SHRIMP FARMING VULNERABILITY AND ADAPTATION TO CLIMATE CHANGE IN CA MAU, VIETNAM

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DECLARATION

I declare that this thesis is my own account of my research and contains as its main content work that has not previously been submitted for a degree at any tertiary education institution.

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ABSTRACT

Shrimp farming is the livelihood for thousands of inhabitants in the Ca Mau of Vietnam, but these shrimp farmers are facing significant risks arising from climate change events. The research aimed to discover the adverse effects of climate change to shrimp production, and the vulnerability and adaptation of the shrimp farmers to climate change events. It was based in the main on the perspectives of shrimp farmers themselves from four shrimp farming systems (rice-shrimp rotation farming– RSRF, integrated shrimp-mangrove farming– ISMF, separated shrimp-mangrove farming– SSMF, and intensive shrimp farming– ISF) along with local experts working in the region. Findings from interviews and focus groups with these stakeholders were subsequently benchmarked against original or already published data. Three research questions guided the study: How might climate change events be affecting shrimp farming in Ca Mau Province? How is shrimp farming in different systems vulnerable to climate change events? How can Ca Mau Province shrimp farmers adapt to the climate change events?

Climate change events in this research include extreme climate events (e.g. tropical storms), sea level rise and high tide, temperature changes, rainfall changes, and irregular weather. The researcher interviewed eleven local experts, surveyed 100 farmer households, documented the relationship between climate parameters and shrimp productivity, and conducted focus group discussions with representatives of the four shrimp farming systems to access the vulnerability of shrimp production.

Key findings regarding the three research questions follow. First, adverse effects of climate change events on shrimp farming have already been occurring according to respondents in the Ca Mau region of Vietnam. The literature likewise provides evidence of this. The five climate change events ranked as most affecting shrimp production during the last decade and similarly identified for the future were seasonal pattern changes, increased intensity or irregular rain, sea level rise and high tides, and extreme climate events. Differences in climate change effects were recorded for different shrimp farming systems. Although ISMF and SSMF farmers (on the coast) were more concerned about extreme climate events, sea level rise and high tides than ISF farmers (further inland), a significantly strong positive relationship between water level and shrimp production suggests there are more benefits for shrimp farming from a higher water level; at least for such rises recorded to date. On the other hand, RSRF farmers were most concerned with seasonal pattern changes and intense

rain or irregular rain; here, a significantly negative relationship between rainfall and shrimp production may suggest more severe impacts arising from these climate changes in the future. These findings contrast with existing published accounts regarding aquaculture in the Mekong Delta in that high water temperature was ranked as the greatest risk in shrimp production.

Second, several contrasting findings regarding vulnerability and adaptation of shrimp farmers to climate change were evident. While the majority of shrimp farmers hoped that their children would change occupation, many nevertheless wished for them to become shrimp farmers and most of these farmers themselves in the four systems expect to continue with shrimp farming in the future, even though shrimp production would likely be seriously impacted by climate change in the future. Intensive shrimp farming operations with higher cultivation levels and greater diversity of income sources for the families involved were found to be the least vulnerable to the perceived current and future effects of climate change. Integrated shrimp-mangrove farming was found to be less vulnerable than rice-shrimp rotation and the separated shrimp-mangrove approach. Higher income shrimp farmers were found to be more likely to already be undertaking adaptation measures to address the consequences of climate change events and those with greater social involvement were more likely to have better adaption capacity to climate change events. While it was found that shrimp farmers had taken responses to the adverse effects of climate change event in the last decade, there were no clear strategies in place for the future. Taken together, these research findings suggest that intensification, integration, and cooperation would be good adaptation options for shrimp farmers in Ca Mau Province in the face of future climate change events.

This research makes an original contribution to knowledge through capturing:

(i) the perspectives of shrimp farmers themselves on how climate change affects their operations in the four farming systems;

(ii) the climate change events most affecting shrimp production in the last decade and posing the greatest threat in the future;

(iii) the significant relationship between shrimp productivity and rainfall and water level;

(iv) the variable vulnerability in the four farming approaches; and

(v) suggestions for shrimp farming intensification, integration, and increased farmer cooperation as key adaptation options to future climate change. The research findings have important policy implications for decision makers who want to support the shrimp farming system to be less vulnerable to existing and expected climate change impacts. The results of this study also have implications for the provincial governments, residents in the Mekong Delta, and in other brackish aquaculture farming regions to gain a better understanding of climate change risks to shrimp production. One such strategy might be to both enhance shrimp farmer resilience to the adverse effects of climate change events and improve cultivation techniques for farmers in different shrimp farming systems.

PUBLICATIONS

Parts of this research have been presented at an international conference and published in the international journals as follows.

- An Van Quach (2015) 'Perspectives of Farmers and Experts in Ca Mau, Vietnam on the Effects of Climate Change on Shrimp Production', presented at *4th International Conference on Climate Change and Humanity- ICCCH 2015*, Taiwan, January 2015. [Chapter 4].

- An Van Quach, Frank Murray, & Angus Morrison-Saunders. (2015). Perspectives of Farmers and Experts in Ca Mau, Vietnam on the Effects of Climate Change on Shrimp Production. *International Journal of Environmental Science and Development,* 6(10), 718-726. Available at: http://www.ijesd.org/vol6/687-A0010.pdf. [Chapter 4]

- An Van Quach, Frank Murray, & Angus Morrison-Saunders. (2016). The vulnerability of shrimp farming income to climate change events: A case study in Ca Mau, Vietnam. *International Journal of Climate Change Strategies and Management*, 9(2), 261-280. Available at: http://doi.org/10.1108/IJCCSM-05-2015-0062. [Chapter 5]

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The critical feedback from the three examiners on the original submission and the two examiners on the re-submission was very helpful. The thesis has been substantially amended and extended accordingly. This process has helped me to improve the quality of this research and further develop my own critical thinking skills.

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CHAPTER 1: Introduction

1.1. Background

Climate change has become one of the biggest challenges of the 21st century for developing countries. Observational evidence shows that many natural systems are being affected by regional climate change due to the altered frequencies and intensities of climate change events, which are very likely to impose negative effects and costs (IPCC, 2007). Vietnam has been identified as one of the countries worst affected by climate change because of its limited resources and assets to cope with this critical situation (WB, 2010).

Millions of people around the world depend on aquaculture and shrimp production to sustain their livelihoods (Blythe et al., 2015) and this sector has already been significantly affected by climate change (Kam et al., 2012; Mackay & Russell, 2011; Roessig et al., 2004; Williams & Rota, 2011). The main consequences of climate change on aquaculture are increased water temperature (De Silva & Soto, 2009), increased flooding and salinity (MONRE, 2012), and changed precipitation (Noyes et al., 2009). Climate change can also reduce environmental quality, toxin release (Noyes et al., 2009) and cause infectious disease outbreaks in shrimp by irregular weather (Ficke et al., 2007; NACA, 2011) and increased shrimp mortality (Mackay & Russell, 2011). Thus the aquaculture sector is expected to be impacted heavily by climate change, and shrimp farmers are predicted to experience increased costs and decreased profitability from their shrimp production (Kam et al., 2012; Smyle & Cooke, 2011). These adverse impacts would cause shrimp farmers to be especially vulnerable to climate change.

Adaptation strategies and measures to reduce damages and to increase resilience to climate change consequences include technical options, engineered infrastructure, and ecosystem-based approaches (Colls et al., 2009; Doswald & Osti, 2011; Noble et al., 2014; Ssheraga & Grambsch, 1998). The following solutions have been proposed or tried: aquaculture insurance (De Silva & Soto, 2009), rapid domestication of marine species and technological transfer mechanisms (Duarte et al., 2007; Cochrane et al., 2009), integrated farming (Joffre, 2013) and aquaculture diversification (FAO, 2009a), aquaculture zoning and monitoring (De Silva & Soto, 2009), maximising profit (Handisyde et al., 2006), and shrimp farmers' self-adaptation.

Although, coastal areas are dynamic, variable, and influenced by multiple processes (Blythe et al., 2015), the coastal area of Vietnam, particularly in the Ca Mau region of the Mekong Delta where shrimp farming systems are dominant, has already demonstrated vulnerability to climate change impacts (ISPONRE, 2009). Shrimp production impressively developed in this area over the past 20 years, and it has become a vital component of this region's economy and the major livelihood for shrimp farmers (Hung, 2011). However, local communes have a high proportion of vulnerable households (Tran et al., 2017). The impacts of climate change are likely to pose a serious threat to this region for both the short term and the long term (NEDECO, 1993) and cause a major threat to Ca Mau Province (Mackay & Russell, 2011), especially on aquaculture and shrimp production (Roessig et al., 2004; Williams & Rota, 2012).

The current literature does not give a clear understanding of impacts, vulnerability, and adaptation to climate change events on shrimp production in the Mekong Delta region, especially as it is perceived by the local experts and shrimp farmers in the different farming systems. The impacts of climate change are well understood at global, national and even local level; and some research has been conducted on climate change impacts on aquaculture, brackish aquaculture, and shrimp and catfish farming in the region. However, there is a gap in the knowledge about the various shrimp farming systems and local shrimp farmers' and experts' perspectives of climate change impacts on these local communities as well as how some climate parameters correlate with shrimp productivity. A further gap detected is in the areas of shrimp farming vulnerability and the adaptation options of shrimp farmers to climate change events in the different shrimp farming systems. This research aims to fill these gaps and provide a better understanding of climate change impacts, vulnerability, and adaptation in different shrimp farming systems.

1.2. Overview of shrimp production, study area, and farming systems

This section presents an overview of the study area and a description of the different shrimp farming systems in operation in Ca Mau Province.

1.2.1. Shrimp production overview

Vietnam produced more than 0.6 million tonnes of shrimp products (GSO, 2016) with exports of US$3.3 billion in 2016 (VASEP, 2016). Most shrimp production is concentrated in Mekong Delta provinces, accounting for around 75% of national shrimp production. Shrimp production is an important sector in the region, and a key component of Ca Mau's economy (Mackay & Russell, 2011); moreover, farming represents over 40% of the shrimp farming area for all the coastal provinces in the Mekong Delta (GSO, 2016). Shrimp farming has become the major livelihood and an increasingly important income base for farmers (Hung, 2012). Ca Mau exported US$1.4 billion (43% of the national shrimp production export) because its large-sized black tiger shrimp are very popular overseas (VASEP, 2016). Shrimp production in Ca Mau and the whole country for the last 20 years are illustrated in Figure 1.1 (Ca Mau Statistics Office, 2016; GSO, 2016).

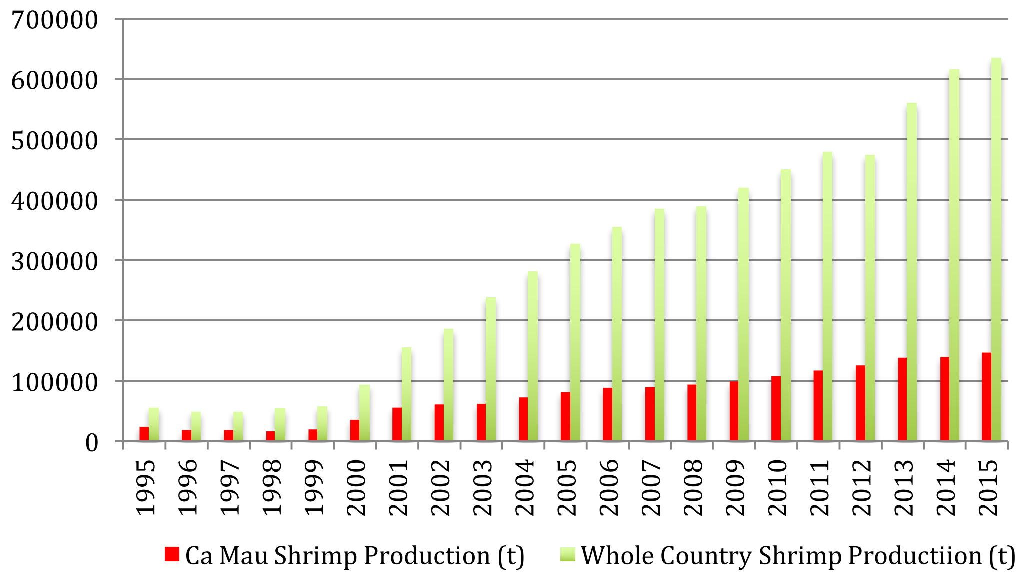

Figure 1.1: Ca Mau shrimp production (ton-t) and the whole country from 1995 to 2015

1.2.2. Ca Mau Province overview

Situated on Ca Mau Peninsula, Ca Mau is a flat and low-lying coastal province in the southernmost extent of the Mekong River Delta (SWIRP, 2008). The province occupies 5,392 km^2, making up more than 13% of the Mekong Delta area and 1.6% of the whole country (CMSO, 2016). Ca Mau is regulated by two conflicting tidal regimes: the East Sea, which is a large amplitude semidiurnal tide, and the West Sea, which is a diurnal tide of smaller amplitude. These tides cause the complex saline – freshwater interaction, with the flat terrain and local geology of the region (SIWRP, 2008). Ca Mau has about 245 km of coastline and it has an elevation of only 0.75 m above mean sea level. The climate of Ca Mau is tropical monsoon with two distinct seasons: the dry season from December to April, dominated by the east-northeast wind direction, and the rainy season from May to November dominated by the west-southwest wind direction. The area supports more than 1.3 million people, with the provincial annual GDP growth rate around 12% over the past 15 years. As indicated above, the majority of Ca Mau households are engaged in aquaculture (Mackay & Russell, 2011) where shrimp farming dominates the entire sector.

1.2.3. Shrimp farming systems in Ca Mau Province

Generally, shrimp farming systems in Vietnam are classified as extensive, improved-extensive, semi-intensive, and intensive (Nhuong et al., 2002; Thi, 2007). The Ca Mau shrimp farming categories are based on pond size, water exchange, feed and chemical use, and stocking density (Anh et al., 2012), as well as land holding rights, harvest and farming practices (Ha, 2012). Furthermore, in addition to the black tiger shrimp, farmers normally cultivate crabs or fish and apply extensive, improved-extensive, and/or semi-intensive practices in different systems, such as mangrove-shrimp combinations or rice-shrimp rotation. Thus, combination models and polyculture are popular in Ca Mau. A brief description of each of the main shrimp farming systems popularly in Ca Mau follows.

Integrated shrimp-mangrove farming system (ISMF)**,** a traditional extensive farming **practice** with farm size varying from 2 to 17 ha; it relies on wild stock trapped during high tides with no feed supply provided (Clough et al., 2002; Minh, 2001). Legally, the area of mangroves required to be conserved should be 70% of the farm size, but in reality, shrimp farmers typically violate this rule, with ditched shrimp pond areas of up to 33–43% of the total farm area (Binh et al., 2008). Those researchers found that a mangrove coverage of 30-50 of the pond area gave the highest annual economic returns (Binh et al., 2008). However, fewer shrimp farmers now practise this model because of natural stock reduction (Graadf & Xuan, 1998). Currently, most shrimp farmers practise ISMF based on artificial stock with a density of 1–3 seeds m^{-2} and yielding 300–400 kg $ha^{-1}year^{-1}$.

Separated shrimp-mangrove farming (SSMF) is similar to ISMF, but the mangrove area (around 60% of the farm size) is separated from the shrimp ponds. SSMF in the Tam Giang Dong Commune has farm sizes varying from 3.5 to 20 ha. Beside the black tiger shrimp product, both ISMF and SSMF also harvest other products, such as wild shrimp species, fish, crabs and cockles (Nhuong et al., 2002). Shrimp productivity fluctuates from 300 to 400 kg $ha^{-1}year^{-1}$.

Rice-shrimp rotation farming (RSRF) has been practised for many decades in the saline affected areas of the coastal provinces of the Mekong Delta (Vuong, 2011). RSRF is practised where salinity fluctuates substantially between wet and dry seasons (Leigh et al., 2017). It is an integrated rice–shrimp system within the same fields with alternative cropping of rice in the wet season and shrimp during the dry season (Brennan et al., 2002). In the dry season, when water salinity is high, the saltwater has to be discharged into the fields to farm shrimp. In the rainy season, farmers use rainwater to flush the fields of residual salinity and then grow rice when the water salinity is suitable. Rice fields are designed with a trench, providing a refuge for the shrimps during rice production with a protective dike around the periphery of each field (Brennan et al., 2002). Shrimp productivity of this system is 200–300 kg $ha^{-1}year^{-1}$ for extensive farming and 300–500 kg $ha^{-1}year^{-1}$ for improved extensive farming. This model has been expanding in the north of Ca Mau Province and has been considered as a sustainable farming system in recent times (Kabir et al., 2016; Tran, 1997).

Improved-extensive shrimp farming (IESF) can practise either monoculture or polyculture systems. In the monoculture system, IESF are constructed similar to RSRF by digging a trench with 2–2.5 m wide and 0.6–0.8 m depth around the fields (Vuong, 2011). Farmers change the water by pumping or opening a concrete gate in areas of high tide amplitude though a settlement channel where the pond is connected to rivers or canals. Stocking density of this system varies from 1–7 seeds m^{-2}; but most farmers release shrimp larvae every month with the first time is about 1–3 seeds m^{-2} and then supplemental over the following months. Tiger shrimps are cultured all year round and the large-sized shrimp are harvested after 5 months of culture (Tho et al., 2011). In polyculture, shrimp farmers apply this model to cultivate tiger shrimp in ISMF and SSMF and in the dry season in RSRF.

Intensive shrimp farming (ISF) started in Khanh Hoa Province of central Vietnam in 1989 and commenced in Ca Mau in the 1990s. The pond size varies from 0.2 to 1.0 ha, with a stocking density from 15 to 30 post larvae m^{-2}, and shrimp productivity of 2,500 – 4,000 kg $crop^{-1}$ ha^{-1} (Nhuong et al., 2002). In Ca Mau Province, the farming system reached 3,428 ha in 2011 and 6,000 ha in 2015 (DARD, 2016). The farm size varies from 1 to 3 hectares with pond size from 1,000 to 6,500 m^2, stocking density from 40 to 50 post larvae m^{-2}, and productivity varying from 4,500 to 6,600 kg ha^{-1} $crop^{-1}$ with an average of two crops per year (Chinh, 2012; DARD, 2016).

There are two main types of shrimp species cultivated in Ca Mau: black tiger shrimp (*Penaeus monodon*) and whiteleg shrimp (*Litopenaeus vannamei*) but *Penaeus monodon* is also farmed across the province, mostly in improved-extensive and extensive shrimp farming in both polyculture, accounting for 62% provincial shrimp area (RSRF, ISMF, SSMF), and monoculture farming for 34%, while ISF farmed both black tiger shrimp and whiteleg shrimp, accounting for only 3.4% of provincial shrimp area (DARD, 2016). Hence, the majority of shrimp farmers are small–scale in Ca Mau Province, and they depend on black tiger shrimp to sustain their shrimp livelihood. Four farming systems – ISMF, SSMF, RSRF and ISF are investigated in this study because IESF has been studied previously (Abery et al., 2009, 2011; Hai et al., 2011; RIA2, 2014). The locations and actual pictures of the four farming systems targeted in this research are shown in Figure 1.2 and 1.3.

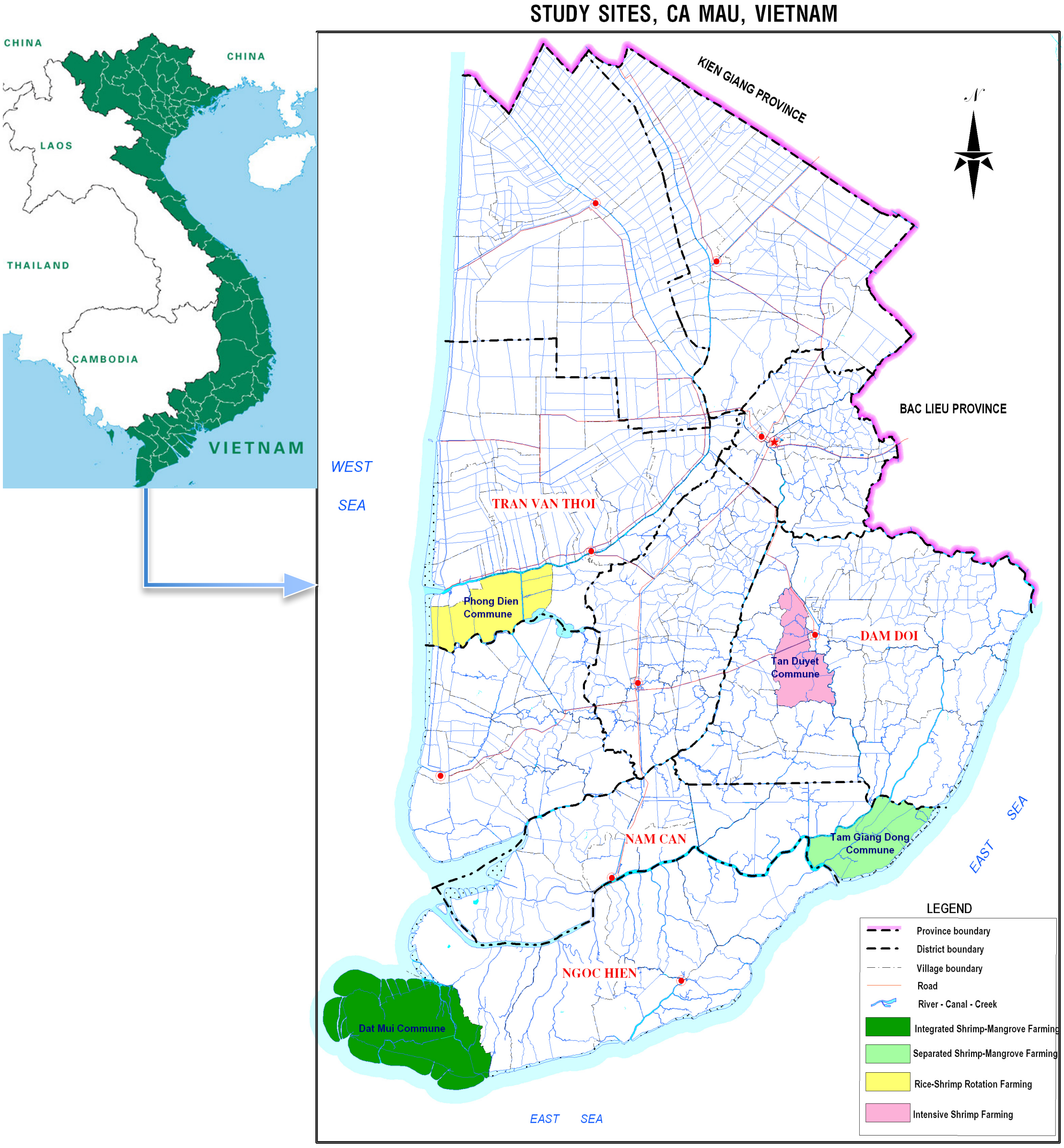

Figure 1.2: Location of the research study sites

Rice-shrimp rotation farming (RSRF) in Phong Dien Commune, Tran Van Thoi District, Ca Mau Province (Source: Author photo)

Integrated shrimp-mangrove farming (ISMF) in Dat Mui Commune, Ngoc Hien District, Ca Mau Province (Source: Author photo)

Separated shrimp-mangrove farming (SSMF) in Tam Giang Dong Commune, Nam Can District, Ca Mau Proince (Source: Author photo)

Intensive shrimp farming (ISF) in Tan Duyet Commune, Dam Doi District, Ca Mau Province (Source: Author photo)

Figure 1.3. Photographs of examples of each of the four types of shrimp farming system investigated in the research

1.3. Research questions

As indicated above, the adverse impacts of climate change are likely to induce temperature change, rainfall change, sea-level rise, irregular weather patterns, and extreme climate events[1] (IPCC, 2007, 2013, 2014). The combination of these factors would increase the vulnerability of shrimp production and adversely affect farming livelihoods. While, climate change impacts are well documented in the Mekong Delta and some researchers have examined its effects on aquaculture, such as on brackish and catfish farming, the current knowledge does not provide a clear understanding of impacts, vulnerability, and adaptation to climate change events[2] on shrimp production, as perceived by shrimp farmers at the local community. There are three research questions to be investigated and answered in this project.

1). How might climate change events be affecting shrimp farming in Ca Mau Province?
2). How is shrimp farming in the four different systems vulnerable to climate change events?
3). How can Ca Mau shrimp farmers adapt to the climate change events?

These questions are pursued mainly from the perspective of the shrimp farmers in the four different farming systems and the local experts[3] as well as examined evidence of climate parameters[4] effecting shrimp production. The results would provide a better understanding of impacts, vulnerability, and adaptation to climate change events in shrimp production for Ca Mau Province as well as the Mekong Delta region.

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[1] Extreme climate events or extreme weather events mentioned in this research include unusual or unseasonal weathers, and or storms

[2] Climate change events addressed in this research include extreme climate events, sea level rise/high tides, temperature changes, rainfall changes, and irregular weathers, such as seasonal pattern changes, intense or irregular rain.

[3] The local experts, defined in this research with criteria based on education and working experience, are those who hold at least an undergraduate degree and a 10–year working experience related to the topic of the study in Ca Mau Province.

[4] Climate parameters using in this research include temperature (average annual, average maximum, and average minimum temperature), rainfall (average annual rainfall, average rainfall in the rainy season, average rainfall in the dry season), and water level in Doc River Station and Nam Can Station (average annual, Average maximum, and average minimum water level).

1.4. Scope of the research

This research was conducted to determine the adverse effects, vulnerability, and adaptation of shrimp farmers to climate change events on shrimp farming in Ca Mau Province of Vietnam (full details of the research methodology are provided in Chapter 3). The research data was collected through household surveys, focus groups, obtained secondary data, and the literature review.

The field research was conducted in Ca Mau, Vietnam, from November 2012 to February 2013; additional data on shrimp production and household assets were collected from June 2016 to July 2016; and hydro-meteorological data[5] were accessed for the period of 1991-2015. Key respondents were the shrimp farmers and the local experts. The research entailed a comparison of shrimp farming vulnerability as perceived by the farmers to climate change events in different farming systems. Shrimp farmers who were currently farming were selected from each of four communes to represent the four farming systems investigated. The four communes were Phong Dien commune (RSRF), Dat Mui commune (ISMF), Tam Giang Dong commune (SSMF), and Tan Duyet commune (ISF).

As the primary research method (Leedy & Ormrod, 2001) in the household survey, the semi-structured questionnaire contained both open-ended and closed questions (Kolb, 2008; Leedy & Ormrod, 2001). The face-to-face interview approach (Kvale, 2004; Leedy & Ormrod, 2001) was used to collect household characteristics, income data and insightful information on climate change impacts, vulnerability, and shrimp farming adaptation.

Focus groups[6] were also a primary research method used to investigate the vulnerability of shrimp farming in the four different farming systems (more explained in sub-section 3.2.4). The focus groups comprised a predetermined scale for ratings (Morgan, 1998), the face-to-face approach (Chase & Alvarez, 2000), and the matrix worksheets to categorise the vulnerability of shrimp farming (Brundell et al., 2011; Mackay & Russell, 2011). IPCC (2007) and many researchers (e.g. Adger, 1999; Adger et al., 2004; Fussel, 2006, 2007; Moss et al., 2001; O'Brien & Liechenko, 2000; O'Brien et al., 2004; IPCC, 2007; Turner et al., 2003; Wolf, 2011) have conducted research in vulnerability to climate change. However, the vulnerability assessment in this research differs in its use of a risk matrix to identify the

[5] Hydro–meteorological data obtained in this research includes air temperature, rainfall, and water level as explained as climate parameters in Section 1.3.

[6] Focus group is a group meeting consisting of target shrimp farmers. The facilitator, supported by a note-taker, facilitates the discussions using the prepared guiding questions for the purpose of the study.

impacts, adaptive capacity, risk, and vulnerability of shrimp farming to climate change events (Brundell et al., 2011; Mackay & Russell, 2011).

The literature review in this study has provided a current picture of concepts, and findings relevant to this research (Bloomberg & Volpe, 2008). The review of published literature includes technical reports from Vietnam and Ca Mau available to near the end of 2017.

1.5. Outline of the thesis structure

The thesis is divided into seven chapters and each is described below:

Chapter 1 – Introduction: This chapter sketches out the background, research questions, and the scope of the research, including a summary of the key methodology and methods sued in the research.

Chapter 2 – Literature review: This chapter provides an overview of climate change impacts, vulnerabilities, and adaptation to climate change with regard to aquaculture and shrimp farming, with a particular emphasis on Vietnam and Ca Mau Province. The first section presents an overview of climate change issues related to the research topic. The second section reviews aquaculture and shrimp farming vulnerability to climate change in Vietnam. The next section presents adaptation to climate change in Vietnam. The final section discusses the current studies on impacts, vulnerability and adaptation of aquaculture and shrimp farming in relation to climate change.

Chapter 3 – Methodology: This chapter is divided into three sections to describe the methods and procedures employed in the research. The first section presents introduction of research methodology. The main section describes research approaches, procedures, data collection and analysis. Finally, the ethical principles and approvals before conducting household surveys are outlined, and a description is given of how the researcher will maintain correspondence with participants after the field research.

Chapter 4 – The effects of climate change on shrimp farming systems: This chapter investigates the perspectives of shrimp farmers and the local experts about the effects of climate change events on shrimp farming and statistical tests of the relationship between hydro–meteorological parameters and shrimp productivity. The first section is introduction. The second section presents perceptions of climate change events on shrimp production including perspectives of shrimp farmers in the four farming systems and the local experts about the negative effects of climate change events in the past 10 years and their predictions for the next 10–20 years. The third section provides hydro–meteorological data recorded in Ca Mau from 1991–2015. The fourth section presents results of correlations between hydro–meteorological parameters and shrimp productivity. The final section then discusses how climate change could affect shrimp farming in the research area into the future.

Chapter 5 – The vulnerability of shrimp farming to climate change: This chapter investigates the vulnerability of shrimp production to climate change events in the four shrimp-farming systems. The first section focuses on perspectives of climate change events on shrimp productivity and diseases. The second section examines shrimp farming vulnerability to climate change events. The final section of the chapter discusses how shrimp-farming income is vulnerable to climate change events in the four systems.

Chapter 6 – Adaptation of shrimp farmers to climate change: This chapter section explores how Ca Mau shrimp farmers adapt to adverse effects of climate change issues on shrimp production. The investigation focused on perspectives of shrimp farmers and the local experts regarding adaptation to climate change events, shrimp production recovery after an extreme climate event surged, shrimp farmer cooperation, and adaptation options. The chapter then discusses how shrimp farmers in the four farming systems responded and adapted to climate change events and what adaptation options and strategies they put in place for expected climate change in the future.

Chapter ***7- General discussion and conclusion:*** This chapter essentially clarifies what the research findings mean and how they will contribute to the literature. The discussion chapter is constructed to answer the three research questions: 1). How might climate change be affecting shrimp farming in Ca Mau Province? 2). How is shrimp farming in the four systems vulnerable to climate change events? 3). How can Ca Mau shrimp farmers adapt to the climate change events? The limitations and applications of the research are then discussed prior to presentation of the overall conclusions arising from the research.

CHAPTER 2: Literature review

2.1. Introduction

This chapter provides a comprehensive review of research about the research topic of climate change events with regard to aquaculture and shrimp farming with particular emphasis on Vietnam and Ca Mau Province wherever possible. There are four main sections in this chapter. The first section reviews climate change events in Vietnam and Ca Mau Province. The second section presents aquaculture and shrimp farming vulnerability to climate change in Vietnam. The third section is followed by an exploration of adaptation to climate change. Finally, there is a summary of current literature about impacts, vulnerability and adaptation to climate change on aquaculture and shrimp farming. Thus, the structure of this chapter follows the sequence of the research question topics.

2.2. Review of climate change events in Vietnam and Ca Mau Province

Vietnam has been ranked in the top 10 countries for aquaculture production and has a heavy reliance on this sector (WB, 2010), especially in the Mekong Delta. The region is considered to be one of the three most vulnerable deltas in the world to climate change (Tuan, 2010), where aquaculture and shrimp farming are very important for the local economy and inhabitants' livelihoods (Phuong, 2003). The risks are already apparent in coastal areas with a large number of people living on its 3,260 km coast, a high population density, and economic activities in coastal areas (WB, 2010). Over the last 30 years Vietnam lost about 1.5% of GDP per year due to disasters and extreme climate events as a result of climate change (Son et al., 2010). Coastal inhabitants were particularly vulnerable because the number of extreme weather events such as unusual, severe or unseasonal weather is increased in intensity and frequency (Lanh, 2010), and about half of those people depend on aquaculture and shrimp farming for their livelihoods.

De Silva and Soto (2009) claimed that climatic change has an impact on different systems and different forms of farming practices, but overall it will have strong impacts on farming systems (Udaya Sekhar et al., 2010). The main parameters of climate change impacts on aquaculture and shrimp farming production are extreme climate events, temperature changes, sea level rise, and changing rainfall patterns (De Silva & Soto, 2009). The major threats of climate change impacts on aquaculture and shrimp farming are now discussed.

2.2.1. Extreme weather events

Extreme weather includes unusual, severe or unseasonal weather (IPCC, 2001). Severe weather refers to any dangerous meteorological phenomena or weather issues with the potential to cause damage, serious social disruption, or loss of human life (Zhu & Toth, 2001). Extreme climate events or extreme weather events mentioned in this research include unusual or unseasonal weathers or storms.

There is observational evidence of changes in extreme climate events in Vietnam. Overall hot summer days would increase, cold winter nights would decrease as consequences of global warming, and dramatic heavy rainfall events would increase in the rainy seasons over the next five decades (Ho et al., 2011). However, looking back in the last five decades, climate events have become more extreme and natural disasters have become more severe (Lanh, 2010; UNDP-IMHEN, 2015) and the frequency of extreme weather events has increased dramatically (IPCC, 2007; Lanh, 2010). Storms have occurred and are projected to continue occurring with a trend to hitting Vietnam more frequently, and increasing in intensity and frequency (Mirza, 2003). Moreover, typhoons with higher wind velocity and extending over longer periods are projected. Storm surge events are likely to shift from one-in-30-years to one-in-10-years (MONRE, 2009).

There are more storms and tropical depressions trending to move to the southern coast of Vietnam (Tan, 2010) and causing heavy rain and flooding. An analysis of typhoon trends by IMHEN (2010a) showed that the frequency of very strong storms (greater level 12) has increased. The peak month for typhoon landfall has shifted from August in the 1950s to November in the 1990s. Consequently, from October to December, storms and tropical depressions affect the southern region more than in the other months, appearing most frequently in November (IMHEN, 2010b). This indicates that the areas in which storms have rarely appeared in the past may increasingly be vulnerable to extreme climate events (Mackay & Russell, 2011).

It is clear from climate simulations that extreme weather events pose a significant threat to Ca Mau Province (Mackay & Russell, 2011). Typhoons are not only dangerous but they are also associated with torrential rains, storm surges and wild sea conditions. Extreme rainfall in Ca Mau would be about 6% larger by 2030 and, based on the B2 scenario (the medium scenario- medium emissions), 10% larger by 2050 (IMHEN, 2010b). Extreme climate events would lead to a reduction in aquaculture productivity, agricultural crops, forestry plants and cash plants, and habitat losses affecting local species, which would have serious consequences for the economy (MONRE, 2009). Storms can destroy shrimp ponds, fishponds, fish cages, and reduce estuarine water salinity, severely affecting aquaculture production (MONRE, 2012). Storms cause physical destruction of aquaculture facilities, loss of stock and spreading of diseases (De Silva & Soto, 2009). Dikes and sluice gates may be damaged, allowing shrimp to escape from the ponds, and contaminating ponds with poor quality water and organisms from the wild (Abery et al., 2009). Hence, costs of adaptation and measures due to extreme climate events are predicted to increase significantly in the future (Nguyen et al., 2016).

2.2.2. Increased temperature

The data recorded from 1958 to 2007 in Vietnam shows that the average air temperature has increased by between 0.5 to 0.7ºC over the past 70 years (MONRE, 2009), and it rose by 0.1ºC per decade over the period 1900–2000. It has become hotter in summer, with the temperature rising by between 0.1 to 0.3ºC per decade (IMHEN, 2010b). The temperature in winter has risen faster than in summer. According to the B2 scenario, the average air temperature is likely to rise by between 0.8 to 1.5ºC by 2050 and 1.6 to 2.8ºC by 2100.

The data recorded from 1972 to 2007 shows that the average air temperature in Ca Mau Province has increased by 1ºC. It has increased more in recent years and from 1996 to 2007 it rose by 0.5ºC. Modelling studies show that Ca Mau Province may experience a warmer seasonal air temperature increase of up to 0.7°C by 2030, 1.4°C by 2050, and 2.6°C at the end of this century. In the whole 50-year period, the average air temperature would increase by between 1.2 to 1.6ºC by 2050 and by 1.9 to 2.8ºC by 2100 (Table 2.1).

Table 2.1: Projected changes in the average air temperature and different seasons in Ca Mau Province (ºC) under B2 scenario (MONRE, 2012)

Scenarios	**Decade**								
	2020	**2030**	**2040**	**2050**	**2060**	**2070**	**2080**	**2090**	**2100**
Winter (XII–II)	0.4	0.6	0.9	1.1	1.4	1.6	1.8	2.0	2.1
Spring (III–V)	4.5	0.7	0.9	1.2	1.4	1.7	1.9	2.1	2.2
Summer (VI–VIII)	0.6	0.8	1.2	1.5	1.9	2.2	2.4	2.7	2.9
Autumn (IX–XI)	0.6	0.9	1.2	1.6	1.9	2.2	2.5	2.8	3.0
Annual average (ºC)	0.5	0.7	1.0	1.4	1.6	1.9	2.2	2.4	2.6

Many researchers have reported on correlations and relationships between the air temperature and the water temperature (Erickson & Heinz, 2000; Harvey et al., 2011). An increase of the air temperature will result in a corresponding increase in the water temperature (Hammond & Pryce, 2007; Harvey et al., 2011). Increased water temperature could have positive impacts on aquaculture, such as enhanced growth and production in tropical and subtropical zones, and enhanced growth rates of cultured stocks; however, it is likely that adverse impacts on aquaculture will be more severe (De Silva & Soto, 2009). A water temperature increase, associated with changes in the hydrology and hydrographical water bodies, exacerbates the occurrence of algal blooms, which could have important impacts on aquaculture (De Silva & Soto, 2009). Harmful algal blooms cause toxin release into the water, reduction of dissolved oxygen concentration, spread of harmful pathogens, and threaten fish health and growth (World Fish Centre, 2009). Moreover, higher water temperature would increase costs for shrimp farmers, such as in semi-intensive shrimp farming where pumping water to maintain water and salinity levels (WB, 2010).

Extreme hot air temperatures for a short duration can increase the surface water temperature of the shrimp ponds and increase water temperature fluctuations between day and night (NACA, 2011). Water temperature change has adverse impacts on fishery health and increases the incidence of disease and parasitic infections (Smyle & Cooke, 2011). It would also have a significant influence on the metabolism, growth and seasonal reproduction of aquatic organisms (Wood & McDonald, 1997) and make them more vulnerable to the presence of diseases and toxins in aquaculture farms (Ficke et al., 2007; MONRE, 2009).

A higher water temperature tends to accelerate the rate of nutrient recycling, further stimulating phytoplankton production and reducing dissolved oxygen concentrations (Najjar et al., 2010). Dissolved oxygen concentration in water would drop rapidly at night, impeding growth and killing fish and shrimp (MONRE, 2012). Moreover, water temperature variations are bound to have an impact on the spatial distribution of species and specific aquaculture activities (De Silva & Soto, 2009), and a stronger impact on their productivity and yields (White & Akvaplan-Niva, 2010). For example, a case study on improved extensive shrimp farming in the Mekong Delta showed that during the dry season high temperatures led to increased salinity and other water quality problems, putting stress on shrimp, lowering shrimp appetite, increasing toxic gases and algae, lowering levels of dissolved oxygen; causing shrimp moulting and slowing growth rate (Abery et al., 2009). Moreover, the water temperature fluctuation between day and night of 3 – 4°C combined with fluctuations of salinity and pH and a high presumptive Vibrio count can trigger a WSSV (white spot syndrome virus) outbreak (Alapide-Tendencia, 2012) and an increase in shrimp mortality (Abery et al., 2009).

2.2.3. Sea level rise

The current and future sea level rise is associated with global warming and it is likely that human-induced warming has contributed to the sea level rise observed in the latter half of the 20th century (IPCC, 2007). It is believed that there has been an increase of high water levels in the coastal areas related to an increase of mean sea level (IMHEN & UNDP, 2015). Sea levels in Vietnam have risen by 20 cm during the period from 1958 to 2007 and the seawater level in the east sea of Vietnam has increased further than the west sea. The average sea levels have risen by 2.8 mm per year in the whole coastal area of Vietnam from 1958 to 2007 (IMHEN, 2010b). Sea levels are expected to rise from 28 to 33cm by 2050 and from 65 to 100 cm by the end of the 21st century (Table 2.2). A sea level rise will significantly affect the low-lying Mekong River Delta in general, and Ca Mau in particular where the whole province could be completely inundated with seawater for some periods of the year (Figure 2.1).

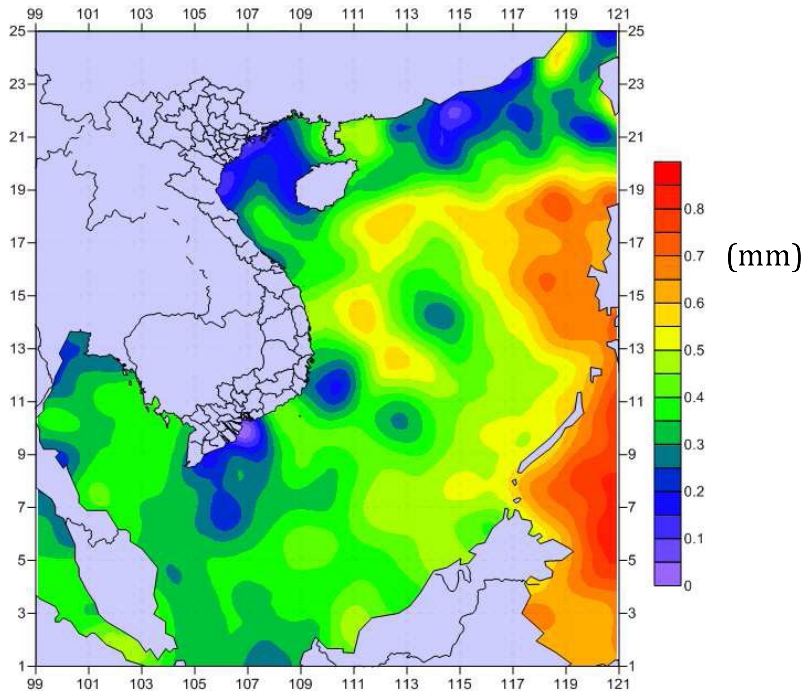

Figure 2.1: Sea level rise (mm) during the period of 1993–2010 in Vietnam (IMHEN, 2010b)

Table 2.2: Projected changes in sea level rise (cm) in Vietnam (MONRE, 2009)

Scenarios	Decade								
	2020	2030	2040	2050	2060	2070	2080	2090	2100
Low emission scenario (B1)	11	17	23	28	35	42	50	57	65
Medium emission scenario (B2)	12	17	23	30	37	46	54	64	75
High emission scenario (A1F1)	12	17	24	33	44	57	71	86	100

Modelling studies in Ca Mau indicate that the sea levels would rise by up to 72 cm at the end of the 21st century in the low scenario (low emissions), 82 cm in the medium scenario (medium emissions), and 105 cm in the high scenario (high emissions) compared with the baseline of 1980–1999 (IMHEN, 2011). In the whole 50-year period, sea levels would rise by about 25–30 cm by 2050 and 62–82cm by 2100 (Table 2.3).

Table 2.3: Sea level rise (cm) under different scenarios for Ca Mau Province compared with the period of 1980–1999 (MONRE, 2012)

Scenarios	Decade								
	2020	**2030**	**2040**	**2050**	**2060**	**2070**	**2080**	**2090**	**2100**
Low emission (B1)	9-10	13-15	18-21	24-28	30-37	36-45	43-54	48-63	54-72
Medium emission (B2)	9-10	13-15	19-22	25-30	32-39	39-49	47-59	55-70	62-82
High emission (A1F1)	9-10	14-15	20-23	28-32	38-44	48-57	60-72	72-88	85-105

Sea level rise for coastal systems and low-lying areas in the Mekong Delta would have devastating effects on coastal habitats: seawater would reach further inland and cause destructive erosion, flooding of wetlands, and habitat losses. At the same time, sea level rise would be accompanied by altered water flow and sediment load by dam construction upstream (Kuenzer et al., 2013) and land subsidence resulting from groundwater extraction (Schmidt, 2015). Therefore, due to these combined effects, coastal erosion and saltwater intrusion is expected to increase greatly in the Mekong Delta.

Sea level rise would also lead to loss of productive land, capital, and forced displacement of populations (Joshi et al., 2016); while the loss of coastal wetlands alone is likely to exceed US703 million US dollars (price in 2000) (Blankespoor et al., 2014). Approximately 68% of coastal wetlands in developing countries are at risk if the sea level rises by 1 m and Vietnam would be among those countries to suffer the most loss (Blankespoor et al., 2014).

Coastal erosion has already been reported as a result of sea levels rising, such as in the Ca Mau area where more than 600 ha of land have been eroded, with 200 m wide strips of land loss in some locations (DONRE, 2011), and the coastline has receded by between 100 m to 1,400 m over the last 20 years (Cat et al., 2005).

Saline intrusion is also a critical issue for the Mekong delta. According to the B2 scenario, within the next 40–50 years the seawater level in the Mekong delta would rise by 65 cm and flood over 5,100 km^2, or 12.8% of Delta land. The models have predicted an increase in areas of high salinity with more than 28‰ (parts per thousand) (IMHEN, 2010a). The saline water would shift landward by 70–80 km, covering almost 63% of the area of the Mekong Delta (Trieu & Phong, 2015). Saline intrusion has already affected the region. In the communes in the U Minh District, Ca Mau Province, saltwater has intruded into large areas of agricultural land. Local farmers cannot plough their fields for the next crop and are facing huge losses (ActionAid & CRES, 2010). Approximately twenty million farmers in the Mekong region are facing serious risks from saline intrusion. In the last few years, salt water has encroached more than 60 km inland (MONRE, 2009) and all districts of Ca Mau Province have already been affected by salinity (IMHEN, 2010b). Saline intrusion due to climate change would severely affect long-term economic efficiency in Ca Mau Province.

There is evidence that the local inhabitants of the Ca Mau region have been experiencing a higher sea level (ActionAid & CRES, 2010). Its impacts on aquaculture could include damage and loss of ponds due to increased coastal erosion and rising sea levels, loss of suitable land area for aquaculture caused by coastal inundation, and rising feed costs (Smyle & Cooke, 2011). Saline intrusion in coastal zones would also cause losses or retreat of mangrove forests. The accompanying loss of habitat would in turn reduce the stocks of fish, mollusc, and crustacean dependent upon these habitats (Smyle & Cooke, 2011). Aquaculture farms along the coastal areas will relocate because of reduction of the mangrove areas and saline intrusion would create habitat losses in Ca Mau Province (Huxtable & Yen, 2009).

While the effects of climate change are mostly associated with adverse outcomes, some studies found beneficial values from a sea level rise in some areas. Sea level rises would create ideal conditions for aquaculture in some areas, such as low-lying areas, through salinisation of groundwater and soil (Cochrane et al., 2009). This will expand suitable areas for brackish or saltwater aquaculture such as shrimp and mud-crab (Brander, 2007; IPCC, 2007; World Fish Centre, 2009). Saline intrusion could allow for some areas to be converted to shrimp farming in areas unsuitable for agriculture, particularly for traditional rice farming (De Silva & Soto, 2009). It is important to note that while although shrimp is a much more highly valued commodity than rice and has a greater potential market than many other agriculture products, it also has higher management risks (De Silva & Soto, 2009).

2.2.4. Changing rainfall patterns

The average annual rainfall in the South of Vietnam has sharply increased during the rainy seasons over the last some decades; conversely, the dry season rainfalls have decreased. It would appear that rainfall patterns have become more complicated (MONRE, 2009). Projected changes in annual average rainfall are for an increase of up to 6% by 2100 in the low emission scenario (B1), 7% in the medium emission scenario (B2), and 10% in the high emission scenario (A1F1) (MONRE, 2012). Rainfall would increase in rainy months by up to 25% and decrease in dry months by 30% to 35% and this takes account of significant seasonal and regional differences (MONRE, 2009). Projected changes in average rainfall in Ca Mau Province would show a change of about 2–3% by 2050 and 4–5% by 2100 and would show a trend to decrease in the dry season and increase in the rainy season (MONRE, 2012) (see Table 2.4). Therefore, the dry seasons would get drier and rainfall in the rainy seasons would be more intense, such as larger volumes in shorter periods. This would exacerbate flooding and drought conditions (Mackay & Russell, 2011).

Table 2.4: Projected changes in annual rainfall (%) under the B2 scenario in Ca Mau Province (MONRE, 2012)

Scenarios	Decade								
	2020	**2030**	**2040**	**2050**	**2060**	**2070**	**2080**	**2090**	**2100**
Winter (XII–II)	-2.9	-4.3	-6.0	-7.8	-9.4	-11.0	-12.4	-13.6	-14.8
Spring (III–V)	-0.8	-1.2	-1.7	-2.3	-2.7	-3.2	-3.6	-4.0	-4.3
Summer (VI–VIII)	0.8	1.1	1.6	2.0	2.5	2.9	3.3	3.6	3.9
Autumn (IX–XI)	2.3	3.3	4.7	6.1	7.4	8.6	9.7	10.7	11.6
Average rainfall change (%)	0.9	1.3	1.9	2.4	2.9	3.4	3.8	4.2	4.6

Rainfall changes have significantly affected local people. For example, farmers in improved extensive shrimp farming (IESF) have perceived that climate change affects shrimp farming (NACA, 2011) and have been concerned about rainfall pattern changes in the last few years, which they see as a critical element in shrimp farming production. Intense and unseasonable rains cause heavy damage to shrimp farming. Moreover, rains have been heavier and lasted longer than usual, leading to a decline in output and a drop in shrimp farmers' income (ActionAid & CRES, 2010). Noyes et al. (2009) showed that rainfall is one of the highest indicators, along with temperature, affecting shrimp production. High rainfall events can cause reduction of water quality, high toxicity, and conditions conductive for outbreaks of infectious diseases for shrimp (Abery et al., 2009). These claims correspond with Tendencia and Verreth (2011) and Waibel et al. (2017) that the main factors affecting shrimp production and fluctuation of physical and chemical parameters of the water are variations in rainfall, temperature, salinity and pH. These factors have also been identified as risk factors for shrimp disease outbreaks (Tendencia & Verreth, 2011).

2.2.5. Impacts of climate change on farmers' livelihoods

Climate change not only impacts on aquaculture, but also strongly impacts on local people's livelihoods (Handisyde et al., 2006). The adverse impacts of climate change are likely to be largely negative for aquaculture and damage the mangrove ecosystem (Smyle & Cooke, 2011). In particular, it could have significant effects on food security and employment in areas that are particularly vulnerable to the impacts of climate change, such as coastal areas.

Therefore, it would have significant impacts on livelihood security of the poorest rural people (Chaudhry & Ruysschaert, 2007).

Tuan and Hong (2012) concluded that local people in rural areas of the Mekong Delta who lack assets and depend on natural resources have suffered more impacts of climate change than those who lived in suburban or urban areas. Children, the elderly, people with disabilities and the poor were shown to be the most vulnerable groups (Tuan & Hong, 2012). These authors indicated that local communities have already perceived the impacts of climate change in the forms of increasing temperature, decreasing rainfall, increasing storm surges in the coastal areas, depletion of water tables, drying up of rivers, spreading of disease among people and livestock, and reducing wildlife and forest resources (as also noted by Halder et al., 2012). Moreover, vulnerability to climate change is intimately linked to poverty (Chaudhry & Ruysschaert, 2007). Poor people, who have a limited capacity to cope with current climate variability, are faced with more severe future climate change impacts (Huxtable & Yen, 2009). They are seriously jeopardised by likely increases in extreme weather events, sea level rises, and warming temperatures, and are therefore particularly at risk and more vulnerable to advancing climate change (Oxfam, 2008).

The major climate change effects on aquaculture and shrimp farming just discussed would pose challenges for local inhabitants in the Mekong Delta. Small-scale farmers and producers have already experienced severe negative effects of climate change (CGIAR, 2016). On this basis, local shrimp farmers would be especially vulnerable to climate change and their livelihoods potentially at risk.

2.3. Aquaculture and shrimp farming vulnerability to climate change in Vietnam

Vulnerability to climate change is a combination of the potential impacts (sensitivity plus exposure) and adaptive capacity (IPCC, 2007). In terms of aquaculture vulnerability (Allison et al., 2009), sensitivity is the degree to which local economies are dependent on aquaculture and therefore sensitive to any change in the aquaculture sector. Exposure is the nature and degree to which shrimp farming production systems are exposed to climate change. The potential impact is whatever may occur without taking into account-planned adaptation. Adaptive capacity is the ability or capacity of aquaculture systems to modify or change to cope with changes in actual or expected climate stress (Macfadyen & Allison, 2009).

The vulnerability to climate change of aquaculture in developing countries may also increase (De Silva & Soto, 2009). In terms of highlighting areas of vulnerability, a vulnerability assessment in aquaculture across the world showed that Vietnam was vulnerable at most levels and particularly through a combination of food security, economic importance, adaptive capacity, freshwater aquaculture, brackish and mariculture to climate change (Handisyde et al., 2006). McElwee (2010) found the key socioeconomic and biophysical zones of vulnerability to climate change and the typologies of livelihood profiles of areas and communities that are vulnerable to climate change. Risk assessment of climate change impacts for key marine species shows a preliminary screening-level risk assessment of each key species to the potential impacts of climate change (Pecl et al., 2011).

The Mekong Delta region is vulnerable to impacts of climate change through sea level rise and saltwater intrusion, as found recently by many scientists (Hak et al., 2016; Trung & Tri, 2016; Smajgl et al., 2015). Those studies showed that that sea level rise and saltwater intrusion would strongly impact on land–use (Trung et al., 2016) and striped catfish farming (Anh, 2014; Nguyen et al., 2014; Trieu & Phong, 2015). Moreover, current brackish areas in the region were more sensitive to changes from future hydrological conditions and water management because of sea level rise and saline intrusion (Trung et al., 2016). Although it is significant to patio-temporal sea level variations along the coastal area of the Mekong Delta, the rate of sea level rise would combine with the effects of land subsidence in the region and that may alarmingly cause the Mekong Delta to experience a high frequency of inundation (Hak et al., 2016). However, the scientists believed that an ensemble between effective adaptation strategies reliant on land use change and investments in water infrastructure would provide the most effective adaptation option for people's livelihoods in the Mekong Delta (Smajgl et al., 2015). More outcomes of other previous studies related to vulnerability to climate change impacts on aquaculture and shrimp production follows.

Those people in coastal areas of Vietnam whose livelihoods depend on marine resources are particularly vulnerable to typhoons or storm surges (ADB, 2009) and sea level rise (Mackay & Russell, 2011). For example, those in brackish water production (such as black tiger shrimp), whose species cultured are often of high value, suffer financially from lost stock and damaged facilities (Handisyde et al., 2006). In particular, the most important effects of a sea level rise relate to the corresponding changes in flooding and drainage, its relative effect on salinity, the importance for low lying areas in terms of increasing coastal erosion, the proneness to inundation, and increases in storm surges and tidal vulnerability. Any change in the mean sea level combined with the effects of storm surges associated with large storms or cyclones are likely to have dramatic consequences, especially for the Ngoc Hien District of Ca Mau Province (Mackay & Russell, 2011). Shrimp mortality may increase due to high water temperatures, increased disease levels and increased mortality of shrimp larvae in farming systems (Mackay & Russell, 2011).

