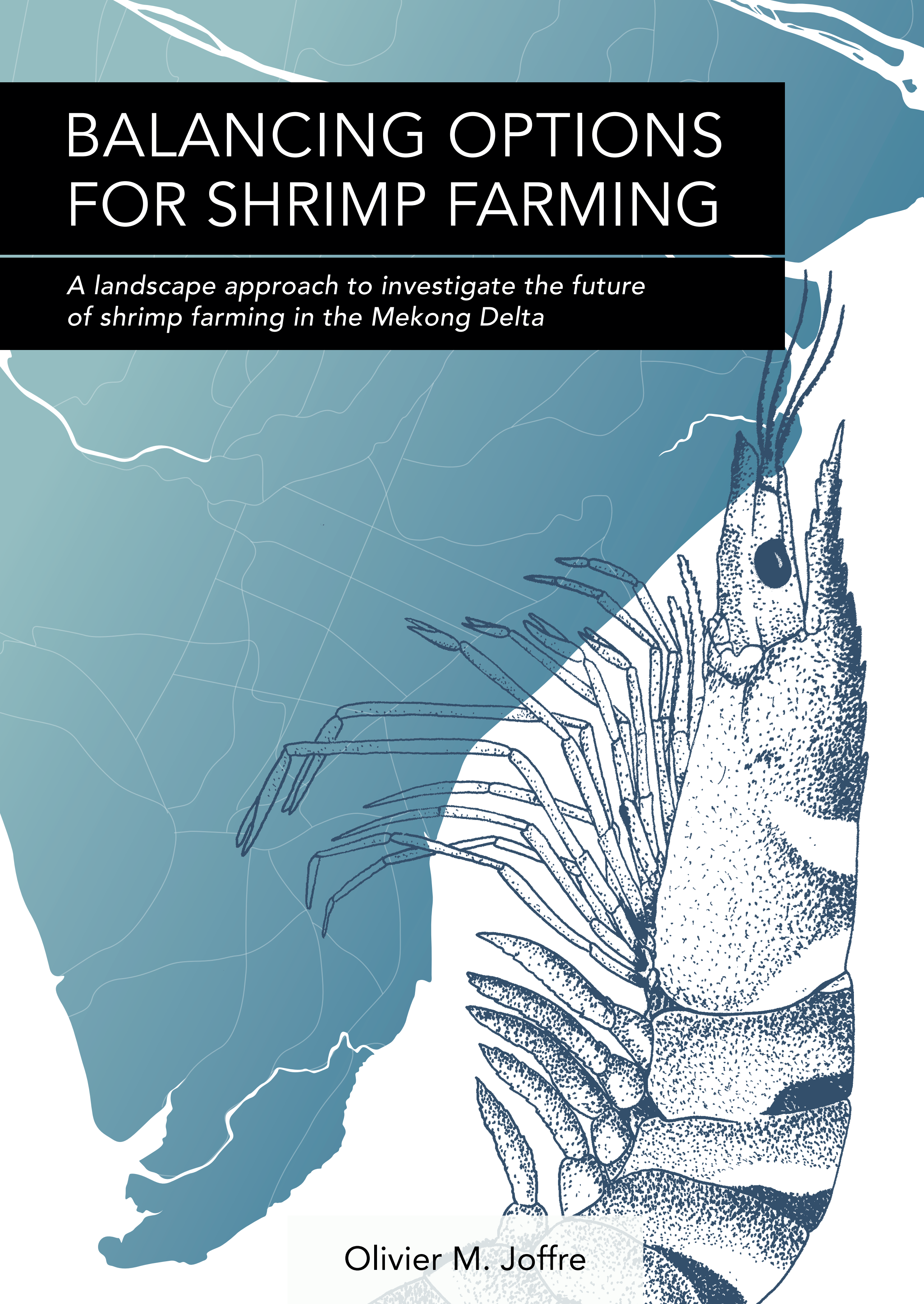
BALANCING OPTIONS FOR SHRIMP FARMING

A landscape approach to investigate the future of shrimp farming in the Mekong Delta



Olivier M. Joffre

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Olivier M. Joffre

Thesis

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Chapter 1

Introduction

1.1 Introduction

1.1.1 Shrimp Aquaculture in the coastal zone

Coastal zones are home to 60% of the world's population (UNDP, 2007) and support much of the world's food production, industry, transportation as well as facilities for recreation. Coastal zones also deliver vitally important ecosystem services such as coastal protection, sediment trapping and habitat provision for coastal fisheries. Driven by industrialization, urbanization, and agricultural development, coastal zones around the world have undergone rapid changes during the last century. These changes have increased environmental pressure, shifted land use, and intensified natural resource use.

One of the main drivers of change in the South East Asia coastal zone has been the fast development of shrimp farming in recent decades. Shrimp farming is seen as an economic opportunity for developing countries, with a high potential to generate export earnings. Shrimp farming has changed the coastal landscape as mangrove forests are converted into shrimp ponds, leading to negative environmental and social changes (Primavera, 1997; Primavera, 2006; Deb, 1998; EJF, 2003). The loss of mangrove leads to the loss of mangrove's ecological functions and negatively affects the overall ecosystem (Manson et al., 2005a; Kautsky et al., 2000). Specifically, mangrove's ecological functions provide a vital source of food and income for poor populations living in the coastal zone through a wide range of natural products such as wood, fruits, fish and other aquatic organisms, medicines and tannin (Primavera, 1997). However, open access mangrove forests have been privatized and converted into shrimp farms, thus reducing people's access to natural resources and requiring a change in their livelihood strategies (Primavera, 2006; Lutrell, 2006; Ocampo-Thomason, 2006; Hossain et al., 2006).

The intensification of shrimp production and the spread of shrimp farming in the South and South East Asian coastal zone has also created a favorable environment for epidemic diseases, the main cause of economic losses in this sector. Thus, the boom in shrimp farming has been tempered by the high risk of disease occurrence.

1.1.2 Problem definition

Coastal zones are complex ecosystems where local livelihoods are dependent on natural resources and exposed to natural hazards. Although the development of shrimp farming is usually associated with high and fast economic return, it is also an unsustainable, high-risk, and poorly resilient production system that significantly affects coastal mangrove ecosystems. These changes to the ecosystem are accompanied by various negative social and environmental impacts (Suzter and Flaherty, 2002; Primavera, 2006; Hossain et al., 2006).

Shrimp production systems are diverse, ranging from integrated mangrove-shrimp systems to intensive closed systems, all with their specificity in terms of productivity, investment and risk. All these production systems can coexist within the same landscape (Bush et al., 2010). For smallholders, the high risk associated with shrimp farming translates into diverse risk management strategies. For example, diversification of production to include brackish water polyculture is a strategy deployed by small-scale shrimp farmers to cope with risk and relies on natural resources supported by mangrove ecosystems. This diversification is only part of the wide spectrum of shrimp aquaculture production systems found along the coastal zone.

Farmers decide on their production system based on both environmental and economic drivers such as bio-physical factors, production and input market prices and regulatory framework (Ha, 2012; Ha, 2012a). Therefore, the diversity of production systems and drivers that influence farmer's decisions are key to future planning. In the meantime, aquaculture planners have to find the right balance between two contrasting options: the first option is to promote the rapid development of shrimp farming at the expense of mangrove forests, leading to an unsustainable but potentially highly productive sector. Alternatively, the second option is to promote the development of extensive integrated mangrove-shrimp systems, a less productive option which restores and maintains the mangrove forests in the coastal zone. These two options are not necessarily antagonistic and can be promoted within the same landscape. However, the support of certain types of production systems will yield different outcomes in terms of production, economic results and social and environmental costs. Trade-offs between policy options are difficult to estimate and anticipate.

Better shrimp aquaculture planning in the coastal zone requires understanding of the diversity and dynamics of current production systems, as well as farmer decision making processes. Identifying and characterizing the main drivers of change that induce or constrain a specific aquaculture system will be necessary to realize the right balance between financially risky intensive production systems and less productive extensive aquaculture systems that are affordable to many. At the same time, shrimp aquaculture planning needs to integrate a spatial component, acknowledging that the coastal zone is not a homogeneous landscape but is diverse and composed of a mosaic of bio-physical conditions and socio-economic actors. There is not yet an approach to support policy making that considers the multitude of drivers that influence shrimp farmer s' decisions. Therefore, an approach that can (1) consider the diverse technical options and risk management strategies, (2) integrate local farmer knowledge, and (3) estimate the trade-off between different policies, is needed.

1.1.3 Development of shrimp aquaculture and interaction with mangrove ecosystem

World shrimp aquaculture production increased from 0.07 million tons in 1980 to reach 4.32 million tons in 2012 (FAO, 2014), of which *Litopenaeus vannamei* and *Penaeus monodon* are the main species. Such growth is spectacular and was supported in the early years by the expansion of shrimp pond area at the expense of mangrove forest (Primavera, 1997). The worldwide loss of mangroves has been attributed to different factors such as urban settlement, infrastructure development and agriculture, but shrimp farming is also considered to be a main cause (Barbier and Cox, 2002, Barbier and Cox, 2003, Nguyen et al., 2013).

In the 1980s and early 1990s, research providing technical inputs for the intensification of the production system facilitated expansion in the shrimp sector (Bene et al., 2005). Support from national policies along with rapid economic gains from shrimp farming drove the sector's fast development. For developing countries like Indonesia, Vietnam and Thailand, the export value of the shrimp industry represents significant macro-economic earnings and has become a major component of their economy, yielding between 1.72, 1.92 and 2.36 billion $US in 2012 respectively (FAO, 2014).

In the early 1990s, the first environmental and social studies on the impact of shrimp farming were published. The rise of environmental concern led to a dialogue between different stakeholders in the sector, ultimately ending with the creation of several national and international standards such as the FAO's code of conduct. This evolution was driven by international NGO's concern for more environmental sustainability in the shrimp industry and producers and local industry had to adapt to international regulations (Bush et al., 2010).

While expansion of shrimp farms is partly responsible for the clearing of mangrove, mangrove and shrimp production are originally part of the same landscape. Coastal aquaculture farms are, to a certain level, dependent on the mangrove ecosystem and the ecosystem services provided. Ecological functions of the mangrove important for shrimp farms include improving water quality (Boonsong et al., 2003; Wu et al., 2008), providing habitat to numerous aquatic species (Pauly and Ingles, 1986; Mumby et al., 2004; Manson et al., 2005a; Sathirathai et al., 2001; Hussain and Badola, 2010) that can be trapped into extensive shrimp ponds, enhancing sediment trapping (Mazda et al., 2006; Das and Vincent, 2009; Mc Ivor et al., 2012) and controlling erosion of the coast and protecting farms (Mazda et al., 1997; Das and Vincent, 2009). Typically, the expansion of shrimp farming replaces mangrove forests with extensive and intensive ponds and the ecological functions of the mangrove are lost. In integrated mangrove-shrimp systems however, where mangrove is planted within or next to the aquaculture pond, these ecological functions are partly restored at the farm level. The mangrove cover in the pond moderates water temperature and water quality fluctuations and provides a less stressful environment to the aquatic fauna (Tendencia et al., 2012).

Concomitantly with the rise of environmental and social concerns, the sector soon faced a new challenge: widespread outbreaks of diseases affecting shrimps in coastal zones throughout the world. The rapid intensification of the production system and the concentration of monoculture shrimp farms in coastal ecosystems generated a favourable environment for epidemic diseases. As a result, smallholders have been deeply impacted by disease outbreaks with limited capacity to respond, thus leading to bankruptcy and abandoned ponds. For example, the White Spot Syndrome Virus (WSSV) and the Yellow Head Virus (YHV) are together directly responsible for economic losses of about US$ 1 billion per year since 1992 (Flegel et al., 2008) and examples of WSSV, or more recently a new disease labelled Acute Hepatopancreatic Necrosis Syndrome (AHPNS), can reduce production by 40% to 60% (Mazid and Banu, 2002; Hoa, 2012, Ligthner et al., 2012; Akazawa and Eguchi, 2013). Shrimp farming was labelled as a 'boom and bust' industry (EJF, 2003; Deb, 1998; Lebel et al., 2002).

Within this context, coastal aquaculture planning does not only concern technical aspects, but requires taking the wider social and ecological system into account. The shrimp industry is now part of and dependent on the coastal ecosystem and the long term results of the sector, in terms of production and socio-economic development, remain linked to this ecosystem. In countries like Vietnam, most shrimp production area remains in the hands of small-scale producers who make technical and economic choices according to their knowledge and investment capacity. The sector (farmer, policy maker, industry) faces a dilemma: to serve the growing demand from overseas markets, it must grow and is driven to intensification. However, to keep its 'license to sell', the sector must also comply with sustainability standards.

1.1.4 Shrimp production system spectrum and risk management strategy

Shrimp farmers developed different strategies to cope with diseases and at the same time adjust to international standard requirements regarding the environment and food safety. Ultimately, a continuum of shrimp production systems can be found in the coastal landscape, with on one end, intensive shrimp farming based on technical knowledge, high level of inputs requiring high investments and that avoids exchange with the local environment. Effluent releases and intakes are controlled and do not disturb the ecological function of the mangrove habitat outside of the farm (Otoshi et al., 2009). Due to the financial capital requirements of such systems, they are not readily accessible to small-scale farmers and cannot be considered a risk management option for this type of producer. On the other end of the spectrum, integrated mangrove–shrimp farms are extensive production systems, requiring low investment, low inputs and technical know-how, and are more suited to small-scale farmers (Figure 1.1). The ecological functions of the mangrove are maintained and contribute to the pond ecology (Tendencia et al., 2012). With this diverse ecosystem, the pond environment is not only better able to respond to environmental changes, but the farm revenue is generated from different commodities, e.g. other crustaceans, fish and timber (Johnston et al., 2000a, Ha et al., 2013). In addition, in certain regions those systems can apply for organic certification and obtain a higher price for their product.

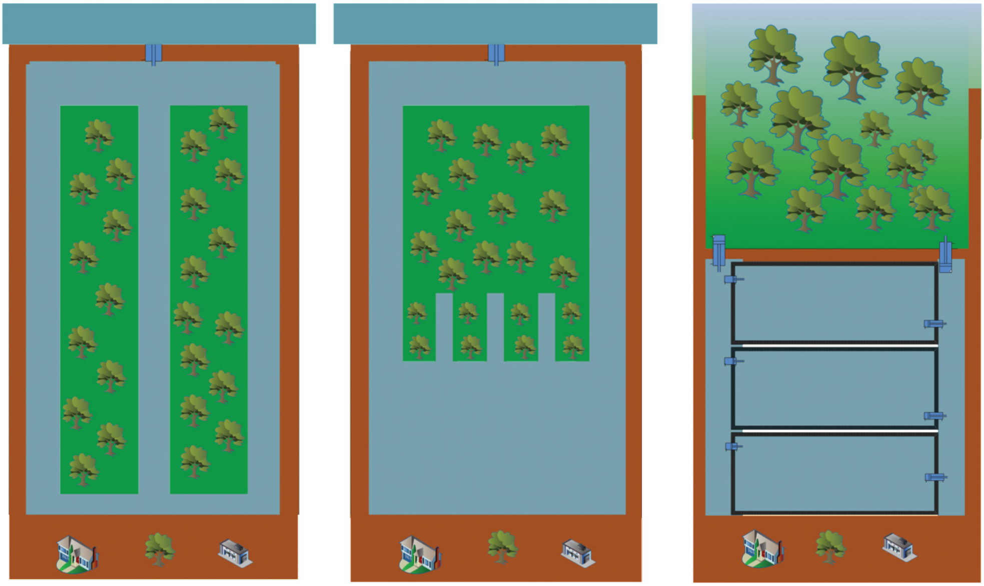

Figure 1.1: Different types of integrated mangrove-shrimp systems, from left to right: (a): the most common integrated system with canals between platforms, (b) associated system having large mangrove areas and larger areas of water, (c) separated system, with dikes separating ponds from forest (adapted from Bosma et al., 2014)

The two production systems are the extreme examples in terms of intensification levels and represent different risk management strategies. They also have different productivity and economic returns. In between these two extreme, a multitude of type production systems are found within the coastal landscape, from commercial shrimp farms to extensive smallholders, all with specific structural characteristics and productivity. To support planning of shrimp aquaculture, it is necessary to have a comprehensive understanding of the diversity of different production systems. One of the causes of this diversity is the need to manage risk in terms of disease outbreaks and financial bankruptcy. Diversification of farm production is commonly described as a risk management strategy for smallholder farmers (Pannell et al., 2000; Hardaker et al., 2004; Heinemann, 2014). Within the context of high risks related to shrimp farming and market oriented aquaculture, the validity of this diversification as risk management for shrimp farmers is questioned, as well as its long term sustainability. From this reasoning, two research questions are formulated regarding: (1) the diversity and the characterization of shrimp production system and (2) the diversification of the production as a sustainable strategy for smallholders.

1.1.5 Farmers decision and simulation

A farmer's choices regarding their production system depends on a multitude of external drivers to the farm and farm's characteristics (Bush and Marschke, 2014; Ha, 2012; Ha, 2012a). In the case of shrimp aquaculture, even small-scale producers are directly linked to international trade and are within the same regulatory framework as large commercial farms.

Bio-physical, social, economic and regulatory drivers that are found at local, national and international levels influence the farmers' decision. This decision will depend on farmer interpretation of, and reaction to, certain drivers. It is important to acknowledge that such drivers are multiple and that their weights in terms of influencing farmer decisions are not equal. Some drivers are more influential than others to incite farmers to invest in a specific production system. With a multitude of drivers that influence farmer decisions it is necessary to understand how farmers react (or not) to those drivers and make their decision regarding production systems. This knowledge is central to design and adjust the regulatory framework that can limit environmental impact, maintain farm and overall yield, and reduce the risk on bankruptcy of shrimp producers.

At the landscape level, methods and approaches to investigate arrangements of production systems and to discuss land use can be re-grouped under the term 'land use planning'. Multiple land use planning methods are available (Trung, 2006) such as Land Use Planning (LUP) (FAO, 1993), the Participatory Land Use Planning (PLUP) (Amler et al., 1999) and Land Use Planning and Analysis System (LUPAS) (Hoanh et al., 2000). Those methods can engage with local stakeholders and integrate local knowledge. However, farmer knowledge and how farmers react individually to different drivers - such as a change in the regulatory framework, the market price or the bio-physical environment - is rarely taken into account when planning shrimp aquaculture development. Approaches used in the past do not allow the flexibility to test and investigate the influence of diverse drivers on individual farmer decisions, decisions that ultimately transform the landscape.

Farmer decisions-making are central to changes in landscape. To investigate the future of coastal aquaculture and estimate trade-offs between different policies, new planning approaches that integrate farmer decisions are required. One recent method integrating human behavior and decision making, and thus simulating and analyzing the dynamics of adaptive systems as aquaculture systems, is agent based modeling. An Agent Based Model (ABM) represent agents (or farmers in this case) that are single autonomous entities who interact between each other and with their environment to achieve their goals (Ferber, 1999; Valbuena et al., 2008; Naivinit et al., 2010). ABMs are often spatially explicit and the model's output includes quantitative values of variables that help to estimate trade-offs or impacts of different policies. Used with different stakeholders, from farmers to decision makers, ABM could be a tool that helps to understand land use changes based on actors' decisions, discuss trade-offs between different policy options, test hypotheses and serve as media for communication between stakeholder groups (Geertman and Stillwell, 2009). ABMs have been developed and used in various cases of natural resource management (Walsh et al. 2013; Hoanh et al., 2008, Cabral et al., 2010), or to investigate trade-offs between policies in the agriculture sector (Vilamor et al., 2014). In the case of aquaculture, ABM could be a tool that integrates farmer knowledge and decision making processes. Individual farmers' behaviors can be spatially represented in a coastal landscape and integrated in a decision support tool used by planners and policy makers to test different policies and assess their trade-offs and impacts on aquaculture production, local economy and social cost. This approach also enables spatial integration of the mutual influence that farmers have on their individual decisions, i.e. neighbor effect (Nguyen and Ford, 2010).

From the above argument, providing new insight for better shrimp aquaculture planning will require researchers: (1) assess the drivers that will influence farmers toward developing production systems that support ecosystem functions, farmer livelihoods and are less risky; (2) develop an approach that spatially integrates farmer decisions-making in order to evaluate and discuss future policies.

1.1.6 Shrimp farming and mangrove forests in the Mekong Delta: study site

The Mekong Delta is composed of 13 provinces and is the heart of the Vietnamese shrimp industry (Figure 1.2). From an area dedicated to shrimp production of 15,000 ha in 1970, the industry grew to reach more than 300,000 ha in 2000 and 623,000 ha for a production of more than 350,000 tons in 2014 (GSO Vietnam, 2014). This rapid growth was the result of economic reforms towards a market economy launched in the 1990s. By 2008, Vietnam became the third world's largest shrimp producer, with an average annual growth of 16.4% between 1998 and 2008 (FAO, 2010). The shrimp industry contributes 4.6% to the country's GDP. The Mekong Delta coastal zone produces 80% of this wealth (Loc et al., 2007).

