2021 Valid until 31/12/2021 which substituted for Decision No. 01/2021/QĐ-TTg, Decision No. 22/2019/QĐ-TTg, Decree No.58/2018/NĐ-CP
2. Non-poor households		20%	
3. Enterprises and organizations applying science and technology		20%	

Source Authors

gained significant results. One of the achievements is regional and local planning. Also, the locals implement national strategies and policies on climate change adaptation activities in aquaculture and fishing.

Propagating and providing adequate information on weather variability and weather-related factors are essential for fishers to make decisions (Soto et al., 2018). Reviewing and capturing information on areas, farming types and varieties and the number of ships and contact information of ship owners is vital to warn timely about EWEs. The locals also implement, coordinate and manage the local infrastructure construction. Additionally, guidelines and recommendations are provided to empower fishers and make appropriate adaptations, which minimize the impact of heatwaves, typhoons and floods.

Local authorities have supported the development of climate change- and EWEs adapted intelligent aquaculture models. These models have mitigated the impact of climate change and EWEs and improved aquaculture productivity. Several models are easy to implement and suitable for investment (e.g., polyculture of black tiger shrimp + blue crab + mullet in Thanh Hoa province). They are also considered to mitigate risks and better manage environmental factors, especially temperature (high-tech model, greenhouse farming). It has shown that higher production efficiency can be created by the aquaculture model combined with rice paddies in the Mekong Delta, the aquaculture–mangrove model (DF, 2022).

Adaptation Strategies from Coastal Fishers

Studies have shown diverse adaptation strategies practiced by coastal fishers currently in Vietnam, including active and passive adaptation (DF, 2022; Johnson & Pham, 2020; Mac et al., 2016), as follows:

- Passive adaptations such as: harvesting early, preparing a high-storage backup generator, reinforcing pond/bank/equipment/cages, transferring fish cages and broodstock to inland ponds, moving to avoid the storm safely and reinforcing the roof with sandbags.
- Proactive adaptations: monitoring and checking the weather hourly and daily and water quantity; changing to aquatic species and breeds with better tolerance, changing production season; investing in modern technology, facilities/devices (including life vests); job diversification or changing careers; reducing the density of aquaculture or applying climate change- and EWEs adapted intelligent models.

However, selecting adaptation types and making adaptation decisions depend on and are driven by many factors or are not always practical. An example is the asynchronous implementation of converting bamboo/wooden cages to Scandinavian-style plastic cages in Nha Trang bay, Vietnam. This asynchrony is due to plastic cages being expensive, leading to plastic cages being broken during storms due to debris from the wooden cages next to them (Johnson & Pham, 2020). Also, greenhouse technology is often expensive and unavailable, and it is not easy to apply in certain areas (e.g., estuary areas). Climate change-adapted smart models in aquaculture in some areas have not always been successful.

4 Potential Adaptation Strategies to EWEs in Vietnam

4.1 Development of Adaptation Strategies at Multiple Levels and the Use of Technology

National and Regional Planning-based Adaptation Strategies

EWEs caused losses, damages and vulnerability can be reduced with appropriate planning strategies and a climate and environmental monitoring system (Soto et al., 2018). Therefore, it will be necessary to plan fishing areas based on the forecast of seasonal climatic factors. The impact of EWEs can be predicted by region in different seasons. Spatial planning for aquaculture at national and regional levels, especially inshore and fish cage farming in the bay areas, must incorporate climate risk factors. Easy accessibility to sheltered places is important.

Spatial planning for the fisheries sector needs to consider the position and mobility and aquaculture forms, trade-offs between technology and investment costs and the relocation of permanent structures and ponds for existing aquaculture systems (Soto et al., 2018). Vietnam is predicted to have potential areas for aquaculture development in lowland coastal areas (IEFP, 2012), and these areas are more feasible for climate change-integrated planning.

Weather-related risk assessments at the regional level are essential in the process of selecting fishing sites and aquaculture areas, and these assessments should be an input to initiate the planning process. Pre-planning risk assessment can help to develop appropriate adaptation strategies for each region. It has also been shown that it is easier for managers to address potential risks in areas with a common water source (Soto et al., 2018). Coastal aquaculture in Vietnam often shares a water source from river basins, bays or lagoons and coastal water.

Vietnam's fisheries production is mainly small scale, which is more likely to be vulnerable to climate change and EWEs. As discussed in the earlier sections, studies showed that the impact of EWEs depends on the type of EWEs; aquaculture type, size and aquatic species; geography and climate forms; aquaculture areas; life cycle and age of species. Also, the severity of impacts depends on exposure and vulnerability levels, existing adaptive capacities and other socio-economic factors. Therefore, an effective form of planning needs to integrate all these factors. Differential impacts of each of these factors are a major challenge, but efforts are required to synthesize the scientific knowledge for a holistic consideration of all factors.

