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Analysing the livelihood vulnerability of shrimp farmers to climate change: A case study in Tra Vinh province, Vietnam

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ABSTRACT

This study measured the livelihood vulnerability index of shrimp farmers to evaluate their vulnerability to climate change by comparing three shrimp farming systems in Tra Vinh province, Vietnam. The analysis is based on the IPCC's framework of vulnerability assessment using three contributory factors – exposure, sensitivity, and adaptive capacity. Forty two indicators were assessed for the three dimensions and five types of livelihood capital (human, physical, natural, social, and financial) under the Sustainable Livelihood Framework of Chambers and Conway (1992). A survey was carried out with 300 households, of which 195 were engaged in intensive, 62 in semi-intensive, and 43 in extensive shrimp farming. In general, results indicate that shrimp farmers were vulnerable to climate change at a medium level, with the extensive system being the most vulnerable. Households engaged in semi-intensive shrimp farming showed the lowest level of vulnerability. The intensive farming system was the most vulnerable to climate change in terms of natural, social and financial capitals, while the extensive system was the most vulnerable in terms of human and physical capitals.

INTRODUCTION

In Vietnam, the brackish-water shrimp farming industry has brought large profits to farmers in recent years. The industry has been developing since 1980 (**MARD, 2015**), and shrimp aquaculture now takes place from the North to the South of Vietnam, especially in the Mekong Delta, where shrimp farmland accounted for 91% (699,725 hectares) of the total in 2014, with an average growth rate of 3.12% per year from 2010 to 2014. The Mekong Delta industry produced 661,074 tons of shrimp in 2014, equivalent to 80.61% of the total national production, a 1.5-fold increase compared to 2010 (**MARD, 2015**). Tra Vinh Province is one of the 12 provinces in Mekong Delta suitable for brackish-water shrimp cultivation with its 65-km coastline and a dense network of rivers and canals. According to the Department of Natural Resources and Environment of Tra Vinh Province, its canal system includes 110 level 1 canals with a total length of 467 km, 690 level 2 canals with a total length of 2,110 km, and 8,800 level 3 canals with a length of 6,620km. The authorities in Tra Vinh consider the shrimp industry to be a vital part of the economic strategy of the Province. By 2018, the shrimp farmland in Tra Vinh Province had expanded to 32,593 hectares and produced 52,778 tons of shrimp (Aquaculture Department of Tra Vinh). In addition, the Tra Vinh provincial authority's **Decision 784/QD-UBND of 27 April (2018)**, 'Developing the shrimp farming industry to 2025', has plans to develop shrimp production based on each natural area of the province: intensive and semi-intensive shrimp cultivation should continually develop, applying new technologies without abusing chemicals or antibiotics to acquire eco-environmental certification to meet the requirements of export markets. Whereas, extensive shrimp farming should consolidate and maintain production to preserve the existing mangrove forest and to balance the ecosystem.

However, in the context of climate change, the shrimp farming industry has suffered significant damage and loss in recent years. In 2018, the Aquaculture Department of Tra Vinh Province reported that 4,330 shrimp farming households had suffered damage to 1,550 ha of shrimp farmland due to drought, fluctuation in temperature, and epidemic disease. Adverse environmental factors and climate change have caused difficulties in the industry. From 1970 to 2007, the average temperature increased by 0.6°C, and the average precipitation increased by more than 94mm per year **(MARD, 2015)**. By 2100, according to the A2 scenario of the Intergovernmental Panel on Climate Change (IPCC) of a 1-metre sea level rise (SLR), 85% of the Mekong Delta area (12,376 km^2) would be submerged. Tra Vinh Province, in particular, would lose up to 45.7% of the natural land area, and coastal land for aquaculture farming would totally disappear (Carew-Reid, 2007). Accompanying SLR, the average temperature is also estimated to increase by about 3°C, which will affect almost all economic areas, and shrimp farming in particular, by 2100 **(MORE, 2016)**. In addition, the rainfall in this area would increase by about 3% and 7% by 2050 and 2100, respectively; therefore, Tra Vinh Province is predicted to experience more rainfall in the future, with the rain focused especially on coastal areas which are regarded as the most suitable for shrimp farming **(JICA, 2013)**.

Aquaculture is vulnerable to climate change. Changes in climate causing higher temperatures, prolonged drought, heavy rain, and seawater intrusion inevitably result in reductions in desirable shrimp yields. In addition, these harsh conditions encourage the growth of harmful microbes whose proliferation can cause epidemics in shrimp farms. This in turn would lead to shrimp farmers increasing their use of uncontrolled chemicals and drugs to treat water and shrimp diseases. The poor quality of water in shrimp farms stems from this and whatever waste is discharged into the environment by the farmers is likely to return in the form of a disease sooner or later (Nyan Taw, aquaculturealliance.org).

Climate change will inevitably pose challenges to the productivity of shrimp farming. Thus, this study aimed to (1) analyse the livelihood vulnerability index (LVI) under the IPCC's climate change scenarios, (2) assess the differences in livelihood vulnerability between three shrimp production systems, and (3) identify suitable solutions to decrease the vulnerability of each method of shrimp production to climate change.

2. LITERATURE REVIEW AND METHODOLOGY

2.1 Literature review

The shrimp farming industry in Vietnam has three prevailing methods of production: intensive, semi-intensive and extensive. The key features of each method are shown in Table (1). Intensive shrimp farming has been the predominant method of production in recent years. It only accounts for 1.8% of shrimp farmland, but it makes up 21.1% of the national shrimp output **(JICA, 2013)**. In Tra Vinh province in particular, the intensive method accounted for 13.6% of the area under shrimp cultivation and 89.37% of the output in 2018 (Appendix C). Under intensive farming, the shrimp are fed wholly on commercial food and are kept at a high stocking density of post-larvae, in the case of *Penaeus monodon* (black tiger shrimp) at 15–30 post-larvae/m^2 and *Litopenaeus vannamei* (whiteleg shrimp) at 40–100 post-larvae/m^2. Thus, the average production of the intensive system is higher than that of the other two methods. However, it requires a large capital investment. Therefore, intensive shrimp farming is practised by households with adequate financial capacity and an average farm size of 1–6 ha and by corporate farms 10–100 ha in size.

Semi-intensive shrimp farming is similar to intensive farming in terms of pond size, facilities, and the equipment used. However, farmers use a fertiliser to generate some natural food for the shrimp and combine it with outsourced food such as small shellfish or molluscs, but the shrimp are fed mostly on commercial food. The density of seeding in this system is lower than that of intensive shrimp farming. It accounts for 8.2% of shrimp farmland, and makes up 35% of the national shrimp output **(JICA, 2013)**. In Tra Vinh province, the Aquaculture Department reported that 1.35% of the shrimp farmland is under the semi-intensive system, generating 1.2% of the output in 2018.

Extensive shrimp farming is the most popular method of shrimp production in Vietnam, accounting for 90% of shrimp farmland, but only 43% of the national shrimp output **(JICA, 2013)**. These numbers are quite different in Tra Vinh, where 85% of the farming area was under extensive shrimp cultivation, producing approximately 9.4% of the output in 2018 (data from the Aquaculture Department of Tra Vinh Province). Extensive shrimp farms are usually located in coastal areas, where there are mangrove forests rich in natural food. Because of the low stocking density of only 5–7 post-larvae/m^2, stock is added regularly due to partial harvesting every month. The annual production average is only about 450–500kg/ha. The shrimps rely entirely on natural food, which makes this system suitable for famers who have low financial capability or do not have access to bank credit. Normally, farmers cultivate shrimp together with other aquaculture species such as crab and fish in order to improve their incomes.

Table 1. Comparison of three shrimp farming systems in Vietnam

Key feature	Intensive shrimp farming	Semi-intensive shrimp farming	Extensive shrimp farming
Pond size	0.1–0.6 ha	0.1–0.6 ha	1–15ha
Average stocking density	15–30 PL/m^2 (*P. monodon*) 40–100 PL/m^2 (*L. vannamei*)	7–10 PL/m^2 (*P. monodon*) 20–50 PL/m^2 (*L. vannamei*)	5–7 PL/m^2 (*P. monodon*)
Average production	2–8 ton/ha (*P. monodon*) 6–15 ton/ha (*L. vannamei*)	1–3 ton/ha (*P. monodon*) 3–9 ton/ha (*L. vannamei*)	0.45–0.5 ton/ha (*P. monodon*)
Number of crops per year	2–3	2–3	Not clear distinction between crops
Type of farmer	Households and corporations	Households	Households
Treatment of effluents	Yes	Yes	No
Aeration system	Installed	Installed	None
Food	Commercial food	Commercial and natural food	Natural food

Note: PL = post-larvae; *P. monodon* = *Penaeus monodon* (black tiger shrimp); *L. vannamei* = *Litopenaeus vannamei* (whiteleg shrimp)

Source: **Hiep *et al.* (2016)** and https://seafood-tip.com

Some definitions from the IPCC's Fourth Assessment Report

Climate change vulnerability is 'the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity'. The definition has four components; namely, exposure, sensitivity, potential impact, and adaptive capacity, which affect the extent to which a system is susceptible to climate change **(Adelphi/EURAC, 2014)** (Fig. 1).