Recent directives and policies in the sector aimed to improve the quality of production while maintaining the sector's growth. In 2006, the government of Vietnam developed a fisheries master plan, effective until 2020. This plan targets the main export markets in Europe, Japan and the United States of America, thus aiming at producing high quality products in large quantities. Within that context, smallholders have to adapt to a new regulatory framework design to support and supply the sector with products that meet volume demands and at the same time comply with quality and food safety standards. While the shrimp aquaculture system intensifies in some specific areas of the country, 60% of the production comes from extensive small scale producers (MOFI, 2005). However, the term 'extensive shrimp farm' covers a multitude of systems with a diverse level of diversification and intensification. Similarly, the term 'intensive shrimp farm' includes systems ranging from small-scale familial farms to large commercial farms. Since the boom of shrimp farming in the Mekong Delta (Be et al., 1999; Brennan et al., 1999; Johnston et al., 2000b), in depth analysis of its shrimp production systems is lacking and little is known about them.

The western part of the Delta, from Soc Trang province at the river mouth of the Bassac river to Ca Mau (the largest production area in the Mekong Delta) contributes most of the sector growth (Figure 1.2). This geographical area was also the location of largest mangrove forest in the country, but with the expansion of shrimp culture, the mangrove area in the Mekong Delta declined. Over the past 50 years, about 220,000 ha of mangrove in the Mekong Delta were lost to urbanization, human settlement, infrastructure development, rice culture and lately, to shrimp farming (Hong and San, 1993; Alongi, 2002; De Graaf and Xuan, 1998; Thu and Populus, 2007; Nguyen et al., 2013). Meanwhile, between 1991 and 2003, the shrimp area increased in the Mekong Delta from 90,000 ha to 460,000 ha (MOFI, 2004) at the expense of mangrove area but also rice land (Hoanh et al., 2003).

In 1999, to control and limit mangrove clearance, the Vietnamese government developed a rigid regulatory framework, dividing the coastal zone into three main areas. The Full Protection zone corresponds to a narrow strip of untouched mangrove, where collecting natural resources and establishing settlements are prohibited. Further inland is the Buffer zone, where integrated mangrove-shrimp farming and settlements are allowed. These farmers have a land lease for 20 years, while the production system is subject to rules and the mangroves are managed by a State Forestry Enterprise. This government entity controls the ratio of forest (60%) and shrimp ponds (40%) and organizes the planting, harvesting and marketing of the timber. The Economic zone is located behind the Buffer zone. In this zone, all economic activities such as shrimp or rice farming can take place without restriction and farmers can decide on their production system. In summary, this regulatory framework protects the remaining mangrove forest from further clearance and controls the mangrove cover in the Buffer zone.

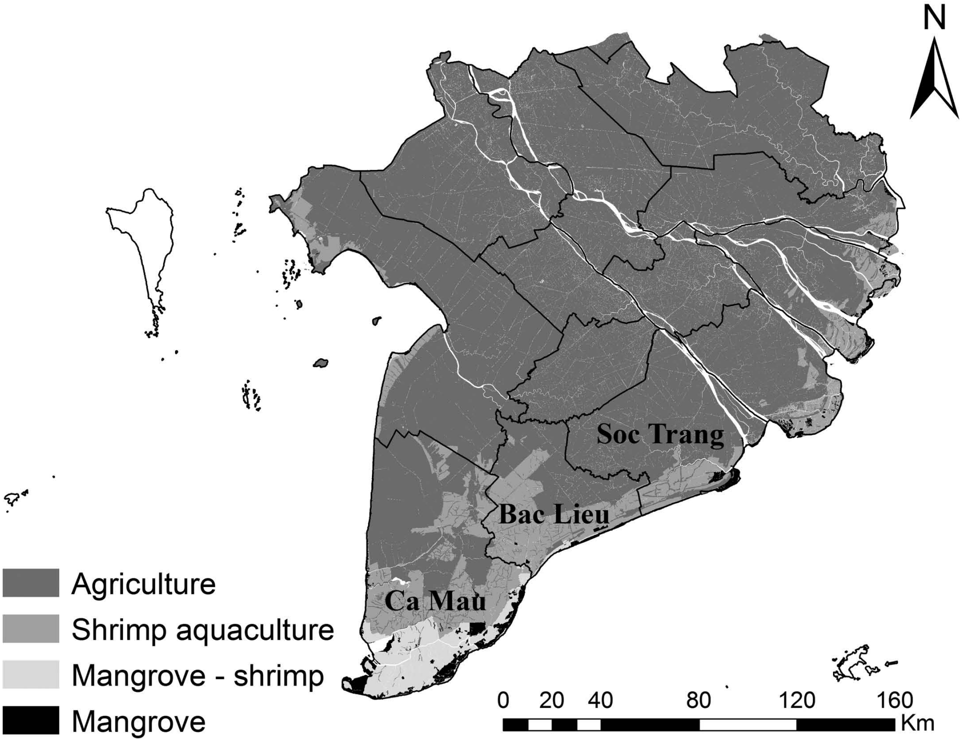

Figure 1.2: Agriculture, coastal aquaculture and mangrove location in the Mekong Delta

In Ca Mau Province, the Economic zone is composed mostly of extensive shrimp ponds owned and managed by smallholder producers with relatively low technical knowledge and equipment. These are dominant in terms of area and production in the Mekong Delta. While semi–intensive and intensive shrimp farms contribute significantly to the total production volume, their area remains limited in the Mekong Delta. For example, in Ca Mau province, extensive shrimp farms represent 65% of the shrimp farm area while integrated mangrove-shrimp systems, limited to the Buffer zone, count for 15%. However, the area dedicated to these integrated systems remains insignificant in other provinces of the Mekong Delta. Even the access to the organic shrimp value chain in specific districts of the Mekong Delta does not push the extensive shrimp farms to transform into integrated mangrove-shrimp production systems in these districts.

1.2 Objectives and outline of the thesis

The overall objective of this work is to develop an approach that integrates individual shrimp farmer's decision making in a decision support tool to better plan shrimp aquaculture. Developing policies and regulatory framework that achieve production targets, with limited environmental cost, while supporting local livelihood and contributing to economic development, is not simple. On the one hand, shrimp farming is a highly lucrative sector for both smallholders and the State. On the other hand, the shrimp sector is considered to be one of the least ecologically sustainable production systems in the world. The challenges facing the shrimp farming sector are diverse and development comes with high risks and environmental costs. The sector needs to provide significant income to shrimp farmers, both smallholder and companies, as well as to other stakeholders including the State while adapting their production system to disease outbreak risks and recent changes in the international market.

Responding to these challenges call for a new approach that will put the farmer's decision at the center of the process and integrate a spatial component. It will require understanding the diversity of production systems and how farmers deal with uncertainty and virus risks, as well as how they integrate risk management strategy into their livelihood portfolio. It will also require understanding of the factors that can motivate farmers to adopt more sustainable aquaculture practices and using this knowledge to elaborate future scenarios for the shrimp sector involving planners and policy makers. In addition, this research acknowledges that investigating aquaculture planning in the coastal zone requires integrating a spatial component. Changing policies and the regulatory framework will not have a homogeneous effect on all farms across the coastal the landscape. The diverse production systems have different requirements and suitability regarding land and water. They are not antagonist and the same landscape can support diverse types of production system. Also, farms are not independent entities within their environment and farmers' decisions influence others' decisions (Nguyen and Ford, 2010). Therefore, supporting decision making for shrimp aquaculture planning needs to be spatially explicit.

This study uses the Mekong Delta as a case to elucidate how aquaculture planners can promote more sustainable coastal aquaculture and combine different shrimp production systems within the same landscape without limiting the productivity and long-term economic results of the sector.

To reach this objective, I elaborate four research questions:

- What is the diversity of shrimp farming in the Mekong Delta and how productive are those systems?
- Is diversification through brackish water polyculture a valid risk management strategy for smallholders?
- What are the drivers for the adoption of diversified and integrated aquaculture practices that restore mangrove cover?
- Can we integrate farmer knowledge and decision making processes into a spatially explicit decision support approach for policy makers to test future aquaculture policies?

To answer those questions this thesis uses the following steps and methods.

Chapter 2 investigates and analyzes the diversity of shrimp farming systems using an on-farm socio-economic survey in one of the coastal province of the Mekong Delta. The analysis will highlight differences in terms of risk of diseases and resource use efficiency between the farm types and create a typology of shrimp farms based on multivariate statistics.

Chapter 3 analyzes risk management strategies of small-scale farmers through a socio-economic survey in six villages of a coastal province. The household surveys investigated the strategies of different types of shrimp farmers facing virus outbreaks and identified linkages between natural resources from the mangroves and these risk management strategies.

Based on consultations with both Vietnamese and international shrimp sector experts, Chapter 4 weighs and ranks the drivers and farm characteristics that allow farmers to continue integrated shrimp farming or shift from traditional extensive shrimp farms to integrated mangrove-shrimp system. These drivers were collected from several PhD research projects supported by the RESCOPAR project (Hoa, 2012; Ha, 2012; Ha,2012a; Gunawan, 2012, Tendencia, 2012; Kusumawati et al., 2013; Haryadi et al., 2014)

Chapter 5 presents a method that combines participatory approaches and agent based modeling to test different policies for developing more sustainable aquaculture planning. This approach is tested in one case study in the Mekong Delta and includes an iterative consultation of farmers using role-playing games to fine-tune and calibrate an Agent Based Model (ABM). Later, the ABM is tested with local aquaculture planners that elaborate different scenarios representing different plausible futures of the shrimp sector. The outputs of the model and the model itself are discussed with local aquaculture planners.

The sixth and last chapter synthesizes the main conclusions and presents a reflection on the overall findings. Finally, it suggests leads and opportunities for future research.

Chapter 2

Typology of shrimp farming in Bac Lieu Province, Mekong Delta

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Olivier M. Joffre & Roel H. Bosma

Abstract

This study aims to update the typology of shrimp farms in a province of the Mekong Delta's coastal area. We analyzed technical and economic characteristics of 170 farms using factor and cluster analysis on the different variables collected during the survey. This allowed us to characterize four different shrimp production systems: intensive commercial and intensive family farms, and the more extensive brackish water polyculture and rice-shrimp farms. The systems differed in their level of intensification, diversification and origin of labor. Labor efficiency was higher in intensive than in extensive farms. The difference in technical practice affected the farm economy and specifically its operational monetary cost which was 25-45 times higher in intensive commercial farms than in brackish water polyculture and rice-shrimp farms, respectively. The intensive commercial farms were significantly less affected by virus outbreak than the extensive brackish water polyculture farms. This last shrimp production system presented a very low shrimp yield but a higher capital use efficiency than intensive commercial farms. Rice-shrimp farms, which are located in a specific agro-ecological environment, presented average sustainability characteristics and an average disease occurrence. Results show that technological investments can reduce the vulnerability to disease outbreak and thus reduce the risk usually associated with shrimp farming.

2.1 Introduction

The development of shrimp culture was a main factor in the transformation of Asian coastal areas with a shrimp production's annual growth rate of 17% between 1970 and 2000. In the late 80s, early 90s, Vietnamese farmers started shrimp culture based on the natural recruitment of the post larvae (PLs) that came in with the tide. Following the example of Central Vietnam, and pushed by companies producing inputs (pellets, brood-stock, drugs, etc.), shrimp farmers in the Mekong Delta started to stock tiger shrimp (*Penaeus monodon*) in their ponds. Shrimp culture expanded throughout the area in the mid-nineties and the pond surface grew from approximately 90,000 ha in 1991 to almost 430,000 ha in 2003 (Vo, 2003).

The high economic return associated with shrimp culture generated the development of commercial shrimp farms and the transformation of traditional rice based farming systems. The main rice producing area in Vietnam is the Mekong Delta, covering about 80-85% of the total cultured area with 70-75% of the total annual production of the nation. In 2005, export revenue from the fishery sector reached 2.65 billion USD. Of this, 1.3 billion USD was generated by the shrimp sector (MOFI, 2005). However, the shrimp sector is not stable and prone to disease outbreak; on average 20-25% of the farmers experience crop failure in Vietnam every year (Sinh, 2004).

The present study assessed the heterogeneity of earthen pond systems found in the coastal area of the Mekong Delta. Within this dynamic environment, few studies have recently analyzed the diversity of shrimp production systems. Aquaculture is driven by national and international markets and pushed by technological innovations from a very active shrimp industry. Analysis of shrimp producing farms is important to define development and research strategies. Michielsens et al., (2002) based their typology of the Asian carp farming systems on resource use efficiency. Using multivariate analysis Kobrich et al., (2003) studied farming systems in Chile and Pakistan and Stevenson et al., (2006) described a typology of coastal aquaculture systems in the Philippines.

The present study analyzed the shrimp farms first from a structural point of view using classification and clustering, and subsequently compared the identified systems for their main resource (labor, feed and capital) use efficiency and for disease outbreak occurrence, shrimp yield and total aquaculture yield.

2.2 Materials and Methods

2.2.1 Sampling and data collection

The primary information upon which this study is based was collected during a survey in Bac Lieu province (Mekong Delta, Vietnam) from February to April 2007, within the Consultative Group on International Agricultural Research (CGIAR) Challenge Program on Water and Food PN10, to enhance our understanding of livelihood changes resulting from regional resources management and farm-level technological interventions. In Bac Lieu province hydrological conditions are diverse due to the construction of a series of sluice gates regulating saline water intrusion since 1994. Survey sites were characterized by different agro-ecological environments; the latter defined primarily in function of the duration of fresh water availability. In this study, a saline environment is permanently under tidal influence and saline water intrusion, a brackish water environment has a maximum of 6 months of fresh water per year and a saline influenced fresh water environment has more than 6 months of fresh water per year. Information on farming site and farm characteristics, labor use, aquaculture techniques, investments, costs, production and benefits was collected at 170 farms. For each survey site, an overview of existing aquaculture production systems was available from the project's baseline survey. Farms included in the survey were selected by extension services, for which an important criterion was farmer availability. Of the surveyed farms 29 were located in a saline influenced fresh water environment, 88 in a brackish environment and 53 in a saline environment.

A range of variables was selected and their values calculated from the data. The land use intensity (LUI) was calculated as the percentage of the farm area dedicated to a specific activity. The variable *number of aquaculture species* indirectly describes the level of aquaculture diversification on the farm. *Contracted workers* is the number of permanent hired workers on a shrimp farm during the shrimp culture cycle, either on monthly or yearly basis. This category of workers is distinguished from *occasional workers* hired on a daily basis during pond preparation or harvest. *Start-up investment* represents the capital invested in equipment, land and pond construction at the start of the aquaculture activity. The *feed conversion ratio* represents the quantity of feed given (kg) per kilogram of aquaculture product (dimensionless). *Labor productivity* represents the total aquaculture production in kg/ha per laborer day. *Capital use efficiency* was calculated as the ratio of gross return to capital cost. Capital cost includes operational cost and start-up investment (including depreciation of equipment). *Fresh water period* represents months with a surface water salinity < 4 ppt (data from the Hydraulic Department of Bac Lieu Province). The salinity was recorded monthly at 87 points distributed over the province with a portable refractometer (Atago Refractometer Model S/Mill E) in primary and secondary canals. For each survey site, we referred to the closest salinity sample point to delimit the time period where salinity is above or under a certain level. We considered 4 ppt the upper limit for rice cultivation.

2.2.2 Classification of farm types

As a first step, factor analysis was used to create a smaller set of composite variables to replace the original 13 variables: farm area (ha) ; LUI rice (%); LUI aquaculture (%); contract workers (person/ha/yr); ratio family labor/total labor (%); fresh water period (months); *P. monodon* stocking density (PL/m^2); number of aquaculture species raised; start up investment (mVND[1]/ha); gross return agriculture (mVND/ha/yr); gross return fish and other crustaceans (mVND/ha/yr); average pond size (ha) and commercial feed used (kg/ha/yr). Fresh water period was included in the original variables set to check if shrimp farms were dependent on water salinity period or if shrimp farming was also developing in fresh water areas. The rice-shrimp production system was included in the analysis, using variables such as LUI rice and gross return of agriculture. However, other agricultural or livestock productions were not integrated in the analysis as their importance at the farm level was relatively small. Following Milstein et al., (2005), all variables were normalized before the analysis. The factors were rotated using VARIMAX with Kaiser Normalization, an orthogonal rotation procedure, to increase the interpretability. In a second step, shrimp farms were clustered according to the new factors, using first a hierarchical clustering technique (Ward's methods, in Ward, 1963) to estimate the number of clusters.

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[1] mVND: Million Vietnam Dong.

Secondly, a K-mean clustering technique procedure was used to obtain the cluster centers. To test if initial variables were significantly different between different clusters, we used ANOVA and post hoc tests (Games and Howell in SPSS, 2007).

2.2.3 Comparison of farm types

After classification, the production systems were compared for their *disease outbreak occurrence* (which represents the percentage of ponds where a shrimp disease occurs during one shrimp crop, calculated for each farm), but also for their *shrimp yield (kg/ha)* and *total aquaculture yield (kg/ha)*. Average shrimp and aquaculture yield and feed, labor and capital use efficiencies were computed only for farms not affected by virus outbreak with the goal of making an unbiased comparison of the farm's performances. Aquaculture and shrimp yield were also computed for only virus affected farms to estimate the loss in productivity. A one-way ANOVA and a Games and Howell post hoc test were used to identify significant differences between production systems ($p<0.05$).

2.3 Results

2.3.1 Classification

Factor analysis identified 3 orthogonal linear combinations of the 13 original variables (Table 2.1), explaining 68 % of the total variance. Factor 1 had 8 main components (component loading with an absolute value above 0.5), 3 with negative signs related to intensification (*shrimp stocking density, start-up investment and commercial feed used*) and 5 with positive signs related to extensive and diversified brackish water aquaculture (*number of aquaculture species, farm area, average pond size, gross return fish and other crustaceans* and *LUI aquaculture*). This factor represented '*intensification and specialization*' of the aquaculture activity, showing the orientation of the production towards intensification (negative loading), with high stocking density in a shrimp monoculture system using high level of inputs and equipment. Positively loaded, we found large extensive farms operating larger ponds stocked with several aquaculture species during the year. Farms with positive loading on this factor represent extensive diversified aquaculture farms. This component accounts for 27 % of the original variance in the set of thirteen variables.

Table 2.1: The rotated factor matrix, result from a principal component analysis based on 13 variables of 170 shrimp producing farms (GR = gross return)

	Component		
	1	*2*	*3*
Farm area (ha)	0.613	-0.112	0.390
Number of aquaculture species	0.745	-0.227	-0.168
Stocking density (PL/m2)	-0.701	-0.509	0.307
Start-up investment cost (mVND/ha)	-0.606	-0.480	0.355
GR fish and other crustaceans (mVND/ha/yr)	0.623	-0.175	-0.132
LUI aquaculture (%)	0.663	0.249	0.157
Average pond size (ha)	0.724	0.235	0.044
Commercial feed (kg/ha/yr)	-0.548	-0.413	0.429
GR agriculture (mVND/ha/yr)	-0.047	0.896	0.015
LUI rice (%)	-0.074	0.921	-0.049
Fresh water period (salinity<4ppt) (month/year)	0.182	0.808	-0.007
Contracted workers (man/ha)	-0.202	-0.172	0.836
Ratio family/total labor	-0.126	-0.153	-0.864
% of the total variation explained	27.2	24.8	16.0

Note: Factors with eigenvalue above 1 were extracted.

Factor 2 had 4 significant loading: *LUI rice*, *fresh water period*, *gross return agriculture* and *stocking density*. This factor represented the '*diversification of the farm production*' with an alternating agriculture-aquaculture system. This component accounts for 24 % of the original variance in the set of thirteen variables. Factor 3 had two significant loading, with *ratio family labor/total labor* and *contract workers* thus representing the '*labor origin*' differencing family and commercial farms. This component accounts for 16 % of the original variance in the set of thirteen variables. The hierarchical cluster analysis based on these 3 factors indicated the presence of 4 clusters. The non-hierarchical K-means cluster analysis was used to obtain the four cluster centers (Table 2.2).

We identified 4 different types of shrimp farms: *brackish water polyculture farm, rice – shrimp farm, intensive commercial farm* and *intensive family farm*. All the 3 factors had an influence on the clustering. However, factor 1 was dominant in defining clusters *brackish water polyculture* and *intensive family*; factor 2 dominated in defining the *rice–shrimp* cluster, whereas labor origin (factor 3) played a major role in defining the cluster *intensive commercial farm*. All variables had a significant role in structuring the data (Table 2.3). For *fresh water period*, a range instead of distinctive characteristics is given.

