Climate proofing aquaculture:
A case study on pangasius farming
in the Mekong Delta, Vietnam.

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Dedicated to my late father

Abstract

Vietnam is among the top five countries that will be most affected by sea level rise. This study aimed to assess the subsequent impacts of flooding and salinity intrusion on, and to evaluate suitable adaptation strategies for the Mekong Delta's pangasius farming sector.

Water level rise and salt water intrusion for three sea level rise (SLR) scenarios (i.e. +30cm, +50cm and +75cm) were simulated by using the MIKE11 model. The results showed that at SLR+50, the 3m flood level would spread downstream and threaten farms located in upstream and midstream regions. Rising salinity for SLR+75 would reduce the appropriate time-window for the culture in coastal areas.

A Chi-Square test and a logit regression model were employed to examine factors which influence pangasius farmers' perception of and adaptation to climate change impacts. Less than half of the respondents were concerned about climate change and actively sought suitable adaptation measures to alleviate its impacts. The adaptive capacity of pangasius farmers can be improved by increasing the information on climate change and introducing early warning systems.

The technical efficiency (TE) of randomly sampled pangasius farms was estimated using Data Envelopment Analysis, and factors affecting technical and scale efficiency were examined with bootstrap truncated regression. The mean TE score assuming constant return to scale was 0.66, and under variable return to scale it was 0.84. TE of downstream farms was higher compared to the upstream and midstream farms due to lower energy costs and stocking once a year at a lower density, but these reduced the scale efficiency of farms affected by salinity intrusion. Upstream and midstream farms needed to pump water and stocked at least three times in two years. Regression analysis showed a positive effect on TE of the farmer's education level, and of having experienced climate change impact through flooding or salinity intrusion in the past.

Using a decision tree framework, this study analyzed possible options for adapting pangasius farming to the projected climate-change impacts. Options to adapt to salinity intrusion are: modify the pangasius farming practice by using e.g. water recirculation systems, stock other species, or stock saline-tolerant pangasius with support from research and extension. A breeding program for saline-tolerant striped catfish requires long-term investments (0.4 % of the present production costs). To adapt to worse flooding, pangasius farms not located within the upgraded government dyke-protected areas could raise the height of the dyke around their pangasius farm, which would increase the total variable costs per ha for one harvest by about 0.34% in the upstream and midstream regions, and by 0.25% in the downstream region.

CONTENTS

Chapter 1

General Introduction

The Mekong Delta is commonly referred to as the food basket of Vietnam in view of its contribution to the country's production of rice, vegetables, fruits and fish. Barange and Perry (2009) and De Silva and Soto (2009) summarized the general impacts of climate change on fisheries and aquaculture, respectively. They made apparent that threats are worse for the tropical and subtropical regions, where most (i.e. 50-70%) of all aquaculture activities occur (De Silva and Soto, 2009). Vietnam was ranked among the top five countries most affected by rising sea levels (Dasgupta et al., 2007). Sea level rise scenarios studies explored the impacts on Mekong Delta's infrastructure (Hoa et al. 2007) and rice cropping areas (Wassmann et al. 2004; Khang et al., 2008). After rice, aquaculture is the second main farming activity of the Mekong Delta. This study aims to assess impacts and to evaluate suitable recommendations and strategies for the pangasius farming sector, which is, next to shrimp the major aquaculture activity in the Mekong Delta, and indeed of great significance in the whole of Vietnam.

1.1.Background

1.1.1. Pangasius aquaculture in the Mekong Delta, Vietnam

The Vietnamese part of the Mekong Delta covers an area of 3.9 million ha (Wassmann et al., 2004). More than 30% area of Mekong Delta is covered by alluvial soil, which is suitable for pangasius aquaculture. This soil is distributed along the Hau and Tien rivers of the Mekong Delta and concentrates in the provinces of Dong Thap, Tien Giang, An Giang, Can Thơ, Ben Tre and Vinh Long (Department of Aquaculture, 2008).

The culture of pangasius (generic name for the two farmed catfish species, the *Pangasius bocourti* and *Pangasianodon hypophthalmus*), started around 1950 in the Mekong Delta, Vietnam. In the beginning, it was a small-scale aquaculture, providing food for household demands only. The pangasius were kept in small ponds and garden canals, and later in cages in the river. Crop residues, manure and household waste were used for feed (fertiliser). However, since the end of 1990s the pangasius aquaculture has been growing very fast and turned into a crop for the global market, relying mainly on export. At the same time, seed production and the pond production intensified due to improved feeding and artificial breeding.

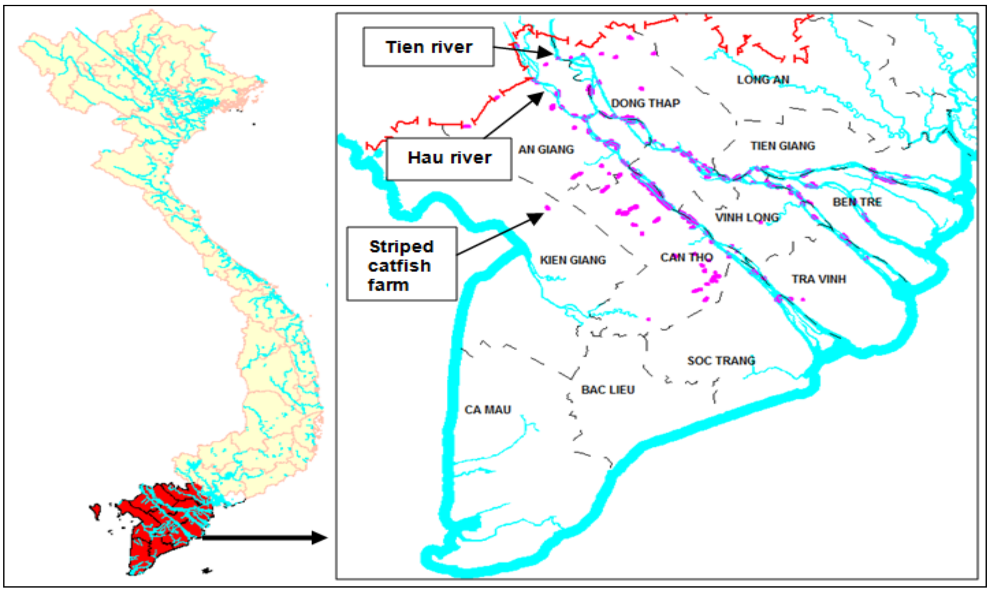

Figure 1.1. Administrative map of the Mekong delta with the locations of the pangasius farms in 2009 (adapted from Anh et al. 2014).

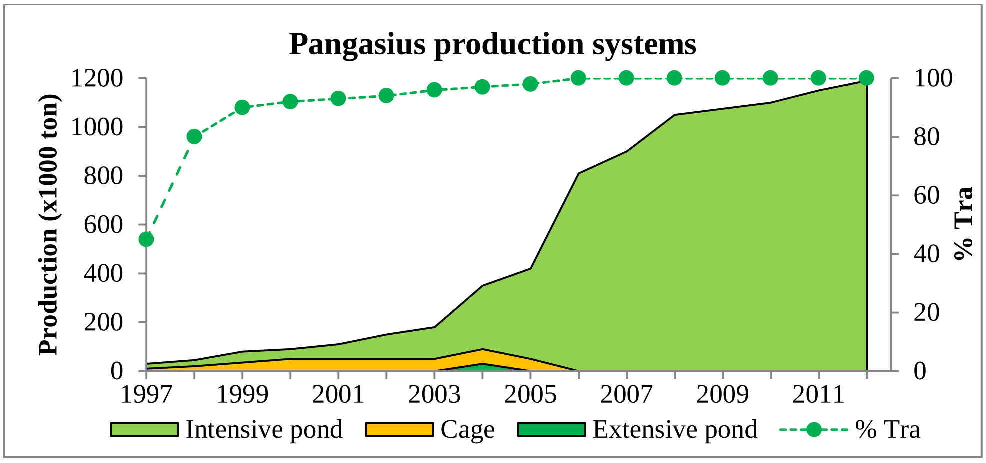

Figure 1.2. Production of pangasius in the Mekong Delta in extensive ponds, cages and intensive ponds (left Y-axis; shaded areas). Originally, both *Pangasius bocourti* (Basa) and *Pangasianodon hypophthalmus* (Tra) were produced, but the share of Tra (righ Y-axis, dots) gradually increased (supplemented from Dzung, 2008).

In 1997, pangasius culture in the An Giang province counted 100 cages, with a total volume of 20 000 m^3. After that, the cage culture developed also in Dong Thap, Can Tho, Vinh Long and Tien Giang provinces and reached the highest amount of cages in 2003 and the highest volume in 2004 with approximately 684 000 m^3. However, since 2004, the pangasius culture in cages decreased very fast in amount and volume (Department of Aquaculture, 2008). Until 1997 the growth rate of cage culture yield was 3,2% per year, then rapidly increased from 1997 to 2002 (143% per year), but decreased dramatically with -65% per year between 2003 and 2007 (Figure 1.2). This decrease had three reasons: profits in cage culture were lower than in pond culture because of higher Feed Conversion Ratios (FCRs), more difficult reproduction of *P. bocourti*, and limited options of environmental control leading to disease out-breaks. The early pangasius production relied entirely on the collection of fingerlings from nature to stock the cages and/or ponds. Artificial reproduction in specialized hatcheries was first mastered for *P. hypopthalmus*. The commercial significance of closing the life cycle that followed the banning of collection of wild fry and fingerlings for aquaculture of *P. hypophthalmus,* have also been highlighted (Nguyen 2009; De Silva and Phuong, 2011). In addition, *P. bocourti* does not perform well in ponds. Together, these two phenomena (i.e. increased production in ponds and artificial reproduction in hatcheries) led to a shift in cultured species. At this moment, *P. hypopthalmus* represents more than 95% of the total production volume.

In 2007, the pangasius farming area covered approximately 6200 ha out of a total deltaic area of 3.9 million ha (Dzung, 2008). In 2007 the pangasius pond area was 4.2 times larger than in 1997. In the same period, the yield of pond culture increased 29.4 times, from 23 250 tonnes to 683 567 tonnes. The average growth rate of the production volume in the period 1997-2007 was 40% per year which was much higher than the growth of the culture area (i.e. 15.5% per year). Apparently, the pangasius production increased not only by expanding the farm areas, but was also based on a fierce intensification of the production process (see Phan et al., 2009; De Silva and Phuong, 2011).

At present, farming of *Pangasianodon hypophthalmus* (commonly referred to as tra catfish) is the most important aquatic farming sector in Vietnam from both a social and an economic point of view, accounting for approximately 60% of the overall aquaculture production. In 2012, the sector produced 1.19 million tons of fish in a pond area of 5600 ha and exported the processed pangasius, mainly in the form of fillets, to over 142 countries with a value of 1.7 billion US$ (VASEP, 2013). The sector provides employment and income to half a million persons of which the processing sector accounts for almost one third. The majority of employees in the processing industry are female, leading to their empowerment and improving households' wellbeing (Phuong et al., 2008). During the past five years, a shift in farm size and business model was noticed. The farming system essentially comprised of small-scale individual holdings, owned, operated and managed by the farmer delivering the harvest to processing companies (Phan et al., 2009; De Silva and Phuong, 2011). However recently small farmers tend to abandon (Bush et al., 2009), and larger pond areas tend to be integrated in large-scale farms, which are mostly owned and operated by processing companies (De Silva and Phuong, 2011).

1.1.2. Climate change, climate variability and its influence on aquaculture

WMO, GCOS, UNFCCC or IPCC all use different definitions for 'climate change' and 'climate variability' (FAO, 2008). According to IPCC (2007), UNFCCC defines climate change as solely induced by the anthropogenic driven, while IPCC included both natural and anthropogenic drivers. Thus, the sufficient definition of climate change can be stated: "*climate change is a change in the state of the climate that can be identified (e.g. using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. It refers to any change in climate over time, whether due to natural variability or as a result of human activity*" (IPCC, 2007).

According to the Intergovernmental Panel on Climate Change (IPCC, 2007), global average surface temperature has increased 0.76°C over the last century, and Southeast Asian countries are the region considered among the world' most vulnerable to climate change (ADB, 2009). Between 1951 and 2000, in Southeast Asia the mean surface air temperature increased by 0.1-

0.3°C per decade, rainfall has been trending down between 1961 and 1998; the number of rainy days have declined, and sea levels raised at the rate of 1-3 mm per year (IPCC, 2007). Nicholls et al. (1999) expressed that if no adaptive measures are taken, a sea level rise of 37-38 cm by the 2080s could enhance coastal flooding and increase coastal wetlands losses. According to IPCC (2007), the frequency of extreme weather events in Southeast Asia has increased: heat waves are more frequent (an increase in the number of hot days and warm nights and decrease in the number of cold days and cold nights since 1950); the number of tropical cyclones was higher during 1990-2003 than before. These extreme weather events have led to massive flooding, landslides and droughts in many parts of the region, causing extensive damage to property, assets and human life (ADB, 2009).

The annual average temperature in Viet Nam, increased by 0.1°C per decade between 1900 and 2000, but during 1951-2000 it was 0.14°C per decade, suggesting temperature rose faster in the latter half of the century. Summers have become hotter in recent years, with average monthly temperatures increasing 0.1-0.3°C per decade. Most regions in Viet Nam are projected to experience an increase in temperature of 2-4ºC by 2100 (Cuong, 2008). Change of annual average rainfalls for the last nine decades (1911-2000) was not distinct and not consistent with each other at every location. On average for the whole country the rainfall over the past half century (1958-2007) decreased by about 2% in total, while a slight increase was observed in the south (MONRE, 2009). For the Mekong river basin, future rainfall trends are not uniform and impacts from sea level rise may dominate the hydrological changes (Chinvanno, 2007; TKK & START, 2009).

According to Ficke *et al.* (2007) the general effects of climate change on freshwater systems are increased water temperatures and decreased dissolved oxygen levels. Increasing temperatures can affect individual fish by altering physiological functions, such as thermal tolerance, growth, metabolism, food consumption, reproductive success and their ability to maintain internal homeostasis in a variable external environment (Fry, 1971). The consequence of changed physiological functions for aquaculture systems is that the fish reaches a harvestable size later or requires more food to grow them to the harvestable size in the same amount of time (Ficke *et al.*, 2007).

De Silva and Soto (2009) synthesised direct and indirect impacts of climate change on aquaculture. Direct impacts include changes in the availability of freshwater, in temperature and in sea level, and increased frequencies of extreme events (e.g. flooding and storm surges) that affect fish farming. Indirect effects on aquaculture may be more important and include, among others, economic impacts, such as cost and availability of feed; uncertain supplies of fishmeal from capture fisheries; declining oxygen concentrations and increased blooms of harmful algae; problems with non-native species invasions; unsuitable local conditions in traditional rearing areas for traditional species; competition of freshwater aquaculture activities with changes in freshwater availability due to agricultural, industrial, domestic and riverine requirements, as well as to changes in precipitation regimes; and flooding of coastal land areas, mangrove and sea grass regions which may supply seed stock for aquaculture species.

The Mekong Delta suffers from climatic change impacts through sea level rise (1cm/year until 2100) (Grinsted *et al.*, 2009) and reduced river flow. This will gradually result in an increased upstream intrusion of saline water (Handiside et al., 2007). The tidal regime and salt water intrusion are important factors determining the potential spread of pangasius farms. According to the Department of Aquaculture (2008), the salt water intrusion negatively affects pangasius culture. Salinity higher than 4‰ is unsuitable for pangasius culture. The water used for pangasius culture comes from Tien and Hau rivers and the canal systems. The areas within 20 to 35 km from the river mouth have a salinity of 4‰ all year and are thus unsuitable (Department of Aquaculture, 2008). Phan et al. (2009) reported a reduced production in catfish farms located downstream, which was attributed to diurnal changes in salinity, albeit small. As a consequence of climate change the production area of farming systems in the Mekong Delta might be altered and at least part of the presently used area may become inappropriate for the culture of pangasius (Handiside et al., 2007).

1.2. Problem formulation

Although a temperature increase may affect pangasius culture, the two main factors of our concern are the water level rise and salinity intrusion induced by sea level rise. Pangasius has a large temperature comfort zone (Department of Aquaculture, 2008) and hence, we don't expect that temperature increase due to global climate change will have strong impact on the farming industry. However, the pangasius farming industry may be affected by increased seawater intrusion in coastal areas or by increased flooding in upstream regions, caused by the sea level rise and exacerbated by a reduced river flow in the dry season or increased water discharge in the rainy season, respectively. Together these would increase salinity and water level significantly and the farmed species might suffer from salinity stress as well as from risks related to flooding (water levels higher than the pond dyke, or pond dyke destruction). Therefore, the farm location and the extent to which pangasius can adapt to brackish water or the extent to which a pond can undergo flooding are factors that affect the decision-making process of the farmers. The appropriate adaptive measures could be hard to select and therefore will have to be accompanied by relevant socio-economic changes within the farming community as well as for those servicing this farming sector.

1.3. Thesis objective and research questions

Assuming that the Mekong Delta's elevation does not change this century, the delta will be subject to major climate change impacts through sea level rise. Climate change combined with sea level rise will increase upstream intrusion of saline water in the dry season and will enhance flooding in the rainy season. As a consequence the production area of pangasius farms might be altered and at least part of the presently used area might become unsuitable for farming pangasius. Hence, the question arises whether the pangasius farming sector in Mekong delta can cope with impacts of climate change?

This study aims to estimate the impact of climate change on pangasius farming, to assess the pangasius farmers' capabilities to deal with potential climate changes and to propose adaptation strategies to support farmers and policy makers. The research questions we try to answer are:

1) Does sea level rise (and the consequent saline water intrusion and river discharge) affect the potential area for pangasius culture?
2) How do farming communities perceive and deal with the effects of sea level rise?
3) Is the technical efficiency of farms impacted by sea level rise?
4) Which are appropriate adaptation and/or mitigation measures?

1.4. Methodology approach

The locations that might be impacted by changes of water level and salt intrusion, can be estimated by GIS based maps and hydrological modelling. After assessing the perceptions of the farmers and their adaptive measures, and using a technical efficiency analysis, this study uses a decision tree framework to formulate recommendations on the possibilities of adaptation to climate change.

1.4.1. GIS and GIS-linked hydrological models

In order to answer the first research question, we need a spatial explicit model that simulates the influential dynamics of water level and salinity intrusion process induced by sea level rise scenarios on pangasius farming location over time. Thus, the two-step approach is applied. Firstly, the hydrological model is employed to project the water level and the salinity intrusion under different sea level rise scenarios. The results from first step then will be combined with the map of pangasius farming location to estimate the affected areas. A broadly applied GIS-linked hydrological model needs to be considered.

According to Hennecke (2004), GIS model was used for simulating the potential physical impacts of rising sea level on the coastal environment. In earlier research, GIS has been used to handle spatial information and assist the decision making process. Kok *et al.* (2001) combined GIS with a dynamic model (included the regional temporal and spatial dynamics) for decision-support systems of land-use change in the coastal zone. Hennecke (2004) indicated that a GIS spatial analysis process may contribute to the reduction of uncertainty in natural hazard risk assessment.

In the Mekong Delta of Vietnam, using the HydroGis model based on Sant-Venant equations, Hoa *et al.* (2008) studied flood variation trends over the 43-year period from 1961 to 2004 and analysed the hydrological effects of infrastructure changes associated with human activities in the period from 1996 to 2001. To evaluate the conflicts between tidal effects and salinity intrusion in inland coastal zones on one hand and synergies in the development of agriculture, fisheries and aquaculture in the Ca Mau peninsula, Mekong Delta, Vietnam on the other, Hoanh *et al.* (2009) applied the hydraulic and salinity model Vietnam River System and Plains (VRSAP). VRSAP is a numerical model using Sant-Venant equations for solving complex flow and mass transport problems in a complex network of interconnecting open channels (Hoanh *et al.*, 2009).

Since the start of this century, sea level rise scenarios in the Mekong Delta were modelled using hydrological and GIS data to estimate the impact of climate change. Hoa *et al.* (2007) studied the impact of the flood and sea level rise to Mekong river catchment, based on the integrated hydraulic model known as HydroGis. Most recent estimations for sea level rise impacts in Mekong Delta, are based on the intermediate emission scenario of the medium scenario group (B2) of IPCC (MONRE, 2009). Using two scenarios for sea level rise of +20 cm and +45 cm from a B2 climate change projection, Khang *et al.* (2008) simulated flow and salinity intrusion changes in Mekong Delta by the MIKE11 model. Applying GIS, rice cropping areas of high and medium vulnerability affected by sea level rise were estimated at 200,000 ha and 400,000 ha, respectively (Khang *et al.*, 2008). Wassmann *et al.* (2004) computed water levels in the flood season in the Mekong Delta under sea level rise scenarios 20 cm and 45 cm to delineate vulnerable rice production areas using the VRSAP model to generate GIS output.

The above evidence shows that a GIS-linked hydrological model based on the Sant-Venant equation is appropriate for our study to estimate the impacts of sea level rise scenarios on pangasius farming locations in the Mekong Delta.

1.4.2. Assessing farmer's perception of and adaptation to climate change

Scientific evidence of the climate threat to agriculture, fisheries and aquaculture is relatively unambiguous (Parry *et al.*, 2007; World Bank, 2008). Therefore, the adaptation capacity to cope with the risks from climatic change should be developed (Shaw, 2006). Individuals, households, communities and nations are challenged to moderate the harms, to live with the impacts or preferably turn them to an advantage (Tompkins *et al.* 2004). To be effective, adaptation should be integrated into national socio-economic strategies and harmonized at the policy and practical levels with other development objectives including environmental sustainability (Newman *et al.*, 2005). Adaptation requires partnerships, capacity building, the involvement of a wide range of stakeholders, and willingness at all levels (Adger *et al.*, 2007).

De Silva and Soto (2009) noted that the social impacts of climate change on capture fisheries have received much attention compared to those on aquaculture. Some of the factors that influenced captured fisheries, include damage to physical capital, impacts on transportation and on marketing chains. These most likely affect aquaculture also. De Silva and Soto (2009) pointed out that the farming communities will be amongst the most vulnerable in the aquaculture sector and the possibilities of reducing their vulnerability are relatively limited.

Adapting to climate change requires the farmers to perceive how the climate changes, and identify suitable adaptations in their production systems to maintain livelihood. Mertz *et al.* (2008) analysed farmer perceptions of climate change and agricultural adaptation strategies in rural Sahel of central Senegal, based on data of focus group interviews and household surveys. Roy (2012) analysed fishers' perceptions and adaptive measures to impacts of climate change on fisheries in West Bengal using data from household survey. Tambo and Abdoulaye (2013) analysed data of household survey to examine the farmer perception of and adaptation to climate change in Nigerian savanna region. While estimating the farmers perception and adaptation, various scientists employed regression models to explore the influence factors affected farmers decision. Maddison (2007) used a Heckman probit model to analyse the perception and adaptation of the farmers in Africa. Others used this model together with a multinomial logit (MNL) model while focusing on farmers in the Nile basin of Ethiopia (Deressa *et al.,* 2008) or the Limpopo basin of southern Africa (Gbetibouo, 2009). Using household survey data and regression analysis, Dang et al. (2014) assessed private adaptive measures to climate change and influential factors of rice farmers in the Mekong Delta, Vietnam.

According to the above statements, applying a regression model based on the household survey need to be considered to investigate the second research question of our study.

1.4.3. Estimating technical efficiency

Allocation and technical efficiency are components of economic efficiency. Koopmans (1951) stated a producer is technically efficient if an increase in any output requires a reduction in at least one other output or an increase in at least one input or vice versa. According to Kaliba and Engle (2006), technical efficiency is measured based on deviations of observed production from the so-called efficiency frontier. If a firm's production is on the efficiency frontier, it is considered efficient. On the contrary, if a firm's production is outside the efficiency frontier, it is considered inefficient. The efficiency frontier can be estimated using two approaches: the parametric method stochastic frontier analysis (SFA) (Aigner et al. 1977; Meusen and van den Broeck, 1977) and the non-parametric data envelopment analysis (DEA) (Charnes et al., 1978), which involve econometric methods and mathematical programming techniques, respectively.

The advantage of the DEA approach is that it eliminates the need for parametric assumptions about the functional form (Sharma and Leung, 2003). However, a frontier estimated by this technique is likely to be sensitive to stochastic noise and other measurement errors in the data because DEA is deterministic and attributes all deviations from the frontier to inefficiencies. Simar and Wilson (2007) stated that many studies on technical efficiency have used a two-stage approach, where efficiency is estimated in the first stage, and then the environmental variables are investigated to find the factors that influence efficiency in the second stage. In the second stage, efficiency is mostly regressed by using a tobit regression or ordinary least square methods. The latter methods, however, estimate DEA efficiencies that are serially correlated (Simar and Wilson, 2007). The above experts suggested single and double bootstrap procedures to improve statistical efficiency in the second stage regression.

Studies investigating technical efficiencies of aquaculture farming systems, particularly for tropical systems, are sparse. According to a review of Sharma and Leung (2003), the first study was conducted in 1996 by Gunaratne and Leung, who examined production characteristics and the levels of technical efficiency among black tiger shrimp farms in Asian countries. The number of studies increased in recent years but it is still much smaller than in agriculture and other industries (Sharma and Leung, 2003). Sharma and Leung (1998) estimated the technical efficiency of carp farms in Nepal using a SFA method. Sharma et al. (1999) applied a DEA technique to measure technical and allocative efficiency of Chinese polyculture fish farms and based the optimum stocking densities for different fish species in this farming system on this analysis. Dey et al. (2000) investigated the level of technical efficiency and its influence factors of tilapia grow-out operations in the Philippines by the SFA method. Using a weight-restricted DEA technique, Kaliba and Engle (2006) estimated the productive efficiency of small- and medium-sized catfish farms in Chicot County, Arkansas, and identified factors leading to a higher level of efficiency. Also using a two-step procedure, Cinemre et al. (2006) measured the cost efficiency of trout farms in the Black Sea Region, Turkey, and indicated factors which determined technical inefficiency. Ferdous and Murshed-e-Jahan (2008) employed the DEA technique to estimate the resource allocation efficiency of prawn-carp polyculture system in Bangladesh, and examined the relationship between efficiency and farm's characteristics.