Exposure is 'the presence of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social or cultural assets in places and settings that could be adversely affected'. Thus, exposure is the nature and magnitude of climate change-related factors, in direct and indirect forms, to which shrimp farming systems are exposed, such as high temperature which causes the spread of shrimp diseases and leads to crop losses, scarcity of water resources, groundwater extraction, etc.

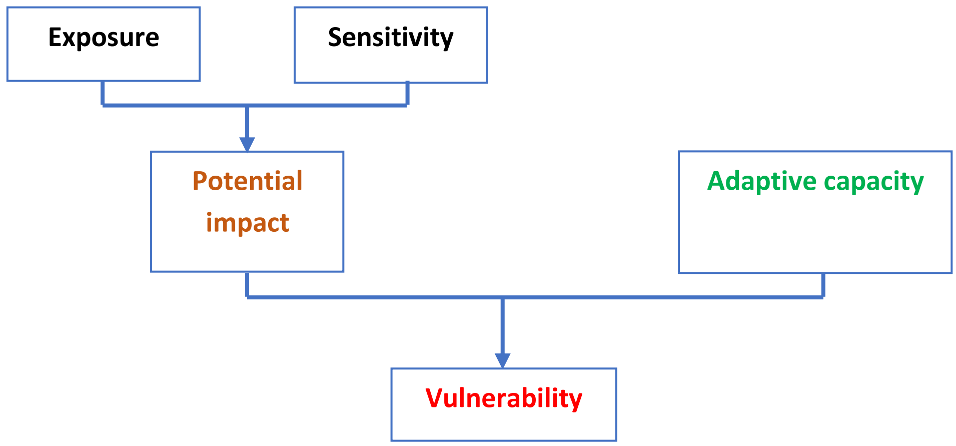

Fig. 1. Components of the vulnerability of a system to climate change
Sources: **Allen Consulting (2005)**, **Adelphi/EURAC (2014)** and **De Sherbinin (2014)**.

Sensitivity is 'the degree to which a system is affected, either adversely or beneficially, by climate-related stimuli. Climate-related stimuli encompass all the elements of climate change, including mean climate characteristics, climate variability, and the frequency and magnitude of extremes. The effect may be direct (e.g., a change in crop yield in response to a change in the mean, range, or variability of temperature) or indirect (e.g., damage caused by an increase in the frequency of coastal flooding due to sea-level rise)'. Climate change could be reshaped and an increase or a decrease in magnitude is expected in the future. Therefore, sensitivity to climate change could be expressed as adverse or beneficial responses to climate-related stimuli. In this study, all indicators of the sensitivity factor reflect adverse effects due to negative climate-related stimuli. The stimuli have a positive relationship with the vulnerability of the shrimp farming system, meaning higher sensitivity which leads to greater vulnerability.

The combination of exposure and sensitivity is the potential impact of climate change on a system. Afterwards, a system's vulnerability is the result of the interaction between the potential impact on the system and its adaptive capacity **(Allen Consulting, 2005; Adelphi/EURAC, 2014)**.

Adaptive capacity is 'the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences'. Thus, the higher the adaptive capacity of a system is compared to its exposure and sensitivity, the less vulnerable it is to climate change (Fig. 2).

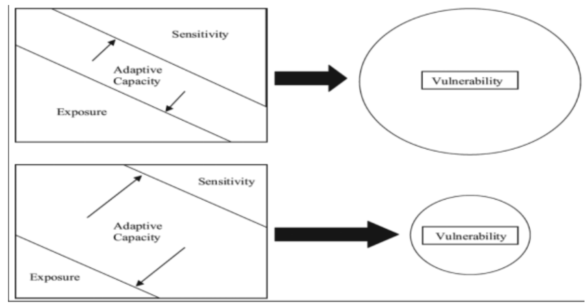

Fig. 2. The impact of adaptive capacity on the vulnerability of a system
Sources: **Engle (2011); Fellmann (2012)**

Vulnerability assessment has been mentioned in many international projects in relation to different aspects and fields. In order to aid populations that have suffered from the lack of staple food, multidimensional indicators have been employed to measure vulnerability **(USAID, 2007a; World Food Programme, 2007)**. In the context of climate change and the emerging concern about how people could adapt to it, several studies have evaluated the vulnerability of households or communities to climate change. **Hahn *et al*. (2009)**, **Urothody *et al.* (2010),** and **Pandey *et al.* (2012)** used seven components to calculate the livelihood vulnerability index (LVI) and LVI-IPCC (LVI incorporating the IPCC framework) at the village level. Based on the IPCC's (2001; 2007) theory of livelihood vulnerability, the seven IPCC components were grouped into the three dimensions, exposure, sensitivity and adaptive capacity, in accordance with the definition of vulnerability. The three dimensions were also measured based on the five forms of livelihood capital under the Sustainable Livelihood Framework of **Chambers and Conway (1992)**, which was applied by **Pandey *et al*. (2017)** with the climate vulnerability index and current adaptive capacity index, and by **Huynh *et al*. (2018)** with LVI at the household level. However, the subjects of all these studies were households with a variety of livelihood strategies, in other words, households with different occupations. However, the assessment of the vulnerability index at the village or community level does not provide an unbiased or complete picture. For example, heavy rain is not good for shrimp farming since it decreases the pH level of pond water, causing a stress to shrimp. However, it is good for rice or fruit farming. In this study, livelihood vulnerability assessment was carried out only for one occupation, i.e. shrimp farming.

2.2 Study area

Tra Vinh Province is located in southern Vietnam at 9°31′46″–10°4′5″N and 105°57′16″–106°36′04″E (Fig. 3). It is one of 12 provinces in the Mekong Delta. Its topography is flat floodplain, with an elevation above the sea level of approximately 1m. It has a 65km long coastline. The province is subject to strong monsoons, a high rate of evaporation and relatively low annual precipitation. The average temperature ranges from 26°C to 27.6°C, and the average annual precipitation is about 1,520mm. The area rarely experiences storms (e.g. Typhoon No. 5 in 1997 and Typhoon Durian in 2006), but extended droughts frequently cause loss and damage to agriculture and aquaculture production (**GSO**–General Statistics Office of Vietnam).

Tra Vinh's dense network of rivers and canals has favoured the development of the shrimp farming industry across the whole province. This study was conducted in Duyen Hai and Cau Ngang districts, which are two of the four most important shrimp farming regions in Tra Vinh Province **(Hiep *et al*., 2016)**. In 2018, the two districts accounted for 93.32% of the shrimp farming area and 89% of the productivity of the Province (Aquaculture Department of Tra Vinh province). The two districts were chosen as being representative of the shrimp farming industry in the province to calculate the LVI to climate change. Because they are coastal districts, they are susceptible to sea level rise, storms and drought **(791/QD-UBND, dated 7 April 2016)**.

Duyen Hai district (area 300.47 km^2) is located in the South of Tra Vinh Province, and has a 55km coastline, 2,640 hectares of rivers and canals, with salinity ranging from 9‰ to 22‰ (Hydrological and Climatic Department of Tra Vinh province, 2018), which is within the optimal salinity range of 15–25‰ for shrimp farming **(Anh *et al*., 2010; MOFI, 2016)**, and more than 100 hectares of coastal land. Its elevation is generally low and ranges from 0.4 m to 1.0 m above sea level. Duyen Hai was the first area to develop shrimp farming in Tra Vinh Province, adopting the mangrove shrimp farming model in 1990, and then semi-intensive and intensive models which emerged quickly. By 2001, the mangrove forest area was dramatically decreased from 21,221 ha in 1965 to 12,796 ha **(Thu *et al*., 2017)**.

Cau Ngang district (area about 325km^2) is located in the Southeast of Tra Vinh Province, along the Co Chien River. Therefore, it is influenced by the tides of the East Sea through this river, which is invaded by sea water in the dry season. It is difficult to plant crops (rice, corn, or watermelon) in this area, but the conditions are beneficial to aquaculture activities, especially shrimp farming. However, the salinity of the Co Chien River ranged from 0.1‰ to 8.1‰ over six months in 2018 **(Hydrological & Climatic Department of Tra Vinh province, 2018)**. The district also has a 10km long coastline which favours fishing.