Table 2.2: The contribution of the three classification factors to the four cluster centers

	Cluster			
Classification factors	*Brackish water polyculture*	*Rice – shrimp*	*Intensive commercial*	*Intensive family*
Intensification and specialization	1.083	-0.122	-0.625	-0.984
Farm diversification	-0.570	1.359	-0.565	-0.730
Labor origin	-0.278	-0.0571	2.716	-0.420

Cluster 1: *Brackish water polyculture farms* are located in areas with 3 months of fresh water on average (Figure 2.1). The aquaculture production of these farms is diverse, with *P. monodon*, mud crab and high value fish; the number of aquaculture species raised is significantly higher than other farm types. Farm area is significantly larger in *brackish water polyculture farms* with an average of 3.0 ± 1.8 ha than in *rice–shrimp farms* and *intensive family shrimp farms*. Average pond size, is also significantly higher in *brackish water polyculture farms* (1.4 ± 0.7 ha) than in *intensive commercial* and *intensive family farms*. Shrimp stocking density is lower than in other farm types; farmers use a multiple stocking technique and do not use manufactured feed pellets. Start-up investment is significantly lower than in cluster 3 and 4. Moreover, gross return from fish and crab is significantly higher than in other farm types. Labor input is mainly based on household labor and occasionally workers are hired for specific tasks such as pond preparation.

Figure 2.1: Harvest in a brackish water polyculture pond

Cluster 2: *Rice–shrimp farms*, are mainly located in a specific agro-ecological area, with an average period of fresh water of 6.5 months (Figure 2.2). In 24% of the cases the rice crop is associated with concurrent fresh water aquaculture (fish or fresh water prawns) during the rainy season. The remaining 76% of the farms do not stock fish or other crustaceans in their rice field and harvest only wild fish trapped in the pond. During the dry season, all farms culture shrimp. These farms use household labor and occasionally hire workers on a daily basis for both rice and shrimp culture. The shrimp stocking density (2.43 ± 1.77 PL/m^2) is significantly lower than in cluster 3 and 4, but significantly higher than in cluster 1 ($p<0.05$). The production system practiced is extensive with low start-up investment and no use of commercial feed. According to the seasonal changes, farmers diversified their production systems, with agricultural production in fresh water environments and shrimp culture in brackish water environments.

Table 2.3: The number of farms and the averages ± standards deviation of a range of characteristics of the shrimp production systems identified by cluster analysis

	Cluster			
	Brackish water polyculture	*Rice – shrimp*	*Intensive commercial*	*Intensive family*
Numbers	56	54	14	46
Farm area (ha)	3.01 ±1.79^{a}	1.93 ±1.30^{b}	2.75 ±3.15^{ab}	1.39 ±0.83^{b}
Average pond size (ha)	1.40 ±0.72^{a}	1.07 ±0.67^{a}	0.36 ±0.08^{b}	0.32 ±0.11^{b}
Contracted workers (man/ha/yr)	0± 0.0	0 ±0.0	1.58 ±0,81^{a}	0.05 ±0.19^{b}
Ratio family labor/total labor	0.79 ±0.24^{b}	0.72 ±0.2^{b}	0.12 ± 0.17^{c}	0.95 ±0.13^{a}
Fresh water period (months)*	<6^{a}	>6^{b}	<6^{a}	<6^{a}
LUI rice (%)	0 ±0.0	77.1 ±11.3^{a}	0 ±0.0	1.5 ±10.0^{b}
LUI aquaculture (%)	95.3 ±2.9^{a}	91.6 ±6.5^{b}	89.1 ± 7.6^{b}	80.2 ±15.8^{c}
Number of aquaculture species	2.3 ± 0.78^{a}	1.28 ±0.52^{b}	1.00 ± 0.0^{c}	1.04 ±0.29^{c}
Shrimp stocking density (PL/m^2)	1.71 ±0.76^{c}	2.43 ±1.77^{b}	21.64 ± 8.87^{a}	18.76 ±8.23^{a}
Start-up investment (mVND/ha)	5.55 ±2.55^{b}	6.56 ±2.37^{b}	61.65 ± 27.49^{a}	45.53 ±27.87^{a}
Commercial feed (mVND/ha/yr)	0	113 ±379^{b}	9245 ±8,248^{a}	4899 ±4,620^{a}
Gross return agriculture (mVND/ha/yr)	-	8.87 ±3.83	-	-
Gross return fish and crustaceans (mVND/ha/yr)	5.30 ±6.33^{a}	1.33 ±1.83^{b}	0 ±0.0	0.05 ±0.24^{c}

* For the variable: 'Fresh Water Period' each cell provides the range of the variable.

^{abc} : Cluster values in one row with no superscript letter in common are significantly different ($p<0.05$).

Cluster 3: *Intensive commercial farms*, are mainly located in areas with 2.6 months of fresh water (Figure 2.3). These farms are specialized in intensive shrimp culture using contract workers on a 6 monthly basis to operate small sized ponds. The average farm size is larger than in cluster 4 and the start-up investment is higher than in all 3 other farm types. Compared to extensive systems (clusters 1 and 2) cluster 3 is characterized by the use of commercial feed and a specialization toward shrimp culture.

Figure 2.2: Rice-shrimp farm during the fresh water period (left) and intensive commercial farm (right)

Cluster 4: *Intensive family farms* (Figure 2.4), were specialized in *P. monodon* culture and presented similar characteristics as cluster 3. However, compared to cluster 1 and 3 the average farm area was significantly smaller ($p<0.05$). Moreover, household members operated small sized ponds (0.3 ± 0.1 ha) and the farms only employed contract workers sporadically; consequently the ratio family labor/total labor was higher than other farm types. Start-up investment and commercial feed used, as well as stocking density (with an average of 18 PL/m^2) were higher than in clusters 1 and 2. Surprisingly, this cluster showed significant lower aquaculture land use intensity than other clusters.

Figure 2.3: Intensive family farms

Actually, on these farms not all the owned or rented land was used for production and it was common for part of the farm to remain fallow due to lack of capital for investment. These farms were relatively close to cluster 3, in terms of specialization and intensification, but they differed in origin of labor.

2.3.2 Aquaculture yield and disease outbreak

Disease outbreak results were based on farmer's records of disease outbreaks in their ponds in 2006. For each pond, farmers were asked if a viral shrimp disease occurred, causing either mass mortality or partial crop loss. In 2006, *intensive commercial farms* presented the lowest disease occurrence, followed by *rice–shrimp farms*. *Intensive family farms* and *brackish water polyculture farms* had a higher virus disease occurrence with more than 30% of each of these types of farms affected by a disease outbreak (Table 2.4).

Table 2.4: The percentage (± SD) of ponds affected by disease outbreak, number of disease free farms, and shrimp and total aquaculture production on disease free farms and in virus affected farms in 2006 by farm type

Type of farm	*Brackish water polyculture*	*Rice- –shrimp*	*Intensive commercial*	*Intensive family*
Virus outbreak (% farms)	49 ± 45^{a}	25 ± 36^{bc}	13 ± 27^{bc}	32 ± 36^{ab}
Number disease free farms*	17 (56)	32 (54)	9 (14)	21 (46)
P. monodon yield in disease free farms (kg/ha/yr)	242 ± 109^{a}	217 ± 167^{a}	6191 ± 4372^{b}	4603 ± 2665^{b}
Aquaculture production in disease free farms (kg/ha/yr)	469 ± 179^{b}	299 ± 163^{a}	6191 ± 4372^{c}	4603 ± 2653^{c}
P. monodon yield in virus affected farms (kg/ha/yr)	77 ± 13^{a}	146 ± 60^{a}	6129 ± 2316^{ab}	1334 ± 315^{b}
Aquaculture production in virus affected farms (kg/ha/yr)	247 ± 28^{a}	213 ±60^{a}	6129 ± 2316^{ab}	1334 ± 313^{b}

*In parenthesis the total number of farms.

abc : Cluster values in one row with no superscript letter in common are significantly different ($p<0.05$).

However, outbreaks on intensive farms having several ponds mostly did not affect all ponds; sometimes only 5–10 % of the ponds were affected. For extensive shrimp culture systems, *rice–shrimp farms* had a significantly lower disease outbreak frequency than *brackish water polyculture farms*.

Shrimp and total aquaculture yields were computed using farms where no disease outbreak occurred and the same analysis was conducted with only farms affected by virus disease. *Intensive commercial* and *intensive family farms* had the highest shrimp yield and total aquaculture production, including fish and other crustaceans or when rice production was included. *Intensive commercial farms* did not show a wide difference in production results between disease free and disease affected farms; in only one farm of this type, more than 50% of the ponds were affected by virus outbreaks. However, 17 of the 25 *intensive family farms* affected by virus outbreak had more than 50% of the ponds affected by viruses, and their shrimp yield and aquaculture production was 71% lower than in disease free farms.

Compared to *rice–shrimp farms*, the total aquaculture production was higher in the case of the *brackish water polyculture farms*, with 49% of the production composed of mud crab (*Scylla spp*), wild and stocked fish such as elongated goby (*Pseudoelongatus apocryptes*) or seabass (*Lates calcarifer).* Fish, mud crab or fresh water prawn (*Macrobrachium rosenbergii*) production always followed extensive raising techniques, with low stocking density (<1 ind/m^2) and based on natural productivity of the pond. For mud crab the average yield was 44 kg/ha/yr in *brackish water polyculture farms* and the average fish production was 116 kg/ha and 96 kg/ha for *brackish water polyculture* and *rice–shrimp* farms respectively. In terms of production, wild fish represented 123 kg/ha/yr and 59 kg/ha/yr for *brackish water polyculture* and *rice-shrimp farms* respectively. Even if the total aquaculture production was higher in *brackish water polyculture farms* than in *rice–shrimp farms*, the total yield was higher in this last farm type when we included agricultural production, with an average productivity of 3497 ±1419 kg/ha/yr compared to 314 ± 202 kg/ha/yr.

On *rice–shrimp* and *brackish water polyculture farms* shrimp yields and the effects of disease were about similar; both of these farm types showed a strong reduction of their shrimp production in the case of virus outbreak. In *brackish polyculture farms* shrimp yield became lower than in *rice–shrimp farms* when we take into account only virus affected farms. However, the overall aquaculture production remains higher than in *rice–shrimp farms*. When we take into account the entire sample (including both virus affected and non-virus affected farms), fish and crab represented 29% of the farm gross return in *brackish water polyculture farms*. The investment of these farms was still oriented toward shrimp culture, with more than 81% of the operational cost allocated to shrimp. Only *rice–shrimp farms* allocated less than 70% to shrimp while all other farm types invested over 80%.

2.3.3 Feed, capital and labor efficiency

The average feed conversion ratio was 1.37 ± 0.37 and 1.53 ± 0.70 for *intensive commercial* and *intensive family farms*, respectively ($p<0.05$). Only these two farm types were using manufactured feed pellets; the aquaculture production in other farm types was based on the natural productivity of the pond.

The operational cost in *intensive commercial farms* (257 mVND/ha/yr, including labor cost, post larvae and other inputs) was 45 and 25 times higher than in *brackish water polyculture farms* (6.65 mVND/ha/yr) and *rice–shrimp farms* (10.34 mVND/ha/yr) respectively. The average operational cost recorded in *intensive commercial farms* showed the level of the investment capacity needed to follow this technology compared to *rice–shrimp* or *brackish water polyculture farms* where the operational cost is for PLs mainly.

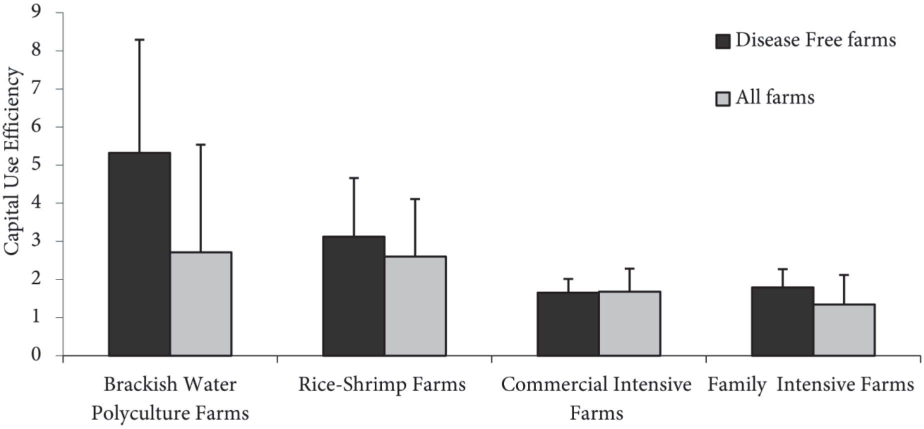

Figure 2.4: Capital use efficiency (ratio of gross return to capital cost) in disease free farms and for all farms (error bars represent standard deviation)

The non-infected *rice–shrimp* and *brackish water polyculture* farms showed a significantly higher capital use efficiency than intensive farms ($p<0.05$) (Figure 2.4). However, the difference with the *intensive farms* was non-significant when including farms affected by virus outbreak in the calculation, as the capital use efficiency was halved in *brackish water polyculture* and slightly reduced in *rice–shrimp farms*.

Labor productivity (Figure 2.5) of the *intensive family* farms, producing more than 15kg/day, was slightly higher compared to the *intensive commercial* shrimp farms. These two farm types were mainly differentiated by their labor origin, with more than 94% of the labor done by household manpower in the case of *intensive family* shrimp farm, whereas *intensive commercial* shrimp farms were mainly operated by hired labor (88%). The labor productivity of the *rice-shrimp* and *brackish water polyculture* extensive shrimp farms types was less than 10kg/day of shrimp. Covariate analysis showed that average pond size does not influence the labor productivity, whereas the farm size has a significant effect ($p<0.05$). A possible explanation is that the higher labor productivity for shrimp production of the intensive farms is due to the different orientation: mono-culture shrimp versus mixed systems for the extensive farms.

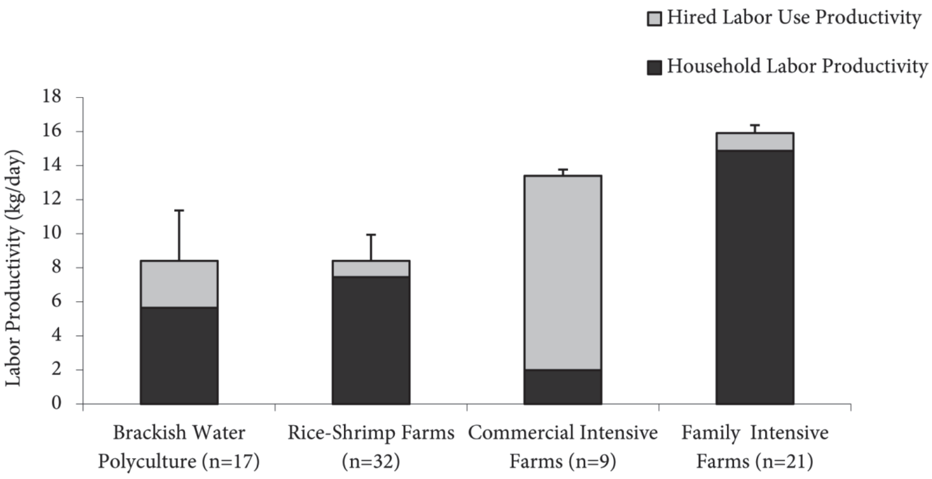

Figure 2.5: Labor productivity based on aquaculture production on disease free farms (error bars represent standard deviation)

Off farm activity revenue was significantly higher in extensive systems than in intensive systems, with average revenue of 1.4 mVND/household/year for *brackish water polyculture* and *rice-shrimp farms*. These households are more dependent on off farm activity such as pond preparation and rice harvest to secure their livelihood and finance their production. Non–farm activity was not significantly different between farm types, even if intensive commercial farms have higher average revenue from non–farm activities.

2.4 Discussion

2.4.1 Scope of the study

The analysis has shown that two types of specialized intensive farms differed by the level of hired labor and two types of extensive farms differed by the agro-ecological environment and the production diversity. Compared to Brennan et al. (2000), our sample was more geographically diversified within Bac Lieu province, with several sample sites located further inland where fresh water availability continues for a longer duration, allowing rice cultivation. Our farm sample included several agro-ecological conditions to obtain an overview of shrimp farms, however our sample remains small. The larger intensive commercial farms could not be included due to strict preventive measures designed to reduce the risk of virus contamination in the production site. Visitors can be potential virus carrier and are not allowed to enter production site. Ways to include data from these large farms in future studies should be explored.

Usually, shrimp farm typologies are based on the level of intensification, using variables such as farm area, stocking density and level of inputs (Nedeco, 1993; World Bank and MOFI, 2006). We used similar variables reflecting the functioning of the shrimp farm and added variables such as agro-ecological factors (fresh water period), or diversification of the production (LUI rice, gross return from agriculture, gross return of fish and crab, number of aquaculture species) and origin of labor. The use of these variables was motivated by a previous survey showing that shrimp farming in the Mekong Delta occurred also in rice based production systems and in mixed saline systems (Joffre, 2006).

2.4.2 Evolution of shrimp farming in the Mekong Delta

Previously, an Australian Centre For International Agriculture (ACIAR) project in 1997 had analyzed the development of shrimp farming in the same region from an economical and environmental point of view (Brennan et al. 2000; Be et al. 1999). Other studies focused on integrated mangrove–shrimp systems (De Graaf and Xuan, 1998; Johnston et al., 2000a; Minh et al., 2001; Luttrell, 2006). Since then, few studies had described the evolution of shrimp farming in the area.

During the past 15 years, driven by the international market and the development of the shrimp industry, Vietnamese shrimp farms had evolved into new production systems. The shrimp aquaculture systems described by Brennan et al., (2000) were all based on extensive shrimp culture and concurrent rice–shrimp culture. In 1997, 46% of the shrimp farms were recruiting wild post–larvae and only 2 % were using *P. monodon* monoculture. At this time the recorded shrimp yields were between 14 and 139 kg/ha, using low inputs (fertilizer and lime) and sometimes additional farm-made feed. At present, natural recruitment of shrimp has totally disappeared and the rice–shrimp culture system described in the saline environment was replaced by brackish water polyculture farms or intensive shrimp farms.

Comparatively, our study shows that shrimp culture has evolved toward diversification with mainly mud crab, and toward intensification fuelled by technology, notably the development of shrimp post–larvae hatcheries. On one side, the intensification of these production systems presents the same pathway as in Thailand several years ago (Lebel et al., 2002). On the other side, diversification of aquaculture production can present an alternative to intensification for small scale farmers with the development of niche markets. In comparison with shrimp production systems described in Thailand or Central Vietnam (Lebel et al., 2002; World Bank and MOFI, 2006), Mekong Delta's shrimp farms practice a wide range of extensive systems and seem to be more diversified. This diversity might allow a different evolution than in other shrimp production areas in South Asia and South East Asia where shrimp farming had a negative social and environmental impact (Primavera, 1997; Deb, 1998; Barbier and Cox, 2002; Lebel et al., 2002; Hossain et al., 2004; Primavera, 2006). However, the future of the shrimp farming in the Mekong Delta is still dependent on the capacity of the production systems to avoid or minimize the effect of virus outbreak.

2.4.3 Virus outbreak

In 1997, Brennan et al., (2000) highlighted disease outbreak as one of the causes of the low yield recorded. This remains the case in 2007, especially for most of the *brackish water polyculture farms. Rice–shrimp* systems, using frequent water exchange, present a relatively low percentage of disease outbreak compared to closed systems such as *intensive family farms*. This result is in accordance with field observation done by Vietnamese researchers in other provinces of the Mekong Delta (N.V. Hao, pers. com.).

The difference of disease outbreak between *intensive commercial* and *family farms* could be explained by technological differences: higher investments in water treatment and water quality monitoring as well as a higher knowledge of shrimp culture. *Intensive commercial farms* sometimes hired engineers to monitor the crop. This result is in accordance with recent observations that the impact of White Spot virus can be strongly reduced by high levels of bio-security (preventive measures against contamination) and minimum water exchange (Sorgeloos, pers. com.; Verdegem, pers. com.). Though even with a higher level of know-how and technology, shrimp farmers are still at risk of massive crop failure. Farmers manage this vulnerability by adopting coping strategies such as increasing the number of ponds. This strategy might be the reasons for the absence of a difference in shrimp yield between virus affected and non–virus affected *intensive commercial farms*. This absence of a difference might also reflect the capacity of shrimp farmers to harvest at the early stage of virus infection while the shrimps are still marketable. Intensification of the production, using technology to prevent virus and increase production did not always prevent from virus infection and massive crop loss; no conclusion can be drawn on the mid–long term sustainability perspective of intensive systems in the Mekong Delta.