Considering these above arguments, the DEA two-stage approach was used to examine the technical efficiency under climate change impacts in order to answer the third research question.

1.4.4. Creative decision tree

The last research question requires a decision making process to choose suitable adaptive measures of pangasius farmers and related decision makers. The relevant support tool for this process should be a decision tree framework. The reasons were revealed by the following discussion.

Hornby (2000) states that the best thing to do after thinking is to make a decision. Thus, decision making is "*the process of deciding about something important, especially in a group of people or an organization"* (Hornby, 2000). In the context of natural resource management and land use, Akombelwa (2011) suggests a process considering actions or a set of actions that would benefit the individual or community most, given a set of prevailing environmental circumstances that limit maximisation of the benefit. There are several decision making models such as the Rational model, the Carnegie model, the Incrementalist model, the Unstructured model and the Garbage Can models (Akombelwa, 2011). Marakas (2003) pointed out that the rational decision model is the systematic analysis of a problem and choice of a solution.

Various tools can support the decision making process but decision tree classifiers have found the widest application (Garofalakis et al., 2003). The latter is due to preeminent properties of decision trees such as (a) easy to assimilate and translate to standard database queries, (b) efficient and suitable to apply for large data sets and for large time-series, (c) no requirement of prior knowledge of statistical distributions of the data and (d) higher accuracy compared to other techniques (Garofalakis et al., 2003). Witten and Frank (2005) expressed decision tree techniques following a top-down induction strategy, and are built as tree-like sequential graph models that can be easily translated into a set of mutually exclusive decision rules.

1.5. Outline of the thesis

The tools used and results acquired to answer the research questions are presented in the following five chapters of this thesis.

Chapter 2 simulates the impacts of climate change on current farming locations of pangasius in the Mekong Delta, Vietnam. In this chapter, the exposure and sensitivity aspects of climate change impacts are investigated to estimate the potential impacts of sea level rise scenarios on the pangasius farming area.

Chapter 3 explores the climate change concerns of pangasius producers. This chapter investigates the pangasius farmer perceptions of climate change and its impacts, the adaptations measures adopted by them, and the factors that influence and affect their thinking.

Chapter 4 examines the impact of climate change on the technical efficiency of pangasius farming. The chapter estimates the technical efficiency of pangasius farms and analyses the relationship between technical efficiency with influence factors caused by climate change impacts.

Chapter 5 goes along with the decision support to enhance climate change adaptations of pangasius farming in the Mekong Delta, Vietnam. This chapter focuses on analysing the impacts of climate change on pangasius farming and the appropriate solutions for the sector in order to support decision making.

Chapter 6 presents a general discussion. In this chapter, the main findings of the study are synthesized and discussed to evaluate the climate change impacts and adaptation strategies for pangasius farming in the Mekong Delta.

The studies presented in each chapter and the general discussion show that my aim was achieved. The impacts of climate change on pangasius farming were identified and the pangasius farmers' adaptive capacity and adaptation strategies were assessed. Finally to support policy-making at farm and institutional level we developed a decision support tool.

Chapter 2

Simulated impacts of climate change on current farming locations of striped catfish *(Pangasianodon hypophthalmus* Sauvage) in the Mekong Delta, Vietnam

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Abstract

In Vietnam, culturing striped catfish makes an important contribution to the Mekong Delta's economy. Water level rise during rainy season and salt intrusion during dry season affects the water exchange and quality for this culture. Sea level rise as a consequence of climate change will worsen these influences. In this study, water level rise and salt water intrusion for three sea level rise (SLR) scenarios (i.e. +30cm, +50cm and +75cm) were simulated. The results showed that at SLR+50, the 3m flood level would spread downstream and threaten farms located in AnGiang, DongThap and CanTho provinces. Rising salinity levels for SLR+75 would reduce the window appropriate for the culture in SocTrang and BenTre provinces, and in TienGiang's coastal districts. Next to increasing dikes to reduce the impacts, the most tenable and least disruptive option to the farming community would be to shift to a salinity tolerant strain of catfish.

2.1. Introduction

Striped catfish (*Pangasianodon hypophthalmus*) (Sauvage) farming in the Mekong Delta (Fig. 2.1) accounts for approximately 60% of Vietnam's overall aquaculture production (Anonymous, 2011). Processed catfish, mainly in the form of fillet, was exported to over 100 countries and was valued at 1.4 billion US$ in 2010 (De Silva and Phuong, 2011). The sector provides employment for more than 170 000 workers (De Silva et al., 2010) and includes both small-scale farmer managed holdings that deliver their produce to processing companies, and fully integrated companies which own feed-mills, ponds, and processing facilities.

Farming of catfish started with *Pangasius bocourti* in cages in the two main branches of the Mekong, Tien and Hau, or its tributaries. The culture gradually moved to ponds after artificial propagation of striped catfish was developed (Phan et al., 2009; Bui et al., 2012). These ponds are deep, enabling yields of 200-400 t/ha/crop (Phan et al., 2009), and cover approximately 6200 ha in total (Bosma et al., 2009). To obtain the desired white fillet colour catfish farming requires regular water exchange. To meet the large volume of water that is required to be exchanged on a very regular basis (Phan et al., 2009) and to reduce costs associated with this exchange (i.e. pumping), most catfish farms are located along the Tien and Hau river branches (c.f. Fig. 1).

These rivers have a relatively high tidal range, though their hydrological regime is affected by tidal and river discharge, depending on the season (Wassmann et al., 2004). The floods from the rainy season (May to November), and the salt intrusion from the dry season (March to April) are important criteria of suitable locations for striped catfish farming. In particular, salinity concentrations higher than 4‰ are deemed unsuitable for striped catfish farming (Department of Aquaculture, 2008; De Silva and Phuong, 2011). Besides the seasonal impact on hydrological regimes, the projected impacts of climate change should be considered. The projected sea level rise of about 1 cm $year^{-1}$ until 2100 (Grinsted et al., 2009) and the simultaneous reduction in river flow cause an upstream increase in saline water intrusion during the dry season, and flooding during the wet season (DFID, 2007).

Considering all sea level rise impact indicators, Vietnam has been ranked as one among the top five countries most affected by rising sea levels (Dasgupta et al., 2007). Vietnam's Ministry of Natural Resources and Environment (MONRE, 2009) computed the country's sea level rise scenarios by using the IPCC SRES projections (Nakicenovic et al., 2000). MONRE (2009) argued that the lowest B1 scenario is very unlikely since conflicting views on climate change mitigation between various countries will hamper the stabilization of greenhouse gas concentrations. On the other hand, with the world's campaign in "combatting climate change", MONRE expects that highest scenario (A2) will not happen either. They expect a sea level rise of 30cm in 2050, 46cm in 2070 and 75cm in 2100, using scenario B2.

Prior to MONRE's sea level rise projections, researchers have already worked on climate change-related studies. To assess sea level rise and salinity intrusion in the Mekong Delta, researchers have begun using hydrological models and GIS data since the start of this century. Specifically, the VRSAP model was used by Wassmann et al. (2004) to map the vulnerable rice production areas and by Nguyen and Savenije (2006) to predict the salinity distribution in the Mekong river branches using topography, tide, and river discharge data. Hoa et al. (2007, 2008) used an integrated hydraulic model, HydroGis, in tracking the impact of sea level rise and flooding in general. Khang et al. (2008) simulated changes in water flow and salinity intrusion for two sea level rise scenarios (+20 cm and +45 cm) by using the MIKE11 model and a GIS.

However, no studies have yet examined the impact of sea level rise on the striped catfish farming areas in the Mekong Delta (Fig.2.1). The vulnerability of pangasius farming has two aspects: (1) the exposure to and sensitivity for climate change impacts, and (2) the perception of risk and possibilities for its mitigation. A later paper will focus on the second aspect. The present study focuses mainly on the exposure and sensitivity. Thereto salinity intrusion predictions and water levels are combined with the current locations of striped catfish farming in the Mekong Delta, to estimate the potential impact of different sea level rises (i.e. +30, +50 and +75 cm) on these striped catfish farming areas.

2.2. Materials and methods

This study mapped the catfish farms in the Mekong delta for 2009. We assessed the impacts of water level and salinity intrusion along the Tien and Hau branches of the Mekong river in time and space by applying model-based scenarios for sea level rise and reduced river flow (e.g. Alcamo et al., 1998; Wassmann et al., 2004; Hoa et al., 2007, 2008; Khang et al., 2008).

2.2.1. The model setup

The river flow and salinity intrusion in the two branches of Mekong river were simulated by using the MIKE 11 model, which was developed by the Danish Hydraulic Institute (DHI, 2003). Two modules of MIKE 11 were applied: a) the hydrodynamic module for flow simulation, and b) the advection-dispersion module for salt expansion. The model used data on water level, rainfall, and salinity from 24 hydro-meteorological stations (i.e. Kratie, PhnomPenh, Tonle Sap, Tan Chau, Chau Doc, Long Xuyen, Ha Tien, Rach Gia, Ca Mau, Ganh Hao, Bac Lieu, Soc Trang, Can Tho, Tra Vinh, My Tho, Vinh Long, Cao Lanh, Sa Dec, My Thuan, Ben Tre, Tan An, Moc Hoa and Tan Son Nhat) and considered boundaries for 68 downstream-end data of tidal water level and salinity, and seven upstream discharge boundaries with updated data of water discharge.

The input data for the model comprised the boundaries, as well as, databases on hydrological and meteorological conditions. The hydraulic data included the hydrology of the Mekong river downstream from the Kratie boundary, including the land levels above sea and the hydraulic elements of rivers and canals system in 2005. The model also included irrigation and water control sluice systems.

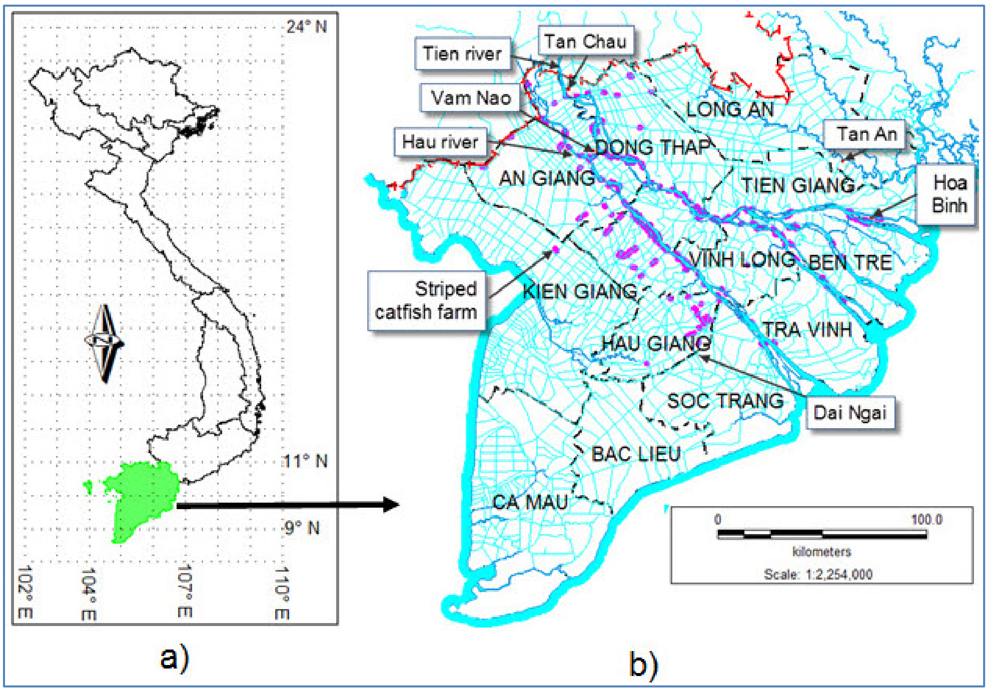


Fig. 2.1 a) Mekong delta part of Vietnam b) Administrative map of the Mekong delta with the rivers and canals system, locations of the striped catfish farms in 2009 and stations for model calibration

2.2.2. Model calibration

To calibrate the two modules of the original MIKE 11 model, we compared the projected change and the actual water level and salinity intrusion for the year 2005 (see 2.3). The data on tidal boundaries for calibration were provided by the Southern Center for Hydro-meteorological Forecasting. The flood data at the Kratie main discharge station were obtained from the Mekong River Commission. The data on water levels, water discharge, and salinity of 2005 were obtained from the Hydro-meteorological Survey Mission for the Mekong delta. Subsequently, the best fit values between simulated and observed parameters were used for scenario predictions.

The calibration process of the hydrodynamic module was performed by adjusting model parameters such as the initial water level in rivers and canals together with Manning coefficients of canal and river segments (Wassmann et al., 2004; Khang et al., 2008). Fig. 2.2 shows the comparison between the computed and observed water level and water discharge at Tan Chau and Vam Nao (in upstream part of the delta) and Tan An (in the coastal part) (c.f. Fig. 2.1). The model accurately simulated the observed data both for water level and water discharge.

The calibration process for the advection-dispersion module was carried out by adjusting the initial salinity concentration and dispersion coefficient for several segments of rivers and canals. This process was more complicated compared to the calibration of the hydrodynamic module, because the saline water spreads under influence of the density of the water network with its dams and sluices, and of the dispersion coefficient which depends on flow velocity and also on wind conditions (Khang et al., 2008). Table 2.1 and Fig. 2.3 illustrate the results of model calibration for salinity intrusion compared with observed data at some stations in the coastal part of the Mekong delta. The result predicts the trend of salinity variation with an acceptable accuracy. Thus the parameters computed after the calibration could be used for the scenarios modeling.

2.2.3. Comparison of maps

Water level and salinity intrusion were projected based on separated baseline maps. We chose the data of serious events of flood and drought in recent year as baseline data according to the highlights of the Mekong River Commission (MRC, 2012) in order to map the maximum potential impact of sea level rise scenarios. Thus, water level was projected based on the water level map of the year 2000, as this was characterized by extreme flooding, both in duration and depth, across the Cambodian lowlands and the Mekong Delta (MRC, 2012). The salinity intrusion was projected based on the salinity map of 2005 when the drought was severe in all four riparian countries, especially in the Mekong Delta, where low stream flows allowed ocean salinity to penetrate further upstream then normal (MRC, 2012). The salinity levels were mapped by using four categories: < slightly saline 4 $^0/_{00}$, slightly to moderately saline 4-10 $^0/_{00}$, moderately to highly saline 10-20 $^0/_{00}$ and highly saline >20 $^0/_{00}$.

The maps of water level and salinity intrusion resulting from the different sea level rise (SLR) scenarios (SLR +30 cm, SLR +50 cm and SLR +75 cm) were compared with those of the baseline map to estimate the impacted area. The current striped catfish farming map was overlaid by the contour line of increased water level and salinity by the GIS software MAPinfo® to determine the striped catfish farming locations at risk in the future.

Table 2.1 Comparison between observed and simulated salinity concentration values at Tra Vinh, Song Doc, My Tho and Tan An station in the coastal part of Mekong delta in 2005.

	Max. of salinity concentration (0/00)			Average of salinity concentration (0/00)		
Station	Simulated	Observed	Diff.	Simulated	Observed	Diff.
Tra Vinh						
10/2 - 13/2/2005	5.8	6.2	0.4	3.5	3.7	0.2
18/2 - 21/2/2005	9.5	8.3	-1.2	5.5	6.2	0.7
26/2 - 01/3/2005	7	6.8	-0.2	3.9	5	1.1
11/3 - 14/3/2005	10	9	-1	5.75	6.5	0.75
29/3 - 01/4/2005	9	10	1	8	7.75	0.25
Song Doc						
10/2 - 13/2/2005	11	10	-1	6	8	2
23/2 - 26/2/2005	11	10	-1	7.5	8.5	1
11/3 - 14/3/2005	13	16	3	12	12	0
29/3 - 01/4/2005	14	16	2	13.5	13	-0.5
My Tho						
10/2 - 13/2/2005	1.2	0.7	-0.5	0.35	0.6	0.25
26/2 - 01/3/2005	1.1	1.1	0	0.6	0.75	0.15
03/3 - 08/3/2005	2.6	2.2	-0.4	1.2	1.6	0.4
17/3 - 21/3/2005	3.5	3.1	-0.4	1.95	2.2	0.25
Tan An						
10/2 - 13/2/2005	5	4.5	-0.5	3	3.25	0.25
26/2 - 01/3/2005	6.5	6.5	0	4.8	5	0.2
11/3 - 14/3/2005	6.8	6.5	-0.3	5.25	5	0.25
19/3 - 21/3/2005	9	8	-1	6	6.5	0.5

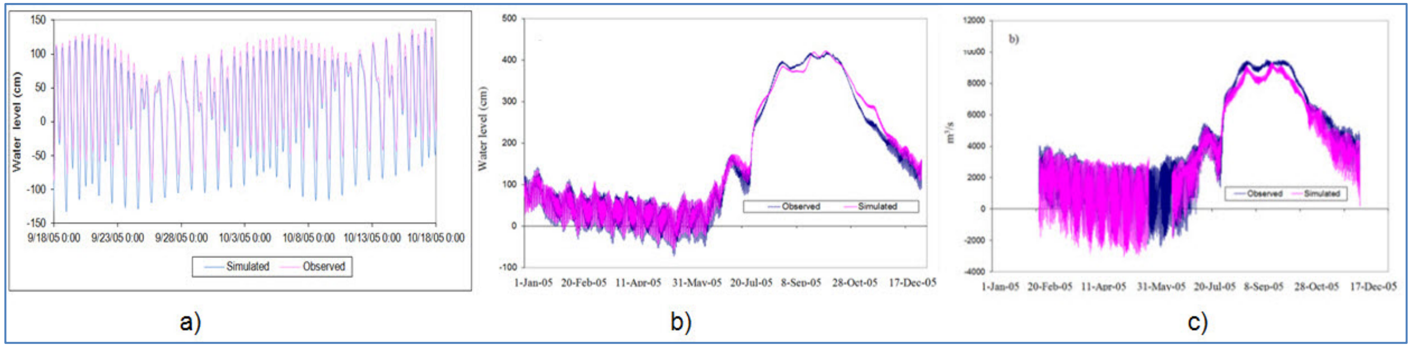
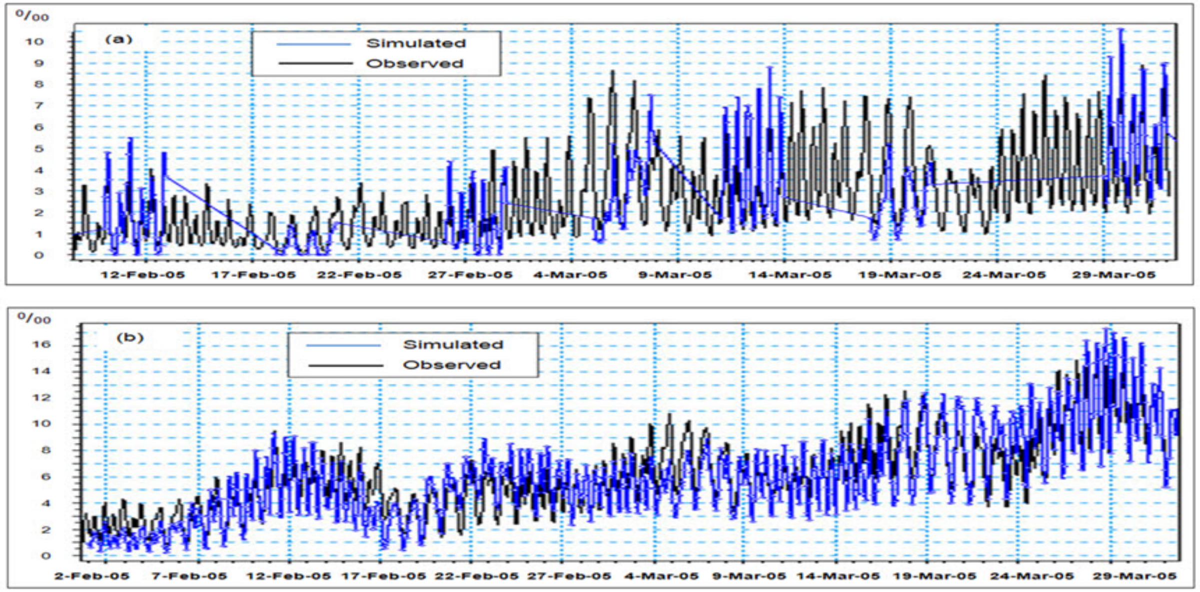


Fig. 2.2 Comparison of observed and simulated value of: a) hourly water level at Tan An station from September to October; b) daily water level at Tan Chau station; and c) daily water discharge at Vam Nao station in 2005.

Fig. 2.3 Comparison of observed and simulated value of salinity concentration at a) Dai Ngai, and b) Hoa Binh stations (c.f. Fig. 1.1) in February and March, 2005.



2.3. Results

2.3.1 Saltwater intrusion according to the SLR scenarios

The area affected by intrusion of low level salinity (i.e. <4 ‰) is currently 4780 km^2 and expands to 1660, 2670 and 3310 km^2 for SLR +30cm, SLR +50cm and SLR +75cm respectively (Fig. 2.4). The saltwater intrudes into the non-coastal provinces starting with the SLR +30cm scenario. However, the expansion of the area affected by salinity levels above 4‰ is smaller: 345 km^2 for the scenario SLR +30; 425 km^2 for SLR +50cm, and 920 km^2 for SLR +75cm (Table 2.2). Thus the 4‰ level expands less while sea level rises from SLR +30cm to SLR +50cm.

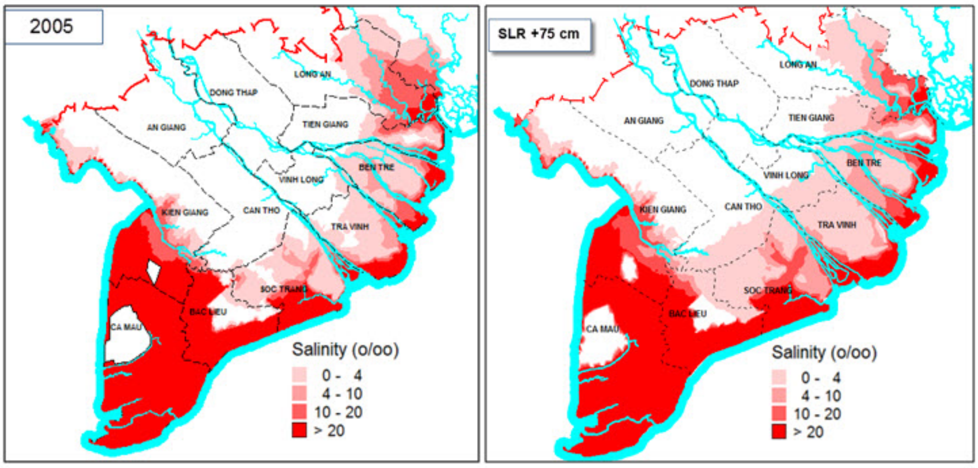


Fig. 2.4 The areas affected by salinity intrusion according in ‰ concentrations for the 2005 baseline and the SLR +75cm scenarios

In some upstream areas, at a specific SLR the fresh water from the river pushed by sea water, is transferred to low-lying areas located inland such as Quan Lo-Phung Hiep. In such areas the salinity levels will be decreasing instead of increasing (Table 2, 10-20‰ and >20‰).

Due to seasonal variation in river discharge, the effect on salinity levels is lower during the SW monsoon, which is the flood season, running from May to

October. Salinity levels rise from January to April (Fig. 2.5). At present, the saline front of 4 ‰ shifts inward 29 km and 32 km in Hau river by end of March and April, respectively. For the SLR +50 cm scenario, the saline front of 4 ‰ in Hau river will reach 10 km inland from the sea in January then extend up to 24 km in February, 35 km in March, and 38 km in April. For the SLR +30cm scenario, the central part of Soc Trang and the coast lines of Ben Tre will be affected by the intrusion of salinity concentration of 4 ‰.

Table 2.2 The total area (km²) of the Mekong Delta affected by the salinity intrusion for the baseline and three SLR scenarios

	2005	**Sea level rise scenarios**					
Salinity (‰)	0 cm	+ 30 cm	%	+ 50 cm	%	+ 75 cm	%
< 4	4 780	6 430	+ 35	7 450	+ 56	8 090	+69
4 – 10	2 360	2 515	+ 7	2 745	+ 16	3 240	+ 37
10 – 20	2 280	2 610	+ 14	2 530	+ 11	2 570	+ 13
> 20	9 380	9 240	- 1	9 170	- 2	9 130	- 3
Total area >4	14 420	14 365	+ 2	14 445	+ 3	14 940	+ 7

2.3.2 Water level according to the SLR scenarios

The water level in the Mekong delta will be affected by changes in tides and floods as a consequence of climate change. The simulated peak water levels at various station will increase when sea level rises (Table 2.3).

Table 2.3 The peak water levels at 4 stations in 2000 and according to the SLR scenarios

Stations	Baseline	Sea level rise scenarios		
	Year 2000	+30cm	+50cm	+75cm
Tan Chau	5.10	5.16	5.24	5.33
Vam Nao	3.87	3.96	4.01	4.10
Dai Ngai	1.78	2.07	2.26	2.50
Tan An	1.60	1.89	2.09	2.32

In the coastal provinces, floods are projected to arrive earlier and persist longer than at present. This early high flood may reduce the window for risk-free farming of striped catfish in Soc Trang, Tra Vinh, Ben Tre and coastal districts of Tien Giang. Inundation areas will also increase in the SLR +30cm and SLR +75cm scenarios (Fig. 2.6). As SLR increases from +50cm to +75cm, the higher flood level will cause flooding in a much larger area of the Mekong Delta for the upstream provinces of An Giang, Dong Thap and Can Tho.