The potential of advances in science and technology, including remote sensing technologies, communication, weather information systems and integrated monitoring systems, should be utilized, as they can increase the effectiveness of existing zoning strategies and management processes. They will also aid in developing new methods of planning and management of the fisheries sector.

However, it is crucial to acknowledge that not all the impacts of EWEs are negative. As discussed above, climate change and EWEs can also bring about certain positive changes, such as the emergence of new fishing and farming areas, new fish species or an extension of the growing season in some species. These can improve productivity, heredity and biodiversity. The EWEs can also increase nutrient diversity and promote better wastewater management and transgenic varieties. It would be better for the managers and other important stakeholders to recognize and integrate these positive impacts of EWEs in development planning.

Adaptation Strategies Based on Climate, Environment and Integrated Monitoring System

The presence of a complete and comprehensive monitoring system for climate and the environment that fishers can trust and use to make decisions is rare worldwide (Soto et al., 2018). While being aware of the severity of EWEs caused impacts and monitoring and capturing complete information about weather variability, the unpredictable changes of EWEs and changes with severe consequences require in-depth studies and information gathered over a long period of time. Currently, early warning systems have been applied in aquaculture and fishing. Noteworthy examples are in China (early weather warning system for aquaculture and fishing) (Chang et al., 2012) and an environment and climate monitoring program for salmon in Chile (Soto et al., 2018). Closely monitoring and early warning systems also help coastal fishers harvest early or relocate from a risk site. In Vietnam, it is essential to continue and replicate the water quality monitoring and evaluation system through the sensor system in aquaculture. Also, applying the early warning system in fishing and aquaculture allows for minimizing the impact of EWEs.

An integrated monitoring system has been proven to be effective in the fisheries sector. It is pointed out by (Soto et al., 2018) that a variable should be continuously measured and reported for an ecological position. In such a scenario, the fishers and experts can provide information and integrate it into the system. The technical team will then analyze, identify and give early warning signals, allowing fishers to make well-informed decisions. The global environmental monitoring system is also connected to early warnings (Soto et al., 2018). A successful example of integrated monitoring and early warning in the Lower Mekong (FAO, 2017) shows the importance of environmental monitoring, rapid adaptations and an early warning system.

Tech-based Adaptation Strategies

Investments in science and technology are considered an effective adaptation measure to deal with EWEs (Soto et al., 2018). Therefore, the governments at the national and regional levels must prioritize investing in the application of science and technology in fisheries, to contribute toward the adaptation strategies. The technologies involved in adapting EWEs are diverse. Information technologies can help to predict and report risks and adaptations and can consist of safety equipment and GPS, camera-based monitoring and early warning systems with powerful sensors and improved data networks. Besides drones and satellite constellations, mobile devices (smartphones, tablets), cloud-based data systems, virtual reality and simulation (Soto et al., 2018) are also available technologies. However, it is essential to identify and prepare solutions for the potential risks of technology-based disinformation as well. This can expose policymakers and coastal fishers to making wrong decisions, which can further result in an increased future vulnerability/exposure of the fisheries industry (IPCC, 2014).

Investing in resilient farming technologies, biotechnology and genetic technologies has been shown to increase resistance and recovery and help in avoiding risks and reduce losses/damages. These technological solutions have been influential in reducing exposure to risks such as typhoons and strong winds as in the case of Lake Malawi and the Caribbean (GEF, 2015), reducing the rate of mortality through cage aquaculture in Taiwan (Chang et al., 2012).

Applying solid materials technology to infrastructure systems and vessels reduces vulnerability to climate change in the fisheries sector. This has been done successfully in countries such as Canada, Canada, Chile, Norway and the USA (FAO, 2014). However, applying these materials should consider the material costs and the financial capacity of fishers. It also integrates tax support and technology costs in the implementation process to make effective adaptation decisions.

Adaptation Strategies Based on Local Adaptation Capacity (Infrastructure and Better Management Practices)

As infrastructure contributes to reducing aquaculture exposure and limiting the vulnerability of fisheries sector, it is essential for the government to continue to build infrastructure, especially ports, berths and shelters. Road, electricity and irrigation systems in concentrated aquaculture zones should receive priority. Soto et al. (2018) pointed out the importance of better management practices and the need to integrate them into the fisheries sector development planning. Recently, investigators have examined that better practices can help to strengthen the species' resilience and farming systems through technology and access to finance and insurance. Better practices can be implemented through water-saving systems or pond design and construction. The use of non-native aquatic species to adapt to climate change and EWEs (Harvey et al., 2017) is also a strategy to be considered.

Better management practices can be done through weather-driven disease and environmental control systems. Pathogen management programs caused by extreme rainfall, heatwaves and severe drought are mentioned as preventing over-treating, improving and controlling capacities, outbreak-monitoring programs, changing the seasonal calendar later or sooner and harvesting early. These practices have effectively reduced diseases, damage and losses.