The World Bank Group (2010) conducted a study on the economics of adaptation to climate change and produced a vulnerability framework and adaptation process as well as an economic analysis framework for shrimp production systems (Zhu & Trarup, 2011). By mapping climate change vulnerability and conducting a spatial assessment, researchers can identify the climatically most vulnerable areas (Anh et al., 2012). A district-based climate change vulnerability assessment would display the spatial distribution of the vulnerability of important sectors (Hung, 2011). While Ca Mau was identified as one of the most vulnerable provinces to climate change in Vietnam (Badjeck et al., 2010), its farming sector was also ranked as a high-risk level and the aquaculture sector would expect to be impacted most heavily (SIWRP, 2008).

A high percentage of farmers involved in small-scale, improved extensive shrimp systems in the Mekong Delta have claimed that high temperature is the most important factor influencing their shrimp farming, while a group of experts argued that rainfall is the most important due to irregular and unusual weather (RIA2, 2014). Moreover, the irregular weather ranked by shrimp farmers as a high risk and the other indicators such as hot weather, storms and water level rise were ranked as medium risk (Abery et al., 2011). These changes made the greatest impact on small-scale shrimp farming with losses of 10–30% or even 100% of shrimp farmers' income in improved extensive shrimp farming system (Hai et al., 2011). Where shrimp farmers are vulnerable to climate change, it would lead to a further reduction of profitability both in semi-intensive, intensive and improved extensive shrimp farming (Kam et al., 2012). Based on these severe weather events, shrimp farmers have developed some activities to immediately adapt to climate change; however, there is an income cost associated with these measures, whereby shrimp farmers generate less profit, and evidence that this critically affects their income (RIA2, 2014). As a result, higher costs will be required to invest in shrimp farming production (Smyle & Cooke, 2011; WB, 2010). Although the majority of farmers investigated have experienced climate change events, recently they have their own ways of adapting to the adverse impacts of the climate change events (Waibel et al., 2017) as the next section attests.

2.4. Adaptation to climate change in Vietnam

Actual and predicted climate change effects in Vietnam are already well documented and some adaptation responses have been collected. A summary of key policies addressing to climate change issued by the Vietnam Government in adaptation options of aquaculture and shrimp farming to climate change events are now addressed in turn.

2.4.1. Key policies and programs on climate change in Vietnam

The Vietnam Government has produced a number of policies and programs since the 1970s to address natural disaster prevention and mitigation, focusing on coping with floods and storms that are common during the monsoon season in several regions (ActionAid & CRES, 2010), and especially recently to cope with climate change. A summary of key policies and programs on climate change in Vietnam from 2003 to 2012 is presented in Table 2.5.

First, the Initial National Communication (INC) to the United Nations Framework Convention on Climate Change (UNFCCC) was the first policy document on climate change in Vietnam. However, the INC explored climate change impacts and adaptation measures only in a preliminary qualitative study (MONRE, 2009). Second, the National Strategy and Action Plan for Natural Disaster Prevention, Response and Mitigation to 2020 (NSDPRM), issued in 2007, set a national framework for disaster management. NSDPRM prioritised increased awareness raising and participation to minimise loss of life and assets, and stressed the importance of finding ways to live with recurring floods. Other key strategy initiatives include the establishment of disaster forecast centres, construction of flood corridors and flood-retention areas in the southern Vietnam. Third, the National Target on Response to Climate Change (NTP-RCC) and the Action Plan Framework for Adaptation to Climate Change in the Agriculture and Rural Development Sector (RCC-ARD) were approved in December 2008. The NTP-RCC aimed to mainstream climate change concerns into the new socioeconomic development strategy for the period of 2011–2020 and into policies on disaster reduction, coastal zone management, and energy supply and use (Lanh, 2010). Action plans to deal with climate change were developed for the period up to 2020 under NTP-RCC in most sectors and all provinces. The NTP-RCC supports research and awareness rising, and helps with coordination. It also promotes international cooperation in order to obtain external support for responses to climate change (MONRE, 2009).

Table 2.5: Some key policies and programs on climate change in Vietnam (MONRE, 2012)

Policies/programs	Abbreviation/ Organizations	Year Issued
The Initial National Communication to the United Nations Framework Convention on Climate Change	INC	2003
National Strategy on Environmental Protection to the year 2010	MONRE	2003
National Program on anti-desertification in the period of 2006–2010 and orientation to 2020	Government	2006
The National Strategy and Action Plan for Disaster Prevention, Response and Mitigation to 2020	NSDPRM	2007
The National Target Program on Response to Climate Change	NTP-RCC	2008
The Action Plan for Climate Change Mitigation and Adaptation in Agriculture and Rural Development	MARD	2008
Climate Change and Sea Level Rise Scenarios for Vietnam	MONRE	2009
Program on Awareness Raising for Communities in Community-Based Natural Disaster Management	MARD	2009
Climate Change, Sea Level Rise Scenarios for Vietnam	MONRE	2012

Review of climate change policies show that the country will be attempting to respond to climate change events over the coming decades. Already since NTP-RCC and RCC-ARD were approved and implemented, investment in climate change responses has tripled compared with the previous fifteen years. The RCC-ARD has a vision to 2050, setting the priorities for each five-year plan (Son et al., 2011). However, it is heavily oriented toward hard adaptation options such as investment in dikes, levees, and hydraulic structures. This normally applies at the national and the regional level, whereas the greatest challenges are likely to be encountered at the provincial level (Smyle & Cooke, 2011).

In spite of the extensive policies and programs on climate change in Vietnam, it has been suggested that current legal documents and regulations on coping with climate change are not aligned with the new policies (ISPONRE, 2009; Lanh, 2010; Oanh, 2012). Some policies do not have legal backing to facilitate the proposed actions related to climate change. In addition, there are no bodies to coordinate ministries, local government and other public and commercial sectors; nor are there effective ways of ensuring that all communities and sectors of the population can participate in the programs to respond to climate change. A policy review conducted by the Rural Development Centre and ActionAid and CRES (2010) found that policies favour rice growers but offer less protection for fishermen or aquaculture farmers.

Overall, the Vietnam policies pursue a top-down approach. Therefore, implementation of climate change policies with the spatial variance from the national to provincial is likely to be one of the big challenges because the policies do not envisage the proper engagement of local stakeholders (McKinley et al., 2015). This lack of engagement can lead to financial planning issues and human resource problems. Recent surveys of the local people in Vietnam on climate change measures and policies in local people of Vietnam show a low awareness to adapt to climate change events because of weak implementation of climate change policies (McKinley et al., 2015).

2.4.2. Adaptation options to climate change for aquaculture and shrimp farming in Vietnam

Adaptation refers to the adjustment process to actual climate effects seeking to moderate or avoid harm or increase beneficial opportunities (IPCC, 2014). In the context of complicated climate change effects both at present and in the future, sustainable livelihoods are to be considered according to three dimensions – economic, social, and environmental – and to resilience and adaptation to climate change (WB, 2010). Based on vulnerability indicators such as exposure, sensitivity, and adaptive capacity, linkages between sustainable livelihood frameworks and climate change variables would help to build sustainable livelihoods and adaptive capacity for each region (Hung, 2011). According to Schmitt at al. (2013) who conducted a study on integrated adaptation to climate change in the coastal areas, co-management is an effective way for both maintaining and enhancing the protection function of the mangrove forest belt and providing livelihoods for local communities. The social dimensions of adaptation to climate change in Vietnam, such as the policy and institutional framework for adaptation, local assessment of existing and potential adaptation options and practices, and participatory scenarios of adaptation pathways might be chosen in the future (McElwee, 2010).

Scientists have reviewed recent adaptation options and practices to adapt to climate change impacts on aquaculture and shrimp farming (Shelton. 2014). These include technical options, engineered infrastructure, and ecosystem-based adaptation approaches (Scheraga & Grambsch, 1998; Colls et al., 2009; Noble et al., 2014). In addition, De Silva and Roto (2009) asserted that adaptation options for aquaculture production could include aquaculture insurance (De Silva & Soto, 2009), technology transfer mechanisms (Duarte et al., 2007), aquaculture diversification (FAO, 2009). Joffre (2013) suggested that integrated mangrove-shrimp production systems help to restore and build resilience of the coastal zone (Joffre, 2013) as well as combine participatory approaches into prediction models is better for planning shrimp aquaculture (Joffre et al., 2015). Finally, aquaculture zoning and monitoring

(Hung, 2012), and shrimp farmers' self-adaptation (Williams & Rota, 2012) have been suggested to be applied as adaptation options. A review of adaptation strategies and options to reduce damages and to increase resilience of vulnerability to climate change in aquaculture and shrimp farming follows.

First, ecological and technical factors are influencing the diversity of shrimp farms in the coastal area of the Mekong Delta. Aquaculture farms are highly affected by disease outbreaks; however, intensification through technical investments and increased biodiversity could reduce the vulnerability of shrimp farmers to disease outbreak (Joffre & Bosma, 2008). Therefore, technology transfer mechanisms and better management practices into small-scale farming practices must reach all farmers (De Silva & Soto, 2009). Furthermore, aquaculture diversification could enable farmers to domesticate new species (Duarte et al., 2007; FAO, 2009). This means that culturing more species provides a form of insurance and offers better adaptation possibilities under different climate change scenarios, especially unexpected events such as diseases (De Silva & Soto, 2009). By focusing on herbivorous species, aquaculture can provide nutritious food with a low carbon footprint; increasing numbers of species are now cultured and considered to be adaptable to climate change (McElwee, 2010). Moreover, flexibility of household livelihood systems allows local people to change in response to climate change impacts (Hung, 2012). There are positive examples of farmers already changing their cultivation cycles or planting different crops (Oxfam, 2008). Diversification of farming systems and shifting to more ecologically sustainable practices would support the aquaculture sector's resilience in the face of climate risks to shrimp and the uncertainties of climate change events (Kam et al., 2012).

Second, when local communities experience the substantial impacts of climate change events, such as sea level rise and salinity intrusion, engineered infrastructure can be applied as hard options to decrease damages and to enhance the resilience of local people (Renaud et al., 2015). Those options include regeneration of coastal ecosystems, the construction of embankments, coastal and river dikes, upstream flow control, investments in water supply systems and its infrastructure, agronomic measures, and shifting to agro ecosystems (Kam et al., 2012; Smajgl et al., 2015; Renaud et al., 2015). Implementation of those hard options would reduce autonomous adaptation costs borne by farmers and supply supplementary benefits to other economic sectors. However, construction of sea dikes, or in a larger picture of Mekong Delta polderization, would reduce opportunities for expanding shrimp farming (Kam et al., 2012). Thus, there are trade-offs to consider between costs and benefits of adaptation options. Having appropriate political discussion and moving to an ensemble of hard and soft options (such as ecosystem-based) are likely to provide the most effective results for local livelihoods. (Kam et al., 2012; Smajgl et al., 2015; Renaud et al., 2015; Thu et al., 2017). On this basis, farmers can undergo income diversification under the influence of both saline and freshwater systems and have an opportunity to change the 'business as usual' mode of tackling water-related problems including climate change events through infrastructure development (Renaud et al., 2015). Because of the different adaptation policies at different scales, the Vietnam lesson shows that engineering measures need to be balanced with ecosystem-based adaptation for more affordable and effective responses to climate change events (Thu et al., 2017).

Third, ecosystem-based approaches to adaptation have been investigated by many researchers (Colls et al., 2009; Doswald & Osti, 2011; Noble et al., 2014; Thu et al., 2017). This approach is defined as the use of biodiversity and ecosystem services as part of an overall adaptation strategy to help people adjust to the adverse effects of climate change (Doswald & Osti, 2011). In the case of Ca Mau Province of Vietnam, site-specific and integrated adaptation to climate change (Schmitt et al., 2013; Thu et al., 2014) using ecosystem-based approaches varies for different shrimp farming systems. For example, financial performance polyculture in the mixed farming systems, is better than monoculture in extensive and semi-extensive shrimp farming (Bosma et al., 2016). Thus, adaptation options for shrimp farmers based on ecosystem within the different farming systems may mean pursuing polyculture systems. However, Viet Nam's climate change policies and ecosystem-based adaptation have been inadequately considered. It has been suggested that intensification of unsustainable production (Turner et al., 2003) limitation of market based incentives to stimulate development of the integrated-farming systems, and rapidly increased production due to climate change in the absence of adaptation measures need to be considered in revisions of climate change policies to integrate ecosystem-based adaptation though different levels (Joffre et al., 2015).

Fourth, aquaculture insurance would ensure that finance is accessible for businesses to recommence operations following disruptions caused by climate change events. This is suitable for a major production such as intensive shrimp farming, but not for small-scale farming, which is particular to Vietnam (Be et al., 2003; Secretan et al., 2007). Governments could make aquaculture insurance mandatory above a certain size to reduce long-term losses in production, livelihoods, and potential environmental damages (De Silva & Soto, 2009).

Fifth, aquaculture zoning and monitoring can be important adaptation measures to cope with climate change. Determining threats through risk assessment analysis will help to select the best aquaculture sites for aquaculture farms, particularly in coastal and more exposed areas. Water warnings and increasing the minimum distance between farms by implementing tight bio-security programs for aquaculture clusters or zones can also be used (De Silva & Soto, 2009). Furthermore, Hung (2012) recommended integrated water management to cope with climate change – for instance, developing a land-use plan with coastal resource conservation and community-based management. The selection of suitable sites in relation to specific culture methods and species will be valuable both for maximising profit and for food production in the face of a changing climate and for predicting vulnerable areas (Handisyde et al., 2006).

Finally, in terms of shrimp farmers' self-adaptation, local communities must be strengthened through the provision of services (such as weather warnings) to reduce risk, support participatory natural resource management and sustainable fishing operations, and assist in post-harvest processing and preservation to maximise value-adding and employment, and minimise waste from both fisheries and aquaculture (Williams & Rota, 2012).

Responses to climate change must centre on boosting adaptive capacity both of communities and the ecosystems on which they depend. The heavy dependency of those in small-scale farming in developing countries on ecosystem services must be recognised and measures taken to increase the health of ecosystems by reducing other stresses such as over-exploitation and pollution (Williams & Rota, 2012).

Local communities have started to adapt to the changing climate by altering their livelihoods and cultural practices (Halder, Sharma, & Alam, 2012). Potential adaptation measures, such as the introduction of new species for both native and exotic species appropriate to the environment and ecology, need to be considered (Hai et al., 2011). Aquaculture extension activities should focus on disseminating culture techniques appropriate for new climatic conditions: weather broadcasts on television should be on time, with more frequency and accuracy; banks or other funding sources should have long-term loans for improving shrimp farming; reforestation of mangrove should be prioritised in the coastal areas (Hai et al., 2011).

It is important to realise that adaptation options to climate change would challenge small-scale shrimp farmers and the poor. Because high cost investments would be required, households and communities would be almost completely reliant on government interventions such as to build and upgrade sea dikes and flood defences to protect infrastructure and production land (Smyle & Cooke, 2011). Meanwhile, the estimated cost for climate change adaptation in the aquaculture sector in the Mekong Delta would be high (Kam et al., 2012), and the coastal households would have to autonomously adapt their living conditions (Kulpraneet, 2013). Therefore, financial capital is considered to be strongly linked to adaptive capacity; hence, where possible, the inclusion of future scenarios should be considered when assessing potential vulnerability (Handisyde et al., 2006).

2.5. Conclusion

Impacts of climate change events are actually happening and influencing shrimp farmers' lives in the coastal areas (Dang & Nuberg, 2014) where millions of people depend on shrimp aquaculture for their livelihoods (Blythe et al., 2015). Major concerns about climate change events in Vietnam from local to national stakeholders include extreme climate events, sea level rise, changes in temperature and rainfall, etc., but those concerns are all related to water issues for aquaculture or shrimp farming (McKinley et al., 2015). A summary of current literature reviews about impacts of climate change events, vulnerabilities, and adaptation options for aquaculture and shrimp farming, particularly highlighting Vietnam and Ca Mau Province, follows.

Handisyde et al. (2016) agreed with the previous researchers (Roessig et al., 2004; Williams & Rota, 2012) that climate change events pose significant impacts for aquaculture. Local people in coastal areas of Vietnam have perceived risks of the main elements, such as storm surges, high temperatures, sea level rise, flooding and inundation, and fluctuations of salinity (De Silva & Soto, 2009; Mackay & Russel, 2011). First, storms trending toward the southern coast of Vietnam are predicted to increase in both frequency and intensity (IMHEN, 2010b; Lanh, 2010; Tan, 2010; Mackay & Russell, 2011). Second, sea level rise could cause loss of productive land, capital, and forced displacement of coastal inhabitants (Blankespoor et al., 2014; Joshi et al., 2016); loss or retreat of mangrove forests (Huxtable & Yen, 2009; Smyle & Cooke, 2011); and accompanying saline intrusion and erosion could be more harmful to local communities and shrimp farming (ActionAid & CRES, 2010; IMHEN, 2010a, 2010b; Smyle & Cooke, 2011; Trieu & Phong, 2015). In addition, changes in water flow and reduction of sediment load because of dam construction upstream (Kuenzer et al., 2013), and sinking of Ca Mau region of the Mekong delta (Schmidt, 2015), are expected to seriously aggravate coastal erosion and saltwater intrusion. On the other hand, however, sea level rise could provide beneficial values and expand shrimp production in suitable low-lying areas

(Brander, 2007; De Silva & Soto, 2009; World Fish Centre, 2009). Third, fluctuations of temperature and precipitation, especially accompanied by irregular weather, are the main factors that reduce environmental water quality, increase toxicity, change salinity, and cause infectious disease outbreaks (Ficke et al., 2007; Abery et al., 2009; Noyes et al., 2009; NACA, 2011; Alapide-Tendencia, 2011).

A high proportion of vulnerable households have been identified in the coastal communes of Vietnam (Tran et al., 2017) where the vulnerability of the aquaculture sector was ranked at a high-risk level to climate change events (SIWRP, 2008; Anh et al., 2012; Hung, 2012). Farmers in coastal areas of the Mekong Delta have perceived higher risks in most dimensions, but production and incomes have so far received greater priority (Dang et al., 2014). Shrimp farmers in small-scale IESF have perceived risks of climate change events and ranked high temperature as the most important factor affecting shrimp production, whereas rainfall was ranked as the most important factor by experts (RIA2, 2014). Both farmers in semi-intensive/intensive and IESF expected to receive further reductions in profitability and increased shrimp farming costs due to climate change events (WB, 2010; Smyle & Cooke, 2011; Kam et al., 2012). In response to bad weather events, IESF farmers have been adapting to adverse effects of climate change, with evidence that it critically affects their income (RIA2, 2014).

Scientists have suggested a number of adaptation options and practices for climate change effects on aquaculture and shrimp farming. First, technical options include the diversity of shrimp farms, crops, and species; investments in technology and transfer mechanisms into small-scale farming practices (De Silva & Soto, 2009; Duarte et al., 2007; Cochrane et al., 2009a; Joffre & Bosma, 2008; McElwee, 2010); the pursuit of alternative livelihoods (Hung, 2012); and changing cultivation cycles (Oxfam, 2008). Second, engineered infrastructure comprises the construction of embankments and dikes, governed water and flow control, investments in water supply systems and related infrastructure, and shifting to agro ecosystems (Kam et al., 2012; Smajgl et al., 2015; (Renaud et al., 2015). And there are many studies on adaptation options to climate change events, showing that engineering measures need to be balanced and integrated with ecosystem-based adaptation (Kam et al., 2012; Smajgl et al., 2015; Renaud et al., 2015; Thu et al., 2017). Third, ecosystem-based measures entail the use of biodiversity and ecosystem services (Doswald & Osti, 2011), such as site-specific and integrated adaptation options (Schmitt et al., 2013; Thu et al., 2014) based on different shrimp farming systems and the performance of polyculture (Bosma et al., 2016; Kabir, 2016). Fourth, aquaculture insurance (De Silva & Soto, 2009) should be suitable for major production (such as intensive shrimp farming), but not for small-scale shrimp farming (Be et al., 2003; Secretan et al., 2007). Fifth, aquaculture zoning and monitoring would help to select the best aquaculture sites, clusters or zones for farming (De Silva & Soto, 2009) and would prove valuable in maximising profit (Handisyde et al., 2006). Finally, shrimp farmers' self-adaptation has been suggested, such as exploiting social networks and community capacity, the introduction of new species, appropriation of culture techniques to new climatic conditions, making better use of weather broadcasts, and long-term loans of funding sources for improving shrimp farming and reforestation of mangrove forests (Hai et al., 2011).

This literature review relates to effects, vulnerability, and adaptation options concerning aquaculture and shrimp farming, with most of the literature focused on the macro, or regional scale for the Mekong Delta with well understood impacts of sea level rise and saltwater intrusion. Some scientists have examined climate change impacts on brackish aquaculture and catfish in the region. However, those studies, while contributing to understanding, have not drilled down to help understand the effects, vulnerability and adaptation to climate change events at the local level, as perceived by the local experts and shrimp farmers in different farming systems along with evidence of climate parameters effecting shrimp production at this local scale. Overall, the literature is not clear about just how much knowledge or understanding shrimp farmers themselves have about effects, vulnerability and adaptation to climate change events in the Ca Mau region. Thus, this research, with its focus on learning from the local experts and shrimp farmers directly as to their perceptions of the impacts, vulnerability and adaptation needs arising from climate change, seeks to make an original contribution to knowledge.

CHAPTER 3: Methodology

3.1 Introduction

This chapter presents approaches that were employed during the research. The methodology presented in this chapter was designed to answer the research questions of how climate change events might be affecting shrimp farming systems in Ca Mau Province; how shrimp farming in different systems is vulnerable to climate change events; and how Ca Mau shrimp farmers can adapt to climate change events. The chapter is divided into three sections: research approaches, data collection and analysis; vulnerability assessment; and the ethical requirements for conducting research.

3.2. Research approaches, data collection and analysis

The research approaches, data collection and analysis in this research will be described below.

3.2.1. Basics concepts, theories, and practices related to impacts, vulnerability and adaptation options to climate change events on aquaculture and shrimp production

The three research questions address the topics of impacts, vulnerability and adaptation to climate change events on shrimp farming; therefore, these need to be explained and defined for the purposes of this research. Explanations are provided in the following paragraphs.

Impacts of climate change events: Impacts are consequences or outcomes of effects of natural and human systems due to climate changes or hazardous climate events (IPCC, 2014). Scientists have implemented a number of methodologies to identify impacts of climate change events on farming systems including: typology, simulating (Anh et al., 2012; Hak et al., 2016; Hung, 2011; Joffre & Bosma, 2008; Nguyen et al., 2014; White et al., 2011), and using the MAGICC/SCENGEN climate modelling tools (Handisyde et al., 2016); using an agent-based model based on a participatory modelling approach to simulate and analyse farming systems from shrimp farmers' decisions (Joffre et al., 2015); and approaches using shrimp based livelihoods (Bosma et al., 2016) by analysing three types of mangrove shrimp systems and comparing with other systems to suggest appropriate shrimp farming model. A number of previous researchers have also investigated impacts of climate change events on aquaculture and livelihoods (Abery et al., 2011; De Silva & Soto, 2009; Hai et al., 2011; NACA, 2011; RIA2, 2011), such as extreme climate events, sea level rise, temperature, rainfall, irregular weathers, and seasonal patterns and mostly based on concepts of climate change impacts of IPCC (2007, 2014). These climate change events were incorporated into this research when investigating expert and shrimp farmer perspectives on impacts of climate change on shrimp production.

Vulnerability to climate change is a combination of the potential impacts (sensitivity plus exposure) and adaptive capacity (IPCC, 2007). The basic concepts of vulnerability assessment used to develop frameworks for climate change vulnerability, impact and adaptation assessment are well established (e.g. Adger, 1999; Adger et al., 2004; Fussel, 2006, 2007; IPCC, 2007, 2014; Moss et al., 2001; O'Brien & Liechenko, 2000; O'Brien et al., 2004; Turner et al., 2003; Wolf, 2011). Although approaches may vary depending on the specific local context and factors under examination, every assessment needs to consider the key components (Metternicht et al., 2014). Cochrane et al. (2009) has reviewed the current knowledge of climate change implications for aquaculture and Macfadyen and Allison (2009) have articulated the vulnerabilities applying to aquaculture assessment. The World Bank and UNEP developed procedures for economic vulnerability assessments in Vietnam (WB, 2010), followed by a comparative vulnerability risk assessment framework based on the approach generally accepted by IPCC to vulnerability assessment in combination with a risk-based approach for assessing the impacts of climate change and its hazards (ADB, 2009, 2013; Mackay & Russell, 2011). Because of large uncertainties regarding the rate of change, the scale, and the distribution of impacts, the adopted risk assessment approach in this study is based on a "risk matrix" to identify the impacts, adaptive capacity, risk, and vulnerability associated with climate change (Brundell et al., 2011; Mackay & Russell, 2011). The rural livelihood framework based on farmer' capitals is used to identify levels of farmers' adaptive capacity in the different farming systems (Brown et al., 2010; Ellis, 2000). Therefore, the degree of exposure and sensitivity to potential impacts, and the combined effect of potential impacts and adaptive capacity gives rise to vulnerability; thus, levels of vulnerability are assessed from a combination of exposure, sensitivity, and capacity to adapt to the changing climate (Brundell et al., 2011). Those approaches, based on risk assessment and the livelihood framework, were included into adaptive capacity and vulnerability assessment in this research to identify shrimp farmers' adaptive capacity and vulnerability to climate change events in different farming systems.

Adaptation to climate changes is a process of adjustment to actual or expected climate and its effects, seeking to moderate or avoid harm or exploit beneficial opportunities in human systems, facilitating adjustment to expected climate and its effects in some natural systems

(IPCC, 2014). Researchers have suggested a number of adaptation options and measures, such as technical options, engineered infrastructure, and ecosystem-based methods, to adapt to climate change events on aquaculture and shrimp farming (Colls et al., 2009; Scheraga & Grambsch, 1998; Shelton, 2014; Noble et al., 2014); and scientists have agreed to balance or integrate between soft and hard adaptation options and measures on aquaculture production to adapt to climate change events (Bosma et al., 2016; Kabir et al., 2016; Kam et al., 2012; Renaud et al., 2015; Smajgl et al., 2015; Thu et al., 2017), including shifting to polyculture (Bosma et al., 2016). Perspectives obtained from experts and shrimp farmers in this research are discussed in these contexts.

3.2.2. Conceptual framework of the study

Based on the three research questions of the study in Section 1.3, the literature review in Chapter 2, and the basics concepts, theories, and practices related to the topic of the study reviewed in Section 3.2, the conceptual framework of the study is constructed and presented in Figure 3.1.

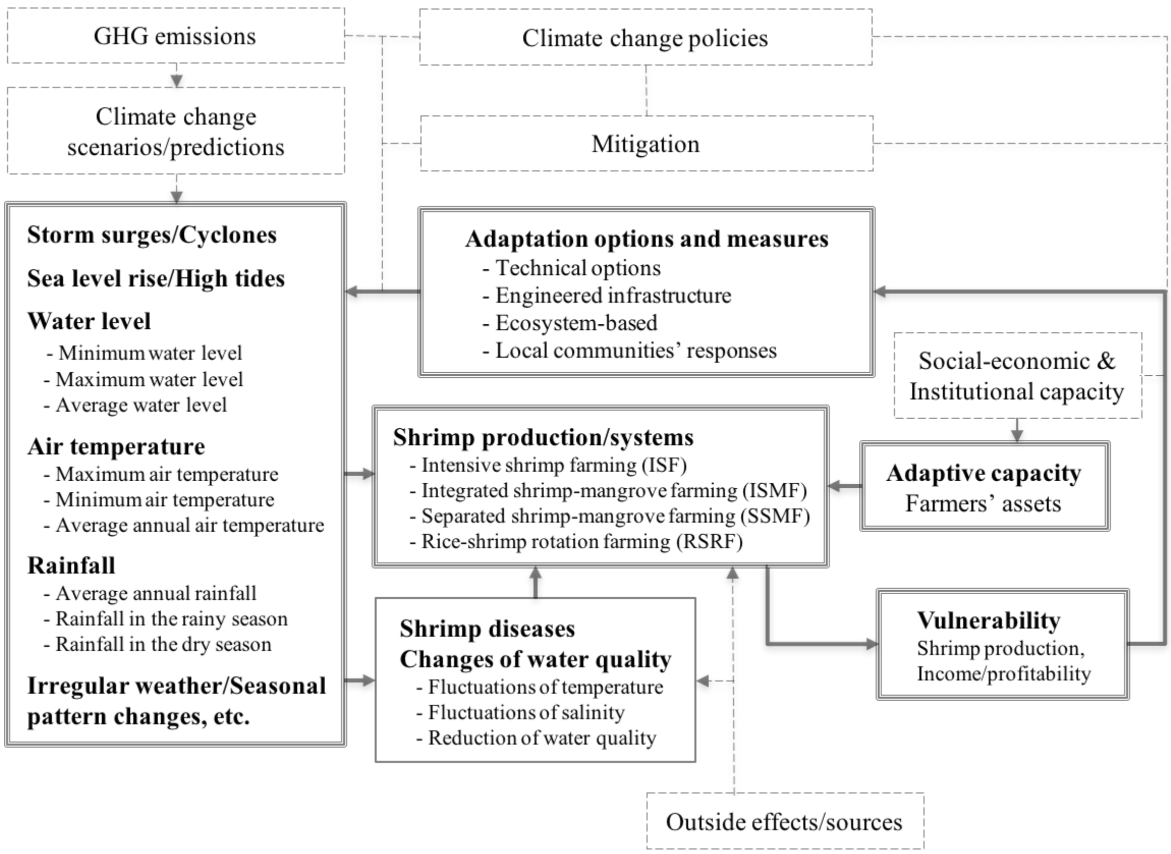

Figure 3.1. Conceptual framework of the study

3.2.3. Literature review

A literature review involves the systematic identification, location, and analysis of material related to the research problem (Bloomberg & Volpe, 2008). It is necessary to research the background (in this case, including climate change scenarios and predictions) that relate to the study, and support the context for discussion and research results (Machi & McEvoy, 2009). A main objective of a literature review as well as its procedure is to provide a clear and balanced picture of current concepts, theories, and relevant data to the project (Blaikie, 2000; Bloomberg & Volpe, 2008). Data sources can include published and unpublished available documents, such as journals, papers, reports and books, emails, Internet publications, discussion groups and bulletin boards, and non-textual materials (Machi & McEvoy, 2009).

For this research, the secondary data and information were collected from journals, books, previous relevant projects and research reports from Internet sources. The related secondary data of government publications and documents were collected from governmental agencies and organisations in Vietnam. There are major sources from international organisations that have conducted climate change research in Vietnam, such as WB (World Bank), Oxfam, and NACA. National and provincial secondary data sources are also very important for the research, such as national climate change scenarios conducted by MONRE (Ministry of Natural Resource and Environment), reports and studies related to impacts, vulnerability and adaptation of aquaculture to climate change conducted by MARD (Ministry of Agriculture and Rural Development), meteorology hydrology data (Vietnam Institute of Meteorology Hydrology and Environment), shrimp production statistics (e.g. MARD, DARD, Statistics Agency), socioeconomic statistics and legal reports (e.g. PC, Department of Planning and Investment, DARD), case studies, projects, and other research related to this research (e.g. Ministry of Science and Technology, Ca Mau DOST, Ca Mau DONRE).

3.2.4. A survey using questionnaire with shrimp farmers and the local experts

Surveying is a primary research method in qualitative and quantitative research (Leedy & Ormond, 2001). The questionnaire (see Appendix A) in this study was developed to investigate the research questions with the main participants, who were shrimp farmers and local experts. In the household survey the questionnaire focused on the general situation of shrimp farming for a sample of shrimp farmers to gain an in-depth understanding of how they perceived climate change impacts, their vulnerability, and their perceptions of shrimp farming adaptation. The quantitative data obtained from the household comprised household characteristics, and costs and earnings for each shrimp farming system. The qualitative data collected were focused on perceptions of climate change impacts, vulnerability, and adaptation to climate change events. The survey with the local experts was conducted using the same procedure as with the survey with farmers in the household surveys.

The field study was undertaken in Ca Mau Province, Vietnam from November 2012 to February 2013. An additional survey was conducted from June 2016 to July 2016 to the same families to gather more data on shrimp production and household assets investigated in the previous field study. Four communes were selected for the household surveys representing the four shrimp farming systems: RSRF, ISMF, SSMF, and ISF. [7]

The surveys collected data and information in the four farming systems through the questionnaire with shrimp farmers and local experts. The selection of households was determined through firstly consulting with local key informants [8] to select four communes representing the four types of shrimp farming systems. Second, a list of complying households in the selected communes was made. Third, a targeted number of households were selected from each commune with from twenty to twenty-five shrimp farmers surveyed for each commune. Finally, a random selection was used in the surveys (Leedy & Ormond, 2001). In total, 100 shrimp farmers were investigated, comprising 22 in RSRF, 31 in ISMF, 26 in SSMF, and 21 in ISF. Based on a study of household level (Few & Tran, 2010), surveys were conducted with one adult shrimp farmer who responded on behalf of each household (Few & Tran, 2010).

The selection of local experts was conducted in the same manner as that for investigating shrimp farmers. There were eleven local experts who hold at least an undergraduate degree and a 10-year working experience related to climate change and or shrimp production in Ca Mau Province. All surveys were semi-structured and the questionnaire was composed of both open ended and closed questions (Kolb, 2008; Leedy & Ormrod, 2001). Interviewers

[7] Phong Dien Commune (RSRF) is a coastal commune, located in Tran Van Thoi district with the area of 5578 ha and 13208 people (CMSO, 2016), and affected by the diurnal tidal amplitude of the West Sea varying between 0.5−1.0 m (Stoop et al., 2015). Dat Mui (ISMF) is the southernmost commune of Ca Mau, located in Ngoc Hien district with the area of 9334 ha and 15390 people (CMSO, 2016), regulated by two conflicting tidal regimes of both the East Sea and the West Sea with the tidal amplitude varying from 2.0 to 3.0 m (Stoop et al., 2015). Tam Giang Dong Commune (SSMF) is located in Nam Can district with the area of 9531 ha and 5468 people (CMSO, 2016), also a coastal commune and affected by a large amplitude semidiurnal tide of the East Sea varying from 3.0 to 3.5 m (Stoop et al., 2015). Tan Duyet (ISF) is further inland commune of Dam Doi district with 2948 ha, 6148 people (CMSO, 2016).

[8] Local key informants in this research are staffs of rural developments and agriculture divisions in the districts and communes investigated.

and participants communicated in Vietnamese during face-to-face interviews (Leedy & Ormrod, 2001; Kvale, 2007). Photographs taken during some of the shrimp farmer interviews are presented in Figure 3.2.

Shrimp farmer interview and a focus group at Phong Dien Commune (Source: Author photo)

Shrimp farmer interview and a focus group at Dat Mui Commune (Source: Author photo)

Shrimp farmer interview and a focus group at Tam Giang Dong Commune (Source: Author photo)

Shrimp farmer interview and a focus group in Tan Duyet Commune (Source: Author photo)

Figure 3.2. Photographs of shrimp farmer interviews and focus groups at the four communes in the four farming systems investigated.

3.2.5. Focus groups

Participants recruited for the surveys were drawn, purposively selected, from the sample of 100 shrimp farmers who had been individually interviewed previously (as per Section 3.2.4). The participants involved in the focus groups were shrimp farmers who had been living in the communes for a long time and had many years of experiences with shrimp production. The size of focus groups varies greatly and depends on the purposes of studies (Carlsen & Glenton, 2011). The selection process in this research was based on that of Morgan and Krueger (1998) and Krueger (2015), with the focus groups comprising from 10 to 20 shrimp farmers for each of the four farming systems. The commune officers served as local key informants to help the researcher to invite participants to the targeted places for the meetings. Due to not having the permission of the shrimp farmers for recording and taping, the researcher used note taking for the focus groups (Krueger, 2015).

In the focus group sessions, participants were asked to work as a group in assigning measures for likelihood and consequences for risk assessment (as laid out in Tables 3.1 and 3.2), as well as scores and rankings for the adaptive capacity assessment (as figured out in Tables 3.4 and 3.5 in Section 3.2.6). The group members discussed each climate change impact in turn facilitated by the researcher. This ensured that every person had an opportunity to speak and share his or her view before arriving at a consensus score for each point examined. In all cases, the consensus position was arrived at quite easily, with no sense that particular individuals dominated proceedings or swayed the views of others. Finally, the focus group results and information were collected and analysed (Morgan, 1998) according to risks, adaptive capacity, and the vulnerability levels of shrimp farming income to climate change events, based on scores and ratings using the matrix worksheets (Brown et al, 2010; Brundell et al., 2011; Mackay & Russell, 2011). The focus group document is presented in Appendix B.

Table 3.1: Likelihood category for climate change impacts

Score	Rating	Recurrent events	Single event
5	Almost certain	Could occur several times/year	More likely than not – Probability (P) greater than 50%.
4	Likely	May arise about once per year	As likely as not – 50/50 change.
3	Possible	May arise once in less than 10 years	Less likely than not but still appreciable- P less than 50% but quite high.
2	Unlikely	May arise once in 10 - 25 years	Unlikely but not negligible – P low but noticeably greater than zero.
1	Rare	Unlikely rise once in more than 25 years	Negligible – P very small, close to zero.

Table 3.2: Consequence category for climate change impacts

Score	Rating	Profitability and growth (shrimp production)
5	Catastrophic	Shrimp production would be unprofitable, contract markedly, making it unviable. It would need to be wound up.
4	Severe	Shrimp production would be unprofitable, contract markedly, and likely unviable even with significant remedial action.
3	Major	Shrimp production would be unprofitable, contract, and require significant remedial action to remain viable.
2	Moderate	Shrimp production would be only marginally profitable with growth stagnant.
1	Minor	Shrimp production would be profitable, with growth achieved but fails to meet expectations.

3.2.6. Adaptive capacity assessment

The adaptive ability of farmers to climate change impacts depend on the degrees of climate change exposure (risks) and on their knowledge, supports, and opportunities in order to respond to that change (Brown et al., 2010). The rural livelihood framework to assess adaptive capacity of farmers based on five capitals: human, social, natural, physical, and financial capitals (Ellis, 2000) to suggest adaptation options at the farm scale (Brown et al., 2010; Rodriguez et al., 2011) for farmers in the different farming systems.

Adaptive capacity assessment is based on scores and rankings and farmers' self-assessment (Brown et al., 2010). A description of five capitals and indicators to assess levels of adaptive capacity is presented in Tables 3.3 and 3.4. Each indicator was scored by shrimp farmers with integer numbers from "0" to "5" based on current adequacy to support shrimp farming in each farming system. A score value of ‘‘0” or ‘‘1” ranked as a low level of adaptive capacity. It means an indicator of adaptive capacity that was not effectively supporting shrimp farming. A score value of ‘‘2” or ‘‘3” ranked as a medium level of adaptive capacity. It explains that the indicator of adaptive capacity could be improved with monitoring and some actions needed to support shrimp farming. Finally, a score value of ‘‘4” or ‘‘5” ranked as a high level of adaptive capacity. This indicator was judged to be supporting shrimp production effectively. Scores and rankings exploited to assess adaptive capacity of shrimp farmers in the four farming systems are presented in Table 3.5.

Table 3.3: Description of the five capitals used in adaptive capacity analysis

Capital	Description
Human	The skills, health and education of individuals that contribute to the productivity of labour and capacity to manage shrimp farming
Social	Reciprocal claims on others by virtue of social relationships, the close social bonds that facilitate cooperative action and the social bridging, and linking via which ideas and resources are accessed
Natural	The productivity of land, and actions to sustain productivity, as well as the water and biological resources from which rural livelihoods are derived
Physical	Capital items produced by economic activity from other types of capital that can include infrastructure, equipment and improvements in genetic resources (crops, livestock)
Financial	The level, variability and diversity of income sources, and access to other financial resources credit and savings) that together contribute to wealth

(Source: Brown et al., 2010; Ellis, 2000)

Table 3.4: Indicators and description of five capitals

Capital	Indicator	Description
Human	Family size	Number of people in a household
	Education	Education of householder, education of household members
	Farming experience	Number of years that householders practiced shrimp farming
	Labour	Number of people at labour age and involved in shrimp farming,
	Health	Age and physical capacity (children and elderly in household)
Social	Membership	Number of shrimp farmers get involved as members of community groups and or shrimp farming groups
	Volunteerism	Volunteering as participation, lead and represent
	Internet and media	Access and usage
Natural	Land resource	Shrimp farming area per household
		Soil health
	Water resource	Water quantity and quality supplied for shrimp farming
	Ecosystem and biodiversity	Mangrove forest planting and conservation
Physical	Infrastructure	Main means of transportation
		Road types and density
		Electricity
	House construction	Types of house or degrees of solidification
	Farm equipment	Sluice gates, embankments, and sea dikes
Financial	Income stream	Number of income sources per household
	Household income	Availability of cash to do shrimp farming
		Total household income
		Shrimp income
	Access to finance	Financial access: from neighbours, relatives, and or local banks

(Source: Brown et al., 2010; Ellis, 2000)

Table 3.5: Scores and ratings for adaptive capacity assessment (Brown et al., 2010)

Scores	Ratings	Description	Action
0 1	Low	Not supporting effective shrimp farming	High priority for action
2 3	Medium	Could be improved	Needs monitoring, may need some action
4 5	High	Supporting effective shrimp farming	Does not need immediate action

3.2.7. Vulnerability assessment

The process of vulnerability assessment in this research is based on risk assessment using the impact risk matrix, and the vulnerability matrix identifies levels of risk and vulnerability of shrimp farming to climate change impacts. The impact risk matrix uses the qualitative measures of likelihood and consequence of climate change impacts to assess the risk levels based on the probability of a particular climate outcome (likelihood) multiplied by its consequences. Likelihood of a climate change impact is classified as “almost certain”, “likely”, “possible”, “unlikely”, or “rare”; consequences are identified as “insignificant”, “minor”, “moderate”, “major”, and “catastrophic”. These classifications were drawn from the work of Mackay and Russell (2011). Scores and ratings based on qualitative measures of likelihood and consequences are presented in Table 3.1 and Table 3.2. The levels of risk[9] classified as “extreme”, “high”, “medium”, and “low”, which were derived by combining likelihood and consequence in the impact risk matrix, are presented in Table 3.3 (Brundell et al., 2011; Mackay & Russell, 2011).

Table 3.6: Risk rating matrix to assess levels of risk by combining likelihood and consequence

Likelihood		Consequences				
		Insignificant (1)	Minor (2)	Moderate (3)	Major (4)	Catastrophic (5)
Almost certain	(5)	M (5)	M (10)	H (15)	E (20)	E (25)
Likely	(4)	L (4)	M (8)	H (12)	H (16)	E (20)
Possible	(3)	L (3)	M (6)	M (9)	H (12)	H (15)
Rare	(2)	L (2)	L (4)	M (6)	M (8)	M (10)
Unlikely	(1)	L (1)	L (2)	L (3)	L (4)	M (5)

[9] **Extreme risk (E ≥ 20)** requires urgent attention to implement adaptation options immediately. **High risk (H = 12-20)** requires attention to develop adaptation options in the near term. **Medium risk (M = 5-12)** expects that existing controls will be sufficient in the short term but will require attention in the medium term and should be maintained under review. **Low risk (L ≤ 5)** requires maintenance under view by control measures but it is expected that existing controls will be sufficient and no further action will be required unless circumstances become more severe.

The vulnerability matrix identifies adaptive capacity to the risks of climate change and determines the level of vulnerability. Assessment to identify levels of adaptive capacity is presented in Section 3.2.6. Adaptive capacity – the ability to adjust to climate change, to moderate potential changes, to take advantage of opportunities or to cope with negative consequences (Brown et al., 2010; Brundell et al., 2011) – is categorised by shrimp farmers as “low”, “medium”, or “high”. A low level of adaptive capacity means it is very difficult and costly to implement adaptation activities effectively or not effectively supporting shrimp farming. A medium level of adaptive capacity perceives some difficulty and expense in implementing change or should improve and conduct monitoring with some actions needed to support shrimp production. A high level of adaptive capacity is where adaptation is feasible and practical for supporting shrimp production effectively. Finally, vulnerability levels are categorised as “low”, “medium”, and “high”, derived from combining impact risk and adaptive capacity (Table 3.7) assigned by shrimp farmers and using a similar approach as that of Brundell et al. (2011) through the above vulnerability matrix.

Table 3.7: Vulnerability rating matrix to determine levels of vulnerability by combining levels of risk and adaptive capacity

Impact	**Adaptive Capacity**		
	Low	**Medium**	**High**
Extreme	High	High	Moderate
High	High	Moderate	Moderate
Medium	Moderate	Moderate	Low
Low	Low	Low	Low

3.2.8. Data analysis

All collected data and information was transcribed onto Excel worksheets and then the qualitative data were summarised, categorised, and grouped according to the techniques of Fielding and Fielding (1986), and Leedy and Ormrod (2001). The quantitative data, such as household characteristics, shrimp income, and frequency of respondents, were inputted onto Excel worksheets and converted via IBM SPSS Statistics 23.0 to descriptive statistics. AVOVA and T - tests were employed to compare different means (p = 0.01 or 0.05) among groups and in pairs of shrimp farmers in the two farming systems with the following variables: respondent age, education, family size, farming experience, income streams, shrimp area, shrimp and household income.

Meteorological data (climate parameters) obtained in Ca Mau Province include air temperature (average annual, maximum, minimum), rainfall (average annual, rainy season, dry season), and water levels in the two typical stations (average annual, maximum, minimum) during the period of 1991-2015. Shrimp production data collected comprises average annual shrimp productivity of whole province and shrimp productivity in ISMF, SSMF and RSRF for the period of 1991-2015, excepting for SSMF with the period of 2004-2015. All meteorological and shrimp production data were subjected to IBM SPSS Statistics 23.0 for descriptive statistics and a general linear model was applied to evaluate trends of air temperature, rainfall, water level, and shrimp productivity over the last 25 years. Each parameter of metrological data was tested with shrimp productivity of the whole province and in ISMF, SSMF and RSRF to evaluate whether they have significant correlations[10] ($p = 0.01$ or 0.05).

3.3. Ethics

This research was carried out in accordance with ethical guidelines for working with human participants. According to the Murdoch University Human Research Ethics Committee (HREC), research ethics approval is compulsory from Murdoch University before conducting household surveys and maintaining correspondence with participants after the field research. It is common practice when conducting research in Australian Universities that it be subjected to scrutiny and required to conform to ethical principles through HREC. These principles require research participants to provide informed consent and protect the identities of the participants unless written or in special circumstances when verbal consent is provided. The principles exist to prevent coercion of participants. The project data are required to be stored for five years after collection. The researcher may provide feedback to participants on the research (Bouma, 2000) if they require. The ethics approval for this project was assigned by HREC in October 2012 with the permit number: 2012/178. It was terminated in December 2017

[10] Test for correlation with the hypothesis that correlation coefficient value or Pearson Correlation (r) = 0 not whether or not there is a strong relationship and is highly influenced by a climate parameter on shrimp productivity. The interpretation of a correlation coefficient: weak (-0.3 to 0.3), moderate (-0.5 to -0.3 or 0.3 to 0.5), strong (-0.9 to -0.5 or 0.5 to 0.9), and very strong (-1.0 to 0.9 or 0.9 to 1.0) (Cohen, 1992).

CHAPTER 4: The Effects of Climate Change on Shrimp Farming Systems

4.1. Introduction

This chapter addresses the first research question, which is concerned with investigating the perceptions of shrimp farmers in the four shrimp farming systems and the local experts about the effects of climate change events. The questionnaire began by eliciting the general perspectives of shrimp farmers and the local experts to determine whether they identified any adverse effects of climate change on shrimp production. Questions were then asked about climate change events that had negatively affected shrimp farming in the last 10 years and would likely adversely affect it in the next 10–20 years (the future). Finally, the shrimp farmers and the local experts were asked to rank a list of climate change events according to how they most affected shrimp production. The chapter also addresses the hydro–meteorology and shrimp productivity data recorded from the last 25 years in Ca Mau Province and reports some statistics tests conducted by the research on relationship between shrimp productivity and climate parameters: air temperature, rainfall, and water level. Statistical analysis of the results on relationship between shrimp productivity and climate parameters is presented in Sections 4.3, 4.4, and 4.5 of this chapter. The final section discusses how climate change events could affect shrimp farming in the research area in the last 10 years and in the next 10–20 years.

4.2. Perceptions of climate change effects on shrimp production

Perspectives of the local experts and shrimp farmers in the four farming systems about effects of climate change events on shrimp production are presented in turn.

4.2.1. Effects of climate change events on shrimp farming have been identified by shrimp farmers and the local experts in the research area during the last 10 years (Question A.1.2.1 & A.2.2, Appendix A)

Surveys were carried out with a total of one hundred shrimp farmers and eleven local experts. The majority of respondents (83%) identified climate change in the area and perceived adverse effects on shrimp production in the last 10 years. However, responses of participants varied within the different shrimp farming systems, with 94% of farmers in integrated shrimp-mangrove farming (ISMF), 81% in separated shrimp-mangrove farming (SSMF), 72% in rice-shrimp rotation farming (RSRF), 71% of farmers in intensive shrimp farming (ISF), and 91%

of the local experts identifying climate change as having significant effects on shrimp farming (Table 4.1). It could be expected that respondents notice changes to the weather and they may know that climate change is happening in the Mekong Delta region, as the literature reviews indicated in Chapter 2. Interviewee rankings for the main climate change impacts for Ca Mau, discussed previously, follow.

Table 4.1: Perceived effects of climate change on shrimp farming in the areas in the last 10 years

Respondents	Yes		No		Not sure	
	Frequency (F)	Per cent (%)	F	Per cent (%)	F	Per cent (%)
RSRF (n=22)	17	77.3	0	0.0	5	22.7
ISMF (n=31)	29	93.5	0	0.0	2	6.5
SSMF (n=26)	21	80.8	2	7.7	3	11.5
ISF (n=21)	15	71.4	5	23.8	1	4.8
Expert (n=11)	10	90.9	0	0.0	1	9.1
Total (n=111)	92	82.9	7	6.3	12	10.8

4.2.2. Perceived adverse effects of climate change events on shrimp farming systems in Ca Mau Province in the last 10 years (Question A.1.2.2 & A.2.3, Appendix A)

4.2.2.1. Extreme climate events

Degrees of agreement of shrimp farmers on the adverse effects of extreme climate events on shrimp farming systems in the last 10 years are presented in Table 4.2. Thirty-four percent of respondents agreed that extreme climate events have negatively affected shrimp farming systems in the last 10 years; 55% disagreed and 11% of shrimp farmers were unable to identify the issue. In particular, the majority of respondents in three shrimp farming systems – 65% in RSRF, 61% in ISMF, and 67% in ISF – disagreed with the issue; while only 38% in SSMF and 36% of experts shared this view. Thus, while a majority of experts agreed that extreme climate events have already adversely affected shrimp farming in the area, the farmers themselves did not share this perception. Perhaps the greater emphasis placed by the local experts than shrimp farmers on extreme climate events was due to Linda Storm, which surged and caused serious losses to human life and property in Ca Mau Province in 1997.

Table 4.2: Extreme climate events have adversely affected shrimp farming in the last 10 years

Respondents	Strongly agree		Agree		Disagree		Strongly disagree		Unable to judge	
	F[11]	%	F	%	F	%	F	%	F	%
RSRF (n=22)	1	4.5	5	22.7	10	45.5	4	18.2	2	9.1
ISMF (n=31)	1	3.2	7	22.6	16	51.6	3	9.7	4	12.9
SSMF (n=26)	2	7.7	11	42.3	9	34.6	1	3.8	3	11.5
ISF (n=21)	1	4.8	4	19.0	11	52.4	3	14.3	2	9.5
Experts (n=11)	3	27.3	3	27.3	3	27.3	1	9.1	1	9.1
Total (n = 111)	8	7.2	30	27.0	49	44.1	12	10.8	12	10.8

4.2.2.2. Sea level rise and high tides

A high percentage of farmers in RSRF, ISMF, and SSMF had the same opinions as the experts on effects of sea level rise and high tides and believed that its effects have harmfully affected shrimp farming. Photographs capturing views of local communities showing present water levels and high tides are presented in Figure 4.1 (at the end of Section 4.2.3). However, the majority of shrimp farmers in intensive shrimp farming thought that the above issues have not affected their shrimp production much. Overall, 78% of total respondents agreed with the adverse effects of a sea level rise on shrimp farming, while 13% disagreed, and 9% of all respondents were unable to judge the issue. Moreover, 73% of shrimp farmers in RSRF, 90% in ISMF, 92% in SSMF, and 91% of the local experts agreed that sea level rise has negatively affected their shrimp farming systems in the last 10 years; in contrast, only 43% in ISF were of this perspective (Table 4.3). Perhaps the less emphasis given by shrimp farmers in ISF on this climate event than shrimp farmers in the other farming systems was because the former may have better shrimp pond construction or farming infrastructures or because their farms are further inland than shrimp farmers in RSRF, ISMF, and SSMF.

Table 4.3: Sea level rise has negatively affected shrimp production in the last 10 years

Respondents	Strongly agree		Agree		Disagree		Strongly disagree		Unable to judge	
	F	%	F	%	F	%	F	%	F	%
RSRF (n=22)	7	31.8	9	40.9	3	13.6	0	0.0	3	13.6
ISMF (n=31)	18	58.1	10	32.3	0	0.0	0	0.0	3	9.7
SSMF (n=26)	17	65.4	7	26.9	0	0.0	0	0.0	2	7.7
ISF (n=21)	3	14.3	6	28.6	10	47.6	1	4.8	1	4.8
Experts (n=11)	8	72.7	2	18.2	0	0.0	0	0.0	1	9.1
Total (n = 111)	53	47.7	34	30.6	13	11.7	1	0.9	10	9.0

[11] F: frequency

The perspectives of respondents regarding high tides are similar to perspectives concerning sea level rise. Overall, 84% of total respondents agreed that high tides are having adverse effects on shrimp production, while 14% disagreed, and 2% of all respondents were unable to judge this issue. In individual cases, 91% of farmers in RSRF, 94% in ISMF, 96% in SSMF, and 100% of the local experts agreed with the issue; however, only 42% of farmers in ISF were of the same opinion as those respondents that high tides have harmfully affected their farming systems (Table 4.4).

Table 4.4: High tides have adversely affected shrimp production in the last 10 years

Respondents	Strongly agree		Agree		Disagree		Strongly disagree		Unable to judge	
	F	%	F	%	F	%	F	%	F	%
RSRF (n=22)	10	45.5	10	45.5	2	9.1	0	0.0	0	0.0
ISMF (n=31)	21	67.7	8	25.8	0	0.0	0	0.0	2	6.5
SSMF (n=26)	17	65.4	8	30.8	1	3.8	0	0.0	0	0.0
ISF (n=21)	6	28.6	3	14.3	12	57.1	0	0.0	0	0.0
Experts (n=11)	10	90.9	1	9.1	0	0.0	0	0.0	0	0.0
Total (n = 111)	64	57.7	30	27.0	15	13.5	0	0.0	2	1.8

4.2.2.3. Seasonal pattern changes

The majority of shrimp farmers were of the view that seasonal pattern changes have adversely impacted on shrimp production. Overall, 86% of total interviewees agreed with the negative effects of rainfall pattern changes on shrimp farming, 5% disagreed, and 9% of all respondents were unable to judge the statement (Table 4.5). With respect to each farming system, 92% of farmers in SMSF, 86% in RSRF, 81% in ISMF, and 76% in ISF chose the agreed rankings. They also agreed that increased intensity or irregular rains and a drier dry season have harmfully affected their shrimp farming, but their perspectives were more variable regarding the issue of a longer dry season. Overall, 87% of all respondents agreed with the climate event of greater intensity or irregular rains, comprising respectively 82% of farmers in RSRF, 84% in ISMF, 84% in SSMF, and 86% in ISF (Table 4.6). In that order, whereas 86% of the farmers in all farming systems who were of the opinion that a drier dry season had negatively affected their shrimp production, this comprised 86% in RSRF, 77% in ISMF, 92% in SSMF, and 90% of shrimp farmers in ISF (Table 4.7). All local experts were of the same opinion as the majority of shrimp farmers on this perspective (Tables 4.5, 4.6, and 4.7).