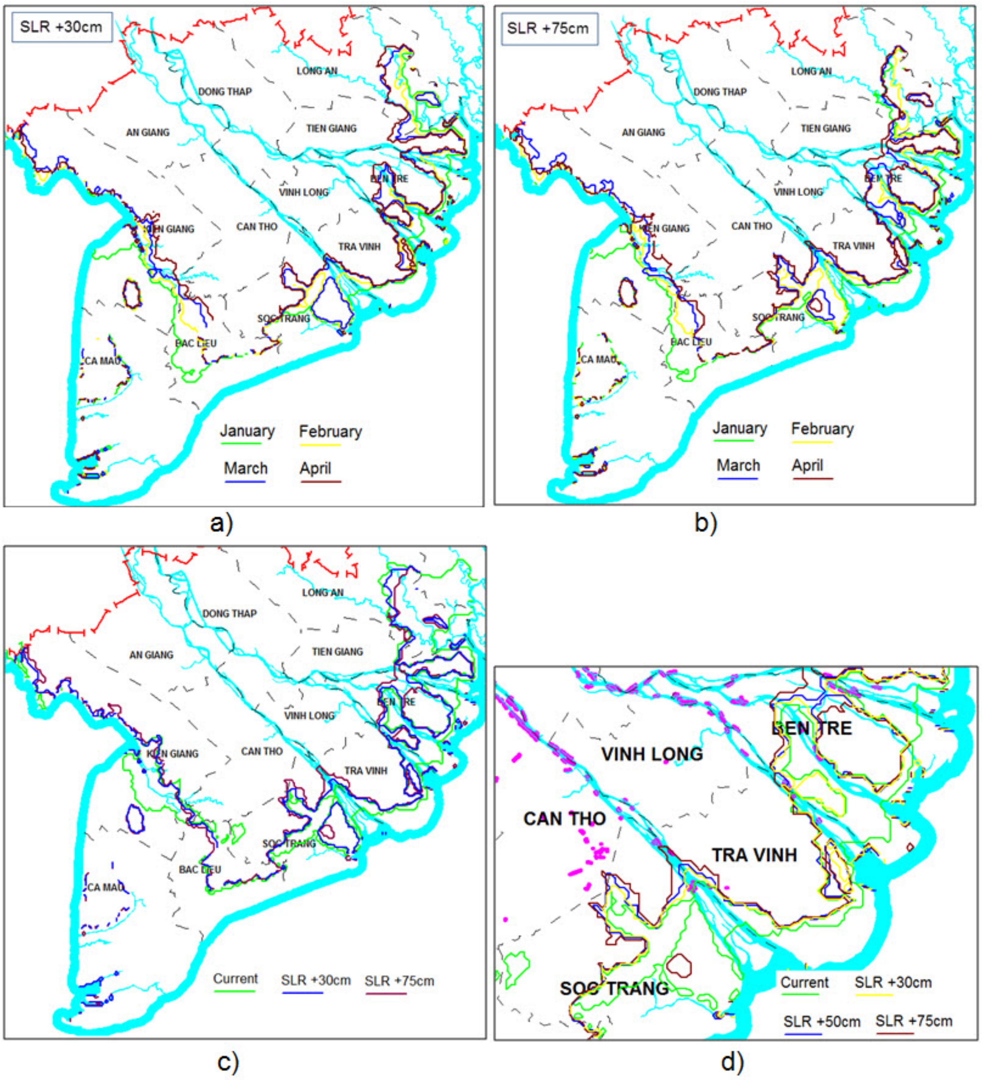


Fig. 2.5 Coastal areas affected by salinity intrusion (4 ‰) from January to April for a) SLR+30 scenario, b) SLR+75 scenario; and in April for c) two scenarios and the baseline, and d) affect the striped catfish farm locations in Ben Tre, Tra Vinh and Soc Trang provinces

2.3.3. Area of striped catfish farming at risk

When the salinity map is overlaid on the map of striped catfish farm locations of 2009 for Ben Tre, Tra Vinh and Soc Trang provinces, it is shown that the effect on the farms is local (Fig. 2.5). In Tra Vinh, the location in the southwestern area is projected to suffer while the conditions for farms in the northeast will not change significantly. In Ben Tre, most farms deal already with 4‰ salinity levels but periods subjected to this salinity may become longer and farms located further upstream (i.e. to the west) may also have to deal with it. In Soc Trang, all farms already have to deal with these prolonged periods.Overlay of the contour map of water level on the map of 2009 striped catfish farm locations shows that all striped catfish farms have to deal with a 2m-flood level for the SLR +50cm scenario (Fig. 2.6). Added to these already affected farms at present are those located downstream in the province Can Tho, Tien Giang and Vinh Long, and all farms in Ben Tre, Soc Trang and Tra Vinh. The number of extra farms to be affected in SLR +75cm, however, is not large.

2.4. Discussion

One of the limitations of our study is the use of current topographical data for projecting the salinity intrusion due to sea level rise scenarios. Nguyen and Savenije (2006) pointed that the high sediment transport capacity of the Mekong river and the lack of updated topographical data will affect the results of our salinity models. In addition, topographical changes are very difficult to predict given that future infrastructure changes are likely to influence water discharge and drainage. Hoa et al. (2007) predicted that *"The future flood control works planned to be completed by 2010 will cause an increase in runoff peaks and prolong the duration of the flood recession."*

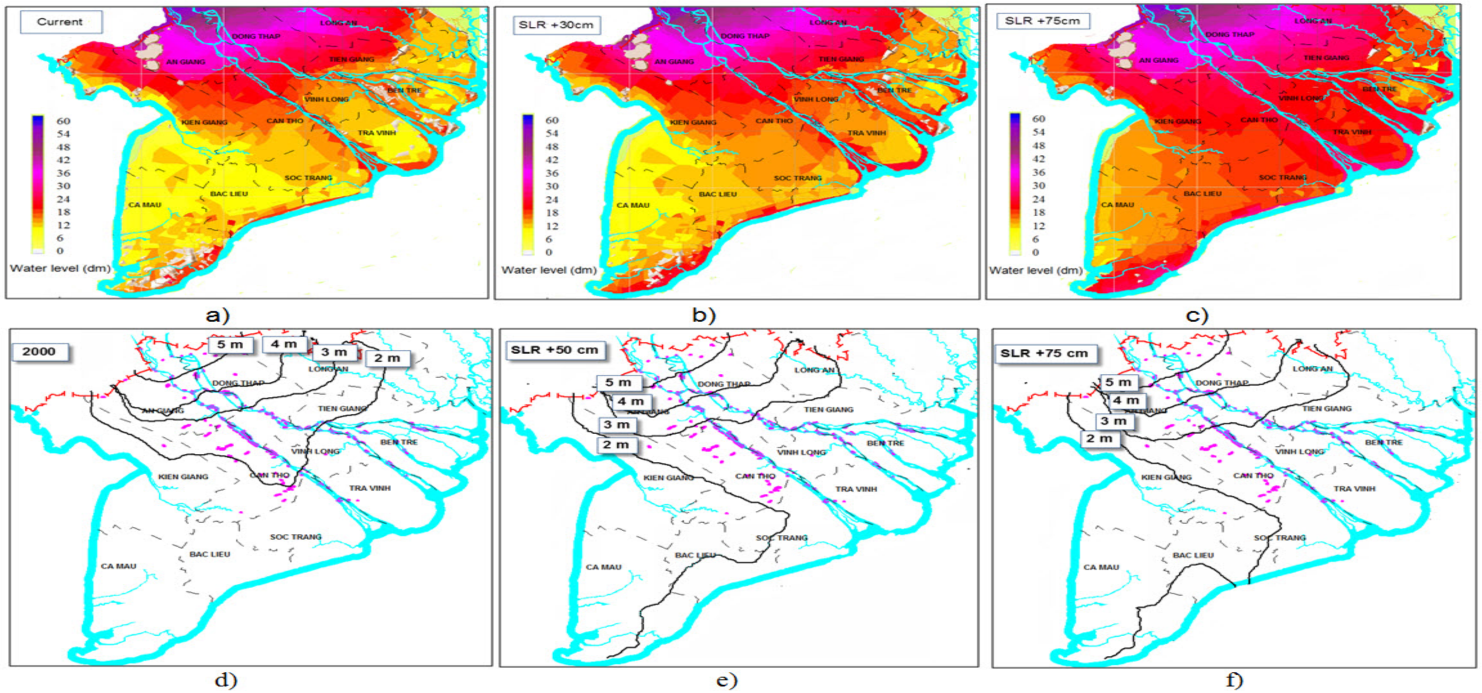


Fig. 2.6 The maximal water levels in October for a) the baseline, b) SLR+30 scenario and c) SLR+75 scenario of sea level rise; and the map of the Mekong delta' striped catfish farm locations and the risk of water level in October for d) the year 2000, e) SLR+50cm scenario and f) SLR+75cm scenario.

The main stream of the lower Mekong River (running through Cambodia, Lao PDR, Thailand and Vietnam) has currently no dams. Plans to do so in the future have provoked controversy and public debate (see Kummu and Sarkkula 2008; Dugan et al. 2010; Keskinen et al. 2012, among others). Li and He (2008) stated that "*the downstream effects of the present dams on water levels are very limited at the annual mean and wet season mean levels*". Delgado (2010) and MRC (2012) concluded that dam construction had little impact on downstream flood levels in the last two decades of 20th century. Wassmann et al. (2004) pointed out that the effect of hydro-dams or reservoirs was insignificant due to the regulation of the Tonle Sap lake in Cambodia and the strong tidal effect from the seas. However, the construction of additional dams will likely affect the water level and the drainage behavior of Tonle Sap, and will increase the possibility of dam ruptures causing floods (MRC 2012). Thus, the hydrological regime of the lower reaches of the Mekong river will rely on the regulatory capacity of Tonle Sap.

De Silva and Soto (2009) predicted that aquaculture activities occurring in deltaic areas of major rivers in Asia, South America and the Caribbean will encounter saline water intrusion caused by climate change. In the Mekong Delta, striped catfish farms of coastal provinces (Tien Giang, Ben Tre, Tra Vinh and Soc Trang) cover approximate 864 ha with a production of 190 000 tonnes, which accounts for 26% of the total catfish farming area in the Delta and contributed 20% to the striped catfish production in 2013 (Directorate of Fisheries 2013). These farms experience currently minor salinity variations depending on tidal amplitude (De Silva and Phuong 2011). Farmers do not stock fingerlings in months with high salinity, and thus their window for farming is reduced. Pham et al. (2009) demonstrated that the annual yield from catfish farms located in the lower reaches of the Mekong River branches is significantly lower, and suggested that the lowered yields could be a result of the diurnal fluctuations in the salinity. Yet, already in 2011 the increased salt water intrusion in Ben Tre province, resulting in salinities up to 15‰, have resulted in increased mortality and in reduced growth rates, compared to those in 2010 (Ben Tre DARD, 2012). For the worst case SLR +75cm scenario, this area will expand further and affect also Soc Trang province and Tien Giang province's coastal districts.

The above analysis shows that the risk from saltwater intrusion reduces the suitable area for catfish farming in the coastal provinces of the Mekong delta, from January to April. Therefore, to produce two crops in a year, farmers must either invest in water recirculation technologies to raise fingerling and reduce grow-out in ponds to three months, or raise other species. A shift to farming other species will need capacity building among rural farming communities, and even changes in infrastructure, in particular that of ponds. In catfish farming a water depth of 4.0 to 4.5 m is preferred, but such deep ponds are unsuitable for other commonly farmed, salinity tolerant species such as Asian seabass or even shrimp. Altering the pond structure is likely to be very costly.

De Silva and Soto (2009) suggested that an alternative solution to the problem may lie in the development of a salinity tolerant strain of striped catfish. This strategy was further elaborated by De Silva and Phuong (2011) suggesting that the use of genomic selection technology would help to speed up the process by improving accuracies of selection (Meuwissen et al. 2001). This technology, widely applied in livestock and crop selection (Goddard and Hayes 2009), was recently attempted in aquatic species, such as for salmon. Furthermore, De Silva and Phuong (2011) pointed out the advantages of such a strategy being that it will bring about minimal changes to farming practices and related infrastructure, and will avoid the need to develop fresh market chains. Whether or not it will be cost effective in the long term has to be studied.

Many experimental studies on the salinity tolerance of a number of freshwater fish species have been conducted and comprehensive reviewing this vast literature is challenging because approaches strongly differ. Among catfish species such studies were conducted by Bringolf et al. (2005), for example showed that juvenile flathead catfish (*Pylodictis olivaris*), which could tolerate exposure to brackish water. Its dispersal may not be limited by estuarine salinities. Capps et al. (2011) studied the salinity tolerance of suckermouth armoured catfish (*Pterygoplichthys Siluriformes Loricariidae*) a strictly freshwater fish, of south-eastern Mexico. Their individuals normally maintained in a salinity of $0.2^{o}/_{oo}$ were able to survive salinities up to $10^{o}/_{oo}$ with little mortality over 10 days. However, few individuals survived salinities up to 11 or $12^{o}/_{oo}$ for 20 hours but none survived after few hours in a salinities of $16^{o}/_{oo}$ and higher.

With respect to striped catfish, several studies have been carried out to test the impact of salinity. Nguyen et al. (2011) studied the effect of salinities of 0, 3, 6, 9, 12 and $15^{o}/_{oo}$ on the physiological changes and growth in fish of an average weight of 25 g. The results indicated that culture of striped catfish in salinity of $9^{o}/_{oo}$ is possible but the growth was significantly reduced. Do et al. (2012) studied the salinity tolerance of egg and larvae of striped catfish. After being artificially fertilized, the eggs were incubated in salinities of 0, 1, 3, 5, 7, 9, 11, 13, 15, 17, and $19^{o}/_{oo}$. The results showed that the embryos of striped catfish can develop and hatch in brackish water up to $11^{o}/_{oo}$. These above results can be seen as an initial success encouraging further studies on mitigating measures to adapt to the impact of salinity intrusion caused by climate change, and also indirectly indicate the potential of developing a salinity resistant strain of catfish without sacrificing its growth and overall yield.

In the rainy season, the increased water levels from August to October may affect the farm infrastructures. In all scenarios the coastal provinces will have to deal with higher water levels. In the SLR +50cm scenarios, the water level of 3 m will spread downstream and not only threaten the striped catfish farms located in An Giang and Dong Thap provinces, but also the farms in Can Tho province. Wassmann et al. (2004) predicted that floods will arrive earlier and persist longer than at present and that the inundation area will also increase. To deal with the rising water level, farmers will need to invest more in the pond (or farm protection) dyke to increase its height and to maintain its protected function, and in increased operational cost of water exchange.

2.5. Conclusion

This study predicted potential impacts of climate change to striped catfish farming, which is the most important aquaculture sector in the Mekong Delta, Vietnam, using scenarios with a sea level rise of respectively +30cm, +50cm and +75cm.

Salinity levels increase from January to April in all scenarios but the affected areas extend most in the +50cm and +75cm scenarios. The low level of salinity (<4‰) expands faster than levels above 4‰, which are harmful for grow-out of striped catfish. The number of affected farms in the coastal provinces of Soc Trang, Ben Tre and Tra Vinh increase not only because of increased salinity intrusion, but also because the period with higher salinity levels will last longer.

Sea level rise will also impede the rivers to discharge their water to the sea. This will lead to longer flood periods and larger inundation areas. The catfish farmers have to increase the height of their pond dykes and invest more in water exchange.

Investment in new striped catfish farms in the coastal provinces of the Mekong delta is not advisable because of these apparent threats. However our analysis does not specify when the impacts are likely to occur. A more sustainable approach that would minimise dislocation of farmers and ensure the continued usage of the existing facilities might be to breed a strain of catfish that is salinity tolerant, up to about 17-20‰. Such an approach will minimise the changes needed in the value chain of this major food production sector, as compared to investing in water recirculation technologies or shifting to euryhaline species.

Acknowledgements

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Chapter 3

Exploring the climate change concerns of striped catfish producers in the Mekong Delta, Vietnam

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Abstract

This study investigated the perceptions on and adaptations to climate change impacts of 235 pangasius farmers in the Mekong Delta, Vietnam. Data were collected using semi-structured household surveys in six provinces, from three regions along the Mekong river branches. A Chi-Square test was used to determine the correlation or association between variables and a logit regression model was employed to examine factors, which influence farmer's perception and adaptation. Less than half of respondents were concerned about climate change and sought suitable adaptation measures to alleviate its impacts. Improving information on climate change and introducing early warning systems can improve the adaptive capacity of pangasius farmers, in particular for those farmers, who are not concerned yet. Farmers rely strongly on technical support from government agencies, but farmers in the coastal provinces do not express the need for training by these institutions. This apparently contrasting result urges to further assess the effectiveness of adaptation measures, such as breeding salinity tolerant pangasius.

Keywords: Mekong Delta, pangasius farmer, climate change, perception, adaptation.

3.1. Introduction

The pangasius (*Pangasianodon hypophthalmus* Sauvage, Striped catfish in English or tra in Vietnamese) farming sector, which originated in the Mekong Delta, is among the fastest growing aquaculture sectors during the past two decades in the world. Its development together with associated controversies, such as criticism on environmental, social and safety credentials, have been well documented (e.g. Bosma et al., 2009; Phan et al., 2009; Bui et al., 2010; De Silva et al., 2010; Nguyen, 2010; De Silva and Phuong, 2011; Little et al., 2012). In 2012, the sector produced 1.2 million tons of fish in a pond area of 5.600 ha and exported the processed pangasius, mainly in the form of fillet, to over 142 countries with a value of 1.7 billion US$ (VASEP, 2013).

The industry started with cage culture of catfish (De Silva and Phuong, 2011) in the upstream part of the main branches of the Mekong river that runs through the provinces An Giang, Dong Thap and Can Tho. However, land-based pond culture of pangasius took a hold gradually, particularly after the successes in artificial propagation that ensured seed stock supplies (Nguyen, 2009; De Silva and Phuong, 2011; Bui et al., 2013). Thereafter the industry expanded downstream to the Vinh Long, Tra Vinh, Soc Trang and Ben Tre provinces. At present the farming system entails independent small-scale farmers and holdings, both delivering their fish to processing companies, as well as fully integrated companies with own feed-mills, ponds and processing facilities.

The Mekong Delta (8°33'- 10°55'N; 104°30'-106°50'E) is ranked among the deltas that will be most affected by climate change (Dasgupta et al., 2007; Syvitski et al., 2009). Due to sea level rise, experts have projected negative impacts of increasing water level and salinity intrusion on dams and infrastructure (Hoa et al., 2007; 2008), rice production (Wassmann et al., 2004; Khang et al., 2008), or the location of pangasius farms (Anh et al., 2014) in Vietnam.

Adaptation is widely recognized as a vital component of any policy response to climate change (Gbetibouo, 2009**)**. Smith et al. (2001) defined adaptation as any adjustment in natural or human systems that takes place in response to actual or expected impacts of climate change, and which are intended either to moderate harm, or to exploit beneficial opportunities. Using descriptive statistics, Mertz et al. (2009) and Tambo and Abdoulaye (2013) analysed the perceptions of climate change and adaptation of farmers in the savanna zone of Senegal and Nigeria, respectively. Other studies (e.g. Deressa et al., 2008; Apata et al., 2009; Gbetibouo, 2009; Fatuase and Ajibefun, 2013) employed logit regression models to investigate the factors influencing farmer's perception and adaptation. The above studies concluded most farmers had noticed changes in climate and adjusted farm practices but lacked precise information on climate change and suitable adaptation measures. Also access to credit limited their adaptation possibilities (Gbetibouo, 2009; Fatuase and Ajibefun, 2013).

In the Mekong Delta, climate change will increase salinity levels and extend its effects in the four coastal and two central provinces and will increase the risk of flooding in the upstream and central provinces (Anh et al., 2014). Consequently, livelihoods of pangasius farmers operating in the lower reaches of the two main branches of the river may be threatened. Kam et al. (2012) show that catfish farmers' operations are vulnerable to climate change. The projected benefits of the inland pangasius farms remain positive when climate change is ignored but disappear when climate change is considered. The farmer's autonomous adaptation measures are too costly (Kam et al., 2012). Coastal pangasius farms will even be more affected by climate change. Their projected benefits will half under climate change. The pangasius farmers' skills and responsiveness can positively influence these benefits but this strongly depends on their awareness of climate change and the possible adaptation choices. The farmers' awareness and choices are, however, poorly known. As such knowledge is crucial for the effective adoption of adaptation strategies, this study investigates the pangasius farmers' perception of climate change and its impacts, the adaptations measures adopted by them, and the relation between impacts and measures with farm characteristics.

3.2. Materials and Methods

Relating to pangasius farmers this study aims to answer the following research question : Are they aware of Climate Change. Did they perceive Climate Change impact? Did they adapt or do they plan to adapt to Climate Change. Which are their implemented or preferred adaptation measures, and would they need information or support to implement these measures?

3.2.1. Data collection

To answer these questions we collected data on variables relating to farm and farmer characteristics, and on the farmer's actions, perceptions and suggestions regarding climate change. A draft questionnaire covering general information on the farmer's household, costs of different inputs, production and income, as well as the farmer's perceptions and strategies to climate change induced changes, was developed by experienced socio-economists and climate-change scientists of the Aquaclimate project (Nagothu et al. 2009). The draft questionnaire was tested modified and finalized for conducting the detailed survey. The survey was conducted through face to face interviews of farmers by trained personnel with past experience on conducting such surveys. Each interview was conducted by two interviewers.

We used proportional random sampling to select farms to interview in each province. The number of farms to survey per province was determined by the overall farm frequency distribution. The respondents were either the farm owners or the farm managers in case of the farm being part of a larger company. Data from five provinces (Dong Thap, Can Tho, Vinh Long, Soc Trang and Tra Vinh) were collected in the framework of the Aquaclimate project in 2009. In 2012, data for An Giang was supplemented to cover the six provinces. We did not include Ben Tre province because most ponds recently became owned by two companies only, and present farm managers had little historical perspective on the impacts of climate related events.

Among others the farmers were asked whether they observed any phenomenon of climate change in the last ten years and whether they were concerned about its impact. The adaptation and mitigation options suggested to the respondents: change farming practice, change target species, or abandon aquaculture, were based upon the answers given during the testing of the questionaires. The survey data were entered into a database developed for the purpose in MS Excel. Data from 235 farms were available consisting of 45, 53, 25, 82, 15, and 15 farms from An Giang, Dong Thap, Vinh Long, Can Tho, Soc Trang and Tra Vinh provinces, respectively.

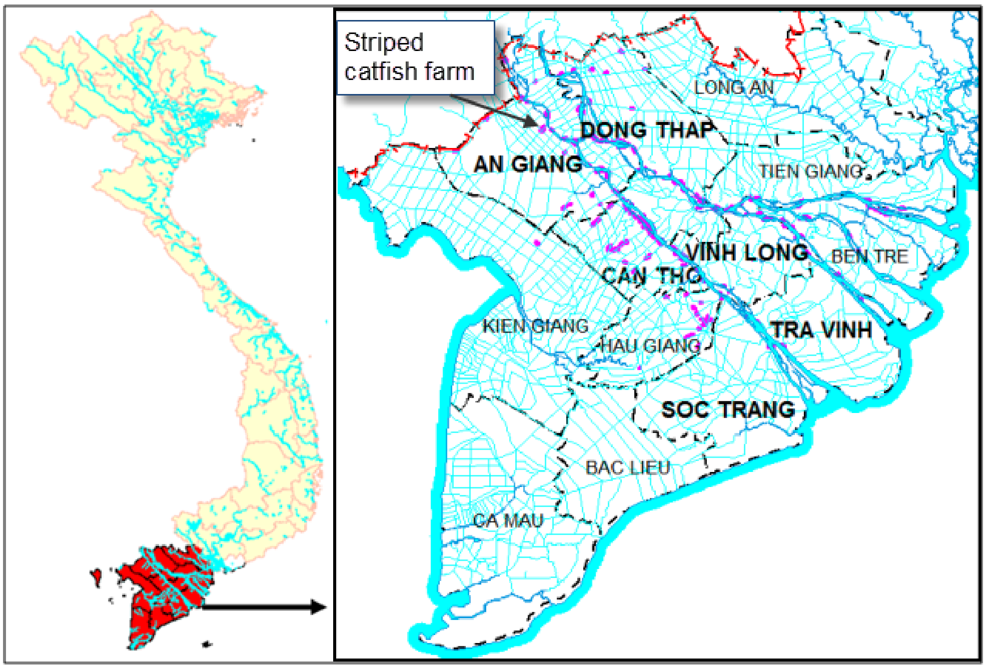

Fig 3.1 Administrative map of the Mekong delta with the locations of the striped catfish farms in 2009 (adapted from Anh et al. 2014).

3.2.2. Data analysis model

The resulting survey variables were ordinal or categorical. To understand the association between these, different statistical methods were used. The Chi-Square test was used to determine the extent of correlation or association between the variables. To examine the factors which influence the farmer perceptions of and adaptations to climate change, a logit regression model was employed (Deressa et al., 2008; Apata et al., 2009; Gbetibouo, 2009; and Fatuase and Ajibefun, 2013). All the statistical analyses were done using R software package.

The standard form of the logit regression model is:

$$ln\left(\frac{p}{1-p}\right) = \beta_0 + \sum_{i=1}^{n} \beta_i X_i + \varepsilon \qquad \text{(Eq. 1)}$$

Where p is the probability that the dependent variable value is 1 and *(1-p)* is probability that dependent variable value is 0; β_i is the parameter estimate for the independent variable X_i , and I is the variable number; and ε is the error term.

Marginal effects of the explanatory variables from equation (1) are estimated as equation (2):

$$\frac{\partial P_j}{\partial x_k} = P_j \ (\beta_{jk} - \sum_{j=1}^{n} P_j \beta_{jk}) \qquad \text{(Eq. 2)}$$

Where j stand for the farmers choice, and k for his perception or adaptation depending on the dataset used.

The marginal effects, according to Green (2000), are functions of the probability itself and measure the expected change in probability of a particular choice being made with respect to a unit change in an independent variable from the mean.

3.3. Results

3.3.1. Surveyed farmers' characteristics

The average age of the interviewed farmers was 45 (Table 3.1). The older farmers lived in the downstream region. Their aquaculture experience ranged from 1 to 20 years with an average of 5.5 years. The average aquaculture experience decreased from 5.7 years to 4.3 years from upstream to downstream. This is likely related to the history of development of pangasius farming along the Mekong branches.

The education level of respondent farmers varied from primary school (level 1) to bachelor degree (level 4) with an average higher than level 2 (secondary school). Among them, 15% finished primary school, 39% had a secondary school certificate, 37% graduated from high school and 8% got a bachelor degree. The education level was highest in the upstream and lowest in the downstream regions.