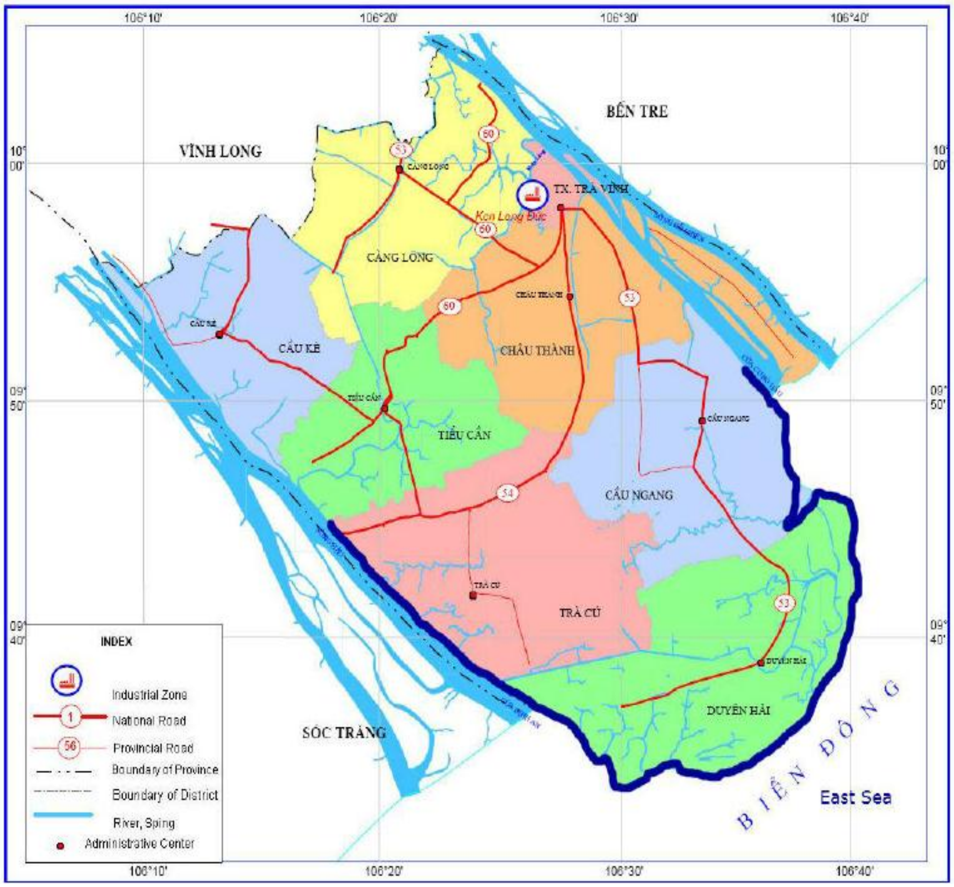

Fig. 3. Map of Tra Vinh Province

Source: *https://khongsolac.com/ban-do-du-lich-va-hanh-chinh-tinh-tra-vinh.html*

2.3 Climate patterns and scenarios in Tra Vinh Province

Status of the climate in Tra Vinh

Tra Vinh has 65km of coastline and a coastal tropical monsoon climate with a relatively high level of evaporation of 1,293mm/year. Tra Vinh receives a high level of solar radiation, with an average temperature of 26°C to 27.6°C; drought adversely affects agriculture and aquaculture annually, with 10–18 days continuously without rain in the rainy season. The level of precipitation, at an average of 1,520mm/year, is intermediate compared to the Mekong Delta. Fig. (4) shows the monthly average temperature and rainfall in 2013.

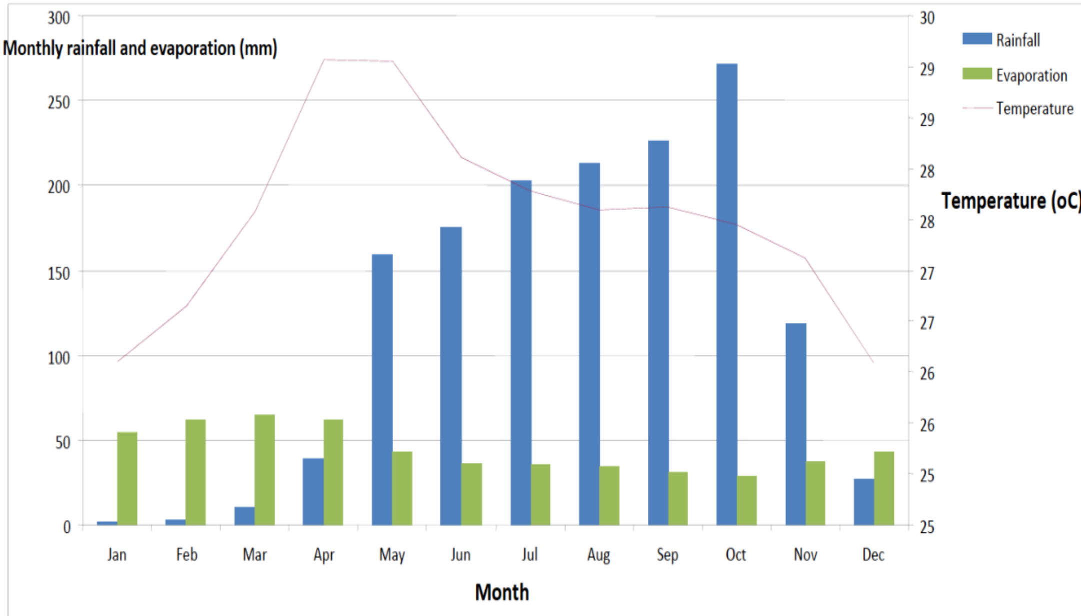

Fig. 4. Recorded climate patterns in Tra Vinh Province in 2013
Source: **Mai V.T et al. (2014)**

Climate scenarios for Tra Vinh Province

The IPCC's Fifth Assessment Report (AR5) used four representative concentration pathway scenarios for greenhouse gas emissions, RCP2.6, RCP4.5, RCP6.0, and RCP8.5, for modelling (IPCC, 2014). In 2016, the Ministry of Natural Resources and Environment (MONRE) predicted climate change in Vietnam based on RCP 4.5 and RCP 8.5. Table (2) shows summary scenarios for predicted changes in average temperature, rainfall, sea level rise, and inundation for Tra Vinh Province.

The RCP scenarios show that climate change will intensify in the 21st century. The RCP 4.5 scenario predicts that the average temperature would increase by 1.8°C by the end of the century, compared to the period 1986–2005, while the RCP 8.5 scenario estimates are likely to be double this increase (3.4°C) for the same period. According to **MORNE (2016)**, the RCP 4.5 scenario has a higher probability of occurrence than the RCP 8.5 scenario. Therefore, the government should base its actions on the RCP 4.5 scenario for short-term plans or programs, and the RCP 8.5 scenario for longer-term and permanent plans or programs. Similar to average temperature, rainfall is forecasted to be heavier under the RCP 8.5 scenario by the end of the century. In the 21st century, Vietnam is predicted to experience an average sea level rise of 55cm (33–75cm) and 77cm (51–106cm) under RCP 4.5 and RCP 8.5, respectively. Specifically, 1,873ha of Tra Vinh would be inundated if the sea level rises by 50cm, and 49,867.5ha would be under water if the sea level rises by 100cm.

Table 2. Climate change scenarios according to the IPCC's Fifth Assessment Report (AR5) for Tra Vinh Province*(1)*

Scenario	**RCP 4.5**(2)			**RCP 8.5**(3)		
Year	2016–2035	2046–2065	2080–2099	2016–2035	2046–2065	2080–2099
Average temperature (°C)	0.7 (0.4–1.2)	1.4 (1.0–2.0)	1.8 (1.2–2.6)	0.8 (0.6–1.2)	1.9 (1.4–2.6)	3.4 (2.7–4.5)
% Rainfall	10.9 (4.9–16.3)	15.7 (5.7–26.8)	17.7 (4.1–30.0)	11.4 (5.6–17.5)	14.6 (8.4–21.5)	18.2 (9.0–28.2)
The risk of inundation of Tra Vinh when sea level rises due to climate change						
Sea level rise	50 cm	60 cm	70 cm	80 cm	90 cm	100 cm
% Inundation	0.8	1.02	1.33	2.38	4.93	21.3
(ha) Area inundated(4)	1,872.96	2,388	3,113.8	5,572	11,542	49,867.5

Source: **MONRE (2016)**. Summary of Climate change and Sea level Rise Scenarios in Vietnam.

Note: (1) Baseline: 1986-2005

(2) The RCP 4.5 is equivalent to B of the IPCC's AR4

(3) The RCP 8.5 is equivalent to A1, FI of the IPCC's AR4

(4) Total area of Tra Vinh is 234,120 ha **(GSO, 2019)**

The IPCC's Third (TAR) and Fourth (AR4) Assessment Reports specified six emissions scenario groups, A1FI, A1B, A1T, A2, B1, and B2 (**IPCC, 2007b**). The **MONRE (2016)** and **Mai *et al*. (2014)** have projected temperature and rainfall by season for some of the scenarios for Tra Vinh Province (Table 3).

Table (3) shows that the precipitation in Tra Vinh is projected to decline in the dry season (from December to May); while an increase in the rainy season (from June to November) is predicted. Similarly, the average temperature is forecasted to increase strongly in the autumn and winter, with a slight increase in the spring and summer. Overall, annual rainfall and average temperature will increase more and more in the future.