Table 4.5: Shrimp farmers and local experts' perspectives on whether seasonal rain pattern changes have adversely affected shrimp production in the last 10 years.

Respondents	Strongly agree		Agree		Disagree		Strongly disagree		Unable to judge	
	F	%	F	%	F	%	F	%	F	%
RSRF (n=22)	14	63.6	5	22.7	2	9.1	0	0.0	1	4.5
ISMF (n=31)	6	19.4	19	61.3	1	3.2	0	0.0	5	16.1
SSMF (n=26)	16	61.5	8	30.8	1	3.8	1	3.8	0	0.0
ISF (n=21)	4	19.0	12	57.1	1	4.8	0	0.0	4	19.0
Experts (n=11)	8	72.7	3	27.3	0	0.0	0	0.0	0	0.0
Total (n = 111)	48	43.2	47	42.3	5	4.5	1	0.9	10	9.0

Table 4.6: Greater intensity or irregular rains have negatively affected shrimp production in the last 10 years

Respondents	Strongly agree		Agree		Disagree		Strongly disagree		Unable to judge	
	F	%	F	%	F	%	F	%	F	%
RSRF (n=22)	13	59.1	5	22.7	2	9.1	1	4.5	1	4.5
ISMF (n=31)	17	54.8	9	29.0	0	0.0	0	0.0	5	16.1
SSMF (n=26)	5	19.2	17	65.4	2	7.7	1	3.8	1	3.8
ISF (n=21)	11	52.4	7	33.3	3	14.3	0	0.0	0	0.0
Experts (n=11)	4	36.4	7	63.6	0	0.0	0	0.0	0	0.0
Total (n = 111)	50	45.0	45	40.5	7	6.3	2	1.8	7	6.3

Table 4.7: Drier dry seasons have negatively affected shrimp production in the last 10 years

Respondents	Strongly agree		Agree		Disagree		Strongly disagree		Unable to judge	
	F	%	F	%	F	%	F	%	F	%
RSRF (n=22)	13	59.1	6	27.3	0	0.0	1	4.5	2	9.1
ISMF (n=31)	5	16.1	19	61.3	3	9.7	0	0.0	4	12.9
SSMF (n=26)	14	53.8	10	38.5	2	7.7	0	0.0	0	0.0
ISF (n=21)	16	76.2	3	14.3	0	0.0	0	0.0	2	9.5
Experts (n=11)	6	54.5	5	45.5	0	0.0	0	0.0	0	0.0
Total (n = 111)	54	48.6	43	38.7	5	4.5	1	0.9	8	7.2

The degree of shrimp farmers' perspectives on the adverse effects of a longer dry season on shrimp production varied considerably: 65% of farmers in ISMF agreed with the issue, which was the same opinion of 18% of experts; but 71% in ISF disagreed; while 54% of people in SSMF were unable to judge the issue; whereas, the percentage of respondents in RSRF was shared among degrees of agreement. Overall, 38% of all respondents agreed with the statement, 42% disagreed, and 21% of all interviewees were unable to judge (Table 4.8). The greatest concern given by shrimp farmers in ISF who disagreed with the issue was because ISF farmers may have frequently accessed updated weather forecast for their intensive shrimp ponds and identified the rainy seasonal changes with increasing intensity or irregular rain as perceived by the majority of respondents in Tables 4.5 and 4.6. A number of ISMF farmers noted that the question regarding the adverse effects of a longer dry season could be related to two types of change weather; the occurrence of irregular but unusually hot weather periods during the dry season and extension to the overall length of the dry season. This dual interpretation may explain the variability in farmer responses between the four farming systems, such as the majority of SSMF farmers who were unable to judge the issue.

Table 4.8: Shrimp farmers and local experts' perspectives on whether effects of a longer dry season have negatively affected shrimp production in the last 10 years.

Respondents	Strongly agree		Agree		Disagree		Strongly disagree		Unable to judge	
	F	%	F	%	F	%	F	%	F	%
RSRF (n=22)	5	22.7	4	18.2	4	18.2	4	18.2	5	22.7
ISMF (n=31)	2	6.5	18	58.1	7	22.6	4	12.9	0	0.0
SSMF (n=26)	1	3.8	5	19.2	4	15.4	2	7.7	14	53.8
ISF (n=21)	0	0.0	6	28.6	5	23.8	10	47.6	0	0.0
Experts (n=11)	0	0.0	2	18.2	4	36.4	1	9.1	4	36.4
Total (n = 111)	8	7.2	35	31.5	24	21.6	21	18.9	23	20.7

4.2.2.4. Temperature increase

Overall, most shrimp farmers agreed that increasing fluctuations of temperature (75%) and salinity (68%) in the shrimp ponds were adversely affecting production (Table 4.9). Regarding temperature, 73% of farmers in RSRF, 65% in ISMF, 81% in SSMF, and 81% in ISF agreed with this climate change impact; while in relation to salinity fluctuation, the distribution was respectively 73% in RSRF, 61% in ISMF, 77% in SSMF, and 62% in ISF (Table 4.10). Regarding local expert perspectives, the majority of experts were of this perspective, corresponding to 82% for temperature and 73% for salinity (Table 4.10).

Table 4.9: Increase of temperature fluctuations has negatively affected shrimp production in the last 10 years

Respondents	Strongly agree		Agree		Disagree		Strongly disagree		Unable to judge	
	F	%	F	%	F	%	F	%	F	%
RSRF (n=22)	12	54.5	4	18.2	2	9.1	0	0.0	4	18.2
ISMF (n=31)	2	6.5	18	58.1	4	12.9	0	0.0	7	22.6
SSMF (n=26)	4	15.4	17	65.4	1	3.8	0	0.0	4	15.4
ISF (n=21)	10	47.6	7	33.3	0	0.0	0	0.0	4	19.0
Experts (n=11)	3	27.3	6	54.5	1	9.1	0	0.0	1	9.1
Total (n = 111)	31	27.9	52	46.8	8	7.2	0	0.0	20	18.0

Table 4.10: Increase of salinity fluctuations has adversely affected shrimp production in the last 10 years

Respondents	Strongly agree		Agree		Disagree		Strongly disagree		Unable to judge	
	F	%	F	%	F	%	F	%	F	%
RSRF (n=22)	10	45.5	6	27.3	2	9.1	0	0.0	4	18.2
ISMF (n=31)	2	6.5	17	54.8	1	3.2	0	0.0	11	35.5
SSMF (n=26)	1	3.8	19	73.1	2	7.7	1	3.8	3	11.5
ISF (n=21)	0	0.0	13	61.9	6	28.6	2	9.5	0	0.0
Experts (n=11)	2	18.2	6	54.5	2	18.2	0	0.0	1	9.1
Total (n = 111)	15	13.5	61	55.0	13	11.7	3	2.7	19	17.1

4.2.2.5. Water quality decrease in the shrimp ponds

A majority of farmers in all farming systems (75%) agreed that water quality has decreased in shrimp ponds and affected shrimp farming over the last 10 years. Referring to the farming perspectives, 87% in ISMF, 85% in SSMF, 64% in RSRF, 57% in ISF believed this view. Regarding the expert perspectives, 82% agreed, 12% disagreed, and 13% were unable to judge the issue (Table 4.11).

Table 4.11: Water quality decrease in the shrimp ponds has negatively affected shrimp production in the last 10 years.

Respondents	Strongly agree		Agree		Disagree		Strongly disagree		Unable to judge	
	F	%	F	%	F	%	F	%	F	%
RSRF (n=22)	11	50.0	3	13.6	3	13.6	3	13.6	2	9.1
ISMF (n=31)	19	61.3	8	25.8	4	12.9	0	0.0	0	0.0
SSMF (n=26)	2	7.7	20	76.9	1	3.8	0	0.0	3	11.5
ISF (n=21)	0	0.0	12	57.1	0	0.0	0	0.0	9	42.9
Experts (n=11)	2	18.2	7	63.6	2	18.2	0	0.0	0	0.0
Total (n = 111)	34	30.6	50	45.0	10	9.0	3	2.7	14	12.6

4.2.3. The five climate change events that have mostly affected shrimp farming in the last 10 years as ranked by shrimp farmers and the local experts (Question A.1.2.3 & A.2.4, Appendix A)

Shrimp farmers in each farming system and the local experts identified the five most important climate change events and consequences to negatively affect shrimp farming, as shown in Table 4.12. The list of climate change events that interviewees were presented with when answering this question comprised: greater intensity or irregular rains, seasonal pattern changes, high tides, sea level rise, drier dry season, fluctuations of water temperature and salinity. The issue of greater intensity or irregular rains was ranked as the most important problem by shrimp farmers in RSRF, ISMF, and in ISF; the second most important by shrimp farmers in SSMF; and the third most by the experts. Seasonal pattern changes were ranked as the second most important by shrimp farmers in RSRF and the experts, the third most in both shrimp farmers in ISMF and SSMF, and the fourth in ISF. High tides were ranked as the second most important issue in ISMF, the third most in RSRF, and the fourth in SSMF and by the experts. A drier dry season was ranked as the third most important issue by shrimp farmers in ISF, the fourth most in RSRF, and the fifth in ISMF. Increased fluctuation of water temperature was considered to be the most important issue by experts, the second most by shrimp farmers in ISF and the fifth by shrimp farmers in RSRF. Sea level rise was the highest concern only for farmers in mangrove areas (SSMF), being otherwise only ranked fourth in ISMF, and fifth by Experts. Overall shrimp farmers placed greater emphasis on increased intensity or irregular rains than the local experts, perhaps because they acknowledged that seasonal pattern changes recently directly affected their shrimp farms based on traditional knowledge they recognised the transition point between two seasons. However, perhaps greater emphasis by the local experts on fluctuations of water temperature was because the fluctuations directly affected shrimp growth, and they (the experts) may have access to updated current knowledge on climate change impacts in the region.

Table 4.12: A ranking of the five most important climate changes and consequences to have adversely affected shrimp production in the last 10 years

Climate change events/Consequences	**Ranking**				
	RSRF	ISMF	SSMF	ISF	Experts
Greater intensity or irregular rains	1	1	2	1	3
Seasonal pattern changes	2	3	3	4	2
Increased intensity of high tides	3	2	4		4
Drier dry season	4	5		3	
Sea level rise		4	1		5
Increased fluctuations of water temperature	5			2	1
Increased fluctuations of salinity			5		

Village on river in Dat Mui Commune

High tide: water covers the road

Travel by dinghy in Tan Duyet Commune

River bank breach/erosion

A village path in Phong Dien Commune

A collapsed path to a village in Tam Giang Dong Commune

Refuelling a motorbike (limited infrastructure)

A new sluice gate for shrimp farming under construction

Figure 4.1: Photographs of local communities showing present water levels and high tides in the research area (Source: Author photo)

4.2.4. Perceived impacts of climate change events on shrimp farming systems in Ca Mau Province in the next 10–20 years (Question 1.2.4 & A.2.5, Appendix A)

Surveys were also carried out with the same questionnaire as for the participants as in section 4.2.3; however, this time focus was on perspectives of farmers and the local experts in the future, being the next 10–20 years. The survey results are presented below.

4.2.4.1. Extreme climate events

Degrees of respondent perspectives on prediction of adverse effects of extreme climate events on shrimp production in the next 10–20 years are presented in Table 4.13. Overall, 71% of all respondents predicted that extreme climate events would have more adverse impacts on shrimp production, while 15% disagreed, and 14% of total respondents were unable to judge the issue. Regarding each farming system, 59% of shrimp farmers in RSRF agreed with the statement, and, respectively, 74% in ISMF, 81% in SSMF, and 66% in ISF. Regarding local experts, 55% were of the same opinion as the shrimp farmers above. However, nearly a quarter of respondents in RSRF (23%) were unable to judge the issue, compared with 18% of experts, 14% in ISF, 13% in ISMF, and 4% in SSMF.

Table 4.13: The percentage of respondents who considered that extreme climate events would negatively affect shrimp farming in the next 10–20 years

Respondents	Strongly agree		Agree		Disagree		Strongly disagree		Unable to judge	
	F	%	F	%	F	%	F	%	F	%
RSRF (n=22)	3	13.6	10	45.5	3	13.6	1	4.5	5	22.7
ISMF (n=31)	8	25.8	15	48.4	4	12.9	0	0.0	4	12.9
SSMF (n=26)	4	15.4	17	65.4	3	11.5	1	3.8	1	3.8
ISF (n=21)	5	23.8	9	42.9	4	19.0	0	0.0	3	14.3
Experts (n=11)	2	18.2	4	36.4	3	27.3	0	0.0	2	18.2
Total (n = 111)	22	20.0	55	51.0	17	14.0	2	1.0	15	14.0

4.2.4.2. Sea level rise and high tides

A high percentage of total respondents agreed that sea level rise and increased intensity of high tides would negatively affect shrimp production in the next 10–20 years. Overall, 89% of respondents agreed on the matter of sea level rise, while 74% of participants agreed on the issue of high tides. Particularly, regarding sea level rise, the majority of respondents believed that a sea level rise would adversely affect their shrimp production in the future, with 86% of farmers in RSRF, 97% in ISMF, 96% in SSMF, 71% in ISF, and 91% of the experts who agreed with the above issue (Table 4.14). Similar to sea level rise, the negative impacts of increased intensity of high tides were noted by the majority of respondents, comprising 86% of shrimp farmers in RSRF, 77% in ISMF, 100% in SSMF, 76% in ISF, and 82% of the experts (Table 4.15).

Table 4.14: The percentage of respondents who considered that increases in sea and river water levels would adversely affect shrimp production in the next 10–20 years

Respondents	Strongly agree		Agree		Disagree		Strongly disagree		Unable to judge	
	F	%	F	%	F	%	F	%	F	%
RSRF (n=22)	8	36.4	11	50.0	2	9.1	0	0.0	1	4.5
ISMF (n=31)	12	38.7	18	58.1	0	0.0	0	0.0	1	3.2
SSMF (n=26)	19	73.1	6	23.1	0	0.0	0	0.0	1	3.8
ISF (n=21)	8	38.1	7	33.3	2	9.5	0	0.0	4	19.0
Experts (n=11)	10	90.9	0	0.0	0	0.0	0	0.0	1	9.1
Total (n = 111)	57	51.4	42	37.8	4	3.6	0	0.0	8	7.2

Table 4.15: The percentage of respondents who considered that increased intensity of high tides would negatively affect shrimp production in the next 10–20 years

Respondents	Strongly agree		Agree		Disagree		Strongly disagree		Unable to judge	
	F	%	F	%	F	%	F	%	F	%
RSRF (n=22)	8	36.4	11	50.0	1	4.5	1	4.5	1	4.5
ISMF (n=31)	17	54.8	7	22.6	2	6.5	0	0.0	5	16.1
SSMF (n=26)	16	61.5	10	38.5	0	0.0	0	0.0	0	0.0
ISF (n=21)	9	42.9	7	33.3	3	14.3	1	4.8	1	4.8
Experts (n=11)	7	63.6	2	18.2	2	18.2	0	0.0	0	0.0
Total (n = 111)	57	51.4	37	33.3	8	7.2	2	1.8	7	6.3

4.2.4.3. Seasonal pattern changes

There was a high degree of agreement from all respondents that seasonal rain pattern changes and greater intensity or irregular rains would adversely impact shrimp production in the next 10–20 years. Overall, 85% of all respondents agreed that a change in rainy season patterns would negatively affect shrimp production; correspondingly, 91% in RSRF, 81% in ISMF, 100% in SSMF, 76% in ISF, and 100% of the experts agreed with the statement (Table 4.16). Regarding the negative impacts of greater intensity or irregular rains, 83% of all respondents in the four shrimp farming systems and the experts agreed with this issue, compared with 77% in RSRF, 81% in ISMF, 85% in SSMF, 81% of shrimp farmers in ISF, and 100% of the experts (Table 4.17).

Table 4.16: Shrimp farmers and local experts' perspectives on whether a change in rainy season patterns would adversely affect shrimp production in the next 10–20 years

Respondents	Strongly agree		Agree		Disagree		Strongly disagree		Unable to judge	
	F	%	F	%	F	%	F	%	F	%
RSRF (n=22)	13	59.1	7	31.8	1	4.5	0	0.0	1	4.5
ISMF (n=31)	5	16.1	20	64.5	6	19.4	0	0.0	0	0.0
SSMF (n=26)	17	65.4	9	34.6	0	0.0	0	0.0	0	0.0
ISF (n=21)	4	19.0	12	57.1	2	9.5	0	0.0	3	14.3
Experts (n=11)	9	81.8	2	18.2	0	0.0	0	0.0	0	0.0
Total (n = 111)	48	43.2	50	45.0	9	8.1	0	0.0	4	3.6

Table 4.17: Shrimp farmers and local experts' perspectives on whether a greater intensity or irregular rains would adversely affect shrimp production in the next 10–20 years

Respondents	Strongly agree		Agree		Disagree		Strongly disagree		Unable to judge	
	F	%	F	%	F	%	F	%	F	%
RSRF (n=22)	12	54.5	5	22.7	2	9.1	0	0.0	3	13.6
ISMF (n=31)	8	25.8	17	54.8	0	0.0	0	0.0	6	19.4
SSMF (n=26)	3	11.5	19	73.1	0	0.0	2	7.7	2	7.7
ISF (n=21)	7	33.3	10	47.6	4	19.0	0	0.0	0	0.0
Experts (n=11)	2	18.2	9	81.8	0	0.0	0	0.0	0	0.0
Total (n = 111)	32	28.8	60	54.1	6	5.4	2	1.8	11	9.9

However, different levels of agreement were apparent across respondents concerning whether the dry season would last longer and negatively affect shrimp production in the next 10–20 years (Table 4.18). In total, 24% of all respondents agreed with the statement, 43% disagreed, and 33% were unable to judge. Regarding each shrimp farming system, 23% of shrimp farmers in RSRF agreed, 36% disagreed, and 41% were unable to judge the above issue; respectively, 26%, 58%, and 16% in ISMF; 27%, 27%, and 46% in SSMF; 24%, 43%, and 33% in ISF; compared with 18%, 55%, and 32% of the experts. Overall, the majority of shrimp farmers in ISMF and the local experts did not perceive the dry season would be longer and adversely impact shrimp production. It is interesting that there were opposite perspectives of shrimp farmers in ISMF about adverse effects of a longer dry season on their shrimp production in the past 10 years (Table 4.8) and in the future (Table 4.18) and there was a high percentage of respondents who were unable to judge the statement (Table 4.18). Taken together the research results indicate that while the majority of shrimp farmers were not concerned about potential adverse effects of a longer dry season, most of farmers believed that seasonal pattern changes and increased intense or irregular rain (as shown in Tables 4.16, 4.17) will negatively impact their shrimp production. This means that changes in rainfall expect are expected to strongly affect shrimp farming in the future.

Table 4.18: Shrimp farmers and local experts' perspectives on whether a longer dry season would adversely affect shrimp production in the next 10–20 years

Respondents	Strongly agree		Agree		Disagree		Strongly disagree		Unable to judge	
	F	%	F	%	F	%	F	%	F	%
RSRF (n=22)	0	0.0	5	22.7	6	27.3	2	9.1	9	40.9
ISMF (n=31)	1	3.2	7	22.6	16	51.6	2	6.5	5	16.1
SSMF (n=26)	1	3.8	6	23.1	6	23.1	1	3.8	12	46.2
ISF (n=21)	0	0.0	5	23.8	6	28.6	3	14.3	7	33.3
Experts (n=11)	0	0.0	2	18.2	2	18.2	4	36.4	3	27.3
Total (n = 111)	2	1.8	25	22.5	36	32.4	12	10.8	36	32.4

4.2.4.4. Temperature increase

The majority of respondents perceived that temperature increases through a drier dry season, increased fluctuations of water temperature and that salinity would negatively affect shrimp production in the next 10–20 years. Overall, 85% of respondents agreed that shrimp production would be adversely affected by a drier dry season in the next 10–20 years, compared with 84% on the issue of increased fluctuations of water temperature, and 80% on salinity. Regarding each issue, 82% of shrimp farmers in RSRF agreed that a drier dry season would negatively affect shrimp production, which is the same opinion as 81% of farmers in ISMF, 96% in SSMF, and 81% in ISF (Table 4.19). As regards the increase in water temperature fluctuations, 82% of shrimp farmers in RSRF, 90% in ISMF, 69% in SSMF, and 91% of farmers in ISF agreed with the statement (Table 4.21). For the increased fluctuations of salinity, the same point was apparent that the majority of farmers in all farming systems agreed with the issue, with 77% in RSRF, 90% in RSMF, 58% in SSMF, and 86% in ISF (Table 4.20). Finally, most local experts were of the same majority opinion as all shrimp farmers, with 82% of the experts agreeing with the issue of a drier dry season, 91% with fluctuations of water temperature, and all experts increased there would be increased negative effects of salinity fluctuations on shrimp production.

Table 4.19: Shrimp farmers and local experts' perspectives on whether a drier dry season would negatively affect shrimp production in the next 10–20 years

Respondents	Strongly agree		Agree		Disagree		Strongly disagree		Unable to judge	
	F	%	F	%	F	%	F	%	F	%
RSRF (n=22)	11	50.0	7	31.8	1	4.5	0	0.0	3	13.6
ISMF (n=31)	10	32.3	15	48.4	6	19.4	0	0.0	0	0.0
SSMF (n=26)	14	53.8	11	42.3	1	3.8	0	0.0	0	0.0
ISF (n=21)	13	61.9	4	19.0	2	9.5	0	0.0	2	9.5
Experts (n=11)	2	18.2	7	63.6	1	9.1	0	0.0	1	9.1
Total (n = 111)	50	45.0	44	39.6	11	9.9	0	0.0	6	5.4

Table 4.20: The percentage of respondents who contended that an increase in fluctuations of salinity would adversely affect shrimp production in the next 10–20 years

Respondents	Strongly agree		Agree		Disagree		Strongly disagree		Unable to judge	
	F	%	F	%	F	%	F	%	F	%
RSRF (n=22)	9	40.9	8	36.4	3	13.6	0	0.0	2	9.1
ISMF (n=31)	11	35.5	17	54.8	3	9.7	0	0.0	0	0.0
SSMF (n=26)	0	0.0	15	57.7	4	15.4	1	3.8	6	23.1
ISF (n=21)	4	19.0	14	66.7	3	14.3	0	0.0	0	0.0
Experts (n=11)	1	9.1	10	90.9	0	0.0	0	0.0	0	0.0
Total (n = 111)	25	22.5	64	57.7	13	11.7	1	0.9	8	7.2

Table 4.21: The percentage of respondents who agreed that an increase in fluctuations of water temperature would adversely affect shrimp production in the next 10–20 years

Respondents	Strongly agree		Agree		Disagree		Strongly disagree		Unable to judge	
	F	%	F	%	F	%	F	%	F	%
RSRF (n=22)	10	45.5	8	36.4	1	4.5	3	13.6	0	0.0
ISMF (n=31)	0	0.0	28	90.3	3	9.7	0	0.0	0	0.0
SSMF (n=26)	2	7.7	16	61.5	2	7.7	0	0.0	6	23.1
ISF (n=21)	3	14.3	16	76.2	1	4.8	0	0.0	1	4.8
Experts (n=11)	2	18.2	8	72.7	0	0.0	0	0.0	1	9.1
Total (n = 111)	17	15.3	76	68.5	7	6.3	3	2.7	8	7.2

4.2.4.5. Decrease of water quality in the shrimp pond

The majority of respondents identified that weather changes would lead to adverse effects of water quality and decreased shrimp production in the future. For instance, 68% of all respondents agreed and strongly agreed with the issue, consisting of 73% in RSRF, 61% in RSMF, 81% in SSMF, 52% in ISF, and 82% of local experts who also supported this point of view. The perspectives of farmers and experts on the adverse effects of water quality as a result of weather changes are presented in Table 4.22.

Table 4.22: The percentage of respondents who predicted that weather changes would cause a decrease in water quality in shrimp ponds and negatively affect shrimp production in the next 10–20 years

Respondents	Strongly agree		Agree		Disagree		Strongly disagree		Unable to judge	
	F	%	F	%	F	%	F	%	F	%
RSRF (n=22)	7	31.8	9	40.9	4	18.2	0	0.0	2	9.1
ISMF (n=31)	6	19.4	13	41.9	7	22.6	0	0.0	5	16.1
SSMF (n=26)	4	15.4	17	65.4	2	7.7	1	3.8	2	7.7
ISF (n=21)	2	9.5	9	42.9	6	28.6	0	0.0	4	19.0
Experts (n=11)	3	27.3	6	54.5	1	9.1	0	0.0	1	9.1
Total (n = 111)	22	19.8	54	48.6	20	18.0	1	0.9	14	12.6

4.2.5. The five climate change events that would most affect shrimp farming in the next 10–20 years as ranked by shrimp farmers and local experts (Question A.1.2.5 & A.2.6, Appendix A)

The five climate change events and the likely consequences are presented in Table 4.23. The events identified comprised seasonal pattern changes, increased intensity of high tides, greater intensity or irregular rains, extreme climate events, sea level rise, drier dry seasons, and an increase in water temperature fluctuations. Generally, greater intensity or irregular rains and extreme climate events were a concern for all five groups; seasonal pattern changes and sea level rise were noted by four groups; increased intensity of high tides was acknowledged by three groups; and drier dry seasons and increased fluctuations of water temperature concerned two groups.

First, seasonal pattern changes were ranked as the most important impact on shrimp production by shrimp farmers in RSRF and by the experts, while it was the third in ISF and the fifth in SSMF. Second, increased intensity of high tides only concerned shrimp farmers in the mangrove forest areas and the experts; it was ranked as the most important issue in ISMF and SSMF, and the fourth most important impact for local experts. Third, greater intensity or irregular rains was perceived by all groups and ranked as the most important impact in ISF, the second most important in ISMF and SSMF, and the fifth in RSRF and by the experts. Fourth, respondents in all groups were concerned by extreme climate events and it was ranked as the third most important impact in RSRF, ISMF, SSMF, and by the experts, and the fourth in ISF. Fifth, sea level rise was ranked as the second most important impact in RSRF and by the experts, the fourth in SSMF, and the least impact in ISMF. Sixth, drier dry seasons was ranked as the second most important in ISF and the fourth in RSRF. Finally, an increase in temperature fluctuations was ranked as the fourth most important impact in ISF and the fifth in ISMF on their shrimp production. Overall, shrimp farmers in mangrove areas (ISMF and SSMF) were concerned about the effects of high tides the most; whereas farmers in RSRF and the experts mostly worried about seasonal pattern changes; but inhabitants in ISF perceived greater intensity or irregular rains as the most important impact on shrimp production in the next 10–20 years

Table 4.23: A ranking of the five most important climate change events and consequences that would adversely affect shrimp production in the next 10–20 years

Climate change issues	Ranking				
	RSRF	ISMF	SSMF	ISF	Experts
Seasonal pattern changes	1		5	3	1
Increased intensity of high tides		1	1		4
Greater intensity or irregular rains	5	2	2	1	5
Extreme climate events	3	3	3	4	3
Sea level rise	2	5	4		2
Drier dry season	4			2	
Increased fluctuations of water temperature		4		5	

4.3. Ca Mau hydro–meteorological data recorded from 1991 to 2015

4.3.1. Air temperature (°C) in Ca Mau Province in the last 25 years

Scatterplots in Figures 4.2, 4.3, 4.4, and Table 4.24 show a positive linear relationship of average annual air temperature (T. average) and of average annual minimum air temperature (T. min) over the last 25 years at the 0.05 significance level, while there was found no linear relationship of average annual maximum air temperature (T. max) during this period. A significant linear relationship was found in T. average [f(1, 23) = 30.56, $p < 0.001$] with $R^2 = 0.57$ and in T. min [f(1,23) = 46.65, $p < 0.001$) with $R^2 = 0.67$. The data analysis revealed that there was a rise of 0.9°C in T. average during this period (Figure 4.2). This is consistent with climate change predictions and observations of MONRE (2012). Nevertheless, T. min has increased more rapidly than T. max, with a rise of 1.6°C (Figure 4.4), while T. max has likely not changed over the last 25 years (Figure 4.3). This tended to reduce the range between T. max and T. min to around T. average, but T. max was more likely fluctuated during the period of 1991–2015.

Table 4.24: Summary results of the simple linear regression test for air temperature over the last 25 years (dependent variable: years)

	Summary of the Simple Linear Regression Models								
	ANOVA				Coefficients				Sig.
					Standardized Coefficients		Standardized Coefficients	t	
	R^2	df1	df2	F	B	SE	Beta (b)		
T. average	.571	1	23	30.56	13.92	2.518	.755	5.53	.000
T. max	.007	1	23	.161	-1.84	4.59	-.083	-.401	.692
T. min	.670	1	23	46.65	10.36	1.52	.818	6.83	.000

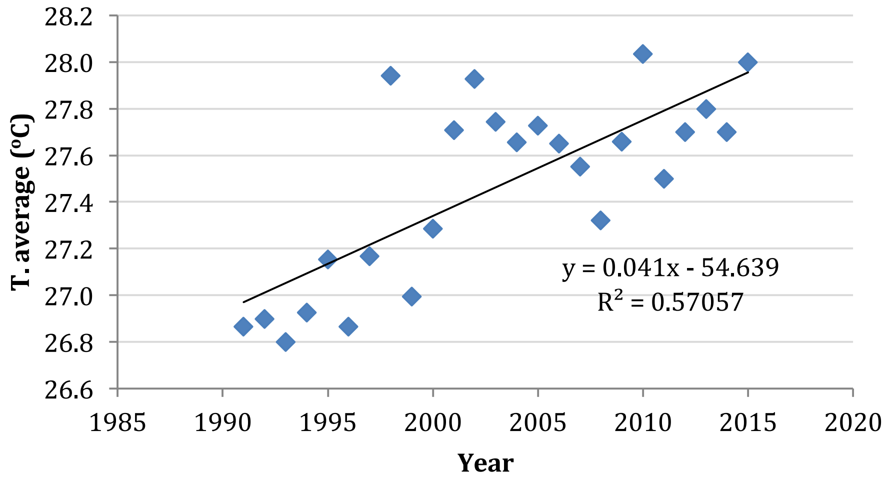

Figure 4.2: Average annual air temperature (ºC) in Ca Mau Province from 1991–2015

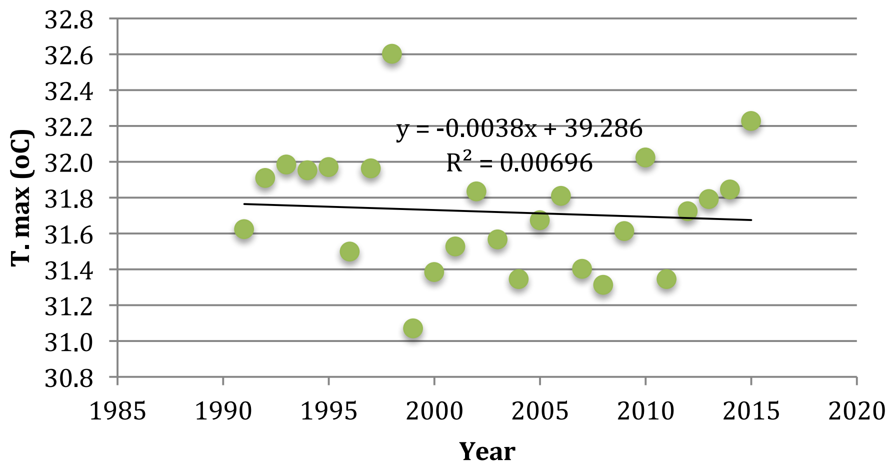

Figure 4.3: Average annual maximum air temperature (ºC) in Ca Mau Province from 1991–2015

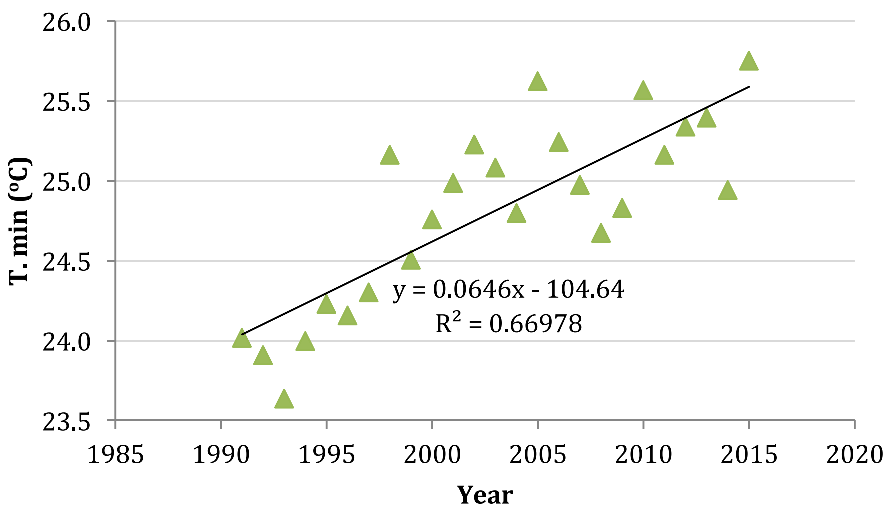

Figure 4.4: Average annual minimum air temperature (ºC) in Ca Mau Province from 1991–2015

4.3.2. Rainfall (mm) in Ca Mau Province from 1991 to 2015

As displayed in Figures 4.5, 4.6, 4.7, and Table 2.25, there was a negative linear relationship of average annual rainfall and of rainfall in the rainy season over the last 25 years at the 0.05 significance level, while there was found no linear relationship of rainfall in the dry season during this period. A significant linear relationship was found in the average annual rainfall [f(1, 23) = 5.84, p = 0.024] with R^2 = 0.203 and in rainfall in the rainy season [f(1,23) = 19.18, p < 0.001) with R^2 = 0.455. The data analysis shows the average annual rainfall has decreased by 380 mm in the 25–year period, relatively 15 mm/year (Figure 4.5). The average rainfall in the rainy season has decreased by 87 cm in this period, comparatively 3.5 mm/year (Figure 4.6); while the average rainfall in the dry season has slightly increased by 15 mm over the last 25 years, relatively 0.6 mm/year (Figure 4.7). However, rainfall in the dry season has fluctuated more than average annual rainfall and in the rainy season during this period. The rainfall in the dry season in 1999 was especially abnormal; it increased to triple times the previous year, from 87 mm to 217 mm (Figure 4.7). Therefore, the average annual rainfall in 1999 was the highest over the last 25 years, up to 3,550 mm/year.

Table 4.25: Summary results of the simple linear regression for rainfall over the last 25 years in Ca Mau Province (dependent variable: years)

	Summary of Linear Regression								
	ANOVA				Coefficients				Sig.
					Standardized Coefficients		Standardized Coefficients	t	
	R^2	df1	df2	F	B	SE	Beta (b)		
Average Annual Rainfall	.203	1	23	5.84	-.010	.004	-.450	-.242	.024
Rainy Season Rainfall	.455	1	23	19.18	-.145	.033	-.674	-4.38	.000
Dry Season Rainfall	.003	1	23	.066	.012	.045	.053	.275	.800

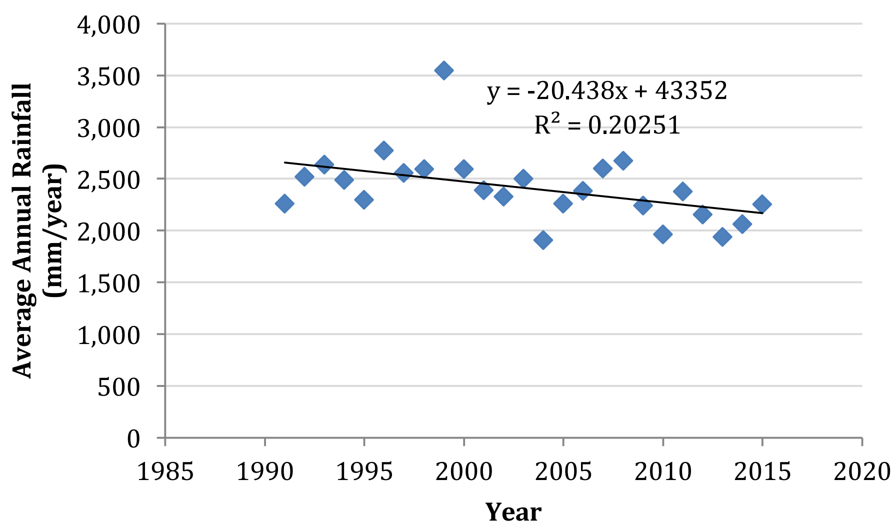

Figure 4.5: Average annual rainfall in Ca Mau Province from 1991–2015

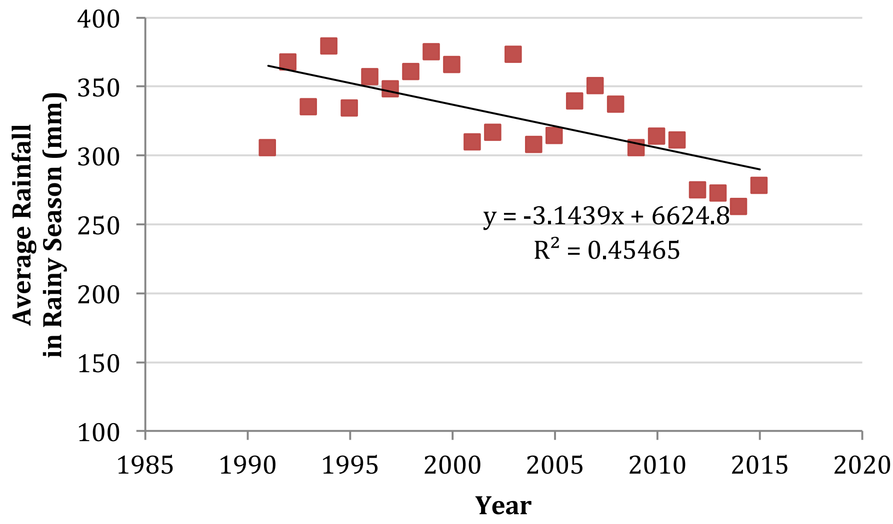

Figure 4.6: Average rainfall of the rainy season in Ca Mau Province from 1991–2015

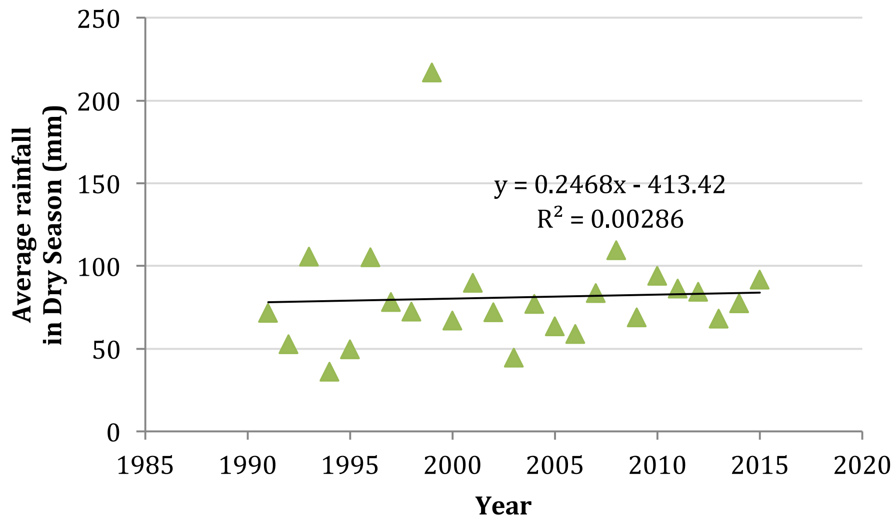

Figure 4.7: Average rainfall of the dry season in Ca Mau Province from 1991–2015

4.3.3. Water level (mm) in Ca Mau Province from 1991 to 2015

There are two hydrological stations to measure the water level in Ca Mau Province: Doc River Station placed on the Doc River in the west coastal area, which is regulated by the tidal regime of the West Sea; and Nam Can Station placed on the Cua Lon River in the east coastal area, which is regulated by the tidal regime of the East Sea. The following data presents the water levels in cm based on the national elevation system VN 2000 (Vn2000).

4.3.3.1. Water levels at Doc River Station from 1991 to 2015 (cm, Vn2000)

Table 4.26 shows a simple linear regression conducted to examine the relationship of the water level in Doc River (average annual water level– H. average, average maximum water level– H. max, average minimum water level– H. min) for the 25-year period in H. max and for the 20-year period in H. average and H. min. A positive linear relationship of H. average, H. max, and of H. min over the period investigated at the 0.05 significance level was recorded. The simple regression model with H. average produced $R^2 = 0.805$, $f(1, 18) = 74.46$, $p < 0.001$, with H. max made $R^2 = 0.795$, $f(1, 23) = 89.31$, $p < 0.001$, and with H. min produced $R^2 = 0.854$, $f(1, 18) = 104.9$, $p < 0.001$. Data recorded in Doc River Station show that H. average was increased by 2.5 cm, relatively 1.2 mm/year during the period of 1995–2015 (Figure 4.8); H. min rose by 20 cm in the period of 1995–2015 or 8 mm/year (Figure 4.9) and H. max increased by 35 cm during the last 25 years, relatively 14 mm/year (Figure 4.10). Overall water levels in Doc River Station were influenced by tidal movement in the West Sea, and their increase was statistically significant over the last 25 years, and H. max increased greater than H. min.

Table 4.26: Summary results of the simple linear regression for water level in Doc River Station over the last 25 years in H. max, 20 years in H. average and H. min (dependent variable: years)

	Summary of Linear Regression								
	ANOVA				Coefficients				Sig.
					Standardized Coefficients		Standardized Coefficients	t	
	R^2	df1	df2	F	B	SE	Beta (b)		
H. average in Doc River	.805	1	18	74.46	.781	.091	.897	8.63	.000
H. max in Doc River	.795	1	23	89.31	.537	.057	.892	9.45	.000
H. min in Doc River	.854	1	18	104.9	.686	.067	.924	10.24	.000

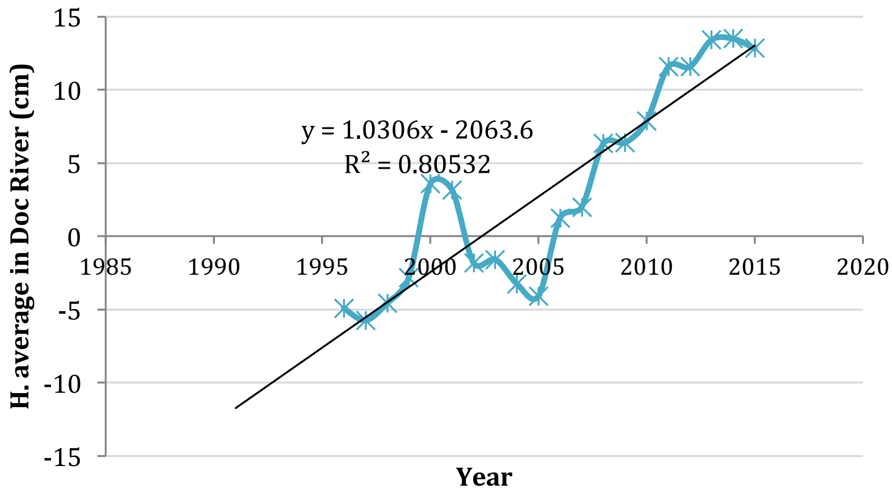

Figure 4.8: Average annual water level (H. average) in Doc River Station from 1995–2015

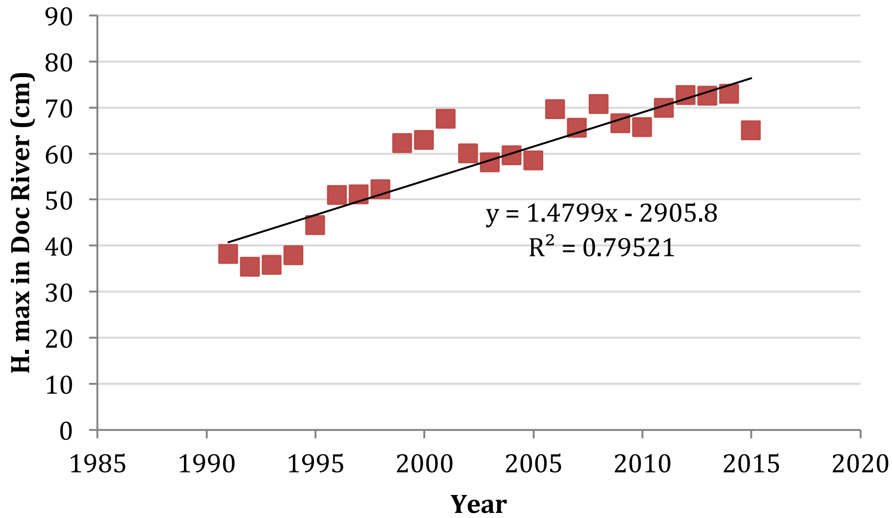

Figure 4.9: Average maximum water level (H. max) in Doc River Station from 1991–2015

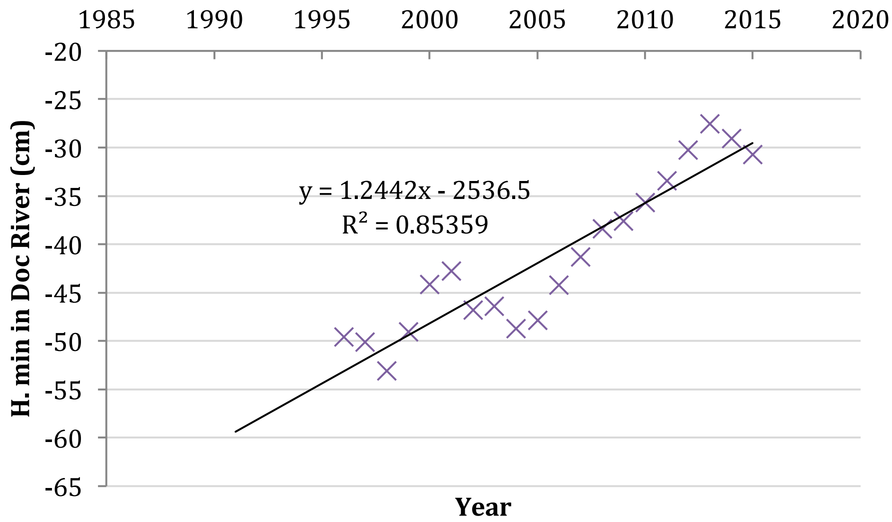

Figure 4.10: Average minimum water level (H. min) in Doc River Station from 1995–2015

4.3.3.2. Water levels at Nam Can Station from 1991 to 2015 (cm, Vn2000)

Figures 4.11, 4.12, 4.13, and Table 2.27 display a positive linear relationship of average annual water level (H. average) and of average maximum water level in Nam Can Station (H. max) over the last 25 years at the 0.05 significance level, while there was no linear relationship of average minimum water level (H. min) during this period at the 0.05 level of significance. A statistically significant linear relationship was found in H. average [f(1, 19) = 85.36, $p < 0.001$] with $R^2 = 0.818$ and in H. max [f(1,23) = 219.2, $p < 0.001$) with $R^2 = 0.927$ (Table 4.27). The data analysis shows that H. max significantly increased by 55 cm over the last 25 years, comparatively 22 mm/year. H. average has significantly increased by 23 cm in the period of 1995–2017, relatively to 1.1 mm/year. Meanwhile, H. min insignificantly rose by 15 cm during the period of 1991–2017 or 0.6 mm/year and it had fluctuations. In general, water levels in Nam Can Station where regulated by tidal movement in the East Sea, and their increase was statistically significant (H. average and H. max) and were found to have a very strong positive linear relationship with the 25–year period.

Table 4.27: Summary results of the simple linear regression for Nam Can Station over the last 25 years in H. max, 20 years in H. average and H. min (dependent variable: years)

	Summary of Linear Regression								
	ANOVA				Coefficients				
					Standardized Coefficients		Standardized Coefficients	t	Sig.
	R^2	df1	df2	F	B	SE	Beta (b)		
H. average in Nam Can	.818	1	19	85.36	.918	.099	.904	9.24	.000
H. max in Nam Can	.927	1	23	291.2	.493	.029	.963	17.07	.000
H. min in Nam Can	.182	1	19	4.22	.283	.138	.426	2.05	.054

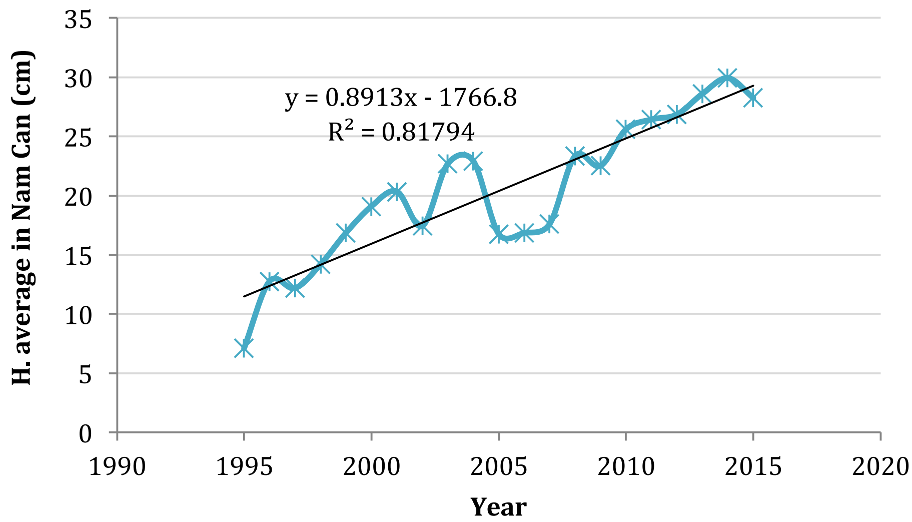

Figure 4.11: Average annual water level (H. average) in Nam Can Station 1995–2015

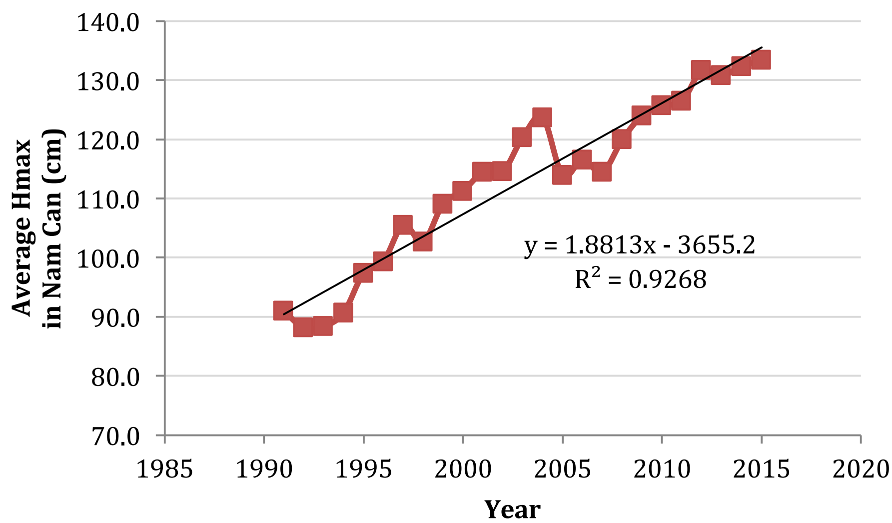

Figure 4.12: Average maximum water level (H. min) in Nam Can Station 1991–2015

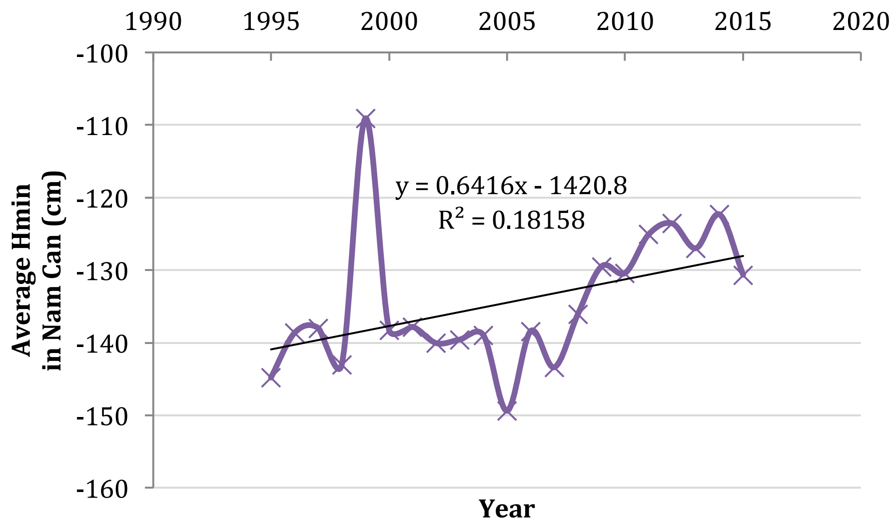

Figure 4.13: Average minimum water level (H. min) in Nam Can Station 1995–2015

4.4. Ca Mau shrimp production recorded from 1991 to 2015

Annual average shrimp productivity was derived from dividing average shrimp production by shrimp farming area in the Ca Mau Province obtained from DARD (2016) and Ca Mau annual statistics reports, Ca Mau Statistics Office (2016). Shrimp productivity in the whole province, in ISMF, SSMF, and in RSRF during the period of 1991–2015 (except 2004–2015 in SSMF) is illustrated in Figures 4.14, 4.15, 4.16, and 4.17. Data on ISF could not be obtained. Table 2.28 displays summary results of the simple linear regression conducted to investigate the relationship of shrimp productivity over the period examined. There was a positive linear relationship of the average shrimp productivity in the whole province, in RSRF and in ISMF over last 25 years at the 0.05 significance level, while there was no linear relationship of shrimp productivity in SSMF during this period of 2004–2015 at the 0.05 significance level. A statistically significant linear relationship was found in the average shrimp productivity for the whole province [$f(1, 23) = 45.47$, $p < 0.001$] with $R^2 = 0.664$], in RSRF productivity [$f(1,23) = 18.63$, $p < 0.001$) with $R^2 = 0.448$], and in ISMF [$f(1, 23) = 29.49$, $p < 0.001$] with $R^2 = 0.562$ (Table 4.28). The data analysis showed that the average shrimp productivity in the whole province had a sharp increase by 193 kg ha^{-1} $year^{-1}$ in the last 25 years, from 330 kg ha^{-1} $year^{-1}$ in 1991 to 523 kg ha^{-1} $year^{-1}$ in 2015 (Figure 4.14). In each farming system investigated, the average shrimp productivity in ISMF increased by 112 kg ha^{-1} $year^{-1}$ in this period, from 330 kg ha^{-1} $year^{-1}$ in 1991 to 442 kg ha^{-1} $year^{-1}$ in 2015 (Figure 4.15); it increased by 52 kg ha^{-1} $year^{-1}$, from 372 kg ha^{-1} $year^{-1}$ in 2004 to 424 kg ha^{-1} $year^{-1}$ in 2015 in SSMF (Figure 4.16); and increased by 98 kg ha^{-1} $year^{-1}$, from 299 kg ha^{-1} $year^{-1}$ in 1991 to 397 kg ha^{-1} $year^{-1}$ in 2015 in RSRF (Figure 4.17). The average shrimp productivity reached its lowest value in 1999 in the whole province and also in ISMF and RSRF. This may link to rainfall in 1999 that reached its highest value in the average annual rainfall and also rainfall in the dry season (see Section 4.3.2) and shrimp disease outbreaks, as commented by shrimp farmers in Tan Duyet Commune (see Section 5.2). Overall shrimp productivity has significantly increased in the whole province, RSRF, and in ISMF especially from 2000 to 2015, but insignificantly increased in SSMF during the period investigated.