The total ponds area per farm in the survey ranged from 0.08 ha to 3.8 ha with an average of 0.8 ha. The average total pond area in the downstream region was only half of that in up and mid-stream. In the up- and downstream region, 80% of the interviewed farmers were land owners whereas only 60% of the farmers in the mid-stream region owned land.

The pangasius revenues contributed 87% to the income of the farm-households upstream, 85% in mid-stream, and only 58% in the downstream region. The downstream farms acquired 1% of their income from rice cropping, 3% from services, 11% from other activities, and 27% from orchards.

Table 3.1 The mean values and standard deviations (±SD) of the main characteristics of the surveyed pangasius farmers for the aggregated six provinces and for the three regions.

	All provinces		**Upstream provinces** An Giang, Dong Thap		**Mid-stream provinces** Vinh Long, Can Tho		**Downstream provinces** Soc Trang, Tra Vinh	
Number of farms	235		98		107		30	
Characteristics	Mean	±SD	Mean	±SD	Mean	±SD	Mean	±SD
Age (year)	44.5	10.4	44.1	9.3	44.1	11.1	47.4	10.6
Total ponds area (ha)	0.8	0.6	0.8	0.6	0.8	0.7	0.4	0.4
Education level of respondents*	2.4	0.8	2.6	0.7	2.4	0.8	1.8	0.9
Land ownership **	0.7	0.5	0.8	0.4	0.6	0.5	0.8	0.4
Culture experience (year)	5.5	3.1	5.7	3.3	5.7	3.2	4.3	1.6
Contribution of pangasius farming to income (%)	82.2	24.2	87.1	17.8	84.5	23.8	58	29.8

* 1 = primary school; 2 = secondary school; 3 = secondary school; 4 = bachelor degree.
** 1: owner and 0: otherwise

3.3.2. Farmer's perceptions on climate change

Table 3.2 presents the awareness of interviewed farmers about climate change. Four categories of climate change impact were proposed to the farmers: stronger flood in rainy season, serious drought in dry season, fluctuated temperature, or expanded salinity intrusion. Less than half of the respondents (43%) had observed the climate change occurence and slightly more (45%) were concerned about is impact. However, none of the downstream farmers had observed or was concerned about climate change, while around 70% of the upstream and 30% of the midsteam farmers had observed and were concerned. The more frequent farmers had experienced extreme weather events the higher their concern. Surprisingly, no pangasius farmers in the coastal provinces appeared to have observed, nor were concerned abourt climate change. The number of upstream farmers observing and concerned about climate change was highest at 68% and 74.5%, respectively, and these numbers were average for mid-stream farmers: 31% for both responses.

More than half of the respondents in upstream area (55%) thought climate change will lead to stronger flooding in the rainy season, whereas only about one-third of the respondents in mid-stream and 20% downstream thought likewise. Inversely, about 80% of the respondents in the mid-stream and down-stream regions expected impact of climate change in the dry season. Less than half of the upstream farmers feared impacts in the dry season.

A change of temperature caused by climate change was expected by respondents in the whole delta, but most in the mid-stream region (75%) and lowest upstream (46%). Almost all downstream respondents (93%) feared an increase of salinity intrusion due to climate change, whereas upstream only 11% and in the mid-stream region none shared this opinion.

The chi-square test confirmed the relation between the farmer perceptions and the region where the farm is located ($p<0.001$). However, the education level did not significantly affect their awareness on climate change ($p>0.05$).

Table 3.2 The perception on Climate Change (CC) and on Climate Change Impacts (CCI) of the interviewed pangasius farmers (% agreed), according to regions

Regions	n	Observed climate change	Concern about CC	CCI in rainy season	CCI in dry season	CCI on temperature	CCI on salinity intrusion
All 6 provinces	235	42.5	45.0	40.5	66.0	60.5	16.5
Upstream	98	68	75	55	45	46	11
Mid-stream	107	31	31	33	81	75	0
Downstream	30	0	0	20	80	57	93

3.3.3. Farmer's preferences for adaptation

Only 47% of the respondents considered to adapt to climate change impact by using one of the proposed adaptation measures whereas the remainders did not know. Among the respondents intending to adapt, close to 40% preferred to change farming practice, while 5 % would change the cultured fish species and another 5% would abandon aquaculture (Table 3.3). Nearly 55% of respondents upstream thought to change farming practice, while about 30% in the mid- and down-stream regions would do so. Part of the farms in the upstream region were located within areas with large flood protection dikes. A farmer in the Chau Thanh district of the An Giang province stated: "I don't need to increase my pond-dyke because the government's dyke is high enough". Change of farming practice included, for example, increase the height of dykes, improve water quality and decrease the stocking density. All these measures are costly. The number of farmers expecting to change the target species was slightly higher up-stream than mid-stream, while down-stream none expected to shift target species. The latter contrasts with the option to abandon aquaculture: 17% of the farmers downstream would prefer and select this option.

The region variables were highly associated with the adaptation options 'change farming practice' and 'change species' ($p<0.001$), and 'abandon fish farming' ($p<0.05$). The education level was associated with the expectation to adapt through abandoning aquaculture ($p<0.05$).

Table 3.3 The farmer's preference among three adaptation options (%).

	Change farming practice	Change species	Abandon aquaculture
All six provinces	39.5	5.0	5.5
Upstream provinces	55	8	5
Mid-stream provinces	28	3	3
Downstream provinces	30	0	17

3.3.4. Farmer suggestions

More than half of the interviewed farmers desired assistance to adapt efficiently to climate change impacts. They preferred to receive information on lessons learned or financial support from their friends or family (Table 3.4). The support of government institutions, local government and private sector would be less appreciated, but some regional differences were apparent.

More than half of the respondents (53%) suggested technical support from government agencies to develop proper adaptation measures, for example by providing adapted seed and practical advices for improvement. More than 20% of respondents in up- and mid-stream wanted to get a loan with appropriate interest rates from the government bank whereas only 7% of the downstream farmers desired this support. Attending training provided by the fisheries extension service may support them to adapt efficiently according to approximately 40% of the up-stream respondents, but only 6.5% in mid-stream and none in down-stream thought this would help (Table 3.4).

Table 3.4 Farmers' suggestions for sources of support to adaptation of climate change, and the focus of this support (% agreed with each suggestion).

	Source of support				Type of support		
Region	Government institution	Local government	Private sector	Friend / family	Tech-nical	Finan-cial	Trai-ning
All 6 provinces	10.2	4.7	6.0	17.0	53.2	20.9	19.6
Upstream	14.3	9.2	5.1	22.4	53.1	24.5	39.8
Mid-stream	8.4	1.9	8.4	15.9	52.3	21.5	6.5
Downstream	3.3	0.0	0.0	3.3	56.7	6.7	0.0

3.3.5. Factors influencing farmer awareness

In general the variation explained by one single parameter of farmer perceptions and expectations regarding climate change and its impacts remained below 0.1 and the total explained variation below 0.2 (Table 3.5). Some factors shifted to negative or positive when the analysis was done per region. The age and education level of farmers, and the income from pangasius aquaculture affected their observations and concerns about climate change slightly positively (Table 3.5). Ownership of the farm positively influenced the farmer's fear for salinity intrusion, but the influence of the contribution of pangasius aquaculture to household income factor was inverse. Aquaculture experience only affected farmer's expectation regarding the impact on temperature ($p<5\%$). Only ownership of the farm significantly ($p< 5\%$) affected the farmer opinions on the option to mitigate the effect of climate change by changing farming practice (Table 3.6).

Table 3.6 Marginal effects of farmer characteristics on their preferred option for adaptation, from the logit model.

Parameter	Change farming practice		Change species		Abandon aquaculture	
	Coeff.	*p-value*	Coeff.	*p-value*	Coeff.	*p-value*
Age of farmer	-0.005	*0.107*	-0.001	*0.409*	0.001	*0.355*
Farm area	-0.068	*0.201*	0.030	*0.098*	0.035	*0.065*
Education level	0.063	*0.108*	0.000	*0.997*	0.019	*0.318*
Ownership	0.143*	*0.049*	0.056	*0.226*	0.060	*0.165*
Income from aquaculture	-0.001	*0.767*	0.000	*0.698*	0.000	*0.811*
Aquaculture experience	0.004	*0.678*	0.004	*0.192*	-0.006	*0.333*

Note: *significant at 5%

Table 3.5 Marginal effects of farmer's characteristics on their perceptions of climate change through correlation coefficients (as determined by the logit model).

	Observed Climate change		Concern about climate change		Impact of Climate Change expected on:							
					Flood		Drought		Temperature		Salinity intrusion	
	Coeff.	*p-value*	Coeff.	*p-value*	Coeff.	*p-value*	Coeff.	*p-value*	Coeff.	*p-value*	Coeff.	*p-value*
Age of farmer	0.010**	*0.003*	0.007*	*0.020*	-0.006	*0.054*	0.002	*0.501*	0.001	*0.940*	-0.002	*0.249*
Total ponds area	0.056	*0.259*	0.080	*0.119*	0.041	*0.416*	-0.060	*0.208*	0.006	*0.898*	-0.016	*0.672*
Education level	0.075	*0.057*	0.077*	*0.050*	0.064	*0.099*	-0.048	*0.205*	-0.021	*0.599*	-0.046	*0.099*
Ownership	0.063	*0.374*	0.015	*0.828*	-0.034	*0.627*	-0.012	*0.858*	0.025	*0.715*	0.127**	*0.003*
Income from aquaculture	0.003*	*0.026*	0.003	*0.060*	-0.002	*0.098*	-0.001	*0.482*	0.001	*0.703*	-0.003***	*0.000*
Aquaculture experience	0.001	*0.900*	0.006	*0.525*	0.005	*0.643*	0.005	*0.628*	0.030*	*0.011*	-0.011	*0.260*

Note: ***significant at 0.1%, **significant at 1%, *significant at 5%

3.4. Discussion

The development of pangasius farming in the Mekong Delta spread out along the Mekong river branches from upstream to downstream providing the farmers in upstream area a longer aquaculture experience than those downstream (average 5.7 compared to 4.3 years, respectively). The downstream farmers are less dependent on the pangasius revenue to household income than those in the mid- and up-stream regions (58% compared to 86%). This might be the result from lessons learned upstream. *Pangasius* farming in the downstream region started after the price dip due to the USA import ban (Tung et al., 2004), and the fluctuation of the pangasius market price stimulated downstream farmers to maintain other components of their farm, such as the high yielding orchards.

In agreement with other studies (Deressa et al., 2008; Apata et al., 2009; Gbetibouo, 2009; Fatuase and Ajibefun, 2013), pangasius farmers in the Mekong Delta were aware of the change in temperature (60% of respondents) and the occurence of droughts (66% of respondents). Their awareness is supported by the reported increase in temperature of about 0.5 to 0.7^{0}C, and by an average decrease in rainfall by about 2% from 1958 to 2007 (MONRE, 2009).

Nevertheless, due to our qualitative method of the semi-structure household survey, combined with the gradual impacts of climate change and the strong effects of extreme weather events on farmer perceptions (MRC, 2012; Anh et al., 2014), the responses of pangasius farmers were influenced by many factors such as farm location, experience and education. Vulnerability as well as the capacity to adapt may differ from one region to another, and within a region there may be differences between communities or individuals (Gallopin, 2006). For instance, 11% of the respondents in the upstream region had never faced salinity intrusion, but were still afraid about its possible occurrence. Thus, farmer responses may be biased causing uncertainty in the statistical analysis.

The farmer perceptions on climate change impacts were influenced by several factors of farm characteristics. The farmers' age had a positive relationship with climate change awareness and concern. Older farmers have experienced more extreme weather events and may have observed changes so that they became more aware of climate change and more concerned about its negative impacts compared to younger farmers. The positive effect of education level on concern about climate change impacts may be due to the fact that educated farmers gained knowledge on climate change and thus expected more negative influences caused by climate change occurrence than less educated farmers.

Being a pangasius farm owner increased the likelihood of expecting salinity intrusion to impact negatively the culture of fresh water species like pangasius, but having a higher part of the income from pangasius aquaculture decreased the fear for salinity. Apparently the ones making a benefit, notwithstanding the salinity intrusion, know how to deal with the problem effectively, even if they were more aware of climate change and had higher concerns on its impacts. They also invested more in measures to reduce the impacts.

Fish farmers in Delta State of Nigeria perceived low yields of fish culture due to adverse impacts of climate change (Aphunu and Nwabeze, 2012). According to these authors, number of fish ponds, income and extent of knowledge positively affected farmers' perception on climate change impact. About 85% of fish farmers in Delta State of Nigeria stated to need more information on climate change (Aphunu and Nwabeze, 2012). Farmers in the Nigerian savanna had limited capacity to adapt because they lacked information on climate change and on suitable adaptation measures (Tambo and Abdoulaye, 2013). In our study, 75% of the upstream farmers were concerned about climate change phenomena, because they had experienced extreme flooding. Downstream farmers were not concerned but had adapted their farming system to salinity. The downstream farmers thought training from extension services would not enforce their capacity to adapt. The low trust in training by farmers in the downstream region reflected the low government priority on pangasius aquaculture in coastal provinces as well as the lack of specific pangasius extension officers. The projected impacts of sea level rise caused by climate change on pangasius farming locations by Anh et al. (2014), showed pangasius farmers in coastal province will seasonally face increasing salinity intrusion for longer periods. Abandoning pangasius farming or changing species will have consequences on the value chain and its rates of return and employment. Therefore future strategies to increase resilience of pangasius farmers to climate change should focus on improving farmers' knowledge and skills, not only on technical aspects but also on awareness about climate variability and measures to address the impacts.

Across the regions, about 50% of the farmers considered adaptation measures. Among the adaptation options, most farmers chose to change farming practice (stocking density, water quality management, improved dykes). Seven to eight times less, farmers expected to change species or to abandon aquaculture. Changing species requires acquiring new knowledge and skills, and refreshing networks. Farmers owning the land were more inclined to change farming practice, inversely abandoning is an option for those renting the land or pond. The latter leaves the land owner a deep pond which has no other agriculture use. According to Kam et al. (2012) the compounding effect of climate change will increase additional cost of adaptation for pangasius farmers and further reduce their profit margins. The latter authors suggested adaptation through reducing cost of electricity and fuel by technical improvements, including the selection for higher salinity tolerant catfish species, the replacement with salinity tolerant species, or the change in farming practices. More than half of the respondents expected support from various government agencies for their adaptation. However they don't fear salinity intrusion and thus the efficiency of introducing a salinity tolerant pangasius breed for climate change adaptation in the downstream region, as suggested by De Silva and Phuong (2011), needs to be evaluated in depth.

3.5. Conclusion

Most pangasius farmers in the upstream region of the Mekong Delta had experienced reduced benefits due to extreme flooding. Downstream, in the coastal provinces, from the start farmers were confronted with seasonally high and gradually increasing salinity levels. They have taken measures, such as increasing height of dyke, or decreasing the number of stockings, or stocking larger fish tolerating higher salinity levels, to adapt to these impacts.

Most farmers, however, will eventually feel the gradually increasing effects of climate change. Less than half of the respondents were, however, concerned about these climate change impacts and sought for suitable adaptation measures.

Farmer's education level, the age and aquaculture experience, the dependency rate on pangasius farming for their income and whether they own the land increase their perception on climate change impacts. At present the respondents mainly count on support and lessons learned from friends and family to realize adaptation measures. Respondent's high expectation on technical support from government agencies contrasts with their low expectations from training in particular in the coastal provinces. Alike in other countries, building more awareness on climate change is required to improve adaptation capacity for pangasius farmers.

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Chapter 4

Impact of climate change on the technical efficiency of striped catfish (*Pangasianodon hypophthalmus*) farming in the Mekong Delta, Vietnam

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Abstract

Technical efficiency of randomly sampled pangasius farms in the Mekong Delta of Vietnam was estimated using Data Envelopment Analysis, and factors affecting technical and scale efficiency examined with bootstrap truncated regression. The mean technical efficiency score assuming constant return to scale was 0.66, and under variable return to scale it was 0.84. Technical efficiency of downstream farmers was higher due to lower energy cost and stocking once a year. Up and middle-stream farms needed to pump water and stocked at least three times in two year. Regression analysis showed a positive effect on technical efficiency of the farmers' education level, and of having experienced climate change impact through flooding or salinity intrusion in the past. Farms affected by salinity intrusion had a lower scale efficiency as they reduce stocking frequency and rate. In general, reducing input costs, increasing scale of operation and being trained in management strategies improves technical efficiency.

Keywords: *Vietnam, pangasius, efficiency, climate change, salinity, flooding*

4.1. Introduction

The Mekong Delta (8°33'- 10°55'N; 104°30'-106°50'E), often referred to as the food basket of Vietnam, is home for the striped catfish or pangasius (*Pangasianodon hypophthalmus,* Sauvage) farming sector. This sector is heralded as one of the most successful aquaculture developments in the world (De Silva & Phuong, 2011). Currently, the sector on average produces in excess of one million tons of fish per year in a pond area of less than 7,000 ha and generate an export income of about 1.4 billion US$. Its input and processing components employ over 180,000 persons directly, often women. Its development over the last two decades, as well as the associated controversies such as criticism on environmental, social and safety credentials, have been well documented (e.g. Bosma et al., 2009; Phan et al., 2009; Bui et al., 2010; De Silva et al., 2010; Nguyen, 2010; De Silva & Phuong, 2011; Little et al., 2012).

Vietnam and especially the Mekong Delta are susceptible to climate change impacts. Dasgupta et al. (2007) ranked Vietnam among the top five countries affected by rising sea levels. De Silva and Soto (2009) noted that impacts of climate change on capture fisheries have received more attention in scientific literature and policy making compared to those on aquaculture. They stressed the need to address vulnerabilities of major aquaculture farming systems and proposed appropriate mitigation and/or adaptation measures to maintain the viability of these systems. Anh et al. (2014) addressed simulated impacts of climate change on current pangasius farming locations in the Mekong Delta. Due to expected climate change impacts on hydrological regimes and on sea level rise, the pangasius farms located upstream and mid-stream regions will encounter longer flood periods and larger inundation areas, whilst downstream larger areas (potentially more farmers) will be affected and farmers may experience higher salinity levels during longer period (Anh et al., 2014).

Studies investigating technical efficiencies (TE) of aquaculture farming systems, particularly for tropical systems are sparse. For instance, Sharma and Leung (1998, 2000) investigated TE of carp production in Nepal and India, respectively using a stochastic frontier production function, and analysed factors influencing the TE by the maximum likelihood estimation approach. Using the same method, Dey et al. (2000) examined the TE and the effect elements of tilapia grow out operations in ponds in the Philippines. Kaliba and Engle (2006) estimated technical and cost efficiency of catfish farms in Arkansas, USA, using Data Envelopment Analysis (DEA), and identified factors determining inefficiency using a tobit regression approach. In the before mentioned studies, the authors focused on the explanatory variables based on socioeconomic factors only because such variables may have a direct influence on production efficiency (Dey et al., 2000). The climatic change impacts on the TE of aquaculture farming systems is poorly understood. We will explore this knowledge gap as this contributes to developing mitigation and adaptation measures (De Silva & Soto, 2009; De Silva, 2012) for this food production sector.

The impacts of climate change on TE have been investigated in various agricultural systems recently. Oyekale (2012) analyzed the impact of climate change on cocoa agriculture in Nigeria, when the effects of changes in temperature and rainfall were found to be statistically significant. Higher intensity and extension of dry season caused the death of cocoa trees by capsids, a pest of cocoa, and yield reduction by black pod disease. Inversely, too much rainfall limited the opportunities for chemical treatments by spraying of cocoa pods (Oyekale, 2012). Makki et al. (2012) pointed out the significant effect of climate factors to TE on paddy farm operations in Kalimantan province, Indonesia. Hossain et al. (2013) examined the effects of rainfall, temperature and humidity factors on efficiency of three types of rice production (AUS, AMAN and BORO) in Bangladesh. According to these authors, humidity has a positive and significant effect on all types; temperature has a negative impact on production efficiency, and rainfall has a positive impact only on BORO production.

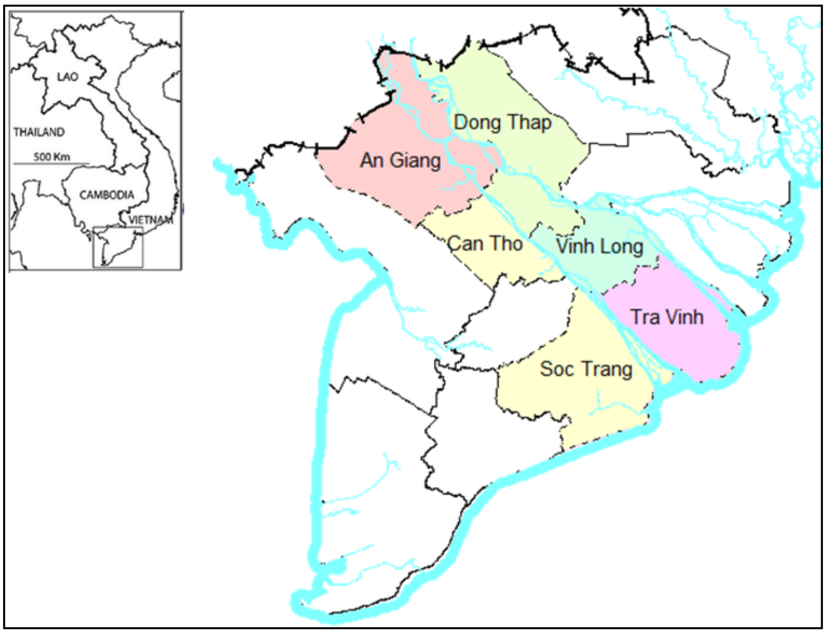
This study identifies the major factors that affect the TE of pangasius farms, and explores the relationships between those factors and climate change, which would influence pangasius farming. The results of this study are expected to provide policy insights to enhance the use of adaptation measures in the pangasius farming sector in particular and in aquaculture in general.

4.2. Materials and Methods

4.2.1. Study area

The study area for this study was similar to that in our previous study (Anh et al., 2014). Briefly, striped catfish farming in the delta occurs along two main branches, Tien river (upper) and Hau river (lower) and the associated canals of the Mekong River. Accordingly, the study was conducted in the six provinces where pangasius farming is most prevalent (Fig. 4.1). For the primary study 4% of the pangasius farms were randomly selected based on the frequency of distribution in the provinces and the lists of farms registered with the provincial authorities.

Fig. 4.1 The six provinces of the Mekong Delta where catfish farming is prevalent.



The database was checked on consistency by calculating the Feed Conversion Ratio (FCR). Data of farms with a FCR below 0.7 and above 3.9 were verified; the lower threshold is hard to reach even for farms using sophisticated re-circulating aquaculture and the farms with an FCR of 4 and higher would have experienced an extreme event, or given erroneous information. When after correction if the FCR remained outside these limits these farms were excluded from the database. The final database contained 184 farms: 35, 43, 16, 63, 13, and 14 farms from each An Giang, Dong Thap, Vinh Long, Can Tho, Tra Vinh, and Soc Trang provinces, respectively. Along the Mekong branches these can be categorized into three production regions namely upstream (An Giang and Dong Thap provinces), mid-stream (Vinh Long and Can Tho provinces), and downstream (Tra Vinh and Soc Trang provinces).

A draft questionnaire covering general information of the farmer household, cost of different inputs, production and income, as well as the owner perceptions and strategies to climate change induced impacts was developed by experienced socio-economists, and climate change scientists. The draft questionnaire is a modified version of that used in an earlier study by Phan et al. (2009). The survey was conducted through face to face interviews of farmers by trained personnel with past experience on conducting such surveys. Each interview was conducted by two interviewers.

In addition to questions on the farm characteristics (size and labor use), revenues and expenses (cost of inputs such as fuel, electricity, chemicals, seed and feed), the survey also included a set of questions related to the effect of Climate Change. E.g. flooding and salinity intrusion were addressed as follows: "Climate change impact –flood (Y/N)", and "Climate change impact -salinity (Y/N)". The survey data were entered into a database developed for the purpose in MS Excel. The data were analyzed in two steps. To examine the efficiency of striped catfish farm operations in the Mekong Delta, the technical efficiency of individual farms was assessed by using the Data Envelopment Analysis (Simar & Wilson, 2000). To identify whether there are significant relationships between a farm's TE and impact from climate change factors and other farm characteristics, a regression model was employed.

4.2.2. Efficiency measurements

The DEA technique, introduced by Charnes, Cooper and Rhodes (1978), was employed to estimate the technical efficiency of a decision making unit (DMUs) that employs multiple inputs to produce multiple outputs. This technique uses linear programming to measure technical efficiency of a DMU relative to a set of referenced DMUs. The technical efficiency (TE) is considered in terms of the optimal level of inputs to achieve a given level of output (an input-orientation) or the optimal level of output that can be produced from a given set of inputs (an output-orientation). The envelopment surface of the oriented models can be either constant returns-to scale (CRS) or variable returns-to-scale (VRS).