2.4.4 Diversification of the production

The development of diversified *brackish water polyculture* production systems aims to compensate for the risk of disease outbreak. By diversifying production with mud crab or high value fish (elongated goby, seabass) and in few cases fresh water prawn, farmers minimize the impact of losing their part of aquaculture crop by having a relatively more secure production such as crab or fish which are less affected by virus outbreak and massive crop failure. For *brackish water polyculture* farms, mud crab and high value fish, together with wild fish trapped in the pond, remained economically important. However, the development of fish culture is limited by the abundance of wild fish trapped in the pond. This abundance of wild fish supplied to local markets, results in low market price and does not motivate farmers to stock fish for diversification of the production. Farmers claim that fish production is not as profitable as shrimp or mud crab. This diversified system presents a high level of disease outbreak and cannot be characterized as economically robust. Diversification of the aquaculture production allows farmers to generate an income even in case of major virus outbreak and increase the land productivity compare to extensive shrimp monoculture.

This option seems to be a coping system to face virus outbreak but it did not reduce the vulnerability to virus. This farm type might be economically interesting when the virus outbreak occurrence is reduced, but this requires technology investments which will reduce its high capital use efficiency. For *rice–shrimp farms*, capital use efficiency and economic results are interesting due to ecological advantages. Though aquaculture yield is higher in *brackish water polyculture farms* the total yield remains higher in *rice–shrimp farms*. The opportunity to grow a rice crop between two shrimp crops allows farmers to diversify their production with a secure crop, thus reducing the economic risk. However, in both *rice–shrimp* and *brackish water polyculture farms*, shrimp yields remain low (under 300 kg/ha/year) and both production systems are partially dependent on wild fish catch.

2.5 Conclusion

Since the early nineties, Mekong Delta's coastal aquaculture is developing fast with the industrialization of the shrimp sector. Changes and evolution of the production systems are part of this development as farmers respond both to the market and to virus outbreaks.

This study shows that ecological and technical factors are influencing the diversity of shrimp farms in the coastal area of the Mekong Delta. *Brackish water polyculture farms* are highly affected by virus outbreak and are no future option for shrimp farming without investments in technology. In contrast, *rice–shrimp farms* with their low shrimp yields, represent a sustainable production system in agro-environments with a long fresh water season. Intensification through technological investments and increased biodiversity reduces disease outbreaks and improves results of farms specialized in shrimp production. Intensive production systems seem to be economically sustainable on a short term period, but studies on mid and long term efficiency of intensive commercial farms including the 'biosecure' commercial farms, are needed.

Chapter 3

Community livelihood and patterns of natural resources uses in the shrimp-farm impacted Mekong Delta

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Abstract

This case study looks at changing livelihood strategies of the coastal population in Soc Trang Province in the Mekong Delta, Vietnam, and their impacts on natural resources. It provides an opportunity not only to document the impact of shrimp farming on coastal livelihood but also to better understand the link between brackish water aquaculture development and natural resource use. The approach includes a socio-economic survey in 6 villages of the province focusing on risk strategies and livelihood diversification. Shrimp farming was found less risky and more profitable for households and private companies with higher investment capacity and access to knowledge than for poorer households. Households facing high risk in shrimp farming diversified their aquaculture production, with other high value species like mud crab and elongated goby as a coping mechanism. The use of natural resources collected is shifting from home consumption towards market-oriented sales of juvenile mud crabs, clams or fish (elongated goby) to supply seed for brackish water aquaculture developments.

3.1 Introduction

The area developed for the farming of shrimps (*Penaeus monodon*) in the Mekong Delta (Vietnam) grew from 90,000 ha in 1991 to 460,000 ha in 2003 (Vo, 2003; MOFI, 2004).The growth was a result of national and international market forces and national and local policy (Lebel et al., 2002). This growth also had a number of socio-economic and environmental impacts. Shrimp farm development in Asia is well known as one of the main factors for mangrove deforestation (Barbier and Cox, 2002; De Graaf and Xuan, 1998; Hossain et al., 2001). Mangrove forests in the Mekong Delta coastal area have been significantly impacted by shrimp farm development with a forest clearance rate estimated to be 5,000 ha per year. It is estimated that the mangrove forest area in the Mekong Delta declined from 117,745 ha to 51,492 ha between 1983 and 1995 (Hong and San, 1993; Phuong and Hai, 1998).

Besides the impact on the environment, livelihoods in the coastal zone have been transformed by the development of shrimp farms. Since the beginning of shrimp farm development in the 90s, farming techniques have evolved and new production methods have become more popular resulting in intensification of production and diversification into brackish water aquaculture (Joffre and Bosma, 2009). Initially extensive production methods were limited to trapping wild post larvae in ponds (Brennan et al., 2000). As a result of the intensification of shrimp farming the coastal population has faced a new socio-economic situation and has consequently developed new livelihood strategies.

One hypothesis is that shrimp farming development modified natural resources use pattern and coastal community livelihood. Empirical data, including social, economic and environmental components, supporting this hypothesis are covered by only few studies (Lebel et al., 2002; Deb, 1998). This paper aims to examine and better understand the new livelihood and risk management strategies of the coastal population in Soc Trang Province in the Mekong Delta, with emphasis on natural resource use. The importance of natural resources for the coastal population is also characterized along with the impact of coastal aquaculture development on the population's livelihoods trough the examples of newly farmed aquaculture species, mud crab (*Scylla spp*) and elongated goby (*Pseudoelongatus apocryptes*).

3.2 Material and Method

A survey was undertaken in the coastal area of Soc Trang Province in 2007, where the shrimp production area increased by 31,150 hectares between 1995 and 2006 (Provincial Statistical Book, 2006), to ascertain whether this change has had an impact on the local economy, livelihoods and natural environment.

3.2.1 Location and description of the study area

The coastal zone in Soc Trang Province includes 3 districts, Vinh Chau, Long Phu and Cu Lao Dung which form the study area (Figure 3.1). The total study area is 1,153 km^2 and comprises 72 km of coastline and 11 communes. The coastal area also comprises more than 10,000 hectares of mudflats which are mainly located in the Cu Lao Dung and Vinh Chau Districts. The local population within the study area is 188,567 and comprises 38,149 households of which 32% are officially considered as poor (Provincial Statistical Book, 2005, District Statistical Book, 2005).

The annual rainfall is 1,597 mm in Mo'O (Long Phu District), with a dry season from November to April (less than 100 mm/month). The rainy season starts from May and ends in October (90% of the total rainfall). The Soc Trang coastal area is a unique environment where inland saline intrusion occurs during the dry season with water from the South China Sea conveyed further inland by strong semi-diurnal tides. Water salinity consequently varies according to season and tidal amplitude. The highest salinity concentration has been recorded in Mo'O station (Long Phu District) in June (31 g/L^{-1}). After this peak in June, the saline water intrusion decreases, with a period dominated by fresh water in October and November. In December, saline water intrusion starts again in the estuary. The southern part of Cu Lao Dung District presents a similar pattern of saline water intrusion, with a fresh water period limited to October and November and water salinity higher than 10 gL^{-1} from January to July. In Vinh Chau District, the coastal area is not affected by the fresh water flow from the Mekong River and inland saline intrusion occurs all year, with the highest salinity of over 30 gL^{-1} recorded by farmers in the dry season (March/April).

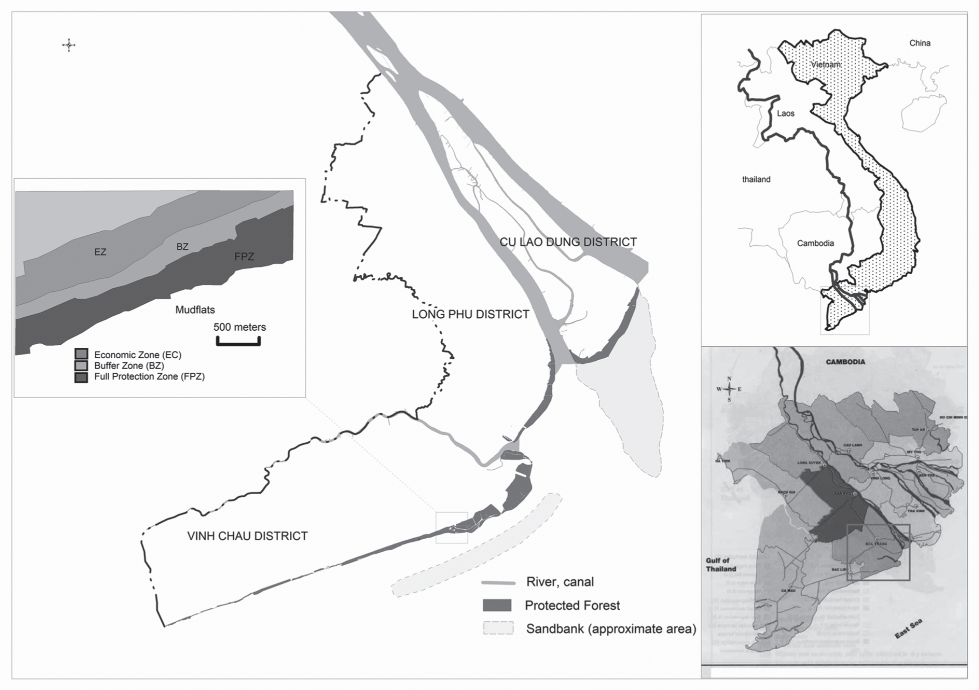

Figure 3.1: Study area: Soc Trang coastal zone

Both Long Phu and Cu Lao Dung District have mangrove forests comprising similar species (mainly *Sonneratia spp*). The mangrove forests in Vinh Chau District comprise mainly Avicennia and Rhizophora species. The status of the mangrove forests along the coast varies by district. Cu Lao Dung has 1,383 ha of forest with a width between 100 m and 1,300 m. Long Phu has 489 ha of forest having a maximum width of 900 m. Vinh Chau has a total of 2,702 ha of forest which is narrow (< 300 m) in the western part of the district and varies between 1,600 to 2,200 m width in the eastern part.

In 1999, Prime Minister Decision 116 defined three distinct zones within mangroves forest areas:

- Full Protection Zone (FPZ), a narrow strip of 500 to 1,000 m where settlement is prohibited as well as tree felling, soil mining, aquaculture, agriculture and collection of fish and shrimp fingerlings.

- Buffer Zone (BZ), a strip of 100 to 5,000 m located behind the FPZ, where economic activities such as settlement and conservation measures are permitted. Sixty percent of the area is supposed to be covered by mangroves and 40% can be converted into ponds or settlement in order to support family livelihoods. Hunting and collecting wild animals as well as tree felling is illegal.
- Economic Zone (EZ) is an area where economic activities can take place without land use restrictions. This zone is located behind the Buffer Zone and is generally bordered by a road running more or less parallel to the coast.

3.2.2 Land Use

In Soc Trang Province the main land use trend during the last 10 years has been the wide spread development of shrimp farms. The area used for aquaculture has increased from 7,802 ha in 1995 to 51,706 ha in 2006, with 32% of the total area used for intensive and semi-intensive production systems. Shrimp production in the coastal districts has grown from 9,999 tons in 2000 to 37,705 tons in 2005, representing 88% of the total provincial production in 2005 (42,837 tons). Brackish water aquaculture also farmed mud crab and elongated goby in the past few years. The expansion of shrimp farming reduced agriculture areas significantly, particularly in Vinh Chau the rice growing area declined from 22,000 ha in 2000 to 2,585 ha in 2005. In addition, 1,691 ha are used for growing onions in Vinh Chau and 1,837 ha for sugarcane in Cu Lao Dung.

3.2.3 Farmer's livelihoods approach

A socio-economic baseline study was carried out to determine the diversity of livelihood strategies within the coastal zone of Soc Trang Province and the importance of natural resource use in the coastal communities. Analysis of household's diversification and coping strategies followed Ellis and Allison (2004) with the aim to get a better understanding of new livelihood pathways and to provide an integrated view of how people make a living within evolving social, economic and environmental contexts.

Twelve possible sampling strata were identified based on a combination of the following criteria: 1) condition of the mangrove belt defined by three different modes (belt widths of more than 1 km, between 250 m and 1 km and less than 250 m), 2) shrimp farming intensity outside the mangrove belt defined by 2 different modes (intensive and semi-intensive shrimp farming, rice-shrimp or extensive shrimp farming) and 3) presence of farming activity inside the mangrove belt defined by 2 different modes (presence or absence of farming activity). The combination of the three different criteria and their modes resulted in 12 possible sampling strata. Within the study area only 6 of the 12 possible sampling strata were present and one village in each stratum was selected for the socio-economic baseline survey.

Definition of wealth groups and selection of households for the survey was carried out in the following way. The head of each village was asked to identify at least two households corresponding to the different official wealth groups, which are based on income only. During Participatory Rural Appraisals the selected households (without the facilitation of local authority representative) were asked to (re)define wealth groups in the village and which criteria can be used to identify them, other than income. The households in each village were ranked according to economic criteria (wealth) including assets, income from aquaculture and agriculture, as well as detailed natural resource use. For each wealth group 3 to 10 households of the village were selected by the participants from the village's census list. The selection of each household required the validation by the entire group but excluded local authorities. To allow the maximum diversity in our sample, geographical clusters of households were avoided.

A survey was undertaken in the selected households to collect quantitative data on household's demographics; household's assets such as transportation, agricultural equipment, land ownership and cultivated land. Detailed questions about agricultural, aquaculture and non-farm income were also included in the survey. Income was calculated as the gross return minus operational cost. Operational cost of aquaculture or shrimp production include the cost of inputs (feed, hired labor, chemical, fuel cost, pond preparation and maintenance). For shrimp farming average disease outbreak occurrence between 2005 and 2006 was calculated as the ratio of ponds where the disease occurred during these two years. Natural resource use, including an estimation of the income derived from it and the specific environment where the resource is collected (e.g. mangrove forest, mudflats or sandbank) was included in the questionnaire. Source of income (farm production, natural resource collection, off farm and non-farm incomes) and household's food origin (market, natural resource collected or farm production) were also ranked by each household in order to understand the economic importance of each activity for household economy and food security. Production and economic results of commercial shrimp farms was assessed in each sampling zone. A total of 8 commercial farms were interviewed. In 2 sampling zones, no commercial farms were present or had no representatives willing to respond. Economic results of commercial farms were not included in the statistical analysis due to large difference of scale with some farms exceeding 150 hectares, while most of household's shrimp farms are around 1 to 3 ha. Instead, operational cost and income per hectare of shrimp farming were used.

The livelihood resources were analyzed to understand the different options and risk strategy (e.g. intensification, diversification or migration) of the wealth groups with a special emphasis on the role of brackish water aquaculture development as diversification strategy. To test if the household's characteristics were significantly different between wealth groups, we used ANOVA and post hoc tests (Games and Howell in SPSS, 2007) for quantitative data. Difference between wealth groups for nominal data such as possession of Land Use Right Certificate, type of income generation activity or type of aquaculture species farmed, source of income and food were tested with Chi square test (SPSS, 2007). Significant differences of household's characteristics between wealth groups are presented in the text.

3.3 Results

For the livelihood approach, the wealth ranking exercise defined three main wealth groups in the different study areas: poor, medium and better off. The entire sample included 92 households (HH) belonging to the wealth groups, poor (45 HH), medium (29 HH) and better off (18 HH). Definition of terminology used in the results section is presented in Table 3.1, including a definition of the different wealth groups in the study area.

3.3.1 Employment and activities

Off-farm employment is significantly different between wealth groups ($\chi^2 = 21.60$; $p<0.05$). Poor households are more frequently involved in off farm employment (60% of households) than for other wealth groups, with most employment opportunities being in agriculture (rice, vegetable or shrimp pond preparation). Only 27% and 13% of medium households are involved in off-farm and non-farm activities respectively, and better off households are not involved in these kinds of activities. Forty four percent and 66% of medium and better off households respectively, diversify their non-farm income by developing services and small scale processing, with a significant difference (χ^2= 20.93; $p<0.05$) compared to poor households (11% of households); moreover 27% and 22% for medium and better off households respectively, are government employees. Better off households have an average income from employment (not including agricultural activities) of over 25 Million Vietnam Dong/year (mVND), whereas the income is under 5 mVND/year and 15 mVND/year for poor and medium households respectively.

Table 3.1: Definition of wealth groups and terms used in the study

Terms	*Definition and examples*
Off –farm employment	Wage or exchange labor on other farms, within agricultural sector, including seasonal migration
Non-farm employment	Wage labor outside the agricultural sector, like construction work, factory.
Small scale processing and service	Refers to cottage industry e.g. basket making, nipa leaf processing for roof construction, fishing net making. Service industry refers to activity using knowledge or skills to generate income, but also labor in owned small shop.
Government employment	Employment under contract with the State: hamlet official, administrative jobs, school teacher.
Poor	Household income is based on off-farm and non-farm employment, with little on-farm employment (aquaculture and vegetable production) when the household has access to land. The households have no access to salaried work on shrimp farms. Natural resource collection plays an important role for both income generation and self-consumption.
Medium	The households have a diversified on-farm production system, with both aquaculture (shrimp, brackish water polyculture) and agricultural production. Households have access to land and can develop semi-intensive and intensive shrimp culture. Off-farm, non-farm, small services and salary employment are important activities for household's income, as well as, natural resource collection.
Better-off	On-farm employment (rice, onion farming, intensive shrimp and elongated goby culture) and small service industry are the main activities. The households are not selling labor. On-farm production is more specialized mainly in intensive shrimp culture.

Off-farm employment opportunities also depend on the local agro-ecosystem. An average of 80 man days of labour/year/HH was available in areas with rice production or cash crops such as sugarcane (Cu Lao Dung District) and onions (Vinh Hai District) compared to 53 man days/year/HH in other areas (Long Phu District, Vinh Chau Town and Vinh Tan communes). Similarly, employment on fishing boats is localized near harbors and landing sites. Employment in commercial and intensive shrimp farms is not possible for local people as farm managers prefer to hire experienced workers from other provinces and have workers live within the farm for bio-security reasons. Shrimp cultivation provides employment for poor and medium households only on local farms for pond preparation using daily wage labour and not long term contracts which are used in commercial shrimp farms.

3.3.2 Landholdings

Table 3.2 illustrates the correlation between land holding size increases and increase of wealth, with poor households having significantly less land, plots and Land Use Right Certificate (LURC) (χ^2= 11.24; $p<0.05$) than other wealth groups. Most poor households (72%) have no cultivated land and 60% of the poor households do not have a Land Use Right Certificate (LURC), settling illegally within the BZ or living on their parent's land. In addition, the absence of any LURC impedes their access to formal loans. Local officials explained that most poor households cannot afford a LURC. Another reason given for the delay with the issuing of LURCs is pending land conflicts in the BZ which reduce the amount of land available for LURCs.

Table 3.2: Mean landholding (± standard deviation) per household (HH) by wealth groups

Wealth group	*Average number of Plots*	*Average land owned (ha)*	*% of households with LURC*
Poor (45 HH)	1.13 ± 0.34^a	0.29 ± 0.54^a	40
Medium (29 HH)	2.93 ± 1.06^b	1.41 ± 1.57^b	75
Better off (18 HH)	3.50 ± 1.58^b	3.39 ± 347^b	73

ab: value followed by the same superscript letter in each column are not significantly different at 0.05 level (a<b).

In general, most land owners in the surveyed locations of Long Phu and Cu Lao Dung Districts, especially those who have shrimp farms, have mortgaged their LURC to banks for loans. In Cu Lao Dung District, the local authorities reported that about 50% of the land is leased or mortgaged. In 2002-03 the government developed a loan policy for local farmers in order to convert their rice fields into shrimp ponds; farmers had the opportunity to borrow between 8 and 10 mVND/0.1 ha owned.

There have been few, if any, small scale shrimp farmers who actually paid off their mortgages as they often cannot repay outstanding loans due to severe crop failures, as well as decreasing selling prices at the farm gate and increasing input prices during the last few years. The development of shrimp cultivation inflated the land market causing an increase of land value from 30 mVND/ha in 2000 to more than 120 mVND/ha in 2007, and a maximum of 600 mVND/ha. The land price varies according to the location and brackish water supply. During the same period, the land leasing fee multiplied by 36 to 96 times, constraining access to land for poor as well as medium households. In addition, the allocation of large land areas in either the EZ or BZ by provincial or district authorities to commercial shrimp farms (more than 600 ha in Vinh Chau for example) has led to tension and conflict between commercial shrimp farms and the local population.

3.3.3 On farm activity

Seventeen percent of medium households and only 11% of better off households are involved in both agriculture and aquaculture production with access to land in different agro-ecological areas. It appears that better off households are more specialized than medium households, with fewer households involved in both agriculture and aquaculture. Poor households are never involved in both activities at the same time, with only 13% of the poor households involved in aquaculture and 16% in agriculture; their livelihoods are based mainly on off-farm employment and natural resource collection. In contrast 67% of better off and 41% of medium households are involved in aquaculture. Involvement of households in aquaculture is significantly different between wealth groups ($\chi^2 = 18.12$; $p < 0.05$).