Review of the impacts of climate change on shrimp farming

Shrimp production is susceptible to changes in climate. Under the scenarios mentioned above, the increasing trend in temperature would have adverse effects on shrimp farming. High or low temperature causes stress to shrimp, affects their immune system and poses a high risk of disease **(MARD, 2015)**. Increased rainfall causes the salinity and pH of the water to drop. This would easily result in shock to shrimp or even cause their death. Using regression analysis based on data collected from 1999 to 2012, MORNE studied the relationship between shrimp productivity (tons) and independent climatic variables, such as average temperature (x_1), annual rainfall (x_2), and typhoons

(x_3). The function was Y = 525.55 – 9.909x_1 – 0.113x_2 – 26.99x_3, with R^2 = 0.989 at $P < 0.05$. Assuming other inputs remain unchanged, based on scenario B2, if the average temperature increases by 0.72°C and annual precipitation by 1.54%, the national brackish-water shrimp production would decrease by approximately 24,550 tons. Shrimp production in Tra Vinh, in particular, would decrease by approximately 1,076 tons (deduced from 'General report of the planning for brackish shrimp farming in Mekong Delta by 2020 and vision toward 2030' [**MARD, 2015**]).

Table 3. Climate change scenarios based on the IPCC's Third and Fourth Assessment Reports for Tra Vinh province

Season	**B1 Scenario**							
	Temparature changes				Rainfall (%)			
	2020	2030	2040	2050	2020	2030	2040	2050
Dec.-Feb.	0.3	0.5	0.6	0.8	-2.7	-4.4	-6.2	-7.7
Mar.-May	0.4	0.6	0.8	0.9	-2.6	-3.6	-5.8	-7.2
Jun.-Aug.	0.5	0.7	0.9	1.1	0.3	0.5	0.6	0.8
Sep.-Nov.	0.5	0.6	0.9	1.2	2.6	3.8	5.0	6.3%
	B2 Scenario							
	Temparature changes				Rainfall (%)			
	2020	2030	2040	2050	2020	2030	2040	2050
Dec.-Feb.	0.3	0.5	0.6	0.8	-3.0	-4.4	-6.2	-8.1
Mar.-May	0.4	0.6	0.8	0.9	-2.8	-4.1	-5.8	-7.5
Jun.-Aug.	0.5	0.7	0.9	1.2	0.3	0.5	0.6	0.9
Sep.-Nov.	0.5	0.6	0.9	1.2	2.6	3.8	5.3	6.8
	A2 Scenario							
	Temparature changes				% Rainfall change			
	2020	2030	2040	2050	2020	2030	2040	2050
Dec.-Feb.	0.3	0.5	0.7	0.8	-3.3	-4.5	-5.9	-7.4
Mar.-May	0.4	0.6	0.8	0.9	-3.0	-4.2	-5.5	-7.2
Jun.-Aug.	0.6	0.7	0.9	1.2	0.4	0.5	0.6	0.8
Sep.-Nov.	0.5	0.7	1	1.2	2.8	3.8	5.0	6.5

Note: Baseline years are from 1989 to 1999.
Source: **Mai V.T *et al.* (2014**).

Furthermore, under the projected climate change scenarios, **Kam *et al*. (2012)** assessed the degree of impact on shrimp production (Table 4).

Table 4. The degree of impact of climate change on shrimp production

	Temperature rise	Drier dry season	Wetter wet season	Sea level rise: flooding	Sea level rise: salinity intrusion
Extensive shrimp farming	**High:** ponds are relatively shallower, with large surface area and limited circulation (aerators not used)	**High:** increased competition for freshwater supply to counteract salinisation of pond water due to salinity intrusion	**Medium:** additional water supply for ponds, but increase in wet season rainfall is minimal	**High**: in areas not protected by sea dikes and considering large pond size and longer perimeter	**High:** particularly in areas not protected from salinity intrusion
Semi-intensive/ intensive shrimp farming	**Medium to high:** depending on amount of organic debris and decomposing leftover feed			**Medium**: in areas not protected by sea dikes	

Source: **Kam *et al.* (2012).**

According to **Diep *et al.* (2015)**, Tra Vinh province is one of four provinces in the Mekong Delta that would be subject to inundation and salinisation, with 23,766ha and 97,720ha affected by the years 2030 and 2050, respectively. In 2004, a total of 15.67ha of mangrove forest, shrimp farms, fruit-growing areas and residential areas were affected by inundation and salinity. **Nguyen *et al*. (2020)** also concluded that, among provinces in the Mekong Delta, Tra Vinh is one of the most vulnerable to salinity intrusion.

2.4 Household survey

In the current survey, 300 households in total were interviewed, of which 195 practised intensive shrimp farming, 62 semi-intensive farming and 43 extensive shrimp productions. The households were randomly selected by each member of the team who was assigned a certain number of households in each village. This survey process was repeated in other villages until a sufficient number of households were interviewed according to the survey plan. The interview team consisted of only two members, with each member having to complete four surveys per day. The survey period was from the beginning of December 2018 till the end of January 2019. Originally, 320 households were surveyed, but 20 were omitted due to incomplete or illogical responses to the survey.

2.5 Study methodology

This study calculated LVI based on the IPCC framework (LVI-IPCC) by selecting suitable indicators from the five livelihood assets in the context of climate change that have direct and indirect impacts on shrimp farmers' livelihoods. Livelihood vulnerability to climate change was measured for three dimensions: exposure, sensitivity, and adaptive capacity **(IPCC, 2007; Hahn *et al.*, 2009; Pandey *et al.*, 2012; Adelphi/EURAC, 2014; Pandey *et al.*, 2017)**. Livelihood assets were based on the DFID framework which has five different types of capitals: human, natural, physical, social, and financial capitals. Each vulnerability dimension was measured using some indicators for each type of livelihood capital mentioned above. A total of 42 indicators were employed to calculate LVI-IPCC, which were selected based on many publications, discussion with experts who have experience in the particular shrimp farming systems. However, some of the indicators depended on the subjective experience of the author and experts. Although these indicators are suitable for this study, it may be necessary to reassess them and change them in future studies. The indicators for each dimension are shown in Appendix (A).

Since, each of the indicators was calculated in different units or at different scales, they first had to be normalised on a rating scale from 0 to 1 for equation (1) **(Vincent, K., 2004; UNDP, 2007; Hahn *et al*., 2009; Urothody *et al.*, 2010; Antwi-Agyei *et al*., 2013; Etongo D. *et al.*, 2021)**:

$$\mathbf{I_v} = \frac{Sv - Smin}{Smax - Smin} \qquad (1)$$

Where, Sv is the average original value of the indicator for each technology (v =1, 2, 3; 1 = intensive farming; 2 = semi-intensive farming, and 3 = extensive farming), Smin and Smax are the minimum and maximum values of the indicator for all samples, and Iv is the normalised average value of the indicator for each technology.

Then, indicators were aggregated for each dimension of vulnerability ($\mathbf{M_v}$) by averaging all its indicators (all $\mathbf{I_v}$ values) using equation (2) **(Hahn *et al*., 2009; Urothody *et al*., 2010; Pandey *et al.*, 2017; Etongo D. *et al.*, 2021)**:

$$\mathbf{M_{vj}} = \sum_{i=1}^{n} \left(\frac{I_{vji}}{n}\right) \qquad (2)$$

Where, $\mathbf{M_{vj}}$ is one of the indices for the dimension of vulnerability for each type of capital; $\mathbf{I_{vji}}$ is calculated by equation (1); **j** is the $\mathbf{j^{th}}$ vulnerable dimension of each type of livelihood capital (**j** = exposure, sensitivity, or adaptive capacity); **i** is the $\mathbf{i^{th}}$ indicator for each dimension; v is the shrimp farming method (intensive, semi-intensive, or extensive), and **n** is the number of indicators in each dimension $\mathbf{j^{th}}$.

For the purpose of simplification, equation (2) assumed that the weight of each indicator was equal, which means that every indicator in each vulnerability dimension has an equal degree of importance and influence. This approach has been employed in previous studies **(Sulliva *et al*., 2002; Eakin *et al*., 2008; Hahn *et al*., 2009; Urothody *et al.*, 2010; Pandey *et al.*, 2017; Etongo D. *et al.*, 2021)**.

Equation (3) was used to calculate the potential impact (PI) **(Adelphi/EURAC, 2014)**:

$$\mathbf{PI = \frac{Exposure + Sensitivity}{2}} \quad (3)$$

The LVI under the IPCC framework for each type of livelihood capital was calculated by equation (4) **(Adelphi/EURAC, 2014)**:

$$\mathbf{LVI\text{-}IPPC_v = \frac{[PI + (1 - Adaptive\ capacity)]}{2}} \quad (4)$$

According to the definitions given above, the exposure and sensitivity dimensions have a positive relationship with vulnerability, which means that higher scores reflect greater vulnerability. In contrast, adaptive capacity has a negative relationship with vulnerability. To ensure a value range of 0 to 1 for the three components in terms of vulnerability, the value of adaptive capacity has to be the inverse ***(1 − Adaptive capacity)*** when aggregating LVI in equation (4) (**Adelphi/EURAC, 2014**). In other words, vulnerability is the consequence of susceptibility to adverse effects and inability to adapt or cope (**De Sherbinin, 2014**).