Table 4.28: Summary results of the simple linear regression for shrimp productivity over the last 25 years (dependent variable: years)

	Summary of Linear Regression								
	ANOVA				Coefficients				
					Standardized Coefficients		Standardized Coefficients	T	Sig.
	R^2	df1	df2	F	B	SE	Beta (b)		
Whole Province	.664	1	23	45.47	.054	.008	.815	6.74	.000
RSRF Productivity	.448	1	23	18.63	.061	.014	.669	4.314	.000
ISMF Productivity	.562	1	23	29.49	.050	.009	.750	5.43	.000
SSMF Productivity	.037	1	10	.389	.018	.030	.193	.624	.547

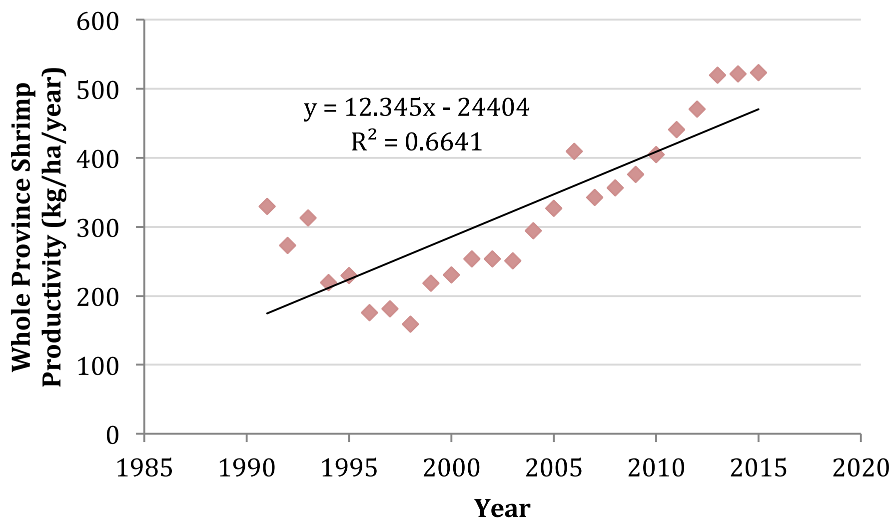

Figure 4.14: Average shrimp productivity of the whole province from 1991–2015

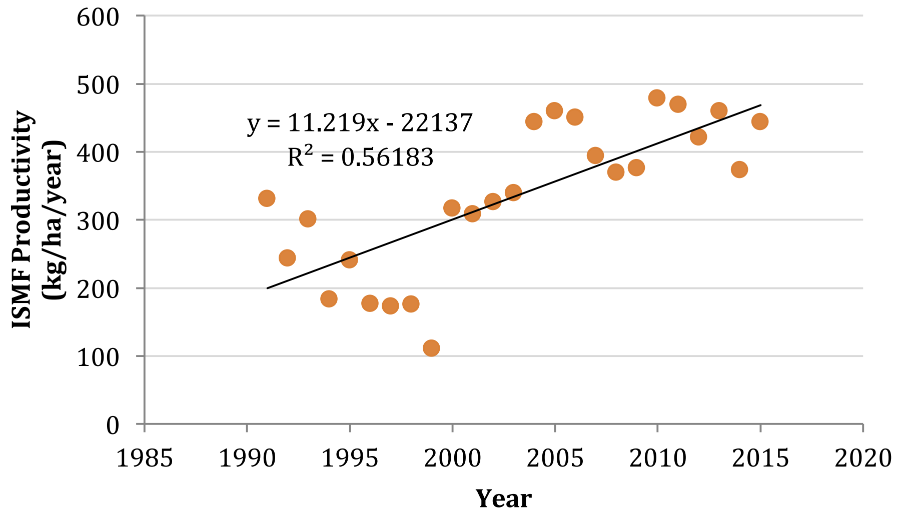

Figure 4.15: Shrimp productivity in ISMF from 1991–2015

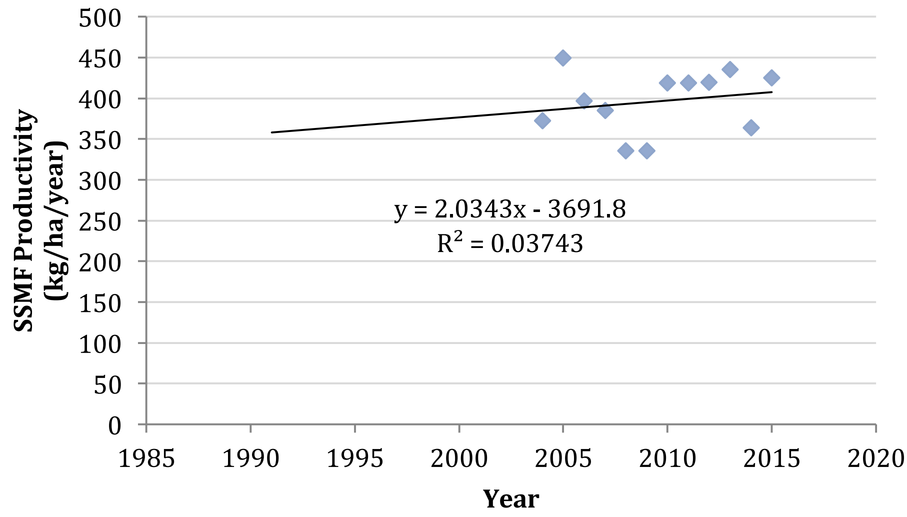

Figure 4.16: Shrimp productivity in SSMF from 2004–2015

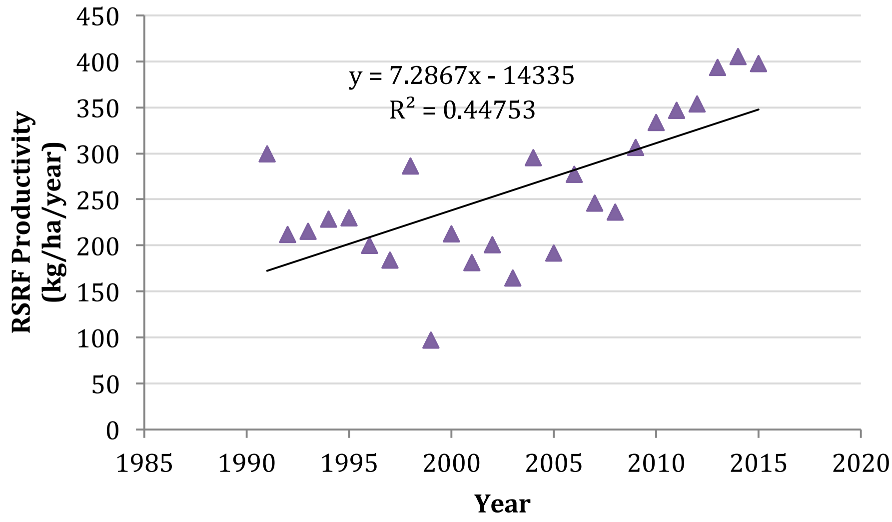

Figure 4.17: Shrimp productivity in RSRF from 1991–2015

4.5. Correlations between hydro–meteorological parameters and shrimp productivity in Ca Mau Province over the period 1991–2015

The hydro–meteorological parameters and shrimp productivity (Sections 4.3 and 4.4) can be used to test the hypothesis that there is a strong relationship between them. The hydro–meteorological parameters considered in this research include air temperature (average annual, average maximum, average minimum temperature), rainfall (average annual rainfall, rainfall in the rainy season, rainfall in the dry season), and water level (average annual, average maximum, average minimum water level in Doc River and Nam Can Station). Shrimp production data comprises average shrimp productivity of the whole province, in RSRF, ISMF, and in SSMF. Descriptive statistics of the parameters examined are presented in Table 4.29.

Table 4.29: Descriptive statistics of mean, standard deviation and sample sizes[12] of climate parameters during the period of years investigated.

Parameters	Mean	Std. Deviation	N
T. average[13] (ºC)	27.46	.399	25
T. max(ºC)	31.72	.333	25
T. min (ºC)	24.81	.581	25
Average Annual Rainfall (mm year^{-1})	2413.79	334.261	25
Average Rainfall in Rainy Season (mm year^{-1})	327.51	34.317	25
Average Rainfall in Sunny Season (mm/year^{-1})	80.89	33.952	25

[12] Sample sizes (N): duration of years that data were obtained

[13] T. average: average annual air temperature; T. max: average maximum air temperature; T. min: average minimum air temperature

Parameters	Mean	Std. Deviation	N
H. average[14] in Doc River (cm)	3.24	6.794	20
H. max in Doc River (cm)	58.56	12.214	25
H. min in Doc River (cm)	-41.35	7.967	20
H. average in Nam Can (cm)	20.38	6.115	21
H. max in Nam Can (cm)	113.01	14.382	25
H. min in Nam Can (cm)	-134.49	9.342	21
RSRF Productivity (kg ha^{-1} $year^{-1}$)	259.93	80.165	25
ISMF Productivity (kg ha^{-1} $year^{-1}$)	334.00	110.157	25
SSMF Productivity (kg ha^{-1} $year^{-1}$)	396.02	37.909	12
Province Shrimp Productivity (kg ha^{-1} $year^{-1}$)	322.81	111.492	25

4.5.1. Correlations between shrimp productivity (kg ha^{-1} $year^{-1}$) and air temperature (ºC) in Ca Mau Province

Scatterplots in Figures 4.18, 4.19, 4.20 and test results in Table 4.30 show that there was a strong positive correlation between average annual temperature (T. average) and average shrimp productivity in ISMF at the 0.01 significance level, and a moderate positive correlation in RSRF at the 0.05 level of significance. A correlation was found between T. average and the average shrimp productivity in the whole province ($r = 0.457$, $n = 25$, $p = 0.022$), in RSRF ($r = 0.475$, $n = 25$, $p = 0.016$), and in ISMF ($r = 0.619$, $n = 25$, $p = 0.001$). However, there was found insignificant correlation between T. average and shrimp productivity in SSMF ($r = 0.551$, $n = 12$, $p = 0.063$). Furthermore, there was a moderate correlation between T. max and shrimp productivity in RSRF, SSMF, and a weak correlation in the whole province and in ISMF, but all pairs of correlation were found insignificant at the 0.05 significance level. Finally, there was a strong positive correlation between T. min and shrimp productivity in the whole province ($r = 0.531$, $n = 25$, $p = 0.006$), in RSMF ($r = 0.671$, $n = 25$, $p < 0.001$), and shrimp productivity in SSMF ($r = 0.893$, $n = 12$, $p < 0.001$) relatively, and a moderate positive correlation in RSRF ($r = 0.445$, $n = 25$, $p = 0.026$). The results from data analysis may help to predict that the significant increase of T. min and T. average over the last 25 years (Figure 4.2 & 4.4) and high fluctuations of T. max (Figure 4.3) may link to shrimp productivity because high variations or a low air temperature can affect shrimp production, such as the occurrence of shrimp diseases (Tendencia et al., 2011), which is later discussed in Section 5.4.1.

[14] H. average: average annual water level; H. max: average maximum water level; H. min: average minimum water level

Table 4.30: Correlations between shrimp productivity kg ha^{-1} year^{-1} and air temperature (°C).

		RSRF	ISMF	SSMF	Whole Province
T. average (°C)	Pearson Correlation	.475*	.619**	.551	.457*
	Sig. (2-tailed)	.016	.001	.063	.022
T. max (°C)	Pearson Correlation	.330	-.097	.440	.026
	Sig. (2-tailed)	.107	.645	.153	.901
T. min (°C)	Pearson Correlation	.445*	.671**	.893**	.531**
	Sig. (2-tailed)	.026	.000	.000	.006

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

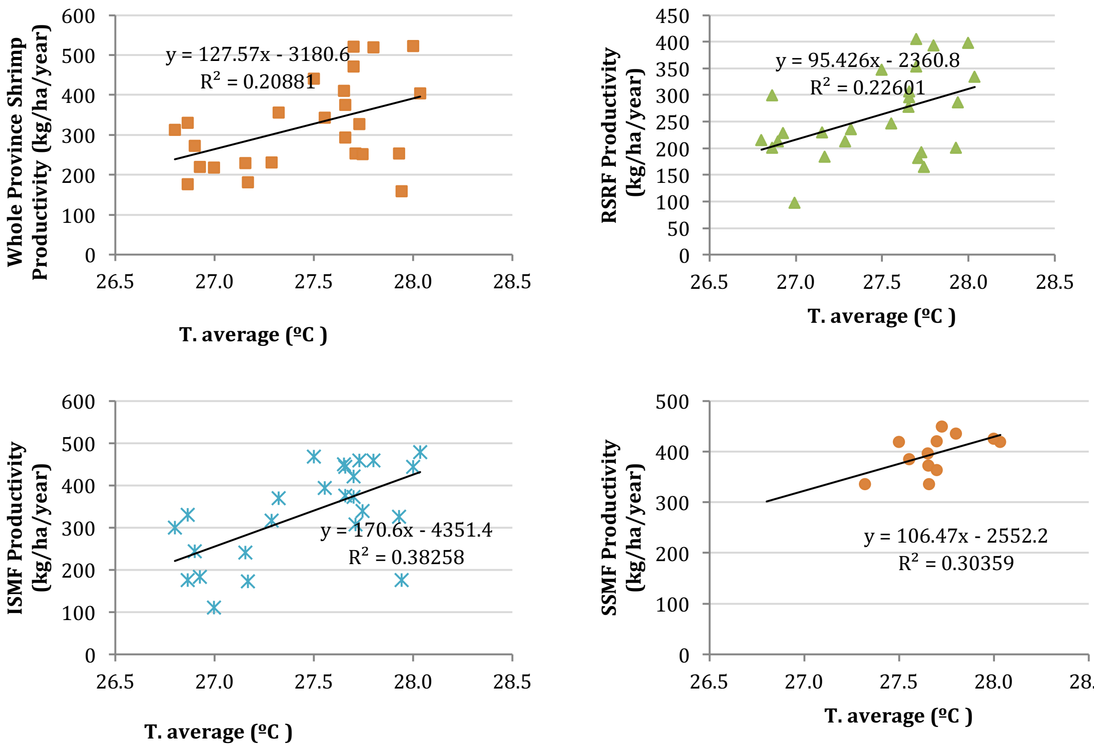

Figure 4.18: Correlations between average annual air temperature (°C) and shrimp productivity in the whole province, RSRF, ISMF, and in SSMF

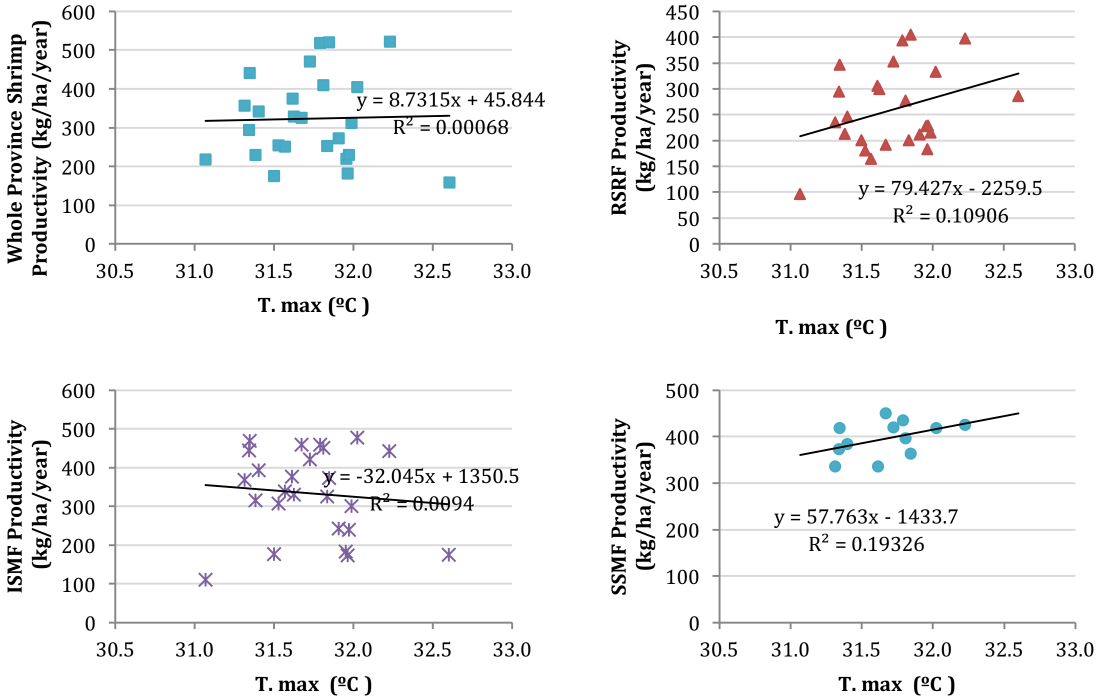

Figure 4.19: Correlations between average maximum air temperature (ºC) and shrimp productivity in the whole province, RSRF, ISMF, and in SSMF

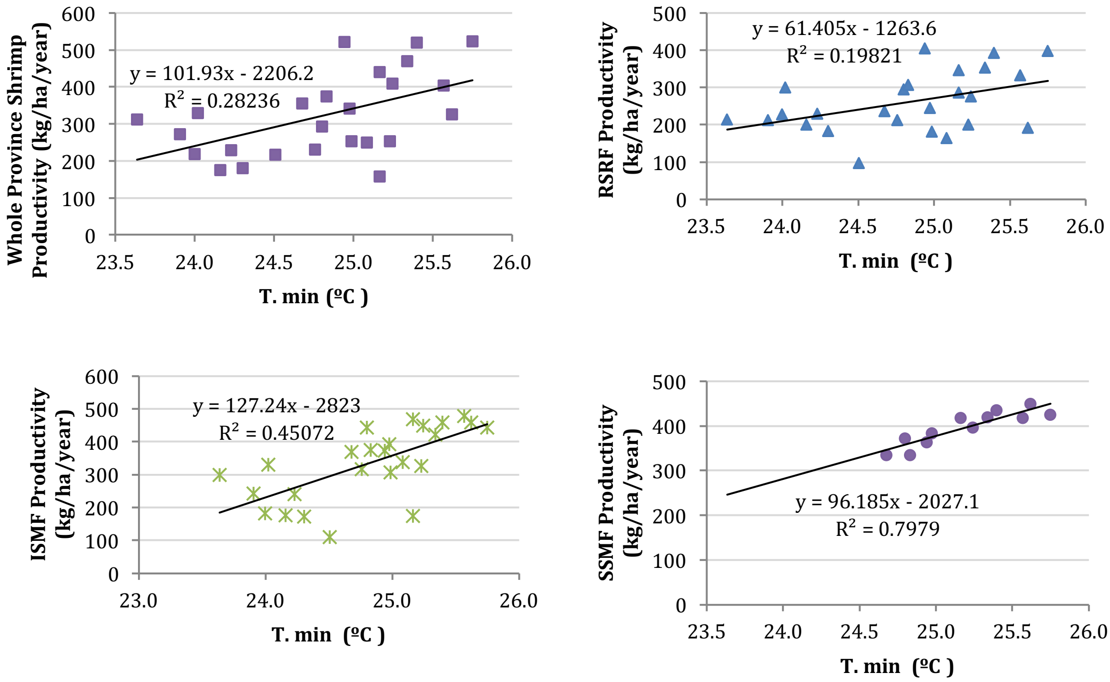

Figure 4.20: Correlations between average minimum air temperature (ºC) and shrimp productivity in the whole province, RSRF, ISMF, and in SSMF

4.5.2. Correlations between shrimp productivity and rainfall in Ca Mau Province

Figures 4.21, 4.22, 4.23 and Table 4.31 display a Pearson product-moment correlation coefficient computed to assess the relationship between rainfall (average annual rainfall, average rainfall in the rainy season, average rainfall in the dry season) and shrimp productivity (average shrimp productivity in the whole province, in RSRF, ISMF, and in SSMF). There was a strong negative correlation between average annual rainfall and shrimp productivity in the whole province ($r = -0.559$, $n = 25$, $p = 0.004$), in RSRF ($r = -0.722$, $n = 25$, $p < 0.001$), and in ISMF ($r = -0.709$, $n = 25$, $p < 0.001$). Likewise, there was also a strong negative correlation between rainfall in the rainy season and shrimp productivity in the whole province ($r = -0.806$, $n = 25$, $p < 0.001$), in RSRF ($r = -0.778$, $n = 25$, $p < 0.001$), and in ISMF ($r = -0.675$, $n = 25$, $p < 0.001$). However, there was not a statistically significant correlation between rainfall (average annual rainfall, rainfall in the rainy season, and rainfall in the dry season) and shrimp productivity in SSMF as well as between rainfall in the dry season and shrimp productivity at all types (Table 4.31). This may be due to rainfall in the dry season varying around 50-100 mm year^{-1} during the last 25 years (Figure 4.7) and the short period of data collection in SSMF. The data analysis revealed that the strong negative relationships between average annual rainfall, as well as rainfall in the rainy season and shrimp productivity, may link to perspectives of shrimp farmers and the local experts that greater intensity or irregular rains have negatively affected shrimp production in the last decade and may help to predict that intense rain can reduce shrimp productivity. More discussion on shrimp productivity is presented in Section 5.4.2.

Table 4.31: Correlations between shrimp productivity kg ha^{-1} year^{-1} and rainfall (mm year^{-1}).

		RSRF	ISMF	SSMF	Whole Province
Average Annual Rainfall	Pearson Correlation	-.722**	-.709**	-.309	-.559**
(mm year^{-1})	Sig. (2-tailed)	.000	.000	.328	.004
Rainy Season Rainfall	Pearson Correlation	-.778**	-.675**	-.262	-.806**
(mm year^{-1})	Sig. (2-tailed)	.000	.000	.410	.000
Dry Season Rainfall	Pearson Correlation	-.261	-.258	-.243	-.041
(mm year^{-1})	Sig. (2-tailed)	.207	.212	.447	.845

**. Correlation is significant at the 0.01 level (2-tailed).

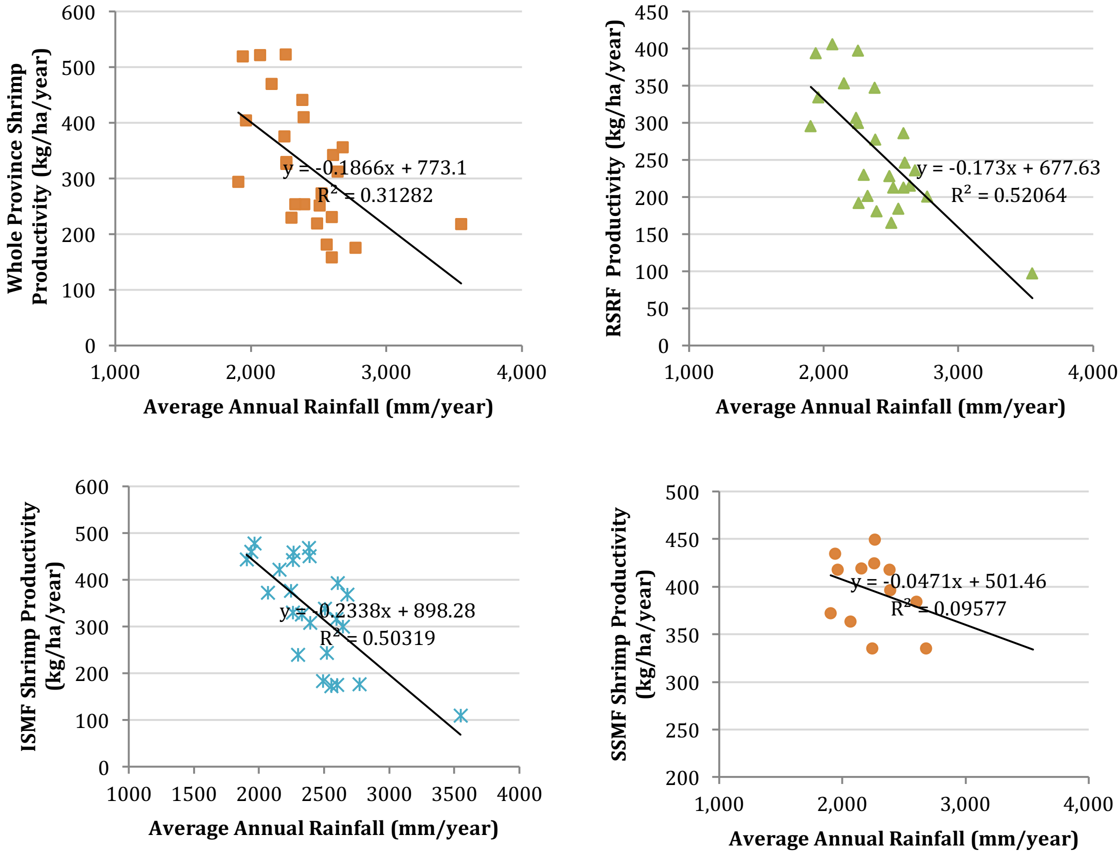

Figure 4.21: Correlations between annual average rainfall and shrimp productivity in the whole province, RSRF, ISMF, and in SSMF

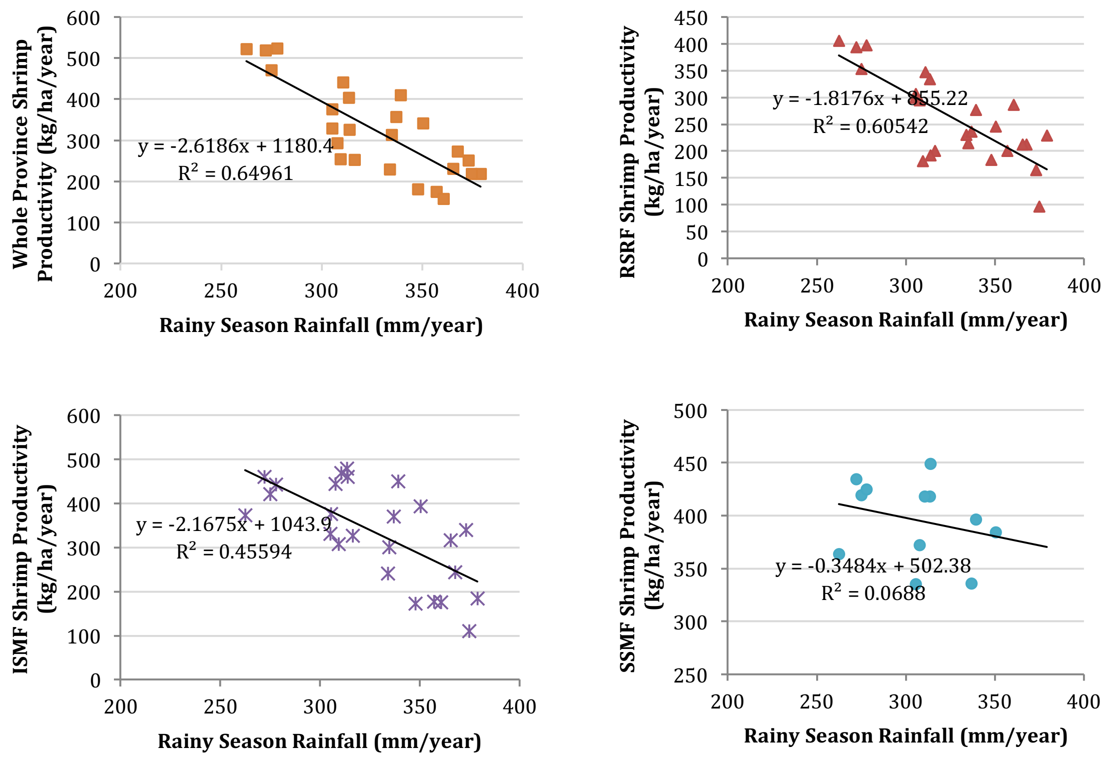

Figure 4.22: Correlations between average rainfall in the rainy season and shrimp productivity

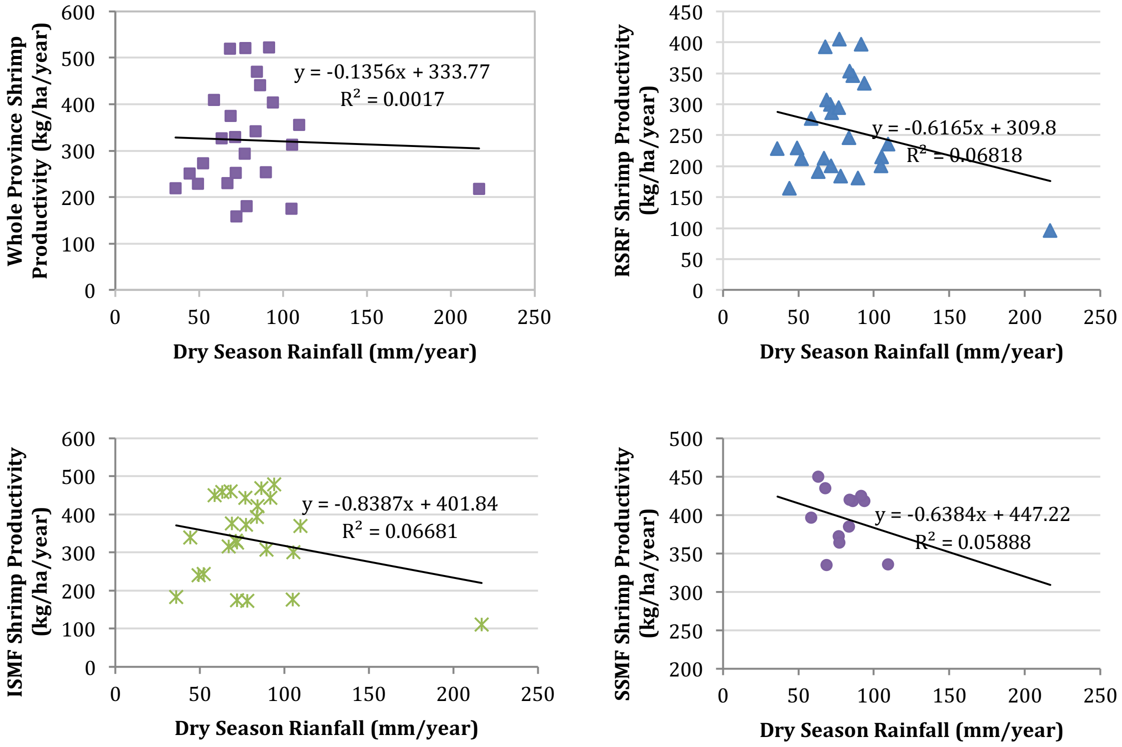

Figure 4.23: Correlations between average rainfall in the dry season and shrimp productivity in the whole province, RSRF, ISMF, and in SSMF

4.5.3. Correlations between shrimp productivity and water levels in Doc River Station and Nam Can River Station

4.5.3.1. Correlations between shrimp productivity and water level in Doc River

Overall evidence was found of a strong positive correlation between shrimp productivity of each sector and water level of each parameter, excluding between SSMF productivity and water level at all parameters (H. average, H. max, H. min) (Table 4.32). In each parameter, shrimp productivity of the whole province had a very strong correlation with H. average ($r = 0.896$, $n = 20$, $p < 0.001$), H. min ($r = 0.927$, $n = 20$, $p < 0.001$) and had a strong relationship with H. max ($r = 0.589$, $P = 0.002$). Furthermore, shrimp productivity in ISMF had a strong correlation with H. average ($r = 0.61$, $p = 0.004$), H. max ($r = 0.59$, $n = 25$, $p = 0.002$), and H. min ($r = 0.64$, $p = 0.003$). Finally, there was evidence of a relationship between RSRF productivity and H. average ($r = 0.80$, $p < 0.001$), H. max ($r = 0.41$, $p = 0.04$), H. min ($r = 0.80$, $p < 0.001$). More explanation of the relationship between shrimp productivity (whole province, RSRF, ISMF, SSMF) and water level (H. average, H. max, H. min) are presented in Figures 4.24, 4.25, 4.26 and Table 4.32. Taken together these results suggest that an increase in water level may increase shrimp productivity. This is because a higher water level may provide both more seawater and higher water quality, which create better conditions for shrimp growth due to higher oxygen, more nutrients, and less chemical pollution. It should be noted that these associations may not necessarily be causal because there are other factors that may be more or less important than the Doc River water level that affect shrimp productivity.

Table 4.32: Correlations between shrimp productivity kg ha^{-1} year^{-1} and water level in Doc River Station (cm).

		RSRF	ISMF	SSMF	Whole Province
H. average in Doc River	Pearson Correlation	.800**	.609**	.083	.896**
	Sig. (2-tailed)	.000	.004	.797	.000
H. max in Doc River	Pearson Correlation	.409*	.588**	-.164	.589**
	Sig. (2-tailed)	.042	.002	.610	.002
H. min in Doc River	Pearson Correlation	.801**	.637**	.141	.927**
	Sig. (2-tailed)	.000	.003	.663	.000

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

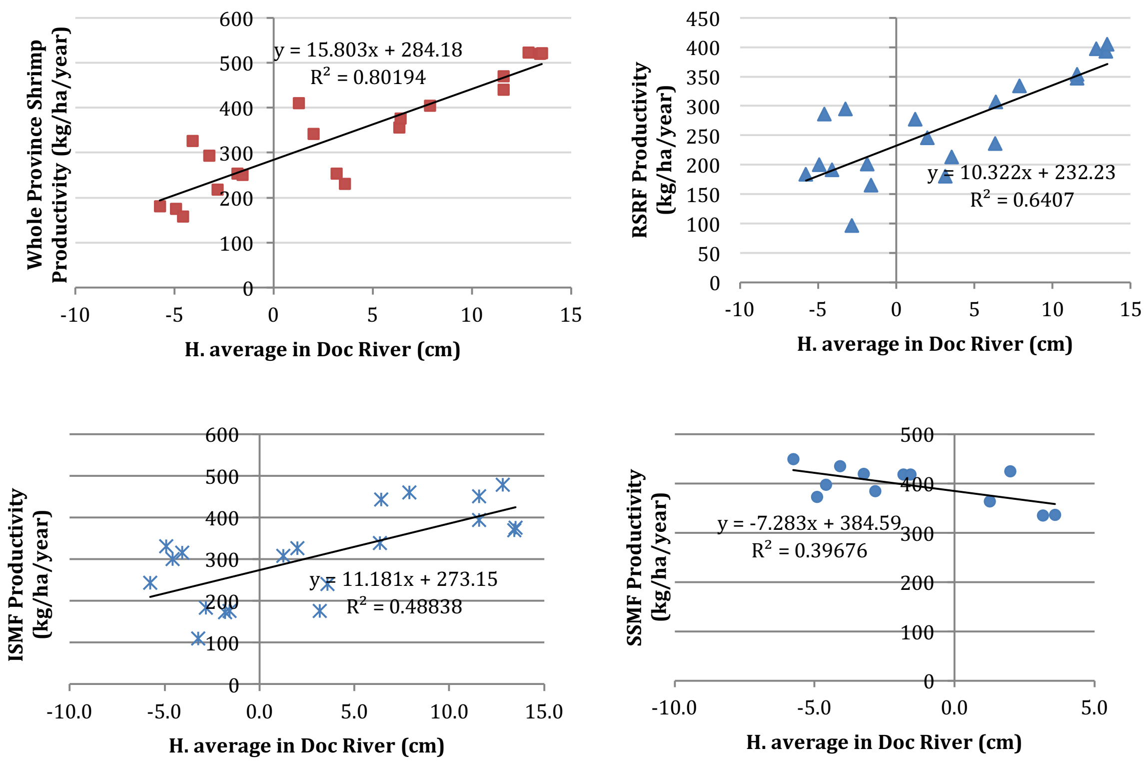

Figure 4.24: Correlations between average water levels in Doc River Station and shrimp productivity in the whole province, RSRF, ISMF, and in SSMF

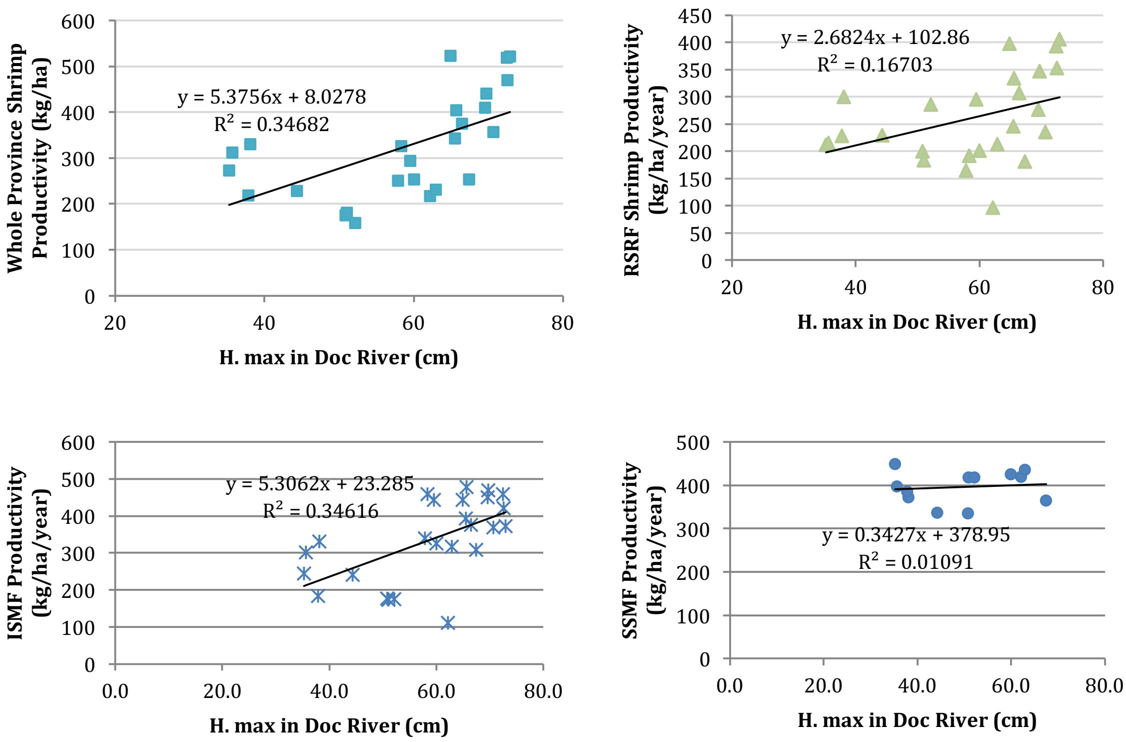

Figure 4.25: Correlations between average maximum water levels in Doc River Station and shrimp productivity in the whole province, RSRF, ISMF, and in SSMF

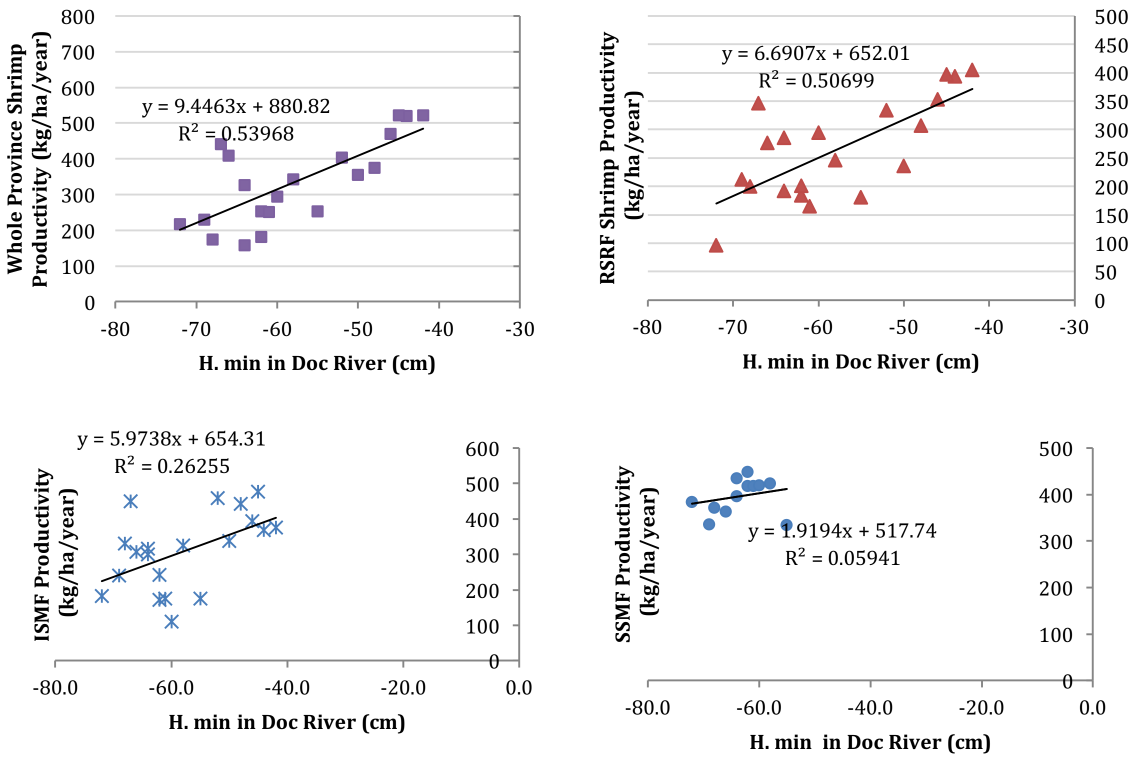

Figure 4.26: Correlations between average minimum water levels in Doc River Station and shrimp productivity in the whole province, RSRF, ISMF, and in SSMF

4.5.3.2. Correlations between shrimp productivity and water levels in Nam Can

The scatterplots in Figures 4.27, 4.28, 4.29 and Table 4.33 show that a Pearson product-moment correlation coefficient was computed to assess the relationship between water level in Nam Can (H. average, H. max, H. min) and shrimp productivity (the whole province, RSRF, ISMF and SSMF). There was a strong positive relationship between H. average and shrimp productivity in the whole province ($r = 0.825$, $n = 21$, $p < 0.001$), in RSRF ($r = 0.700$, $n = 21$, $p < 0.001$), and in ISMF ($r = 0.682$, $n = 21$, $p = 0.001$). Moreover, a strong positive correlation between H. max and shrimp productivity was found in the whole province ($r = 0.710$, $n = 25$, $p < 0.001$), in RSRF ($r = 0.580$, $n = 25$, $p < 0.001$), and in ISMF ($r = 0.705$, $n = 25$, $p < 0.001$), while there was insignificant correlation between H. min and shrimp productivity at all sectors at the 0.05 significance level. There was also found no evidence of relationship between water level at all parameters and SSMF productivity (Table 4.33) at the 0.05 level of significance. Overall statistical test results show that water level possibly highly influenced (H. average and H. max) shrimp productivity in the whole province, RSRF and in ISMF, with evidence of a strong positive relationship at the 0.01 significance level. Therefore, as mentioned previously (Section 4.5.3.1), data analysis results may help to predict that a rise increase of water level may increase shrimp productivity due to it may providing more and better quality seawater, this providing improved growing conditions for shrimp production.

Table 4.33: Correlations between shrimp productivity kg ha^{-1} $year^{-1}$ and water level in Nam Cam Station (cm).

		RSRF	ISMF	SSMF	Whole Province
H. average in Nam Can	Pearson Correlation	.700**	.682**	.054	.825**
	Sig. (2-tailed)	.000	.001	.867	.000
H. max in Nam Can	Pearson Correlation	.580**	.705**	.122	.710**
	Sig. (2-tailed)	.002	.000	.705	.000
H. min in Nam Can	Pearson Correlation	.271	-.025	-.066	.432
	Sig. (2-tailed)	.236	.914	.838	.050

**. Correlation is significant at the 0.01 level (2-tailed).

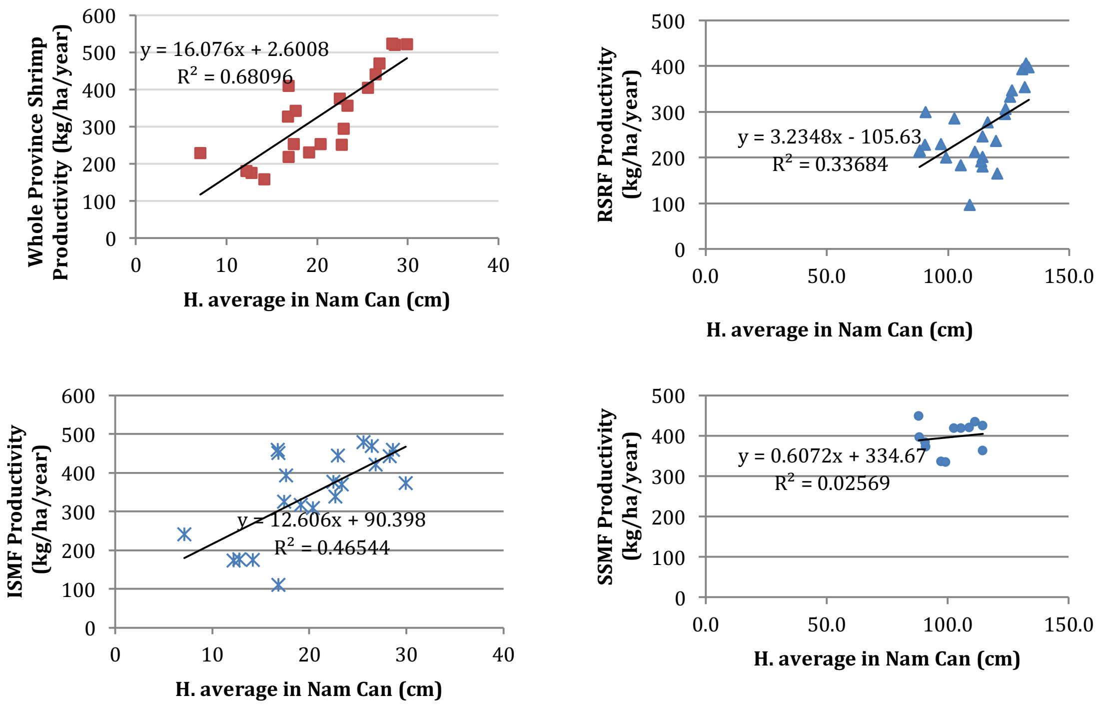

Figure 4.27: Correlations between annual average water levels in Nam Can Station and shrimp productivity in the whole province, RSRF, ISMF, and in SSMF

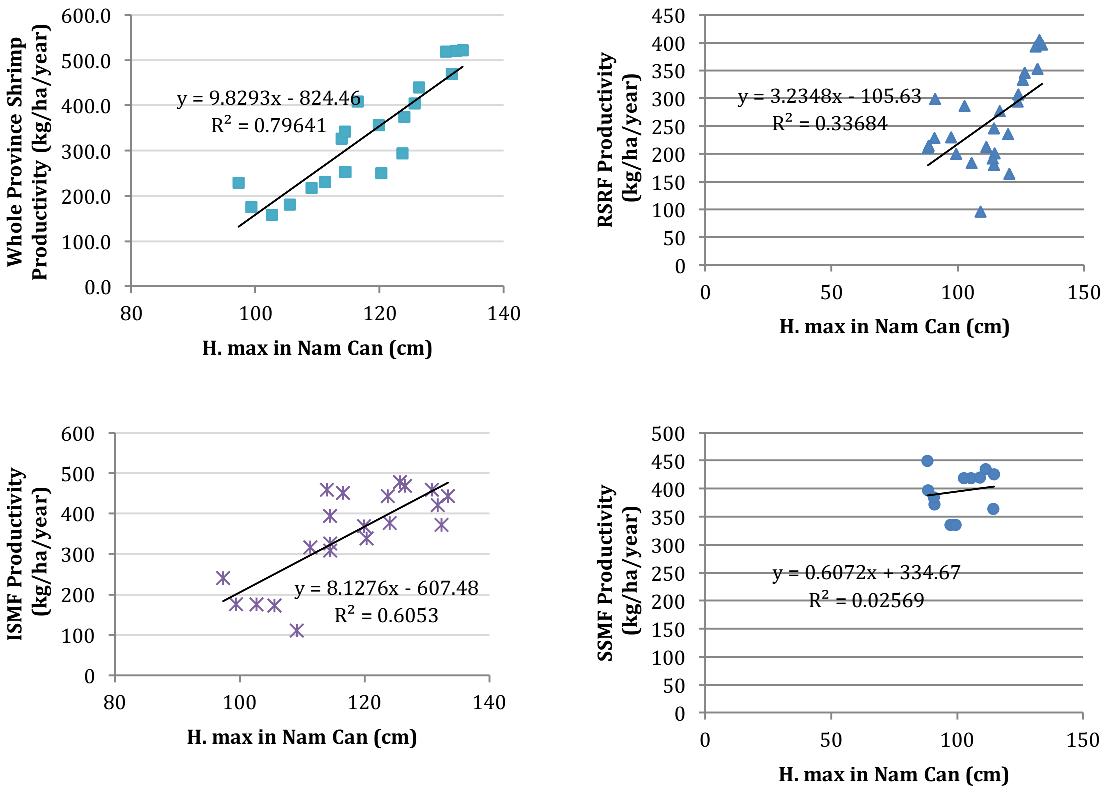

Figure 4.28: Correlations between average maximum water levels in Nam Can Station and shrimp productivity in the whole province, RSRF, ISMF, and in SSMF

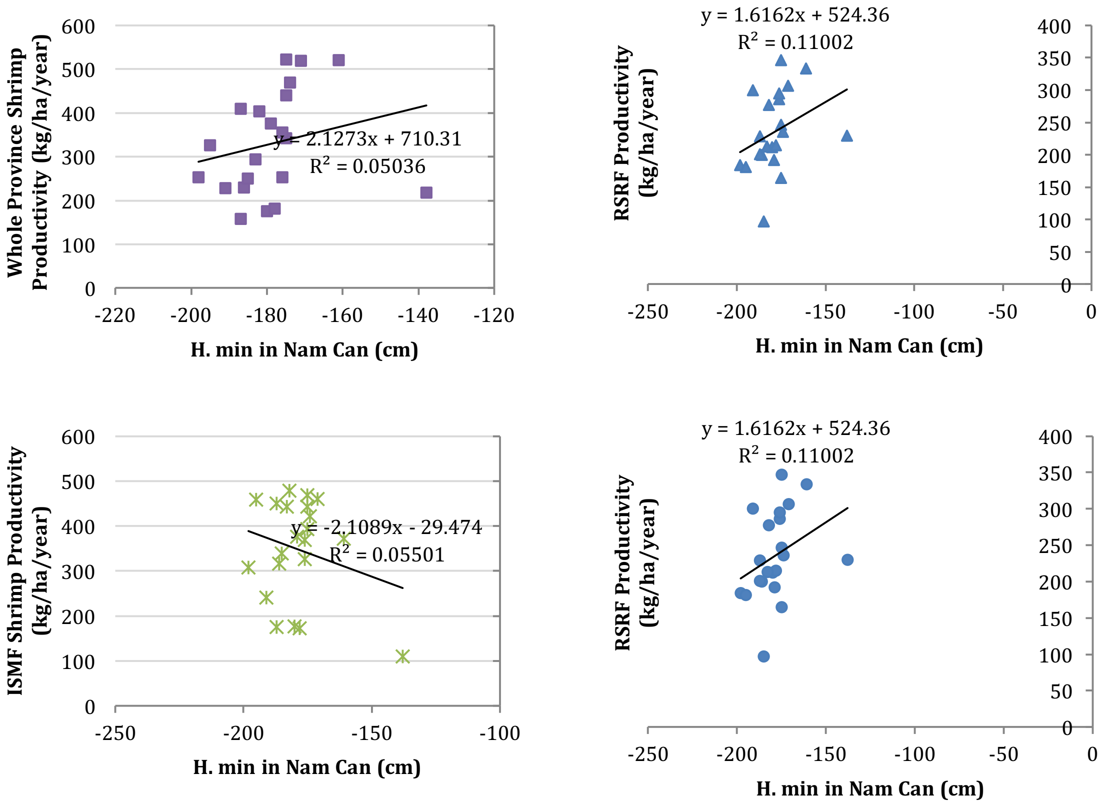

Figure 4.29: Correlations between average minimum water levels in Nam Can Station and shrimp productivity in the whole province, RSRF, ISMF, and in SSMF

4.6. Discussion

The literature review in Chapter 2 demonstrated that climate change impacts have been studied and well understood at the macro level such as in the Mekong Delta by the general farming sector, and that the provincial government has recognised this and is taking action. Also some researchers have conducted studies on the effects of climate change on aquaculture and case studies on brackish aquaculture and catfish farming in the region. However, those studies while contributing to understanding have not drilled down to access the effects of climate change events at the local level as perceived by the local experts and shrimp farmers in the different farming systems. The research results in this chapter present the different perspectives of shrimp farmers and the local experts on how climate change events could affect shrimp production. Further this chapter presents some evidence of the relationship between shrimp productivity and some climate parameters.

4.6.1. Climate change events have affected Ca Mau shrimp production

The research results presented in Section 4.2 show perceptions of shrimp farmers in all four shrimp farming systems and the local experts that climate change events being experienced in Ca Mau Province had affected shrimp production over the last 10 years. This was borne out by the majority of shrimp farmers and the local experts, who acknowledged extreme climate events, sea level rise and increasing intensity of high tides, greater intensity or irregular rains, seasonal pattern changes, increased fluctuations of water temperature and salinity. Moreover, statistical analysis results show some evidence of the relationship between shrimp productivity and climate parameters. Further to the numerical data, shrimp farmers and the experts provided insightful comments and explanations regarding their perspectives of climate change events, which are now briefly addressed.

The local experts gave greater emphasis than shrimp farmers in the different farming systems to the effects of extreme climate events on shrimp production in the last 10 years. And a minority of shrimp farmers (32%) in all shrimp farming systems were of the same opinion (Table 4.2). To support their claim for extreme weather events, the local experts stated that there were more frequencies of tropical depressions and storms moving to the south of the East Sea, which caused irregular rains and affected shrimp production in Ca Mau Province. These statements of the local experts are supported by various published studies (De Silva & Soto; IMHEN, 2010a; Mackay & Russell, 2011; Mirza, 2003). Although the majority of shrimp farmers argued that there were no tropical storm surges or typhoons that occurred in this area during the last 10 years, the Tropical Cyclone Linda storm of 1997 was recalled. Perhaps shrimp farmers have a lack of information and knowledge about extreme climate events in the East Sea that have impacted the region in the last 10 years or simply have not noticed these events relative to their experiences during storm Linda.

Although the majority of respondents perceived sea level rise (78%) and high tides (84) in the last 10 years that have negatively affected shrimp production, but there was less emphasis by shrimp farmers in intensive shrimp farming (ISF) on this issue. The majority of shrimp farmers in ISF stated that they had not identified the adverse effects of sea level rise (53%) and high tides (57%) on their shrimp production (Tables 4.3, 4.4), pointing out that ISF is a closed system and has more investment in shrimp pond embankments and sluice gates to reduce impacts from high tides. By contrast, most shrimp farmers in the other systems perceived that sea level rise, especially water levels in rivers, and high tides have been increasing during the last 10 years, particularly the intensity of high tides in the period from October to November in recent years. This evidence is consistent with data obtained in Ca Mau Province (CHMC, 2016) that water levels in both Doc River Station and Nam Can Station have significantly increased during the last 25 years. Moreover, it should be noted that sea level rise may accompany land subsidence because of heavy groundwater extraction (Schmidt, 2015) due to greater water level and flooding. However, statistical tests in Section 4.5.3 show evidence of a strong positive relationship between water level and shrimp productivity in the whole province and in RSRF and ISMF. It means that water level increase may predict a strong positive influence on shrimp production. This finding is consistent with previous studies providing general predictions about the benefits of sea level rise for expanding brackish or saltwater aquaculture (Brander, 2007; De Silva & Soto, 2009; World Fish Centre, 2009).