Aquaculture production systems in the coastal area range from traditional brackish water aquaculture production fattening wild fish and crustaceans trapped in ponds to semi-intensive and intensive shrimp production systems. In between, all sorts of production systems can be found, varying in their levels through intensity and use of inputs. In addition, fish (elongated goby, sea bass and tilapia) and crab cultivation are more popular among medium households (Table 3.3). A significant difference in the type of aquaculture species farmed was found between wealth groups for shrimp ($\chi^2 = 16.15$; $p < 0.05$), elongated goby ($\chi^2 = 7.90$; $p < 0.05$) and other fish ($\chi^2 = 9.08$; $p < 0.05$). Better off households tend to focus their investment on higher value fish such as elongated goby and shrimps on a larger scale, compared to medium households, allocating on average 1.96 ha to elongated goby culture in the rainy season and 3.61 ha to shrimp culture in the dry season. Poor households use mainly extensive shrimp farming methods. Some of the poor households may use a daily catch of goby fry and mud crab juvenile to stock their ponds, but this technique is not widely used due to the lack of land and investment capacity for pond construction.

Overall experience with shrimp farming ranges from 4.7 to 6.5 years (average), while experience with fish aquaculture is more recent (2 to 3.6 years on average).

Table 3.3: Average aquaculture area (± standard deviation) and proportion of households (HH) involved in aquaculture production per wealth groups and per type of production

	Aquaculture area in ha for		*Percentage of households farming*			
	Fish & crab	*P. monodon*	*P. monodon*	*Elongated goby*	*Other fish (tilapia, sea bass)*	*Crab*
Poor (45 HH)	0.46 ± 0.19^a	0.96 ± 0.89^a	13	2	0	4.5
Medium (29 HH)	1.07 ± 1.84^a	1.76 ± 1.28^a	41	28	14	17
Better off (18 HH)	1.96 ± 2.62^a	3.61 ± 3.98^a	67	16	0	0

abc: value followed by the same superscript letter in each column are not significantly different at 0.05 level (a<b<c).

Economic survey results (Table 3.4) show that the operational cost of aquaculture production (shrimp and other aquaculture production) varies significantly ($p<0.05$) among wealth groups due to differences in farming intensity, technical input and cultivated area. The better off group is able to invest in intensive shrimp and intensive fish production (elongated goby), with an average investment of between 452 and 628 mVND/year/HH respectively, whereas medium households invest between 42 and 133 mVND/year/HH in each kind of production. For poor households involved in aquaculture, the investment for shrimp production is lower than 3 mVND/year/HH.

The operational costs for other aquaculture production for poor households could not be estimated due to the extensive techniques used, including several stockings of wild seed and multiple harvesting. The difference in operational costs depends mostly on pond inputs (shrimp feed, water treatment etc.) and stocking density. The better off group uses high technical skills for intensive shrimp and fish production on a large scale (3.61 ha on average), whereas the medium group uses less intensive techniques (lower investment) on a smaller scale (1.76 ha on average).

Table 3.4: Annual average (± standard deviation) investment in and income from aquaculture in million Vietnam Dong (mVND) per household and per wealth groups (n=57)

	Shrimp culture operational cost	*Income from shrimp culture*	*Virus Outbreak (% ponds)*	*Operational cost for other aquaculture*	*Income from other aquaculture*
Poor	2.9 ± 3.6^{a}	-2.9 ± 3.6^{a}	69 ± 40^{b}	-	-
Medium	133.3 ± 170.4^{b}	41.5 ± 145.2^{ab}	50 ± 42^{b}	42.8 ± 73.0^{a}	33.8 ± 90.7^{a}
Better off	628.2 ± 265.9^{c}	240.3 ± 355.6^{bc}	27 ± 26^{a}	452.8 ± 762.5^{b}	149.1 ± 275^{b}
Commercial farms (mVND/ha/year)	352 ± 140	432 ± 270	-	-	-

abc: value followed by the same superscript letter in each column are not significantly different at 0.05 level (a<b<c)

The standard deviation of economic results shows a wide range in shrimp farming and aquaculture production. These ranges highlight the economic risk associated with shrimp farming, with harvest failures due to disease outbreak recorded in 2005 and 2006 varying from 25% to 100% in semi-intensive shrimp production systems, 12% to 80% in intensive shrimp production systems and 46% in extensive systems. No significant difference was found between shrimp production systems, probably due to wide differences in terms of inputs use and technical management within each type of production system. However, shrimp harvest failed significantly less among better off ($p<0.05$) compared to other wealth groups. This difference is partly explained by higher input and technology used by better off households. Poor and medium households are more vulnerable to virus spread than better off households. A higher disease outbreak recorded in the medium wealth group can explain their diversification strategy to cope with virus outbreaks.

Volatile market price and the subsequent low market price at the farm gate is also one of the factors for shrimp farm bankruptcy. Farmers invested in shrimp farming while market prices were high and then unable to repay their loans due to a drop in market prices in the following years. Between 1991 and 2001 in Vietnam the average annual price increase for export shrimps was 8.7%; in 1991 the export price was $US 4.20/kg and in 2001 the price peaked at $US 8.92/kg (FAO, 2004). This can explain the ‘gold rush’ mentality of the farmers during this time. Farm gate prices declined by about $US 2/kg between 2003 and 2005 (130,000 VND/kg to 100,000 VND/kg for 30-40 shrimps per kg) (CTU, 2006), while the production costs increased (Christensen, 2003). In addition, on a shorter time scale, lack of storage facilities forced small farmers to sell their harvest during the peak harvest time at sub-optimal prices (10,000 to 15,000 VND/kg lower). Volatile market prices can be considered one of the key causes of bankruptcy of poor and medium households involved in shrimp farming, together with a lack of knowledge, equipment and investment capacity.

Agriculture production is restricted to higher elevated land which is less affected by saline intrusion and where rice, onions, sugarcane or *Derris spp* can be cultivated. Within the survey sample, cultivated areas vary on average from 0.2 ha for poor households (n=7), 0.7 ha for medium households (n=14) and 0.9 ha for better off households (n=10). Poor households cultivate vegetables and onions whereas medium and better off households also cultivate sugarcane and derris roots. Agriculture generated 60 mVND/year/HH, which is less compared to aquaculture activities for both medium and better off households but is a less risky investment than shrimp farming.

3.3.4 Natural Resource Use

It was not possible to estimate revenue and income derived from natural resources during interviews due to the high variability of this activity (climate, location and seasonal dependency), but the importance of natural resources could be assessed. Natural resources appear to be important for poor and medium wealth groups not only as a source of food but also as an important source of income (Figure 3.2). Members of less wealthy households were significantly ($p<0.05$) more involved in natural resource collection with between 2 and 3 members in poor households (average 2.2) and between 1 and 2 members in the medium well-off households (average 1.7). The better off households were not involved in natural resource collection for income generation or self-consumption. Forty-seven percent of the poor households ranked natural resource collection as their first source of income (mainly juvenile mud crabs, goby fry, clams and cockles), and 62% of the poor households ranked natural resources as their first source of food.

Natural resources such as fish from canals, frogs (unidentified species), sesarmid crabs (*Episesarma spp*), and snails (unidentified species) were the main species for self-consumption due to their low market value. Other species such as juvenile clams, mud crabs, goby fry, adult clams (*Meretrix lyrata*), cockles (*Anadara granosa*), shrimp (several species) and high value fish (*Harpadon neherus*, *Mugil spp*, *Plotosus canius* etc.) were sold to middlemen. The type of natural resources collected was not correlated with their economic status but more correlated to the geographical areas, with some specific areas for clams collection for example.

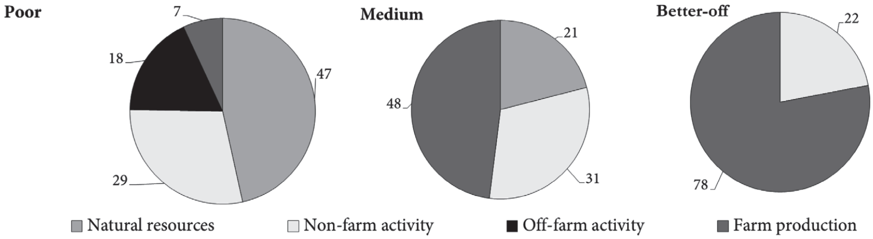

Figure 3.2: First source of income per wealth group (n=92)

Twenty-one percent of households from the medium well-off group ranked natural resource as their main income source and 41 % of this group rank natural resources as their main source of food. Their income sources were diversified between farm, non-farm and natural resources, while the better off depended on farm and non-farm activity only. The importance of natural resource for household income and diet was significantly different between the three wealth groups (χ^2= 15.03; $p<0.05$ and χ^2= 20.33; $p<0.05$).

Mangroves areas are mainly used to collect sesarmid crabs, juvenile mud crabs and elongated goby (Table 3.5) as well as wood for fuel. The mudflats and sandbanks are the main areas for natural resource collection due to the absence of regulation and the abundance of high value species (clams, cockles, mud crabs, clams and cockle seeds). Small shrimps (*Exopalaemon styliferus, Macrobrachium equidens, Parapenaeopsis hardwickii, Parapenaeopsis sculptilis* and *Acetes spp*) are collected mainly in the rainy season with peak periods corresponding with high tides.

Elongated goby fry and juvenile mud crabs are also collected during the rainy season whereas clams and cockles are collected in the dry season. There is a spatial and temporal differentiation in natural resource collection, with sandbanks being exploited in the dry season for clams and cockles, and mudflats and mangrove forest being exploited in the rainy season for elongated goby, small shrimps and juvenile mud crabs (Figure 3.3).

Table 3.5: Main products collected on mudflats, sandbanks and in forests and estimated income

Species	*Percentage of HH (n=74) involved in collection from*		*Income*
	forest	*mudflat/sandbanks*	*(1,000 VND/day)*
Sesarmid crab	20	-	4 -120
E. goby fry	14	14	20 – 100
Juvenile mud crab	58	58	20 – 50
Small shrimp	-	24	3 – 5
Juvenile clams	-	16	50 – 80
Adult clams	-	10	30 - 45
Fin fish	-	40	n.d.

n.d.: data not available

Juvenile mud crabs are the most common species collected in the mangrove forests and on the mudflats. Together with juvenile clams and elongated goby fries these species are collected to supply the regional market for aquaculture farms in Ben Tre, Tra Vinh, Tien Giang and Bac Lieu Provinces in the Mekong Delta. International market demand and virus outbreak in shrimp farming pushed the diversification of brackish water aquaculture production in the recent years. With the development of a market for juvenile species, the collection methods have now evolved towards more intensive methods using fixed nets on the mudflats to collect juvenile mud crabs and elongated goby, and the use of trawlers to collect juvenile clams and cockles.

Figure 3.3: Mud crab collector (left), fixed nets on the mudflats (center), juvenile fish and crab trader (right)

3.4 Discussion

The study shows that shrimp farming appears to be more profitable and less risky for households and private companies who can afford to invest in knowledge, techniques and inputs so that they can reduce the occurrence of virus outbreaks. Medium and poor households with limited resources are highly susceptible to virus outbreaks. Shrimp farming is well known to be prone to disease outbreaks and having a negative impact on coastal zones as reported in several countries in South and South East Asia (Primavera, 1997; Lutrell, 2002; Barbier and Cox, 2002; Hossain et al., 2004; Primavera, 2006; Alam et al., 2007). Hossain et al., (2006) reports that in the neighboring province of Bac Lieu, shrimp farming development has had a negative impact on the livelihoods of the poor and on those having marginal land as they are unable to invest in technology. The better off are the main beneficiaries of shrimp farm development (Tuong et al., 2003). Lebel et al., (2002) and Hossain et al., (2006) found that aquaculture development had increased the overall prosperity in financial terms of coastal communities but also increased inequities. This study clearly shows the difference from on-farm generated income between better off households and other wealth groups as well as the dependence on natural resources.

One of the arguments for shrimp industry development has been that it creates salaried employment in commercial shrimp farms and processing factories in the coastal areas which usually lag behind other regions in terms of industrial development (Gowing et al., 2006). However, shrimp processing factories are not located in the coastal areas but farther inland (in Soc Trang City for example), and commercial shrimp farms are not employing local labor but prefer to hire outsiders. Coastal populations do not have access to employment in the semi-industrial aquaculture sector and poor households do not benefit directly from development of semi-industrial shrimp aquaculture sector. This situation was also reported in Bangladesh where tension and social conflicts emerged when large shrimp pond owners did not hire local people (Deb, 1998). In addition, shrimp farming is less labour intensive than rice farming, creating less employment opportunities than the rice based farming systems that were replaced by the shrimp farms (Ibid).

Poor households are either landless or own very little land, and therefore wage labour and access to natural resources is even more important in their livelihood strategy. Household members involved in collecting natural resources for daily income and off-farm and non-farm employment is an important source of employment as opposed to on-farm activities which are more important for medium and better off households. Poor households are extremely dependent of natural resources for food and income. Even medium wealth households still show high level of dependency on natural resources especially as direct food source. On the other hand, better off households do not engage in natural resources collection at all.

Consequently one of the livelihood adaptation strategies for poor and medium households is to base their livelihoods more on natural resource collection than before the advent of shrimp farming particularly in areas with large-sized intensive shrimp farms. The large farms limit access to land and agricultural production (which can reduce demand for wage labour for the landless poor) and also increase pressure on natural resources as poor and medium households lose opportunities for other sources of income for their daily needs.

According to Ruerd (2007) household's diversification strategy via aquaculture can be seen as defensive purposes, to reduce household vulnerability. One of the reasons for brackish water aquaculture diversification in the Mekong Delta, in addition to market demand, has been the increase of disease outbreaks in shrimp farms. Farmers developed a coping strategy by diversifying aquaculture production with other crustaceans and fish production; this in turn developed a new market for mud crab and high value fish (Duyen et al., 1999; Joffre et al., 2010).

This case study clearly showed the effect of the development of brackish water aquaculture on natural resources use through the reliance of poorer households on natural seeds mainly. Local populations who previously collected natural resources for food security are now shifting to a market oriented natural resource collection in order to supply aquaculture ponds and the overall development of regional brackish water aquaculture (clam raising, elongated goby and mud crab farming).

Although this study does not include an historic assessment of changes in natural resource use patterns, it is apparent that collection of larvae by poor households for sale to farms has started only relatively recently. Collecting elongated goby fry, mud crabs, juvenile clams and cockles has started within the last 5 to 10 years, collection of juvenile mud crabs and juvenile clams and collection of elongated goby started less than 4 years ago. The culture pond area of mud crab in Tra Vinh Province increased, from 1,439 ha in 2000 to 11,603 ha in 2008. A similar trend was observed in Bac Lieu Province, with 136 ha cultivated in 2000 and 1,306 ha in 2008. According to Department of Fisheries (DoF), 90% of the shrimp ponds in Ca Mau

Province (more than 200,000 ha) are now stocked with mud crabs in an extensive polyculture system. Elongated goby, the most recent production system is mainly located in Bac Lieu Province (1,304 ha in 2008) and in a lower extent in Soc Trang (522 ha in 2008), with an increase of the cultivated area by 3.7 times in those provinces between 2005 and 2008.

The increasing demand leads to intensification of resource collection, using more intensive collection methods and having individuals collecting natural resources migrating from one place to another, seeking specific high value products. The intense collection of elongated goby fry and mud crab juvenile will certainly have a severe effect on the natural stock of these species. Already observations by local fishers of abundance and size of mud crab and elongated goby juveniles show a decline of the resource. It is interesting to note that shrimp farming both in the Mekong Delta (Brennan et al., 2000; Johnston et al., 2000b) and in Bangladesh (Hossain et al., 2004; Milstein, 2005; Mazid, 1995; Frankenberger, 2002) started shrimp production using wild post larvae which were trapped in ponds or collected from the wild until the drastic decrease of the resource and the development of hatcheries. It can be expected that the development in the Mekong Delta will follow a similar pattern.

Development of small scale hatcheries and nurseries for these species for poor people could be an interesting option to diversified household portfolio. However, in the current situation, the life cycle of the elongated goby has not been completed in a controlled environment and thus hatchery reared juvenile cannot be produce. Seeds produced in government owned mud crab hatcheries in the Mekong Delta are not popular because farmers prefer juvenile collected from the wild. Therefore, most cultivation relies on wild seed and juveniles collected on the mudflats and sandbanks.

With new market opportunities for crabs and elongated goby juveniles and the development of brackish water aquaculture, natural resources become more important for livelihood of poor and medium household. The sustainability of these resources, however, might be questionable in the near future because increasing intensification of the capture will affect the livelihood pathways of the local population. The dependence of aquaculture on wild seeds highlights the importance of mangroves as shelter and nursery grounds for a wide range of species which have recently become economically more important. After a period of mangrove deforestation for the expansion of brackish water aquaculture it now seems that the future of coastal aquaculture relies on the effective protection of mangroves for sustainable and economically viable seed collection.

3.5 Conclusion

Natural resource collection has increasingly become a livelihood strategy for poor households which do not have access to land or technology to develop brackish water aquaculture systems. Shrimp farming appears to be a more profitable and economically less risky livelihood strategy for households and private companies, who can afford to invest in knowledge, techniques and inputs compared to poorer households. Poor households depend on off-farm activities and collection of natural resources to sustain their livelihoods. These households rely even more on natural resources in areas where large-sized intensive shrimp farms limit access to land and agricultural production.

Alternatives are needed for local populations in order to develop less risky production systems to provide employment opportunities and reduce pressure on natural resources. Diversification of aquaculture production with production systems requiring less investment might be an option to overcome potential loss due to shrimp disease. However, the sustainability of this option which relies on wild seeds is questionable. Therefore, efforts to develop hatchery reared seeds are needed, together with protection and sustainable management of the mangroves which provide shelter and nursery ground for these species.

Chapter 4

What drives the adoption of integrated mangrove-shrimp aquaculture in Vietnam?

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Abstract

The development of shrimp farming in Vietnam has eroded the social-ecological resilience of the coastal ecosystem. Recent literature supports the idea that integrated mangrove-shrimp production systems can contribute to rebuilding this resilience in the Mekong Delta. Two experts panels, international and Vietnamese, were consulted to validate and weight drivers identified from literature that enable or constraint farmers to shift from extensive production system to integrated mangrove-shrimp system or to continue such integrated system. Though a combination of drivers is needed to enhance changes, two sets of drivers were given the highest weight. Experts considered the ecosystem function of the mangrove an enabling driver pushing farmers to plant mangrove in order to improve the pond's water quality and limit disease outbreaks. They perceived the drivers related to the current regulatory framework as constraining because these limit the financial return associated with integrated mangrove-shrimp systems. The analysis indicates that the adoption of these integrated systems requires more equitable distribution of benefits from shrimp and timber production between farmers and other stakeholder in these value chains. We recommend to develop a regulatory framework that can optimize the financial benefits of the integrated mangrove-shrimp production systems for farmers.

4.1 Introduction

Shrimp farming in Southeast Asia has been a major driver of land use change in coastal regions. The impact of shrimp farming coastal landscapes and ecosystems has been considerable over the previous four decades; between 1970 and 2000 the areal grew at an average rate of 17% per annum (Gowing et al., 2006; Primavera, 2006; Lebel, 2002; Nguyen, 2014). Mangrove forests have been particularly impacted, leading to a degradation of ecosystem services such as coastal protection, erosion control, habitat function, nutrient and waste cycling (Daily, 1997; Norberg, 1999; Sathirathai, 2001; Dahdouh-Gueba, et al. 2005; Alongi, 2008; Hussain and Badola, 2010; Manson et al., 2005a & b; Saravanakumar et al., 2008; Turner, 1977; Pauly and Ingles, 1986; Lee, 2004). The productivity and long term resilience of shrimp aquaculture is also dependent on many of these same ecosystem services (e.g. Primavera, 2006; Barbier et al., 2008; Bosma et al., 2014).

Bush et al., (2010; p.15) defined the resilience of a shrimp farm as '*the capacity to maintain [its] integrity when responding to external changes and feedbacks within their wider coastal social-ecological system*'. The resilience of a farm is therefore dependent on both the capacity of a producer to make decisions and adapt to changes and shocks, as well as on the capacity of the ecological system in which the farm is embedded to absorb changes and shocks while maintaining its main functions. Decisions affecting the resilience of shrimp production are also not independent, as they are embedded within wider processes of social, political, economic and environmental change (Bush and Marschke, 2014). These processes are also directional because they influence decisions to shift from one practice to another. On this basis they can be defined as 'drivers' of change, and by characterizing these drivers of change it might be possible to understand how changes at the farm level ultimately influence the coastal landscapes.