The present study applied the input-oriented model since in agriculture farmers have more control over the inputs rather than the outputs. In the case of the catfish farming sector in the Mekong Delta also, under certain constraints of high costs of inputs, especially of feed (Phan et al., 2009), the choice of the DEA input-oriented models seems the most appropriate. Suppose we have n DMUs (DMUj : $j = 1,2, \ldots, n$), which produce s outputs y_{rj} ($r = 1,2,\ldots, s$) by utilizing m inputs, x_{ij} ($i = 1,2,\ldots, m$). An input-oriented model which exhibits CRS (Charnes, Cooper and Rhodes, 1978) and is referred to in the literature as the CCR model, can be written as Equation 1.

$$
\begin{aligned}
&\text{Min} \quad \theta_o \\
&\text{subject to} \quad \sum_{j=1}^{n} \lambda_j x_{ij} \leq \theta_o x i_o, && i = 1,2, \ldots, m, \\
&\sum_{j=1}^{n} \lambda_j y_{rj} \geq y r_o, && r = 1,2, \ldots, s, \\
&\lambda_i \geq 0, && j = 1, \ldots, n, \qquad \text{(EQ. 1)}
\end{aligned}
$$

In Equation 1, x_{io} and y_{ro} are, respectively, the i_{th} input and r_{th} output for a DMUo under evaluation, respectively. Solving that model n times results in optimal values of the objective function and the elements of intensity variables vector θ for each farm. For the DMU*o* the optimal value θ^*_o measures the maximal proportional input reduction without altering the level of outputs. The vector θ^*_j indicates participation of each considered farm in the construction of the virtual reference farm that the DMUo is compared with. Solving the CCR model, the technical efficiency measure θ^*_o (CCR) is obtained by comparing small scale units with large scale units and vice versa without considering the economies of scale. The CRS approach compares the farms with a benchmark of farms that operate at an optimal scale. However, imperfect competition, lack of access to finance and government regulations, may preclude a farm operating at an optimal scale. Therefore, the BCC model, developed by Banker et al. (1984) and called the input-oriented BCC model, allows farms to operate at increasing, constant or decreasing returns to scale. The input-oriented VRS model is obtained from the CRS model by adding a convexity constraint $\sum\theta = 1$ to the CCR model (EQ. 1), and can be written as Equation 2.

$$\text{Min } \theta_o$$

$$\text{subject to } \sum_{j=1}^{n} \lambda_j x_{ij} \leq \theta_o x i_o, \qquad i = 1,2, \ldots, m,$$

$$\sum_{j=1}^{n} \lambda_j y_{rj} \geq y r_o, \qquad r = 1,2, \ldots, s,$$

$$\sum_{j=1}^{n} \lambda_j = 1, \qquad \text{(EQ. 2)}$$

The scale efficiency (SE) measures were computed as the ratio of the measure of technical efficiency calculated under the assumption of CRS to the measure of technical efficiency calculated under the assumption of VRS (Banker et al., 1984; Fare et al., 1985). If the value of SE is equal to 1 then DMUo is considered as a scale efficient unit and this unit shows the constant returns to scale property (CRS), and if SEj < 1 then the production mix of DMU_o is not scale efficient.

Although the application of this method is straightforward, it leads to over-estimation of technical efficiency since the empirical sample is usually a fraction of the entire population of DMUs. This problem can be solved by the bootstrapping method (Simar & Wilson, 2000; 2007). Therefore in this study we used the DEA-bootstrap running in R environment to estimate technical efficiency and confidence intervals to allow for statistical inference (Bogetoft and Otto, 2011).

4.2.3. The influencing factors on farm technical efficiency

In order to assess the impact of different farm characteristics and climate change related variables on technical and scale efficiency, we applied the bootstrap truncated regression model developed by Simar and Wilson (2007). This approach accounts for the truncation and correlation in the dependent variable.

$$D_i \approx \beta_0 + \sum_{m=1}^{k} \beta_m Z_{mi} + \epsilon_i \qquad \text{(EQ. 3)}$$

Where D_i is the distance of the observed input-output level of farm i to the efficient frontier ($D_i = 1/TE_i$) and has a value greater than or equal to 1, $Z's$ are explanatory variables that affect farm operation efficiency, k is the number of explanatory variables, β_m are parameters of the model, and ϵ_i are random error term. The D_i is inverse to technical efficiency so that positive influence on D means negative influence on TE, or inversely.

Due to the tendency to increase scale of operations of downstream pangasius farms, the relation between farm characteristics, climate change impacts and SE were investigated:

$$SE_i \approx \alpha_0 + \sum_{m=1}^{k} \alpha_m Z_{mi} + \mathcal{E}_i \qquad \text{(EQ. 4)}$$

Where SE_i is the scale efficiency for farm i, $Z's$ are explanatory variables that affect farm scale efficiency, k is the number of explanatory variables, α_m are parameters of the model, and $\mathcal{E}_i$ are random error term.

The explanatory variables in Equation 3 and 4 included: age of farmer (years), aquaculture experience of farmer (years of aquaculture performance), education level of farmer (1: higher than elementary school, 0: elementary school or lower), access to extension training (1=yes, 0=no), flood effects (1=yes, 0=no), salinity intrusion effects (1=yes, 0=no), upstream location (dummy with 1=yes, 0=no), and mid-stream location (dummy with 1=yes, 0=no). The dummies were included to separate the farm level impacts of flooding and salinity from the general regional impact. The bootstrap truncated regression model was employed using STATA software.

4.2.4. Data description

The variables used to estimate TE of farms were calculated per pond unit for one year (Table 1). The input data included the pond area, the number of workers, the cost of energy (US$) consisting of fuel and electricity, the cost of chemicals (US$) including drugs, anti-biotics and others, the cost of feed (US$) including vitamins, and industrial and farm-made pellets; and the number of seed (fingerling) stocked. The exchange rate used was 1 US$ = 20,000 VND. The output data were pangasius productions (ton). The surveyed factors affecting TE included age of farmers, aquaculture experience, education level, aquaculture training participation of farmers, impact of flooding and salinity intrusion, and the regions (Table 4.1).

The surveyed farms had a pond area from 0.08 to 1.2 ha and produced 10 to 1,000t of striped catfish per year (Table 4.1). The use of inputs was comparable for *seed*, *labour* and *feed*, but the use of *chemicals* (including veterinary drugs) varied much more between farms. The use of energy also varied a lot, partly due to the fact that some downstream farms, benefitting from gravity flow, did not use fuel or electricity for pumping water. *Energy* and *chemicals* were aggregated inputs, and were measured in monetary value because farmers usually do not remember nor keep records of exact quantities of these inputs. In practice, the cost of *feed* and *seed* were the highest cost factors in pangasius farming.

On a per ha basis (Table 4.2), farm operational cost was highest upstream and lowest downstream. Conversely, the production (yield) of farms was highest upstream and lowest downstream; farmers downstream stocked less fish also, and mostly stocked once a year instead of three times in two years as is the practice in middle and upstream farms. The average age of the household' heads was 44 years, both overall as well as in the upstream and middle-stream regions; farmers in the downstream regions were on average 4 years older. Aquaculture experience in pangasius farming varied from 1 to 20 years, farmers in the upstream and middle-stream regions, where striped catfish culture originated, had longer time than those in the downstream region. Most of the farmers (80%) had an education level higher than elementary school; education level was lowest in the downstream and highest in the upstream area. More than half of the farmers had attended training courses for striped catfish aquaculture offered by local fisheries extension services, universities and or private companies. All farmers in the upstream and most in the middle-stream regions felt the effect of flooding in the past seven years, but none downstream, whereas salinity intrusion affected the downstream provinces only.

Table 4.1 Summary statistics of input and output variables for 184 striped catfish farms in the Mekong Delta, Vietnam (pond^{-1} year^{-1}).

Variable	Mean	SD	Min.	Max.
Pond area (ha)	0.37	0.23	0.08	1.2
Labour (persons)	1.8	1	1	7
Energy cost (US$)	325	947	0	7,200
Chemical cost (thousands of US$)	5.4	6.8	0.07	45
Seed (thousands of pieces)	237	183	15	1,500
Feed (thousands of US$)	140	132	5.3	885
Striped catfish production (t)	187.2	150.63	10	1,000
Age (years)	44	10	22	71
Aquaculture experience (years)	5.4	2.9	1	20
Education	0.8	0.4	0	1
Access to extension training	0.55	0.5	0	1
Flood effect	0.73	0.44	0	1
Salinity effect	0.11	0.32	0	1

Most farmers (85%) experienced either flooding or salinity intrusion in the past seven years. Farmers in the upstream and middle stream region estimated the economic losses due to hazardous flooding either as a 10% to 100% and decrease of production or as a 5% to 300% increase of cost for fish disease treatment. Farmers experiencing salinity could not attribute specific losses as they adjusted the farming system to accommodate the seasonally recurring event.

Table 4.2 Summary statistics of input and output variables of the sampled striped catfish farms of the Mekong delta, Vietnam, according to production region (ha^{-1} $year^{-1}$).

	Upstream (n=78)			Mid-stream (n=79)			Downstream (N=27)		
Variable	**Av.**	**SD**	**Range**	**Av.**	**S D**	**Range**	**Av.**	**SD**	**Range**
Pond area (ha)	0.42	0.27	0.1 - 1.2	0.38	0.21	0.1 - 1.2	0.21	0.13	0.08 - 0.6
Labor (persons)	6.8	5.6	2 - 33	5.7	3.2	2 - 20	6.7	3	3 - 13
Energy cost (US$)	1409	2,587	0 - 11,906	454	1,063	0 - 7,143	46	114	0 - 550
Chemical cost (thousands of US$)	26.2	50	0.45 - 300	13	11.5	0.23 - 55.8	8.1	6.5	0.7 - 29.1
Seed (thousands of pieces)	641	236	100 -1,400	717	286	133 -1,400	445	245	125 -1,100
Feed (thousands of US$)	511	447	67 - 2,204	355	162	85 - 905	189	91	46 - 411
Striped catfish production (t)	580	373	80 - 2,500	533	230	57 - 1,200	297	139	83 - 610
Age (years)	44	8.7	27 - 68	44	11.1	22 - 66	48	10.4	25 - 71
Aquaculture experience (years)	5.4	3.1	1 - 20	5.7	3.1	1 - 15	4.3	1.6	1 - 8
Education	1	0.2	0 - 1	0.8	0.4	0 - 1	0.6	0.5	0 - 1
Access to extension training	0.6	0.5	0 - 1	0.5	0.5	0 - 1	0.7	0.5	0 - 1
Flood effect	1	0.2	0 - 1	0.7	0.4	0 - 1	-	-	-
Salinity intrusion effect	-	-	-	-	-	-	0.8	0.4	0 - 1

4.3. Results

4.3.1. Technical efficiency (TE) scores

The Benchmarking with DEA was used to calculate TE under CRS and VRS with the assumption that the true technology is CRS, and that TE under CRS is not statistically significant different from TE under VRS (the null hypothesis). The estimated results rejected the null hypothesis. The TE scores under VRS of farms varied from 0.45 to 1.00 with a mean value of 0.84, which were higher than TE score under CRS with mean value of 0.66. SE ranged from 0.13 to 1.00 with mean value of 0.80 (Table 4.3).

The mean TE for all farms was 0.84 under VRS. This implies that farmers produced pangasius at on average 84% of the potential efficiency level of technology and input levels. It also means that farms can reduce their inputs by 16% and still reach the same level of production. More than 30% of the farms have a TE below 0.6, and thus have a large scope for reducing the use of inputs and improving their profits.Under CRS, the majority of the farms had TE scores below 0.80, with slightly more than half in the range of 0.60 to 0.80. Vice versa, under VRS, more than 55% of the farms had a TE higher than 0.80 (Table 4.3). The SE of 56% of the farms was above 80%, and thus at least 44% of the farms may improve the efficiency by increasing scale.

Table 4.3 Distribution of farm technical and scale efficiency scores using DEA input orientation.

Five classes of TE	TE scores under CRS		TE scores under VRS		SE scores	
	Number	Frequency (%)	Number	Frequency (%)	Number	Frequency (%)
<= 0.2	1	0.5			1	0.5
0.2 to 0.4	8	4.6			3	1.6
0.4 to 0.6	49	26.6	21	11.4	24	13.0
0.6 to 0.8	96	52.2	61	33.2	53	28.8
0.8 to 1	30	16.3	102	55.4	103	56.0
Mean	0.66		0.84		0.80	
SD	0.15		0.17		0.17	
2.5% value	0.64		0.82		0.78	
97.5% value	0.68		0.87		0.83	

Comparison of TE among up-, mid- and downstream regions

Under VRS, farm TE in the downstream area scored significantly higher compared to the other regions ($P<0.05$). Under CRS, the mean TE did not differ between the three areas (Table 4.4). The SE was lowest in the downstream region ($P<0.05$), which aligned with the lower stocking density and frequency.

Table 4.4 Farm's efficiency scores using DEA input orientation in the three regions.

Regions	TE scores under CRS			TE scores under VRS			SE scores		
	Mean	SD	95% conf. interval	Mean	SD	95% conf. interval	Mean	SD	95% conf. interval
Upstream	0.64	0.17	0.61-0.68	0.82	0.19	0.78-0.86	0.81	0.18	0.76-0.84
Mid-stream	0.68	0.14	0.65-0.71	0.82	0.16	0.79-0.86	0.84	0.16	0.80-0.87
Downstream	0.66	0.08	0.62-0.69	0.96	0.12	0.91-1.00	0.69	0.11	0.66-0.74

4.3.2. Factors affecting the farm' technical efficiency

The bootstrap truncated regression of the distance demonstrated that farmer's age, farmer's aquaculture experience, having received training by extension services affected the distance to the TE' frontier positively. This means that these factors reduced the technical efficiency. Inversely, the impacts of education, flooding, salinity intrusion on distance were negative, and so they improve TE. The level of the factor for salinity was double that of flooding; the latter was higher than the effect for education. The effects of age, aquaculture experience, flood and salinity intrusion were statistically significant at the 5% level (Table 4.5).

The results of the bootstrap truncated regression model in Table 4.6 demonstrate that age, education, training and flood effected the farm's scale efficiency (SE) positively. Inversely, the impact of experience and salinity intrusion on SE were negative. These effects were statistically significant at the critical 5% level (Table 4.6). The factor for the effect of salinity is about double to fifty-fold larger than other factors.

Table 4.5 Bootstrap truncated regression estimates of the model using Distance to the TE' frontier as outcome.

	Mean	95% confidence intervals	
β_0	1.257	1.099	1.412
Age of famer	0.003*	0.001	0.005
Aquaculture experience	0.023*	0.016	0.029
Education	-0.047	-0.112	0.015
Access to extension training	0.026	-0.015	0.067
Flooding effect	-0.074*	-0.137	-0.009
Salinity intrusion effect	-0.159*	-0.289	-0.034
Upstream region (dummy)	0.089	-0.048	0.217
Mid-stream (dummy)	-0.100	-0.237	0.021

Marked with a * indicates that factor is significant at a 5% confidence level

4.4. Discussion

Our study used interview data. Both the one time survey on economic data and the farmers' responses to questions regarding their appreciation could cause a degree of uncertainty. The farmer might estimate their cost and production and thus could make mistakes, or have missed bills while accounting if answers were based on written documentation. Although the survey was conducted in a year with normal weather, the farmers appreciated the influence of climate change and resulting impacts on their pangasius farming operation based on past experience.

Table 4.6 Bootstrap truncated regression estimates of the influence of the explanatory variables on the scale efficiency.

	Mean	95% confidence intervals	
α_0	0.964*	0.787	1.142
Age of farmer	0.005*	0.002	0.007
Aquaculture experience	-0.018*	-0.027	-0.009
Education	0.133*	0.052	0.221
Access to extension training	0.145*	0.092	0.199
Flooding effect	0.093*	0.013	0.175
Salinity intrusion effect	-0.281*	-0.486	-0.117
Upstream region (dummy)	-0.215*	-0.370	-0.066
Middle-stream region (dummy)	-0.022	-0.169	0.113

Marked with a * indicates that factor is significant at a 5% confidence level

Under the assumption of CRS the technical efficiency score of the pangasius farms was lower (0.66) than under VRS (0.84). These scores are both higher than technical efficiencies of the catfish farms in Chicot, Arkansas: 0.57 and 0.73, under CRS and VRS, respectively (Kaliba and Engle, 2006). The TE scores under VRS (0.84) are comparable to those of the aquaculture sector in other countries, such as trout pond farming in the Black Sea Region, Turkey (0.82) (Cinemre, 2006), tilapia pond operations in the Philippines (0.83) (Dey et al., 2004), semi-intensive/intensive carp farming in India (0.80) (Sharma & Leung 2000), Chinese fish farms polyculture (0.83) (Sharma, 1999), and the carp farming of Bangladesh (0.85) (Ferdous and Murshed-e-Jahan, 2008). However, except for the target species, these TEs could not really be compared because the farming technologies, input and output variables as well as the scale of operation may be very different.

The TE under VRS being nearly 20% higher than the TE under CRS is indicative for the fluctuation of the scale of the farm operations. A higher TE under VRS of farms located downstream (0.96) compared to those upstream and mid-stream (0.82) can be explained by the lower cost of operation related to a smaller pond area, and lower cost for energy from fuel and electricity. The latter is due to the lower need for pumping to exchange the water because of the larger possibility to use the tidal regime. However, the scale efficiency of farms downstream is lowest, which may be due to the fact that some of these farms stock only once per year. These arguments imply that measures to increase TE of pangasius farms include the reduction of input cost as well as the increase of the scale of operation of smaller farms.

The range of calculated TEs is large which might indicate that the input-output market of pangasius is very volatile, which is in agreement with the observation of De Silva and Phuong (2011). When prices offered are below production cost, traditional farmers tend to wait for better market prices, however sometimes without success: while their feeding cost increases the weight of the fish hardly increase, and they accumulate losses. Progressive farmers may have another strategy (Box 1). The lower TE of the older farmer, the more aquaculture experienced farmer and the trained farmer, contrasts with the higher TE of the better educated farmers. This confirms the mentioned contrast between traditional and higher educated farmers. The higher education level might make farmers more able to adapt better to fluctuating input and output markets, while the others lacked this flexibility to adapt, perhaps because of the poor understanding of the interactive factors.

Box 1: Production and market strategy of Mr. Nguyen Thanh Son, An Lac Tay commune, Ke Sach district, Soc Trang province
"I plan my production and sell as scheduled: some harvests I loose, others I gain, and on average I make good money."
"I sell to the company having the best price and I check at forehand with the bank if the company is capable of paying me as fast as possible, to reduce my cost of interest."

Salinity and flooding apparently increased the technical efficiency. This might be due either to precautious measures having a positive effect or to the subjective measurements of the effects of flooding and salinity by the farmers self-reported effects. The self-reporting may introduce a bias in the sense that the more efficient farmers may be the ones that are more likely to report flooding and salinity. Farmers culturing pangasius in a location with risk of flooding might have taken measures to reduce the risk of heavy losses, thus becoming the most efficient upstream farmers. The number of farmers suffering from salinity is much smaller than those suffering from flooding, while the factor in the regression function for salinity is doubled. Indeed salinity effect is strongly correlated to the downstream region. Most farmers downstream also have lower cost and therefore higher TE; preventing impact from salinity by reducing stocking density or frequency of stocking might strengthen efficiency.

The age of the farmer, education and training significantly increased scale efficiency. The older farmers may gradually have acquired larger farms. The better educated farmers might have better access to capital to increase scale of operation of their farms, or be more interested to rationalise their farm activities. The farmers having larger ponds might have received preference for training related to new technology of pangasius aquaculture. However, longer aquaculture experience in traditional practices may also become an obstacle to improve performance and scale.

Farmers in upstream and mid-stream areas having to deal with increased and prolonged periods of high water levels, may have built larger ponds with higher dykes and larger pumping systems; to recover their investment they stock more seed. These factors explain the positive effect of flooding on scale efficiency. Inversely, salinity intrusion occurs seasonally every year and forces the farmers in downstream region to adjust their cropping plan and avoid stocking young fish in the seasons at high salinity levels, and therefore reduces scale capacity.

In the future, climate change impact may cause prolonged and more frequent flooding and expand the area of salinity intrusion in the dry season (De Silva and Phuong, 2011; Anh et al., 2014 in press). To mitigate these effects of climate change, the upstream and mid-stream farms will have to invest in dyke enforcement, while the downstream farms might opt for stocking fingerling at a more advanced age, after nursing them on higher grounds (Anh et al., 2014 in press). The government might support the design of adaptation strategies including studies on the cost efficiency of these strategies. In particular the cost efficiency of strategies proposed for climate change adaptation in downstream areas, such as producing a salinity tolerant strain of pangasius (De Silva & Phuong, 2011) need in-depth studies.

4.5. Conclusions

The technical efficiency of pangasius farms in the Mekong Delta of Vietnam observed in this study is on par with fish farms operated in other countries. The higher educated farmers and the more efficient farmers perceived impact of climate change and knew how to deal with these influences. Pangasius farmers in the flood prone areas of the upstream and mid-stream regions had a larger scale of operation, whereas salinity intrusion reduced the scale of farms located in the downstream region. More efficient use of inputs, such as feed, seed, labour, and an increased scale of operation, as well as intensified training will be the key for lifting productivity. The overall adaptation strategy, better dykes, requires a one-time investment, while the increased salinity level downstream will require also increased recurrent operational cost either at sector level (breeding salinity tolerant pangasius) or at farm level (prolonged nursery phase).

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Chapter 5

A decision tree analysis to support potential climate change adaptations of striped catfish farming in the Mekong Delta, Vietnam

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Abstract

Using a decision tree framework, this study analyzed possible options of pangasius farming in the Mekong Delta, Vietnam, to adapt to projected climate-change impacts. After summarizing the risks for impacts we analyzed both farmers' autonomous and planned public adaptations using primary and secondary data. A proportion of the pangasius farms located in the coastal provinces will be affected by salinity intrusion in the dry season. Options to adapt to this are: modify the pangasius farming practice, stock other species or stock saline tolerant pangasius. With research and extension support, farmers can further improve their already adopted practice to deal with salinity or use water recirculation systems for prolonged nursery rearing. A breeding program for saline tolerant striped catfish requires a relative medium to long term investments (0.4 % of the present production costs) from the government and or a private company. The pangasius farms in up- and mid-stream regions, and in coastal areas, which are not located within upgraded government dyke protected areas, will be affected by flooding at the end of each rainy season. This would imply an increase of the costs for dykes to about 0.34% and 0.25% of the total variable costs for one harvest per ha in the up- and mid-stream regions, and in the downstream region, respectively.

Keyword*s: Mekong Delta, striped catfish culture, climate change, adaptation*

5.1. Introduction

The farming of striped catfish (*Pangasianodon hypophthalmus* Sauvage; commonly called pangasius in English or ca tra in Vietnamese), which originated in the Mekong Delta, is acknowledged to be one of the most successful aquaculture developments in the world (De Silva and Phuong, 2011). The industry started on fattening of river catfish (*Pangasius bocourti*) in cages in the upstream part of the two main branches of the Mekong River flowing through the provinces of An Giang, Dong Thap, and Can Tho (see Figure 1). However, land-based farmers gradually overtook the sector by culturing striped catfish in ponds after the artificial propagation of this fish was developed and successfully disseminated (Nguyen 2009; Phan et al., 2009; Bui et al., 2013). Thereafter, the industry expanded more downstream to Vinh Long, TraVinh, Soc Trang and Ben Tre provinces (Figure 1). At present the farming sector includes independent small-scale farmers and holdings, both delivering their fish to processing companies, as well as fully integrated companies with own feed-mills, ponds, and processing facilities. In 2012 and in 2013, the sector produced 1.19 million tons of fish in a pond area of 5600 ha and exported the processed pangasius mainly in the form of fillet to over 142 countries valued at 1.7 billion US$ (VASEP, 2013).

Vietnam and especially the Mekong Delta are likely to encounter adverse impacts of climate change. Dasgupta et al. (2007), for example, ranked Vietnam as one among the top five countries most affected by rising sea levels. Studies used sea level rise scenarios to explore impacts on Mekong Delta's infrastructure (Hoa et al*.,* 2007), rice cropping areas (Wassmann et al., 2004; Khang et al., 2008) and current pangasius farming locations in the Mekong Delta (Anh et al., 2014). Pangasius farms in upstream and middle-stream regions will encounter longer flood periods and thus higher risks of flooding, while downstream farms will be affected by higher salinity levels and a longer period of salinity intrusion (Anh et al., 2014). Projecting the impact of climate change on the profitability of pangasius farmers, Kam et al. (2012), found that the short-term benefits of the inland pangasius farms remain positive when climate change is ignored but benefits soon disappear when climate change impacts are considered. Coastal pangasius farms will even be more affected by climate change when projected benefits are predicted to be halved (Kam et al., 2012). Therefore, arriving at decisions on adaptation strategies are urgent in order to counteract the negative impacts of climate change on this important Vietnamese aquaculture sector that sustains over 170,000 employment opportunities among the rural poor (De Silva and Phuong, 2011).

While reviewing the impacts of and possible adaptations to climate change in developed and developing economies, Nath and Behera (2011) indicated that adaptation also could enhance the resilience against increasing influences of climate change. Adaptation can refer to natural or socio-economic systems, can be reactive or anticipatory based on timing, and can be autonomous or planned depending on the degree of spontaneity (Smit et al., 2000). Frankhauser et al. (1999) adopted the definition of autonomous adaptation first defined by Carter et al. (1994) as *"natural or spontaneous adjustments in the face of a changing climate"* and consequently defined planned adaptation as *"requires conscious intervention".*

The Ministry of Agriculture and Rural Development (MARD) of Vietnam has established the action plan for adaptation of agriculture and rural development for the period 2008-2020. The action plan focuses on ensuring the safety of residents, stability of agriculture production and food security, and safety of dykes, levees and infrastructure. In order to achieve these objectives, five main tasks were implemented: (1) conduct a communication and information program; (2) develop human resources and conduct adaptation studies; (3) develop a policy system; (4) promote international cooperation; and (5) establish priority adaptation activities (MARD, 2008). The implemented activities addressed the impacts of climate change on fisheries and aquaculture nationally (Hien et al., 2010) but did not yet develop regional adaptation plans for this sector.

Anh et al. (forthcoming-a) revealed that adaptation measures by pangasius farmers focused on changing their farming practices or on changing the cultured species, in some cases with financial and technical support of private, government and research agencies. Nath and Behera (2011) noted that government and civil society played a crucial role in enabling efficient adaptation methods. The adaptation strategies for pangasius farming, therefore, should combine both autonomous and planned adaptations at private and public levels. According to Smit et al. (2000), the estimation of costs and benefits is an important aspect of the evaluation of adaptations and provides support to recommendations of the most appropriate adaptations. Kam et al. (2012) analysed the cost of autonomous farmer' adaptation; their analysis revealed that these costs can be reduced by planned public adaptation measures.

This paper aims to analyse the adaptation measures that may diminish the climate change impacts for the pangasius farming sector in the Mekong Delta (Figure 1). Suitable adaptation strategies are best decided through a decision making process. Such a process is defined as the systematic analysis of a problem (i.e. cause - effect - response chain) and the final choice of effective solutions (Marakas, 2003). We analyse one by one the problems induced by climate change and the related suggested solutions of both autonomous and planned adaptations. We framed this in a decision tree framework in order to facilitate adequate policy making.