The value of $LVI\text{-}IPCC_v$ ranges from 0 to 1, where 0 means least vulnerable and 1 means most vulnerable. Equations (3) and (4) were repeated for each type of livelihood capital. The overall LVI-IPCC is an average of the five livelihood capitals' LVI. For aggregation of equations (3) and (4), a weighted arithmetic mean was applied using equal weights. **Appendix D** shows how the above equations were used.

3. RESULTS AND DISCUSSION

3.1 Human capital.

The exposure dimension was aggregated by three indicators – the percentages of households with insufficient food, poor health, and unable to afford school for their children – reflecting the impact of climate change on human capital. Most households reported that they had sufficient food (HE1). As it is the local custom, every family had the same routine for meals with three meals per day on the whole. In addition, it was easy for the households to obtain three different kinds of food for each meal, which was facilitated by the flourishing natural resources (for example, wild fish in rivers or canals) and farmed livestock, such as fish, chickens, and ducks, and vegetables. This factor also enhanced households' capacity to adapt to climate change, with extensive farming households reporting a much higher rate of adaptive capacity (86%) than intensive (55%) and semi-intensive (60%) farming households (HA5; **appendix B**). Because of the technologies adopted for production (**Table 1**), extensive farmers had more free time than the others for keeping livestock and cultivating vegetables to supplement their food supplies.

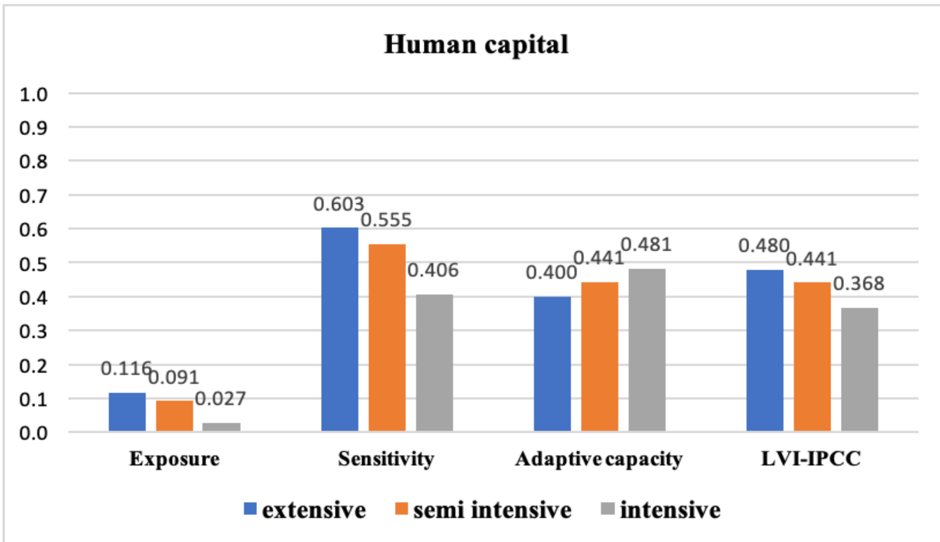

Figure 5. Exposure, sensitivity and adaptive capacity of human capital in different shrimp farming systems.

The percentages of semi-intensive and extensive farmers living far from hospital are nearly the same (HS2). According to the history of the shrimp farming industry, the extensive method was initially dependent on being located around the mangrove forest which is far from the centre of town, and the majority of semi-intensive farmers are those who decided to change the method of shrimp farming from extensive to semi-intensive. By contrast, intensive shrimp farming was developed later, and intensive farms are located in inland areas where there are rivers or canals and are closer the centre of town. This factor exacerbates the sensitivity problem, with higher percentages of households practising extensive or semi-intensive methods with illnesses (HS1) and poor health (HE2). Unsurprisingly, the data also showed a higher percentage of extensive and semi-intensive farming households living far from their children's schools than intensive households (HS3). Therefore, approximately 21% and 16% of children from extensive and semi-intensive farming households, respectively, discontinued schooling (HE3; **appendix B**) while this was the case with almost zero percent of intensive farming households.

Therefore, respondents practising intensive shrimp farming reported almost no exposure to climate change at 0.027, whereas extensive and semi-intensive households showed slight exposure to climate change at 0.116 and 0.091, respectively (**Fig. 5**). The sensitivity dimension was also similar; it was lower for intensive farming households compared to extensive and semi-intensive households (**Fig. 5**).

Furthermore, the adaptive capacity index (to which five indicators contributed [**Table 2**]) of the intensive shrimp farming households was slightly higher than that of the others (**Fig. 5**). The main indicators that contributed to this result are the level of education of the household (HA2) and the percentage of households taking part in training (HA4). Both indicators were favourable to intensive shrimp farming (**Appendix B**). Usually, the head of the household is the person who decides every important thing (**Gilligan, 1982**). However, the final decision is also based on ideas from all family members whose education has an influence on the livelihood strategy of the household. The level of education of households, therefore, is used to measure the capacity to adapt to climate vulnerability. Taking part in training courses brings many benefits, such as updated knowledge of shrimp cultivation, environmental responsibility in farming, and controlling and treating diseases. All of these increase the ability of shrimp farmers to adapt to climate change. This study found that the majority of intensive and semi-intensive farmers, more than 61% and 74% respectively, undertook training (**appendix B**), whereas almost no extensive farmers participated in courses because of the simple technology they used for shrimp farming compared to the complex and high-risk farming of the intensive and semi-intensive methods. However, the survey also identified other key reasons for farmers not participating in these training courses, e.g. lack of time, difficulties in applying, or the courses not being innovative enough compared to their own experience. This suggests that local authorities should listen to farmers' feedback when designing suitable courses.

As a result of the three dimensions mentioned above, the LVI-IPCC of human capital was at a medium level, and was highest for extensive farming and lowest for intensive farming (**Fig. 5**) because extensive farming had the highest exposure and sensitivity but the lowest adaptive capacity while intensive farming showed completely the opposite results.

3.2 Natural capital

Natural resources play an important role in shrimp farming. The primary natural resource is water which is mainly drawn from rivers or small canals. The quality of water and its salinity, pH, and temperature are factors directly affecting the shrimp farming process. The status of water during the farming period is always a concern for shrimp farmers because of the need to respond quickly to adjust and balance the parameters of the water in ponds. Even minuscule changes in pH could be a big problem for the health of the shrimp. Polluted water or abrupt changes in water temperature could have a severe effect on shrimp (**Macusi E.D. *et al*., 2022**). Therefore, effects of climate change and human behaviour on the natural environment, in turn, would lead to vulnerabilities in farming activity in general.

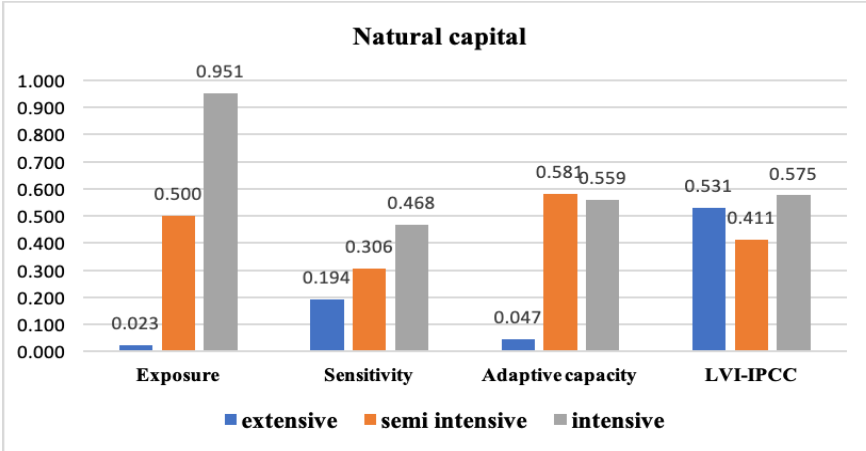

Figure 6. Exposure, sensitivity, and adaptive capacity of natural capital in different shrimp farming systems.

Fortunately, none of the shrimp farmers reported any unusual diseases in shrimp in the last three years (NS2). This indicator was included in the sensitivity dimension to reflect new hazards like diseases caused by climate change. Unusual diseases are regarded as an indirect result of climate change, and are assumed to be a factor causing vulnerabilities in shrimp farmers' livelihoods. However, the percentage of farmers reporting normal diseases in shrimp due to the climate (NE1) was considerable – 100% of intensive shrimp farmers and 72.6% of semi-intensive shrimp farmers over the past three years. By contrast, only 4.7% of the extensive shrimp farmers reported diseases in shrimp. The main factor that reduces the vulnerability to climate change of extensive production is the density of stocking (**Table 1**). Some normal diseases in shrimp farming, such as yellowhead disease, Taura syndrome virus, monodon baculovirus, white spot syndrome virus, and hepatopancreatic parvovirus were recorded. Although shrimp diseases have many direct and indirect causes such as the low quality of post-larvae, polluted water, and infection transmitted from other ponds, climate factors appear to exacerbate the situation.