The drivers that shape coastal landscape and specifically mangrove ecosystems, are classified as human induced (such as food production systems, urbanization and industrialization, see Nguyen 2014), and nature-induced (including changes in the hydrological system causing coastal erosion or accretion and sea level rise and cascading effects and feedbacks from ecosystem change, see Friess et al., 2012; Balke et al., 2011; Liu et al., 2007). These human and natural drivers of mangrove loss are widely documented, as are the technical aspects of mangrove conservation and reforestation. However, less attention is given to the governance of mangrove reforestation and rehabilitation (Lewis, 2005;

Thinh et al., 2009). Just as replanting and/rehabilitating mangroves in and around shrimp ponds can take many forms, steering producers to change their production systems can be done in a variety of ways. One example of conservation and reforestation measures are the different types of integrated mangrove-shrimp production systems providing also livelihoods to shrimp farmers. In these systems shrimp are stocked in ponds with mangroves planted either within the pond or on bunds and/or platforms in and around ponds. These systems are thought to be more sustainable as they are ecologically embedded within the wider coastal ecosystem (Primavera, 2000). Yet despite their potential integrated mangrove-shrimp production systems are not widely practiced.

In this paper we focus on the bottlenecks and potential of steering farmers towards integrated mangrove-shrimp aquaculture systems to contribute in re-building the resilience of coastal zones, and the how farmers can be steered towards (continuous) investment in them. We contribute to on-going debates over coastal change and resilience (Bush and Marschke, 2014) by identifying and weighing the importance of the human and natural drivers in the decisions that farmers make about both shrimp culture practices, shrimp production systems and mangrove cultivation. Using the Mekong Delta in Vietnam as a case study, we investigate the relative importance of these drivers for farmer's decisions to either continue with or adopt integrated mangrove-shrimp farming systems. Our analysis is based on the results of a series of consultations, in which international and Vietnamese experts weighed the relative importance of a series of drivers identified through a review of recent research on farm level decisions that may or may not expand integrated mangrove-shrimp farming in the Mekong Delta.

The paper is divided into three main parts. We first describe the methodology adopted in this research before presenting our results. We then discuss on how different drivers of change influence the resilience of shrimp aquaculture systems, and which new policies can support a more resilient aquaculture development within the coastal zone of the Mekong Delta.

4.2 Material and method

This study uses multi-criteria decision analysis using qualitative weighting of drivers of change (Prato and Herath, 2007). This method was adopted because of the limited quantitative data and information available on many of the drivers identified. The analysis involved three steps. First, a review of recent academic research was completed to characterize extensive shrimp production. Second, a further literature review identified 'drivers' for the adoption or continuation of integrated mangrove-shrimp systems. Third, a relative weight was assigned to the drivers of change by consultations of Vietnamese and international experts.

4.2.1 Characterizing the extensive shrimp production systems

The analysis of the diversity of shrimp farms in the Mekong Delta is based on i) their interaction with the environment; ii) the regulatory framework supporting the development of shrimp farms and the trade of shrimp through global value chains; and iii) the implementation of disease management practices at the farm level.

The Mekong Delta is characterized by a complex range of shrimp aquaculture systems (Table 4.1). At one end of the spectrum (Bush et al., 2010), intensive shrimp farming systems are designed to maximize production, with high stocking densities (number of post larvae stocked per square meter), chemical inputs, mechanical aeration, and a single harvest per crop cycle. Farmers manage the production risk by controlling and closing the production system from the surrounding environment, in an attempt to manage the water quality in the ponds and to avoid disease related infections (Joffre and Bosma, 2009). Intensive systems in the Mekong Delta represented about 51,000ha, less than 10% of the total shrimp production area (553,998 ha) in 2009 (Provincial Department of Fisheries in the Mekong Delta, 2009).

The other end of the spectrum is characterized by extensive systems with frequent water exchange, and the natural recruitment of fish, shrimp and crabs through the tidal intake of water, mixed with the frequent stocking of hatchery reared tiger shrimp (*Penaeus monodon*) at low densities of 1 to 3 post larvae per square meter (Ha, 2012). These extensive systems use limited inputs and the risks associated with production are spread over the year through multiple harvests of small to larger sized shrimp. In between these two extremes a range of stocked production systems with intermediate intensity levels of stocking density, water exchange, feeding and water treatment are found. In the Mekong Delta these intermediate systems are labeled as 'improved extensive' and 'semi-intensive' systems; the latter being considered closer to intensive systems because of the higher stocking density and the use of commercial feed.

Table 4.1: Main characteristics of the shrimp farms in the Mekong Delta, with incomes based on the prices in 2007 and 2008, (adapted from Joffre and Bosma, 2009; Son et al., 2011; Ha, 2012 and Ha, 2012a)

	Unit	*Integrated mangrove-shrimp system*	*Extensive shrimp*	*Intensive shrimp*
Farm /% pond area to total farm area	ha	5 to 15 /40%	2 to 4 / 90%	0.2 to 3 / 90%
Water exchange		Bi- monthly tidal	Bi monthly tidal or pumping	Limited
Stocking density and stocking frequency	Post Larvae/m^2	1 - 3 5-8 times a year	1.7 - 3 at initial stocking + monthly 10% of initial stocking	15 – 30 in single stocking
Yield *P. monodon*	kg/ha/year	228-365	242 – 475	2,400 - 6,000
Proportion of the annual farm income from other aquatic products than shrimp.	%	28	9	0
Range of Annual Income (based on examples found in literature)	$US/ha/year	700-850	1,050-2,050	3,400 – 12,300
% of total shrimp area in Ca Mau Province	%	17.5	82	0.5
% of total shrimp area in the Mekong Delta	%	8.5	82.5	9

Extensive production systems in the Mekong Delta are typically farmed by smallholders who raise high value tiger shrimp. These systems make up 90% (~502,470 ha) of the total shrimp (production area and 60% of the total volume produced in the region (~322,000 tons) (Provincial Department of Fisheries in the Mekong Delta, 2009). Extensive farms are run by households composed of 5 to 7 persons, from which males are generally in charge of technical decisions (Ha et al., 2013). These households generally have low access to capital, and limited access to infrastructure and electricity. About 75% of the extensive shrimp farmers are indebted, after acquiring formal and informal loans from relatives and/or suppliers. Access to knowledge on production is mostly limited to neighbors, relatives and input suppliers. Extension services have relatively low influence. Shrimp farming is the main income source, but the collective livelihoods of these households remain diverse. The poorest households in these areas remain dependent on inshore fisheries and collection of natural resources from the mangrove ecosystems (Joffre and Schmitt, 2010).

Extensive farms are rarely upgraded to semi-intensive or intensive production because of poor access to finances by small holder producers and volatile price fluctuations. In addition, poor biosecurity and frequent water exchange make these farms highly vulnerable to disease transmission (Hoa et al., 2011). Since the first outbreak in 1994 (de Graaf and Xuan, 1998), White Spot Syndrome Virus (WSSV) has been highly prevalent in the Mekong Delta. In recent years other diseases, such as Acute Hepatopancreatic Necrosis Syndrome, have also become endemic (Lightner et al., 2012; Akazawa and Eguchi, 2013). However, despite their apparent vulnerability to diseases and external shocks, these extensive systems also demonstrate a high degree of resilience to disease. As demonstrated by Dieu et al., (2010), disease causing viruses are less virulent in open extensive systems than they are in intensive systems which invest in higher levels of biosecurity (Hoa et al., 2011).

Extensive systems that integrate the cultivation of mangrove trees have much lower production levels per area than other extensive systems, but also demonstrate a much lower overall risk of crop loss (Ha, 2012). In 2009, integrated mangrove-shrimp systems accounted for 17.5% (~43,222 ha) of the cultivated area in Ca Mau province. In the other provinces of the Mekong Delta the area of the integrated mangrove-shrimp systems is negligible. Two types of integrated mangrove-shrimp ‘sub-systems’ exist in the Mekong Delta: a mixed system with mangrove trees planted on raised beds (bunds) within the pond, and a so-called separated system having larger mangrove area(s) inside the farm’s water area (Figure 4.1). Shrimp production benefits from the ecosystem services of the mangrove forest stands, including water filtration and shading in the case of mixed systems (Tendencia et al., 2012). Other aquatic products and timber provide additional income and their harvesting is viewed as a risk minimizing strategy for farmers (Ha et al., 2014). Extensive integrated mangrove-shrimp systems are also characterized by low shrimp yields (Table 4.1). However, in terms of resilience these low yields demonstrate an important trade-off with lower inputs and the lower virulence of WSSV (Hoa et al., 2011), leading to lower incidence of disease and lower mortality rates.

In the Mekong Delta, more than 90% of integrated mangrove-shrimp farms are contracted by either a State Forest Enterprise or Forest Board Management (Ha et al., 2014). These contracts provide farmers with a relative short-term lease (20 years), compared to farmers outside of the mangrove belt, and stipulate a specific forest-to-pond area ratio, tree plantation density and also timber marketing. Compared to non-integrated extensive systems, integrated mangrove–shrimp systems allow producers to access specific niche markets through the certification of organic standards offering a price premium in export markets (Ha et al., 2012). Organic certification was introduced in 2002. Until 2009, the area of organic shrimp in Ca Mau province in the Mekong Delta covered 2,100 ha, with 335 certified farms. These externally audited third-party organic standards also regulate the ratio of pond to forest area on the farm, thereby incentivizing the perpetuation of integrated systems. The Naturland organic standard stipulates that this ratio should be 50:50, while the government regulation requires a ratio of 40:60 pond to forest area for farms smaller than 3ha. Farms certified against the Naturland standards have access to a premium price of 20%. In practice this premium is distributed along the value chain (processors, collectors, and farmers) with farmers capturing only 6% of this added value (Ha et al., 2012).

Figure 4.1: Mixed mangrove-shrimp system (left), and separated mangrove-shrimp system (right), with mangroves in the back

Despite their advantages in reducing the risk associated with shrimp culture and restoring important ecosystem services, integrated mangrove-shrimp systems are not widespread in the Mekong Delta. Therefore, the drivers that either push farmers to continue integrated mangrove-shrimp production or enable them to shift from extensive shrimp farms without mangrove stands towards integrated mangrove-shrimp production are of primary interest.

4.2.2 Drivers for integrated mangrove-shrimp systems

In order to identify and assess drivers for integrated mangrove-shrimp systems a two-step approach was used. First, the drivers of changes were listed and defined, based on a literature review. Different expert groups were then asked to weigh the importance of these drivers during two rounds of consultation. The results were then analysed and the most significant drivers supporting or constraining a continuation of integrated systems, or the shift from extensive systems without associated mangrove stands to integrated systems, identified.

The initial drivers used in these consultations were derived from scientific peer reviewed papers and PhD research from the ‘Rebuilding resilience of coastal populations and aquatic resources’ (RESCOPAR) program (Verreth et al., 2012). From this literature, we identified a series of social and regulatory (Ha, 2012a; Ha et al., 2012b; Gunawan, 2012; Kusumawati et al., 2013), as well as ecological and epidemiological (Tendencia et al., 2013; Haryadi et al., 2015; Desrina, 2014) drivers of change influencing farmer’s decision in their farm management and choice of production system. We then focused on short and medium term farm-level decisions related to an integrated mangrove-shrimp production cycle (15 years). This delimitation excluded long-term drivers like climate change or sea level rise from the analysis. Two types of drivers of change in the wider socio-ecological system were identified: ‘external’ drivers outside the control of the farmer, and ‘internal’ drivers within the boundary of the production system and therefore under the control of a farmer. Internal drivers are part of the production system and therefore affect and are affected by management decisions, whereas external drivers are not part of the production system (Walker et al., 2012).

External drivers were divided into four subsets of drivers related to ‘Market and value chain’, ‘Governance and regulatory framework’, and ‘Production’ and ‘Bio-physical aspects’ (Table 4.2). Each of these external drivers operates at a different scale: bio-physical and production system drivers are tangible at the local scale, while governance, market and trade drivers are tangible at the national or international scale. Each driver was defined in the current context with a single direction, enabling (+) or constraining (-) change towards integrated mangrove-shrimp systems. In a few cases, drivers could have two directions (+ or -), i.e. enabling or constraining the changes or continuation of integrated mangrove-shrimp system. Whether a driver has a uni- or bi-directional force depends on the wider context within which it operates.

Table 4.2: Consolidated list of external drivers influencing farmer's decision making to shift to integrated mangrove–shrimp system or to continue such system, with their direction and description in the current context. Based on literature review and expert consultations (indicates a driver with null or low weight and not selected by experts; # indicates the drivers added during international expert consultation)*

External Drivers	*Description and behavior*	*Direction (+/-)*
Market and value chain		
Access to value chains requiring quality standards with premium prices	Presence of eco-certified value chains, including organic, and the possibility to access to premium prices. In the case of the organic value chain, the premium price is set at 20% (Ha et al., 2012).	+
Organization and function of marketing	The organic value chain is characterized by a delay of payment to the farmers (several weeks), lack of transparency in the premium price calculation (Hop, 2012) and un-attractive premium price (only 6% instead of the 20%) (Ha et al., 2012).	-
Market price fluctuation of *P. monodon*	The market price fluctuation is less important than in other systems, because during the multiple harvests in their quasi continuous production system the farmers select only large sized shrimp which are less affected by market price fluctuation (Ha, 2012).	+
Employment opportunity outside the farm*	Diversification of household income with other livelihood activities (Ha, 2012).	+/-
Price for other aquaculture products (fish and crabs)	Market prices of crab, fish can be an incentive (high price) or an obstacle (low price) for farmers to plant mangroves and shift to polyculture (shrimp, fish and crab) (Ha, 2012; Gunawan, 2012).	+/-
Governance and regulatory framework		
Services and incentives#	Subsidies and services such as PES and REDD+ from government agencies and private sector that farmers will receive in exchange of planting mangrove forest (international expert consultation ; Brugère, 2011; Schmitt, 2011; Ha et al., 2008, Albert et al., 2012).	+
Mangrove to pond area ratio regulation	In integrated mangrove-shrimp systems that are under the short term lease (Green land certificate) the ratio varies from 40:60 to 60: 40 according to the total size of the land. Organic standards require a minimum ratio of 50: 50 and smallholder with less than 3 ha might prefer not to follow this rule to allow a larger pond area (Ha, 2012; Ha, 2012a; Ha et al., 2012b).	-
Land use planning*	Land use planning determines the ability to develop a specific farming system in one area. This driver is especially relevant for the development of intensive farms, which are not allowed everywhere in the coastal zone (Hoanh, 2003).	-

Continuation of Table 4.2

Benefit sharing for forest exploitation	Complex, non-transparent benefit sharing mechanism for mangrove exploitation by the State Forest Enterprise and the constraining forest management guidelines reduce the benefit generated from mangrove and the incentive of farmers to properly manage properly the forest cover (Ha et al. 2012b). Benefits from forest exploitation in integrated mangrove-shrimp farmers are estimated to be seven times lower than its value on the auction market when sold independently of the State Forest Enterprise (Ha et al., 2014).	-
Production driver		
Access to input and knowledge*	Represent the availability; effectiveness and quality of extension services It includes both private and public extension services of the sector (Ha, 2012).	+
Access to loan (formal and informal)	Characterizing the capacity of the farmer to access capital for investment (Ha, 2012).	+
Capacity to organize in clustering*	This driver illustrates the capacity of producers to organize into clusters and the effectiveness of the collaboration that translating into lower production cost and improved quality management (Ha et al., 2013).	+
Availability of labor*	This driver concerns the availability of means (persons or capital) for farms to cover the labor requirement (Ha, 2012).	+
Bio-physical drivers		
Environmental risk factors	This driver relates to environmental factors that influence the risk of disease such as temperature or salinity changes in the pond (Tendencia et al., 2010; Tendencia et al., 2011; Tendencia.et al., 2013).	+
Mangrove cover quality*	This driver concerns the size and the fragmentation of the mangrove, in terms of forest cover and continuity (van Zwieten et al., 2006; Zavalloni et al., 2014) Farms without mangrove forest in the neighborhood will have less incentive to plant more mangroves. (Ha pers. com).	+
Tidal Influence*	This driver relates to the tidal influence in the production area. Mangrove trees require tidal fluctuation (Clough et al., 1999).	+/-
Water quality (in the production area)	This driver relates to deterioration of the hydrological conditions and water quality in the production area. With a lower water quality in the production area, farmers will plant mangrove within their farms to improve water quality (Tendencia et al., 2012).	+

For example, the 'Price for other aquaculture products' will enable change towards integrated mangrove-shrimp system (+) when prices of aquaculture commodities are high, but plays a constraining role (-) when prices are low.

Table 4.3: Consolidated list of internal drivers influencing farmer's decision making to shift to integrated mangrove–shrimp system or to continue such system, with their direction and description in the current context. Based on literature review and expert consultations (# indicates driver added during international expert consultation)

Internal Drivers	*Description and Behavior*	*Direction (+/-)*
Market and trade organization		
Compliance with quality standards	Complying to 'Standard defined production practices' in a farmers choice of shifting to or continuing a mangrove-shrimp production and access to premium price (Ha et al., 2012b).	+
Join a farm cluster	Joining a cluster of farms in a farmers choice of shifting to a mangrove-shrimp production system and save operational cost, improve bargaining power; reduce environmental risk (Ha et al., 2013).	+
Production system		
Revenue from *P. monodon*	Deciding to intensify shrimp culture by increasing stocking density of *P. monodon* (Ha et al., 2013).	-
Revenue from fish and crab	Diversifying farm revenue with other aquaculture production : fish and crab (Ha, 2012), based on the habitat function of the mangroves.	+
Revenue from timber	Diversifying farm revenue with timber production from mangroves (Ha et al., 2014; Ha et al., 2012b).	+
Multiple stocking	Reducing income shock due to virus by stocking *P. monodon* multiple times along the years and spread revenue over the year with multiple harvests (Ha, 2012).	+
Farm landholding#	Deciding to convert part of the farm into a mangrove stand , when landholding is larger than 3ha (international expert consultation).	+
Bio-physical drivers		
Water control management	Controlling water exchange and water quality using water treatment and pond preparation (Ha et al., 2013).	-
Environmental function	Having mangrove trees on the farm to buffer climate shock and improve water quality (Tendencia et al., 2012; Tendencia.et al., 2013).	+

The price can fluctuate and the direction of the driver can change rapidly according to the economic context. Internal drivers were divided into three subsets of drivers: 'Market and trade organization', 'Production system' and 'Bio-physical' (Table 4.3). These drivers operate at the farm level and are under the control of the farmers.

4.2.3 Consultation and weighing the drivers

The selected drivers were then submitted to two panels with a broad range of expertise, who were asked to weigh their relative importance. The first panel was made up of Vietnamese experts, including representatives of farmers ranging from integrated mangrove-shrimp system farmers to intensive production farmers (n=6), district and provincial officers of the Department of Fisheries (n=13), and shrimp buyers representing the value chain (n=2). These Vietnamese experts were composed of people working at the 'grassroots' level of the sector (Van der Hoeven et al., 2004). Experts first validated the selection of each driver before specifying the definition and scale of each driver. They were then split in three break-out groups representing the view of extensive shrimp farmers, integrated mangrove-shrimp farmers, and intensive shrimp farmers to weigh the drivers. External drivers and internal drivers were weighed (on a scale of 100%) by their importance to: i) influence farmers to move from extensive to integrated mangrove-shrimp production systems (A), and ii) influence farmers to continue integrated mangrove-shrimp farming (Figure 4.2).

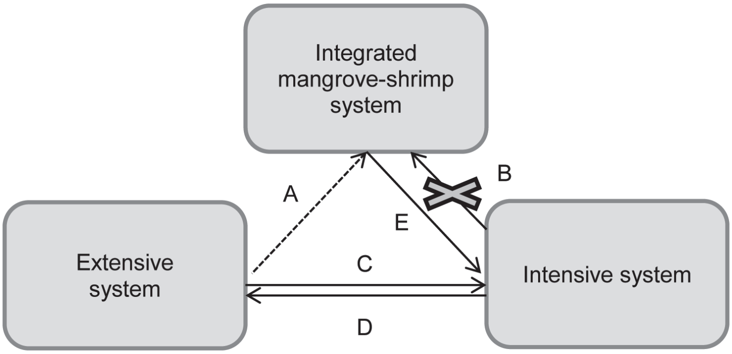

Figure 4.2: Potential shift of farmers between extensive, intensive and integrated mangrove-shrimp systems. The dashed arrow represents the shift of system from extensive to integrated mangrove-shrimp system (A). Shift from intensive to integrated mangrove-shrimp system (B) was found not possible (grey cross). C: shift from extensive to intensive system. D: shift from intensive system to extensive and E: shift from integrated mangrove-shrimp system to intensive

Given the aim of this paper, other possible changes between systems were not investigated. Also a shift from intensive to integrated system was deemed unfeasible by the Vietnamese experts because of the low financial returns of integrated systems. In addition, intensive systems cannot be transformed into integrated mangrove-shrimp production systems without significant investment. Each group was asked to reach a consensus on the relative weight of each driver, thereby providing an indication of the overall influence of each driver to the transformation from one farming system to another. The break-out group discussion on driver weights was facilitated by an independent researcher and the results were presented and discussed in a plenary session.