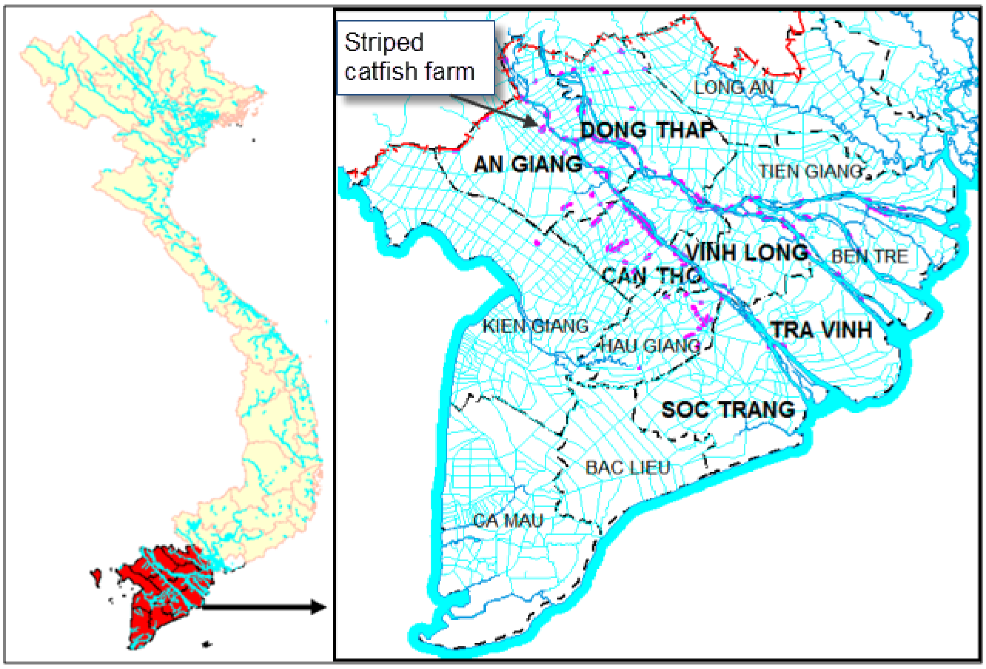

Fig. 5.1 The administrative map of the Mekong Delta with locations of the pangasius farms (Adapted from Anh et al., 2014).

5.2. Analytical framework

5.2.1. Data

This study used both primary and secondary data. Primary data were already collected for our previous studies on climate change impacts on pangasius farming (i.e. Anh et al*.,* 2014; Anh et al., forthcoming-a; Anh et al*.,* forthcoming-b). Primary data on the cost of a pangasius breeding program were acquired from an expert, and complemented with secondary data. Secondary data were collected from the scientific and professional literature, and statistical reports from the Vietnamese government and aquaculture organisations. The cost of autonomous adaptation was collected from several studies(e.g. Kam et al.,2012), and included measures, such as dyke enforcement.

5.2.2. Decision tree framework

Decision-making is a process of problem analysis and solution design, implementation and monitoring. All steps involve decisions, which can alter the systems and thus require visiting earlier steps; the inherent feed-back loops make the process recursive (Gladwin*,*1983). To support policy-making the present study developed a simple rule-based decision support tree (Fig. 5.2). A decision tree is a decision support tool that uses a tree-like schematic representation or a model of the possible consequences of specific decisions, and the plausible interactions thereof.

To develop the decision tree, we elucidated the reasons and the recommendations for decision-making at the various nodes of the decision tree following the steps as below:

- Identify the problems (event nodes) and the specific decisions to be made (decision nodes).
- Build the structure of the decisions and its consequences, like a tree with the roots and the branches.
- Clarify the cost (disadvantages / trade-offs) and benefit (advantages / synergies) of each alternative decision in order to determine the most favourable decision.

In the present case, the event nodes represent a problem (e.g. salinity intrusion) requiring an assessment (will it affect my farm or not?), and then a decision (adapt or not?); upon the choice to adapt follows an analysis of options for adaptation. Each option (e.g. change of species) requires an analysis of the cost (disadvantage / trade-off) and benefits (advantage/ synergy) before a decision to apply could follow. If the decision is negative then the decision-maker may analyse another option making the process recursive (feedback loop), and finally enabling to make a decision to adapt or not to adapt.

5.3. Climate change impacts requiring adaptation of the pangasius farming sector

5.3.1. Flooding

Induced by sea level rise, flooding in the Mekong Delta of Vietnam likely worsens in the long term (Hoa et al., 2007) as floods will arrive earlier and persist longer (Wassmann et al., 2004). According to Anh et al. (2014) sea level rise (SLR) scenarios of +50 to +75 cm will cause an additional expansion of flooding in the upstream provinces of An Giang, Dong Thap and Can Tho, and increase the inundation areas in the coastal provinces of Soc Trang, TraVinh and Ben Tre (see Fig. 5.1).

Under a SLR +50cm scenario, Kam et al. (2012) predicted the greatest increments in flooding depth in An Giang, Dong Thap and Can Tho provinces, which have the largest concentration of pangasius farms. Anh et al. (2014) predicted that pangasius farms in all provinces have to deal with a 2 m flood level in case of the SLR +50cm scenario. Anh et al. (forthcoming-a) revealed that 55% of the interviewed pangasius farmers in upstream provinces were concerned about flooding caused by climate change. Pangasius farmers in those provinces estimated their economic losses at 10% to 100% of their current income. For example, they estimated that their costs for fish disease treatment would increase up to 300% due to such hazardous flooding (Anh et al., forthcoming-b).

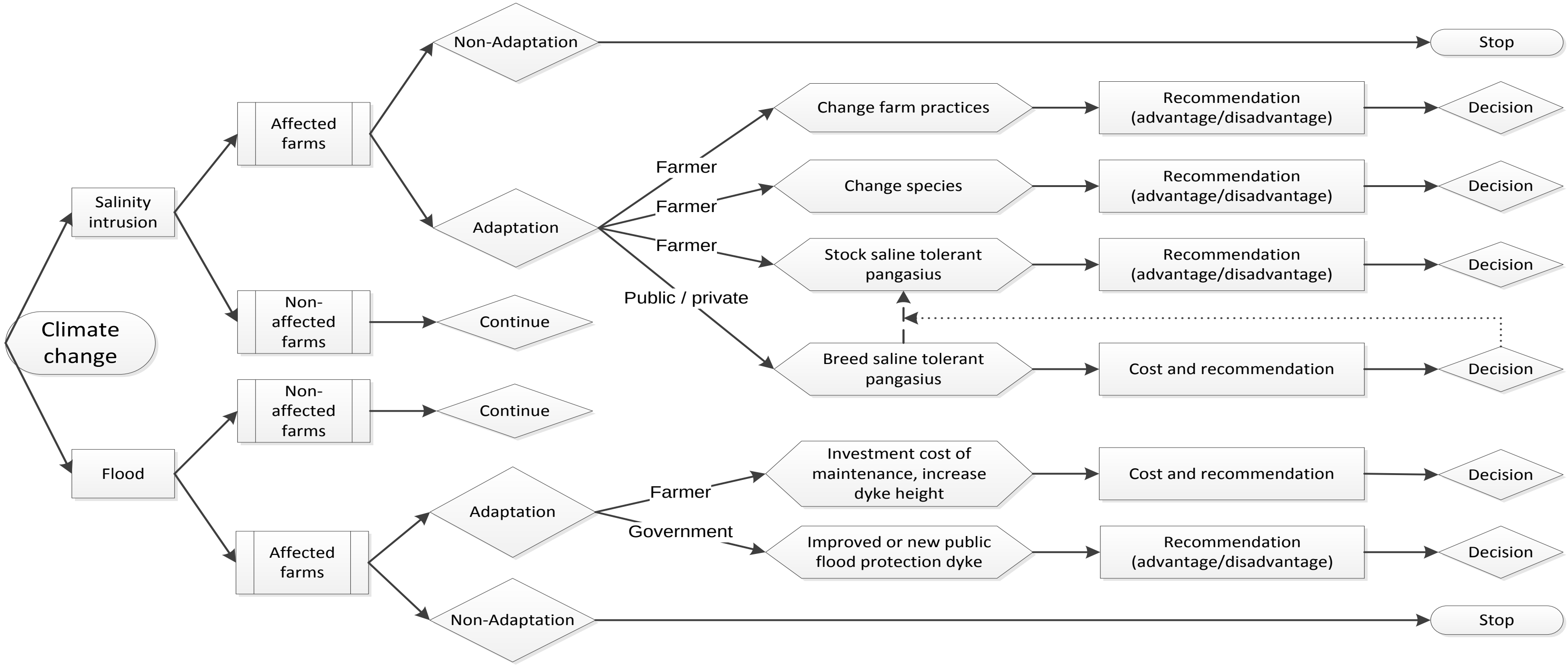

Fig. 5.2 The decision tree framework used for the decision making process of adaptation choices with event nodes and decision nodes.

The pangasius farmers in the affected areas have to choose. They can either stop the farming operation, or increase the height of pond dykes as an autonomous adaptive measure. Pangasius farms located in areas protected from flooding by flood protection dykes from government can benefit from the planned adaptation. We will analyse more details on these adaptive measures in Sections 5.4.4 and 5.4.5. To avoid the impact of the degraded quality of water in the flooding period, farmers can change the pond practice as presented in Section 5.4.1.

5.3.2. Salinity intrusion

Anh et al. (2014) presented the effect of salinity intrusion on the pangasius farms location in the coastal provinces of the Mekong Delta. All pangasius farms located in the south western area of the TraVinh province and most farms in the Ben Tre and Soc Trang provinces are already subjected to diurnal fluctuations of a 4‰ salinity level. The periods of this salinity threat, however, are likely to become longer. Anh et al. (forthcoming-a) found that the majority of the interviewed farmers (i.e. 93%) in the downstream region were concerned about salinity intrusion induced by sea level rise.

According to Phan et al. (2009), the yield of pangasius farms located in the downstream region was significantly lower than in the other regions. Farmers could not stock pangasius fingerlings in months with high salinity thereby reducing the cropping period of pangasius culture in these provinces (Anh et al., 2014).

To deal with this problem, the pangasius farming sector has to choose: farmers may adapt or stop. Adaptation may be autonomous at farm level through for instance changing pond practice or shifting to farming another species that has a high degree of salinity tolerance (i.e. an euryhaline species). On the other hand, planned adaptation such as shifting to a salinity resistant strain of pangasius requires the involvement of other stakeholders (refer to Sections 5.4.1, 5.4.2 and 5.4.3).

5.4. Analysis of options for adaptation of pangasius farming in the Mekong Delta

5.4.1. Changing pangasius farming practice

Some pangasius farmers in the coastal area can extend the nursing period of pangasius fingerlings to reduce the grow-out period in ponds during the months of high salinity (Anh et al., forthcoming-a). An extended nursery period will result in slightly higher cost for transport, as juveniles will be heavier, and perhaps at an increased risk (De Silva and Phuong, 2011).

In Vietnam, pangasius farms started experimenting with RAS (recirculating aquaculture systems), both for the nursery and grow-out phase. This can also be regarded as an autonomous adaptation. Results seem promising but the full costs and benefits are not known yet (Nhut et al., 2013). The water intake in these RAS systems is very restricted, except for the last weeks of the grow-out period. These RAS systems would simultaneously reduce water pollution and this is an additional benefit for the mitigation of the environmental impact of the pangasius sector (Bosma et al., 2011), a bone of contention of many environmental lobby groups (De Silva et al., 2010) which may contribute to the mitigation of climate change impact also.

5.4.2. Shifting to another species

To deal with saltwater intrusion, pangasius farmers in the coastal provinces of the Mekong Delta might also choose to crop another species (Anh et al., 2014). This option requires to develop a new adaptive capacity by farmers, and probably even requiring changes in infrastructure, in particular that of ponds. A pond with water depth of 3 to 4 m is preferred for pangasius grow-out but such deep ponds are unsuitable for most other commonly farmed salinity tolerant species, such as Asian seabass or shrimp. Pond restructuring is required especially for ponds located directly next to the rivers or main canals, and is likely to be very costly as lowering the water level will increase, for example, the pressure on the dykes. For other ponds, lowering pond depth may be realised by just using a lower water level. Both technical and economic aspects of the feasibility of shifting to another species need further study.

5.4.3. Breeding salinity tolerant pangasius

Many farmers, who face the risk for salinity intrusion prefer to continue producing pangasius rather than shifting to another species because they believe that only by farming pangasius, revenues can be maintained at a high level that enable the recovery of their investments (Anh et al., forthcoming-a). Therefore, De Silva and Soto (2009) suggested developing a salinity tolerant strain of pangasius. De Silva and Phuong (2011) noted that such a tolerant strain will require a minimal change to farming practices and the related infrastructure, and will avoid the need to develop new market chains.

Anh et al. (2014) reviewed several experimental studies on the salinity tolerance of several freshwater fish species and especially on pangasius in the Mekong Delta. The embryos of striped catfish can develop and hatch in brackish water of $11^{0}/_{00}$ (Do et al., 2012); 25g individuals can grow in salinity of up to $9^{0}/_{00}$ (Nguyen et al., 2011). Though these results indicate a potential for developing a salinity resistant strain of pangasius, one should consider that pangasius matures at more than 3 year (Trong et al., 2002). This increases the generation interval and slows down the breeding program On the other hand, the use of modern molecular genetic techniques in selective breeding has reduced the time period required to develop a strain with a desired trait, in this instance for example, tolerance to salinity, has reduced very significantly the time required compared to the traditional selective breeding programs used in the past.

According to Trong (personal communication), the generic cost of breeding program, starting from 150 individuals of wild broodstock of various origins in the Mekong river is about US$ 120,000 (Table 5.1). Due to the generation interval the actual cost will be fourfold (US$ 480,000). The cost per kg of pangasius produced in the coastal provinces, estimated at 10% of the total 1.2 million tonnes, would be US$ 0.004kg^{-1}. This is slightly more than 0.4% of the present production cost (US$ 1.1 kg^{-1}) and seems a feasible investment. Whether or not such a program can successfully breed a salinity tolerant pangasius, however, remains to be seen. The relatively long time frame and large costs of such a program requires the continuous and persistent involvement of public agencies or a private company.

Table 5.1. The generic cost (US$) of a fish breeding program in Vietnam, respecting the principles of an effective population size as established by Ponzoni et al. (2011).

	Year 1	Year 2	Year 3	Year 4
Fixed cost of infrastructure for renting a 1.5 ha farm with 1.1 ha of ponds*	7,200	7,200	7,200	7,200
Salary cost	4,700	6,400	6,000	4,250
Materials: broodstock and feed	4,000	6,800	16,100	16,000
Accessories, disposable tools	480	2,850	950	950
Electricity, gasoline, diesel	320	1,700	320	320
Equipment	1,400	250	12,700	0
Maintenance cost	700	2,100	1,600	1,400
Total	18,800	27,300	44,870	20,120

* Cost of land US$ 30,000 and of infrastructure US$ 23,0000; accounted for an interest rate of 8% and a depreciation of infrastructures over 20 years, exchange rate 21,000 VND for 1 US$.

(Source of primary data: Dr. Trinh Quoc Trong, Director of National Breeding Centre for Southern Freshwater Aquaculture, Vietnam, personal communication).

5.4.4. Increasing the height of the pond' dyke

The dykes of the pangasius farms and ponds have been threatened by flooding due to the increased water levels in the rainy season. This risk will worsen in the context of sea level rise caused by climate change (Anh et al., 2014). Pangasius farmers need to increase dyke heights to deal with flooding. Thus, both the investment and the operation cost for dyke and water exchange will increase.

According to Sinh (2008), the cost for dyke maintenance of pangasius farms in up- and mid-stream regions accounted for 0.23% of the total variable costs (per ha and per crop) and in the downstream region it was 0.12% depending on the threat of a flooding peak and farm location. While investigating autonomous adaptation measures of pangasius farmers, Kam et al. (2012) estimated the costs for individual dyke upgrading in the period of 2010-2020 to be about US$14.6 million in the up- and mid-stream regions and US$3.0 million in the downstream region. The costs for dyke upgrading of the entire pangasius farming sector will be approximately 1% of the total annual pangasius export value in 2013 as given by VASEP (2013).

In comparison with data from Sinh (2008) for this decade, the operation cost for dyke upgrading (per ha) of the pangasius farms in up- and mid-stream is expected to increase six times, and fifteen times downstream, respectively. The extra cost of autonomous adaptation by dyke upgrading per ha and per crop would be US$222 in the up and mid-stream region, and US$223 in the downstream region. These figures were obtained by dividing US$14.6 million and US$3.0 million by the number of ha (4380 and 896, respectively) and by the number of crops over ten years (15 for both regions). This would imply an increase of the costs for dykes to about 0.34% and 0.25% of the total variable costs (per ha and per crop) in the up- and mid-stream regions and in the downstream region, respectively.

5.4.5. Increasing the height of the public flood protection dyke

The action plan of MARD (2008) foresees improvements of the government dyke system as an appropriate adaptation measure to protect agricultural activities against flooding. The pangasius farms located within these dykes, therefore, will have lower autonomous adaptation cost for dyke upgrading at farm level.

The cost of this adaptation measure will be higher because of its larger extent. However, the benefits accrue to the entire economy of the protected area and therefore the cost cannot only be accredited to the pangasius farming.

5.5. Discussion and conclusion

According to Kabari and Nwachukwu (2013), decision trees are specifically used in decision analysis to support an identification of strategies. This study analysed the plausible adaptive measures of both autonomous and planned adaptation to deal with impacts of climate change using a decision tree framework. Decision support tools are often built through modelling (Gladwin, 1983; McIntosh et al., 2011; Kabari and Nwachukwu, 2013). Modelling is appropriate to support decision makers choosing suitable adaptation option when referring to data from statistics or from observational studies such as household surveys. However, without time series of sea level rise impacts and adaptation processes, the statistical uncertainty of modelling is high. We chose for a rule-based decision support tree, also because the preliminary analysis summarized above (Anh et al., 2014; Anh et al., forthcoming-a) showed that in most cases the problems are well circumscribed, and consequently the number of choices is limited.

This study used results from Kam et al. (2012) for the analysis of the autonomous adaptation. Just like all economic studies of climate change adaptation, their study was subjected to uncertainty surrounding the impacts of climate change projection, as well as to changes in input and output of commodity prices, in production technologies among others (Kam et al., 2012). The future changes, both in the market and in the international trade policies may affect the pangasius sector without linear adjustment of the farm gate prices. Thus predictions on the financial capacity of farmers to adapt may not be valid. At present, the profit margins of pangasius farming are lower than in the past (Khiem et al., 2010; De Silva and Phuong, 2011). The estimated increase of cost due to the climate change adaptations will further reduce profits. Thus if the margins do not improve, the risk of not recovering investments is high. If a farmer decides not to adapt to the impacts of climate change, the investment cost will be less than the cost for the farmers who adapt, but the former will face the risks induced by sea level rise. Some farmers may terminate farming operation either because they do not want to compromise the benefits they have accumulated already from pangasius culture, or because they think that they will not be able to recover investment costs.

The economic efficiency of farmers' autonomous adaptations by replacing species or changing aquaculture practice need to be considered. The preparation of these measures needs long term (public) investments, first for the studies and later for support to the transfer of technology. The autonomous adaptation thus becomes planned adaptation involving more parties such as institutes and local government (Smit et al., 2000).

Reinforcing a pond dyke or improving the public dyke system are both appropriate measures to protect pangasius farming against increased flooding risks. It is also important to point out that increasing public dyke heights will not only benefit pangasius farmers but also most other agricultural activities as well as rural and urban infrastructures. Hence this option is attractive to the government in general, though trade-offs on bio-diversity and on deposition of fertile sediments in e.g. rice-fields need to be considered (Lebel et al., 2009; Marchand et al., 2014).

In the downstream region, the breeding of a salinity tolerant strain of pangasius might be the most efficient option for about 10% of the sector to adapt to the salinity intrusion due to the least disruption to livelihoods, the minimal change requirement in infrastructure and the maintenance of existing and reputedly highly established market channels. The use of modern molecular genetic techniques have shortened the time period required to develop strains with specific traits significantly (Hulata, 2001). Perhaps pangasius offers a good opportunity to develop a selected trait of salinity tolerant strain relatively fast. On the other hand, breeding and selection needs to be a continuous process otherwise the acquired characteristics will be diluted and might be lost (Syrstad and Ruane, 1998; Ponzoni et al, 2007). The case of tilapia shows very well what happens if selection is not continuous (Fessehaye et al, 2005), and special breeding programs have been designed to maintain stock quality when institutional capacity is low (Fessehaye et al, 2006).The Vietnamese pangasius farmers, in the upstream and middle stream regions also, need to organise themselves continuous breeding and selection programs in order to prevent a decline in broodstock and seeding quality.

Acknowledgements

We acknowledge the Aqua-climate project coordinated by the Network of Aquaculture Centres of Asia-Pacific (NACA), under the auspices of the Norwegian International Development Agency for funding part of our study. We also would like to thank Dr. Trinh Quoc Trong for contributing to our study.

Chapter 6

General Discussion

In the geological history of our planet, climate has always changed. This is well documented. Some of these changes have resulted in the disappearance of flora and fauna prevalent at that period. For example, dinosaurs disappeared in the "Mesozoic era" from the planet; such extinctions are likely due to long-lasting, extremely harsh weather conditions after a large meteorite impact or a large volcano eruption (Hardy, 2003). Currently, our planet is also experiencing a climate change, , however, this may not entirely be a natural phenomenon. Human activities intensified since the beginning of the industrial revolution in the 19th century. This intensification resulted in continuous increases of greenhouse gas emissions and, subsequently, in the climate change (e.g. increases in temperature, frequency of extreme and unusual weather events, sea level rise and melting glaciers) that we are now experiencing. The need for a scientific basis of climate change mitigation options led to the establishment of the International Panel on Climate Change in 1988 (IPCC, 2013). IPCC assesses and summarises the published peer-reviewed research on climate change and its impacts and evaluates adaptive and mitigating measures. This impartial scientific body provides an unbiased account of issues associated with climate change to the general public,. For example, the findings of the IPCC's Fourth Assessment Report (AR4) consolidated by AR5 (IPCC, 2007a; 2013) are :

- There is a 95 percent certainty that human activities are responsible for the current increase in temperature;
- The atmospheric carbon dioxide levels are unprecedentedly high compared to the last 800,000 years;
- Sea level will rise at a faster rate than in the last 40 years; and
- Over the last two decades, the Greenland and Antarctic ice sheets have been melting and glaciers have receded in most parts of the world.

As such, climatic change is a reality and has been to a great extent anthropogenic. Humanity has to find mitigating measures to combat these impacts. At a global scale, since 1994 the United Nations Framework Convention on Climate Change (UNFCCC) prepares policies for mitigation, such as the Kyoto protocol (FAO, 2008). Climate change will likely have impact on agriculture and aquaculture, and therefore the poor and developing economies depending mainly on the food production are particularly vulnerable to climate change (Parry et al., 2004; WFP, 2009). In this regard Vietnam, depending largely on both agriculture and aquaculture, is no exception.

According to the General Statistic Office of Vietnam (GSOV database, 2014), the yield of capture fisheries doubled from 363 to 646 thousand tonnes in the Mekong Delta of Vietnam whereas the aquaculture production grew eight times from 267,000 tonnes to 2,132,000 tonnes between 1995 and 2011 (Figure 6.1). These production trends illustrate the important contribution of aquaculture to food security whereas the capture fisheries reached its limits in Vietnam. This reflects also the global trend (FAO, 2014).

The pangasius farming sector has contributed significantly to the success of Vietnamese aquaculture (Phan et al., 2009; De Silva and Phuong, 2011; VASEP, 2013) accounting in excess of more than half of the aquaculture production of the Mekong Delta in recent years (Fig. 6.1). However, the Mekong Delta is already facing the impacts of sea level rise caused by climate change (Dasgupta et al., 2007; Grinsted et al., 2009). This sea level rise may adversely impact aquaculture (Handiside et al., 2007; De Silva and Soto, 2009).

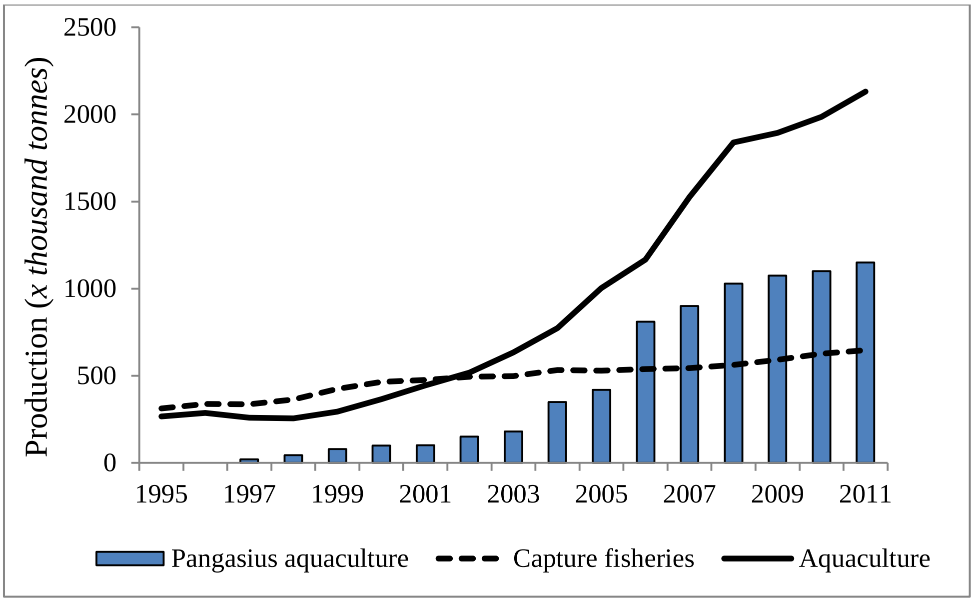

Fig. 6.1 The trend of production from capture fisheries and aquaculture, and the share of pangasius to aquaculture, in the Mekong Delta in the period of 1995-2011.

In view of the importance of the pangasius farming system to the economy and food security of Vietnam, and its vulnerability to climate change through sea level rise, this study was initiated. This thesis aimed to estimate the impact of climate change on pangasius farming, to assess the pangasius farmers' capabilities to deal with potential climate changes and to propose adaptation strategies to support farmers and policy makers. In this regard the following four specific questions were addressed:

(1) Does sea level rise (and the consequent saline water intrusion and river discharge) affect the potential area for pangasius culture?