The survey team recorded adverse climate patterns that can cause shock to shrimp, such as large differences in temperature between day and night, heavy rain, sudden rains in the dry season, and drought. According to **Bui Q. T. (2003)**, shrimp are highly sensitive to temperature; a water temperature that is too high or too low is unfavourable for shrimp growth. The threshold water temperature for shrimp is 28–32 °C. There is evidence that although high temperatures stimulate shrimp to grow rapidly, they also make them highly susceptible to disease (**Wyban *et al*., 1995**). Therefore, temperature rise has both advantages and disadvantages. The metabolic rate of shrimp may increase when water temperature rises, which could promote digestion and enhance the growth rate. However, organic decomposition also increases with high water temperature, leading to the lowering of dissolved oxygen which is one of the main causes of mass die-off of shrimp **(Kam *et al*., 2012**).

Drought also led to another exposure indicator: extraction of groundwater (NE2) to compensate for water evaporation from ponds. Groundwater extraction is lower in cost than treatment with river water and may help to avoid the risk of diseases in river water. If water from shrimp ponds with disease is discharged into the river directly without any prior treatment, for someone else to charge their ponds with river water, even with thorough treatment before pumping the water, is a high-risk activity. In addition, water is added to ponds at the growing phase of shrimp, the most susceptible stage of production. Therefore, farmers are very careful in using river water if they are not able to control the quality of the water. This issue was highlighted by 90% of intensive farming households compared to 27.4% of semi-intensive farming households, which tend to use groundwater for supplying shrimp ponds. No extensive farming households identified this issue due to the lower density of seeding.

Furthermore, extraction of groundwater for cultivation of other crops as well as for shrimp farming is inevitable. In the dry season, the scarcity of freshwater is a serious problem. Many reserved water dams have been built upstream of the Mekong River (in China, Thailand, Laos, and Cambodia). Thus, downstream of the Mekong River, not enough water is available for cultivation in the Mekong Delta and seawater has invaded the Delta in recent years. In addition, groundwater has depleted by about 2–5 m in depth, which has forced farmers to drill deeper into the ground to find freshwater (the average depth of wells is about 15–20 m) (**Cong, N.V, 2017**). However, the sad fact is that most farmers realised that the volume of groundwater was decreasing only when asked about the consequences of extracting groundwater, and none of them had a conception of the accompanying land subsidence that would threaten their livelihoods and exacerbate the flooding caused by sea level rise in the foreseeable future. According to **Erban *et al*. (2014)**, the average rate of land subsidence in the Mekong Delta is 1.6 cm per year, the main cause being groundwater extraction, with a recorded number of about 553,135 wells extracting approximately 1,923.681 m^3 per day in 2010 (**Ha *et al*., 2015**). However, farmers using this limited water resource still do not have any better strategies for the future. Groundwater use does not meet sustainable strategy for shrimp farming under the Sustainable Livelihood Framework (**Chambers and Conway, 1992; DFID 1999**)- sustainable livelihood strategy is the ability to cope with climate change by using available resources without overusing them by disregarding posterity. Groundwater extraction-induced subsidence is outpacing the global sea level rise, which raises significant concerns in the context of climate change.

Overall, intensive shrimp farming had the highest exposure (0.951), nearly double that of semi-intensive shrimp farming (0.5) while exposure was insignificant for the extensive method (0.023) (**Fig. 6**). Many factors cause shrimp disease, one of which is polluted water. In the survey, 85%, 63% and 39.5% of intensive, semi-intensive, and extensive shrimp farmers, respectively, agreed that the river water is currently polluted (NS1). The farmers' responses demonstrate the threat posed by polluted water to shrimp cultivation. In other words, polluted water resources add to the predicament of shrimp farmers in the context of climate change. Water pollution is caused by farming and other activities. First, when farmers discharge water from their ponds into rivers, it can contain pollutants as well as chemicals. For example, 1–1.5 tons of lime per ha used in shrimp farming (**Anh *et al*., 2010**), fertiliser, and large amounts of shrimp feed are discharged into the surrounding surface water. Second, there is no waste collection system in rural areas (no waste bins); hence, waste generated from farming and household activities, such as plastic bags and bottles, are burnt or buried, or in some cases thrown into the river, inevitably contributing to environmental pollution. According to the results of water quality tests carried out in 2012 (**MARD, 2015**), the pollution levels of all main rivers were 1.5 to 3 times higher than the permitted level. MARD forecast that in the future further industrialisation and modernisation of Vietnam would cause greater pollution of rivers, where livelihoods based on aquaculture are carried out. Generally, the sensitivity of intensive shrimp farming to climate change was twice as much as that of extensive shrimp farming, with semi-intensive shrimp farming ranked at medium sensitivity (**Fig. 6**).

However, the adaptive capacity of natural capital was the highest for semi-intensive farming (0.581), intermediate for intensive farming (0.559), and the lowest for extensive farming (**Fig. 6**). This dimension was measured by changing the model of shrimp farming (NA1), changing cropping time (NA2), and having reserve ponds (NA3). Supporting the results for this index, the percentage of households changing cropping time was considerably high in both the intensive and semi-intensive systems (both 87%), whereas in the extensive system it was difficult to change cropping time (7%) due to its characteristic production method. Some reasons for changing shrimp cropping time were heavy rain reducing the level of water salinity (the optimal salinity range is 15‰–25‰ for shrimp farming [**Anh *et al*., 2010; MOFI, 2016**]) and drought causing severe evaporation and increasing the risk of disease; in such situations, farmers postpone the new crop until conditions are more suitable.

Moreover, the flexibility of changing the method of shrimp farming was different between the different cultivation systems. It is impossible to change the intensive system to the extensive model due to the small area and closed design of ponds which are not suitable for the latter. The intensive system can only change to semi-intensive by decreasing the density of stocking. In the case of heavily polluted water or a shortage of water due to drought, intensive shrimp farmers can decide to change to semi-intensive forms to adapt to adverse climate events. In contrast, under favourable climate conditions, semi-intensive farmers can change to intensive farming to improve profits due to the higher density of stocking. Extensive shrimp farmers would find it difficult to change to other forms because they require significant investment in facilities and equipment. Therefore, 15% of intensive shrimp farmers, 32% of semi-intensive farmers, and only 7% of extensive farmers would change the model of shrimp cultivation (**Appendix B**). As described by farmers, reserve ponds help them to cope with water shortages in the dry season and avoid diseases transmitted from river water by treating it before using in shrimp ponds. The results for this indicator showed that 65% of intensive shrimp farming households have reserve ponds compared to 54.8% of semi-intensive shrimp farming households. In contrast, due to the method used in extensive shrimp farming, which lets river water in and out of ponds frequently, this system does not need reserve ponds.

The highest exposure and sensitivity to climate change of natural capital was shown by the intensive production system while its adaptive capacity was half the potential impact, leading to the highest LVI-IPCC for natural capital in this system (0.575). The semi-intensive farming system showed an intermediate level of vulnerability (0.531), whereas the vulnerability of the extensive shrimp farming system to climate change was relatively low (0.411; **Fig. 6**). The adverse impact of climate change on shrimp farming is obvious and will be more serious in the future, which is not only demonstrated by contemporary scientific evidence but also perceived by the farmers themselves (**Table 5**).

Table 5. Shrimp farmers' perception of related climate events in the past and the future.

What extent of these events compared to the past 10 years.						
Droughts occur more often.	Droughts are shorter than they used to be.	Storms occur more frequently	Heavy rains occur more often.	Floods are less severe.	Sea level is higher than it was 10 years ago.	Coastal land is lost to the sea.
4.423	1.637	2.243	4.134	3.590	4.103	3.983
What extent of these events will be in the next 10 years.						
In the future, droughts will occur more often	In the future, droughts will become shorter than they used to be.	In the future, storms will occur more frequently	In the future, heavy rains will occur more often.	In the future, floods will be less severe.	In the future, sea level will be higher.	In the future, more coastal land will be lost to the sea.
4.693	2.157	2.600	4.457	2.747	4.390	4.537

Note: The responses were rated using a Likert scale from 1 to 5, where 1 means 'definitely has not/will not' and 5 means 'definitely has/will'.

Source: Survey data

3.3 Physical capital

Based on the Sustainable Livelihood Framework, physical capital in this study comprises internal and external property of the household that could be vulnerable to climate change. Internal property is the house and shrimp ponds and external property is freshwater, electricity supply, and roads. No intensive and semi-intensive shrimp farming household reported damage to the house due to climate (PE1) because the majority occupied cement and brick houses (PA1). While 53.5% of the extensive shrimp farmers lived in cottages or bungalows, 9% suffered damage due to climate (**Appendix B**). The second indicator also showed less exposure to climate change, with rain and floods affecting 16% of the extensive shrimp ponds, but only 3.6% and 4.8% of the intensive and semi-intensive shrimp ponds (PE2). Extensive shrimp ponds are normally constructed with narrow, low dikes. Extensive shrimp farms located near coastal areas are frequently affected by tidal waves and sea level rise, and are easily flooded in the rainy season. In contrast, intensive and semi-intensive ponds are built carefully and firmly, and they are located far from coastal areas. Therefore, the exposure of extensive shrimp farms was higher than that of the other systems, but not considerably.