In addition, the majority of the local experts and shrimp farmers in ISMF, SSMF stated that there had been stronger intensity of high tides, especially more severe high tides in the last three years, which resulted in increased erosion in sea dikes, river mouths and river embankments. Especially in coastal areas, sea level rise was accompanied with high tides that overflowed shrimp embankments and sluice gates, and caused shrimp losses. Those findings are supported by previous studies (ActionAid & CRES, 2010; Smyle and Cooke, 2011). Moreover, recent scientists (Kuenzer et al., 2013; Schmidt, 2015) have emphasized that coastal erosion and saltwater intrusion may increase more greatly because of upstream dam construction and excessive groundwater extraction in the Mekong Delta. Meanwhile the majority of shrimp farmers in RSRF perceived adverse effects of saline intrusion damaged rice fields. This evidence is consistent with surface water monitoring in Ca Mau Province over the last 15 years that water salinity at the level of 4‰ occurred in most of the province during the rainy season (IMHEN, 2010a). Therefore, rice cultivation in RSRF is likely at risk if water salinity exceeds the salinity tolerance ability of 6‰ (Preston & Clayton, 2003).

The majority of shrimp farmers and the local experts (86%) contended that irregular weather has negatively affected shrimp production (Table 4.5). Information recorded through the survey shows that there are two seasons in the region, but the seasonal pattern has been changing, especially in recent years. The rainy season has been arriving earlier and lasting longer, especially in 2009, 2010, and 2012. Respondents suggested that this makes it more difficult to recognise the transition point between the two seasons. Consequently, shrimp farmers increasingly found it difficult to forecast the weather based on traditional experience and knowledge.

While rainfall is an important factor affecting shrimp production (Noyes et al., 2009), the majority of shrimp farmers perceived that rains were abnormal recently; for example, scattered showers happened frequently during the dry season in 2010, which had never previously occurred. Moreover, based on farmers' experiences, whereas the 5th May of lunar year is traditionally regarded as the beginning of the rainy season, recently rains have come earlier and occurred intensely – with irregular rains, and localised torrential rains not only in the rainy season but also in the dry season. This causes water quality to change rapidly, especially in water temperature, salinity, dissolved oxygen etc., and these conditions are conductive to shrimp disease outbreaks (Abery et al., 2009; Tendencia & Verreth, 2011; Waibel et al., 2017). This, in turn, reduces productivity, as shrimps do not adapt easily to wide ranges of environmental factors and disease. Those statements of shrimp farmers are consistent with data recorded in Ca Mau Province over the last 25 years: that rainfall in the dry season has been slightly increasing, but inconsistent with average annual rainfall, and rainfall in the rainy season decreasing (see the trend-lines in Figures 4.4-4.6, Section 4.3.2). This finding is contrary to MONRE (2012) who predicted that rainfall will increase in the rainy season and decrease in the dry season. Furthermore, to support shrimp farmers' perspectives, test results in Table 4.25 show a negative relationship between rainfall and shrimp production for all the systems investigated. However, there is no evidence of a relationship between rainfall in the dry season and shrimp productivity, while there was significant evidence of a strong negative relationship between rainfall in the rainy season as well as average annual rainfall and shrimp productivity (see test results in Section 4.5.2). Research results have also shown that rainfall in 1999 was the highest over the last 25 years, with 3549 mm (annual average = 2414 ± 334 mm), which reduced 13% of the whole province shrimp productivity, 38% of ISMF, and 66% of RSRF productivity compared with the previous year (see Section 4.3.2 and 4.4). Overall those discussions explain that rainfall increase is possible to decrease of shrimp production, especially irregular rain or intense rain in the dry season.

Furthermore, the majority of shrimp farmers are of the same opinion as the local experts perceived that increased fluctuations of water temperature (75%) (Table 4.21), salinity (69%) (Table 4.20) and drier dry seasons (87%) (Table 4.19) have adversely affected shrimp production over the last 10 years. Many researchers have found that the fluctuation of water temperature can create an unsuitable environment for shrimp growth and cause shrimp disease outbreaks (Abery et al., 2009; De Silva & Soto, 2009; Najjar et al., 2010; Alapide-Tendencia, 2012; Waibel et al., 2017). In contrast, 25-year data recorded in Ca Mau Province show that the average minimum temperature has increased rapidly, while the average maximum temperature has seemingly been unchanged during the last 25 years. Therefore, the average annual temperature tended to reduce the variation. However, the statistical tests show that there was some evidence of a positive correlation between the average minimum temperature as well as average annual temperature and shrimp productivity at the 0.01

significance level, but no evidence of the relationship between average maximum temperature and shrimp productivity.

Finally, shrimp farmers in the four shrimp farming systems and the local experts had different perspectives on which climate events have affected shrimp production the most (see results in Table 4.12). The research results show that shrimp farmers involved in RSRF, ISMF, and ISF concurred that increased intense or irregular rain had the most impact on shrimp farming, whereas shrimp farmers in SSMF were highly concerned about the sea level rise in the last 10 years. Meanwhile, Abery et al. (2009) reported that farmers in IESF mostly considered the irregular seasons as their greatest concern. The local experts interviewed in this research identified increased water temperature fluctuations as having the most effect on shrimp production in Ca Mau Province. This perception is consistent with data on climate change scenarios and predictions of MONRE (2012). This latter perspective matches the finding of a study of shrimp farmers in IESF in the Bac Lieu Province, which showed that the high water temperature (NACA, 2011) or findings of Noyes et al. (2009) was ranked as the greatest risk factor affecting shrimp production. The local experts stated that climate change would have more impacts on extensive shrimp farming than intensive shrimp farming because water quality control and environmental water management in intensive production is better than in extensive systems, and this corresponded with the view of the majority of shrimp farmers in ISF, as discussed in the previous paragraph. Overall the greatest concern on which climate change event affects shrimp production varied among shrimp farmers, the local experts, and the previous researchers. However, irregular weather, such as irregular seasons, increased intense or irregular rain was perceived by most shrimp farmers, such as in RSRF, ISMF, and in ISF as having the most negative impact on shrimp production.

4.6.2. Perceptions of climate change impacts on shrimp farming over the next 10–20 years

This section discusses the conceptions of shrimp farmers in all four farming systems and the local experts that climate change events would likely have negative impacts on shrimp production in Ca Mau Province in the next 10–20 years.

There was greater emphasis given by farmers on the likely impacts of extreme climate events on shrimp farming for the next 10–20 years than they claimed for the last 10 years. Overall, the majority of all shrimp farmers (71%) – and in all shrimp farming systems – and the local experts were concerned that extreme climate events, such as increased intensity and frequency of tropical storm surges or cyclones, would increase in frequency and strongly negatively impact on their shrimp systems in the future (Table 4.13), compared with the minority of all shrimp farmers (34%) who were of the same opinion concerning the last 10 years (Table 4.2). Moreover, extreme climate events emerged as the third most important impact on shrimp production ranked by shrimp farmers in all farming systems (Table 4.23). However, the local experts stated mostly the same perspective from the past to the future and agreed that extreme climate events would negatively impact shrimp production in the next 10–20 years. Perhaps shrimp farmers demonstrated more concern about extreme climate event for the next 10-20 years because they recalled the Tropical Linda Storm surge in 1997 and therefore they had more alarm for the future.

The research results in this study showed that the majority of farmers in all shrimp farming systems are very concerned about the negative effects of climate change events on shrimp production, which presents as 85% of agreement on seasonal pattern changing, 89% on sea level rise, 74% on high tides, 83% on greater intensity or irregular rains, 85% on drier dry seasons, 80% on increased fluctuations of salinity, and 84% on increased fluctuations of water temperature. Moreover, most of the local experts agreed with these points of view. Those above findings are consistent with climate change scenarios in Vietnam on sea level rise, that intense rain would increase in the rainy season, and rainfall would decrease in the dry season (MONRE, 2012). Moreover, the findings also match with the previous studies (De Silva & Soto, 2009; Smyle & Cooke, 2011; World Fish Centre, 2009) on negative impacts of increase and fluctuation of water temperature on aquaculture. However, the perception of shrimp farmers and the local experts showed a discrepancy of views on whether a longer dry season would negatively impact shrimp production. Shrimp farmers in ISMF claimed opposite views of this issue for the last 10 years and the future, while a high percentage of respondents were unable to judge the statement (Tables 4.8 & 4.18), and the majority of local experts have not contended this climate change event. Therefore, while a high percentage of respondents seem unlikely to agree that the dry season would last longer and negatively affect their shrimp farming, a majority of shrimp farmers and local experts alike indicated that irregular weather (Table 4.5) through seasonal pattern changes, increased intense rain and irregular rain would strongly impact shrimp production in the future.

In a regional study, McKinley et al. (2015) found that the importance of climate challenges mostly related to water issues in the Mekong region with the ranking order of salinity, flood, drought, storms or climate hazards, and rainfall trends. At the local level, shrimp farmers and the local experts in this research had a different emphasis on what climate change events would have the most impact on shrimp farming in the next 10–20 years. Increased intensity of high tides was mostly the concern of shrimp farmers in ISMF and SSMF. Meanwhile farmers in ISF mostly focused on increased intense or irregular rains as the greatest impact on their farming, whereas people in RSRF and the local experts were typically concerned with seasonal patterns changing and agreed that this event has the greatest impact on shrimp production. Although they had variable emphases, shrimp farmers and the local experts agreed that seasonal pattern changes, high tides and increased intense or irregular rain would most likely impact shrimp production.

4.7. Conclusion

Overall, in light of the seemingly well researched climate change impacts at the macro level for the region, there was a high level of agreement in the views of individual farmers and local experts in this research that effects of climate change events on shrimp farming are happening. While there was a different emphasis between the local experts and shrimp farmers in the four farming systems concerning adverse effects of climate change events on shrimp farming, shrimp farmers described the adverse effects of climate change and identified the five climate change events most affecting shrimp farming over the last decade. The researcher found a statistically significant strong positive relationship between water level and shrimp production, while there was a statistically significant strong negative relationship between annual rainfall and shrimp production. Also some evidence was found of a relationship between average annual rainfall, average water level, average annual temperature with shrimp production in whole province, RSRF, ISMF. Questioned as to which climate change impacts pose the greatest risk to shrimp farming in the next 10–20 years, local experts and shrimp farmers in RSRF identified the issue of seasonal pattern changes, whereas high tides and greater intensity or irregular rains were identified by shrimp farmers in ISMF, SSMF, and ISF. Moreover, extreme climate events emerged in the range of the five most climate change events agreed to by all respondents. It might be expected that these findings provide a better level of detail and understanding regarding effects of climate change events on shrimp farming perceived by shrimp farmers and the local experts as well as providing more evidence of relationship between shrimp production and climate parameters of temperature, rainfall, and water level.

CHAPTER 5: The Vulnerability of Shrimp Farming to Climate Change

5.1. Introduction

This chapter presents the results of the investigation into shrimp farmers and the local experts on the vulnerability of shrimp farming to climate change addressing the research question: How is shrimp farming in the different systems vulnerable to climate change events? The foci of the chapter are to investigate perspectives of shrimp farmers and the local experts about effects of climate change events regarding shrimp productivity and diseases, to examine characteristics of shrimp farmers, and to investigate the adaptive capacity of shrimp farmers and vulnerability of shrimp farming in the four farming systems.

5.2. Perceptions of climate change events regarding shrimp diseases and productivity (Questions A.1.3.1, A.1.3.2, A.2.7, A.2.8, Appendix A)

Shrimp farmers in the four farming systems and the local experts alike were asked their level of agreement with the statement that climate change events have increased shrimp diseases (Table 5.1), and negatively affected shrimp productivity (Table 5.2) in the last 10 years. Regarding shrimp diseases, 73% of all shrimp farmers agreed with the statement, with 68% in RSRF, 77% in ISMF, 73% in SSMF, and 71% in ISF. A similar result was obtained for shrimp productivity (72%), with 78% of shrimp farmers in RSRF, 73% ISMF, 70% SSMF, and 86% in ISF. All the local experts agreed that climate change events have increased shrimp diseases and negatively affected shrimp productivity. Overall, the research results from both shrimp farmers and the local experts' perspectives show a high level of agreement in response to the statement that climate change events have negatively affected shrimp productivity and increased shrimp diseases in the last decade.

Table 5.1: Shrimp farmers and local experts' perspectives on whether climate change events have increased shrimp diseases in the last 10 years.

Respondents	Strongly agree		Agree		Disagree		Strongly disagree		Unable to judge	
	F[15]	%	F	%	F	%	F	%	F	%
RSRF (n=22)	6	27.3	9	40.9	2	9.1	0	0	5	22.7
ISMF (n=31)	7	22.6	15	48.4	4	12.9	0	0	5	16.1
SSMF (n=26)	1	3.9	16	61.5	3	11.5	0	0	6	23.1
ISF (n=21)	12	57.1	6	28.6	1	4.8	0	0	2	9.5
Experts (n=11)	6	54.5	5	45.5	0	0	0	0	0	0
Total (n = 111)	32	28.8	51	46	10	9	0	0	18	16.2

Table 5.2: Shrimp farmers and local experts' perspectives on whether climate change events have adversely affected shrimp productivity in the last 10 years.

Respondents	Strongly agree		Agree		Disagree		Strongly disagree		Unable to judge	
	F	%	F	%	F	%	F	%	F	%
RSRF (n=22)	3	13.6	12	54.6	2	9.1	1	4.5	4	18.2
ISMF (n=31)	10	32.3	14	45.1	0	0.0	0	0.0	7	22.6
SSMF (n=26)	4	15.4	15	57.7	3	11.5	0	0.0	4	15.4
ISF (n=21)	5	23.8	10	47.6	2	9.5	1	4.8	3	14.3
Experts (n=11)	3	27.3	8	72.7	0	0.0	0	0.0	0	0.0
Total (n = 111)	25	22.5	59	53.2	7	6.3	2	1.8	18	16.2

Interview results from shrimp farmers show that shrimp deaths by diseases occurred during relatively abnormal weather from 2002 to 2012, especially in recent years when abnormal weather occurred more frequently. A farmer in Tan Duyet commune (ISF) made this claim about the occurrence of shrimp diseases in the area:

> Looking back at shrimp farming history, I rarely heard about shrimp diseases before 1995, then locally they appeared from 1996 to 1999; but shrimp diseases emerged more frequently from 2000 to 2012 and very severely occurred in 2012 along with irregular weather.

Shrimp farmers also explained that more frequencies and kinds of shrimp diseases, such as white spot syndrome virus (SSMV), yellow head virus (YHV) and early mortality syndrome (EMS), have occurred over the last two years. According to shrimp farmers' perspectives, there have been more shrimp diseases regularly appearing at the stage of two–months old, after releasing post larvae shrimp, because of abnormal weather such as irregular rains and droughts. For example, in recent years shrimp farmers in ISMF, SSMF, and RSRF had to harvest shrimp earlier to avoid risks caused by irregular weathers and shrimp diseases. They also claimed that shrimp diseases appeared more frequently on extensive and improved

[15] F: frequent response of shrimp farmers and the local experts

extensive shrimp farming systems, showing losses and damages of 30–40% of shrimp productivity. However, farmers in ISF claimed that shrimp diseases in intensive shrimp farming occurred less frequently than in the other systems, but when diseases occurred in this model there were more losses and damages, which was thought to be as high as more than 80% or total loss of shrimp.

5.3. Shrimp farming vulnerability to climate change events

This section presents the research results from household surveys conducted with 100 shrimp farmers representing the four shrimp farming systems. The investigation results include characteristics of respondents and households as well as statistical tests, status of household incomes, and the vulnerability levels of shrimp farming to climate change events.

5.3.1. Respondent and household characteristics and the differences between groups of shrimp farmers

5.3.1.1. Respondent and household characteristics in the four farming systems

Of the 100 shrimp farmer respondents investigated in this research, 25% were female and 75% male (Table 5.3). The average age of shrimp farmers was 51 ± 11 years old; average education was 7 ± 3 years; average family size was 5.6 ± 1.6 persons. A summary of interviewed shrimp farmers' age, education, and family size in each farming system is presented in Table 5.4. The majority of household members achieved secondary schooling. The highest percentage of illiterate household members was 14% for SSMS and 13% for RSRF. The majority of family members fell within the normal working age (16–60 years), with just over half of all family members engaged in shrimp farming (50–58%) for each of the four farming systems (Table 5.5). The overall average age of shrimp farmers was similar among groups, but the average education and family size of shrimp farmers in the four farming systems varied (Table 5.4).

Table 5.3. Sample size and gender of shrimp farmers in the investigation

Shrimp Farmers	Sample size (N)	Gender	Responses	
			Frequency (F)	Percent (%)
RSRF	22	Female	7	22.6
		Male	24	77.4
ISMF	31	Female	5	22.7
		Male	17	77.3
SSMF	26	Female	9	34.6
		Male	17	65.4
ISF	21	Female	4	19.0
		Male	17	81.0

Table 5.4. Summary of shrimp farmers' characteristics in the four farming systems

		N	Mean	Std. Deviation	Std. Error	Min	Max
Age (Year)	ISMF	31	49.64	9.99	1.7958	33.0	67.0
	RSRF	22	52.77	9.06	1.9328	38.0	68.0
	SSMF	26	50.61	11.17	2.1923	37.0	68.0
	ISF	21	52.09	12.14	2.6502	32.0	71.0
	Total	*100*	*51.10*	*10.51*	*1.0518*	*32.0*	*71.0*
Education[16] (Year)	ISMF	31	7.77	3.12	.56	.0	12.0
	RSRF	22	5.36	3.48	.74	.0	11.0
	SSMF	26	6.42	3.73	.73	.0	12.0
	ISF	21	8.38	2.29	.49	4.0	12.0
	Total	*100*	*7.02*	*3.37*	*.33*	*.0*	*12.0*
Family size (Person/Household)	ISMF	31	5.32	1.66	.29	3.0	9.0
	RSRF	22	5.59	1.25	.26	4.0	8.0
	SSMF	26	6.26	1.66	.32	3.0	10.0
	ISF	21	5.04	1.32	.28	3.0	7.0
	Total	*100*	*5.57*	*1.55*	*.15*	*3.0*	*10.0*

Table 5.5. Education of household members and labour distribution in the four farming systems

	Education of household members (Year–%)					Labour distribution (%)	
	Illiterate	1–5	6–9	10–12	Higher	Labour Age	Aqua. Labour
RSRF (n=22)	13.0	6.5	51.2	16.3	14.6	76.4	54.5
ISMF (n=31)	6.1	12.8	50.0	22.6	8.5	67.1	56.1
SSMF (n=26)	13.8	10.1	38.4	27.7	10.1	64.2	49.7
ISF (n=21)	3.7	9.3	45.8	28.0	7.5	71.0	57.9
Total (n=100)	9.4	9.9	46.1	23.7	8.5	69.1	54.2

[16] Education investigated in this research refers to school years or grade that shrimp farmers attended school. There are 12 years of formal education in Vietnam from primary school to high school, adding number of years if respondents attend higher degrees.

5.3.1.2. Different characteristics (age, education, and family size) between groups of shrimp farmers in the four farming systems

Table 5.6 shows a one-way ANOVA test that was conducted to compare the different characteristics of age, education, and family size for groups of shrimp farmers in the four farming systems at the 0.05 significance level. There were statistically significant differences for groups of shrimp farmers in education for the three conditions [f(3,96) = 4.03, p = 0.01] and for groups of shrimp farmers in family size [f(3,96) = 2.95, p = 0.036]. However, average age was not a statistically significant difference for groups of shrimp farmers in the four farming systems at the 0.05 significance level [f(3, 96) = 0.45, p = 0.713]. Therefore, the mean of education and family size is not the same for all groups of shrimp farmers. The next step is to explore where the differences between mean of education and family size are found in a paired-samples t-test.

Table 5.6. One-way ANOVA analysis of variance of age, education, and family size in groups of shrimp farmers in the four farming systems

		Sum of Squares	Df	Mean Square	F	Sig.
Age (Year)	Between Groups	154.07	3	51.35	.45	.713
	Within Groups	10798.92	96	112.48		
	Total	10953.00	99			
Education (Year)	Between Groups	126.15	3	42.05	4.03	.010
	Within Groups	1001.80	96	10.43		
	Total	1127.96	99			
Family size (Persons hh^{-1})	Between Groups	20.35	3	6.78	2.95	.036
	Within Groups	220.16	96	2.29		
	Total	240.51	99			

The paired-samples t-test in Table 5.7 was conducted to compare the average education of shrimp farmers in the four farming systems. The test results show that there was a statistically significant difference for average education at the 0.05 level of significant in Pair 1 of ISF–SSMF (t = 2.23, p = 0.037), Pair 2 of ISF–RSRF (t = 4.25, p < 0.001), and Pair 6 of RSRF–ISMF (t = -2.93, p = 0.08). However, there was no statistically significant difference for average education at the 0.05 significance level in Pair 3 (ISF–ISMF), Pair 4 (SSMF–RSRF), and Pair 5 (SSMF–ISMF). On average, education in ISF is greater than in SSMF and RSRF, whereas average education in RSRF is smaller than in ISMF.

Table 5.7. Descriptive statistics and t-test results for average education of shrimp farmers in the four farming systems

		Paired Differences							
					95% CI for Mean Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	T	df	Sig. (2-tailed)
Pair 1	ISF – SSMF	2.09	4.30	.93	.13	4.05	2.23	20	.037
Pair 2	ISF – RSRF	3.28	3.53	.77	1.67	4.89	4.25	20	.000
Pair 3	ISF – ISMF	.47	3.80	.82	-1.25	2.21	.57	20	.572
Pair 4	SSMF - RSRF	1.04	4.70	1.00	-1.04	3.13	1.04	21	.309
Pair 5	SSMF – ISMF	-1.53	5.11	1.00	-3.60	.53	-1.53	25	.138
Pair 6	RSRF - ISMF	-2.68	4.29	.91	-4.58	-.78	-2.93	21	.008

As displayed in Table 5.8, the results of the paired-samples t-test show that average family size statistically differed for Pair 1 (t = -3.05, p = 0.006) and Pair 5 (t = 2.24, p = 0.034) at the 0.05 significance level, while there was no statistically significant difference for Pairs 2, 3, 4, and 6. Although all groups had similar average ages (Table 5.6), the average family size in ISF was smaller than in SSMF, whereas the average family size in SSMF was bigger than ISMF.

Table 5.8. Descriptive statistics and t-test results for family size of shrimp farmers in the four farming systems

		Paired Differences							
					95% CI for Mean Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	Sig. (2-tailed)
Pair 1	ISF - SSMF	-1.28	1.92	.42	-2.16	-.40	-3.05	20	.006
Pair 2	ISF - RSRF	-.52	1.83	.40	-1.35	.31	-1.30	20	.205
Pair 3	ISF - ISMF	-.19	2.33	.51	-1.25	.87	-.37	20	.713
Pair 4	SSMF - RSRF	.90	1.54	.32	.22	1.59	2.16	21	.052
Pair 5	SSMF – ISMF	1.07	2.44	.48	.08	2.06	2.24	25	.034
Pair 6	RSRF – ISMF	.40	1.68	.35	-.33	1.15	1.14	21	.266

5.3.2. Households' income status and their statistics tests

5.3.2.1. Income streams of shrimp farmers in the four farming systems

Descriptive statistics of the income streams (income sources of households) for shrimp farmers in the four farming systems are presented in Table 5.9 and Figure 5.1. It was found that farmers in the four shrimp farming systems engaged in different activities to generate income sources, although they were mostly concerned with farming cultivation. The main income-generating activities of shrimp farmers included shrimp farming, poultry and pigs, wages from hired labour, vegetables, aquatic exploitation, and local trading (such as shrimp middlemen, shrimp feeds, nurseries, and hatcheries). The proportions of income streams of shrimp farmers in the four farming systems are presented in turn.

Of the shrimp farmers in SSMF, 77% had only one income source to generate family income, compared with 35% of shrimp farmers in RSRF, 25% in ISMF, and 22% in ISF. The majority of shrimp farmers in ISF (62%) and in RSRF (55%) had two income streams, with lower proportions in ISMF (44%) and in SSMF (15%). Meanwhile, there was a small number of farmers who had three income streams: 25% in ISMF, 16% in ISF, 11% in RSRF, and 8% in SSMF. Finally, a very small number of shrimp farmers in ISMF had four income streams (7%). The results indicate that the majority of shrimp farmers in SSMF had only one income stream, whereas two-income streams were common in ISF and RSRF, and the greatest number of income streams were in ISMF (Figure 5.1).

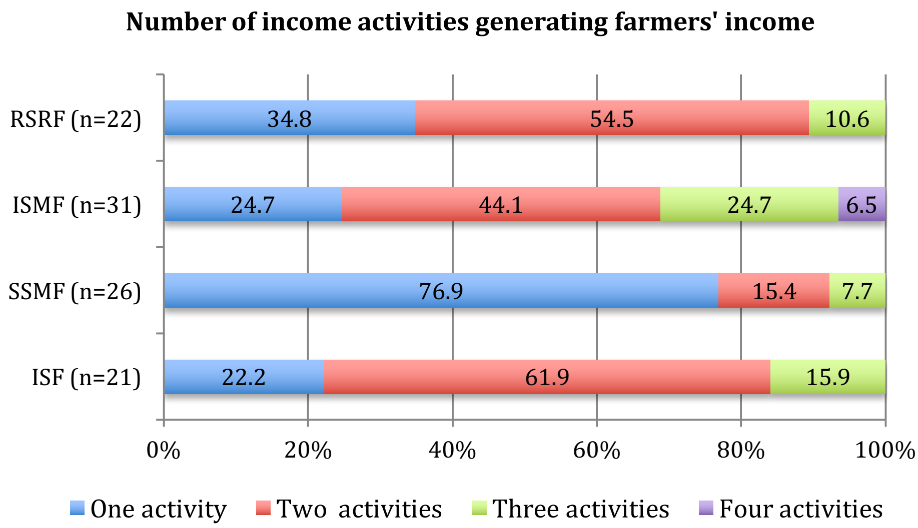

Figure 5.1. Number of main activities to generate income for shrimp farmers in the four farming systems

Moreover, the average income stream varied among shrimp households in the four farming systems, with the greatest in ISMF (2.0 ± 0.7), then in ISF (1.9 ± 0.6) and in RSRF (1.8 ± 0.7), and the lowest in SSMF (1.3 ± 0.6). The average income stream was greater in farmer families, indicating that those families had more activities to generate household income.

Table 5.9. Descriptive statistics for income streams of shrimp farmers in the four farming systems

		N	Mean	Std. Deviation	Std. Error	Min	Max
Income streams	ISMF	31	2.00	.73	.13	1.0	4.0
	RSRF	22	1.82	.73	.16	1.0	3.0
	SSMF	26	1.31	.62	.12	1.0	3.0
	ISF	21	1.91	.62	.14	1.0	3.0
	Total	100	1.79	.86	.08	1.0	4.0

5.3.2.2. Farming experience[17] of shrimp farmers in the four farming systems

Farmers investigated in this research had variable lengths of experience in the shrimp farming industry. Table 5.10 shows that ISMF farmers (Dat Mui Commune) had 19.7 ± 7.4 years to practise shrimp farming, RSRF (Phong Dien Commune) had 11.0 ± 4.0 years, SSMF (Tam Giang Dong Commune) had 12.8 ± 7.4 years, and ISF (Tan Duyet Commune) farmers had 18 ± 6.2 years' experience in shrimp farming. The results suggest that shrimp farmers in ISMF and ISF have had greater farming experience than those farmers in SSMF and RSRF. A cause of these different means could be explained by the land-use policies in Ca Mau Province, where the government has encouraged change from rice to shrimp production since 2000 in some areas, such as Phong Dien Commune, whereas the majority of shrimp farmers in Tam Giang Dong Commune have received forest land approvals to practise separated shrimp-mangrove farming (SSMF).

Table 5.10. Descriptive statistics for farming experience (year) of shrimp farmers in the four farming systems

		N	Mean	Std. Deviation	Std. Error	Min	Max
Farming experience	ISMF	31	19.67	7.35	1.32	6.0	41.0
	RSRF	22	11.04	2.95	.63	7.0	16.0
	SSMF	26	12.80	7.39	1.45	5.0	41.0
	ISF	21	18.00	6.15	1.34	7.0	29.0
	Total	100	15.64	7.26	.72	5.0	41.0

5.3.2.3. Shrimp area, shrimp income and household income of shrimp farmers in the four farming systems

Table 5.11 shows descriptive statistics of the shrimp area, shrimp income, and household income of shrimp farmers in the four farming systems. The average shrimp area in SSMF was largest with 3.5 ± 1.5 ha, with 2.1 ± 0.2 ha in ISMF and 1.7 ± 0.5 ha in RSRF, whereas the average shrimp area in ISF was smallest with 1.2 ± 0.5 ha. Irrespective of farming system

[17] Farming experience in this research is defined as number of years that shrimp farmers have practised shrimp farming

types, farmers in ISF earned the most from average shrimp income with 222.6 ± 291.5 VND$ M ha^{-1} $year^{-1}$ and this was much higher than the other systems, with 42.0 ± 20.1 VND$ M ha^{-1} $year^{-1}$ in ISMF, 18.7 ± 11.4 VND$ M ha^{-1} $year^{-1}$ in SSMF, and 16.5 ± 8.7 VND$ M ha^{-1} $year^{-1}$ in RSRF. Similar to shrimp income, the average household income of shrimp farmers in ISF was greatest with 321 ± 517.6 VND$ M hh^{-1} $year^{-1}$, then ISMF with 128.1 ± 113.2 VND$ M hh^{-1} $year^{-1}$ and in SSMF with 91.0 ± 66.9 VND$ M hh^{-1} $year^{-1}$, whereas shrimp farmers in RSRF earned the lowest the average household income with 49 ± 34.5 VND$ M hh^{-1} $year^{-1}$. Shrimp farmers in ISF had smallest average shrimp area, but earned greatest in both shrimp and household income, whereas shrimp farmers in RSRF had the smallest shrimp and household income, and shrimp farmers ISMF had a more favourable income than in RSRF and SSMF. However, the average shrimp income and household income fluctuated among households in the four farming systems, but were greatest in ISF.

Table 5.11. Descriptive statistics for shrimp area (ha hh^{-1}), household[18] income (VND$ M hh^{-1} $year^{-1}$), and shrimp income (VND$ M ha^{-1} $year^{-1}$) of shrimp farmers in the four farming systems

		N	Mean	Std. Deviation	Std. Error	Min	Max
Shrimp area (ha hh^{-1})	ISMF	31	2.08	1.11	.20	.70	5.80
	RSRF	22	1.69	.53	.11	.80	3.10
	SSMF	26	3.51	1.52	.73	1.50	8.00
	ISF	21	1.16	.53	.11	.50	3.00
	Total	100	2.54	2.47	.24	.50	13.30
Household income (VND$ M hh^{-1} $year^{-1}$)	ISMF	31	128.10	113.18	20.32	8.0	455.0
	RSRF	22	49.00	34.46	7.34	17.0	165.0
	SSMF	26	90.96	66.86	13.11	3.0	280.0
	ISF	21	321.90	517.59	112.94	10.0	1886.0
	Total	100	141.74	262.52	26.25	3.0	1886.0
Shrimp income (VND$ M ha^{-1} $year^{-1}$)	ISMF	31	41.99	20.60	3.70	8.00	89.66
	RSRF	22	16.50	8.69	1.85	.00	34.37
	SSMF	26	18.69	11.35	2.22	.75	40.80
	ISF	21	222.62	291.60	63.63	.00	1215.00
	Total	100	68.26	154.48	15.44	.00	1215.00

5.3.2.4. Statistic tests for differences between groups of shrimp farmers in farming experience, income stream, shrimp income and household income

As displayed in Table 5.12, a one-way ANOVA test was conducted to compare characteristics between groups of shrimp farmers in the four farming systems for mean of

[18] M: million; Household: hh; Hectare (ha) per household: ha hh^{-1}; Total income per household per year: VND$ M hh^{-1} $year^{-1}$; Shrimp income per hectare per year: VND$ M ha^{-1} $year^{-1}$

farming experience, income stream, shrimp income, and household income. There were statistically significant differences between groups at the 0.05 level of significance for farming experience [f(3,96) = 10.53, p < 0.001], for income stream [f(3,96) = 14.19, p < 0.001], for shrimp income [f(3,96) = 12.0, p < 0.001], and for household income [f(3, 96) = 5.13, p = 0.002]. Because of these differences in the four farming systems a paired-samples t-test was used to explore significant differences between the mean of each indicator for a pair of groups of shrimp farmers in the four farming systems in Tables 5.13-5.16.

Table 5.12. One-way ANOVA analysis of variance of farming experience (year), income stream, shrimp income (VND$ M ha^{-1} year^{-1}), and household income (VND$ M hh^{-1} year^{-1}) in groups of shrimp farmers in the four farming systems

		Sum of Squares	Df	Mean Square	f	Sig.
Farming experience (Year)	Between Groups	1295.27	3	431.75	10.53	.000
	Within Groups	3933.76	96	40.97		
	Total	5229.04	99			
Income streams (Income sources)	Between Groups	22.92	3	7.64	14.19	.000
	Within Groups	51.67	96	.53		
	Total	74.59	99			
Household income (VND$ M hh^{-1} year^{-1})	Between Groups	943669.03	3	314556.34	5.13	.002
	Within Groups	5879095.57	96	61240.57		
	Total	6822764.60	99			
Shrimp Income (VND$ M hh^{-1} year^{-1})	Between Groups	644579.35	3	214859.78	12.00	.000
	Within Groups	1718252.50	96	17898.46		
	Total	2362831.86	99			

The results of the paired-samples t-test as displayed in Table 5.13 show that the mean of farming experience had a statistically significant difference at the 0.05 significance level for shrimp farmers in ISF–SSMF (Pair 1) (t = 3.29, p = 0.004), in ISF–RSRF (Pair 2) (t = 3.99, p = 0.001), in SSMF–ISMF (Pair 5) (t = -3.22, p = 0.004), and in RSRF–ISMF (Pair 6) (t = -5.47, p < 0.001), but there was no statistically significant difference for the ISF–ISMFF (Pair 3) and the SSMF–RSRF (Pair 4). On average, there was statistical evidence that shrimp farmers in ISF and ISMF had more experience in the farming industry than in RSRF and SSMF.

Table 5.13. Descriptive statistics and t-test results for farming experience of shrimp farmers in the four farming systems

		Paired Differences							
					95% CI for Mean Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	Sig. (2-tailed)
Pair 1	ISF – SSMF	6.33	8.81	1.92	2.32	10.34	3.294	20	.004
Pair 2	ISF – RSRF	6.95	7.97	1.74	3.32	10.58	3.993	20	.001
Pair 3	ISF – ISMF	-1.23	7.66	1.67	-4.72	2.24	-.741	20	.468
Pair 4	SSMF – RSRF	.63	5.69	1.21	-1.88	3.16	.524	21	.606
Pair 5	SSMF – ISMF	-5.65	8.96	1.75	-9.27	-2.03	-3.215	25	.004
Pair 6	RSRF – ISMF	-7.95	6.81	1.45	-10.97	-4.93	-5.476	21	.000

Table 5.14 shows there were statistically significant differences at the 0.05 significance level in mean of income streams for Pair 1 (ISF–SSMF) ($t = 2.75$, $p = 0.012$) and for Pair 5 (SSMF–ISMF) ($t = -4.32$, $p < 0.001$), but not for ISF–RSRF (Pair 2), ISF–ISMF (Pair 3), SSMF–RSRF (Pair 4), and for RSRF–ISMF (Pair 6). Overall there was statistical evidence that shrimp farmers in ISMF and ISF had more activities to generate family income than farmers in SSMF; however, there was no statistical evidence that shrimp farmers in RSRF had more or fewer activities to generate household income than those shrimp farmers in ISF, ISMF, and SSMF.

Table 5.14. Descriptive statistics and t-test results for income streams of shrimp farmers in the four farming systems

		Paired Differences							
					95% CI for Mean Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	T	df	Sig. (2-tailed)
Pair 1	ISF – SSMF	.52	.87	.19	.13	.92	2.75	20	.012
Pair 2	ISF – RSRF	.10	.94	.21	-.33	.52	.46	20	.649
Pair 3	ISF – ISMF	-.29	1.15	.25	-.81	.24	-1.14	20	.267
Pair 4	SSMF – RSRF	-.45	1.06	.23	-.92	.01	-2.02	21	.057
Pair 5	SSMF – ISMF	-.77	.91	.18	-1.14	-.40	-4.32	25	.000
Pair 6	RSRF – ISMF	-.36	1.00	.21	-.81	.08	-1.70	21	.104

As shown in Table 5.15, the results of the paired-samples t-test indicate statistically significant differences at the 0.05 significance level in mean of shrimp income for Pair 1 ($t = 3.20$, $p = 0.004$), for Pair 2 ($t = 3.20$, $p = 0.004$), for Pair 3 ($t = 2.78$, $p = 0.011$), for Pair 5 ($t = -5.11$, $p < 0.001$), and for Pair 6 ($t = -6.19$, $p < 0.001$). However, there was no statistically significant difference for Pair 4 (SSMF–RSRF). Thus, mean of shrimp income (VND$ M ha^{-1} $year^{-1}$) for shrimp farmers in ISF was higher than the mean of shrimp income of shrimp farmers in ISMF, RSRF, and in SSMF; and the average shrimp income of shrimp farmers in SSMF and RSRF were lower than in ISMF.

Table 5.15. Descriptive statistics and t-test results for shrimp income (VND$ M ha^{-1} $year^{-1}$) of farmers in the four farming systems

		Paired Differences							
					95% CI for Mean Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	Df	Sig. (2-tailed)
Pair 1	ISF – SSMF	203.39	290.72	63.44	71.06	335.73	3.20	20	.004
Pair 2	ISF – RSRF	205.99	294.57	64.28	71.90	340.08	3.20	20	.004
Pair 3	ISF – ISMF	176.23	289.93	63.26	44.25	308.21	2.78	20	.011
Pair 4	SSMF – RSRF	3.12	15.02	3.20	-3.54	9.78	.97	21	.341
Pair 5	SSMF – ISMF	-25.02	24.96	4.89	-35.10	-14.93	-5.11	25	.000
Pair 6	RSRF – ISMF	-29.13	22.07	4.70	-38.92	-19.34	-6.19	21	.000

Finally, Table 5.16 demonstrates a paired-samples t-test that was conducted to compare average household income of shrimp farmers in the four farming systems. The results show statistically significant differences at the 0.05 significance level in mean of household income for Pair 1 ($t = 2.20$, $p = 0.040$), for Pair 2 ($t = 2.72$, $p = 0.013$), for Pair 4 ($t = 4.52$, $p < 0.001$), and for Pair 6 ($t = -4.04$, $p = 0.001$); however, there were no statistically significant differences for Pairs 3 (ISF–ISMF) and 5 (SSMF–ISMF) at the 0.05 significance level. Overall, the average household income (VND$ M hh^{-1} $year^{-1}$) of shrimp farmers in ISF was higher than in SSMF and in RSRF, whereas the average household income of shrimp farmers in ISMF and SSMF were higher than in RSRF.

Table 5.16. Descriptive statistics and t-test results for household income (VND$ M hh^{-1} $year^{-1}$) of shrimp farmers in the four farming systems

		Paired Differences							
					95% CI for Mean Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	Df	Sig. (2-tailed)
Pair 1	ISF – SSMF	178.54	372.46	81.27	9.00	348.09	2.197	20	.040
Pair 2	ISF – RSRF	232.26	391.90	85.52	53.86	410.65	2.716	20	.013
Pair 3	ISF – ISMF	144.00	397.44	86.72	-36.91	324.91	1.660	20	.112
Pair 4	SSMF – RSRF	57.13	59.26	12.63	30.86	83.41	4.522	21	.000
Pair 5	SSMF - ISMF	-21.29	127.18	24.94	-72.66	30.07	-.854	25	.401
Pair 6	RSRF - ISMF	-85.84	99.69	21.25	-130.04	-41.63	-4.039	21	.001

Putting all the above findings together, an interesting picture of shrimp farmer characteristics in this research emerges, indicating that there are some linkages between household income and household characteristics – with certain ramifications. While all groups had no different average ages, shrimp farmers in ISF and ISMF had smaller family size (than in SSMF), higher years schooling (than in RSRF), greater farming experience, more income streams, and higher both shrimp income and household income than shrimp farmers in RSRF and SSMF. It would appear that shrimp farmers in the systems that had higher education, smaller family size, diverse household income streams, more experience in the farming industry earned higher incomes than did shrimp farmers in the other farming systems. This is relevant to vulnerability of shrimp farmers in the four farming systems to climate change events, as presented in the next section.

5.3.3. The vulnerability of shrimp farming to climate change events

5.3.3.1. Risk assessment results

The important climate change events ranked by shrimp farmers that adversely affected shrimp production in the four shrimp farming systems, as presented in Chapter 4, were discussed in the focus groups. Participants were asked to categorise the likelihood of occurrence (ranging from 1 – rare, to 5 – almost certain) and consequence (1 – insignificant, to 5 – catastrophic) to obtain the level of risk of climate change events on shrimp production. The levels of risk were derived from multiplying the scores of livelihood and consequence, ranked as extreme risk (E ≥ 20), high risk (H = 12–20), medium risk (M = 5–12), and low risk (L ≤ 5). The results of the risk priority matrix of each climate change event on farmers' shrimp production in each of the farming systems are presented in Table 5.17. Overall, all shrimp farmers considered the climate event of "greater intensity or irregular rains" as "high risk"; and all other climate change events as a "medium risk" to shrimp farming.

Table 5.17. Risk priority matrix of climate change events on shrimp farming income ranked by shrimp farmers in the four farming systems

Climate change events	Farming systems	Consequence	Likelihood	Risk
	RSRF	4	5	20
	ISMF	3	5	15
Greater intensity or irregular rains	SSMF	4	4	16
	ISF	2	5	10
	Average	***3.3***	***4.8***	***15.4***
	RSRF	4	4	16
	ISMF	3	3	9
Seasonal pattern changes	SSMF	3	3	9
	ISF	2	2	4
	Average	***3***	***3***	***9***
	RSRF	3	4	12
	ISMF	3	4	12
Increased intensity of high tides	SSMF	4	5	20
	ISF	1	2	2
	Average	*2.8*	*3.8*	*10.3*
	RSRF	2	3	6
	ISMF	3	4	12
Sea level rise	SSMF	5	5	25
	ISF	1	1	1
	Average	***2.8***	***3.3***	***8.9***

Climate change events	Farming systems	Consequence	Likelihood	Risk
Drier dry season	RSRF	1	4	4
	ISMF	1	3	1
	SSMF	2	3	6
	ISF	2	5	10
	Average	***1.5***	***3.8***	***5.6***
Increased fluctuations of water temperature	RSRF	2	4	8
	ISMF	1	3	3
	SSMF	1	4	4
	ISF	4	5	20
	Average	**2**	**4**	**8**
Extreme climate events	RSRF	4	3	12
	ISMF	4	2	8
	SSMF	4	2	8
	ISF	3	1	3
	Average	***3.8***	***2.0***	***7.5***

Other perceived risk levels of climate change impacts in each shrimp farming system (summarised in Table 5.18) are noteworthy. First, shrimp farmers considered "greater intensity or irregular rains" as "high risk" in RSRF, ISMF and SSMF, but "medium risk" in ISF. Second, seasonal pattern changes were ranked as "high risk" by farmers in RSRF, "medium risk" in ISMF and SSMF, and "low risk" in ISF. Third, increased intensity of high tides was judged "high risk" in SSMF, "medium risk" in RSRF and ISMF, and "low risk" in ISF. Fourth, people in SSMF ranked sea level rise as an "extreme risk" to their shrimp production, and a "medium risk" in ISMF; whereas shrimp farmers in the other farming systems considered this climate issue a "low risk". Fifth, a drier dry season was ranked as a "medium risk" in SSMF and ISF. Sixth, shrimp farmers considered increased fluctuations of water temperature as a "high risk" in ISF, a "medium risk" in RSRF, and a "low risk" in ISMF and SSMF. Finally, only farmers in ISF considered extreme climate events as "low risk", while farmers in the other systems ranked this as a "medium risk". Overall then, the perceived risk level to shrimp farming income for all climate change impacts was highest in SSMF, then in RSRF and ISMF, while the lowest risk was in ISF.

These results may help those concerned to understand that shrimp farmers have acknowledged and experienced effects of some climate change events in the Ca Mau region, such as greater intensity or irregular rains, seasonal pattern changes, high tides, and fluctuations of water temperature. This experience corresponded with perspectives of the majority of shrimp farmers and local experts that these issues have adversely affected shrimp production in the last 10 years (see Section 4.2.2) as well as perceptions of climate change events regarding shrimp diseases and productivity (Section 5.2). Furthermore, rainfall is a very important parameter affecting shrimp production (Noyes et al., 2009) and rainfall increase may possibly decrease shrimp productivity (Table 4.31), especially intense rain or irregular rains (Section 4.6.1). More discussion related to risks on shrimp farming vulnerability to climate change events is presented in Section 5.4.3.

Table 5.18. Summary of risk level of climate change impacts on shrimp farming income

Climate change events	Levels of risk			
	RSRF	ISMF	SSMF	ISF
Greater intensity or irregular rains	High (20)	High (15)	High (16)	Medium (10)
Seasonal pattern changes	High (16)	Medium (9)	Medium (9)	Low (4)
Increased intensity of high tides	Medium (12)	Medium (12)	High (20)	Low (2)
Sea level rise	Low (6)	Medium (12)	E (25)	Low (1)
Drier dry season	Low (4)	Low (1)	Medium (6)	Medium (10)
Increased fluctuations of water temperature	Medium (8)	Low (3)	Low (4)	High (20)
Extreme climate events	Medium (12)	Medium (8)	Medium (8)	Low (3)
All climate change events	Medium (11.0)	Medium (8.0)	High (12.2)	Medium (6.4)

5.3.3.2. Adaptive capacity of shrimp farmers in the four farming systems

The adaptive capacity of shrimp farmers is based on five capitals: human, social, natural, physical, and financial capital (Ellis, 2000). The description of the capitals, indicators, cores and rankings to assess the adaptive capacity of shrimp farmers in the four farming systems is presented in Table 3.3, 4.4, and 3.5 (see Section 3.2.6, Chapter 3). Each indicator was scored by shrimp farmers with numbers from "0" to "5" and ranked as low adaptive capacity with a score value of "0" or "1", medium adaptive capacity with a score value of "2" or "3", and high adaptive capacity with a score value of "4" or "5". Scores and rankings for adaptive capacity of shrimp farmers in the four farming systems are summarized in Table 5.19.

Table 5.19. Summary of cores and rankings based on capitals of shrimp farmers in the four farming systems

Capitals	Indicator	RSRF	ISMF	SSMF	ISF	*Average*
Human	Education	3	3	2	3	*2.75*
	Farming experience	3	5	4	4	*4*
	Family members at aged labour and involved in shrimp farming	4	3	3	4	*3.5*
	Health (physical capacity and dependant members)	4	4	3	4	*3.75*
	Total Human	*3.5*	*3.75*	*3*	*3.7*	*3.5*
Social	Involved community organizations and or shrimp farming groups	4	2	2	5	*3.25*
	Volunteering as participation, lead and represent	2	2	2	3	*2.25*
	Usage and access to Internet and local media	3	2	2	4	*2.75*
	Total Social	*3*	*2*	*2*	*4*	*2.75*
Natural	Shrimp farming area	2	4	5	2	*3.25*
	Soil health	2	5	4	5	*4*
	Water quantity supplied for shrimp farming	3	5	5	4	*4.25*

Capitals	Indicator	RSRF	ISMF	SSMF	ISF	*Average*
	Water quality supplied for shrimp farming	3	4	4	3	*3.5*
	Biodiversity and conservation	3	5	4	2	*3.5*
	Total Natural	*2.6*	*4.6*	*4.4*	*3.2*	*3.7*
Physical	Transportation convenience	4	2	2	5	*3.25*
	Electricity usage	4	4	4	5	*4.25*
	Types of house or degrees of solidification	3	2	2	4	*2.75*
	Sluice gates, embankments, and sea dikes	2	3	2	5	*3*
	Total Physical	*3.25*	*2.75*	*2.5*	*4.7*	*3.31*
	Income stream variety	2	4	2	3	*2.75*
	Availability of cash to do shrimp farming	1	2	1	3	*1.75*
	Total household income	2	3	2	4	*2.75*
Financial	Shrimp income	2	4	3	4	*3.25*
	Ability of access to finance	4	3	3	5	*3.75*
	Total Financial	*2.2*	*3.2*	*2.2*	*3.8*	*2.85*
	Total capitals	**2.9**	**3.3**	**2.8**	**3.9**	***3.2***

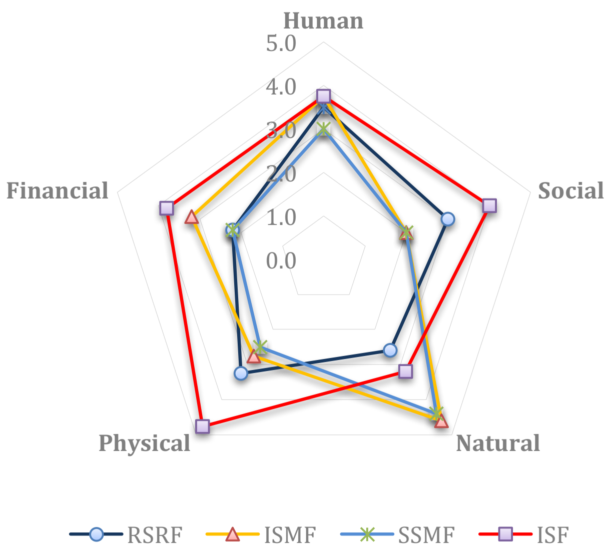

Figure 5.2. Adaptive capacity ranking based on five capitals perceived by shrimp farmers in the four farming systems.

All shrimp farmers in the four farming systems were ranked as having medium adaptive capacity to climate change events on shrimp production based on the five capitals (Table 5.19). However, the average score of ranking for adaptive capacity of shrimp farmers in ISF was the greatest, next was in ISMF, then in RSRF and SSMF was the least. Regarding each capital, the adaptive capacity ranking of shrimp farmers varied considerably to type of shrimp farming system. Whereas shrimp farmers in ISMF and SSMF had greatest adaptive capacity in natural assets, shrimp farmers in ISF had greatly adaptive capacity in their physical, financial and social assets (Figure 5.2).

Regarding each climate change event, shrimp farmers in the four farming systems classified levels of adaptive capacity variously (Table 5.20). The levels of adaptive capacity of farmers in ISF and ISMF were perceived to be higher than those of farmers in SSMF and RSRF. This is because of greater adaptive capacity based on the five capitals (Table 5.19); the farmers in ISF and ISMF earned a higher family income, as previous results have revealed. More specifically, shrimp farmers in ISF had a high adaptive capacity to the climate change events of increased intensity of high tides, sea level rise, and increased fluctuation of water temperature; whereas, as might be expected, all shrimp farmers in all systems had a low adaptive capacity to seasonal pattern changes. In ISMF, farmers had a low adaptive capacity to seasonal pattern changes and sea level rise, but had a medium adaptive capacity in relation to all other climate change events. Finally, farmers in SSMF and RSRF recorded a medium adaptive capacity to increased intensity of high tides and increased fluctuation of water temperature, and a low adaptive capacity to the remaining climate change events on the list.

Table 5.20. Levels of adaptive capacity to climate change events for each farming system categorized by shrimp farmers

Climate change impact	**Levels of adaptive capacity**			
	RSRF	**ISMF**	**SSMF**	**ISF**
Greater intensity or irregular rains	Low	Medium	Low	Medium
Seasonal pattern changes	Low	Low	Low	Low
Increased intensity of high tides	Medium	Medium	Medium	High
Sea level rise	Low	Low	Low	High
Drier dry season	Low	Medium	Low	Medium
Increased fluctuations of water temperature	Medium	Medium	Medium	High
Extreme climate events	Low	Medium	Low	Medium

5.3.3.3. Vulnerability of shrimp farming income to climate change events

The vulnerability levels of shrimp farming income of farmers in each farming systems in relation to climate change impact were formulated by combining levels of risk and adaptive capacity (Table 5.21). Both RSRF and SSMF showed mostly high and moderate levels of shrimp farming income vulnerability to climate change events, with ISMF and ISF fairly evenly split between moderate and low vulnerability levels.

Table 5.21. Vulnerability level of shrimp farming income derived from combining risk level and adaptive capacity

Climate change impact	Levels of Vulnerability			
	RSRF	ISMF	SSMF	ISF
Greater intensity or irregular rains	High	Moderate	High	Moderate
Seasonal pattern changes	High	Moderate	Moderate	Low
Increased intensity of high tides	Moderate	Moderate	Moderate	Low
Sea level rise	Low	Moderate	High	Low
Drier dry season	Low	Low	Moderate	Moderate
Increased fluctuations of water temperature	Moderate	Low	Low	Moderate
Extreme climate events	Moderate	Moderate	Moderate	Low

5.4. Discussion

From the original data and information collected in Ca Mau Province, there is evidence that shrimp production is vulnerable to climate change events as perceived by shrimp farmers in the four farming systems and the local experts. This vulnerability is borne out by the perspectives of shrimp farmers and local experts on shrimp diseases and productivity, status of household income, and their vulnerability of shrimp farming ranking in all four shrimp farming systems to climate change events.

5.4.1. Perceptions that climate change events increased shrimp diseases

The majority of shrimp farmers (72%) in the four farming systems agreed that climate change events have increased shrimp diseases in the last decade, whereas all local experts were in strong agreement with the statement (Table 5.1). Based on local experts' perspectives, shrimp losses and deaths by disease had been increasing and were more prevalent during the last 10 years, especially in the last 3–5 years. The experts ranked three climate events that had likely increased shrimp diseases: (i) seasonal pattern changes; (ii) greater intensity or irregular rains, and irregular droughts; and (iii) increased fluctuations of the water temperature and salinity in the shrimp ponds. In support of this point of view, the majority of shrimp farmers also contended that irregular weather – such as greater intensity or irregular rains and increased water temperature – were likely main causes that increased shrimp diseases. The experts explained that heavy rains frequently appeared in the sunny season or increased in frequency over prolonged hot spells, followed by local droughts in the rainy season for 20 to 30 days, and then heavy rains occurred again, leading to changes and fluctuation in water temperature and salinity.

Broad support for those above perspectives resides with scientists' claims that disease outbreaks highly affect aquaculture farms (Joffre & Bosma, 2008) and that climate change events, such as irregular weather and fluctuations of temperature and precipitation reduce water quality, create an inconvenient environment for shrimp growth, and cause shrimp disease outbreaks (Abery et al., 2009; De Silva & Soto, 2009; Ficke et al., 2007; NACA, 2011; Najjar et al., 2010; Noyes et al., 2009; Tendencia et al., 2011; Tendencia & Verreth, 2011). However, climate is only one of the risk factors for shrimp diseases such as for white spot syndrome virus (WSSV) (Tendencia & Verreth, 2011). There were some arguments that transmission of WSSV can be increased by some cultivation techniques or environmental issues. For example, the occurrence of WSSV in IESF (improved extensive shrimp farming) can be caused by recycling between ponds. And WSSV in semi-intensive shrimp farming is mainly transmitted from neighbouring farms (Hoa et al., 2011b), environmental stress (Direkbusarakom & Danayadol, 1998). Furthermore, WSSV occurs in ISF when waste stream exceeds environmental standards (Anh et al., 2010). Nevertheless, the variation of WSSV loads was correlated with climate change events (Zhang et al., 2016). For instance, scientists have concluded that low ambient atmospheric temperature and high daily atmospheric variation were prompting factors for WSSV occurrence (Tendencia et al., 2011; Piamsomboon et al., 2016; Waibel et al., 2017), but shrimp cultivation during the warmer season was less likely to experience WSSV (Corsin et al., 2005, as cited in Tendencia et al., 2011).