(2) How do pangasius farmers perceive and deal with the effects of sea level rise?

(3) Is the technical efficiency of farms impacted by sea level rise?

(4) Which are appropriate adaptation and/or mitigation measures?

The study investigated the answers for these questions and addressed them separately in the chapters 2 to 5. This concluding chapter 6 discusses and attempts to "tie up" the main findings from the previous chapters by discussing the answers to the above questions and placing them in a broader context in sections 6.1 to 6.4. Thereafter I will discuss the fate of aquaculture in relation to climate change and food security (in section 6.5). The role of government and institutes in climate change adaptation to aquaculture will be discussed in section 6.6. The conclusion that Vietnamese pangasius aquaculture can adapt, is presented in section 6.7.

6.1. Impacts of sea level rise scenarios on pangasius farm locations

Sea level rise scenarios applied to the Mekong Delta, Vietnam

IPCC (2007a) projected global sea level to rise at a greater rate during the 21st century than in the period from 1961 to 2003. IPCC's AR4 pointed out that *"global sea level gradually rose in the 20th century and is currently rising at an increased rate, after a period of little change between AD 0 and AD 1900. Sea level is projected to rise at an even greater rate in this century."*(IPCC, 2007a). The AR5 (IPCC, 2013) confirmed that the rate of global mean sea level rise has continued to increase since the early 20th century. According to IPCC (2013), future emissions of GHGs, aerosol particles and other forcing agents through anthropogenic activities, together with land use changes which are dependent on socio-economic factors, are affected by global geopolitical agreements to achieve mitigation of emissions. The climate change models from the AR4 using the Special Report on Emission Scenarios (SRES) did not include additional climate mitigating initiatives, such as the UNPCCC's Kyoto Protocol (IPCC, 2013). The AR5 used the Representative Concentration Pathways (RCPs) representing a larger set of mitigation scenarios (IPCC, 2013). For example, RCP2.6 stays within the targeted maximum global mean temperature increase of 2°C and RCP8.5 indicates business as usual conditions, i.e. no changes of policies and practices regarding mitigation measures.

The current study used sea level rise scenarios of +30, +50 and +75 cm to estimate the affected pangasius farming locations (Chapter 2). These levels were based on sea level rise scenarios projected by the Ministry of Natural Resources and Environment of Vietnam (MONRE, 2009). MONRE estimated climate change and sea level rise scenarios for Vietnam based on the six different SRES scenarios, namely low (B1, A1T), medium (B2, A1B) and high (A2, A1FI) (MONRE, 2009). Considering the global emission scenarios and future socio-economic development, MONRE proposed to apply the B2 scenario for projecting climate change and sea level rise for Vietnam and estimated the sea level rise in 2100 at about 75 cm (MONRE, 2009). The mean of the global sea level rise projected by AR4 using SRES' medium emission scenario A1B (60 cm), is in range of the results estimated by AR5 using RCP6.0 and RCP8.5, +55 cm and +74 cm respectively (Table 6.1). The highest sea level rise used in Chapter 2 (+75 cm) is about the same as the mean of the worst case scenario of AR5 (+74 cm). This demonstrates the applicability and timeliness of the scenarios that MONRE selected.

All scenarios have a large margin of uncertainty (Table 6.1) due to assumptions on inputs of climate change models and on outcomes of human activities. Specific uncertainties for the Mekong Delta relate to the unknown changes in upper reaches of the river that may affect the volumes of water and sediment passing through the Mekong Delta (Chapter 2).

Table 6.1 The projected global mean sea level rise (m) in 2100 based on the Special Report on Emission Scenarios (SRES: IPCC, 2007a) and the Representative Concentration Pathways (RCP: IPCC, 2013)

	SRES A1B (AR4)	**RCP2.6 (AR5)**	**RCP4.5 (AR5)**	**RCP6.0 (AR5)**	**RCP8.5 (AR5)**
Global mean sea level rise in 2100	0.60 (0.42 to 0.80)	0.44 (0.28 to 0.61)	0.53 (0.36 to 0.71)	0.55 (0.38 to 0.73)	0.74 (0.52 to 0.98)

Affected pangasius locations

Pangasius farming occurs in the lower reaches of the Mekong along the two main branches (Tien and Hau rivers) and associated channels covering six provinces. Farms near the coast experience reduced production and this is thought to result from minor fluctuations in salinity (2-5$^{0}/_{00}$) from the tidal influences (Phan et al., 2009). As Vietnam is predicted to be the fifth most vulnerable country to sea level rise in the world (Dasgupta et al., 2007), the current investigation will determine the plausible extent of impacts of different sea level rise scenarios and associated upstream flooding on the pangasius farming sector (Chapter 2). Based on the simulations that were carried out for sea level rises of +30, +50 and +75 cm, the areas that could be affected by flooding and salinity intrusion with longer flood periods and larger inundation areas in up- and mid-stream regions, were determined together with the increase of the areas affected by salinity intrusion as well as those with a longer period of higher salinity level in the coastal provinces (Chapter 2). Frequency and extend of flooding are not expected to change for the farms in the downstream regions but these farms have to increase the height of their dykes.

According to IPCC (2014), climate change will adversely impact fisheries and aquaculture on a global scale. Negative impacts of climate change on aquaculture could occur directly through changes of water temperature and dissolved oxygen levels or indirectly by an inability to catch sufficient quantities of feed-fish to meet production needs, increasing flood risks and salinity intrusion (De Silva and Soto, 2009; IPCC, 2014). As suggested by IPCC (2014), the pangasius farming operations based on pond production are particularly at risk in low-lying coastal areas in the Mekong Delta. When starting their venture, on average six years ago, the farmers in those areas deliberately accepted these impacts because of lower production costs (Chapter 4). In the downstream regions near the coast, farmers may adjust their production systems (see 6.2). The pangasius farmers in upstream regions such as the An Giang province face risks, such as flooding from increased rainfall and storm surges, and inundation from rising sea levels (IPCC, 2014; Chapter 2, 3). In the past the pangasius farmers in the up- and mid-stream regions experienced increased cost for treatment of fish disease due to hazardous flooding, while others lost (part of) their stock due to diseases (Chapter 4). The exact diseases were unknown but the farmers assumed that changes in water quality had caused stress that challenged fish's health. This point corroborates the suggestion of IPCC (2014) that fish raised in freshwater aquaculture are at risk from an increased frequency of disease outbreaks, which are also exacerbated by stress. The stressors that are suggested by IPCC (2013), include higher water temperatures and lower dissolved oxygen levels. However, deteriorated water quality should be added.

6.2. Perception of climate change of pangasius farmers

The perceptions of the farming communities on climate change and its impacts on primary production systems, whether on land or in water, are highly relevant (IPCC, 2007b). These perceptions are important to assess the willingness to adopt adaptations to cope with the impacts of climate change (Gbeitbuo, 2008), as well as to adopt mitigation measures.

Pangasius farmers gained the bulk of their knowledge on climate change from mass communication media. Their experience related to climate change was shaped by extreme climatic events. Meanwhile the gradual changes of the climate, such as sea level rise are perceived less well. This difference in their perception can affect their motivation to adapt to climate change impacts. Chapter 3 reveals that education level of pangasius farmers , their age, the years of aquaculture experience, the dependency rate on pangasius farming for their income and whether they own the land or not, increase their perception on climate change impacts. Most pangasius farmers in the upstream region of the Mekong Delta had experienced reduced benefits due to extreme flooding. Downstream, in the coastal provinces, from the start farmers were confronted with seasonally high and gradually increasing salinity levels.

6.3. Technical efficiency in relation to climate change factors

The evaluation of technical efficiencies provides opportunities to identify aspects of the farming systems that need to be changed to increase cost effectiveness of the production. However, the technical efficiencies have not been determined for most different types of aquaculture systems . For example, only the technical efficiencies of trout pond farming in the Turkish Black Sea Region (Cinemre, 2006), tilapia pond operations in the Philippines (Dey et al., 2004), semi-intensive/intensive carp farming in India (Vereena et al., 1999; Sharma & Leung 2000), Chinese fish farms polyculture (Sharma, 1999) and the carp farming of Bangladesh (Ferdous and Murshed-e-Jahan, 2008) are examined. If changes have to be made in the aquaculture systems to combat climate change, the evaluation of the technical efficiency enables an assessment whether these changes permit farms to remain productive and cost effective or not.

The technical efficiency of pangasius farms in the Mekong Delta of Vietnam was on par with fish farms operated in other countries (Chapter 4). Pangasius farmers in the flood prone areas of the upstream and mid-stream regions had a larger scale of operation, whereas salinity intrusion reduced the scale of farms located in the downstream region (Chapter 4). More efficient use of inputs, such as feed, seed and labour, and an increased scale of operation, as well as intensified training will be essential for lifting productivity. The overall adaptation strategy (e.g. stronger dykes) requires a one-time investment, while the increased salinity level downstream will require also increased recurrent operational costs either at sector level (e.g. breeding of salinity tolerant pangasius) or at farm level (e.g. a prolonged nursery phase or reduced number of stockings/harvests).

Our analysis, however, did not establish a firm influence of climate change on the technical efficiency. Perhaps, data sets of a larger number of farms on a longer timeframe that include years/crops that were affected by rare weather events, are required to obtain more robust and statistically valid observations.

Moreover these longitudinal datasets need to include one or more specific parameters related to climate change impacts such as salinity level or/ and height and length of water (flood) level.

6.4. Adaptation options

According to Smit et al. (2000), adaptive responses to climate change varies in process and forms. Carter et al. (1994), distinguished between 'autonomous' (i.e. automatic, spontaneous, passive or natural) adaptation(s) and 'planned' (i.e. strategic or active) adaptation(s). Smit et al. (2000) noted that the autonomous adaptations in unmanaged natural systems diffed from consciously planned adaptations based on intent or purposefulness with respect to an expected climate stimulus. Adaptations that are initiated by public agencies, are usually planned but adaptations by individuals or groups may be autonomous or planned, or some combination of the two (Smit et al., 2000). IPCC (2014) indicated several available measures to help aquaculture to adapt to climate change impacts. For example, the shellfish farmers in the north-western US adapted autonomously to changes in the acidity of seawater by immediately blocking the intake when pH levels fall below a certain threshold, or actively planned to move their hatcheries to Hawaii. To adapt to the expected climate change impacts the proposed and already applied measures by pangasius farmers included increasing dyke height, and, especially downstream, decreasing the number of stockings or stocking larger fish. Larger pangasius are probably capable of tolerating higher salinity levels without a negative effect on their performance (Chapter 3), but conclusive scientific eidence is yet to obtained.

Facing the risk of flooding and salinity intrusion induced by sea level rise on the pangasius farming sector in the Mekong Delta (Chapter 2, 3 and 4), Chapter 5 proposed plausible measures that include autonomous and planned adaptation(s). The farmers in different administrative units are or feel affected differently by the impacts of climate change. Our straightforward decision support tree aims at helping the stakeholders by clearly defining the conditions under which specific decisions should be taken. The proposed suitable autonomous adaptive measures of pangasius farmers are: increasing pond dyke height, changing pond practice(s) (spontaneous adaptation) and shifting to farm other (more salinity tolerant) species (spontaneous adaptation). However, the last adaptation measure may only be selected by few farmers because it requires investments in new buildings, other professional networks and restructuring of the ponds (Chapter 5). The planned adaptation measures include improving flood protection dykes (i.e. strategic adaptation), developing a salinity tolerant strain of pangasius (active adaptation), and stocking this salinity tolerant strain by the pangasius farmers (active adaptation). These measures should be implemented by the national or provincial governments, public agencies or private companies.

Chapter 5 revealed the costs of autonomous adaptation. When pangasius farmers improve their pond dyke by increasing the height, they increase the total variable costs (ha^{-1} $crop^{-1}$) by about 0.34% and 0.25% in the up- and mid-stream regions, and in the downstream region, respectively. The improvement of flood protection dykes reduces the need for further autonomous adaptations of individual pangasius farmers and is also beneficial for other sectors but may have negative effects for biodiversity and rice-farmers (Lebel et al, 2009; Marchand et al. 2014).

When balancing the evidence, taking into account socio-economic conditions, costs and benefits, the most convenient option for the downstream farms would be to develop a salinity tolerant strain of pangasius. This option likely results in the least disruption to livelihoods, requires minimal changes in infrastructure and permits to maintain the well-established market channels. In the wake of the current advances in molecular genetic techniques applicable for selective breeding, innovative technologies may allow to achieve desired targets relatively soon. Chapter 5 estimated the annual cost of such a breeding program to produce and maintain a salinity tolerant strain of pangasius at about US$ 120,000. However, as pangasius is a late maturing species, this type of multi-generation breeding requires a long term program of selection and breeding to maintain the desired characteristics in the produced broodstock, and cannot be dealt with through a project approach as most governments tend to do (Chapter 5). This means a 0.4% increase of present production cost for the downstream farms producing about 10% of the export volume. Either a larger private sector company/organisation or a farmers organisation should take a lead role to develop and supply the salinity tolerant pangasius seed.

6.5. Climate change, aquaculture and food security

According to FAO (2012 and 2014), the annual mean global consumption of fish increased from 16 kg per capita in 2000 to more than 19.2 kg per capita in 2012. In 2012, close to half of direct human consumption of fish was provided by aquaculture (FAO, 2014), about six year sooner than earlier estimates (FAO, 2012). The Asian-Pacific region contributes the major share to global fish supply from farming. Freshwater finfish aquaculture in this region dominates with nearly 88% of the global finfish production (Aquaculture Service, Network of Aquaculture Centres in Asia-Pacific, 2011). Vietnam is within the top-ten ranked aquaculture producers with a significant contribution of the pangasius farming sector (Aquaculture Service, Network of Aquaculture Centres in Asia-Pacific, 2011; Chapter 1).

Belton and Thilsted (2014) demonstrated the shifts in the structure of the global fisheries sector where the supply of aquaculture production increases relative to capture fisheries yields. The impacts of climate change impose challenges to food security (Ruckelshaus et al., 2013). While pressures on marine fisheries will increase, the capacity to meet future fish demand in the context of climate change will more than ever rely on the performance of aquaculture (HLPE, 2014). Thus, to ensure sufficient fish for food security, a projection of future fish demand-supply scenarios and of the investments in aquaculture will be needed (Cleasby et al., 2014). Based on such projections, aiming at satisfying the future national fish demand, European Union countries (including the Netherlands) support the sustainable development of (among others) the Vietnamese pangasius sector.

HLPE's (2014) argues that pangasius farming is a sector with high rural growth, job creation and new income generating activities contributing to both local, national and global food security (De Silva and Phuong, 2011; Chapter 1). Complementary to the important role of pangasius exports which contribute to global food consumption, De Silva and Phuong (2011) pointed out that the pangasius sector also provides livelihoods for many rural households. This improves socio-economic conditions and increase local food security. Pangasius farming is a diversity of aquaculture systems with different operation scales (from pond surfaces less than 1 ha to more than 5 ha), different degrees of intensity of capital (from US$ 46,000 to US$ 2,500,000) and labor intensity (from 2 to 33 workers) (Phan et al., 2009; De Silva and Phuong, 2011; Chapter 4). Although 82% of the pangasius farms are still small and have other agriculture components, most of the pangasius for export is produced on larger mono-culture ventures (De Silva and Phuong, 2011). The larger farms can cover the certification costs required for most export markets and thus produce over 90% of the export volume (Loc et al., 2010). The various components of the sector include extension and research, finance, veterinary pharmacy, feed, transport of input and product, hatcheries, nurseries, grow-out, processing and export (Loc et al., 2010), and provide income and thus food security for at least 170,000 people (De Silva et al., 2010).

Chapter 5 analyzed the options of the sector for adaptation to climate change impacts, including technologically advanced options (HLPE, 2014), such as breeding a salinity tolerant strain of pangasius and the use of recirculating aquaculture systems which are adapted to the local farming conditions. The findings of this study could enable the relevant authorities, pangasius farming communities and other involved stakeholders to choose the appropriate solutions to the perceived climate change impacts in order to maintain the sustainable development of this important economic activity contributing to food security.

6.6. Role of governments and institutes in climate change adaptation of aquaculture

According to IPCC (2007b), government institutions and policies play an important role in enhancing the ability of local populations to adapt their production systems to cope with climate change, or in mediating the supply of, and access to, food and related resources. Both IPCC (2007b) and our research in Chapter 3 suggest that important and effective measures to enhance the adaptive capacity and the acceptance of mitigation measures are education and providing easily accessible information on climate change. Additionally, Chapter 5 suggested governments to improve the flood protection dykes.

Considering the adaptation options suggested in Chapter 5 together with the role of aquaculture to supply food security in section 6.5, the priority areas of institutional and policy measures suggested by De Silva and Soto (2009) could be applied to the pangasius farming sector. These include implementing an ecosystem approach to aquaculture and enhancing the use of suitable inland water bodies through culture-based fisheries and appropriate stock enhancement practices. Such an ecosystem-based approach needs support from relevant research including physical, ecological, social and economic aspects. This research should include monitoring for new diseases, and developing preventive treatments, better feeds and feeding practices that are more ecosystem friendly (De Silva and Soto, 2009). These technologies must also be communicated to the sector stakeholders, including farmers. In coastal areas, applying an integrated coastal management approach could also enhance the adaptive capacity. According to Troadec (2000), integrating fisheries and aquaculture into coastal zone management would increase the coping capacity of small communities in East Asia, South Asia and South-East Asia to sea-level rise.

6.7. Conclusions and recommendations

In Vietnam, some of the expected climate change impacts are unavoidable. The most threatening for the Mekong Delta is sea level rise. To answer its first research question this study simulated the water level and salinity intrusion induced by three different sea level rise scenarios. This simulation showed that the pangasius farms threatened by more frequent and higher levels of flooding are mainly located in up- and mid-stream regions, and those threatened by high salinity concentration in the downstream region. The analysis related to the 2nd research question revealed that the pangasius farmers experienced impacts through extreme climatic events while they poorly perceived the gradual climate changes, such as sea level rise. The technical analysis done to answer the 3rd research question demonstrated that the pangasius farms in the flood prone areas of the upstream and mid-stream regions had a larger scale of operation compared to those in the downstream region. Here salinity intrusion already reduced the scale of operation. In the downstream region, farm size was thus smaller and farmers stocked less fish per hectare. This reduced stocking rate might be related to the practice of downstream farmers to stock older juveniles; older pangasius seem to be less sensitive to higher salinity levels in the ponds. This change of pond practice is an autonomous adaptation that likely can be used to counteract the impacts of climate change.

Through a decision-making framework we assessed other appropriate adaptation and/or mitigation measures to answer the 4th research question. Other autonomous adaptations of the pangasius farmers include heightening the pond dyke, shifting to other salinity tolerant species, or stocking a salinity tolerant pangasius. Farmers prefer to continue farming pangasius to recover their investments. The development of a salinity tolerant strain of pangasius requires a strategic planned intervention of government/public agencies or private companies. The improvement of flood protection dykes by government requires further planned adaptation. I recommend to initiate policy discussions on these strategic adaptive measures as soon as possible, further developing the decision-making tree presented in this thesis, in order to maintain and improve the sector and the associated livelihoods.

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SUMMARY

The present state of our knowledge of earth's climate change and tectonic plate movements indicates that sea level rise will greatly affect the Mekong Delta. Pangasius farming is intensively done particularly along the Mekong river branches, Tien and Hau rivers, and the associated channels in Vietnam. The contribution of the pangasius sector to the economy and food security of six Vietnamese provinces is important; the sector is one of the biggest employers in the Mekong Delta. Considering this setting, the author initiated this study to estimate the impact of climate change on pangasius farming, assess the capabilities of pangasius farmers in dealing with potential climate changes, and propose adaptation strategies useful to farmers and policy makers. The following four specific questions were addressed:

(1) Does sea level rise (and the consequent saline water intrusion and river discharge) affect the potential area for pangasius culture?

(2) How do pangasius farmers perceive and deal with the effects of sea level rise?

(3) Is the technical efficiency of farms impacted by sea level rise?

(4) Which are appropriate adaptation and/or mitigation measures?

Chapter 2 presents the plausible impact of three climate change scenarios and associated sea level rise levels (SLR) on the pangasius farming sector. Based on the model simulations that were carried out for SLRs of +30, +50 and +75 cm, the study was able to project which areas would be affected by flooding and salinity intrusion. Flood periods will be longer and larger areas will be inundated in upstream and mid-stream regions. In the coastal provinces, there will be more areas that will be affected by salinity intrusion; and the already affected areas will experience a longer period of higher salinity level. The results showed that at SLR+50, the 3m-flood level would spread downstream and threaten farms located in upstream and midstream regions. Rising salinity levels for SLR+75 will reduce the window appropriate for the culture of pangasius in the coastal areas. Frequency and extent of flooding, however, are not expected to change for the farms in the downstream regions. But these farms have to increase the height of their pond dykes when they are located outside the public flood-protection dykes.

The pangasius farming operations based on pond production will be particularly at risk in low-lying coastal areas in the Mekong Delta. However, farmers choose to be there and accept trade-offs because of lower production costs (See Chapter 4). Many pangasius farmers in the upstream and midstream regions incurred increased cost to treat fish disease due to hazardous flooding. The more unfortunate ones, either had totally lost their stock, or just lost a part of it. Although the exact disease was unknown, the farmers assumed that change in water quality has stressed the fish and challenged their health.

Chapter 3 analyses the perception on and adaptation to climate change impacts of pangasius farmers. Results show that they have gained knowledge on climate change from mass communication media. However, they have a low perception on the gradual impacts of climate change, such as sea level rise. Their experience related to climate change has been shaped by extreme climatic events. Their perception on climate change impacts is positively correlated with the education level of pangasius farmers, their age and aquaculture experience, the dependency rate on pangasius farming for their income and whether they own the land..

Most pangasius farmers in the upstream region of the Mekong Delta said that they had experienced a reduction of benefits due to some extreme floodings. To adapt they had or planned to increase the height of their farm's dykes. In the coastal provinces, most farmers experienced seasonally high and gradually increasing salinity levels. To adapt to the perceived climate change impacts, they increased the height of the farm's dykes, decreased the number of stockings, or stocked larger fish. Farmers perceived that larger pangasius were more tolerant to higher salinity levels; although conclusive scientific evidence has yet to be obtained. Other adaptations suggested by farmers were to stop farming, change species or breed salinity-tolerant pangasius. To learn adaptation knowledge and skills, farmers expressed their strong reliance on technical support from government agencies, but those from coastal provinces did not express the need for training by these agencies. Chapter 3 suggests the provision of education and easy access to climate change-related information as effective measures to enhance the autonomous adaptive capacity as well as the acceptance of mitigation measures.

Chapter 4 analyses the technical efficiency of the pangasius farming operation and its relationship to climate change impacts factors. Knowing the technical efficiency of a production process provides planners and implementers with a solid basis on identifying which aspects of the enterprise need to be changed to increase cost-effectiveness of the production. If farmers were to make some changes to combat climate change, the evaluation of the technical efficiency will enable them to assess if these changes would make their farms remain either productive and cost-effective or not. The mean technical efficiency score assuming constant return-to-scale is 0.66, and under variable return-to-scale, 0.84. The technical efficiency of pangasius farms in the Mekong Delta of Vietnam is at par with that of the fish farms operated in other countries. Pangasius farmers in the flood-prone areas of the upstream and mid-stream regions have a larger scale of operation, while those in the salinity-prone areas located in the downstream regions have a smaller scale of operation. Technical efficiency of downstream farmers is higher due to lower energy cost and stocking once a year; in contrast, upstream and midstream farms needed to pump water and stocked at least three times in a two-year cycle. To increase their productivity, farmers will need to more efficiently use inputs, such as feed, seed, labour, and increase their scale of operation, as well as, intensify their training related to pangasius culture. The results of regression analysis showed a positive effect on technical efficiency of the farmers' education level, and of having experienced climate change impact through flooding or salinity intrusion in the past. Our analysis, however, does not establish a firm influence of climate change on the technical efficiency. Data sets of a larger number of farms, on a longer time frame that includes years in which farms are affected by weather events, are needed for us to obtain robust statistically valid observations. Moreover these longitudinal datasets need to include one or more specific parameters related to climate change impacts such as salinity level and/or height and length of water (flood) level.

Facing the risk of flooding and salinity intrusion induced by sea level rise on the pangasius farming sector in the Mekong Delta (Chapters 2, 3 and 4), Chapter 5 proposes a framework for decisions on plausible autonomous and planned adaptation(s). The proposed suitable adaptive measures of pangasius farmers in categories of autonomous adaptation are:

- increasing height of pond dykes (autonomous adaptation),
- changing pond practice(s) (spontaneous adaptation), and
- stocking a salinity-tolerant pangasius if available (spontaneous adaptation).

The cost of autonomous adaptation by pangasius farmers through increasing the height of the pond dykes is estimated at about 0.34% of the total variable costs (ha^{-1} $crop^{-1}$) in the upstream and mid-stream regions; and 0.25% in the downstream region.

In the categories of planned adaptation, the appropriate solutions include:

- improving flood protection dykes by government (strategic adaptation),
- developing a salinity-tolerant strain of pangasius through the intervention of government/public agencies or private companies (active adaptation), and
- shifting to farming other salinity-tolerant species (spontaneous adaptation).

However, the last of the above-mentioned adaptation may be chosen by few farmers because this requires investments in new know-how and networks, and in restructuring the ponds. The expansion and improvement of the government's flood protection dyke system may decrease the need for autonomous farmer's adaptation and may positively affect other sectors as well. However, the decision makers need to consider that the construction of a flood protection dyke system will negatively affect sedimentation and biodiversity (Chapter 5 and 6). On the balance of arguments, and taking into account socio-economic conditions and cost benefits, I recommend to develop a salinity-tolerant strain of pangasius for the downstream region. This option will likely result in the least disruption of livelihoods, require minimal changes in infrastructure, and permit to maintain the already well-established market channels. Current advances in molecular genetic techniques applicable for selective breeding might allow scientists to breed salinity-tolerant strain of pangasius in a relatively shorter time frame. Chapter 5 presents also the estimated annual cost of a classical breeding program to produce and maintain a salinity-tolerant strain of pangasius: about US$ 120,000. This means a 0.4% increase of present production cost for farmers in the downstream region assuming this region produces 10% of the volume. Preferably, either a private sector or a farmers' organisation could take the role to develop and supply the salinity-tolerant pangasius broodstock.