In the case of the sensitivity dimension, the shrimp farmers were satisfied with the electricity supply (PS1) provided through the sustainable shrimp farming strategy of the government. In contrast, none of the households had access to piped water (PS2), which contributes to health problems. This indicator has a positive relationship with the household's sensitivity to climate change. All households reported that rainwater and groundwater were used for cooking and sanitation, whereas groundwater was regarded as the main supply of freshwater, which could be vulnerable due to flooding or sea level rise (**T. Peolma *et al*., 2021**). Furthermore, living far from the road, transport was considered to be susceptible to climate change. Approximately 80% of the extensive farmers found it difficult to access the main roads due to their distance from farms (PS3), while only 42% of semi-intensive and 23% of intensive shrimp farmers were in that situation. As a result, extensive households were more sensitive to climate change in relation to physical capital than the others **(Fig. 7**)

The adaptive capacity index was augmented by the percentage of households with cement and brick houses (PA). A high-quality house would help the household to feel secure and cope with extreme climatic events. In the Mekong Delta, a house built of cement and brick is regarded as safe in storms. While 80–90% of semi-intensive and intensive families lived in cement-brick houses, only 46.5% of the extensive families did. Therefore, the adaptive capacity of both intensive and semi-intensive shrimp farmers was more than double that of extensive farmers (**Fig. 7**).

The survey data showed that the LVI-IPCC of extensive shrimp farming was the highest compared to intensive and semi-intensive systems (**Fig. 7**) due to the extensive system having higher sensitivity and lower adaptive capacity, while intensive and semi-intensive systems showed the opposite trends for all components.

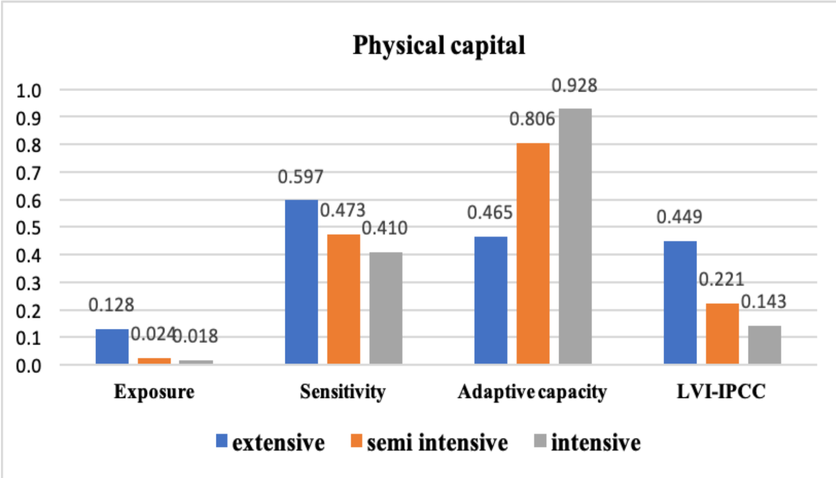

Figure 7. Exposure, sensitivity, and adaptive capacity of physical capital in different shrimp farming systems.

3.4 Social capital

According to **DFID (1999),** social capital concerns the relationships, networks, and access to information that people in the community use to pursue their livelihood strategies. Under a sustainable livelihood strategy, it is difficult to determine the level of social capital in a short time; it must be observed and assessed over an extended period (**DFID, 1999**). However, when measuring vulnerability to climate change, it is reasonable to evaluate the vulnerability index through related indicators such as access to information, means of communication, frequency of visiting relatives, entertainment, relationships with neighbours, and sharing experience of shrimp farming (**Appendix A**).

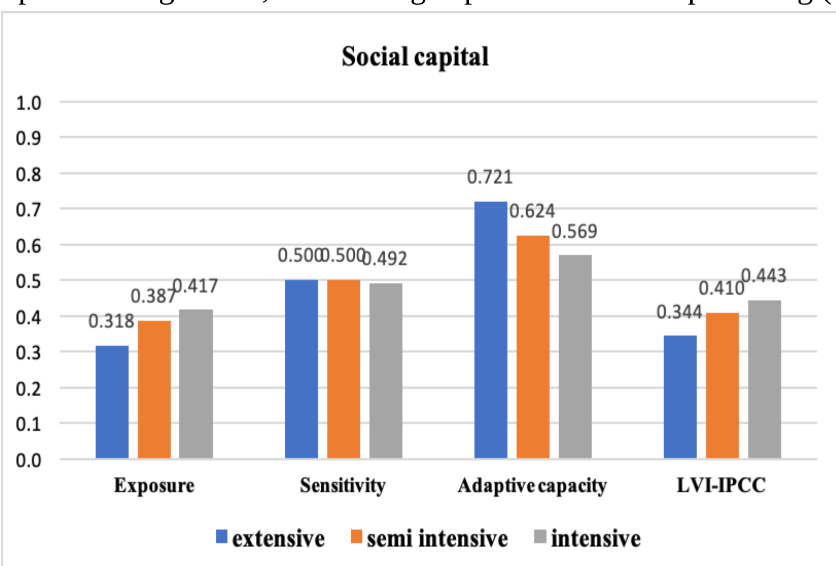

Figure 8. Exposure, sensitivity, and adaptive capacity of social capital in different shrimp farming systems.

The social capital could be affected by climate change in relation to accessing information daily, frequency of visiting relatives, and participating in local community activities (**Dat N.T., 2021**). For instance, storms and heavy rain could cause electrical power outages leading to interruption of access to news via electronic media. Due to adverse climate patterns, farmers tend to pay more attention to their shrimp ponds; therefore, time would not be free to visit relatives or participate in community activities. The extensive shrimp farmers' exposure index was slightly lower than those of semi-intensive and intensive shrimp farmers (**Fig. 8**) because farmers involved in extensive shrimp cultivation have more free time to visit their relatives (SE2) and take part in local community activities (SE3) more frequently than the farmers engaged in semi-intensive or intensive shrimp farming (**Appendix B**). However, farmers in all three models of farming had a similar sensitivity index because they all own mobile phones for communication in any case (SS2) and almost all families rely on television to entertain them every day (SS1). Therefore, values for the sensitivity dimension were the same for the three systems of shrimp farming.

In terms of the capacity to adapt to climate change, extensive shrimp farming was more favourable compared to the other systems. Due to living near to relatives (SA3), extensive shrimp farmers might benefit in case of hardship. All farmers in the study had a good relationship with their neighbours (SA1) and were ready to share their experiences (SA2) with others, which are considered social norms among rural people in Vietnam.

With a sensitivity index similar to that of the other two systems and lower exposure and higher adaptive capacity, households involved in extensive shrimp farming were less vulnerable to climate change in their social capital compared to shrimp farmers in the semi-intensive and intensive systems (**Fig. 8**).

3.5 Financial capital

Financial capital indicates all types of material property whose cash value can be estimated. It includes financial resources that can be accessed, invested, and consumed to achieve livelihood objectives (**DFID, 1999**). In shrimp farming, financial resources play a very important role in deciding whether to continue farming or whether to give up in case of suffering crop losses or needing to invest in more facilities and equipment to adapt to severe changes in climate (**Dat N.T., 2021**).

The percentage of households that did not have access to bank loans was similar for extensive and intensive shrimp farming systems. Between 37.5% to more than 40% of the households were refused bank loans (FE1). The main reasons for this problem were the banks' fear of the high risk in intensive shrimp farming and the low mortgage value of the properties of extensive shrimp farmers. In contrast, the semi-intensive shrimp farmers had more opportunities to obtain bank loans (only 23.6% of the households were refused bank loans) because this system is perceived as lower risk as demonstrated by only 16% of the households losing the recent shrimp crop (FE3) and the failure of only 19.4% of the households to pay their loans (FE2), compared to 40% and 52% for the same indicators for intensive farming. Although very few extensive farming households had lost the last shrimp crop (2.3%), 66.7% failed to pay back their bank loans. As a result, semi-intensive farming had the lowest exposure to climate change in terms of financial capital, while the highest exposure was shown by the intensive farming system (**Fig. 9**).

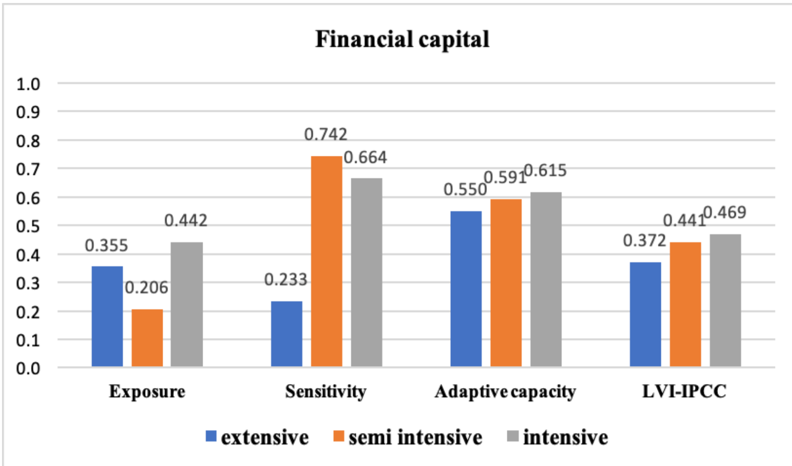

Figure 9. Exposure, sensitivity, and adaptive capacity of financial capital in different shrimp farming systems

The sensitivity dimension of financial capital was higher for both intensive and semi-intensive farming systems (**Fig. 9**), which was due to the large proportion of households having bank loans (FS1) and depending on shrimp farming as the only source of income (FS2) which would make these households vulnerable if they experience consecutive losses of crops. By contrast, extensive farming had a variety of sources of income, making its sensitivity index the lowest.