However, the claims above seem unlikely for shrimp farms in Ca Mau Province because shrimp farmers there mainly cultivate shrimp in the warm season (dry season). Moreover, data recorded over the last 25 years shows that, although the average temperature has increased, variation between maximum temperature and minimum temperature has decreased (Figures 4.2-4.4). Nevertheless, climate factors such as irregular rains and droughts have been strongly emphasised by both the local experts and Ca Mau shrimp farmers as being associated with shrimp diseases. Shrimp farmers in ISF recognised particularly shrimp disease occurrence with high frequency, such as white spot syndrome virus (WSSV), yellow head virus (YHV). A majority of the local experts claimed that shrimp diseases occurred more frequently in RSRF, ISMF, SSMF (extensive or improved extensive shrimp farming) than ISF (intensive shrimp farming). The above claim matches with Hoa et al. (2011a) that there were more WSSV occurrence in improved-extensive farming than in semi-intensive farming because WSSV populations in extensive farms would be more stable over longer period of time (Dieu et al., 2011). However, the virus in the more intensive systems are more virulent (Dieu et al., 2011). Therefore, the virus may be present in extensive and improved extensive systems may show signs, but the outbreaks are more deadly in the intensive systems, also because of the higher density. Recently, new kinds of shrimp diseases have appeared in Ca Mau, such as early mortality syndrome (EMS); therefore, shrimp farmers seem to have more reasons to be worried because of inadequate explanations and solution option uncertainties.

5.4.2. Perceptions that climate change events affected shrimp productivity

The perspectives of shrimp farmers in the four farming systems and the local experts show a high level of agreement (76%) in response to the statement that climate change issues have adversely affected shrimp productivity in the last decade (Table 5.2). In support of this point of view, the majority of shrimp farmers agreed that climate change events increased shrimp diseases in the last 10 years (Table 5.1). The majority of shrimp farmers asserted that irregular rain was the main cause of affecting, reducing, and fluctuating shrimp productivity. For example, shrimp farmers in RSRF claimed that irregular rains caused shrimp reduction of 80% shrimp productivity in 2012. A RSRF farmer asserted that irregular rains exacerbated acidity and released acidic substances into the shrimp ponds causing massive shrimp losses. Some shrimp farmers in ISMF also argued that this climate event affected shrimp growth because shrimp died at an early stage. Moreover, the majority of farmers in RSRF agreed that rice productivity has reduced and fluctuated in the last five years because of irregular weather and climate changes. There has been a great impact on rice production because rice cultivation depends on natural conditions, such as rainwater and saltwater sluicing to cultivate rice. Therefore, a full illustration of climate change events shows increased shrimp diseases and reduced shrimp productivity, plus decreased rice productivity. The data analysis of results of a 25-year period in Ca Mau Province, as discussed in Chapter 4, correspond with those above perspectives and provide some evidence of a relationship between shrimp productivity and the amount of rainfall for shrimp production (Table 4.31).

The above research results are compatible with the literature. For example, Allison (2009) predicted that climate change events (such as sea level rise, irregular weather, seasonal change, temperature changes, storm severity) would impact on aquaculture and cause poor water quality, rapid water quality change, lower productivity, slow growth, stress and diseases. Muralidhar et al. (2012) also asserted that extreme climate weather events such as drought, storms, floods, and variations in climate parameters would potentially lead to production losses. This is consistent with shrimp farmers stating that high temperatures and irregular weather have caused massive losses for shrimp farming, along with too much rain, sea level rise, and storms (Albery et al., 2009). These conditions lead to productivity reductions (Allison et al., 2009). However, beside climate factors and shrimp diseases, shrimp productivity could be affected by other issues, such as stocking density for different farming systems (Nhuong et al., 2002; Tho et al., 2010; Vuong, 2011) and environmental pollution from industry and waste streams from other shrimp farms (Anh et al., 2010).

5.4.3. Shrimp farming vulnerability to climate change events

The primary data collected shows farmers' own perceptions of shrimp farming vulnerability to climate change events. It is apparent that the perceived vulnerability of shrimp farming income of farmers to actual or expected climate change impacts vary considerably according the farming system.

The research results show that shrimp farming income is the most important contribution to farmer incomes in the four farming systems, with the majority of shrimp families depending on this income stream to sustain livelihoods. The majority of shrimp farmers in the four farming systems recognised the adverse effects of climate change events on shrimp production and strongly agreed that those effects have increased shrimp diseases and negatively affected shrimp productivity in the last decade (Table 5.1 and 5.2). Previous research conducted on small-scale shrimp farmers in IESF supports this view that the adverse effects of sea level rise, high temperatures, irregular weather, and intense rain have had the most impact on shrimp production, with losses ranging from 10% to 100% of shrimp farming income (Hai et al., 2011). However, research of Chinh (2012) conducted in Ca Mau Province identified some problematic issues in ISF caused by poor farming infrastructure and water management in the shrimp ponds. The above research is consistent with research of Hoa et al. (2011b) suggesting that most transmissions of shrimp diseases into semi–intensive shrimp farms were from neighbours.

An interesting way to understand the vulnerability of shrimp farming income to climate change events in Ca Mau in light of the results presented previously is to consider the characteristics and ramifications for each farming system in turn. The following discussion is based on combining individual results from Section 5.3.

5.4.3.1. RSRF shrimp farming income

The research found shrimp farming income in RSRF to be at high risk from the greater intensity or irregular rains and seasonal pattern changes that could result in high levels of vulnerability. This is because farmers have low adaptive capacity to these climate change events. Descriptive statistics and test results in Section 5.3.2.4 show statistically significant evidence that shrimp farmers in RSRF have fewer years of practising shrimp farming than farmers in the other farming systems (see Table 5.13). Moreover, shrimp income and household income in RSRF is lowest, relatively to those farmers in the other systems. In addition, shrimp farmers in RSRF have fewer years of attending the school than shrimp farmers in ISF and in ISMF (Table 5.7). Whereas RSRF shrimp farmers have three types of household incomes on average, some 35% of them depend entirely on the shrimp farming income stream (Figure 5.1). Although RSRF farmers have adapted the rice-shrimp systems for many decades and cultivated shrimp in the dry season to increase their farm household incomes, there were many concerns regarding of soil salinisation, land degradation, poor farming practices, stock quality, and financial capital in RSRF (Preston & Clayton, 2003). Nevertheless, scientists have argued that shrimp farmers in rice-shrimp systems (Tran, 1997) and in improved extensive shrimp farming (Kam et al., 2012) are more sustainable than semi–intensive and intensive shrimp farming (ISF) both environmentally and economically. Furthermore, (Kabir et al., 2016) agreed that rice-shrimp systems as polyculture systems are more sustainable and less risky than the rice or non-rice systems as monoculture systems because polyculture may be more economically viable and provide higher returns.

5.4.3.2. ISMF shrimp farming income

The research found shrimp farming income in ISMF to be at high risk from greater intensity or irregular rains, and medium to low risk from the other climate change events. As a result, shrimp farmers in this system have a moderate to low vulnerability level of shrimp farming income to all climate change events and a medium level of adaptive capacity to most of the climate change impacts. Descriptive statistics and survey results illustrate that the shrimp farming income of shrimp farmers in ISMF are higher than in RSRF and SSMF. Moreover, shrimp farmers in ISMF have more experience in the shrimp farming industry than farmers in RSRF and in SSMF. In addition, shrimp farmers in ISMF have more years of attending school than shrimp farmers in RSRF, and a smaller family size than shrimp farmers in SSMF. Overall, because the ISMF farms contain mangroves integrated with the shrimp ponds and are identified as having the highest adaptive capacity in natural capital, this would presumably provide shelter for shrimp and thereby offer some natural or inbuilt climate change resilience. These findings may support the previous studies who found that shrimp farming systems with polyculture were better than with monoculture in terms of both environmental and economic benefits (Bosma et al., 2016; Ha et al., 2014; Kabir et al., 2016; Tran, 1997). Specifically, integrated shrimp farming systems have low capital requirement, livelihood diversification, regular income provision, and organic farming practice (Bosma et al, 2014) and ISMF provide a higher annual net return than both SSMF and non-mangrove systems (Ha et al., 2014).

5.4.3.3. SSMF shrimp farming income

The research found shrimp farming income in SSMF to be at high risk from greater intensity or irregular rains and increased intensity of high tides, and extreme risk from sea level rise, all of which point to a high level of vulnerability. Although the survey results show that individual farms are large and contain mangroves separated from shrimp ponds and are ranked as having the highest adaptive capacity in natural capital alongside with ISMF, these aspects could also be expected to provide some climate change resilience. Meanwhile, however, shrimp farmers in SSMF have a low adaptive capacity to most of the climate change events. This is because shrimp farmers in SSMF have a lower shrimp and family income than farmers in ISMF and ISF, bigger family size[19] than in the other farming systems, a fewer number of years attending school than in ISF, the least income stream of all farming systems, and shrimp farmers in SSMF have fewer a number of years practising shrimp farming than ISF and ISMF. While there are up to three types of income in SSMF households, the majority of shrimp farmers (77%) had only one income stream and were the most dependent overall on shrimp production. The above differences may be also due to the difference in natural and physical conditions of the farming systems. More detailed descriptive statistics and test results are presented in Section 5.3.2. However, scientists have argued that SSMF design with connection of mangroves to open water and separating the pond from mangrove forest can improve the connectivity between farms and natural ecosystems and provide more intensification on a separated pond (Bosma et al., 2016). For this potential to be realised, farmers in SSMF would need to practise forest management policies effectively so that shrimp farmers would have the right to access private timber markets to increase their income (Ha et al., 2014). Therefore, Bosma et al. (2014) suggested converting those mixed farming systems, such as extensive and semi–intensive farming systems into partly SSMF to provide a better livelihood for local shrimp farmers. However, the findings in this research indicate that shrimp farmers in SSMF have lower adaptive capacity on the financial, physical and social capital and their shrimp farming income was more vulnerable than ISF and ISMF.

[19] Family size in the rural area of Vietnam was a strong negative relationship with household income (Binh, 2011) and bigger family size was related to poverty (White & Masset, 2000).

5.4.3.4. ISF shrimp farming income

The research found shrimp farming income in ISF to be at high risk from increased fluctuations of water temperature, but at low risk from most of the other climate change impacts. The shrimp farmers in ISF had low to moderate vulnerability levels of shrimp farming income to climate change events and a high to moderate adaptive capacity to most climate change impacts. More particularly, shrimp farmers in ISF had the highest adaptive capacity overall in three capitals: physical, financial, and social. Moreover, the descriptive statistics and test results in Section 5.3.2 on household characteristics and income status explain that these farmers had the highest shrimp farming income and household income, more income stream than SSMF, greater farming experience and education than SSMF and RSRF, and smaller family size than SSMF. Furthermore, the large majority of farmers (78%) in ISF had two or three income streams within their households to sustain livelihoods. Supporting the ISF benefits, Tendencia et al. (2013) claimed that ISF can minimize shrimp disease risks. This is consistent with studies showing that technological investments in ISF reduce the risk in shrimp farming and reduce vulnerability to disease outbreak (Joffre & Bosma, 2008). However, scientists have argued that although shrimp households practicing with a higher input results in significantly more income, they also face a high risk associated with shrimp mortality (Be et al., 2003). The work of Ha et al. (2013) and Ha (2012) also supports the above author that ISF was vulnerable because of more frequent harvest failure, fluctuating shrimp prices, and market competition.

Overall, climate change impacts pose a high level of risk to shrimp farming income, which could result in high levels of vulnerability in each of the four farming systems. The risk levels of shrimp farming income based on perspectives of shrimp farmers themselves to each climate change impact found in this research varied substantially among the four farming systems and contrasts with the findings of RIA2 (2014). The level of adaptive capacity to each climate change impact on shrimp production also differed substantially among the four farming systems. Farmers in ISF had higher levels of adaptive capacity than farmers in the other systems for most of the climate change impacts, whereas shrimp farmers in RSRF and SSMF alike registered the lowest levels of adaptive capacity. Overall then, the vulnerability level of shrimp farming incomes in ISF to the effects of climate change would appear to be lower than in the other farming systems. This is because the ISF farmers had lower risk levels and a higher adaptive capacity to climate change events, as explained previously, and their performance characteristics regarding number of income streams, total family income, family size, and education levels were comparatively favourable.

5.5. Conclusion

Drawing upon the perspectives of the farmers and the local experts to address how shrimp farming in different systems is vulnerable to climate change events, this chapter shows that farmers in the Ca Mau region of Vietnam have been experiencing shrimp income losses in the last few years and are vulnerable to climate change events. The majority of shrimp farmers and all experts agreed that climate change issues increased shrimp diseases and adversely affected shrimp productivity.

While there are some differences between farmers' perspectives in the four shrimp farming systems concerning the vulnerability level of shrimp farming income to climate change events, important linkages between the characteristics and ramifications for each farming type and the perspectives of shrimp farmers on the vulnerability of shrimp farming income can be made. ISF shrimp farmers with a higher level of cultivation (for example, ISF) had higher adaptive capacity, earned more money than the other farmers, and had lower levels of vulnerability. However, they had experienced fluctuations in shrimp income, which Chinh (2012) links, at least in part, to problems associated with cultivation techniques relating to poor infrastructure and water management. This issue may need to be considered further along with enhanced technical support for Ca Mau shrimp production.

In general, the results suggest that from an income perspective, farmers operating in the intensive shrimp farming systems appear to be less vulnerable to existing and expected climate change effects relative to those in the other systems. This finding contrasts with that of Ha et al. (2013) and Kam et al. (2012) who considered ISF to be more vulnerable farming system, and Kabir et al. (2016) and Tran (1997) who considered rice-shrimp systems as the sustainable model for shrimp production. The research finding may support the previous studies of Bosma et al. (2014) and Ha et al. (2014) who argued that polyculture was better than monoculture in shrimp farming systems. These differences no doubt reflect the different foci within each study. Nevertheless, it has implications for policy makers who encourage economic development such as that afforded by intensive shrimp farming as a strategy for enhancing farmer resilience to the effects of climate change events, as well as improving cultivation techniques for shrimp farmers. It also points to the value in further research of the relative resilience and vulnerabilities of different shrimp farming systems to climate change.

CHAPTER 6: Adaptation of Shrimp Farmers to Climate Change

6.1. Introduction

This chapter presents the concerns of the shrimp farmers and local experts to address the third research question of how Ca Mau shrimp farmers can adapt to climate change events. The focus is on the perspectives of shrimp farmers regarding adaptation to climate change events, the recovery of shrimp production after an extreme climate event, the cooperation of shrimp farmers, and their adaptation options. The chapter also discusses how shrimp farmers have already responded and adapted to climate change, and what adaptation options and strategies identified would respond to expected climate change on their shrimp production in the next 10-20 years.

6.2. Shrimp farmers have responded and adapted to climate change events in the last 10 years (Question A.1.4.1, Appendix A)

Shrimp farmers in the four farming systems were asked to detail any shrimp damages or losses they had suffered, and any activities they had used to adapt to climate change events effecting their shrimp production in the last 10 years. Shrimp farmers identified extreme climate events (tropical storms), sea level rise and high tides, seasonal pattern changes, irregular hot weather and droughts, and increased intensity or irregularity of rain, which elaboration to follow.

6.2.1. Extreme climate events (tropical storms)

Table 6.1 shows that there have not been any storm surges in the research areas in the last 10 years, but that Tropical Storm Linda, which surged in 1997, completely damaged about half of all shrimp ponds in RSRF and affected seriously those in ISMF. The majority of shrimp farmers in RSRF asserted that storms appeared in the east sea and affected the Ca Mau Province. More clearly, those shrimp farmers in Phong Dien Commune stated that intense rain for two days in the early dry season of 2013 reduced about 50% of shrimp production in the village. Although the majority of shrimp farmers in ISF and SSMF did not acknowledge any storm surges in the last 10 years, an elderly shrimp farmer in ISMF gave the following description of extreme climate events in Ca Mau Province.

> I have been living here for 52 years and seen only the Tropical Storm Linda surge in Ca Mau Province in 1997. From then, storms have frequently appeared in the east sea and surged in the northern and central Vietnam. Ca Mau Province has only been affected by these climate events afterwards, such as too much rain and winds.

The majority of shrimp farmers in the four farming systems have seemingly not managed to implement any solutions or responses to storm surges. This lack of response/solution may be attributed to the research area being rarely affected by tropical storms, or to the shrimp farmers not understanding the critical impacts of extreme climate events, or to a lack of concern this issue. However, lack of concern of ISF shrimp farmers about extreme climate events would occur because they lived further inland than the shrimp farmers in near coastal areas (RSRF, ISMF, and SSMF). Therefore, exposure to extreme climate events may be important because the Tropical Linda Storm recalled in 1997 effected RSRF, ISMF, and SSMF more than in ISF. This is further explained in Section 6.3.

Table 6.1: Responses and adaptation measures of shrimp farmers in the four farming systems to effects of extreme climate events on shrimp production over the last 10 years

	Shrimp effects/damages/losses	Responses/Adaptation
RSRF	A storm occurred in the east sea in early 2013 causing intense rain, shrimp productivity loss up to 50% in Phong Dien commune	Don't know how to adapt
ISMF	Linda Storm occurred in 1997 and caused serious damage for shrimp ponds in Dat Mui commune.	Clearing fallen trees, repairing sluice gates, upgrading shrimp pond, preparing for a new crop after Linda Storm 1997
SSMF	Linda Storm occurred in 1997 and caused some damage for shrimp ponds.	Do not have any adaptation options
ISF	No response	

6.2.2. Sea level rise and high tides

Although shrimp farmers in RSRF, ISMF and SSMF were close to coastal areas, only the majority of shrimp farmers in SSMF recognised the effects of sea level rise (Table 6.2). This may reflect that SSMF is in the east coastal region where it is regulated by stronger semidiurnal tides, whereas RSRF and ISMF in the west coastal are regulated by a diurnal tide of smaller amplitude. However, it seems that shrimp farmers in SSMF did not really notice any shrimp losses or damages, although they stated that it has affected infrastructure, for instance recently flooding shrimp farmers' houses and rural roads, especially when it was accompanied with high tides.

However, it was evident that farmers have experienced shrimp losses and damages by high tides in the last few years (Table 6.2). The majority of shrimp farmers in ISMF and SSMF identified shrimp losses and damages to their shrimp production, such as: increased intensity of high tides, which caused an overflow of seawater into shrimp ponds, damaging embankments, breaking sluice gates and shrimp escape; rapid increase of water salinity, which also caused shrimp shocks and deaths; and seawater depositing large amounts of sediment into shrimp ponds. Moreover, the majority of farmers in RSRF acknowledged that seawater overflowed sluice gates, embankments, and damaged up to 80% of rice production in Phong Dien village in 2010, while high tides flooded sluice gates and embankments causing shrimp escape in 2012. A shrimp farmer in Tam Giang Dong Commune (SSMF) described these effects of high tides on their shrimp production:

> This ground floor has never been flooded by high tides before, but it flooded up to 10cm in 2010. Intensity of high tide surges has increased over the last five years and occurred from September to October, especially on 6/8/2012 it overflowed and damaged shrimp ponds. Therefore, shrimp pond embankments and sluice gates have to be upgraded more frequently to avoid damages from high tides.

Overall, the majority of shrimp farmers in RSRS, ISMF and SSMF were very concerned about high tides because they perceived high tides increased intensity and directly affected their farm production. Moreover, RSRF, ISMF, and SSMF are near coastal areas, while shrimp farming in ISF are further inland (Figure 1.2). Therefore, shrimp farmers in RSRF, ISMF, and SSMF may have been more vulnerable to sea level rise and high tides than those shrimp farmers in ISF, especially in SSMF where there have been stronger semidiurnal tides than the others, as explained previously. This finding is consistent with the perspectives of the shrimp farmers in the four farming systems and the local experts (see Table 4.3, Section 4.2.2) and risk level of sea level rise and high tides in SSMF (see Table 5.18, Section 5.3.3.1). Despite concerns about the effects of sea level rise and high tides, recent increased average water levels have actually increased shrimp production. Statistical tests show that there was a strong positive relationship between water level and shrimp productivity in the whole province (Section 4.5.3).

Although the majority of shrimp farmers did not specify reasons why high tides increased in intensity recently, about half the farmers in ISMF and SSMF claimed that they had responded and adapted to the issue with such actions as upgraded sluice gates and embankments to prevent seawater overflow into the ponds and protect shrimp farms. In addition, while shrimp farmers in ISMF regularly dug and removed sediments after high tide surges, shrimp farmers in RSRF increased water management and updated weather warnings and tidal forecasts to reduce losses and damages from high tide surges. Therefore, there is clearly a financial cost to farmers in these extra water level protection works which would affect shrimp farmers' profitability.

Table 6.2: Responses and adaptation measures of shrimp farmers in the four farming systems to effects of sea level rise and high tides on shrimp production over the last 10 years

	Shrimp effects/damages/losses	Responses/Adaptation
RSRF	High tides: affected rice production in 2010, productivity reduction approximately 80% in the commune; affected shrimp production in 2012, shrimp escape.	Checking tidal forecasts and weather warnings regularly, increasing shrimp pond management.
ISMF	High tide: overbanks, broken embankments and sluice gates causing salinity shock and deaths, escape, and losses.	Upgrading sluice gates and embankments, digging and removing sediments more regularly
SSMF	Sea level rise accompanying with high tides affected infrastructure, flooding houses, rural roads	
	High tides: Overbanks, broken embankments and sluice gates causing increasing salinity rapidly, shrimp shock, deaths, and escape.	Upgrading sluice gates and pond banks, building new sluice gates
ISF	No response	

6.2.3. Seasonal pattern changes

Table 6.3 shows that seasonal pattern changes were identified by the majority of shrimp farmers in the four farming systems. This is consistent with the perspectives of shrimp farmers in the four farming systems and the local experts about negative effects of rainfall pattern changes on shrimp farming (see Table 4.5, Section 4.2.2). Each year the government of Ca Mau produces a seasonal calendar for shrimp farmers which provides information and advice on what production and cultivation activities should take place for each season, and farmers make their own calendars to guide their operations too. A majority of shrimp farmers surveyed indicated that changes to these calendars are necessary in light of changing weather conditions associated with climate change because rainy seasons are longer, arriving earlier and lasting longer. Those farmers found it difficult to forecast and adjust their seasonal calendar for releasing shrimp post larvae. For example, if tiger shrimps' post larvae are released in unsuitable weather and environmental conditions, this would lead to low shrimp survival density and growth rate, a longer harvest cycle and more risks of shrimp diseases. Moreover, seasonal changes hamper both shrimp and rice production in RSRF, causing low shrimp yields and rice productivity fluctuation. To respond to these negative impacts, shrimp farmers in the four farming systems regularly checked the radio and TV for the weather forecasts to release the shrimps' larvae at a suitable time, adjusted the seasonal calendar following weather changes, tested salinity, and shrimp farmers in RSRF undertook shrimp conditioning of post larvae to adapt to the wide range of salinity changes and chose new rice varieties to tolerate with a higher salinity (Table 6.3).

Table 6.3: Responses and adaptation measures of shrimp farmers in the four farming systems to effects of seasonal pattern changes on shrimp production over the last 10 years

	Shrimp effects/damages/losses	Responses/Adaptation
RSRF	Difficult for planning rice and shrimp crops;	Checking weather predictions and forecasts to release post larvae shrimp;
	Effecting shrimp growth and productivity;	Testing salinity and tried conditioning of stockings before releasing;
	Fluctuating rice production.	Choosing new rice varieties to tolerate with higher salinity.
ISMF	Finding harder to predict and forecast weather based on experiences and traditional knowledge to release shrimp' post larvae than in the past.	Watching TVs and radio for weather forecasts to release stock.
SSMF	Arriving earlier and lasting longer rainy seasons; difficult to forecast and adjust seasonal calendar to release stock;	Regularly listening the radio for the weather forecasts to release shrimps' post larvae;
	Tiger shrimps' post larvae have been released in unsuitable weather and environmental conditions; those lead to lowering shrimp survival and growth rate, longer harvest circle and more risks to shrimp diseases.	Changing the seasonal calendar according weather changes.
ISF	Stocks released in unsuitable weather caused lowering shrimp survival rate and more risks to shrimp diseases because of fluctuations of environmental water quality.	Watching farming news on TV; checking weather forecast to release shrimp post larvae; adjusting seasonal calendar based on changing rainy seasons.

6.2.4. Irregular hot weather or droughts

Based on traditional knowledge and experiences, a high number of shrimp farmers in SSMF acknowledged that there 5–15–day droughts have started to occur, called the "Ogress Drought", and that even 15–25 day–droughts occurred more regularly during the rainy seasons, causing difficulties for shrimp production (Table 6.4). Moreover, most farmers in RSRF identified that there is an increased frequency of localised, intense heat for several days, causing major shrimp loss in Phong Dien commune. In addition, hot weathers have caused inadequately water supply for shrimp ponds, especially in March and April, and therefore increased costs for pumping the water supply in RSRF. Furthermore, the hotter and drier dry season caused algae bloomed and aquatic weeds, which decreased shrimp growth rate and productivity. Shrimp farmers in ISMF and ISF have also recognised that irregular hot conditions caused fluctuations of environmental indicators, acidic substances released into the shrimp ponds and those factors led to lowering shrimp growth, longer harvesting cycle, and more risks to shrimp diseases. Therefore, above the findings may explain that irregular hot periods or droughts identified by shrimp farmers in the research areas are related to temperature fluctuations in short periods. This is consistent with the previous results in Table 4.9 (Section 4.2.2, Chapter 4) that increased of temperature fluctuations have negatively affected shrimp production in the last 10 years perceived by majority of shrimp farmers in the four faming systems and the local experts.

Due to the effects of irregular hot weather or droughts, shrimp farmers have adapted by adding more chemicals and fertilisers to treat and balance the water quality in shrimp ponds, increasing water placement and management, increasing the green area cover and trees around shrimp ponds due to hot weather, and running aeration systems (ISF). For example, shrimp farmers in RSRF kept deeper water levels and exchanged water regularly, increased pumping water supply, using chemicals to increase the pH and balance environmental conditions in the ponds (Table 6.4). Those activities have led to further costs for shrimp production due to adapting to the effects of irregular hot and droughts.

Table 6.4: Responses and adaptation measures of shrimp farmers in the four farming systems to effects of irregular hot weather or droughts on shrimp production over the last 10 years

	Shrimp effects/damages/losses	Responses/Adaptation
RSRF	Localized intense hot for several days caused temperature and salinity increase rapidly, shrimp loss over 50% in 2013;	Keeping a higher water level and exchanging the water more regularly;
	Lack of saltwater supply for shrimp ponds on March and April;	Increasing pumping water supply;
	Hotter in the dry season bloomed algae and aquatic weeds decreased shrimp growth rate and productivity.	Using chemicals to treat water before supplying shrimp ponds.
ISMF	Showering shrimp growth, increasing shrimp diseases, lower product quality and price	Exchanging water more regularly; increasing water management.
SSMF	"Ogress Drought" with 5-15-day-droughts or 15-25 day-droughts appeared more frequently in the rainy season, effected shrimp production.	Increasing water quality control, adding more fertilizers and increasing water exchange.
ISF	Fluctuations of environmental conditions;	Running aeration systems to balance temperature among water layers, increasing the green area cover and trees surrounding shrimp ponds;
	Releasing acidic substances into shrimp ponds;	Adding chemicals to balance environmental conditions;
	Lowering shrimp growth, longer harvesting cycle, more risks to shrimp diseases.	Increasing water monitoring and chemicals to control water quality.

6.2.5. Increased intensity or irregular rain

Table 6.5 shows that intense rain or irregular rain has been identified in the four faming systems. Irregular rains have occurred more frequently, in particular, intense rain appearing in the period of transition between the rainy season and the dry season or at the end of the rainy season. This is known to acerbate acidification, release acidic substances from acid sulfate soils into shrimp ponds, and decrease water pH, thereby reduced the water quality. Quick changes in water quality due to irregular rain or intense rain cause lower shrimp growth, increased risks to shrimp diseases, and result in massive shrimp losses. For example, shrimp farmers in RSRF indicated that 80% of shrimp deaths and losses in Phong Dien commune in 2012 were due to irregular rains and localised torrential rains (Table 6.5). Moreover, a shrimp farmer in SSMF claimed irregular rains in the region over the last decade.

> Normally raining starts from April to September of the lunar year, but recently there was a prolonged rainy season; heavy rains appeared in late February or early March and lasted until the end of November. And in the mid–rainy season prolonged droughts occurred more frequently. Erratic and heavy rains caused massive mortality for black tiger shrimps.

Due to the adverse effects of increased intensity or irregular rains, many measures that have been applied to adapt to the changes of environmental conditions in shrimp ponds (Table 6.5). For example, shrimp farmers in RSRF spent more money and employed more people to control the water quality, for instance by adding more $CaCO_3$ to increase the pH and adding fertilisers to treat and balance the water quality in shrimp ponds, increasing water management in shrimp ponds. They also tried conditioning shrimp post larvae to adapt to a wide range of salinity. A management strategy employed by farmers in ISMF and SSMF is to discharge and change the top layer of the surface water of shrimp ponds immediately after heavy rains. Moreover, farmers in ISF applied aeration systems to balance the temperature and environmental indicators among water layers, and used chemicals to balance pH and increased water monitoring to control diseases (Table 6.5).

Table 6.5: Responses and adaptation measures of shrimp farmers in the four farming systems to effects of increase intensity or irregular rain on shrimp production over the last 10 years

	Shrimp effects/damages/losses	Responses/Adaptation
RSRF	Acerbating acidification and releasing acidic substances into shrimp ponds, causing massive shrimp loss (80% shrimp losses in Phong Dien commune in 2012 due to irregular rains or localized torrential rains).	Using $CaCO_3$, fertilizers, and other chemicals to increase pH and balance environmental conditions; Discharging the surface water layer; Trying conditioning of shrimp post larvae to adapt with wide range of salinity.
ISMF	Water quality reduction;	Replacing the top layer of water surface;
	Lowering shrimp growth, longer harvesting cycle, more risks to shrimp diseases.	Exchanging water more regularly.
SSMF	Intense rain in the seasonal transition point or at the end of the rainy season caused massive shrimp deaths;	Changing the top layer of surface water pond after heavy rains;
	Irregular rains decreased water pH, releasing acidic substances into shrimp ponds, quickly changes in water quality, increasing shrimp diseases and deaths.	Exchange water more regularly, using chemicals to increase pH and balance environmental conditions.
ISF	Changing environmental conditions in shrimp ponds, water quality reduction;	Replacing the top water layer, running aeration systems to balance environmental indicators among water layers;
	Shrimps growing slowly, longer harvesting cycle, more risks to shrimp diseases.	Increasing water quality monitoring and using chemicals to control diseases.

6.3. Shrimp farming recovery after extreme climate events (Tropical Storm Linda in 1997) (Question A.1.4.2, Appendix A)

Shrimp farmers in the four farming systems were asked to rank the level of damages to shrimp farming from extreme climate events (such as Tropical Storm Linda in 1997). The rankings were no damage, little damage, damaged 50%, and completely destroyed. Then, they were asked to estimate the period of time taken to recover to the same state as before the extreme events occurred. All shrimp farmers in the research area stated that only Tropical Storm Linda surged and that was in 1997. Regarding the damage levels of shrimp production by this extreme climate event, overall 30% of all farmers identified it as no damage, 21% as little damage, 14% as damaged 50%, and 36% of shrimp farmers said their production was completely destroyed. In each farming system, 50% of shrimp farmers in RSRF perceived that their shrimp farming had been destroyed by the storm, compared with 61% in ISMF, 12% in SSMF, and 14% in ISF. In contrast, only 5% of farmers in RSRF and 16% in ISMF claimed that the Tropical Storm Linda in 1997 had not affected their farms, which this compared to 50% in SSMF, and 52% in ISF. The damage levels of shrimp production by the extreme climate event in the four farming systems are presented in Table 6.6.

Table 6.6: Levels of shrimp farming damages caused by Tropical Storm Linda in 1997

Respondents	No damage		Little damage		Damage 50%		Completely destroyed	
	F*	%	F	%	F	%	F	%
RSRF (n=22)	1	4.5	6	27.3	6	27.3	11	50.0
ISMF (n=31)	5	16.1	3	9.7	2	6.5	19	61.3
SSMF (n=26)	13	50.0	6	23.1	4	15.4	3	11.5
ISF (n=21)	11	52.4	6	28.6	2	9.5	3	14.3
Total (n=100)	30	30.0	21	21.0	14	14.0	36	36.0

F: Frequency*

Regarding the time taken to recover, all shrimp farmers agreed that it took an average of 1.2 months for shrimp farms to recover to their original state in the case of little damage, 3.4 months in the case of 50% damage, and 7.9 months where the farm facilities were completely destroyed. Where there was little damage, it took 1.2 months for shrimp farmers in RSRF to recover, 0.8 months in ISMF, 0.5 months in SSMF, and 2.2 months in ISF. When shrimp production was damaged by up to 50%, it took 2.3 months to recover in RSRF, 3.0 months in ISMF, 3.8 months in SSMF, and 2.5 months to recover shrimp production in ISF. Where the facilities were completely destroyed, the time taken to recover in SSMF was longer than for the other systems, with 9.3 months compared to 9 months in RSRF, 7.4 months in ISMF, and 6 months in ISF. Overall, the time taken for shrimp production to recover to the level before the storm surged was longest in SSMF with the highest level of damages, while it is the shortest in ISF with this damage level when compared with the others (Figure 6.1). This finding links to adaptive capacity to extreme climate events presented in Table 5.21, Section 5.3.3.2 that shrimp farmers in SSMF had a lower level of adaptive capacity to this climate change event than shrimp farmers in ISF.

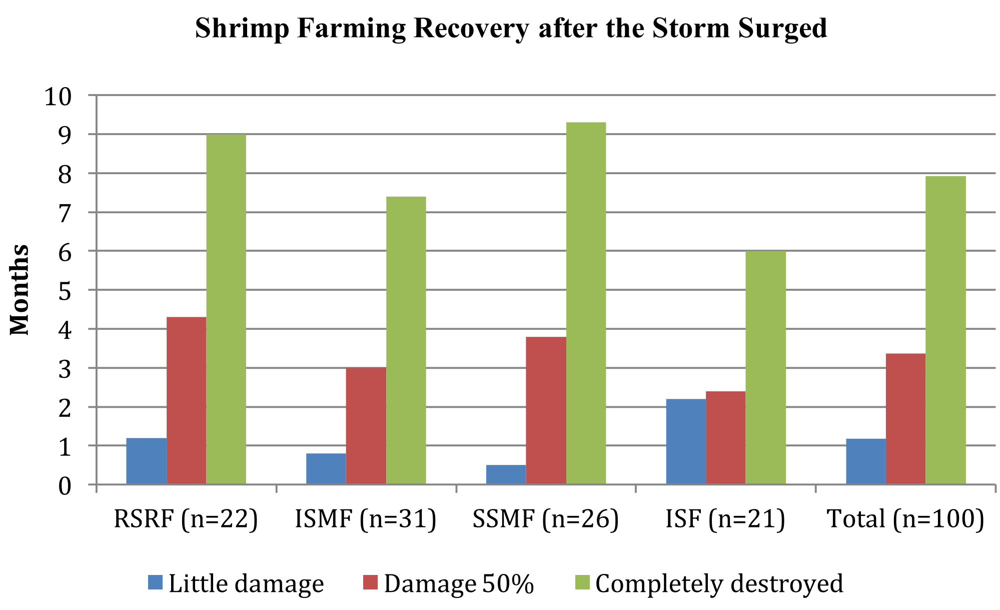

Figure 6.1: Levels of shrimp farming recovery after Storm Linda surged in 1997 (months)

6.4. Shrimp farmers' cooperation (Question A.1.4.3, Appendix A)

Shrimp farmers in the four farming systems were members of different groups, clubs, and/or community organisations (Table 6.7). However, clubs or community organisations related to shrimp farming only consisted of Farmers Union, Shrimp Cooperatives, and Good Production Farmers Club. Overall, all shrimp farmers in ISF were members of clubs, unions, and/or community organisations: correspondingly 59% in RSRF, 87% in ISMF, and 54% in SSMF. Moreover, the number of farmers in ISF who attended clubs and/or community organisations related to shrimp production was greater than the other farming systems with 38% being members of Farmers Union, 67% being members of shrimp cooperatives, and 24% being members of Good Production Farmers Club, compared with 14%, 27%, and 0% in RSRF, while farmers in ISMF and SSMF attended only the Farmers Union, respectively 39% and 8%. Finally, shrimp farmers with non-membership of any group were greatest in SSMF (46.2%), then in RSRF (40.9%), and in ISMF (12.9%). The results show that shrimp farmers in ISF got more involved in community groups than shrimp farmers in the other farming systems. This may link to social capital rankings: shrimp farmers in ISF overall demonstrate higher level of social capital than shrimp farmers in RSRF, ISMF, and SSMF (Table 5.19 and Figure 5.2, Section 5.3.3.2).

Table 6.7: Shrimp farmers' membership of community groups or local organizations in the four farming systems

Member of groups, clubs, community organisations	RSRF (n=22)		ISMF (n=31)		SSMF (n=26)		ISF (n=21)	
	F*	%	F	%	F	%	F	%
Farmers Union	3	13.6	12	38.7	2	7.7	8	38.1
Shrimp Cooperatives	6	27.3	0	0.0	0	0.0	16	76.2
Good Production Farmers Club	0	0.0	0	0.0	0	0.0	5	23.8
Women Union	2	9.1	5	16.1	1	3.8	3	14.3
Veterans Association	4	18.2	3	9.7	5	19.2	4	19.0
Youth Union	1	4.5	1	3.2	1	3.8	0	0.0
Village officials	6	27.3	5	16.1	3	11.5	1	4.8
Elders Union	1	4.5	1	3.2	1	3.8	4	19.0
Others	0	0.0	7	22.6	2	7.7	0	0.0
Non–member	9	40.9	4	12.9	12	46.2	0	0.0

F: Frequency*

6.5. Adaptation options to climate change events on shrimp production in the next 10-20 years (Questions A.1.4-A.1.6, A.2.10, Appendix A)

Shrimp farmers in the four farming systems were asked to list any support they received for responding to climate change events and to make suggestions for responding to future climate change events. The majority of shrimp farmers responded that they have found their own ways to respond to climate change events in the last 10 years. However, most people acknowledged that they had received some external support, such as food (rice, noodles), blankets, mosquito nets, grants to repair houses, and loans to recover shrimp farming after the Tropical Storm Linda surged in 1997.

According to shrimp farmers in the four farming systems, a summary of the priority adaptation options needed to respond to climate change events is as follows:

a. Sea dikes need to be upgraded or built to protect people and shrimp livelihoods.
b. The government should have forewarning programs for community resilience and disaster prevention, resettlement support, and to encourage sustainable shrimp farming livelihoods.
c. Seasonal calendars should be provided which include timely information provided to shrimp farmers about when to cultivate to reduce risks.
d. Shrimp farmers should create and attend shrimp cooperatives to support each other in shrimp production.
e. High quality shrimp stocks should be sought, supplied, and controlled to adapt to irregular weather and climate changes in all farming systems; in addition, new

rice varieties should be sought to adapt to a wide range of acidity and salinity in RSRF.

f. Technical training should be given to shrimp farmers to adapt to climate change.
g. Mangrove forests should be protected and reforested; meanwhile, however, the proportions to be retained for mangrove and shrimp production areas in ISMF and SSMF should be changed to be suitable to the reality of shrimp production.
h. Financial capital should be provided for shrimp farmers with low interest rates to recover shrimp cultivation following damaging events, and insurance services should be implemented for shrimp farming.

Local experts were asked to give suggestions on adaptations to the adverse impacts of climate change on shrimp production in Ca Mau in the next 10–20 years (Question A.2.10, Appendix A). A summary of the priority adaptation measures and options to climate change events in the future suggested by the local experts was as follows.

i. Sea dyke systems need to be protected and upgraded to avoid the sea level rise and high tides damaging shrimp ponds. Besides this, the state government should have a strategy to build infrastructure to adapt to climate change and sea level rise, especially for shrimp production, water control, and integrated shrimp farming systems.
ii. Weather forecasts and climate warnings are needed to inform shrimp farmers in time to respond to irregular weather changes. A seasonal calendar needs to be prepared and updated in a timely manner for shrimp farmers, and especially be suitable with seasonal pattern changes.
iii. Shrimp farmers should be provided with information that promotes capacity, and offered training to adapt to the negative impacts of climate change.
iv. Shrimp farming should be more varied; farmers should be encouraged to adopt integrated shrimp farming systems and change to change farm more suitable aquatic species that could adapt to environmental and climate change, especially new species with less vulnerability to climate change.
v. Farmers should be supported to change from extensive to semi–intensive and intensive shrimp farming.
vi. New techniques and scientific advances in shrimp production to adapt to climate change should be transferred and implemented for shrimp farmers, especially for shrimp post larvae control, shrimp disease control, and reduced water exchange and increased quality control.

vii. Land cover vegetation should be increased, mangrove forest protection promoted, and more trees planted around shrimp ponds to protect embankments, and prevent erosion and environmental damage to shrimp production.

Most of the adaptation options by shrimp farmers and the local experts clearly coincide, but some differences are apparent. The local experts gave more emphasis to diversifying farming systems and suitable aquatic species, and encouraged shifting from extensive to semi-intensive and intensive shrimp farming, technical transfers and applications. Shrimp farmers were more focused on shrimp farmer cooperatives, financial capital, and insurance services. These differences perhaps reflect their own personal involvement in the shrimp farming industry to a large extent. A more detailed account of options is given in Section 6.6.3.

Considering the next generation and the adverse effects of climate change events, shrimp farmers were asked what they expect their children will do in the next 10–20 years. In general, 42% of all farmers wanted their children to become shrimp farmers, 39% would like their children to look for new jobs in the surrounding areas, while 13% of all parents wanted their children to move to a new place to live (Table 6.8). Looking at each shrimp farming system, 58% of SSMF farmers stated that they would like their children to become shrimp farmers, and likewise 23% in RSRF, 39% in ISMF, and 38% in ISF. Sixty-four percent of RSRF shrimp farmers expected their children to seek new jobs in the surrounding areas; this figure compares with 42% in ISMF, 12% in SSMF, and 43% in ISF. Shrimp farmers expected their children to move to a new place to live regarding to 32% in SSMF, 9% in RSRF, 7% in ISMF, and 14% in ISF. Overall less than half of shrimp farmers in the four farming systems wanted their children to become a shrimp farmer, with the majority hoping that their children change occupation in the future. The finding that the majority of SSMF farmers expected their children to become a farmer possibly because they had the greatest shrimp area per household (3.5 ha/household) relative to shrimp farmers in the other farming systems (Table 5.11, Section 5.3.2.3).

Table 6.8: What shrimp farmers expect their children will do in the next 10–20 years.

Responses	RSRF (n=22)		ISMF (n=31)		SSMF (n=26)		ISF (n=21)		Total (n=100)	
	F*	%	F	%	F	%	F	%	F	%
A shrimp farmer	5	22.7	14	45.2	15	57.7	8	38.1	42	42.0
New jobs in the surrounding areas	14	63.6	13	41.9	3	11.5	9	42.9	39	39.0
Move to a new place	2	9.1	2	6.5	6	23.1	3	14.3	13	13.0
Other	1	4.5	2	6.5	2	7.7	1	4.8	6	6.0

F: Frequency*

Shrimp farmers in the four shrimp farming systems were asked whether they would rather change to other livelihood activities if shrimp production were to reduce by up to 40% due to the adverse effects of climate change events in the next 10–20 years. Overall, the investigation results show that 64% of all shrimp farmers would remain in shrimp farming, 5% would change to a new aquaculture species, 7% would change to new jobs, 3% would wait until climate change has a serious impact, and 21% of all shrimp farmers don't know what they would do and don't have any plans. In each shrimp farming system, the majority of farmers in the four farming systems agreed that they would continue to farm shrimp despite likely serious adverse effects of climate change on their shrimp farming, corresponding to 68% in RSRF, 65% in ISMF and SSMF, and 57% of shrimp farmers in ISF. The remarkable consistency of the majority of shrimp farmers' perspectives across the four farming systems in those above results indicates that shrimp farming will remain a very important livelihood for farmers, just as it has for the majority of those farmers in the last 10 years (see shrimp and family income in Table 5.11, Section 5.3.2.4). There is great potential for exporting shrimp to other countries as evidence of good market for Ca Mau shrimp products in the past decade. Moreover, shrimp farming has been practised for a long time and Ca Mau shrimp farmers have been closely associated with this livelihood for decades. Thus, they have been familiar with shrimp farming and they would find it difficult to change to other livelihoods even though adverse effects of climate change events would seriously impact shrimp production. However, 21% of shrimp farmers don't have any plans for the future (Table 6.9). This may indicate: that they do not expect impact from climate change events; they are too old to think about the future (i.e. the mean age of shrimp farmers is over 50 years as shown in Table 5.4); or the shrimp farming may not be their main livelihood. The details of shrimp farmers' perspectives across the four farming systems regarding whether they would like to change shrimp production to other livelihood activities due to the adverse effects of climate change in the future are presented in Table 6.9.

Table 6.9: How shrimp farmers would respond if climate change events decreased shrimp production up to 40% in the next 10–20 years

Responses	**RSRF (n=22)**		**ISMF (n=31)**		**SSMF (n=26)**		**ISF (n=21)**		**Total (n=100)**	
	F*	%	F	%	F	%	F	%	F	%
Sustain shrimp farming	15	68.2	20	64.5	17	65.4	12	57.1	64	64.0
Change to new aquaculture species	1	4.5	1	3.2	1	3.8	2	9.5	5	5.0
Change to new jobs/professionals	2	9.1	3	9.7	1	3.8	1	4.8	7	7.0
Wait until climate changes seriously	0	0.0	0	0.0	2	7.7	1	4.8	3	3.0
Don't have any plans	4	18.2	7	22.6	5	19.2	5	23.8	21	21.0

F: Frequency*

6.6. Discussion

From the original data and information collected, the research findings show that shrimp farmers in the Ca Mau region have experienced and adapted to climate change events to some extent already and have identified some adaptation measures due to the adverse effects of climate change events on shrimp production in the last 10 years. The local experts and shrimp farmers also suggested some important adaptation options to climate change in the future.

6.6.1. Shrimp farmers have adapted to climate change events in the last 10 years

In the past 10 years shrimp farmers in the four farming systems have adapted to the adverse effects of climate change events, such as increased intensity of high tides, seasonal pattern changes, irregular hot weather and drought, and increased intensity or irregular rain. A summary of responses and adaptation measures of shrimp farmers to the effects of climate changes over the last 10 years is presented in Table 6.10.

Shrimp farmers in ISF have not responded to sea level rise and high tides because they have not recognised adverse effects from these issues. Whereas shrimp farmers in RSRF, ISMF, and SSMF have identified damages due to high tides on their shrimp farming and they have responded by checking tidal forecasts, increasing frequency of upgrading sluice gates and embankments, and or building new sluice gates. Shrimp farmers in SSMF especially have identified that sea level rise accompanied by high tides have damaged infrastructure. As explained in the previous Section 6.2.2, shrimp farmers close to coastal areas are more vulnerable to sea level rise and high tides than shrimp farmers further inland. This finding is similar to effects of extreme climate events in Section 6.2.1. Supporting this, shrimp farming income in SSMF was thought to be at high risk from high tides and extreme risk from sea level rise (Table 5.18, Section 5.3.3.1).

Seasonal pattern changes, such as increase in intense or irregular rain, irregular hot weather and drought, which have caused damage and losses on shrimp farming, were identified by shrimp farmers in the four farming systems (Tables 6.3-6.5). Most of the shrimp farmers have responded to those climate change events with similar activities. For instance, they have been regularly checking weather forecasts and adjusting seasonal calendars to release stock according to seasonal pattern changes; keeping a higher water level and exchanging water more frequently in the case of irregular hot weather and drought; removing the top water layer after heavy rains and increasing their frequency of water exchange as a response to increased intensity or irregular rain. And shrimp farmers in RSRF have taken actions in response irregular weather, such as testing salinity and conditioning of shrimp stock before releasing it, using more chemicals to increase pH, and choosing new rice varieties. These activities suggest that soil health and water usage in RSRF may be more sensitive to climate change events. Sixty-seven percent of land in Ca Mau is comprised of acid sulfate soils and most of RSRF belongs to those soils (DONRE, 2011). There are two seasons in Ca Mau, with normally six months for each season. Shrimp farmers in RSRF need saltwater in the dry season to farm shrimps and completely depend on rainwater to cultivate rice in the rainy season. A seasonal pattern change will change the seasonal calendar for both shrimp and rice. Irregular rains or intense rains or irregular hot weather affect shrimp due to fluctuations of salinity and water temperature and reduce pH because of acidic substances releasing into shrimp ponds. Consequently, it is perhaps not surprising that shrimp farmers in RSRF were more active in adapting to irregular weather than shrimp farmers in the other systems. However, shrimp farmers in RSRF were not the only ones at high risk from the greater intensity or irregular rain; this was case also for shrimp farmers was ISMF and SSMF (Table 5.18, Section 5.3.3.1). Whereas, shrimp farming income in ISF was at high risk from increased fluctuations of water temperature, shrimp farmers in this system have adapted to irregular weather by increasing aeration systems, using more chemicals to control water quality, and increased the green area cover surrounding shrimp ponds.

These research findings partly correspond with aquaculture practice recommendations of Shelton (2014) and adaptation measures of RIA2 (2014) to the adverse effects of high temperature, storms and typhoons, sea level rise, and rainfall identified by farmers in IESF. In particular, IESF farmers have changed the water surface, made ponds deeper, increased dike heights, and made ditches wider in response to high temperatures (RIA2, 2014; Shelton, 2014). For storms and typhoons, farmers improved the pond dikes by making them wider and stronger, used pro-biotics to improve water quality, and improved sluice gates. For the sea level rise, they improved pond dikes, improved attention to forecasts, used nets to prevent shrimp escaping, and used water-pumps. For rainfall effects, farmers used lime to adjust water quality, changed the water surface, and used aerators (RIA2, 2014). Compared to the published literature, the findings in this research show there is diversity in the adaptation measures perceived by shrimp farmers themselves to climate change events in the last 10 years, which should increase the understanding overall.

Table 6.10: Summary of responses and adaptation measures of shrimp farmers in the four farming systems to effects of climate change events on shrimp production over the last 10 years

Climate change issues	Shrimp effects/damages/losses	Responses/Adaptation
Increased intensity of high tides	Overbanks, broken embankments and sluice gates, shrimp losses, and deaths	Upgrading sluice gates and embankments, building new sluice gates
Rainy season pattern changes (longer rainy season, arriving earlier and lasting longer).	Difficult to forecast and adjust seasonal calendar to release stock, rice productivity reduction (RSRF), shrimp survival and growth rate decrease, longer circle of harvest and increase of shrimp diseases	Regularly checking the radio for the weather forecasts to adjust seasonal calendars, releasing stocks based on weather forecast and predictions, salinity tests and taming of stocks to adapt to wide range of salinity, choosing new rice varieties to tolerate higher salinity.
Irregular hot weathers and droughts	Rapid increase of water temperature and salinity, lack of water supply for shrimp ponds, algae bloom and aquatic weeds decreased shrimp growth rate and productivity, acerbating acidification and releasing acidic substances into the shrimp ponds causing massive shrimp losses.	Keeping a higher water level and exchanging water more regularly, using chemicals to treat water before supplying the ponds, running aeration systems to balance temperature among water layers (ISF), increasing the green area cover and trees around shrimp ponds.
Increased intensity or irregular rain	Decreased salinity and increased water temperature fluctuation, reduced pH because of releasing acid sulfate soils into the shrimp ponds, water quality reduction, decreased shrimp growth and increased shrimp diseases (white spots and red body), massive shrimp deaths and losses.	Control of water quality and diseases (ISF) by using chemicals, running aeration systems to balance environmental indicators among water layers (ISF), and fertilisers to treat and balance environmental conditions, removing the top water layer after heavy rains, increasing water exchange, taming of post larvae shrimps to adapt to wide range of salinity.

6.6.2. Farmer cooperation and recovery after an extreme climate event

The research results reveal that shrimp farmers in ISF, with higher levels of cultivation, were more involved and cooperated more in the community groups than shrimp farmers in the other systems in this research. For example, the number of shrimp farmers in ISF who attended clubs, groups, and organisations related to shrimp production was greater than the number of shrimp farmers in RSRF, ISMF, and SSMF (Table 6.7). Shrimp farmers in ISF explained that their membership related to shrimp farming enable them to get more benefits – for instance, easier to access financial support, receive technical trainings from the local government, and share experiences and information on shrimp production. This finding links to the adaptive capacity of shrimp farmers in the four farming systems based on the five capitals. For example, the shrimp farmers who got more involved as members of community groups in this research had greater social capital (Figure 5.2), which may offer these farmers a solution such as mobilizing financial resources, improving the sustainability of their farming and thereby improving their welfare, social networks and environmental responsibility (Ha et al., 2013). Consequently, shrimp farmers who are members of shrimp production groups could be expected to have more adaptation capacity to the adverse impacts of climate change events. Moreover, shrimp farmers in ISF with their greater financial, physical, and social capital, had a higher adaptive capacity to climate change events (Tables 5.19, 5.20) such as the case in responding to an extreme climate event like Tropical Linda Storm.

The research results indicated that levels of damage as a result of Storm Linda surging in 1997 were more serious in ISMF and RSRF than in the other systems (Table 6.6). The time taken to recover for shrimp production after the storm shows results according to the levels of damage. For example, regarding the level completely destroyed by the storm, the recovery time for shrimp production in SSMF and RSRF was the longest (Figure 6.1), which may have been due to their financial capital being the lowest (Table 5.19). However, shrimp farmers in ISMF, SSMF, and RSRF who are close to coastal areas, as discussed in the previous section, were more vulnerable to extreme climate events than ISF further inland, even though ISMF and SSMF farmers had the greatest natural capital.

6.6.3. Shrimp farmers' expectation and adaptation options to climate change events in the future

According to their predictions for future generations, shrimp farmers expect their children to focus on three main options: become a shrimp farmer, look for a new job in surrounding areas, or move to a new place to sustain new livelihoods, but they favour the first and second option (Table 6.8). The majority of farmers in SSMF would like their children to become shrimp farmers, while the majority of shrimp farmers in RSRF expect their children to look for new jobs in the surrounding areas.

With regard to their perspectives on future livelihood strategies, shrimp farmers responded to five options for the adverse impacts of climate change on shrimp production: continue with shrimp farming; change to new aquatic species; change to new jobs; wait until the climate changes seriously; or do not have any plans. The majority of shrimp farmers in all farming systems opted to sustain shrimp farming in the next 10–20 years, even if shrimp productivity was reduced by 40% due to the negative impacts of climate change (Table 6.9). These shrimp farmers explained they would continue with shrimp production for various reasons. Farmers in RSRF indicated that they are familiar with shrimp production and don't have experience with other livelihoods. They would try to adapt, increase resilience in shrimp farming and apply new cultivation techniques in shrimp production. ISMF farmers stated that they are elderly, have a limited education, and have only ever known shrimp farming and this traditional experience. They would also attempt to adapt to adverse impacts on shrimp farming because they don't know what else they could do or where they could go. Shrimp farmers in SSMF also stated that they only know shrimp farming and that their land is suitable for shrimp production; however, they indicated that they would wait and change their livelihood if the negative impacts of climate change were to become serious. Finally, farmers in ISF contended that they would still cultivate shrimp because they are familiar with the traditions of shrimp farming; however, if the adverse impacts on shrimp production of climate change were serious, they would farm shrimp with lower stock density.

The above research findings show that the majority of shrimp farmers expect to continue shrimp farming even though climate change events would seriously affect shrimp production in the future. Therefore, the livelihood strategies and adaption options proposed by the local experts and shrimp farmers (Section 6.5) to climate change events in the next 10–20 years in Ca Mau region need to be considered in this research, as follows.

1. Protecting, upgrading, and or building sea dike systems to protect inhabitants and shrimp livelihoods, building infrastructure for water control in shrimp production, especially in integrated shrimp farming systems (a, i);
2. Having forewarning programs, climate warnings, and weather forecasts for community resilience and disaster prevention (b, ii);
3. Diversifying farming systems and aquatic species to adapt to climate change events, encouraging integrated shrimp farming systems, and sustainable shrimp farming livelihoods (vi, b);
4. Supporting the change from extensive to semi–intensive and intensive shrimp farming (iv);
5. Transferring and implementing new techniques and scientific advances to adapt to climate change for shrimp farmers, especially for shrimp post larvae, shrimp disease control, water exchange reduction, and shrimp quality control (v);
6. Controlling and providing high quality shrimp stock, choosing new shrimp species with less vulnerability, and new rice varieties suitable for a wide range of acidity and salinity (e, v, vi);
7. Providing technical support for shrimp farmers: seasonal calendars, technical

training, financial capital, insurance services, and information about shrimp production (c, f, f, ii, iii);

8. Creating and attending community groups or shrimp cooperatives to support each other in shrimp production (d);
9. Protecting mangrove forests, increasing land cover surrounding shrimp ponds to protect embankments and prevent erosion, considering the proportions between mangrove and shrimp pond areas for suitable with the reality of shrimp production (g, vii).