The second panel consisted of fifteen international researchers in the fields of ecology, economics, sociology and aquaculture production systems. All had extensive working experience in the field of shrimp farming in Vietnam or other Southeast Asian countries. The meeting was convened in the Netherlands to validate the drivers in a group session. Definitions of drivers selected from the literature were presented to the group and experts were asked to validate or exclude their selection within the final list. Individual responses were further collected and detailed via e-mail correspondence. Eight additional experts in the fields of mangrove conservation, shrimp farming and coastal zone management who were not able to join the group session, were also asked to weigh the set of drivers constructed in the group session. In addition, international experts added two new relevant drivers which were not found in the literature: 'Services and incentives' (external driver) and 'Farm landholding' (internal driver).

Because of the order of the expert consultations these additional drivers could not be weighed by the Vietnamese experts. Therefore the weights of those two drivers are presented and discussed separately. The different approach of the two consultations, with answers per group for Vietnamese expert and individual responses in the case of international experts was due to the difference in the number of experts consulted and the time allocated to each consultation. Both the Vietnamese and international expert groups answered the same questions, with a similar process of validation and weighing.

Weights of the drivers are presented separately for each panel of experts. To evaluate the agreement on weights, the coefficient of variation (CV) of the driver's weight was calculated in the case of the international experts, and in the case of the three groups of Vietnamese experts we provide the average and the range of weighing. The CV gives an indication of the consensus between experts. Later, we scale the level of consensus between ‘high’ (CV below 33%), ‘medium’ (CV between 33% and 65%) ‘low’ (CV above 65%) scores (van Zwieten et al. 2010). For each driver common to the two panels of experts, we averaged the weight given by the international experts with the weight given by the group of Vietnamese experts. This average was then interpolated on a scale of 100. Based on this average weight, we compared drivers to assess the conditions under which farmers would shift to integrated mangrove-shrimp system or continue with extensive production system. The difference in methodology between the two groups of experts did not allow statistical analysis and comparative analysis of the weights between the two expert panels.

4.3 Results and discussion

Both the Vietnamese and international experts acknowledged the importance of maintaining mangroves stand as a mean to improve pond environmental conditions and reduce the risk of disease, as well as the role of value chain governance and regulatory framework in farmer’s decisions to continue or move to integrated mangrove-shrimp production systems. Several internal and external drivers included in the original list were attributed a zero weight or an aggregated weight below 5%, and are not considered in the results and discussions hereafter. For example the external driver ‘Tidal influence’ received a very low weight for shifting or continuing integrated mangrove–shrimp system, and was considered a pre-requisite condition and not a driver. Therefore we focus our analysis on those drivers of changes that were deemed to have a strong influence over farmer decision making.

4.3.1 Overall perception of drivers and consensus

The expert panels identified two main drivers that promote the continuation and/or the shift to integrated mangrove-shrimp. Both ‘Benefit sharing for forest exploitation’, an external driver, and ‘Environmental function’ of mangrove, an internal driver, were attributed a remarkably higher weight than all other drivers (Table 4.4 and 4.5). Consensus between Vietnamese expert groups is found only for some drivers to influence the shift to integrated mangrove-shrimp such as ‘Access to value chains requiring quality standards with premium prices’, ‘Benefit sharing for mangrove forest exploitation’, ‘Environmental risk factors’ and ‘Water quality in the production area’ and ‘Compliance with quality standards’.

Table 4.4: Main external drivers influencing farmer's decision making to shift to integrated mangrove–shrimp system or to continue such system, based on expert consultations. Average and coefficient of variation for international experts (n=15) and ranges of answer of the three Vietnamese expert groups in parenthesis. (Viet. = Vietnamese Expert, Int. = International expert)

Identified External Drivers	*Continuing Integrated mangrove-shrimp*			*Shifting to Integrated mangrove-shrimp*		
	Viet. (%)	*Int. (%)*	*Experts Average (%)*	*Viet. (%)*	*Int. (%)*	*Experts Average (%)*
Market and value chain						
Access to value chains requiring quality standards with premium prices	10.0 (6-12)	10.1 (0.54)	10.1	18.0 (15-21)	11.7(0.45)	14.8
Organization and function of marketing	10.0 (5-16)	10.3 (0.59)	10.1	7.0 (1-10)	11.6 (0.65)	9.3
Market price fluctuation of *P. monodon*	12.0 (6-19)	11.9 (0.66)	12.0	9.0 (7-11)	15.8 (0.40)	12.4
Price for other aquaculture products (fish and crabs)	4.0 (1-7)	4.0 (1.87)	4.0	4.0 (2-5)	13.3 (0.42)	8.7
Governance and regulatory framework						
Mangrove to pond area ratio regulation	11.0 (7-12)	11.2 (0.56)	11.1	7.0 (4-9)	11.5 (0.67)	9.3
Benefit sharing for forest exploitation	27.0 (17-34)	27.1 (0.50)	27.0	22.0 (19-26)	0 (0)	11.0
Production driver						
Access to loan (formal and informal)	6.0 (2-12)	5.5 (1.17)	5.8	7.0 (5-9)	11.9 (0.40)	9.4
Bio-physical drivers						
Environmental risk factors	10.0 (8-12)	10.1 (0.58)	10.0	13.0 (12-15)	11.7 (0.52)	12.3
Water quality (in the production area)	10.0 (8-12)	9.9 (0.65)	10.0	13.0 (12-15)	12.4 (0.26)	12.7
TOTAL (rounded to 100)	100	100	100	100	100	100

Table 4.5: Main internal drivers influencing farmer's decision making to shift to integrated mangrove–shrimp system or to continue such system, based on expert consultations. Average and coefficient of variation for international experts (n=15) and ranges of answer of the three Vietnamese expert groups in parenthesis (Viet. = Vietnamese Expert, Int. = International expert)

Internal Drivers	*Continuing Integrated mangrove-shrimp*			*Shifting to Integrated mangrove-shrimp*		
	Viet. (%)	*Int. (%)*	*Experts Average (%)*	*Viet. (%)*	*Int. (%)*	*Experts Average (%)*
Market and trade organization						
Compliance with quality standards	12.0 (8-16)	14.8 (0.44)	13.4	11.0 (9-13)	16.6 (0.42)	13.8
Join a farm cluster	12.0 (6-18)	11.8 (0.55)	11.9	9.0 (5-11)	13.3 (0.48)	11.2
Production system						
Revenue from *P. monodon*	11.0 (9-15)	10.4 (0.51)	10.7	11.0 (5-16)	11.7 (0.69)	11.3
Revenue from fish and crab	10.0 (2-15)	13.8 (0.34)	11.9	13.0 (8-19)	11.7 (0.26)	12.4
Revenue from timber	12.0 (5-16)	9.3 (0.50)	10.6	5.0 (2-9)	6.9 (0.58)	5.9
Multiple stocking	10.0 (6-17)	14.1 (0.31)	12.0	8.0 (7-11)	13.5 (0.41)	10.8
Bio-physical factors						
Water control management	10.0 (5-14)	10.9 (0.55)	10.5	4.0 (2-7)	13.2 (0.34)	8.6
Environmental function	23.0 (14-30)	14.9 (0.52)	18.9	39.0 (25-55)	13.1 (0.47)	26.1
TOTAL (rounded to 100)	100	100	100	100	100	100

International experts did not reach a strong consensus on the latter drivers as demonstrated by a coefficient of variation above 33%. This variability in the weights indicates that in general no clear consensus exists on the impact of the drivers, in particular 'Market price fluctuation of P. monodon', 'Price for other aquaculture products', 'Mangrove to pond area ratio regulation' have a low level of consensus as experts have different perceptions on how these drivers influence decisions.

Expert panels had different opinions about the importance of the following drivers: 'Price for other aquaculture product', 'Access to value chains requiring quality standards with premium prices'; 'Market price fluctuation of *P. monodon*' and 'Benefit sharing for forest exploitation'. The cause of the differences is not investigated. In contrast, a greater degree of consensus is found for internal drivers. The two expert panels differed only in opinion regarding 'Environmental function' and 'Water control management'.

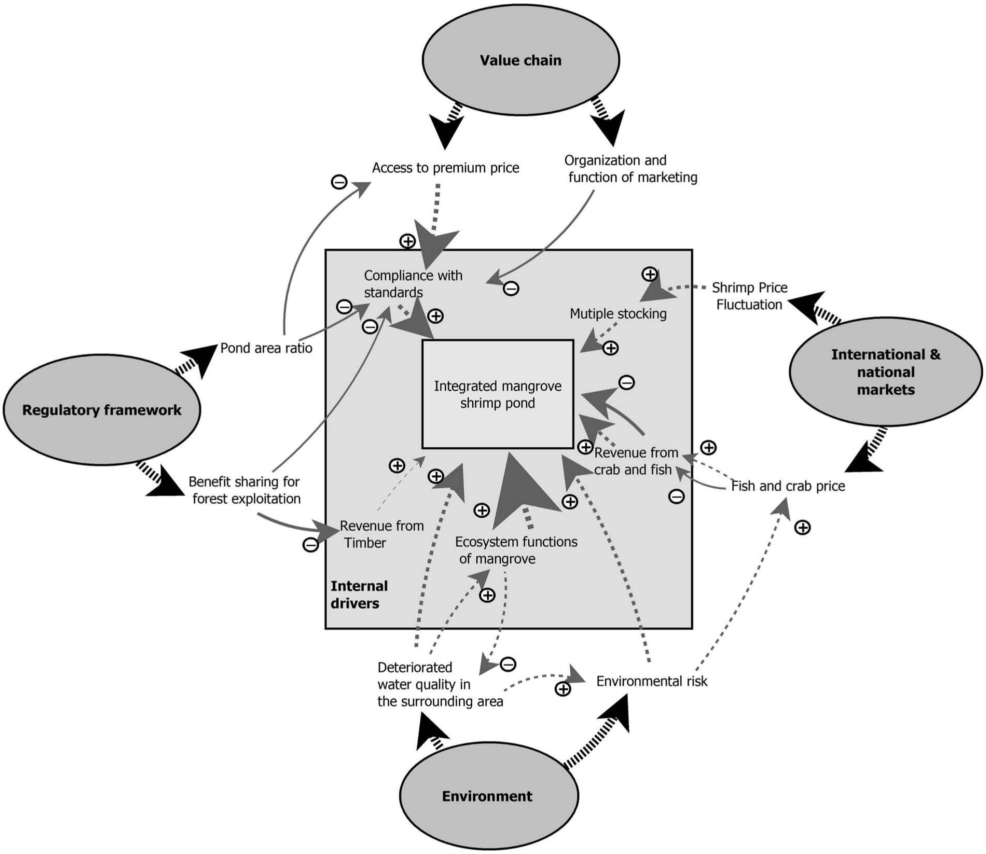

Figure 4.3: The main internal and external drivers influencing the shift to integrated mangrove-shrimp culture. Plain arrows represent negative drivers (also identified by – sign) on farmer decision to shift to integrated mangrove-shrimp system; dashed arrow represent positive drivers (associated with sign +) on farmer decision to shift to integrated mangrove-shrimp system. Arrow width is proportional to the weight of the driver. Thick dotted arrows represent interactions not further developed. The box represents the farm where internal drivers have influence

A majority of drivers have an average weight between 10 and 15%. This result clearly illustrates that a farmer' decision to plant mangroves within their farms depends on a multitude of drivers and that multiple regulatory mechanisms are needed to steer farmers towards integrated mangrove-shrimp systems. Moreover, the drivers are not independent: they may interact through feedback loops (Figure 4.3).

For instance bio-physical (or environmental) drivers related to disease risk and uncertainty of market prices are pushing factors for the shift to integrated mangrove-shrimp systems. For example a degradation of the water quality in the production area will push farmers to plant mangrove on their farm for mangrove's ecosystem function to improve the water quality in the pond. Ultimately, the mangrove's ecosystem function will also improve the water quality of the production area. External drivers that inhibit internal drivers and constrain the shift to integrated mangrove-shrimp systems are related to regulatory framework and value chain. 'Mangrove to pond area ratio regulation' or 'Benefit sharing for forest exploitation' have a negative influence on farmer's incentive to comply with quality standards of the organic value chain and benefit from premium price. Thus these drivers constrain the shift to integrated mangrove-shrimp production system.

4.3.2 Influence of mangrove ecosystem functions

The experts linked the ecosystem functions of mangroves to 'Environmental risk factors' (water salinity and temperature), and deterioration of hydrological conditions ('Water quality'). These external drivers were selected because of their role in stimulating a diversity of production functions in the coastal area, but also for their effect on diseases. The average weight given by the two expert panels on the 'Environmental function' of mangroves in buffering temperature shocks and improving water quality in the pond is the highest among the internal drivers (Table 4.5). The average weight of this driver is 1.4 and 1.9 times higher than the next most influential driver ('Compliance with quality standards') for continuing and shifting to integrated mangrove-shrimp respectively.

The Vietnamese experts considered 'Environmental function' as the most important driver for pushing farmers to shift and to continue integrated systems, while international experts gave this driver an average weight. All expert panels expected mangrove's bio-filtering function to improve water quality and to buffer temperature fluctuations, increasing the resilience of the production system to disease outbreaks. The level of consensus in both groups was about the same. The habitat function of the mangrove, reflected in driver 'Revenue from fish and crabs' from integrated farms, was given an average weight. The 'Environmental function' of mangroves was also considered an important farm characteristic by both expert groups. It was also considered more important than 'Water control management', indicating the importance of the mangrove's environmental function to contribute to the pond ecology and pond water quality for farmers, opposite to a management based on external inputs and necessitating technical knowledge and financial investment.

4.3.3 Influence of disease risks

The capacity to recover from external shocks such as disease incidence using the environmental functions of a mangrove, was identified as a driver for both shifting to and continuing integrated mangrove-shrimp systems, but had a higher weight in the case of shifting to integrated mangrove-shrimp system (Figure 4.4). This means that when water quality is degraded, shifting to an integrated mangrove-shrimp system is an option for farmers to manage the risk of disease.

This is also illustrated by the higher weights received by the external driver 'Water quality' (deteriorate hydrological conditions in the farm surroundings) in the case of shifting to integrated mangrove-shrimp system. Consensus existed between experts on the weight given to this driver. In contrast to the intensive systems, where pond management is based on isolation strategies and on intensive use of inputs, management practices in integrated mangrove–shrimp systems are based on an ecological approach to lowering potential stress related to water quality and aquatic flora and fauna.

Stress is recognized as a key risk factor for WSSV (Mohan et al., 2008). Fluctuation of climatic and water quality parameters are stress factors that may cause the spread of infection. A low level of infection may not result in an outbreak leading to high mortality, especially if shrimp are not stressed. Experiments cited by Tendencia et al., (2010) and observations of ponds (Tendencia et al., 2011) show that fluctuations of temperature (3-4°C in less than 10 h period), salinity (below 15 ppt or above 25 ppt) and pH (fluctuation of 1 within 1h) are risk factors that will result in infection and disease outbreaks. Recent research on the Acute Hepatopancreatic Necrosis Syndrome highlighted the importance of water pH as environmental trigger of the disease (Akazawa and Eguchi, 2013). However, as already mentioned, several water quality parameters may influence infection rates as well, and the presence of mangrove in itself does not necessarily reduce the risk of disease outbreaks. Whether the effect on pond water quality, and shrimp performance and mortality is positive or negative depends on the mangrove species, density and age, as well as on the design of the integrated system and the management of water and shrimp (Bosma et al., 2014).

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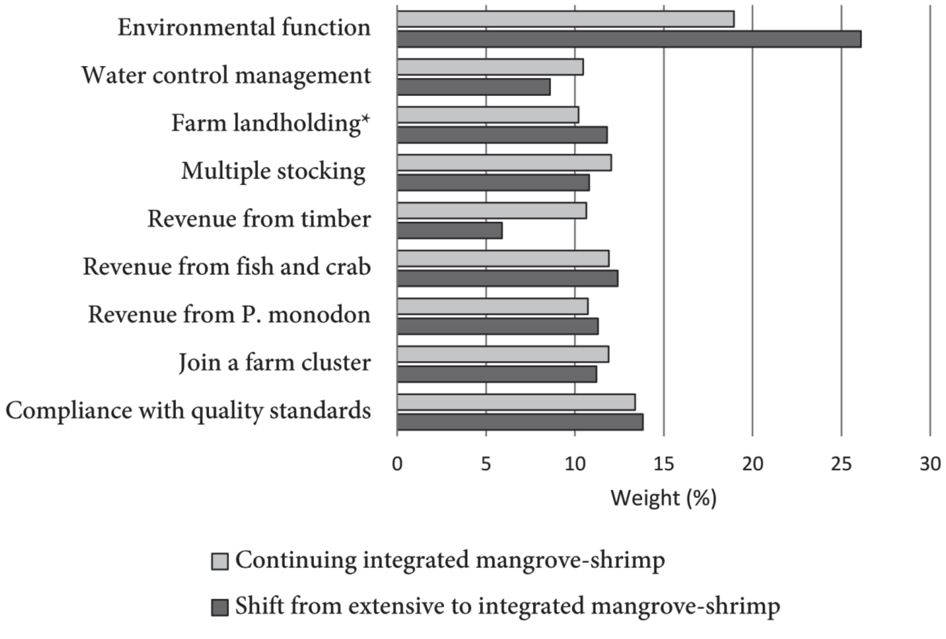

Figure 4.4: Internal driver's weight for changing to and continuing with integrated mangrove-shrimp systems (indicates that this driver was not weighted by the Vietnamese expert panel)*

4.3.4 Influence of value chain governance

The decision of farmers to adopt this system within the intertidal zone also depends on the access to markets and the governance arrangements, both external drivers shaping the economic return of the system. 'Access to value chains requiring quality standards with premium prices', 'Market price fluctuation of *P. monodon*', were identified as drivers having an important influence over farmers deciding to change their production system to integrated mangrove-shrimp. Both experts' panels reached some consensus about the influence of these drivers on shifting to integrated systems, but had a different opinion on the weight of each driver. Vietnamese experts gave more weight to 'Access to value chains requiring quality standards with premium prices', while international expert considered 'Market price fluctuation of *P. monodon*' as more influential.

Overall, the result of the expert consultation highlights that a farmer's decision to shift to or continue integrated farming depends on the volatility of shrimp markets. More volatility may push extensive farmers towards integrated mangrove-shrimp systems. 'Market price fluctuations of *P. monodon*' was given an average weight above 12%, reflecting the expectation that farmers have the capacity to respond to market shocks by marketing larger size shrimp and by multiple selective harvesting (Ha, 2012).

'Compliance with quality standards' is assessed as the second most important internal driver for shifting to integrated mangrove-shrimp system when weights of both expert panels are averaged. 'Compliance with quality standards' and the external driver 'Access to value chains requiring quality standards with premium prices' are directly associated with increased farm revenue, creating a financial incentive for farmers. Incentives for shifting or continuing integrated mangrove-shrimp system are related to receiving a premium price for certified organic shrimp, together with a better organization of the value chain from the farm to the processor.

While 'Access to value chains requiring quality standards with premium prices' is considered as a positive driver, the 'Organization and function of marketing' is a negative one with a medium weight, limiting the incentive to continue or shift to integrated mangrove-shrimp. For example, a recent study in the Mekong Delta shows that the organic shrimp producers on average obtain a 6% premium, while in total 20% was paid as a bonus to the exporter (Ha et al., 2012). Farmers consider delays in payment, their low bargaining power, as well as the weak legitimacy and credibility of auditing practices (Ha et al., 2012), and the lack of transparency in benefit sharing (Hop, 2012; Ha et al., 2012b), as constraints to contract farming. These constraints in turn limit the further adoption of the organic shrimp value chain.

4.3.5 Influence of the state regulatory framework

Both expert groups identified the regulatory framework governing aquaculture and forest production as highly influential over the choice of farmers to shift to an integrated mangrove–shrimp system. In particular they noted that regulation was a major determinant for the success of other market or value chain drivers, such as accessing premium prices.

The ‘Mangrove to pond area ratio regulation’ by the Vietnamese government and certification standards, a negative driver, was given an average weight below 10% in the case of shifting to an integrated mangrove-shrimp system. As outlined by Ha et al., (2012), to qualify as an organic shrimp producer farms must have a mangrove to pond area ratio higher than 50%, while government standards require only a ratio of 40% for farms smaller than 3 ha. The conflict between the state regulation and the Naturland standards disqualifies most smallholders that would have to reduce their water area and thus their shrimp production capacity, to comply with the organic standard.