Most of the farmers owned the land under shrimp cultivation (FA1), which contributed to the increase in their adaptive capacity. In addition, a considerable number of shrimp farmers had savings accounts (FA2), especially intensive (74.9%) and semi-intensive farmers (72.6%) compared to extensive farmers (48.8%). However, 18.6% of the extensive shrimp farmers could borrow money from their relatives (FA3), a slightly higher proportion than that for semi-intensive and intensive shrimp farmers. Although loans from relatives also have to be paid back, they are less burdensome than bank loans because they do not tend to carry an interest rate and are not based on mortgaged properties, but on the relationship and prestige. In general, the adaptive capacity index of the three shrimp farming methods was relatively high, and were 0.550, 0.591, and 0.615 for extensive, semi-intensive, and intensive farming, respectively (**Fig. 9**). Finally, based on the three dimensions, intensive shrimp farming was the most vulnerable to climate change in relation to financial capital and the least vulnerable was extensive shrimp farming (**Fig. 9**).

3.6 Overall indices

Overall, the shrimp farmers of the three farming systems were significantly sensitive to climate change in all livelihood assets. The intensive and semi-intensive shrimp farming systems were exposed strongly to climate change in their natural capital, while human and physical capital had a very low exposure index. Therefore, the potential impact which is combined between exposure and sensitivity dimensions was relatively high in general. Although the potential impacts were higher on intensive and semi-intensive farming systems than on the extensive farming system for three out of the five types of livelihood capital, the adaptive ability of intensive and semi-intensive systems was higher for almost all types livelihood capital compared to that of the extensive farming system (Fig. 10). As a result, the overall LVI-IPCC of extensive farmers was the highest (0.435) and that of the intensive farmers was intermediate (0.4), while that of the semi-intensive farmers was the lowest (0.385), indicating that they are the least vulnerable to climate change.

This study’s findings are similar to the results of **An V.Q. *et al*. (2016)** that intensive shrimp farming was less vulnerable to climate change than extensive farming because the intensive shrimp farmers have higher adaptive capacity than other farmers. By contrast, **Kam *et al*. (2012) and Ha *et al*. (2013)** concluded that intensive shrimp farming was more vulnerable to climate change than other forms because intensive farmers faced frequent crop losses due to poor water quality management and unstable shrimp prices (**Ha *et al.,* 2013**). **Kam *et al.* (2012)** argued that lower operational costs and autonomous adaptation costs resulted in extensive shrimp farming being less vulnerable than semi-intensive and intensive farming systems. These differences in results may be due to different approaches, methods of vulnerability assessment, and study locations.

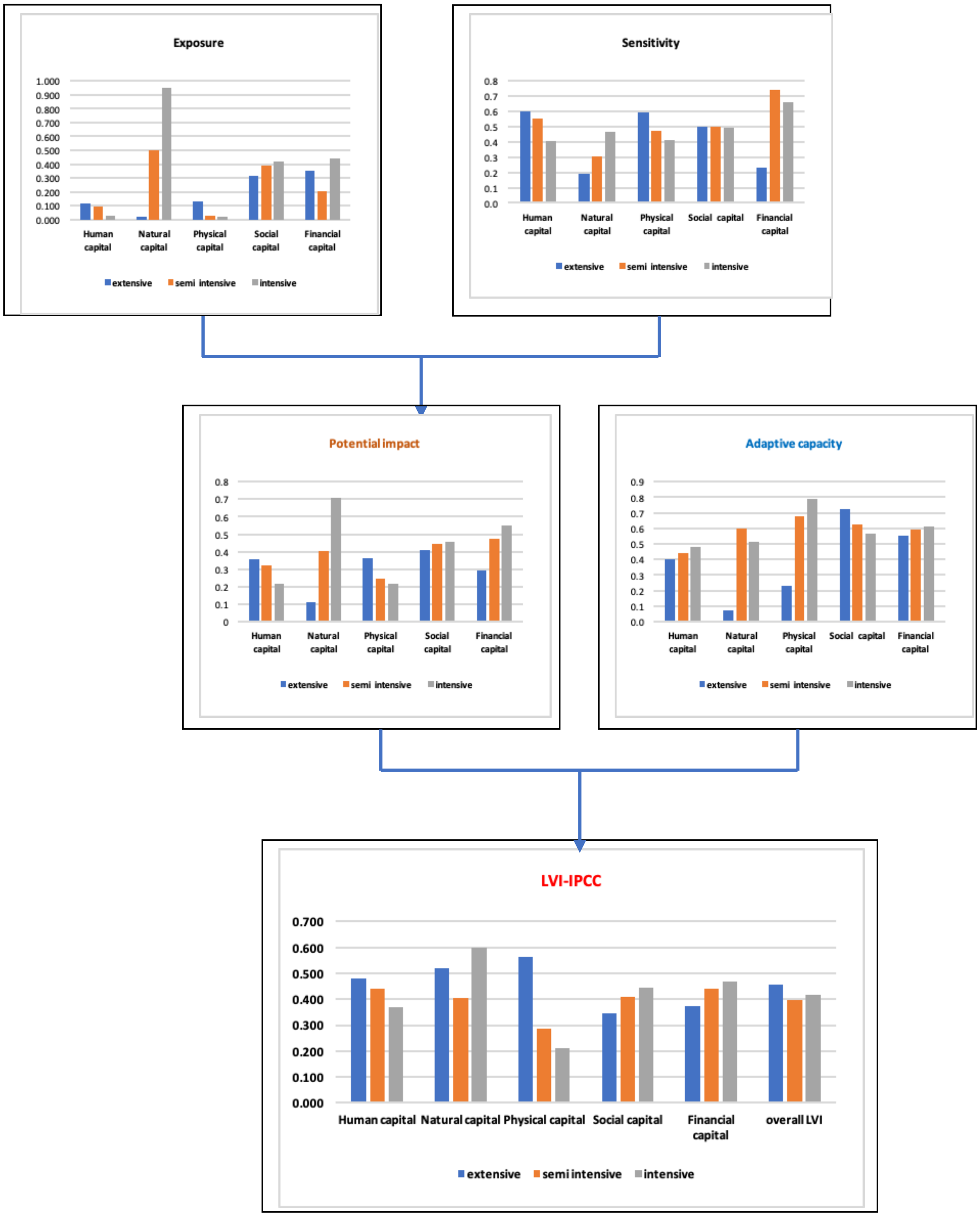

Figure 10. Summary of the vulnerability assessment process.

4. CONCLUSIONS

This study assessed the LVI of shrimp farming households under the IPCC framework (LVI-IPCC) using several indicators based on five livelihood assets in the context of climate change. It found that the livelihood of extensive shrimp farming households was the most vulnerable to climate change. Households engaged in semi-intensive shrimp farming had the lowest level of vulnerability.

In relation to human capital and physical capital, extensive shrimp farmers were the most vulnerable to climate change (**Fig. 10**) because their farms are located in coastal areas and they live far from hospitals (HS1), schools (HS3), and main roads (PS3). Therefore, extensive shrimp farmers could suffer from poor health (HE2) and illnesses (HE3), and their children stop schooling early (HS2). In addition, their ponds are damaged due to sea level rise and tidal waves (PE2).

Intensive shrimp farmers were the most vulnerable to climate change in terms of natural, financial, and social capital (**Fig. 10**). The emerging problems include disease outbreaks in shrimp (NE1) and the use of groundwater for farming (NE2) due to irregular climate patterns such as drought and fluctuating temperature between night and day. In addition, polluted water resources (NS1) would exacerbate sensitivity to climate change in the future. The hazards of climate change caused farmers to have no free time to visit their relatives (SE2) or join community activities (NE3). Furthermore, intensive shrimp farmers found it difficult to access credit from banks (FE1) and relatives (FE2) due to frequent crop losses (FE3). The semi-intensive shrimp farmers had an intermediate level of vulnerability for all assets except for natural capital in which case their vulnerability was the lowest.

This study is limited due to the shortage of data for natural disasters caused by climate change that have affected shrimp farmers' livelihood. All 42 indicators were selected based on many publications and expert knowledge, which may have introduced bias, although the indicators are suitable for the shrimp farming systems in the Mekong Delta in general and Tra Vinh province in particular. However, the results of this study may contribute to the understanding of the vulnerability of shrimp farmers in Tra Vinh to climate change, and may provide a useful and specific picture of the LVI of each shrimp farming system, which would help policymakers to support farmers with appropriate solutions based on plans for economic development of the Province.

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