Most of the priority adaption options were supported by the local experts and shrimp farmers, but there were some differences in terms of priority or perceived importance (see Section 6.5). While shrimp farmers gave more emphasis to farming cooperatives, financial capital, and insurance services to support their shrimp production, the local experts concentrated more on farming diversity, suitable aquatic species, and encouraged shifting from extensive to semi-intensive and intensive shrimp farming.

A shrimp farming cooperative is a group of farmers united in volunteering to advance their shrimp production. Normally in Ca Mau Province, farming support for local communities happens through legal organizations. Farming cooperatives are organizations in which shrimp farmers can get benefits such as easier access to loans from financial institutions, and receiving more technical training and market information on shrimp production. Moreover, shrimp farmers also help each other through participation and information sharing during meetings of farming cooperatives; for example, they might discuss when the period of high tides is due which is important for sourcing good quality water inputs to ponds or if a particular farmer is experiencing poor water quality, they might advise neighbours so that their discharged water is not taken up by others. It would appear that shrimp farmers who are more cooperative members can be more successful by sharing knowledge with and learning from others (Ha et al., 2013), and increasing their social networks. In addition, shrimp farmers suggested recognised the value of financial support because this is important for shrimp farmers to recover after a failure crop or an adverse effect of climate change events. Furthermore, shrimp farmers noted their need to be insured because of increased risks on shrimp production in the future; although insurance services for shrimp farming have not been popular in Ca Mau in the past because it was unsuitable for small-scale shrimp farmers (Be et al., 2003; Secretan et al., 2007). According to the local expert perspectives, diversity of farming systems and suitable aquatic species would reduce risks for the shrimp farming sector because to diversify livelihoods would reduce risk and improve income (Ha et al., 2013), while new quality seed or shrimp stock would help them to adapt to a wide range of environmental changes as a result of climate change impacts. By transferring new techniques and scientific advances on shrimp production, shrimp farmers could improve their cultivation techniques and shift to a higher level, such as from extensive to semi-intensive and intensive shrimp farming systems. This would help to adapt to effects of climate change events due to applying new technologies to control stockings, disease, and environmental water indicators.

These findings add the understanding of previous studies. De Silva and Soto (2009) found that adaptation to climate change could be strengthened by transferring technologies; however, these authors were working with the general aquaculture sector and this finding may not be applicable to shrimp farming because technological transfer may not reach small-scale shrimp farmers in Ca Mau Province.

Joffre and Bosma (2008) analysed technical and economic characteristics of shrimp farmers (170 farms with four types – intensive commercial, intensive family farms, extensive polyculture and rice-shrimp farming) in Bac Lieu Province. The researchers found that technology applied by commercial intensive farms decreased the vulnerability to disease outbreak. However, the gross income on these farms and on intensive family farms remained lower than the polyculture shrimp farms. The above suggestion would apply to all kinds of shrimp farming systems in Ca Mau Province, but the study lacks analysis specially related to climate change factors. Furthermore, Ha et al. (2013) suggested more adaptive measures, such as Better Management Practice (BMP), Good Aquaculture Practice (GAP) and organic shrimp farming as means to reduce disease risks, provide higher shrimp product quality, and enhance sustainability prospects. Most of the local experts in this research claimed that those suggestions could be applied successfully to shrimp farming systems in Ca Mau if shrimp farmers are to be encouraged and get involved in cooperatives and or farming clustering. Moreover, they also asserted that BMP and GAP have been popular practises to date already, but prove to be less successful because of the lack of cooperation between small-scale farmers and individual farms. Moreover, organic shrimp farming has been practised in ISMF in Ca Mau Province, but it has expanded only very slowly because of dependence on a small market in Europe (DARD, 2016) and because it requires clustering of farms to be effective (Bosma et al., 2016). Although adaptive measures related to technical transfers or applications were found by the above authors, recommendations for shifting from extensive to semi-intensive and intensive shrimp farming systems have not been reported on. However, Joffre et al. (2015) argued that it would be possible to shift between extensive, intensive and integrated mangrove-shrimp farming, but impossible to shift farming from intensive or improved-extensive to integrated mangrove shrimp farming. This needs to be considered in livelihood strategies and adaptation options, in terms of mangrove protection and management. Mangroves provide several important benefits to shrimp farmers such as reducing the risk of shrimp disease (Joffre et al., 2014), nutrient cycling (Reef et al., 2010), micro-climate regulation (Lima & Galvani, 2013), and providing a source of timber. These benefits of mangrove retention have clear implications for enhancing resilience to future climate change events.

6.7. Conclusion

The third research question of how Ca Mau shrimp farmers can adapt climate change events has been addressed in this chapter. The research findings provide a variety of adaptation measures perceived by shrimp farmers themselves to climate change events in the last 10 years and these findings partly agree with aquaculture practice recommendations of other authors such as Shelton (2014) and the adaptation measures of RIA2 (2014) to the adverse effects of climate change on IESE. The research also found that shrimp farmers in ISF with higher levels of cultivation were more involved and cooperated more in community groups than shrimp farmers in the other systems and ISF farmers expected to have more adaptation capacity to the adverse impacts of climate change events. This supports the findings presented in Chapter 5 – in particularly that in the future the majority of shrimp farmers would continue with shrimp farming even though climate change events would seriously negatively affect shrimp production. The list of priority adaptation options suggested by shrimp farmers and the local experts mostly align; however, experts emphasised the need to diversify farming systems, find suitable aquatic species, and shift from extensive to semi-intensive and intensive shrimp farming; whereas shrimp farmer were more concerned with farming cooperatives, financial capital and insurance services. These above findings may have implications for decision–makers when planning and practising adaptation options and livelihood strategies regarding the effects of climate change on farmers and the farming sector in the Ca Mau Province and in the Mekong region more broadly.

CHAPTER 7: General discussion and conclusion

7.1. Introduction

Many previous studies concerning impacts of climate change on aquaculture and shrimp farming have operated at the macro scale showing well understood impacts of sea level rise and saltwater intrusion in the Mekong Delta, but this leaves questions about the effects, the vulnerability, and the adaptation options to climate change events at the local scale in the different farming approaches. This research helps fill these gaps in research knowledge by capturing the climate change events most affecting shrimp farming in the last decade and for the near future, the relationship between shrimp production and climate parameters, the variable vulnerability in the four farming approaches, and suggestions for priority adaptation options for shrimp production to build resilience to future climate change. The research project used household surveys, focus groups, a vulnerability assessment, and analysis of secondary data benchmarked against a literature review. Moreover, a field study was undertaken in Ca Mau Province of Vietnam with four selected communes representing the four shrimp farming systems: RSRF, ISMF, SSMF, and ISF. This chapter contains a summary of research findings and integrates original data from the investigations with the review of published material in relation to the three research questions: 1. How might climate change events be affecting shrimp farming in Ca Mau Province? 2. How is shrimp farming in different systems vulnerable to climate change events? 3. How can Ca Mau shrimp farmers adapt to the climate change events? The chapter ends with a summary of the findings for each of three key insights follows that emerge from the overall research.

7.2. How might climate change events be affecting shrimp farming in Ca Mau Province?

This research focused on the farmers and experts perceived effects of climate change events on shrimp production in the last 10 years and into the future. The research found a strong agreement among respondents about adverse effects of climate change events on shrimp production. The major concerns were extreme climate events, sea level rise and high tides, seasonal pattern changes, increased intense rain or irregular rain, and irregular hot or fluctuations of temperature. Together these pose multiple challenges for farmers, and they inter-relate.

Extreme climate events

This research found that the Ca Mau shrimp farmers closest to the coastal areas were more exposed to extreme climate events than shrimp farmers living further inland (Section 6.2.1 and 6.6.1). Previously Tan (2010) noted that tropical storms had been stronger and more frequent on the Southern coast of Vietnam. Most shrimp farmers in RSRF recognised that tropical storms had occurred in the East Sea and affected the Ca Mau region as intense rain (Table 6.1). Mackay and Russell (2011) and Abery et al. (2011) found extreme weather posed a serious threat to aquaculture activities in coastal areas of Ca Mau Province. Abery et al. (2011) and De Silva and Soto (2009) reported that extreme weather destroyed shrimp ponds and farming facilities, causing shrimp escape. The majority of the Ca Mau local experts generally concurred with the findings of these studies regarding the effects of extreme climate events on shrimp production (Table 4.2). A stand out event for farmers was tropical storm Linda which surged in 1997 causing serious losses of human life and property in Ca Mau Province and damaged more than half the RSRF and ISMF shrimp farms (Table 6.6). Fortunately, the majority of shrimp farmers reported no major tropical storm surges in the area within the last 10 years (Table 4.2). The majority of shrimp farmers and the local experts (Table 4.13 and 4.23) agreed with Mackay and Russell (2011) that Ca Mau has experienced fewer storms in the Mekong Delta compared with other regions, but they expected the region would face more extreme climate events in the future.

Sea level rise and high tides

The research found that shrimp farming in coastal areas of Ca Mau was more threatened by with sea level rise and high tides than shrimp farming further inland. A strong agreement of the negative effects of sea level rise and high tides on shrimp production was more obvious among shrimp farmers in ISMF, SSMF, and RSRF than in ISF (Table 4.3 and 4.4). Shrimp losses and damage related to those above issues were reported by shrimp farmers (Table 6.2), especially sea level rise accompanied by high tides. These findings are supported by Actionaid and CRES (2010) and Smyle and Cook (2011) found shrimp pond damage made areas of shrimp farming in IESF unsuitable because of coastal erosion due to sea level rise and high tides.

Most shrimp farmers did not acknowledge other possible reasons for a higher water level. In contrast, Erban et al. (2014) found that the Mekong Delta region has been sinking due to land subsidence at an average rate of 1.6 cm year^{-1} because of over-extraction of groundwater. In later studies researchers confirmed that the delta, particularly in the Ca Mau Province, has sunk on average of 18 cm in the past 25 years because of groundwater exploitation (Minderhoud et al., 2017; Schmidt, 2015). All of these three studies agreed that land subsidence compounded by the threats of a sea level rise would accelerate even greater inundation risk and saline intrusion in the region (Erban et al., 2014; Minderhoud et al., 2017; Schmidt, 2015).

Kuenzer et al. (2013) found that dam construction in the upstream regions of the Mekong River may cause further risk of coastal erosion and saline intrusion downstream, such as coastal farmers in the Ca Mau region, because of water flow changes and sediment load reduction. Converse to most concerns regarding climate change as causing adverse impacts on aquaculture, many previous studies have argued that sea level rise may produce benefits for shrimp farming by facilitating expansion of shrimp farming into low–lying areas (Brander, 2007; De Silva & Roto, 2009; Cochrane et al., 2009; WFC, 2009). An analysis of this research found that there was a significant steady increase of water level in Ca Mau Province in two monitoring stations in the past 25 years (Table 4.26 and 4.27) and found a significantly strong positive relationship between average water level and average shrimp productivity at the 0.01 significance level (Table 4.32 and 4.33). Thus, although Ca Mau shrimp farmers have already experienced sea level rise and high tides, the overall outcomes will be influenced by multiple factors, and may not represent a threat to shrimp productivity.

Changed seasonal patterns and rainfall changes

The research found there was a strong agreement among Ca Mau shrimp farmers in the four farming systems and the local experts about adverse effects of seasonal pattern change (Table 4.5 and 4.16) and increased intensity of rain or irregular rain (Table 4.6 and 4.17) in the last 10 years on shrimp production. Damage to shrimp production due to irregular rain has been recognized by shrimp farmers (Table 6.3 and 6.5). They indicated that the rainy season has been arriving earlier and lasting longer. This caused changes in the seasonal production calendar and shrimp farmers have had increasing difficulty in timing the release of shrimp stock based on traditional experience and knowledge of weather forecasting.

The research also found that increased intensity of rain or irregular rain have been strongly affecting shrimp farming especially localised torrential rains in the dry season according to the majority of shrimp farmers. For example, a major reduction of shrimp productivity in SSMF occurred in 2012 due to intense rain; meanwhile, there were massive shrimp losses in RSRF as a result of abnormal rains, which released acidic substances into the shrimp ponds. The above finding agreed with the previous studies that high rainfall and/or unseasonable rains reduced salinity and decreased water quality resulting in increased disease and shrimp mortality (Abery et al., 2009, 2011; Udaya Sekhar, 2010). Moreover, the research results also found that rice productivity reduction to be recently recognised by the majority of shrimp farmers in RSRF. They stated that irregular rainfall has likely had a large effect on rice production because of the dependence on rainwater to sluice saltwater. These above findings match with the predictions of Allison (2009), Albery et al. (2009), and Muralidhar et al. (2012). For instance, while average annual rainfall and rainfall in the dry season during the last 25 years were highest in 1999 (Figure 4.5 and 4.7), shrimp production reduction was greatest in ISMF (Figure 4.15) in RSRF (Figure 4.17) in the same year.

The majority of shrimp farmers and the local experts also strongly agreed about the negative impacts of seasonal pattern changes and intense rain or irregular rain on shrimp production (Table 4.16 and 4.17). Ho (2011), IMHEN (2010b) and MONRE (2012) predicted that rainfall in Ca Mau would increase with increased intense rain in the rainy season while becoming drier in the dry season. The research found no statistically significant relationship between rainfall in the dry season and shrimp production (Table 4.31 and Figure 4.23) at all farming systems investigated. However, the research found a significant strong negative relationship between average annual rainfall and shrimp production in the whole province, in RSRF and in ISMF at the 0.01 significance level (Table 4.31, Figure 4.21). A similar result was also found for rainfall in the rainy season at the 0.01 significance level (Table 4.31 and Figure 4.22). Hence, rainfall increase or intense rain are associated with reduced shrimp production in Ca Mau Province and this could have impacts in the future.

Shrimp disease

All local experts and the vast majority of shrimp farmers in the four farming systems in this research believed that climate change events have increased the incidence of shrimp disease (Table 5.1) and decreased shrimp productivity (Table 5.2). Shrimp farmers in the four farming systems attributed the cause of increased shrimp disease to irregular weather (Tables 6.3-6.5) in the last 10 years. According to (DARD, 2016), diseases causing shrimp losses and damage have increased over the last 10 years in the Ca Mau Province, and remarkably so over the last five years.

Most of the local experts acknowledged that seasonal pattern changes, greater intensity or irregular rains and droughts, and increased fluctuations of water temperature and salinity were the main climate change factors to increase shrimp diseases and reduce shrimp production. The local experts asserted that increased intensity or frequency of irregular rains and droughts rapidly changed causing fluctuations in environmental water parameters and probably increased shrimp disease. This research found a strong agreement of all respondents about adverse effects of water temperature fluctuation (Table 4.9 and 4.21), salinity variation (Table 4.10 and 4.20), and water quality reduction (Table 4.11 and 4.22) on shrimp production. Supporting the above research findings Tendencia et al. (2011) and Tendencia and Verreth (2011) stated that fluctuation of climate factors and water quality parameters are stress factors which may cause the spread of shrimp disease infection. De Silva & Soto (2009) claimed that the harmful impacts of temperature increases are likely to be severe on aquaculture. NACA (2011) and Ficke et al. (2007) also found that increased fluctuations of temperature may increase shrimp vulnerability to diseases and toxins, and slow shrimp growth and increase mortality (Abery et al., 2009).

The research results show that average annual air temperature recorded in Ca Mau rose by 0.9ºC over the last 25 years (Figure 4.2), with a trend of higher air temperature in the dry season (CHMC, 2016), average minimum air temperature increased greater than maximum air temperature, and maximum air temperature showed increased fluctuations (Figure 4.3). The research found a statistically significant positive relationship between average minimum air temperature and shrimp productivity at the 0.01 significance level, but found no evidence of relationship between maximum air temperature and shrimp productivity in all types tested at the 0.05 significance level (Table 4.30). The former of these research findings contrasts with a study by Rimi et al. (2013) who found no evidence of a relationship between shrimp production and changing temperature parameters in the coastal region of Bangladesh.

These finding may imply that an increase in average minimum air temperature would have a positive impact on shrimp production because low air temperatures are associated with shrimp disease occurrence (Tendencia & Verreth, 2011). However, as mentioned in Section 4.6.1 and 5.4.1, increased fluctuation of water temperature is a risk factor that would cause an inconvenient environment for shrimp growth whist enhancing the incidence of white spot syndrome virus (WSSV) (Tendencia et al., 2011; Piamsomboon et al., 2016). Fluctuations of maximum air temperature were found in this research to increase risk for shrimp farming in Ca Mau.

Despite the association between shrimp disease outbreak and climate factors as discussed in this section, some studies suggest that other factors may cause shrimp disease transmission. Anh et al. (2010) conducted a study in Can Gio district of Ho Chi Minh City and found that water pollution and the spread of diseases were related to intensive shrimp farming because a large number of individual farms have waste streams that exceed water quality standards. Shrimp disease outbreaks may also relate to poor farming performance associated with other aspects of water management. Hoa et al. (2011a) found that transmission of WSSV in improved-extensive shrimp farming had increased due to recycling of water between ponds over time, while shrimp diseases were transmitted into semi-intensive shrimp farming from neighbouring farms. A recent study on effects of soil and water quality highlighted that ammonia is a major issue for shrimp farming because it may cause more severe disease outbreaks (Zafar et al., 2015). Akanawa and Eguchi (2013) found that the importance of pH water is a key environmental trigger for Early Mortality Syndrome (EMS). The study suggested that this disease appears only when water pH reaches 8.5 – 8.8, while at pH around 7.0 the disease disappears. Moreover, poor post larvae quality is also a factor in some shrimp diseases because infected post larvae may spread into shrimp farms (Akanawa & Eguchi, 2013). Therefore, these findings may suggest Ca Mau shrimp farmers may need to better to manage water quality in their shrimp ponds to reduce risk of shrimp disease outbreaks. Such controls may prove to be more important than potential risks or causes of shrimp disease currently attributed to climate change by the farmers surveyed in this research.

Perceived risks posed by climate change events in the last 10 years

This research produced a ranking of the five climate change events that mostly affected shrimp farming in the last 10 years and a ranking of the climate change events that will most impact shrimp production in the next 10-20 years as perceived by shrimp farmers in the four farming systems and the local experts (Table 4.12 and 4.23). Shrimp farmers in RSRF, ISMF, and ISF ranked the climate change events of greater intensity or irregular rains as having the highest impact on their shrimp farming systems, whereas sea level rise was ranked as having highest impact by shrimp farmers in SSMF (Table 4.12). These research findings partly agree with the study of Abery el al. (2009), which found that shrimp farmers in IESF had the greatest concern about irregular seasons.

The majority of shrimp farmers had concerns about intense rain or irregular rain because evidence of shrimp losses and damages had been identified in all farming systems, especially in RSRF (Table 6.3 and 6.5). However, it is interesting that while shrimp farmers in SSMF were mostly concerned about impacts of sea level rise, there was actually more evidence of effects on their shrimp farming from high tides (Table 6.2). Possibly this is because sea level rise may be confused with high tides and SSMF farmers had directly seen adverse effects of high tides on their shrimp farms. In contrast, the local experts considered that fluctuations of water temperature were having the most effect on shrimp production in Ca Mau. The local expert perceptions correspond with NACA (2011) and Noyes et al. (2009) who conducted a study in the neighbour province of Bac Lieu and found that high water temperature was the greatest climate concern of shrimp farmers in IESF and ranked this as the greatest risk factor for shrimp production.

Perceived risks posed by climate change events in the future

Shrimp farmers in ISMF and SSMF were most concerned about high tides (Table 4.23) impacting on shrimp production in the future because these shrimp farmers are closest to the sea and more affected by a stronger tidal amplitude than RSRF and ISF farmers. For example, the tidal amplitude varies between 2.0–3.0 m in ISMF, 3.0-3.5 in SSMF, and 0.5–1.0 m in RSRF (Stoop et al., 2015).

In contrast, shrimp farmers in ISF have indicated greater intensity or irregular rains as likely to have the most impact on their shrimp production in the future because they may acknowledge that this would rapidly change water quality and strongly impact their shrimp ponds as found in the last 10 years (Table 6.5). Shrimp farmers in RSRF were most concerned about impacts of seasonal pattern changes on their shrimp farming as a changing seasonal calendar would cause difficulties for both shrimp and rice production. Likewise, the local experts were typically concerned about seasonal pattern changes (Table 4.23) and the majority of the local experts claimed that shrimp farming in ISF would be at less risk from climate change events than other shrimp farming systems in the Ca Mau Province because water quality control and management in this system is better than in the other systems.

7.3. How is shrimp farming in different systems vulnerable to climate change?

While considerable literature has been published to date on likely impacts of climate change on Ca Mau, the Mekong Delta, and aquaculture more generally relative little has been published regarding the vulnerability of shrimp farmers in different farming systems to climate change events. This research makes an important contribution in this regard, generating data and insights from the perspectives of farmers in the four different farming approaches.

Notwithstanding some of the other factors that may be impacting shrimp production discussed above, the perspectives of shrimp farmers in the four farming systems and the local experts described in Chapter 4 and the previous discussion show a strong agreement regarding the adverse effects of climate change events on shrimp production in Ca Mau Province. From the original data collected and discussed in Chapter 5 and evidence of shrimp losses and damages in Chapter 6, the research identifies the vulnerability of shrimp farming to climate change events in the four farming systems. The research findings were derived from research results presented previously and from relating them to the characteristics and ramifications for each farming system. The findings reveal variable vulnerability of shrimp farming to each climate change impact found in the four farming systems. These findings present a means for drilling down to a more specific understanding of how climate change is affecting particular farmers, and thus to understand shrimp farmer vulnerability to climate change events in Ca Mau. Details relevant to the individual farmer level in the different farming systems have not previously been published, so this current research makes an important original contribution here.

This research suggests that shrimp farmers in intensive shrimp farming (ISF) with higher cultivation levels and or greater income are less vulnerable to climate change events than shrimp farmers in the other farming systems (RSRF, ISMF, and SSMF). This finding contrasts with the work of Ha (2012) and Ha et al. (2013) who maintained that ISF was risky and unsustainable because of poor water management, a high frequency of harvest failure, fluctuations of shrimp prices, and market competition. The difference may because this study was conducted in a year with a higher market price than that for the above authors. This research found that shrimp farming in ISF had a lower risk to most of the climate change events (except to increased fluctuations of water temperature) (Table 5.18). The research also found that ISF shrimp farmers had a high to moderate adaptive capacity to most climate change impacts (Table 5.20) because those farmers had highest levels of financial capital, physical capital, and social capital, comparing with shrimp farmers in the other farming systems (Table 5.19). Overall, shrimp farmers in ISF had a low to moderate vulnerability level to climate change events (Table 5.21). There is some evidence in the literature to support the above findings as the following example attest.

Shrimp farmers who have higher household income have more adaptive capacity to climate change events because they have more financial resources to undertaken adaptation measures. Franzel (1999) found that households with higher income had a better possibility to invest in their farms. These farmers may be better able to access technologies to enhance their farm production and to adapt to climate change events because family income significantly affects adaptation options adopted by farmers (Anyoha et al., 2013; Uddin et al., 2014). This research found some linkages between household income and household characteristics and its ramifications in the four farming systems. Descriptive statistics and results (Section 5.3.1.2 and Section 5.3.2.4) show that shrimp farmers in ISF and ISMF with higher household income have smaller family size, higher education, greater farming experience, and more income stream diversity than shrimp farmers in RSRF and SSMF, although average ages are similar in all groups. The bigger family size is related to poverty (White & Masset, 2000). Binh (2010) found that family size in the rural areas of Vietnam had a strong negative relationship with household income. Farmers with better education are believed to have better access to climate change information (Deressa et al., 2008) and that this has a positively influence on decisions regarding adaptation to climate change (Deressa et al., 2008; Maddison, 2007). Anyoha et al. (2013) and Uddin et al. (2014) show that adaptation options undertaken by farmers were significantly affected by educational level and farming experience.

The research also found that shrimp farmers who were more involved and cooperated in social groups were likely to have greater adaptive capacity to climate change events. The research results show that shrimp farmers in ISF had greatest social capital (Table 5.19) on that basis that they are more involved as members of community groups than farmers in the other farming systems (Table 6.7). As mentioned in Section 6.6.2, shrimp farmers who attended community groups related to shrimp production considered that they obtained more benefits from the farming experience of peers, technical training, and financial support than shrimp farmers without such membership. Weibel et al. (2017) claimed that membership of social-political organizations, considered as one kind of social capital, may provide more opportunities for farmers to learn new farming practices. Ha et al. (2013) contended that farmers' cooperation in shrimp farming groups mobilised financial resources and improved farming sustainability. Similar findings were reported by Ha (2012) who suggested that farmer groups particularly related to political and commercial interests strongly affected their farming success. Many other studies agree that cooperative involvement or social organizations had significant positive relationships with adoption of adaptation options by farmers to climate change (Anyoha et al., 2013; Uddin et al., 2014; Waibel et al., 2017).

In the medium vulnerability category, the shrimp farmers in ISMF were considered as medium to low risk (except to the climate change event of greater intensity or irregular rains, of which it is at high risk) (Table 5.18). They had a medium level of adaptive capacity to most of the previously identified climate change impacts (Table 5.20). This is because shrimp farmers in ISMF had more diversified income streams than shrimp farmers in the other farming systems, as a large majority of farmers had two or three income streams within their households to sustain livelihoods (Figure 5.1). Moreover, this research shows evidence that shrimp farmers in ISMF had a higher shrimp and family income (Tables 5.15, 5.16) than shrimp farmers in RSRF and SSMF. Ha et al. (2014) also stated that annual net return per hectare from the integrated shrimp-mangrove farming was greater than separated shrimp-mangrove farming and non-mangrove farming systems. Moreover, by comparing the economic value of integrated mangrove-shrimp farming systems with intensive shrimp farming systems, Ha et al. (2013) and Ha et al. (2014) found that ISMF produced a quarter of the revenue of ISF, ISMF harvested larger shrimp sizes, sold at better prices, and the benefit-cost ratio was three times higher than ISF.

Also relevant here is that ISMF was ranked as having the highest natural capital and the integration of mangroves with the shrimp ponds in ISMF farms would probably provide shelter for shrimp and in that way, offer some natural increased climate change resilience. Furthermore, this research also found that shrimp farmers in ISMF had longer experience in the shrimp farming industry (Table 5.13), more collaborative involvement than farmers in RSRF and SSMF (Table 6.7), smaller family size, and higher education level than RSRF. Hence, ISMF was considered to have a moderate to low vulnerability to all climate change events (Table 5.21).

This research found that while both shrimp farming in RSRF and in SSMF had high to medium risk to most climate change events (Table 5.18), farming in RSRF systems was more at risk to irregular weather (seasonal pattern changes and greater intensity or irregular rain), while shrimp farming in SSMF was more at risk for sea level rise and high tide. Both shrimp farmers in RSRF and SSMF had similar low adaptive capacity to each of the climate change events (Table 5.20). Therefore, shrimp farming in the two systems had a high to medium level of vulnerability to most of climate change events (Table 5.21). It was interesting that there were no significant differences between household characteristics of

RSRF and SSMF shrimp farmers in average age, education level, farming experience, income stream, and shrimp farming income. Nevertheless, the family income of farmers in SSMF was significantly greater than in RSRF at the 0.01 significance level (Table 5.16). This can cause RSRF farmers with lower household income to have less access to new techniques to improve their farming practices and sell products (Adeoti & Sinh, 2009). However, more than two thirds of all families in SSMF depended entirely on shrimp production (Figure 5.1), which may decrease farmers' resilience because they were highly dependent on only one income source to sustain their livelihoods. Although shrimp farmers in SSMF were less involved as members of community groups related to shrimp farming than RSRF farmers, shrimp farmers in SSMF had individual farms with large and contained mangroves separated from shrimp ponds, and these features could provide some climate change resilience.

Overall, the study found some important linkages between the characteristics for each farming type and the perspectives of shrimp farmers on the vulnerability of shrimp farming. The research results show that the level of vulnerabilities varied by farming system, with farmers operating in intensive shrimp farming systems (ISF) and integrated shrimp-mangrove farming (ISMF) appearing to be less vulnerable to existing and expected climate change impacts than those in separated shrimp-mangrove farming and rice-shrimp rotation farming systems. In contrast, Ha et al. (2013) and Kam et al. (2012) considered ISF to be one of the more vulnerable shrimp farming systems, while Kabir et al. (2016) and Tran (1997) considered RSRF to be one of the more sustainable shrimp farming systems. This research shows that shrimp farmers in ISF and ISMF had lower risk levels and a higher adaptive capacity to climate change events than those farmers in the other systems, and ISF and ISMF shrimp farmers' performance characteristics regarding number of income streams, farming experience, shrimp farming income and total family income, family size, education levels, and social group involvement were relatively favourable. Therefore, shrimp farmers with a higher level of cultivation and integration, such as ISF and ISMF, would be less vulnerable to climate change events than those shrimp farmers in RSRF and SSMF. These nuanced findings of differences amongst the four farming systems can help guide policy and on the ground action by government authorities for providing assistance to shrimp farmers in Ca Mau Province – it is clear that not all farming systems will experience the effects of climate change in the same way, meaning that the kind of assistance extended to them by authorities will need to be suitably tailored.

7.4. How can Ca Mau shrimp farmers adapt to climate change events?

Shrimp farmers in ISMF, SSMF, RSRF had experienced and adapted to the adverse effects of high tides by increasing the frequency of upgrading sluice gates and embankments (Table 6.2). During seasonal pattern changes, they had adjusted their seasonal calendars, conditioning of shrimp stocks, and chosen new rice species to adapt to the wide range of water salinity (RSRF) (Table 6.3). Furthermore, during greater intensity or irregular rains, shrimp farmers had removed the top water layer after heavy rains (ISMF, ISF), used chemicals and run aeration systems (ISF), and applied fertilisers and limestone to balance the water quality (SSMF, RSRF) (Table 6.5). When experiencing temperature changes, farmers had exchanged water more frequently to balance the pond water temperature (ISMF, SSMF), kept higher water levels (RSRF), or run aeration systems (ISF) (Table 6.4). The adaptation options were undertaken by the Ca Mau shrimp farmers in RSRF, ISMF, SSMF, and ISF were similar to adaptation measures identified by farmers in IESF (RIA2, 2014) and generally consistent with aquaculture practice recommendations of Shelton (2014).

It seems likely that shrimp farmers with higher level adaptive capacity may have more social involvement and better recovery ability after an extreme climate event. The levels of damage caused by the Storm Linda surge in 1997 (Table 6.6) and the time taken for farms in the four farming systems to recover to the original state (Figure 6.1) were investigated. The results show that shrimp farmers in ISF and ISMF, who had a shorter recovery time after their production was completely destroyed by the extreme climate event, demonstrated higher financial capital adaptive capacity to the adverse effects of climate change than shrimp farmers in RSRF and SSMF. This research also found that shrimp farmers in ISF who were more involved in the community groups related to shrimp industry had the highest social capital. The above findings link to the adaptive capacity levels of shrimp farmers in the four farming systems in Table 5.19 and discussed in Section 6.6.2. Therefore, Ca Mau shrimp farmers who had low adaptive capacity, such as in RSRF and SSMF, would need to increase their resilience to climate change events in order to sustain their business into the future.

This research found a strong agreement among respondents of adverse effects of climate change events on shrimp farming in the last 10 years. Despite this the majority of shrimp farmers in the four farming systems will remain in shrimp farming in the future even though they expect climate change events to seriously adversely impact their shrimp production (Table 6.9). It also found that the majority of farmers expected their children to become farmers and/or be looking for new jobs in the surrounding areas, whereas only a minority of farmers wanted their children to migrate to new places and/or gain higher education to seek a better life (Table 6.8). As mentioned in Section 6.5 and Section 6.6.3, shrimp farmers will remain in shrimp farming due to the following reasons. Shrimp farming is the traditional livelihood and the Ca Mau shrimp farmers have experienced this livelihood for decades. Farmers may not have other better options to encourage them to change their current livelihood. Shrimp farmer may not know how to change livelihoods because they are elderly, have a low education level, and or they are uncertain about future impacts of climate change (Table 6.9).

Finally, the farmers consider that there is a large potential market for shrimp exports as Ca Mau shrimp products have been exported to many countries in the world at a good price for the last 20 years. Hence, the majority of shrimp farmers will try to adapt to the negative impacts of climate change events by applying new techniques, increase climate change resilience, and increase farming management if climate change impacts seriously on shrimp production. On the basis of shrimp production in the future, policy responses should focus on managing the existing shrimp farming industry with an emphasis on promoting actions that will strengthen shrimp farmers' resilience, such as climate change adaptation measures and modes of production tailored to each of the four farming system circumstances that fare best in the face of climate change effects identified in this research.

From the previous discussions in this Chapter and adaptation options put forward by shrimp farmers and the local experts (Section 6.6.3), this research suggests that intensification, integration, and cooperation in shrimp farming would be good options for Ca Mau shrimp farmers to adapt to climate change events in the future. In terms of intensification, there is a need to support shrimp farmers to shift from extensive to semi-intensive and intensive shrimp production because although it accounts for only 3.4% of 278,642 ha shrimp farms in Ca Mau Province (DARD, 2016) intensive shrimp farming has a large potential for future production. Intensification of existing farming systems is a sustainable option to increase aquaculture production (Bosma & Verdegem, 2011). Sustainable intensification of aquaculture practice should improve production and resource use efficiency, provide environmental benefits, strengthen farmers' resilience and economic diversity, and improve social acceptance and equality (FAO, 2016). Boyd et al. (2017) showed that intensification of shrimp production increased efficiency due to reduced resource use and decreased environmental impact per metric ton of shrimp product. Angel et al. (2017) supported this hypothesis by finding that intensive shrimp farming in Vietnam and Thailand achieved greater resource use efficiency per metric ton of shrimp produced and more economically sustainable than extensive shrimp production. Intensive production can reduce costs per metric ton of shrimp production and its products are more competitive commercially. However, there are some challenges for expansion of intensive shrimp farming in Ca Mau province including variable shrimp stock quality, high production cost, poor disease control, and low technical knowledge (Ahmed & Diana, 2015). Nevertheless, as suggested by the local experts and shrimp farmers in this research, technology transfer, implementation of new techniques, and scientific advances would help to control stock quality, shrimp disease, reduce water exchange, and increase shrimp production (Section 6.5).

Although the practicality of the application of new technologies suitable for small-scale farms is still being debated, Vandergeest et al. (1999), Iliyasu et al. (2014) suggest that small-scale shrimp farms may be as intensively managed as large-scale shrimp farms because productivity and income of per hectare for small and large farms were not significantly different (Hai, 2005). Biotechnologies, such as bio-flocs and bio-films, can increase efficiency of resource use and shrimp production (Bosma & Verdegem, 2011).

In terms of integration, it is possible to increase shrimp intensity in polyculture such as integrated farming systems to boost shrimp livelihood and adapt to climate change events. With integrated shrimp-mangrove farming (ISMF) and separated shrimp-mangrove farming (SSMF), consideration may be given to convert them to partly separated shrimp-mangrove systems because there is a higher contribution to ecological services in the mangrove areas and shrimp farming intensification in separated ponds (Bosma et al., 2016). Those integrated systems may provide a better option for both the farmers and the national economies (Bosma et al., 2012) because shrimp farmers may optimise their income due to mangrove forest and aquaculture products (Ha et al., 2013). In rice-shrimp rotation systems (RSRF), it may be necessary to increase intensity of brackish shrimp production in the dry season and integrated rice-with less sensitive aquatic organisms (Bosma et al., 2016) such as *Macrobrachium rosenbergii* in the rainy season.

In terms of cooperation, an increase of social involvement is likely to increase social capital and the adoption of adaptive strategies to climate change (Anyoha et al., 2013; Uddin et al., 2014). Beside the benefits discussed in Section 6.6.3, cooperation or cooperatives may enhance the value chain of shrimp production by selling products though shrimp processing enterprises, not middle men. Furthermore, by collaboration and or clustering, shrimp farmers may more easily achieve certificates for organic products, apply successfully for Better Management Practice (BMP) and Good Aquaculture Product (GAP) status, as proposed by Ha et al. (2013), and attain other international certificates for international market requirements. Ha (2012) suggested that cooperatives or shrimp farmer clusters should integrate into a value chain to produce high quality and safe shrimp products and engage in sustainable farming practices. Thus, increase of shrimp production intensification though technological transfers, integration, and cooperation in shrimp production for Ca Mau shrimp farmers may gain a better shrimp livelihood and increased resilience to climate change events in the future.

7.5. Research limitations

This research has provided an evaluation of impacts, vulnerability, and adaptation to climate change events in relation to shrimp production through household surveys, focus groups, and secondary data analysis. The main limitations in this research that would need to be considered follow.

First, as a direct consequence of this methodology, it should be noted that the surveys and the focus groups were reliant on the self-reporting of shrimp farmers who sometimes had biases and lack a full understanding of climate change events. Moreover, the perspectives of shrimp farmers and the local experts are subjective and qualitative and may be influenced by other non–climate change related factors. These would influence their perceptions of existing exposure and sensitivity to climate change effects.

Second, the research survey design was through the questionnaire with constructed questions in this research mostly focused specifically on climate change topics or factors. This may possibly give less opportunity for respondents to perceive other causal factors of observed changes than those factors related to climate change.

Third, the research drew the attention of shrimp farmers to consider to what extent they agreed with aspects of climate change events. This may overlook or avoid some alternative relevant possible reasons for impacts on shrimp production because the study directed farmers' attention to climate change issues exclusively and they were not specially prompted to consider alternative explanations.

Fourth, although shrimp production and hydro-meteorological data were obtained for the 25-year period, farm input data in the four farming systems to examine shrimp and household income was collected only for the three-year period. This may neglect an opportunity to explore more deeply interactions between an analysis of shrimp farming income and shrimp farmers' perceptions on impacts of climate change events.

Finally, it should be noticed that while correlation analysis results in this research may help to predict relationships between hydro-meteorological parameters and shrimp productivity, further research examining causalities and effects of those parameters and shrimp production in the fields would be valuable because shrimp productivity may be affected by multiple factors.

7.6. Research applications

The research has provided useful findings with applications for future management of the farming sector through identifying the impacts, vulnerability levels, and adaptation strategies of farmers in the different farming approaches in relation to shrimp aquaculture and climate change events. This study not only provides practical applications for shrimp farmers in the Ca Mau Province but has potential relevance for the wider Mekong Delta and in other tropical coastal regions, along with the provincial governments, and policy makers responsible to regulating aquaculture. It also contributes to new knowledge to climate change research on shrimp aquaculture. The research suggests that despite clear perceptions of impacts and challenges posed by climate change, it is likely that shrimp farming will continue in the coming decades. Therefore, practical responses to the main findings of the research lie in government policy and strategic management of the existing shrimp farming sector. The main implications from the research findings are described below.

First, although many previous researchers have examined effects of climate change on aquaculture, catfish and shrimp in the Mekong region, there has previously been very little study of perspectives of shrimp farmers in different farming approaches and local experts on the adverse effects of climate change events on shrimp production. This study contributes to scientific knowledge by providing new findings. Each of the four farming systems is different and the farmers perceive and react to climate change effects differently; some are more vulnerable to specific climate change events, and some are adapting in particular ways. It is important for the provincial governments, the farming enterprises, and residents in the Mekong Delta and other coastal regions to fully understand the differences in farming systems in order to provide useful assistance to shrimp farmers. Key differences identified in this research include more nuanced and detailed understanding of the perceived impacts of climate change on shrimp farming operations in the past and future and the different concerns of coastal farmers relative to those operating further inland. These findings could also help policy makers to identify priority issues for managing the existing shrimp farming systems and what might be done to increase climate change resilience for shrimp farmers and local inhabitants.

Second, the vulnerability levels of shrimp farming in different farming approaches to climate change events as perceived by shrimp farmers to climate change events have not been published by previous researchers. This research contributes to scientific knowledge by providing evidence that intensive farming systems are the least vulnerable, integrated farming approach exhibit medium vulnerability, and rotation farming and separated farming approaches have greatest vulnerable to climate change events. These findings have policy implications for decision makers, who are advised to encourage economic and sustainable farming development. For instance, decision makers should determine which shrimp farming system emerges as least vulnerable to the existing and expected climate change impacts, and suggest strategies to both enhance farming resilience to the adverse effects of climate change events and improve cultivation techniques in different shrimp farming systems. Encouraging more intensive and integrated shrimp farming approaches could reduce vulnerability and enhance farming resilience to climate change events. These findings are relevant to the provincial governments, farming enterprises, and residents of the Mekong Delta as well as to equivalent stakeholder groups in and tropical coastal regions more generally.

Third, even though climate change events are expected to seriously adversely impact on shrimp production in the future and that many farmers lack adaptation options and livelihood strategies to cope with climate change issues, shrimp farmers in the four farming systems are equally determined to sustain their shrimp farming livelihood. This finding has policy implications for decision makers who consider integrating people's expectations with adaptation options and livelihood strategies to face the impacts of climate change in the future.

Fourth, while there was evidence of shrimp losses and damages perceived by shrimp farmers in the four farming systems, the research found the priority adaptation options to the adverse impacts of climate change events in the future and suggests that be given to consider intensification, integration and cooperation in shrimp production. There findings can be used to advise shrimp farmers on how to successfully farm shrimp and enhance their resilience in the face of climate change events in the future along the following lines:

- Joining a cooperative or cooperation to realise benefits from sharing information in shrimp farming, technological transfers, and weather and climate risks; increase social networks; make it easier to access financial support and technical training; and to enhance the value chain by directly selling shrimp products to processing enterprises;

- Shift to intensive farming as this offers a number of benefits for shrimp farmers, such as accessing new cultivation techniques and technological transfers, improving pond management and shrimp disease control, increasing shrimp production and resource use efficiency, and therefore, improving farmer household income;
- Adopt integrated approaches to shrimp farming, especially protecting mangroves as this will diversify farm income sources for shrimp farmers due to the opportunity to harvest a variety of aquaculture products and providing benefits from timber and ecological services;

To implement this advice, governments will need to provide the necessary technical support to shrimp farmers such as supporting the transition into intensification and cooperation and integration, providing seasonal production calendars, technical training, financial capital, insurance services, and information about shrimp production all aligned to enhance shrimp farmers and community resilience to climate change impacts.

Finally, the research findings provide some more general learnings which may have value for decision makers, governments, farming enterprises, and residents in the coastal tropical countries to consider when seeking to understand how best to address the effects of climate change on aquaculture as follows:

- There is value in understanding the perspective of farmers, including communicating with people about their experiences and concerns about climate change;
- There is value in understanding the specific differences in risks, vulnerability, and adaptation options for different farming approaches. Current scientific reports and government policy tends to treat all shrimp farming aquaculture as through it is all the same and even to include other forms of aquaculture. In other words, policy and guidance needs to be tailored to the local context and details;
- Also, there is value in promoting and enhancing cooperation between farmers. Whilst this study has only considered shrimp farmers in Ca Mau, it is reasonable to assume that initiatives such as the cooperatives would be useful in the wider Mekong Delta and other countries. Technical information transfer and sharing of knowledge through cooperatives relevant to shrimp farming experience likely will equally may apply for other types of farming production;

- The combination of intensification of operations but at the same time integration with nature protection (e.g. mangroves) may provide benefits for tropical coastal inhabitants to enhance both economic and environmental resilience to climate change through diversifying income sources and increasing values of ecological services capable of buffering and recovering from the effects of climate change.

7.7. Conclusion

This research gives the unique aspect of the impacts, vulnerability, and adaptation to climate change events on shrimp production perceived by the local experts and shrimp farmers in the four different farming approaches in the Ca Mau region of the Mekong Delta. The research also examines the relationship between rainfall, temperature, and water level with shrimp production. The study has addressed these important findings to make a unique and original contribution to knowledge, especially by contrasting the findings derived from the different perspectives of the shrimp farmers in the four farming systems with the opinions of experts, the published literature, and climatic and hydrology records.

First, although different perceptions were evident between local experts and farmers in the four farming systems and these were compared with the climatic and hydrology records, it is clear from these comparisons that adverse effects of climate change events on shrimp production have been occurring according to respondents in the Ca Mau region of Vietnam. The study also sought to expose the inter-related nature of climate change events, although these may not demonstrate a relative hierarchical importance. While shrimp farmers on the coast (ISMF, SSMF) were more concerned by adverse effects of extreme climate events, sea level rise, and high tides than farmers further inland (ISF), a significantly strong positive relationship between water level and shrimp production may suggest more benefits from a higher water level for expanding shrimp production. Whereas shrimp farmers in RSRF were most concerned with seasonal pattern changes and intense rain or irregular rain, a significantly negative relationship between rainfall and shrimp production may suggest more severe impacts in the future. The five climate change events most affecting shrimp farming over the last decade and the future have been identified to be seasonal pattern changes, increased intensity or irregular rains, sea level rise and high tides, and extreme climate events.

Second, the perceived vulnerability of shrimp farming to climate change events varied significantly across farming systems, with evidence that intensive shrimp farming with higher cultivation level and greater income was less vulnerable overall, while integrated shrimp–mangrove farming was better than rice–shrimp and the separated shrimp–mangrove approach. Shrimp farmers with higher household income would be more likely to undertake adaptation measures and those farmers with greater social involvement or community groups were considered likely to have better adaptive capacity to climate change events.

Third, with respect to adaptation, the shrimp farmers identified actions they had already taken in response to climate change effects, but no clear strategy was evident to address likely future events. Although the majority of shrimp farmers hoped that their children change occupation, most farmers in all four systems expected to continue with shrimp production into the future, despite identifying serious impacts from climate change on their shrimp livelihood. From the priority adaptation measures perceived by shrimp farmers and the local experts, as well as published literature, the study suggested that intensification, integration and cooperation would be good adaptation options for future climate change.

Based on these research findings, one of the most significant issues to consider is that it would be advantageous for local governments, farming enterprises, and residents in Ca Mau Province, the Mekong Delta, and other tropical coastal regions alike to gain a better understanding of climate change risks to shrimp farming and related livelihoods, and to encourage development of the farming approaches that minimise climate change vulnerability. While there have been many studies concerning proportions of mangrove and shrimp pond areas in integrated shrimp-mangrove farming systems, an appropriate level of integration may consider in further research to fulfill both ecological services and the sustainable livelihood needs of local communities. Further work needs to be incorporate climate factors within components of the project to re-design the current rice-shrimp systems to a sustainable rise shrimp system for the Mekong Delta because rice-shrimp rotation farming systems in this research were likely too sensitive to environmental conditions and high vulnerable to climate change.

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APPENDEX

Appendix A1: Shrimp farming questionnaire (for shrimp farmers)

My name is An Van Quach, a PhD candidate at School of Environmental Science, Murdoch University under the supervisor of Associate Professor Frank Murray and Associate Professor Angus Morrison-Saunders. The interview aims to collect information for my research "***Shrimp farming vulnerability and adaptation to climate change in Ca Mau Province, Vietnam***". It will take about 35 minutes to answer the questionnaire. Feel free to express your opinions because there are no right or wrong answers. Feel free to not answer a question if you don't want to and you can stop the survey at any time if you wish. Your name or other information that will identify you will not be presented in the final writing up and individual persons will be not identified. The questionnaire results will be stored in a safe place in Murdoch University. If you have any problems or need more information, feel free to contact the Human Ethics Office or my Supervisors (provide business cards).

- Household ID: …………………………………………………………………...
- Respondent ID: ……………………………………………………………......................
- Gender: [ ] (Code: 0 = Male, 1 = Female)
- Address: ....
- Interview day: __/__ __/20____ [MM/DD/YYY]
- Start Time __ __:__ __ AM [*Circle One.*] [HH:MM]
  __ __:__ __ PM

A.1.1. Basic information

A.1.1.1. What is the area (in ha) of your shrimp farm?

A.1.1.2. How would you describe your shrimp farming systems? [*Circle all that apply*]

[a]. Extensive [b]. Improved extensive

[c]. Semi-intensive [d]. Intensive

A.1.1.3. Do you cultivate only shrimp or integrate it with other production (If answer [a] and [b] in question A.1.1.2)? [*Circle ones that apply*]

[a]. Only shrimp production [b]. Integrating shrimp farming

If answer [b], please detail………………………………………………………

A.1.1.4. What are main income-generating activities of your household from 2010 to 2012?

No.	Main activities	Unit	Amount	Productivity/result	Price	Notes
2010						
1	Shrimp farming					
2						
3						
4						
5						
…						
2011						
1	Shrimp farming					
2						
3						
4						
5						
…						
2012						
1	Shrimp farming					
2						
3						
4						
5						
…						

A.1.1.5. Could you please quantify the shrimp farming input costs over last 03 years?

No.	Year	Unit	Amount	Results	Notes
1	2010				
2	2011				
3	2012				

A.1.1.6. What were key challenges or issues for your shrimp farming production in the last 10 years?

A.1.2. Climate change impacts on shrimp farming

A.1.2.1. Have you identified any adverse effects of climate change on your shrimp farming systems in the last 10 years?

[1]. Yes [0]. No [2]. Not sure

A.1.2.2. To what extent do you agree or disagree with the following statements concerning climate change events that may have adversely affected shrimp farming in the last 10 years?

Climate change events/irregular weather changes	Strongly agree	Agree	Disagree	Strongly disagree	Unable to judge
Extreme climate events (more frequency and/or intensity of storms)					
Sea level rise					
- Increase in sea and river water levels					
- Increased intensity of high tides					
Rainfall changes					
- Rain season pattern changes					
- Greater intensity or irregular rains					
- Water quality decrease in shrimp ponds					
- Increased fluctuations of salinity in the surface water of the shrimp ponds					
Temperature changes					
- Drier dry season					
- Longer dry season					
- Increase fluctuations of the temperature water in the shrimp ponds					

A.1.2.3. Please rank the five climate change events that have most affected shrimp farming in the last 10 years? *(please place in order 1 - 5)*

A.1.2.4. To what extent do you agree or disagree with the following statements concerning climate change events that will negatively affect shrimp farming in next 10 – 20 years? (*Tick one box for each line*).

Climate change events/Irregular weather changes	Strongly agree	Agree	Disagree	Strongly disagree	Unable to judge
Extreme climate events (more frequency and/o intensity of storm surges)					
Sea level rise					
- Increase in sea and river water levels					
- Increased intensity of high tides					
Rainfall changes					
- Rain season pattern changes					
- Greater intensity or irregular rains					
- Water quality decrease in shrimp ponds					
- Increased fluctuations of salinity in the surface water of the shrimp ponds					
Temperature changes					
- Drier dry season					
- Longer dry season					
- Increased fluctuations of the temperature water in the shrimp ponds					

A.1.2.5. Please rank the five climate change events that will most affect shrimp farming in the next 10 – 20 years? *(please place in order 1 - 5)*

A.1.3. Shrimp farmer vulnerability to climate change

A.1.3.1. To what extent do you agree or disagree with the statement that climate change events have adversely affected shrimp farming productivity in the last 10 years? (*Tick one box*).

Strongly agree	Agree	Disagree	Strongly disagree	Unable to judge

If you answer "strongly agree" and "agree", could you please make a list of 5 climate change events that have most severely affected shrimp farming productivity?

A.1.3.2. To what extent do you agree or disagree with the statement that climate change events increase shrimp diseases? (*Tick one box*).

Strongly agree	Agree	Disagree	Strongly disagree	Unable to judge

A.1.3.3. Could you please detail any shrimp losses or damages by disease related to climate change events over the last 10 years?

A.1.4. Shrimp farmer responses and adaptation

A.1.4.1. Could you please identify any activities to respond to or adapt to climate change events for your shrimp farm over the last 10 years?

Climate change issues	Activities	How long?	Costs
Storms and extreme climate events (more frequency and/or intensity of storms)			
Sea level rise			
- Increase in sea and river water levels			
- Increased intensity of high tides			
Rainfall changes			
- Rain season pattern changes			
- Greater intensity or irregular rains			
- Water quality decrease in shrimp ponds			
- Increased fluctuations of salinity in the surface water of the shrimp ponds			
Temperature changes			
- Drier dry season			
- Longer dry season			
- Increase fluctuations of the temperature water in the shrimp ponds			

A.1.4.2. How much damage have extreme climate events done to your shrimp farm and how long did it take to recover?

Level of damage	Yes/no	How long it took to recover?
Little damage		
Damage 50%		
Completely destroy		

A.1.4.3. Could you please list any groups, clubs, or community organizations that you attended as a member (e.g. a group of shrimp farmers sharing the surface water)?

A.1.4.4. Could you list any support your received to respond to with climate change events and what supports do you need or suggestions to adapt to the future climate change events?

A.1.4.5. What will you expect your children to do in the next 10 – 20 years?

[a]. Same as parent (shrimp farmer); [b]. Looking for new work (detail)…………

[c]. Move to a new place; [d]. Others (detail)………………………….

A.1.4.6. If climate change in the next 10 – 20 years decreases 40% of your shrimp production, what things will you choose to change for your production or what will you do?

Thank you very much for your responses!

Appendix A.2. Shrimp farming questionnaire (For the local experts)

My name is An Van Quach, a PhD candidate at School of Environmental Science, Murdoch University under the supervisor of Associate Professor Frank Murray and Associate Professor Angus Morrison-Saunders. The interview aims to collect information for my research "***Shrimp farming vulnerability and adaptation to climate change in Ca Mau Province, Vietnam***". It will take about 30 minutes to answer the questionnaire. Feel free to express your opinions because there are no right or wrong answers. Feel free to not answer a question if you don't want to and you can stop the survey at any time if you wish. Your name or other information that will identify you will not be presented in the final writing up and individual persons will be not identified. The questionnaire results will be stored in a safe place in Murdoch University. If you have any problems or need more information, feel free to contact the Human Ethics Office or my Supervisors (provide business cards).

- Respondent ID: ……………………………………………………………………........................
- Gender: [ ] (Code: 0 = Male, 1 = Female)
- Address: ....
- Interview day: __/__ __/20____ [MM/DD/YYY]
- Start Time __ __:__ __ AM [*Circle One.*] [HH:MM]
  __ __:__ __ PM

A.2.1. What were key challenges or issues for shrimp farming production in the province in the last 10 years?

1) …………………………………………………………………………………………….
2) …………………………………………………………………………………………….
3) …………………………………………………………………………………………….
4) …………………………………………………………………………………………….
5) …………………………………………………………………………………………….

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

A.2.2. Have you identified any adverse effects of climate change events on your shrimp farming systems in the last 10 years? *(Tick one box)*

[ ]. Yes [ ]. No [ ]. Not sure

A.2.3. To what extent do you agree or disagree with the following statements concerning climate change events that may have adversely affected shrimp farming in the last 10 years?

Climate issues and irregular weather changes	**Strongly agree**	**Agree**	**Disagree**	**Strongly disagree**	**Unable to judge**
Extreme climate events (more frequency and/or intensity of storms)					
Sea level rise					
- Increase in sea and river water levels					
- Increased intensity of high tides					
Rainfall changes					
- Rain season pattern changes					
- Greater intensity or irregular rains					
- Water quality decrease in shrimp ponds					
- Increased fluctuations of salinity in the surface water of the shrimp ponds					
Temperature changes					
- Drier dry season					
- Longer dry season					
- Increase fluctuations of the temperature water in the shrimp ponds					

A.2.4. Please rank the five climate change events that have most affected shrimp farming in the last 10 years? *(please place in order 1 - 5)*

A.2.5. To what extent do you agree or disagree with the following statements concerning climate change events that will negatively affect shrimp farming in next 10 – 20 years? (*Tick one box for each line*).