A variety of smart adaptation models to EWEs contributed significantly to better management practices in aquaculture. Vietnam needs to study and widely apply these models to appropriate regions. Fishers need to visually approach the models and adjust their production activities to suit the characteristics of each region. Turning awareness into actions through practice, approach and learning good techniques and adaptations is a process that should be imbibed by all the concerned stakeholders.

4.2 Improving Resilience and Adaptive Capacity for Local Authorities and Coastal Fishers

Training-Based Adaptive Capacity Improvement

A successful adaptation strategy is determined by adaptive capacity at national, regional, community and household levels. The IPCC (2014) showed that adaptation experience to climate change and EWEs is improving; it is recognized and integrated into development plans. Unfortunately, a primary factor affecting adaptive capacity is the accessibility and effective use of livelihood assets (Bueno & Soto, 2017). For example, African fishers respond better to climate change and EWEs as they access new technologies (Hassan & Nhemachena, 2008). Also, this accessibility is well practiced under a good local institution and better governance. The government, therefore, should design priority programs for local adaptation capacity building, including local authorities and coastal fishers.

It is noteworthy that having access to adaptation strategies and livelihood capital resources does not necessarily mean successful adaptation practices. It is essential to understand the adaptation process and how to apply it to production activities. Sometimes, it is challenging for coastal fishers, especially small-scale and illiterate or less literate fishermen. An example of integrated monitoring and early warning in the Lower Mekong (FAO, 2017) showed the importance of environmental monitoring, farmer-gathered information, rapid adaptation and early warning measures, behavioral change and long-term investment. However, this process requires farmers (including fishers) to have a strong base of knowledge. As they come from different backgrounds, it should be mandatory to provide training for each farmer and technician. Therefore, governments and local authorities need to ensure that policies and plans regarding EWEs and climate change recognize this fact and develop effective methods of imparting knowledge and capacity building. Also, fishers need to be aware of the dynamics and the impact pathways of EWEs for their adaptive decision-making. The government should also prepare timely reports on the certainty of predictive models and solutions. Fishers must equip their adaptive capacity and preparedness in terms of awareness, technology, knowledge and experience.

Social Capital Resources and Local Institution

Unlike other capital resources, the social network is an invisible and value-driven force that many individuals use as a refuge or a safety net for adversities, including the impact of EWEs and climate change (Deb & Haque, 2017). Without fishers realizing the importance of a social network, it will not be beneficial and may even impede resilience. EWEs caused disasters can lead to a breakdown in kinship relationships, work support, work overload and possible exclusion from means of living (Deb & Haque, 2017). Therefore, coastal fishers need to be aware of the importance of social networks and actively participate in these networks as a road leading to successful adaptation.

All responses to climate change and EWEs ultimately occur at the local and household levels. Although fishers have access to all livelihood capital resources and can take self-adaptation measures, the success of these adaptations and the adaptation capacity will not be sustainable without support from local institutions and a good form of governance. It is vital to acknowledge the role of community groups, non-governmental organizations and all other civil society organizations in improving capacity and aiding the government sector in developing and implementing plans and policies in connection with the community.

Credit and Insurance

Accessibility to financial resources contributes significantly to reducing EWEs caused losses and damage and improves fishers' adaptive capacity (Soto et al., 2018). However, fishers face many challenges in accessing financial resources. For example, fishery insurance contributes to mitigating natural disaster-caused losses/damages in Vietnam. However, only large-scale households and offshore fishers can access this insurance policy. In certain regions, aquaculture insurance is also limited to white-leg shrimp, black tiger shrimp and basa fish farmers. Financiers often shy away from loans and insurance for small-scale fishing households with low affordability. Adaptation strategies will be difficult to succeed if fishers cannot access appropriate credits and insurance. Therefore, it is essential to design financial policies to make financing accessible to all fishers. Loan guarantees and affordable credit are critical for effective adaptation practices (Karim et al., 2014). So, the government should continue to implement insurance packages and expand the insurance scale.

Livelihood Diversification

Livelihood diversification is key to successful adaptation. However, it requires much effort from both local authorities and the fishers. Livelihood diversification requires alternative livelihoods (Blythe et al., 2014), the integration of indigenous knowledge and government intervention (Leal Filho, 2011) and even the vulnerability to climate change and EWEs of alternative livelihoods. Therefore, the local government should guide through possible barriers, and fishers should also be proactive in capturing the opportunities to successfully diversify livelihoods.

Applying technology and smart adaptation models is considered to be an effective livelihood diversification. However, it is necessary to consider diverse contexts and conditions, for example which kinds of technology are suitable for small and medium-sized households with low financial capacity and skill. It is also vital to consider the environmental characteristics of each region to apply these models and technologies. There is a need to incorporate local authorities and fishers in implementing this adaptation strategy, creating the availability and accessibility of technology for fishers.

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