The overall adaptation strategy which involves construction of stronger dykes, requires mainly a one-time investment; while the increased salinity level downstream will require also increased recurrent operational cost either at sector level (breeding salinity-tolerant pangasius) or at farm level (prolonged nursery phase or reduced number of stockings/harvests). The findings of this study are expected to enable the relevant authorities, pangasius farming communities, and other involved stakeholders to choose appropriate solutions on the perceived climate change impacts. This study provides a baseline to planners for developing strategies that will maintain the sustainable development of pangasius farming which is an important economic activity contributing to food security in Vietnam.

SAMENVATTING

De huidige kennis van het klimaat gecombineerd met de tektonische bewegingen van continenten, toont aan dat gevolgen van klimaatverandering onafwendbaar zijn voor Vietnam. Het meest bedreigende gevolg voor het Vietnamese deel van de Mekong Delta is zeeniveaustijging. De kwetsbaarheid van de Mekong Delta voor de gevolgen van deze stijging was de aanleiding voor deze studie.

De in Nederland veel verkochte Pangasius visfilet wordt vooral geteeld langs de twee grootste takken van de Vietnamese Mekong (namelijk de Tien en Hau tak) en de daarmee verbonden kanalen in zes kustprovincies. De bijdrage van de pangasius sector aan de Vietnamese economie en voedselzekerheid is groot. Deze op vijverteelt gebaseerde sector is bijvoorbeeld één van de grootste werkgevers in de Mekong Delta. De in deze thesis beschreven studies duiden de ruimtelijke gevolgen van klimaatverandering op verschillende pangasius bedrijven, kwantificeren de capaciteit van de pangasius telers om de potentiele gevolgen van klimaatveranderingen op te vangen, en analyseren de adaptatie strategieën ten behoeve van telers en beleidsmakers. De studie behandeld vier specifieke onderzoeksvragen:

(1) In hoeverre bedreigt zeeniveaustijging (en de daardoor veroorzaakte zoutwaterindringing en extreme waterniveaus) de locaties van pangasius productie bedrijven?
(2) Welke gevolgen van de zeeniveaustijging nemen de pangasius producenten waar en welke aanpassingen zijn zij van plan te nemen of hebben ze al genomen?
(3) Is de technische efficiëntie van de bedrijven aangetast door waargenomen veranderingen?
(4) Welke adaptatie en/of mitigatie maatregelen zijn het meest geschikt?

Hoofdstuk 2 bepaalt de verwachte gevolgen van verschillende klimaatscenario's op basis van de huidige locaties van de pangasius productiebedrijven. De simulaties, gedaan voor zeeniveaustijgingen (ZNS) van +30, +50 en +75 cm, lokaliseren de gebieden die met overstromingen en zoutwaterindringing te maken krijgen, evenals de tijdsduur en de hoogte van de overstromingen, en de tijdsduur en het hogere zoutgehalte. Overstromingen zullen langer duren en grotere gebieden omvatten in de midden- en bovenstroomse gebieden. Hier kunnen hogere en sterkere vijver dijken of publieke dijken bescherming bieden. In de kustprovincies krijgt een groter gebied te maken met zoutwaterindringing en krijgen de meeste bedrijven langere periodes en hogere zoutniveaus te verduren. De resultaten geven aan dat bij ZNS+50, het gebied met overstromingen van meer dan drie meter waterhoogte zich zal uitbreiden en meer bedrijven in midden- en bovenstroomse gebieden gaat bedreigen. Het zoutgehalte bij ZNS+75 zal de geschikte periode voor de teelt in de kustgebieden sterk verkorten. De benedenstroomse bedrijven krijgen naar verwachting nauwelijks te maken met meer en langere overstromingen, maar bedrijven buiten de beschermingsdijken moeten wel hun vijverdijken verhogen en versterken. De op vijverteelt gebaseerde pangasius productie is dus vooral bedreigd in de lager gelegen delen van de kustprovincies in de Mekong Delta waar boeren zich onlangs bewust hebben gevestigd vanwege de lagere productiekosten. Zij moeten de risico’s op de koop toe nemen. Verder geeft Hoofdstuk 4 aan dat als gevolg van plotselinge overstromingen veel pangasius telers in de midden- en bovenstroomse gebieden hogere kosten hebben gemaakt voor, bijvoorbeeld, de behandeling van visziektes, terwijl sommigen telers alle of een deel van hun vissen verloren. De telers kunnen geen duidelijk beeld van de ziekte schetsen, maar ze nemen aan dat stress ten gevolge van de verminderde waterkwaliteit de vissen heeft verzwakt en hun weerstand heeft verlaagd.

Hoofdstuk 3 beschrijft de waarnemingen van en de aanpassingen aan de gevolgen van klimaatverandering door de pangasius telers. De meeste kennis over klimaatverandering hebben ze vergaard via radio en televisie. Hun ervaringen met klimaatverandering zijn vooral gevormd door extreem weer. Ze hebben minder begrip van de langzame veranderingen van het klimaat en de stijging van het zeeniveau. Dit verschil in perceptie kan hun motivatie verminderen om zich aan te passen aan de gevolgen van klimaatverandering. Hun perceptie van klimaatverandering is positief gecorreleerd met opleidingsniveau, leeftijd, duur van ervaring in de vijverteelt, de mate waarin ze voor hun inkomen afhankelijk zijn van de pangasius teelt, en of ze zelf eigenaar zijn van het land. De meeste pangasius telers in het bovenstrooms gebied van de Mekong Delta hebben al eens lagere inkomsten ten gevolge van extreme overstromingen ervaren. Benedenstrooms, in de kust provincies, hebben de telers die vanaf het begin te maken hadden met hoge zoutgehaltes en binnen enkele seizoenen een geleidelijk stijging hebben ervaren, zich aangepast door slechts eenmaal per jaar te produceren en dan minder maar oudere pootvis in de teeltvijvers te plaatsen. Deze oudere pootvis kan hogere zoutgehaltes verdragen terwijl ze, volgens zeggen, even goed blijven groeien. Om de gevolgen van hoger water en overstromingen te voorkomen versterken en verhogen alle pangasius telers hun vijverdijken. Andere door telers gesuggereerde aanpassingen waren: stoppen met deze teelt, veranderen van vissoort, of het kweken van een zouttolerante pangasius. Voor technische ondersteuning voor deze aanpassingen vertrouwen de telers op overheidsdiensten, maar de telers in de kustprovincies voelden nauwelijks behoefte aan training door deze diensten. Hoofdstuk 3 suggereert dat educatie en het verschaffen van toegang tot klimaatverandering gerelateerde informatie, effectieve maatregelen zijn om de autonome aanpassingscapaciteit en acceptatie van mitigatiemaatregelen te ontwikkelen.

Hoofdstuk 4 onderzocht de technische efficiëntie van de pangasius productie bedrijven en de relatie tot de gevolgen van klimaatverandering. De evaluatie van de technische efficiëntie informeert over mogelijkheden om de kost-efficiëntie van de bedrijfsproductie te verbeteren. Ook kan deze methode bepalen of bedrijven kostenefficiënt blijven na het doorvoeren van aanpassingen die nodig zijn om klimaatverandering op te vangen. De gemiddelde score van de technische efficiëntie onder constante ‘return to scale’ was 0.66 en onder variabele ‘return to scale’ 0.84. De technische efficiëntie van pangasius bedrijven in the Mekong Delta van Vietnam was vergelijkbaar met die van visproductiebedrijven in andere landen. Pangasius bedrijven in de midden- en bovenstroomse gebieden met verhoogde overstromingsrisico’s produceerden op grotere schaal dan die benedenstrooms, waar verhoogde zoutwatergehaltes een bedreiging vormen. Echter, de technische efficiëntie van de benedenstroomse telers was hoger, dankzij de lagere energiekosten en de aankoop van minder pootvis voor de enige jaarlijkse productiecyclus. Midden- en bovenstroomse bedrijven moeten verversingswater pompen maar produceren tenminste driemaal in twee jaar. Bedrijven kunnen de productiviteit verbeteren door het efficiënter gebruik van voer, pootvis en arbeid, door intensievere training, en door uitbreiding van de productieschaal. Regressie analyse toont een positief effect op de technisch-efficiëntie van het niveau van genoten onderwijs en van ervaring met overstromingen of zoutwaterindringing. Deze analyse bevestigde niet het effect van klimaatverandering op de technische efficiëntie. Indien deze al bestaat, dan had onze steekproef meerdere jaren en meer bedrijven waar de bedrijfsvoering door extreem weer was aangetast, moeten omvatten om deze te kunnen aantonen. Bovendien, om de gevolgen van klimaatverandering te kwantificeren is het nodig om in een dergelijke longitudinale studie gegevens van een of meer specifieke parameters te verzamelen. Specifieke parameters als het zoutgehalte van het water en de hoogte en duur van overstromingen waren niet beschikbaar voor de bedrijfslocaties.

Met het oog op het verhoogde risico van overstromingen en van zoutwaterindringing voor de pangasius sector in de Mekong Delta (Hoofdstukken 2, 3 & 4), ontwikkelt Hoofdstuk 5 een raamwerk ter ondersteuning van de besluitvorming rond aannemelijke en mogelijke autonome en geplande aanpassingen. De gebruikte autonome aanpassingen van de pangasius telers zijn: verhoging van de vijverdijk, veranderingen in vijver- en vismanagement; ook het gebruik van een zout-tolerante pangasius, indien deze beschikbaar is, past onder de autonome aanpassingen van de telers. De voorgestelde planmatige regionale aanpassingen zijn het verbeteren en uitbreiden van het netwerk van publieke beschermingsdijken, het ontwikkelen van een zout-tolerante pangasius lijn, en het overstappen op een zout-tolerante vissoort. De laatste aanpassing heeft niet de voorkeur van de telers, omdat het investeringen vraagt in nieuwe kennis en netwerken, en waarschijnlijk in aanpassingen van de vijver. De meest brede strategie van aanpassingen, hogere en sterkere dijken, vergt vooral een eenmalige investering, terwijl aanpassing aan het verhoogde zoutniveau benedenstrooms ook verhoogde operationele kosten op sector niveau (het continue selectieprogramma van een zouttolerante pangasius) of op bedrijfsniveau (oudere en dus duurdere pootvis voor slechts een teeltperiode per jaar) met zich meenemen. De kosten van het verhogen van de bedrijfsdijken zijn ongeveer 0.34% van de totale variabele kosten (ha^{-1} $oogst^{-1}$) in de midden- en bovenstroomse gebieden, en 0.25% in het benedenstroomse gebied. Uitbreiding en verbetering van het netwerk van publieke overstromingsbeschermingsdijken vermindert de behoefte voor autonome aanpassingen voor bedrijven die binnen deze dijken opereren, en hebben een positief effect op andere sectoren. Echter deze strategie heeft negatieve effecten voor sedimentatie en biodiversiteit (Hoofdstukken 5 & 6).

Alle sociaaleconomische condities en kosten-baten overwegend, beveel ik aan om een zout-tolerante pangasius lijn te ontwikkelen. Voor het benedenstroomse deel van de sector vergt dit de minste infrastructuurveranderingen en verstoort dit de bedrijven en de markten het minst. Een dergelijk fokprogramma kan wellicht binnen korte tijd zijn doel bereiken met behulp van de huidige moleculaire genetische technieken. Hoofdstuk 5 schat de jaarlijkse kosten van een klassiek fokprogramma voor het ontwikkelen van een zouttolerante pangasius lijn op ongeveer USD 120,000. Dit verhoogt de huidige productie kosten met 0.4% voor de telers in het benedenstroomse gebied, veronderstellende dat dit gebied een tiende van het totale pangasius volume produceert. Bij voorkeur neemt een telersorganisatie of een privaat bedrijf het initiatief voor het fokken en het leveren van broed en pootvis van een zouttolerante pangasius.

De resultaten van mijn studie kunnen de relevante autoriteiten, de pangasius producerende bedrijven en andere belanghebbenden in de sector behulpzaam zijn bij het kiezen van aanpassingen aan de gevolgen van klimaatverandering. De keuze van de meest geschikte aanpassingen zal een duurzame ontwikkeling van deze belangrijke economische sector en zijn bijdrage aan de voedselzekerheid mogelijk maken.

TÓM TẮT

Việt Nam nằm trong những nước bị tác động mạnh do biến đổi khí hậu gây ra mà cụ thể chính là mực nước biển dâng. Bộ Tài nguyên và Môi trường Việt Nam đã xây dựng các kịch bản nước biển dâng và dự báo mực nước biển sẽ cao thêm 75 cm vào năm 2100. Điều này sẽ tác động như thế nào đến nghề nuôi cá tra nằm dọc hai bờ sông Tiền sông Hậu và hệ thống kênh chủ yếu thuộc sáu tỉnh An Giang, Đồng Tháp (thượng lưu), Vĩnh Long, Cần Thơ (trung lưu), Trà Vinh và Sóc Trăng (ven biển), vốn đang phát triển mạnh mẽ trong những năm qua và đóng góp quan trọng vào sự phát triển kinh tế xã hội của đồng bằng sông Cửu Long. Đó chính là cơ sở để tác giả tiến hành nghiên cứu này. Các kết quả nghiên cứu trình bày trong luận văn này sẽ đánh giá tác động của biến đổi khí hậu thông qua mực nước biển dâng đến nghề nuôi cá tra, tìm hiểu khả năng thích ứng của người nuôi và đề xuất chiến lược thích ứng cho người nuôi và các nhà hoạch định chính sách. Các kết quả trên nhằm trả lời các câu hỏi sau:

(1) Mực nước biển dâng (và hệ quả của nó là xâm nhập mặn và lũ lụt) sẽ ảnh hưởng như thế nào đến khu vực nuôi cá tra?

(2) Người nuôi cá tra nhận thức như thế nào về tác động của biến đổi khí hậu và các biện pháp đối phó với nó?

(3) Mực nước biển dâng có ảnh hưởng đến hiệu quả kỹ thuật của nghề nuôi cá tra?

(4) Các biện pháp ứng phó nào phù hợp?

Chương 2 trình bày ảnh hưởng có thể có của nước biển dâng và các hệ lụy của nó đối với nghề nuôi cá tra thông qua việc mô phỏng theo ba kịch bản nước biển dâng là +30, +50 và +75 cm. Các kết quả kịch bản nước biển dâng cho thấy thời gian lũ sẽ kéo dài trên diện rộng gây ngập lụt ở vùng thượng lưu và trung lưu. Còn ở các tỉnh ven biển, diện tích bị xâm nhập mặn gia tăng và thời gian bị xâm nhập mặn sẽ kéo dài hơn. Với kịch bản nước biển dâng +50 cm, mực nước ở độ cao 3 m sẽ mở rộng xuống tận hạ lưu và đe dọa các ao nuôi cá tra ở thượng lưu và trung lưu. Độ mặn tăng khi mực nước biển dâng +75 cm sẽ làm giảm diện tích có thể nuôi cá tra ở vùng ven biển. Tuy nhiên tần xuất và phạm vi của lũ lụt sẽ không ảnh hưởng nhiều đến ao nuôi cá tra ở vùng hạ lưu.

Chương 3 tìm hiểu nhận thức và các biện pháp thích ứng của người nuôi cá tra trước những ảnh hưởng của biến đổi khí hậu. Người nuôi hiểu biết về biến đổi khí hậu qua các phương tiện truyền thông đại chúng. Tuy nhiên họ không để ý đến ảnh hưởng từ từ của quá trình diễn ra biến đổi khí hậu chẳng hạn mực nước biển dâng. Kinh nghiệm của họ về biến đổi khí hậu thực chất gắn với các hiện tượng khí hậu cực đoan. Nhận thức của người nuôi cá tra về biến đổi khí hậu tỷ lệ thuận với trình độ học vấn, tuổi tác và kinh nghiệm nuôi cá tra, mức độ phụ thuộc kinh tế vào nghề nuôi cá tra hay họ có là chủ đất hay không.

Phần lớn người nuôi cá tra ở vùng thượng lưu cho rằng họ đã từng thua lỗ khi lũ lụt lớn xảy ra. Để hạn chế thiệt hại họ phải nâng cao bờ đê. Trong khi đó ở vùng ven biển, hầu hết người nuôi cho biết ảnh hưởng của xâm nhập mặn vào mùa khô và độ mặn ngày càng tăng. Để đối phó, người nuôi phải giảm số vụ nuôi hoặc chỉ thả con giống có kích thước lớn hơn vì cho rằng con giống lớn có thể chịu mặn tốt hơn. Người nuôi cũng nghĩ đến việc dừng sản xuất, chuyển sang nuôi đối tượng khác hoặc chỉ thả giống cá tra đã được thuần hóa với ngưỡng độ mặn cao. Chương 3 cũng đề xuất giải pháp tăng cường khả năng thích ứng với biến đổi khí hậu của người nuôi cá tra qua việc đẩy mạnh tuyên truyền và cung cấp thông tin liên quan đến biến đổi khí hậu.

Chương 4 phân tích hiệu quả kỹ thuật của nghề nuôi cá tra và tác động của các yếu tố biến đổi khí hậu. Việc đánh giá hiệu quả kỹ thuật giúp cho việc xác định các yếu tố cần thay đổi để việc nuôi đạt hiệu quả kinh tế hơn. Nếu người nuôi dùng các biện pháp đối phó với biến đổi khí hậu, việc phân tích hiệu quả kỹ thuật sẽ giúp họ đánh giá các biện pháp này có làm thay đổi hiệu quả kinh tế hay không. Hiệu quả kỹ thuật của nghề nuôi cá tra ở đồng bằng sông Cửu Long gần như tương đương nếu so sánh với nghề nuôi các đối tượng khác ở các nước khác. Quy mô nuôi cá tra ở vùng thương lưu và trung lưu lớn hơn vùng ven biển. Tuy nhiên hiệu quả kỹ thuật ở vùng ven biển lại cao hơn vì chi phí cho cấp nước thấp hơn và số vụ nuôi trong năm cũng ít hơn. Để tăng hiệu quả sản xuất, người nuôi phải sử dụng hợp lý hơn chi phí sản xuất như thức ăn, giống, lao động cũng như tăng quy mô sản xuất. Các kết quả thống kê cho thấy hiệu quả kỹ thuật tỷ lệ thuận với trình độ học vấn cũng như kinh nghiệm đối phó với các hiện tượng khí hậu cực đoan đã xảy ra của người nuôi cá tra.

Để đối phó với các rủi ro do lũ lụt và xâm nhập mặn gây ra dưới tác động của mực nước biển dâng đối với nghề nuôi cá tra (đã trình bày trong các Chương 2, 3 và 4), Chương 5 đề xuất các giải pháp thích ứng bao gồm:

- nâng cao bờ bao của ao nuôi,
- thay đổi phương thức sản xuất,
- thả giống cá tra thích nghi độ mặn cao,
- tu bổ hệ thống đê chống lũ lụt của nhà nước,
- nhà nước và các doanh nghiệp liên kết nghiên cứu sản xuất giống cá tra thích nghi độ mặn cao, hay
- thả nuôi các loài thủy sản chịu mặn khác.

Chi phí để người nuôi tôn cao bờ bao ao nuôi vào khoảng 0.34% của tổng chi phí sản xuất (tính trên ha và vụ nuôi) ở vùng thượng lưu và trung lưu, và 0.25% ở vùng ven biển. Giải pháp về việc thả nuôi các loài thủy sản chịu mặn khác có lẽ sẽ ít được người nuôi chọn lựa vì phải đầu tư vào đối tượng mới với nhiều thách thức cũng như phải cải tạo lại ao nuôi. Việc mở rộng và tôn tạo hệ thống đê chống lũ lụt của nhà nước sẽ giúp cho việc giảm chi phí vào bờ bao ao nuôi của người nuôi cũng như bảo vệ một số ngành kinh tế khác. Tuy nhiên cũng cần cân nhắc đến sự ngăn chặn quá trình bồi lắng phù sa và tác động xấu đến đa dạng sinh học (Chương 5 và 6). Đối với nguy cơ xâm nhập măn, giải pháp tốt nhất là phát triển giống cá tra thích nghi độ mặn cao. Giải pháp này sẽ không tác động đến sinh kế, không đòi hỏi thay đổi cơ sở hạ tầng cũng như vẫn duy trì thị trường hiện có. Chương 5 cũng ước tính chi phí hàng năm cho chương trình tạo giống cá tra chịu mặn vào khoảng 120 000 US$ tức là tăng khoảng 0.4% chi phí sản xuất hiện nay đối với người nuôi ở vùng ven biển với giả thuyết vùng này sản xuất 10% sản lượng cá tra của cả đồng bằng sông Cửu Long.

Tóm lại, những kết quả của nghiên cứu này hy vọng có thể giúp cho các nhà quản lý, cộng đồng người nuôi cá tra và các bên liên quan khác chọn được giải pháp phù hợp ứng phó với biến đổi khí hậu. Nghiên cứu này cung cấp cơ sở để các nhà lập kế hoạch đề ra chiến lược phát triển bền vững cho nghề nuôi cá tra, một hoạt động kinh tế rất quan trọng đóng góp vào an ninh lương thực ở Việt Nam.

About the author

Nguyen Lam Anh was born on November 22nd , 1968 in Ha Noi, Vietnam. He obtained the Bachelor degree from Da Lat University in 1990. He immediately worked as a Researcher at Nha Trang Institute of Oceanography in the field of Marine resources. He moved to Hai Phong Research Institute for Marine Fisheries and joined the Assement of Living Marine Resources of Vietnam project funded by DANIDA in 1996. He was a seconded staff representative of the Ministry of Fisheries of Vietnam working at the Southeast Asian Fisheries Development Center (SEAFDEC) in Bangkok, Thailand from 2000 to 2001. After 2 tenures in SEAFDEC, he enrolled in the Asian Institute of Technology (AIT) for a Master study in the Aquaculture and Aquatic Resources Management program and gained the MSc degree in 2003. Since 2004, he has become a Lecturer of Faculty of Aquaculture (Institute of Aquaculture now), Nha Trang University with subjects of Fish stock assessment, Fisheries managment and Integrated Coastal Zone Manegement. In 2009, he got a sandwhich scholarship of Wageningen University then started his PhD program at Aquaculture and Fisheries Group of Wageningen University. His thesis studies were funded by the Aqua-climate project coordinated by the Network of Aquaculture Centres of Asia-Pacific (NACA) under the auspices of the Norwegian International Development Agency.

WIAS training and supervision plan

The Basic Package (4.5 ECTS)	
- WIAS Introduction Course	2009
- Course on philosophy of science and/or ethics - Lithuania	2009
Scientific Exposure (11.3 ECTS)	
International conferences	
- 8th IOC/WESTPAC International Scientific Symposium on Climate change in Busan, Korea	2011
- International Fisheries Symposium 2012: Sharing knowledge for sustainable develop-ment of aquaculture and fisheries in Southeast Asia, Can Tho, Vietnam.	2012
- 9th Diseases in Asian Aquaculture (DAA9), Ho Chi Minh City, Vietnam.	2014
Seminars and workshops	
- 1st Aqua-climate Project annual workshops, Can Tho, Vietnam	2010
- 2nd Aqua-climate Project annual workshops, Sri Lanka	2011
- SUPA economic workshop, HoChi Minh city, Vietnam	2011
- Can Tho workshop on Tra catfish research, Can Tho, Vietnam	2012
Presentations	
- Pangasius aquaculture farmer's perception and adaptation to climate change in the coastal of Mekong Delta, Vietnam. Busan, Korea, poster	2011
- Modelling the impact of salt water intrusion caused by sea level rise on suitable striped catfish aquaculture location in the Mekong delta, Vietnam, oral	2012
- Study results presentation at Aqua-climate project anual workshop, oral	2011
- Study results presentation at Aqua-climate project anual workshop, oral	2012
- PhD results presentation at Can Tho workshop on Tra catfish research, oral	2012

In-Depth Studies (8.0 ECTS)

Disciplinary and interdisciplinary courses

- GIS and hydrological models - Ho Chi Minh city	2009
- ANTER-net summer course on biodiversity, France	2009

Advanced statistics courses *(optional)*

- Statistics for the Life Science	2009

Professional Skills Support Courses (3.1 ECTS)

- High-impact writing	2013
- Project and Time Management	2014
- Working with EndNote X	2009

Research Skills Training (11 ECTS)	year
- Preparing own PhD research proposal	2009
- RS&GIS course *"The Application of RS for Study of Marine and Coastal Processes and related Bio-Resources"*, Nha Trang, Vietnam	2011

Didactic Skills Training (15.2 ECTS)

Lecturing

At Nha Trang University in *Integrated Coastal Zone Management, and in Utilisation & Management of Aquatic Ressources*	2010 - 2012

Supervising practicals and excursions

- MSc practice on diversity of North fishes, Wageningen	2013

Supervising theses

- 5 BSc thesis at Nha Trang University	2009-2011

Management Skills Training (0.3 ECTS)

Membership of boards and committees

Member of the Review Committee of RIA-3 Aquaculture Disease Monitoring project	2012

Education and Training total: 53.4 ECTS

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Colophon

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Propositions

1. Sea level rise induced by climate change will affect pangasius farms in the upstream region through hazardous flooding and the farms in the coastal provinces through higher salinity levels. (this thesis)

2. Shifting to another fish species is not an appropriate adaptation for pangasius farmers in the downstream region. (this thesis)

3. The near-extinction of the cod resulted in the development of the currently well yielding shrimp fisheries in Greenland and Newfoundland. (*Vilhjalmsson and Hoel 2004. ACIA Scientific report: Chapter 13 Fisheries and aquaculture. p. 691-780; http://www.acia.uaf.edu/pages/scientific.html*)

4. An increase in global mean air temperature does not result in corresponding increases of inland aquaculture production. (*De Silva and Soto, 2009. FAO Technical paper 530:151-210*)

5. The intensive aquaculture sector provides livelihoods and thus food security to many households, but the land area required for the production of the fish' feed can produce food for many more people.

6. A strong leadership style is a consequence of the male domination in leadership functions and is not favourable for optimal staff and enterprise performance.

Propositions belonging to the thesis entitled:

"Climate proofing aquaculture: a case study on

pangasius farming in the Mekong Delta, Vietnam".

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