Climate issues and irregular weather changes	**Strongly agree**	**Agree**	**Disagree**	**Strongly disagree**	**Unable to judge**
Extreme climate events (more frequency and intensity of storms)					
Sea level rise					
- Increase in sea and river water levels					
- Increased intensity of high tides					
Rainfall changes					
- Rain season pattern changes					
- Greater intensity or irregular rains					
- Water quality decrease in shrimp ponds					
- Increased fluctuations of salinity in the surface water of the shrimp ponds					
Temperature changes					
- Drier dry season					
- Longer dry season					
- Increased fluctuations of the temperature water in the shrimp ponds					

A.2.6. Please rank the five climate change events that will most affect shrimp farming in the next 10 – 20 years? *(please place in order 1 - 5)*

A.2.7. To what extent do you agree or disagree with the statement that climate change events have adversely affected shrimp farming productivity in the last 10 years? (*Tick one box*).

Strongly agree	Agree	Disagree	Strongly disagree	Unable to judge

If you answer "strongly agree" and "agree", could you please make a list of 5 climate change events that have most severely affected shrimp farming productivity?

A.2.8. To what extent do you agree or disagree with the statement that climate change issues increase shrimp diseases? (*Tick one box*).

Strongly agree	Agree	Disagree	Strongly disagree	Unable to judge

A.2.9. Could you please detail any shrimp losses or damages by diseases related to climate change events over the last 10 years?

A.2.10. Could you please suggest any activities to respond to or adapt to climate change events or irregular weather changes on shrimp production over the next 10 – 20 years?

Thank you very much for your responses!

Appendix B: Focus group document (Focus groups of shrimp farmers)

- Focus group ID:…………………………………………………………..........
- Commune: ....
- Total participants: …………………………………………………………...
- Date: __/__ __/20____ [MM/DD/YYY]
- Start Time __ __:__ __ AM [*Circle One*.] [HH:MM]
  __ __:__ __ PM

B.1: Determine likelihood category for the impact of climate change events on shrimp farming

Using the Table B.1.1 below to consider the likelihood for the impact of the climate change events on shrimp farming occurring being in one of the following categories scoring from 5 to 1 corresponding either almost certain, likely, possible, unlikely or rare. The participants in the focus group then discusses and decides a score or rating for each climate change event in Table B.1.2.

Table B.1.1. Livelihood categories describing the occurrence of each impact on shrimp farming

Score	Rating	Recurrent events	Single event
5	Almost certain	Could occur several times/year	More likely than not - Probability (P) greater than 50%
4	Likely	May arise about once per year	As likely as not - 50/50 change
3	Possible	May arise once in less than 10 years	Less likely than not but still appreciable- P less than 50% but quite high
2	Unlikely	May arise once in 10 - 25 years	Unlikely but not negligible - P low but noticeably greater than zero
1	Rare	Unlikely rise once in more than 25 years	Negligible - P very small, close to zero

[Researcher as a facilitator provides a list of climate change events that would adversely impact shrimp production from the household surveys previously and explains for participants clearly understanding of likelihood categories describing the occurrence of each climate change impact].

Table B.1.2. Determine livelihood category for the impact of each climate change events on shrimp farming

Climate change events	Likelihood category				
	Almost certain (5)	Likely (4)	Possible (3)	Unlikely (RIA2)	Rare (1)
Climate change event 1					
Climate change event 2					

B.2: Determine consequence category for the impact of climate change events on shrimp farming

Using the Table B.2.1 below to consider the consequence of the impact of climate change events on shrimp farming production if the climate change event occurred. The consequence of climate change events occurring being in one of the following categories scoring from 5 to 1 corresponding either catastrophic, severe, major, moderate, minor. The participants in the focus group then discusses and decides a score or rating for each climate change event in Table B.2.2.

Table B.2.1. Consequence categories for assessing risk for shrimp production

Score	Rating	Shrimp profitability and growth (Shrimp production)
5	Catastrophic	Shrimp production would be unprofitable, contract markedly, making it unviable. It would need to be wound up.
4	Severe	Shrimp production would be unprofitable, contract markedly, and likely unviable even with significant remedial action.
3	Major	Shrimp production would be unprofitable and contract and require significant remedial action to remain viable.
2	Moderate	Shrimp production would only be marginally profitable with growth stagnant.
1	Minor	Shrimp production would be profitable, with growth achieved but fails to meet expectations.

[The facilitator explains for participants clearly understanding of consequence categories describing the occurrence of each climate change impact].

Table B.2.2. Determine consequence category for the impact of each climate change events on shrimp farming production

Climate change events	Consequence category				
	Catastrophic (5)	Severe (4)	Major (3)	Moderate (2)	Minor (1)
Climate change event 1					
Climate change event 2					

B.3: Determine adaptive capacity of shrimp farmers in the four farming systems to the impact of climate change.

Using the Table B.3.1 below, each indicator is scored with number from "0" to "5" and ranked as low adaptive capacity with a score value of "0" or "1", medium adaptive capacity with a score value of "2" or "3", and high adaptive capacity with a score value of "4" or "5". The participants in the focus group then discusses and decides a score or rating for each indicator in the five capitals in Table B.3.1.

Table B.3.1. Scores and rankings based on capitals of shrimp farmers

Capital	**Indicator**	**Score**	**Ranking**
Human	Education		
	Farming experience (shrimp production)		
	Family members aged labour and involved in shrimp farming		
	Health (physical capacity and dependent members)		
Social	Involved community organizations or shrimp groups		
	Volunteerism as participation, lead or present social events		
	Usage and access to Internet and social media		
Natural	Land resource (farming area)		
	Soil health: good, medium, bad for production or cultivation		
	Water quantity supplied for shrimp farming		
	Water quality supplied for shrimp farming		
	Ecosystem and biodiversity		
Physical	Infrastructure (transportation convenience)		
	Electricity usage (for household and shrimp production)		
	House construction (types of houses or degrees of concrete)		
	Farm equipment (sluice gates, embankments, sea dikes)		
Financial	Income stream variety		
	Availability of cash for shrimp production		
	Household income		
	Shrimp income		
	Ability to access to finance		

[The facilitator explains for participants clearly understanding of each indicator and how to score in each indicator of the five capitals].

B.4: Determine adaptive capacity to each climate change event on shrimp production.

Using the similar procedure as in B.3, the Table B.4.1 below is a guide to consider adaptive capacity to each climate change event on shrimp production. The level of adaptive capacity is corresponding low, medium, or high for each climate change event. The participants in the focus group then discuss and decide a rating for each climate change event in Table B.3.2.

Table B.4.1. Adaptive capacity categories to the impact of climate change events for shrimp production

Rating	Shrimp profitability and growth (Shrimp production)
Low	Very difficult and costly for shrimp production to implement adaptation activities that are effective
Medium	Some difficulty and expense in implementing change, however it is possible
High	It is feasible and practical to implement adaptation activities

[The facilitator explains for participants clearly understanding of adaptive capacity of shrimp farmers to each climate change event].

Table B.4.2. Determine adaptive capacity to the impact of each climate change events for shrimp production

Climate change events	Adaptive capacity		
	Low	Medium	High
Climate change event 1			
Climate change event 2			

Appendix C: Phong Dien Commune (Rice-Shrimp Rotation Farming – RSRF

C.1. Household information in RSRF

Code	Respondents (Household's head)				Education of family members						Labour distribution of household family				
	Gender	Age	Education	Farming experience	Illiterate	Primary	Secondary	High School	Diplomas	Higher	Family size	<15 age	16–60 age	>60 age	Aquaculture labour
PD1	M	45	11	9			2	1			4	1	3		2
PD2	M	53	7	8			4	2			6		6		3
PD3	M	44	9	12			4				5	1	2	2	2
PD4	M	62	3	11		2	3		1	1	7		5	2	5
PD5	M	66	0	16	2		2		1		5		4	1	2
PD6	F	47	8	8		1	2				4	1	2	1	2
PD7	M	50	6	12			5				5	1	4		4
PD8	M	47	11	11			3	1			4		4		2
PD9	M	59	4	9		2	2	2	2		8		8		4
PD10	M	65	0	10		1	4				7	1	5	2	2
PD11	F	44	5	15			2	2			6		4	2	2
PD12	M	66	2	16	2	2	2	2			8	1	5	2	3
PD13	M	57	3	9			4	1			5		5		4
PD14	M	49	7	7			4			1	5		5		4
PD15	M	52	5	14	2		2	1	1		6		6		3
PD16	F	45	6	8			4	1			5		5		5
PD17	M	68	0	16	2		2	1	1		6		4	2	3
PD18	M	49	9	12			1	2		1	4		4		2
PD19	M	64	3	13	2		4	1			7	2	3	2	3
PD20	F	49	4	9			3	1			4		4		4
PD21	F	38	4	7	4		2				6	2	2	2	2
PD22	M	42	11	11	2		2	2			6		4		4

C.2: Household and shrimp farming income in RSRF (2010-2012) (VND$ Million)

Codes	Shrimp Area (Ha)	2010					2011					2012				
		Income streams	Household Income	RSRF Cross income	RSRF Costs	RSRF Net Income	Income streams	Household Income	RSRF Cross income	RSRF Costs	RSRF Net Income	Income streams	Household Income	RSRF Cross income	RSRF Costs	RSRF Net Income
PD1	1.20	1	40.74	40.74	12.50	28.24	1	17.50	17.50	5.70	11.8	2	5.00	321.15	5.10	-0.10
PD2	2.00	1	18.00	18.00	19.00	-1.00	2	61.40	72.50	7.50	53.9	2	66.00	70.10	18.20	47.80
PD3	1.30	2	43.00	27.00	10.00	17.00	2	33.10	49.10	12.00	21.1	2	33.60	39.00	13.00	20.60
PD4	1.50	1	84.90	84.90	16.00	68.90	1	75.70	75.70	17.50	58.2	1	46.25	46.25	19.00	27.25
PD5	3.00	2	107.50	102.00	25.00	77.00	2	70.00	75.50	30.00	40.0	2	37.00	42.50	30.00	7.00
PD6	1.00	1	44.20	44.20	11.50	32.70	1	56.20	56.20	15.00	41.2	1	97.50	97.50	21.50	76.00
PD7	1.70	2	17.40	10.00	5.50	4.50	2	15.00	22.60	5.50	9.5	2	15.00	22.60	3.50	11.50
PD8	0.60	2	34.60	33.10	3.00	30.10	2	30.65	32.15	3.00	27.7	2	21.00	22.50	3.50	17.50
PD9	2.80	1	27.50	27.50	4.00	23.50	1	30.00	30.00	7.00	23.0	1	22.50	22.50	6.00	16.50
PD10	2.20	2	39.40	34.40	14.50	19.90	2	30.00	33.50	14.00	16.0	2	13.50	17.00	14.00	-0.50
PD11	2.00	2	40.00	30.00	8.00	22.00	2	25.00	30.00	10.00	15.0	1	31.00	31.00	5.00	26.00
PD12	2.80	2	70.00	0.00	67.00	-67.00	2	400.00	470.00	366.00	34.0	2	320.00	370.00	130.00	190.00
PD13	1.50	1	35.00	35.00	15.00	20.00	1	11.00	11.00	15.50	-4.5	2	0.00	17.00	13.50	-13.50
PD14	1.30	3	90.50	38.00	17.00	21.00	3	39.00	96.50	14.00	25.0	3	48.50	118.00	18.00	30.50
PD15	0.70	2	52.00	32.00	10.40	21.60	1	27.00	27.00	6.00	21.0	1	17.00	17.00	8.00	9.00
PD16	1.26	1	22.00	22.00	15.00	7.00	1	23.00	23.00	15.00	8.0	1	77.75	77.75	84.50	-6.75
PD17	1.50	1	57.50	57.50	13.50	44.00	1	75.50	75.50	15.00	60.5	1	59.50	59.50	16.00	43.50
PD18	1.00	3	55.70	28.70	7.00	21.70	3	23.00	46.00	8.00	15.0	2	22.50	37.00	10.00	12.50
PD19	3.50	3	62.40	49.40	10.00	39.40	2	41.00	46.00	15.00	26.0	1	21.00	21.00	9.00	12.00
PD20	2.20	3	44.40	30.00	10.00	20.00	2	48.75	63.15	12.00	36.8	2	35.00	49.40	10.00	25.00
PD21	1.30	2	37.00	25.00	6.00	19.00	1	145.00	145.00	230.00	-85.0	2	140.00	152.00	50.00	90.00
PD22	2.20	2	47.05	37.05	10.00	27.05	2	35.45	44.45	9.50	26.0	2	32.50	42.10	12.00	20.50

Appendix D: Dat Mui Commune (Integrated Shrimp-Mangrove Farming – ISMF)

D.1. Household information in ISMF

Code	Respondents (Household's head)					Education of family members					Labour distribution of household family				
	Gender	Age	Education	Farming experience	Illiterate	Primary	Secondary	High School	Diplomas	Higher	Family size	<15 age	16–60 age	>60 age	Aquaculture labour
DM1	M	65	2	25		1	3	2			6	1	3	2	3
DM2	M	47	11	16			2	3			5		5		5
DM3	M	45	9	22			3	1			4	1	3		3
DM4	M	61	0	18	1		6			1	8	1	6	1	5
DM5	F	39	6	12			3				3	1	2		2
DM6	M	55	11	15			1	1	1		3		3		2
DM7	M	44	9	12			3	1			4	1	3		3
DM8	M	35	8	13			3	1			4	2	2		2
DM9	F	39	12	7			2		2		4	2	2		2
DM10	F	45	8	16		1	5				6	3	3		3
DM11	M	40	9	21			5	2			7	1	4	2	4
DM12	M	47	12	14				3		2	5		5		3
DM13	M	52	8	24		1	4				5		5		5
DM14	M	54	9	23	1		2	1		1	5	1	4		3
DM15	M	51	5	20	2	1	1	2			6	3	3		3
DM16	M	56	9	22			4				4		4		4
DM17	F	62	4	25	2	2	1				5	2	2	1	2
DM18	F	37	12	22				3			3		3		2
DM19	M	49	11	24				5		3	8	1	7		4
DM20	M	50	6	23		1	4				5	1	4		2
DM21	M	66	5	30	1	2	5			1	9	2	5	2	3
DM22	M	49	11	14			1	3			4	1	3		3
DM23	F	65	5	22		5	2				7	3	2	2	2
DM24	M	59	7	16		2	4				6	2	3	1	3
DM25	M	33	9	6		1	2				3	1	2		2
DM26	M	42	9	18			4	1			5	1	4		2
DM27	M	67	1	41	1	1		2			4	1	2	1	2
DM28	M	58	9	29			2	1	1	2	6		6		3
DM29	F	52	8	31	1	1	4	1			7	3	4		4

Code	Respondents (Household's head)					Education of family members					Labour distribution of household family				
	Gender	Age	Education	Farming experience	Illiterate	Primary	Secondary	High School	Diplomas	Higher	Family size	<15 age	16–60 age	>60 age	Aquaculture labour
DM30	M	36	9	17			2	3			5	2	3		3
DM31	M	39	7	12	1	2	4	1			8	3	3	2	3

D.2: Household and shrimp farming income in ISMF (2010-2012) (VND$ Million)

Codes	Shrimp Area (Ha)	2010					2011					2012				
		Income streams	Household Income	ISMF Cross income	ISMF Costs	ISMF Net Income	Income streams	Household Income	ISMF Cross income	ISMF Costs	ISMF Net Income	Income streams	Household Income	ISMF Cross income	ISMF Costs	ISMF Net Income
DM1	3.0	3	205	220	62	143	3	233	308	62	171	3	266.5	379.5	62	204.5
DM2	3.1	2	178	218	40	138	2	196	256	45	151	3	215	485	15	200
DM3	1.8	2	90	102	25	65	3	87	109	25	62	4	105	147	30	75
DM4	5.4	1	410	410	95	315	1	540	540	90	450	1	412	412	85	327
DM5	4.2	1	397	397	80	317	1	454	454	60	394	1	268	268	90	178
DM6	3.0	2	235	265	85	150	2	253	288	80	173	2	200	240	60	140
DM7	1.8	2	130	200	25	105	2	140	205	20	120	2	140	190	30	110
DM8	1.8	2	62	102	20	42	2	71	96	18	53	2	70	135	22	48
DM9	1.7	2	67	82	14.5	52.5	2	88	105	17	71	2	75	92	12	63
DM10	1.0	1	25	25	10	15	1	45	45	15	30	1	47	47	25	22
DM11	1.6	3	75	90	20	55	3	81	96	25	56	3	77	86	20	57
DM12	0.6	1	22	22	10	12	1	30	30	7	23	1	32	32	14	18
DM13	3.4	4	74	100.5	20	54	3	86	111	20	66	3	95	110	30	65
DM14	1.5	1	45.5	45.5	15	30.5	1	58.5	58.5	12	46.5	1	64	64	20	44
DM15	0.9	1	50	50	15	35	1	55	55	15	40	1	25	25	19	6
DM16	2.1	3	40	60	20	20	3	30	55	15	15	3	20	32	10	10
DM17	2.5	2	140	170	30	110	2	110	130	32	78	2	100	128	50	50
DM18	0.8	3	40	65	6	34	2	35	55	9	26	3	31	61.5	11	20
DM19	3.1	2	83	95	20	63	2	39	49	28	11	2	46	53	18	28
DM20	1.3	3	67	100.5	47	20	3	91.75	130.75	18	73.75	3	42	85	7	35
DM21	1.8	2	88	98	60	28	2	88	168	58	30	2	65	140	55	10
DM22	2.0	2	74.5	110	32	42.5	2	75	105	25	50	2	60	86	15	45

Codes	Shrimp Area (Ha)	2010					2011					2012				
		Income streams	Household Income	ISMF Cross income	ISMF Costs	ISMF Net Income	Income streams	Household Income	ISMF Cross income	ISMF Costs	ISMF Net Income	Income streams	Household Income	ISMF Cross income	ISMF Costs	ISMF Net Income
DM23	2.8	3	93	114	21	72	2	85	90	18	67	3	71.8	81.1	18	53.8
DM24	2.4	1	40	40	12	28	1	37	37	8	29	1	31	31	13	18
DM25	2.0	4	59	73	30	29	3	96	127	20	76	3	44	64.5	30	14
DM26	1.6	4	110	140	40	70	4	110	230	40	70	4	125	150	50	75
DM27	0.8	2	50	70	10	40	2	55	85	20	35	2	55	105	15	40
DM28	0.7	2	40.5	160.5	15	25.5	2	20	100	6	14	2	28.5	148.5	20	8.5
DM29	1.0	1	18	18	17	1	0	0	12	27	-27	1	21	21	28	-7
DM30	1.7	2	65	85	10	55	2	77	127	20	57	2	55	75	10	45
DM31	1.6	3	47.5	81	25	22.5	2	49.5	52	14.5	35	1	44.5	44.5	10	34.5

Appendix E: Tam Giang Dong Commune (Separated Shrimp-Mangrove Farming – SSMF)

E.1. Household information in SSMF

Code	Respondents (Household's head)				Education of family members						Labour distribution of household family				
	Gender	Age	Education	Farming experience	Illiterate	Primary	Secondary	High School	Diplomas	Higher	Family size	<15 age	16–60 age	>60 age	Aquaculture labour
TGD1	M	40	10	9			1	2		2	5		5		3
TGD2	M	49	4	7	2		2	2			6	2	2	2	2
TGD3	M	52	8	11			2	2		3	7		5	2	3
TGD4	M	62	5	9	1	2	2	1	1	2	9	1	6	2	4
TGD5	F	55	5	16		1	4	2			7	2	5		5
TGD6	F	54	7	20		1	3	1			5	2	3		3
TGD7	F	46	6	12			4				4	1	3		3
TGD8	M	37	9	5		2	1	2			5	1	4		2
TGD9	M	68	0	22	3	1	2	1		1	8	2	5	1	3
TGD10	M	40	11	22		1	2	2			5	1	2	2	2
TGD11	F	59	6	15			4	2			6	1	5		3
TGD12	M	43	7	7	4		3	2			9	4	5		5
TGD13	M	67	0	10	3			2	1	1	7	1	4	2	2
TGD14	M	43	11	8			4	2			6	1	5		4
TGD15	M	57	7	17		1	2	2			5	1	4		5
TGD16	F	43	12	6				2		3	5		5		2
TGD17	F	40	9	12	2	2	4				8	3	5	2	4
TGD18	M	37	6	41		1	3	2	1		7	2	3	2	3
TGD19	M	38	10	12			1	2			3	1	2		2
TGD20	F	68	1	13	4		1	3			8	3	3	2	3
TGD21	M	40	9	10			2	3		1	6	2	4		3
TGD22	M	40	12	7			2	4			6		6		4
TGD23	M	63	3	8	1	1	2	1			5	2	2	1	2
TGD24	M	43	7	12			3				3		3		3
TGD25	F	67	0	13	2	1	5				8	2	4	2	2
TGD26	F	65	2	9		2	2	2			6	2	2	2	2

E.2. Household and shrimp farming income in SSMF (2010-2012) (VND$ Million)

Codes	Area (Ha)	2010					2011					2012				
		Income streams	Household Income	SSMF Cross income	SSMF Costs	SSMF Net Income	Income streams	Household Income	SSMF Cross income	SSMF Costs	SSMF Net Income	Income streams	Household Income	SSMF Cross income	SSMF Costs	SSMF Net Income
TGD1	1.8	2	135.8	173.6	15.8	120	3	53.2	89.4	11.2	42	3	19	57.7	9.4	9.6
TGD2	1.7	1	86.2	86.2	32	54.2	1	60.9	60.9	24	36.9	1	36.5	36.5	21	15.5
TGD3	1.5	3	43	128	15	28	2	46	132	15	31	2	25	78	15	10
TGD4	4	3	310	318	70	240	3	307	313	70	237	3	220	231	65	155
TGD5	2	2	95.5	105.5	30	65.5	2	35	45	41	-6	2	38	50	15	23
TGD6	5	1	180	180	65	115	1	175	175	75	100	1	140	140	70	70
TGD7	3.7	1	150	150	35	115	1	150	150	20	130	1	140	140	20	120
TGD8	5	1	168	168	40	128	1	138	138	20	118	1	108	108	50	58
TGD9	2.8	1	26.5	26.5	6.5	20	1	31.5	31.5	4.8	26.7	1	22.5	22.5	5.2	17.3
TGD10	2.4	2	55.5	65.5	45	10.5	2	180.5	191.5	60	120.5	2	92	122	33	59
TGD11	2.5	1	57	57	15	42	1	62.5	62.5	6	56.5	1	20.5	20.5	25	-4.5
TGD12	5	2	185	189	40	145	2	153	157.5	45	108	2	142	146	50	92
TGD13	4	1	129	129	40	89	1	95	95	30	65	1	55	55	40	15
TGD14	3.5	1	214.5	214.5	40	174.5	1	170	170	40	130	1	134.5	134.5	30	104.5
TGD15	3.5	1	227.5	227.5	35	192.5	1	185	185	40	145	1	104	104	30	74
TGD16	3.6	1	107	107	35	72	1	122.5	122.5	20	102.5	1	37.5	37.5	35	2.5
TGD17	5.5	1	204	204	30	174	1	183.5	183.5	30	153.5	1	153.5	153.5	32	121.5
TGD18	6	1	55	55	35	20	1	41	41	52	-11	1	40.5	40.5	60	-19.5
TGD19	2.5	1	45	45	13	32	1	43.5	43.5	14	29.5	1	16.5	16.5	10	6.5
TGD20	2.5	1	55.5	55.5	15	40.5	1	47.5	47.5	15.5	32	1	55.5	55.5	27	28.5
TGD21	3	1	25	25	5.5	19.5	1	30	30	6	24	1	20	20	4	16
TGD22	2	1	33	33	20	13	1	26.5	26.5	19.5	7	1	7	7	6	1
TGD23	2.8	1	157.5	157.5	100	57.5	1	141.6	141.6	45	96.6	1	114	114	45	69
TGD24	4	1	41.6	41.6	6	35.6	1	11.5	11.5	5.5	6	1	3	3	6	-3
TGD25	3	1	106	106	35	71	1	97	97	15	82	1	85	85	45	40
TGD26	8	1	470	470	108	362	1	350	350	94	256	1	280	280	112	168

Appendix F: Tan Duyet Commune (Intensive Shrimp Farming – ISF)

F.1. Household information in ISF

Code	Respondents (Household's head)				Education of family members						Labour distribution of household family				
	Gender	Age	Education	Farming experience	Illiterate	Primary	Secondary	High School	Diplomas	Higher	Family size	<15 age	16–60 age	>60 age	Aquaculture labour
TD1	F	32	12	15	1	2	1	1			5	1	2	2	2
TD2	M	59	9	25							4		4		4
TD3	M	64	9	24			2	3		2	7		5	2	3
TD4	M	71	5	19		1	2		2		5		4	1	2
TD5	F	42	9	22			5	1			6		6		3
TD6	M	55	8	15			1	3			4		4		4
TD7	M	39	12	14							3	1	2		3
TD8	M	40	11	15			2	3			5	1	4		4
TD9	M	56	9	17			2	3		2	7	2	5		3
TD10	M	62	5	22		1		2			3		2	1	2
TD11	F	57	8	9			2	1	1		4		4		3
TD12	M	35	9	15	1		3	2			6	2	4		4
TD13	M	61	9	22			3	2			5		3	2	3
TD14	M	44	8	21		1	2	2			5	3	2		2
TD15	M	70	4	11		2	3	1		1	7	1	4	2	3
TD16	M	48	8	18			3	1			4		4		4
TD17	M	37	12	7			1	2			3	1	2		2
TD18	F	40	7	9		1	5	1			6	3	3		3
TD19	M	56	9	29		1	4				5		5		3
TD20	M	59	8	21	2		5	1			8	2	5	1	3
TD21	M	67	5	28		1	3	1			5	1	2	2	2

F.2. Household and shrimp farming income in ISF (2010-2012) (VND$ Million)

Codes	Area (Ha)	2010					2011					2012				
		Income streams	Household Income	ISF Cross income	ISF Costs	ISF Net Income	Income streams	Household Income	ISF Cross income	ISF Costs	ISF Net Income	Income streams	Household Income	ISF Cross income	ISF Costs	ISF Net Income
TD1	1.50	1	57.5	-	-	-	1	15	-	-	-	2	-70	350	415	-65
TD2	1.00	1	20	-	-	-	2	-60	110	155	-45	2	263	451	186	265
TD3	2.70	1	139.5	-	-	-	2	322.8	526.8	312	214.8	2	85.9	271.6	252.3	19.4
TD4	1.60	3	312	560	281	279	3	160	320	186	134	2	116	280	192	88
TD5	1.30	3	62	210	174	36	3	-143	0	162	-162	3	9.5	180	187	-7
TD6	5.00	2	3335	4800	250	3193.5	2	1010	2400	120	2280	2	32	580	600	-20
TD7	2.50	2	183	150	35	115	2	-40	0	120	-120	2	65	60	40	20
TD8	1.00	2	1676	976	300	676	2	1146	546	300	246	2	1286.4	686.4	600	86.4
TD9	1.40	2	649.8	1146.6	573.3	573.3	2	504	880	440	440	2	876	1590	795	795
TD10	1.20	2	89	115	30	85	2	67	90	30	60	1	90	117.5	27.5	90
TD11	2.00	2	1303	1700	467	1233	2	-367	0	387	-387	1	-239.5	0	261	-261
TD12	3.70	2	-185	98	290	-192	1	-5	-	-	-	2	7	0	0	0
TD13	2.20	2	145	197	87	110	1	30	-	-	-	1	80	480	400	80
TD14	1.34	2	23	-	-	-	3	22	400	400	0	3	-180	0	200	-200
TD15	0.77	1	-50	150	200	-50	1	60	135	75	60	1	138.5	200	61.5	138.5
TD16	2.00	2	114.5	148	67	81	2	-30	0	82	-82	2	-115	0	122	-122
TD17	5.00	2	840	1020	200	820	2	-2	178	200	-22	2	118.5	378	280	98
TD18	1.50	1	380	850	470	380	3	-29	320	380	-60	3	-76	120	233	-113
TD19	0.50	3	179	328	160	168	1	195	347	152	195	2	-40	67	141	-74
TD20	4.25	2	250	278	152	126	2	92	118	114	4	2	13	0	131	-131
TD21	1.50	2	136	312	206	106	2	127	284	198	86	2	-130	17	162	-145

APPENDIX G: Hydro – Meteorological Data

G.1. Air temperature (ºC) in the Ca Mau Province from 1991 to 2015

G.1.1. Annual air temperature (ºC)

Year	Month												Average Annual
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
1991	26.0	26.2	26.6	28.1	28.2	27.8	26.9	26.9	26.9	26.5	26.3	26.1	26.9
1992	24.9	26.0	27.3	28.7	28.6	27.4	27.4	26.9	27.4	26.4	26.1	25.7	26.9
1993	25.4	25.0	27.1	28.3	28.3	27.5	27.5	27.1	26.6	26.7	26.6	25.5	26.8
1994	25.6	26.5	27.7	28.3	27.8	27.2	26.9	26.6	26.3	26.6	27.2	26.4	26.9
1995	25.9	25.9	27.3	28.9	28.8	27.6	27.6	27.5	26.7	27.1	27.0	25.5	27.2
1996	24.7	25.6	27.2	28.1	28.1	27.7	27.3	27.4	27.2	26.7	26.8	25.6	26.9
1997	24.9	26.4	27.1	28.3	28.1	28.1	26.9	27.4	27.5	27.2	27.4	26.9	27.2
1998	27.2	27.5	28.9	29.8	30.0	28.5	28.4	27.9	27.3	26.8	27.1	25.8	27.9
1999	26.3	26.3	27.9	27.7	28.0	27.0	27.1	27.2	27.7	27.0	26.7	25.1	27.0
2000	26.3	26.7	27.6	28.2	28.2	27.3	27.5	27.1	27.7	26.8	27.2	26.9	27.3
2001	26.6	27.0	28.0	29.2	28.6	27.6	28.6	27.9	27.9	27.2	26.8	26.9	27.7
2002	26.4	26.7	28.1	29.5	29.6	28.1	28.5	27.3	27.3	28.0	27.6	27.9	27.9
2003	26.4	27.3	28.4	29.8	28.6	28.7	27.3	28.1	27.2	27.1	27.8	26.2	27.7
2004	26.5	26.5	28.1	29.5	29.0	27.9	27.4	27.5	27.7	27.4	28.0	26.5	27.7
2005	26.0	27.3	27.9	29.5	29.0	28.7	27.3	28.2	27.8	27.7	27.5	25.8	27.7
2006	26.3	27.4	28.1	29.0	28.4	27.9	27.4	27.2	27.2	27.6	28.2	26.9	27.7
2007	26.3	26.6	28.2	29.3	28.5	28.3	27.4	27.4	27.6	27.2	26.8	27.0	27.6
2008	26.4	26.7	27.5	28.8	28.0	27.7	27.6	27.5	27.1	27.3	26.8	26.3	27.3
2009	25.2	26.8	28.8	29.0	28.3	28.9	27.3	28.3	27.2	27.6	27.5	26.9	27.7
2010	26.8	27.7	29.0	30.0	30.3	28.6	27.9	27.8	27.9	26.7	26.8	26.9	28.0
2011	26.3	26.4	27.4	28.0	28.7	27.9	27.7	27.9	27.2	28.1	27.5	26.4	27.5
2012	26.6	27.2	28.1	29.0	28.2	28.4	27.5	27.8	26.6	27.8	27.8	27.8	27.7
2013	26.5	27.5	28.5	29.3	29.3	28.2	27.3	27.6	27.7	27.5	27.6	26.1	27.8
2014	25.3	25.9	27.9	29.5	29.4	28.2	27.7	28.0	27.6	27.5	27.6	27.2	27.7
2015	25.7	26.0	27.9	29.5	29.7	28.2	28.7	28.3	27.6	28.3	28.0	27.8	28.0

G.1.2. Maximum air temperature (T. max, ºC)

Year	Month												Average T. max
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	
1991	31.7	32.0	32.5	33.6	33.6	32.1	30.9	30.8	30.8	30.5	30.6	30.6	31.6
1992	30.3	31.7	33.2	34.6	34.4	32.1	32.0	31.0	32.2	30.7	30.2	30.5	31.9
1993	31.0	31.1	33.1	34.4	34.4	32.5	32.0	31.7	31.2	31.1	31.3	30.0	32.0
1994	30.9	32.6	33.0	34.4	33.1	32.0	31.2	30.9	30.6	31.4	32.0	31.5	32.0
1995	31.3	31.5	32.9	34.3	34.5	32.5	32.3	31.9	30.9	31.5	30.7	29.4	32.0
1996	29.4	30.7	32.8	33.7	33.2	32.3	31.8	31.8	31.3	30.9	30.8	29.3	31.5
1997	30.0	31.2	32.6	34.0	33.3	32.6	31.1	31.7	32.0	31.9	31.6	31.6	32.0
1998	32.9	32.9	34.6	35.2	35.3	33.3	32.6	32.1	31.7	30.5	30.8	29.3	32.6
1999	30.1	30.8	32.9	32.1	32.3	31.3	30.9	31.3	31.5	30.9	30.5	28.2	31.1
2000	30.4	31.1	32.3	32.9	32.5	31.3	31.5	31.0	31.8	30.4	30.7	30.5	31.4
2001	30.2	31.3	32.1	33.6	32.9	31.3	32.4	31.4	32.1	30.8	30.0	30.2	31.5
2002	30.6	30.8	32.3	33.5	33.9	32.3	32.2	31.2	31.2	31.4	31.3	31.4	31.8
2003	30.5	31.3	32.2	34.0	32.3	32.9	31.3	31.9	31.2	30.8	31.3	29.4	31.6
2004	30.2	30.1	32.1	33.7	32.8	31.3	31.4	30.8	31.6	31.0	31.3	29.8	31.3
2005	29.7	31.4	31.7	33.4	33.5	33.0	31.3	32.3	31.9	31.6	31.1	29.0	31.7
2006	30.3	31.6	32.0	33.6	32.9	32.4	31.2	31.5	31.3	31.9	32.3	30.8	31.8
2007	29.7	30.8	32.3	33.4	32.9	32.4	31.2	31.0	31.2	31.1	30.0	30.8	31.4
2008	30.1	30.5	31.5	33.0	32.5	31.7	31.7	32.1	31.1	31.4	30.4	29.7	31.3
2009	29.0	30.8	32.9	33.1	32.5	32.8	31.4	32.3	30.8	31.7	31.0	31.1	31.6
2010	30.4	31.9	33.2	34.4	35.0	33.3	31.9	31.5	32.1	30.3	30.3	30.1	32.0
2011	30.2	30.5	31.3	32.2	32.0	32.3	32.2	32.0	31.2	32.2	31.2	29.1	31.3
2012	31.6	33	33.7	35.2	34.1	33.6	33.5	33.3	33.1	33.2	32.8	33.2	35.2
2013	32.5	33.4	35.4	35.8	35.5	34.2	33.4	33.5	33.9	33	33	31.6	35.8
2014	32	32.4	34.1	35.7	35.7	34.5	33.4	34	33.9	33.4	33.1	33.5	35.7
2015	31.7	32.6	33.7	36.5	36	34.8	34.5	34.4	34	34	33.8	33	36.5

G.1.3. Minimum air temperature (T. min, ºC)

Year	Month												Average T. min
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
1991	23.0	22.8	22.8	24.5	25.0	25.3	24.1	24.3	24.8	24.3	23.8	23.5	24.0
1992	21.9	22.8	23.4	25.0	25.3	24.6	24.4	24.2	24.7	24.1	23.6	22.8	23.9
1993	22.2	21.2	23.5	23.9	24.6	24.7	24.7	24.2	24.0	24.3	24.0	22.5	23.6
1994	22.6	22.9	24.5	24.4	24.9	24.6	24.2	24.2	23.9	24.0	24.2	23.6	24.0
1995	22.7	22.5	23.7	25.0	25.4	25.2	24.8	24.8	24.3	24.7	24.6	23.1	24.2
1996	21.9	22.6	23.7	24.8	25.4	25.2	24.4	24.6	24.6	24.6	24.6	23.4	24.2
1997	22.0	23.6	23.7	24.5	24.9	25.0	24.5	24.6	25.1	24.7	24.9	24.2	24.3
1998	23.9	24.3	25.3	26.2	26.9	25.9	25.9	25.2	24.9	24.8	24.9	23.8	25.2
1999	24.0	23.5	25.0	25.1	25.5	24.6	24.5	24.8	25.1	24.7	24.5	22.7	24.5
2000	23.7	24.1	24.8	25.2	25.7	25.0	24.7	24.6	25.2	24.8	24.8	24.7	24.8
2001	23.9	24.1	25.6	26.3	25.8	25.0	25.4	25.6	25.6	24.9	23.9	23.9	25.0
2002	23.6	24.0	25.2	26.4	26.6	25.4	25.9	24.9	25.0	25.5	25.1	25.3	25.2
2003	23.9	24.7	25.9	26.4	25.9	25.8	24.6	25.4	24.7	24.8	25.3	23.6	25.1
2004	23.9	23.6	24.9	26.2	25.8	24.9	24.8	24.8	25.1	24.8	25.2	23.7	24.8
2005	23.0	24.1	24.9	26.4	26.3	26.0	24.8	25.6	31.9	25.4	25.3	23.9	25.6
2006	24.3	25.1	25.6	26.2	25.7	25.5	24.8	25.0	25.2	25.4	25.7	24.3	25.2
2007	24.0	22.3	25.3	26.6	26.1	25.9	25.0	25.2	25.4	24.9	24.4	24.5	25.0
2008	23.9	24.4	24.8	26.0	25.4	24.9	24.7	24.7	24.3	24.8	24.6	23.7	24.7
2009	22.2	24.0	26.0	26.1	25.5	26.2	24.5	25.3	24.6	25.1	25.0	23.5	24.8
2010	24.0	25.0	26.2	27.1	27.2	26.4	25.7	25.3	25.6	24.7	24.8	24.8	25.6
2011	24.0	24.3	25.3	25.5	26.1	25.6	25.2	25.6	25.0	25.8	25.3	24.2	25.2
2012	24.9	24.9	25.4	26.2	25.5	25.7	24.9	25.5	24.4	25.4	25.8	25.4	25.3
2013	24.9	25.0	25.8	26.8	26.7	25.7	25.0	25.1	25.5	25.3	25.3	23.7	25.4
2014	21.5	23.2	25.3	26.2	26.6	25.7	25.2	25.3	25.0	25.2	25.1	24.8	24.9
2015	22.7	23.2	25.0	26.5	26.3	25.3	26.2	25.8	25.0	25.7	25.7	31.6	25.7

G.2. Rainfall (cm) in the Ca Mau Province from 1991 to 2015

Year	Month												Average annual
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
1991	0.2	16.5	49.4	182.4	162.7	202.9	548	383.7	232.2	300.7	156.4	23.3	2258.4
1992	14.1	80.7	0.2	96.2	206.1	432.9	311.8	589.4	204.2	460.6	86.4	37	2519.6
1993	4.8	1.2	3.5	29.8	284.3	593.6	470.5	315.9	314.8	329.1	245.7	47.7	2640.9
1994	22.9	0	37.9	12.9	448.3	419	398.4	456.4	447.4	104.2	65.4	76.9	2489.7
1995	35	0	17.8	27.9	204.7	463	266.7	197.2	493.2	378.4	108	107.5	2299.4
1996	62.5	15.8	5.6	238.2	190.8	257.2	473.4	253.4	276.5	690	265.4	42.7	2771.5
1997	0.1	56.8	28.1	144.7	262	337.4	441.2	401.9	321.5	323	231.6	7.9	2556.2
1998	0	0	0	9	82.6	285.4	271	354.8	420.4	748.7	286.5	137.3	2595.7
1999	115.7	61.7	77.5	446.5	262.2	496.2	406.6	321.1	286.2	475.4	371.5	228.8	3549.4
2000	14	6	76.8	158.6	395.2	285.8	367.3	376.1	150.4	617.7	146.4	0	2594.3
2001	34.8	57.7	146.5	107.8	237.3	446.6	160.3	286.9	236.8	427.2	193.9	56.7	2392.5
2002	3.5	0	0.6	0.4	274.2	354.4	145.6	541	390.8	191.2	373.9	52.7	2328.3
2003	3.3	0	0	38.9	209.9	294.5	521.5	354.7	412.2	445.3	201.5	22.6	2504.4
2004	2.6	0	0	132.8	200	260.1	302.9	395.6	258.1	207	146.6	0	1905.7
2005	0	0	6.5	5	213.3	227	400.2	166.3	379.6	496.6	207.4	161.1	2263
2006	69	0.4	0.1	115.9	231.3	324.3	474.8	450	373.6	240.9	79.6	27	2386.9
2007	37.6	0	39.1	86	173.6	322	420.5	370.8	307	507.6	339.4	0	2603.6
2008	113.3	8.3	0	94.1	271.8	380.6	331.6	260	428.8	348.1	269.5	171.7	2677.8
2009	22.7	101.3	2.2	201.4	342.4	169.3	413.5	210.1	488.3	208	65.6	19.6	2244.4
2010	0.9	0	0	5.4	112.2	222.9	276.5	299.3	227.3	441.8	357.3	19.8	1963.4
2011	19	0	87.2	91	241.9	362.3	296.9	236.8	592.1	133.9	242.6	78.4	2381.1
2012	7.3	24.4	233.7	136.7	249.7	166.3	288.5	218.4	533.3	192.4	91.4	11.8	2153.9
2013	36.9	8.1	0	104.3	296	291.6	258.7	288.3	233	265.1	230.5	29.1	1941.3
2014	8.3	0	0	61.2	153.6	190.3	388.6	314.7	273.3	254.4	291.3	103	2065.7
2015	43.4	0	0	6.4	131.4	447.3	200.7	251.5	643.3	231.7	271.5	48.5	2257.7

G.3. Water level (cm) in the Ca Mau Province from 1991 to 2015

G.3.1. Water level (cm) in Doc River Station (National Elevation System−Vn2000)

G.3.1.1. Maximum water level (H. max) in Doc River Station (cm, Vn2000)

Year	Month												H. max	Average H. max
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec		
1991	42	40	29	30	30	27	31	37	36	55	53	47	55	38.1
1992	45	35	27	39	30	23	25	23	35	54	50	37	54	35.3
1993	39	37	34	39	25	23	21	25	37	56	45	47	56	35.7
1994	43	33	39	39	35	27	23	21	31	51	65	47	65	37.8
1995	49	51	37	35	37	32	34	27	43	59	67	61	67	44.3
1996	52	61	35	36	30	56	63	49	40	57	61	70	70	50.8
1997	63	57	41	52	36	48	53	58	50	39	58	57	63	51.0
1998	58	44	40	37	55	53	45	48	58	58	58	72	72	52.2
1999	73	52	43	74	48	81	57	47	52	64	64	91	91	62.2
2000	70	69	51	40	49	59	59	73	52	68	84	81	84	62.9
2001	79	76	60	48	60	88	52	86	53	60	72	75	88	67.4
2002	64	58	56	46	59	78	50	77	42	58	70	62	78	60.0
2003	71	62	47	37	40	43	65	50	50	77	79	74	79	57.9
2004	72	55	54	40	46	50	62	78	47	66	64	80	80	59.5
2005	66	46	68	46	36	63	56	45	64	59	78	73	78	58.3
2006	74	60	59	49	93	47	60	88	71	64	74	96	96	69.6
2007	79	58	53	48	49	60	75	59	73	73	84	75	84	65.5
2008	70	61	52	50	75	56	87	84	57	77	91	88	91	70.7
2009	89	59	62	58	57	55	65	53	62	62	93	83	93	66.5
2010	75	51	55	50	61	56	63	74	52	76	87	88	88	65.7
2011	78	67	67	50	50	76	59	55	59	89	86	101	101	69.8
2012	76	62	74	55	54	75	77	68	98	77	71	84	98	72.6
2013	91	61	62	72	54	63	95	60	69	70	84	88	95	72.4
2014	82	58	58	50	57	73	95	56	91	74	78	103	103	72.9
2015	75	66	56	60	48	52	58	56	73	73	84	78	84	64.9

G.3.1.2. Minimum water level (H. max) in Doc River Station (cm, Vn2000)

Year	**Month**												**H. min**	**Average H. min**
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec		
1996	-46	-47	-53	-53	-68	-63	-58	-49	-46	-36	-34	-42	*-68.0*	-49.6
1997	-41	-38	-48	-56	-62	-62	-53	-56	-46	-46	-46	-47	*-62.0*	-50.1
1998	-53	-48	-49	-60	-62	-64	-58	-62	-50	-27	-50	-54	*-64.0*	-53.1
1999	-44	-46	-43	-57	-57	-72	-58	-57	-54	-41	-36	-24	*-72.0*	-49.1
2000	-39	-39	-38	-50	-51	-69	-53	-52	-40	-40	-26	-33	*-69.0*	-44.2
2001	-40	-34	-40	-50	-50	-55	-51	-48	-43	-37	-30	-35	*-55.0*	-42.8
2002	-47	-36	-39	-53	-56	-62	-54	-54	-43	-45	-31	-42	*-62.0*	-46.8
2003	-41	-38	-40	-50	-57	-60	-61	-49	-45	-45	-42	-29	*-61.0*	-46.4
2004	-51	-51	-48	-48	-58	-58	-60	-51	-50	-34	-42	-34	*-60.0*	-48.8
2005	-43	-44	-43	-58	-64	-58	-60	-52	-42	-36	-36	-38	*-64.0*	-47.8
2006	-40	-32	-42	-45	-52	-66	-52	-50	-42	-43	-41	-26	*-66.0*	-44.3
2007	-33	-46	-36	-45	-51	-58	-55	-45	-43	-34	-19	-31	*-58.0*	-41.3
2008	-37	-29	-37	-43	-50	-48	-46	-40	-45	-29	-31	-26	*-50.0*	-38.4
2009	-26	-33	-32	-42	-48	-48	-44	-44	-42	-32	-26	-34	*-48.0*	-37.6
2010	-32	-36	-39	-33	-45	-52	-47	-43	-37	-32	-13	-19	*-52.0*	-35.7
2011	-20	-22	-28	-41	-46	-67	-43	-39	-38	-26	-17	-14	*-67.0*	-33.4
2012	-27	-20	-20	-45	-43	-46	-38	-37	-31	-19	-20	-17	*-46.0*	-30.3
2013	-20	-20	-25	-30	-42	-44	-42	-37	-26	-18	-16	-11	*-44.0*	-27.6
2014	-26	-28	-30	-32	-41	-42	-41	-31	-28	-20	-20	-10	*-42.0*	-29.1
2015	-23	-26	-29	-36	-45	-45	-41	-39	-35	-21	-19	-10	*-45.0*	-30.8

G.3.1.3. Average annual water level (H. average) in Doc River Station (cm, Vn2000)

Year	Month												Average
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
1995	18	16	6	2	-6	-16	-11	-6	1	18	32	31	7
1996	22	26	7	12	-1	-6	-5	-1	6	30	33	30	13
1997	27	26	14	7	-1	-7	0	-4	10	21	24	29	12
1998	22	14	18	10	5	-2	-2	3	10	28	29	35	14
1999	31	25	16	14	9	-6	-5	-2	8	31	35	46	17
2000	35	35	27	9	4	-3	2	-1	14	23	46	38	19
2001	34	35	22	18	5	-4	1	5	13	32	44	39	20
2002	30	28	20	15	10	-1	-3	3	5	23	40	39	17
2003	32	31	25	12	10	2	6	9	15	36	44	50	23
2004	36	30	26	15	8	3	4	6	18	45	43	41	23
2005	35	25	27	16	1	1	-5	-4	8	25	34	38	17
2006	30	30	17	11	9	-5	-4	0	10	24	34	46	17
2007	35	15	20	18	6	1	-3	0	10	25	45	39	18
2008	34	38	24	18	11	1	7	9	10	30	49	49	23
2009	47	26	24	20	16	3	4	7	11	27	47	38	23
2010	36	26	27	24	15	7	8	11	14	37	54	48	26
2011	49	35	41	25	9	2	3	8	10	32	49	54	26
2012	39	36	36	18	8	5	9	10	22	43	44	52	27
2013	46	41	28	27	16	10	10	9	18	41	48	49	29
2014	41	34	34	25	18	10	10	14	20	44	51	58	30
2015	47	38	30	29	12	8	9	10	19	38	47	52	28

G.3.2. Water level (cm) in Nam Can Station (National Elevation System−Vn2000)

G.3.2.1. Maximum water level (H. max) in Nam Can Station (cm, Vn2000)

Year	Months												H. max	Average H. max
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec		
1991	95	93	82	83	83	80	84	90	89	106	107	100	107	91.0
1992	98	88	80	92	83	76	78	76	88	106	103	90	106	88.2
1993	92	90	87	92	78	76	74	78	90	106	98	100	106	88.4
1994	96	86	92	92	88	80	76	74	84	104	116	100	116	90.7
1995	102	104	90	88	90	85	87	80	96	112	120	114	120	97.3
1995	102	104	90	88	90	85	87	80	96	112	120	114	120	97.3
1996	101	102	81	98	88	88	92	92	100	123	113	114	123	99.3
1997	120	110	97	97	88	90	90	90	114	116	146	108	146	105.5
1998	110	104	102	98	92	90	85	90	100	118	120	123	123	102.7
1999	120	110	98	103	108	93	87	88	112	126	126	138	138	109.1
2000	127	123	105	99	97	97	98	88	111	125	133	132	133	111.3
2001	128	130	113	104	93	99	95	105	114	127	136	129	136	114.4
2002	127	123	112	106	104	101	92	93	114	131	140	131	140	114.5
2003	124	121	119	109	101	91	110	102	128	152	143	144	152	120.3
2004	137	130	128	111	113	107	107	100	122	139	145	145	145	123.7
2005	134	126	127	103	93	99	92	87	110	131	134	131	134	113.9
2006	133	127	117	106	118	93	91	105	113	119	135	141	135	116.5
2007	121	108	119	106	100	89	95	99	123	136	142	135	142	114.4
2008	127	124	115	108	105	99	100	106	118	135	152	150	152	119.9
2009	151	124	121	124	110	105	105	113	118	123	152	142	152	124.0
2010	134	122	115	117	114	118	112	116	119	138	156	147	156	125.7
2011	145	135	123	115	101	107	101	106	127	148	153	156	153	126.4
2012	135	133	138	124	103	117	109	121	136	159	149	156	159	131.7
2013	149	139	127	121	118	110	111	111	125	150	154	154	154	130.8
2014	146	142	131	118	112	107	117	114	128	155	151	167	155	132.3
2015	150	137	129	120	112	119	113	118	134	155	166	147	166	133.3

G.3.2.2. Minimum water level (H. min) in Nam Can Station (cm, Vn2000)

Year	Month												H. min
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
1995	-134	-130	-112	-160	-188	-191	-183	-167	-144	-108	-120	-101	-191
1995	-131	-142	-126	-126	-169	-178	-180	-160	-128	-91	-120	-113	-180
1996	-111	-124	-103	-147	-169	-178	-159	-158	-129	-118	-139	-121	-178
1997	-139	-126	-117	-166	-172	-187	-172	-151	-129	-104	-137	-116	-187
1998	-116	-141	-110	-144	-176	-204	-188	-166	-126	-110	-106	-96	-204
1999	-118	-113	-110	-128	-166	-182	-186	-172	-142	-98	-108	-136	-186
2000	-133	-112	-114	-142	-184	-198	-172	-145	-124	-101	-105	-124	-198
2001	-142	-121	-121	-128	-169	-174	-176	-169	-138	-101	-101	-141	-176
2002	-132	-118	-107	-156	-185	-183	-164	-152	-130	-107	-121	-120	-185
2003	-124	-124	-112	-139	-171	-177	-183	-158	-122	-88	-137	-133	-183
2004	-127	-135	-123	-162	-195	-189	-188	-168	-134	-123	-129	-120	-195
2005	-126	-108	-114	-154	-171	-187	-170	-153	-126	-127	-126	-99	-187
2006	-119	-151	-115	-164	-175	-168	-175	-164	-128	-140	-100	-122	-175
2007	-140	-100	-107	-163	-175	-171	-176	-138	-135	-107	-109	-112	-176
2008	-94	-99	-111	-158	-179	-169	-149	-139	-128	-124	-90	-114	-179
2009	-130	-115	-113	-124	-148	-182	-157	-134	-121	-132	-98	-111	-182
2010	-95	-84	-100	-152	-165	-175	-159	-136	-118	-137	-95	-85	-175
2011	-133	-91	-81	-150	-174	-152	-139	-127	-105	-104	-125	-102	-174
2012	-95	-124	-116	-144	-171	-170	-138	-139	-109	-116	-96	-106	-171
2013	-125	-109	-96	-128	-161	-158	-144	-135	-109	-97	-107	-99	-161
2014	-101	-121	-105	-150	-158	-169	-175	-140	-128	-112	-103	-106	-175
2015	-134	-130	-112	-160	-188	-191	-183	-167	-144	-108	-120	-101	-191

G.3.2.3. Average water level (H. average) in Nam Can Station (cm, Vn2000)

Year	Month												H. average
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
1995	18	16	6	2	-6	-16	-11	-6	1	18	32	31	7
1995	22	26	7	12	-1	-6	-5	-1	6	30	33	30	13
1996	27	26	14	7	-1	-7	0	-4	10	21	24	29	12
1997	22	14	18	10	5	-2	-2	3	10	28	29	35	14
1998	31	25	16	14	9	-6	-5	-2	8	31	35	46	17
1999	35	35	27	9	4	-3	2	-1	14	23	46	38	19
2000	34	35	22	18	5	-4	1	5	13	32	44	39	20
2001	30	28	20	15	10	-1	-3	3	5	23	40	39	17
2002	32	31	25	12	10	2	6	9	15	36	44	50	23
2003	36	30	26	15	8	3	4	6	18	45	43	41	23
2004	35	25	27	16	1	1	-5	-4	8	25	34	38	17
2005	30	30	17	11	9	-5	-4	0	10	24	34	46	17
2006	35	15	20	18	6	1	-3	0	10	25	45	39	18
2007	34	38	24	18	11	1	7	9	10	30	49	49	23
2008	47	26	24	20	16	3	4	7	11	27	47	38	23
2009	36	26	27	24	15	7	8	11	14	37	54	48	26
2010	49	35	41	25	9	2	3	8	10	32	49	54	26
2011	39	36	36	18	8	5	9	10	22	43	44	52	27
2012	46	41	28	27	16	10	10	9	18	41	48	49	29
2013	41	34	34	25	18	10	10	14	20	44	51	58	30
2014	47	38	30	29	12	8	9	10	19	38	47	52	28
2015	18	16	6	2	-6	-16	-11	-6	1	18	32	31	7

Appendix H: The average shrimp productivity of RSRF, ISMF, SSMF, and the whole province in the period of 1991 – 2015 (kg ha^{-1} $year^{-1}$)

Year	Average shrimp productivity (kg ha^{-1} $year^{-1}$)			
	RSRF	**ISMF**	**SSMF**	**Whole Province**
1991	299.8	330.0	-	329.7
1992	212.3	243.3	-	273.2
1993	215.2	300.0	-	312.8
1994	228.6	183.1	-	219.3
1995	229.9	240.0	-	229.1
1996	200.3	176.2	-	175.5
1997	184.1	172.5	-	181.4
1998	286.3	175.0	-	217.9
1999	96.9	110.2	-	185.5
2000	212.8	316.0	-	230.7
2001	181.1	307.7	-	253.9
2002	201.1	325.6	-	253.2
2003	164.9	338.8	-	250.9
2004	295.2	443.4	372.2	293.9
2005	192.0	459.1	449.3	326.5
2006	277.2	450.0	396.6	409.7
2007	246.3	393.2	384.4	342.3
2008	236.1	368.8	335.6	356.5
2009	306.8	375.8	335.0	375.6
2010	333.9	477.8	418.2	404.5
2011	347.0	468.3	418.2	440.8
2012	353.7	420.9	419.4	470.4
2013	393.5	459.2	434.7	519.5
2014	405.6	372.3	363.8	521.3
2015	397.6	442.7	424.8	523.0