Reflecting on these regulatory conflicts in the Mekong Delta, the Vietnamese experts proposed to apply the (eco) quality standards at landscape level instead of at farm level in order to consider a pond to forest ratio at a wider scale and to allow a greater opportunity for small holders to comply. The expert proposal is reinforced by the argument that the connectivity of the mangrove stand to the tidal estuarine system needs to be strengthened (van Zwieten et al., 2006; Zavalloni et al., 2014). The importance of recognising ecosystem functions beyond the farm scale is also reflected in a recent proposal for ecosystem and landscape approaches to aquaculture regulation – either through public state regulation or private (eco) quality standards (e.g. Soto et al., 2008). For example, the Aquaculture Stewardship Council have recently included neighboring public forest areas when considering a cluster of integrated mangrove–shrimp farms with too small forest area to comply with organic certification criteria (ASC, 2014).

Both groups of experts consider that continuing an integrated mangrove-shrimp system is influenced most by the degree to which the benefits from the mangrove’s forest exploitation are shared with shrimp farmers. This result is highlighted by the larger weight given to the drivers 'Benefit sharing for mangrove forest exploitation' (Figure 4.5) and 'Revenue from timber' (Figure 4.4). Regulatory frameworks set rules on the benefit sharing from forest exploitation in favor of state forest companies. The Vietnamese experts in particular view 'Benefit sharing for mangroves forest exploitation' as the most important driver of the regulatory framework of the integrated systems (Table 4.4).

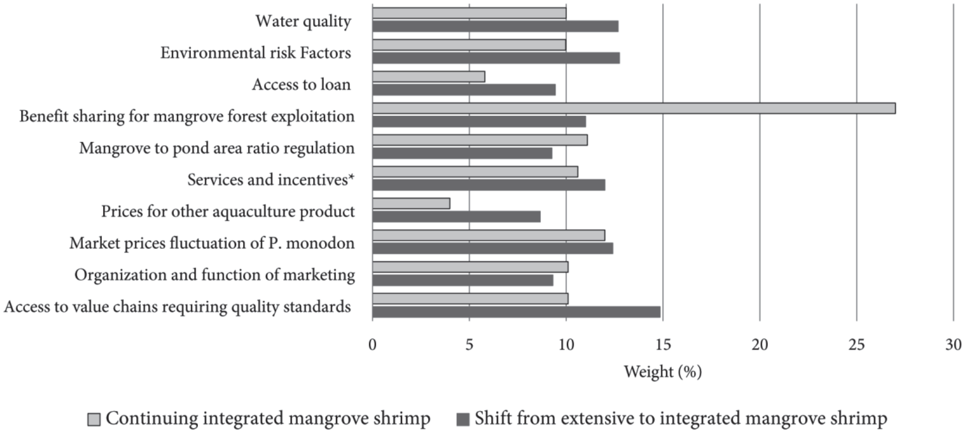

Figure 4.5: External driver's weight for changing to and continuing with integrated mangrove-shrimp systems (indicate that this driver was not weighted by the Vietnamese expert panel)*

Empirical research shows that regulations constraining the timing of timber harvesting place additional costs on forestry companies, and lead to non-transparent pricing. The resulting low benefit sharing for farmers limits the income derived from the mangrove forest compared to that derived from shrimp culture (Ha, 2012; Ha et al., 2012b). Consequently forest products are less important in the management of the farming system and farmer's decision making over mangroves is dominated by considerations around shrimp production. International experts attributed no influence to 'Benefit sharing for forest exploitation' in shifting to integrated mangrove-shrimp systems, while Vietnamese experts broadly agreed that this driver has a high degree of influence. This might be the result of a very distinct interpretation of this driver. Vietnamese expert panel interpreted 'management' to be control by State Forestry Enterprise over the conversion process to integrated production. However, international experts interpreted management as farm-level decision making, with farmers independently selling their timber to the market. The importance of 'Revenue from timber' is identified as an internal driver to continue integrated mangrove-shrimp system rather than shifting to integrated mangrove-shrimp system, with an average weight twice as high as in the case of continuing integrated mangrove-shrimp, but without a clear consensus between experts in both expert panels.

Conversion of 50% of the farm into mangrove will directly translate into a significant loss of income, unless the forested area can provide an equivalent source of income. International experts highlighted the issue of land size by adding an internal driver ('Farm landholding'), stipulating that only farms over three hectares could shift to integrated shrimp system and convert half of their land into mangrove area. This driver was added and weighed only by international experts and received an average percentage weight of 10.2 and 11.8 in the case of continuing or shifting to integrated mangrove-shrimp system (Figure 4.4). In the current policy and regulation context, only large farms will be able to shift without jeopardizing their household income. Ha et al., (2012b) concluded that sustainable management of the forest can be improved if more rights and responsibilities are transmitted to enable them to increase their benefits from the mangrove.

Organic certification can support the spread of integrated mangrove–shrimp farming, but needs to be more economically attractive than non-forested extensive systems. Other approaches are also possible. For example, incentives for planting mangroves in a way that enables the shift to integrated mangrove–shrimp production can be facilitated through Payment for Environmental Services (PES). Vietnam already has a legal framework for PES (Ha et al., 2008; To et al., 2012), which is realized mostly in the upland area (Mc Elwee, 2012). This type of financial incentives was expressed by the international expert group with a new driver labeled 'Service and incentives' that received average weights of 11.6% and 11.9% for continuing or shifting to integrated system (Figure 4.4). In both cases, the consensus between experts was moderate (CV between 33% and 65%), perhaps reflecting the difficulty to implement such schemes in the future in Vietnam with private farmers. However, plans for implementing similar systems for mangrove conservation in the Mekong Delta have been explored (Hawkins, 2010). Related systems that combine compliance to (eco) quality standards with carbon financing options have also been identified for Vietnam (Mc Ewin and McNally, 2014) and Thailand (Brugère, 2011).

4.3.6 Potential role of integrated systems in restoring mangrove habitat function

Despite the positive weights given to the environmental function of integrated mangrove-shrimp systems by both expert groups, it remains questionable what contribution this system has to the wider ecosystem services; particularly in relation to the nursery function of mangroves to the coastal fisheries (Bosma et al., 2014). In most designs of integrated systems that have mangroves on bunds or platforms within the ponds, the nursery habitat function is not restored.

The linkage between mangroves and fisheries is variable and depends on a range of hydrological and topographical factors, and on the ecological connectivity of the mangrove patches to the hydrological network (van Zwieten et al., 2006; Zavalloni et al., 2014). The dikes of most integrated shrimp–mangrove systems create a barrier to processes of sedimentation and habitat formation and to migration of aquatic organisms thereby limiting connectivity between forest patches and other habitats. The connectivity between mangrove covered habitats and other habitats therefore depends on the farm design. Mixed systems with mangrove trees planted on a raised bed inside the pond and with a low flooding frequency, have a low connectivity with the rest of the forest and aquatic system. As outlined by Clough et al., (1999), connectivity may in fact be higher in truly separated systems, where mangroves, planted outside of the pond can be flooded more regularly through the tidal system, as well as connected to a shrimp pond through canals with sluice gates. New designs need to enable a more regular flooding of the mangrove that ensure a higher connectivity between forest and aquatic system, while maintaining the benefits for the shrimp ponds. In that way the natural mangrove forest environment and its associated environmental services can be mimicked, which can be beneficial to aquaculture and fisheries production, as well as other ecosystem services.

4.4 Conclusions

The development of more resilient integrated mangrove-shrimp aquaculture for small-scale farmers is potentially driven by a combination of bio-physical drivers and drivers related to the value chain and the regulatory framework, which together influence the disease risk and the economic profitability of farms. Our results show that the role mangroves play in managing pond conditions and reducing disease risks is a major driver for farmers to continue investing in mangrove-shrimp integrated farming systems. However, for farmers, drivers related to the economic profitability of integrated mangrove-shrimp system appear to be more important. The results also show that profitability is not only dependent on production related decisions, but also on the structure and function of the value chain and the prevailing regulatory framework over both shrimp aquaculture and mangrove management.

The most striking results are related to influence of the regulatory framework over farmers decisions to continue integrated farming. Regulations that influence the balance of benefits derived from shrimp and timber production to farmers and foresters appears to be of high importance. Following Barbier et al., (2008), this in turn also indicates that farmers do maintain a degree of agency. In the context of an effective benefit sharing mechanism farmers will respond to financial incentives for changing production practices and can ultimately contribute to the expansion of mangrove forest cover. The consequence is that, at least in the case of adjusted sharing rules in Vietnam, quality standards and other incentive mechanisms such as PES, can be used to promote integrated mangrove-shrimp farming.

To promote such incentive mechanisms, and in doing so to promote the expansion of integrated farming, our results point to the following pre-requisite conditions:

- Arrangements within the value chains through which shrimp are traded need to deliver incentives to extensive farmers to shift to integrated mangrove-shrimp system in a transparent, equitable and timely manner;
- Conflicting regulations, or regulations which undermine the ecosystem services provided by the mangrove forest, as well as incentives to shift to integrated mangrove-shrimp systems, should be identified and amended;

- Ecosystem services, trade and regulation need to be aligned in such a way that they enable farmer decision making to transcend the farm-level, and in doing so enable landscape scale governance of mangroves and shrimp aquaculture.

If these conditions can be met, we estimate that one of the key challenges of developing more resilient coastal areas can be overcome: providing farmers with conditions under which they are able to make decisions that move them away from vulnerable production practices. Moreover, we can also identify and monitor how the decisions of farmers then feedback on the wider social-ecological system constituted by the ecosystem, value chain, and regulatory conditions listed above. Together these drivers and conditions and the feedback between them can inform a better understanding of the resilience of shrimp farms and ultimately help to design appropriate regulation that can steer a transition towards a particular production system – in this case mangrove-shrimp integrated systems.

How, exactly, farmer decisions can be identified and monitored, and the extent to which new regulations can support farming transitions, should be the focus of further research. Questions should focus on the degree to which farmers will react to market and regulatory incentives. In particular knowledge about the nature of linkages between farmer's decisions, farming systems and spatial arrangements at the landscape level is lacking still, as well as the spatial dimension – connectivity and contiguity - of a mangrove forest's provision of ecosystem services. Better understanding of those mechanisms is needed to fully assess the potential for the expansion of landscape integrated mangrove–shrimp systems.

Chapter 5

Combining participatory approaches and an Agent-Based Model for better planning shrimp aquaculture

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Abstract

In the Mekong Delta coastal zone, decision makers must weigh trade-offs between sustaining the shrimp sector and thus ensuring economic development, while also promoting sustainable, environmentally friendly practices and planning for climate change adaptation. This study investigates future scenarios for development of shrimp aquaculture using a spatially explicit, agent-based model (ABM) simulating farmers' production-system choices. A role playing game (RPG) with farmers was used to calibrate and validate the model. Four scenarios, representing different visions of aquaculture in the next 15 years, were elaborated with decision makers before discussing the different outputs of the model. Iterative consultation with farmers helped to fine-tune the model and identify key parameters and drivers in farmers' decision making. The recursive process allowed us to construct a model that validly represents reality. Participants stated that use of the RPG improved their insight for planning. Results of the scenarios indicate that (i) intensification of production is unsustainable, (ii) market-based incentives are too limited to stimulate development of an integrated mangrove-shrimp production system and (iii) climate change will cause rapid diminishment of production in the absence of adaptation measures. RPG appeared to be a valuable method for formalizing local farmers' knowledge and integrating it into the planning approaches used by decision makers. The ABM, thus, can also be considered a medium or communication tool facilitating knowledge-sharing between farmers and decision makers.

5.1 Introduction

Shrimp farming is part of a complex socio-ecological system involving high risk and rapid changes of land use. Expansion of shrimp farming in the late 19th century modified coastal landscapes in many tropical countries. These changes have been driven by potentially high returns on investments in shrimp farms. As a result, mangrove forests and rice fields have been converted to make way for shrimp culture, though this in many cases has led to bankruptcies and abandoned farms when aquaculture failed (Lebel et al., 2002; Luttrell, 2002). Shrimp farming came to the Mekong Delta in Vietnam in the late 1990s and early 2000s, fueling rapid conversion of rice fields (Tuong et al., 2003) and mangrove forests (Hong and San, 1993; Phuong and Hai, 1998; Luttrell, 2002; Nguyen et al., 2013), while improving local farmers' livelihoods and providing a source of growing earnings for the nation.

The transformation from mangrove to shrimp culture is often described as the spread of intensive shrimp farms. However, the shrimp farms are not all intensive. Farms within the same landscape vary from small-scale extensive to large-scale commercial (Joffre and Bosma, 2009) next to a farm type called 'integrated mangrove-shrimp', in which forest cover and shrimp production are combined. Each shrimp production system has its own characteristics regarding production, operating budget and returns, as well as environmental and social costs (Ha et al., 2013; Ha et al., 2014).

The Mekong Delta, specifically Ca Mau Province, provides an interesting example of the complex trade-offs involved in land use choices. Decision makers here seek to achieve both sustainable economic growth and ecosystem conservation by influencing farmers' choices of production system. Researchers and local government have developed various land use planning methodologies employing participatory approaches that bring in local knowledge, as well as methods incorporating socioeconomic aspects, hydrology and soil science to optimize resource use (Tuong et al., 2003; Hoanh et al., 2003). These planning methods have yielded valuable outcomes regarding specific objectives, such as productivity or economics. However, they have failed to incorporate the diversity of farmers' decisions and the impact of these at the landscape level. The difficulty of devising reasonable scenarios that integrate political and economic objectives and are appropriate for the local context, including farmers' decision making, was recently illustrated in Ca Mau. The government here planned two rather oppositional objectives for the shrimp sector: conversion of all integrated mangrove-shrimp farms to certified organic systems (Ha et al., 2012) and in the meantime increasing the area of intensive shrimp farms to 10,000 ha (Ha, 2012a). Neither of these targets came near to being achieved.

Existing models to capture trade-offs in coastal aquaculture decisions (Schmitt and Brugère, 2013) are based on expert consultations, thus bypassing farmers' knowledge and the considerations by which farmers' make production decisions. As yet, however, there are no analytical tools that adequately incorporate the diverse factors that influence farmers' behavior.

Decision makers are thus left to design policies without a proper understanding of the range and magnitude of the consequences that their new policies might bring at the farm level. Farmers' make their decisions largely based on farm characteristics and on drivers external to the farm (Bush and Marschke, 2014; Ha, 2012). Shrimp farming is highly dependent on biophysical, social, economic and regulatory factors at the local, national and international level. Farmers' interpretations of and responses to these drivers depend on their own (local) knowledge. This latter, however, is rarely taken into account in scenario-development for coastal planning. Moreover, the decisions that farmers make do not always reflect what researchers, practitioners and decision makers know about how farmers decide (Moss, 2008).

Agent-based modeling is a tool used to represent, simulate and analyze the dynamics of adaptive systems such as aquaculture. Agent-based modeling represents human behaviors and decision-making processes through 'agents', which are single, autonomous entities that interact among themselves and with their environment to achieve their goals (Ferber, 1999; Valbuena et al., 2008; Naivinit et al., 2010). The tool can be used to promote dialogue between stakeholders, researchers and decision makers (O'Sullivan, 2008). Authors refer it as a 'social learning tool', as it can facilitate discourse and discussion among stakeholders (Greiner et al., 2014). Modeling with stakeholders is known to enhance their ownership and trust in a model (Voinov and Bousquet, 2010; Lagabrielle et al., 2010), to deliver a decision-making tool that better responds to the needs of end users (Matthews et al., 2007) and to improve decision making under conditions of uncertainty (Puig et al., 2009). It provides participants a greater understanding of complex systems at a larger scale (Krueger et al., 2012), allowing them to consider other stakeholders' perceptions and to reframe their own thinking about a situation (Barnaud et al., 2013; Pooyandeh and Marceau, 2013). Rather than predicting the future, agent-based modeling expands understanding of land use changes based on actors' decisions, opinions and viewpoints. It thus also serves as a medium for communication, to test hypotheses and to trigger discussion (Geertman and Stillwell, 2009).

Role playing games (RPGs) are a method of both conceptualizing and validating agent-based modeling. The RPG set-up is similar to a computerized model (Bousquet et al., 1999; Gurung et al., 2006). Knowledge acquired during an RPG can subsequently be implemented in agent-based modeling to test policy measures. Combining RPGs and agent-based modeling might therefore yield an instrument to improve understanding between stakeholders. However, issues remain, such as acquiring sufficient empirical knowledge about agents' decision-making behavior and developing adequate understanding of interactions within the agent population.

The current research investigates the merit of combining RPGs and agent-based modeling to improve communication and bridge gaps between farmers and policymakers. This paper explores and demonstrates the value of this method and identifies remaining knowledge gaps. The method is demonstrated by a case study in Dam Doi District, Ca Mau, Vietnam.

5.2 Material and method

5.2.1 Overview of the approach

The method presented here is based on a participatory modeling approach described by Voinov and Bousquet (2010). Underlying the approach is an agent-based modeling exercise developed for this study and labeled Coastal Aquaculture Spatial Solutions (CASS), which aims (i) to integrate local and stakeholder knowledge with knowledge at higher levels; (ii) to analyze effects and consequences of planning scenarios on the landscape, agricultural potential and livelihoods of shrimp farmers; and (iii) to present the results to the stakeholders and actors involved. To obtain meaningful insights on farmers' behavior and to define and refine behavioral rules, surveys were supplemented by RPGs with farmers. Figure 5.1 presents the scenario-development process used in this research, beginning with acquisition of model inputs and their validation by stakeholders. This was followed by construction of the model and iterative loops to update and calibrate it. Thereafter, scenarios were elaborated and discussed with stakeholders to test the model structure and outputs and further fine-tune the model in response to end users' needs.

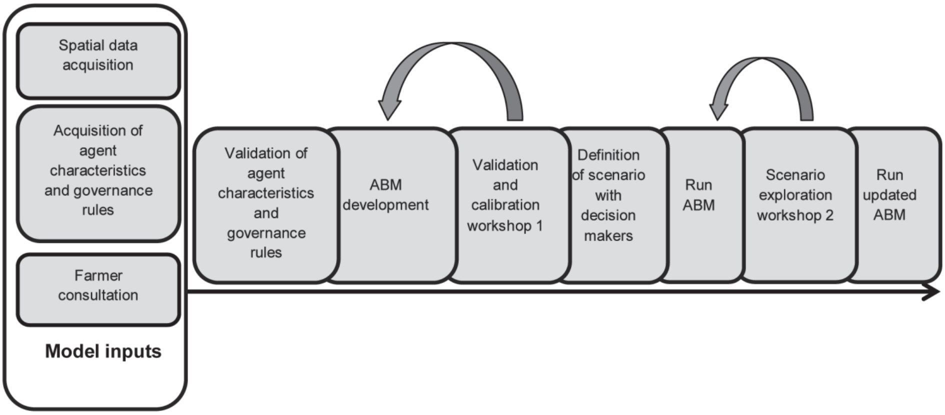

Figure 5.1: The scenario development process followed in this research (ABM: agent-based model)

5.2.2 Agent-Based Model specification

The aim of the CASS agent-based model (ABM) is to simulate and analyze production system changes resulting from decisions made by shrimp farmers. The CASS model is parameterized with empirical data on social, policy, economic and biophysical drivers, and refined and calibrated through RPGs. The model uses a GIS-based detailed cadastral map showing the location and size of each individual farm, as well as outputs of hydrological modeling to estimate the suitability of plots for different shrimp production systems. The CASS model was developed using Gama 1.6 software (Grignard et al., 2013).

Two types of entities are defined in the ABM: farmers and plots. The farmers, or agents, manage their plots, and each farm is composed of a single plot. The plots are described by their production system(s), area, suitability for each type of production, potential yield, risk of disease outbreak due to a virus and financial situation (operational cost). Four production systems are possible: extensive (EXTS), improved extensive (IES), intensive (INTS) and integrated mangrove-shrimp (IMS). These correspond to different levels of intensification (Figure 5.2 and Table 5.1). INTS represents the greatest intensification, as it uses the highest levels of inputs, labor, equipment and stocking densities, and also has the highest risk of disease. This system requires significant investment capacity and is costly to operate. It has both the highest cost and the greatest potential economic returns. At the opposite end of the spectrum, EXTS is based on low input use, frequent water exchange, low economic returns and a lower risk of disease. IES is an intermediary system, with a substantial risk of disease outbreak and intermediate operational costs and economic returns. Finally, IMS is a shrimp production system in which half of the farm is covered by mangrove forest. This system is low cost and low productivity, and presents the least risk of disease outbreak. Plots can also be hybrid, for example, combining INTS and EXTS (or IES and EXTS). Our model investigates shifts of production systems implemented by agents over time. A shift implies a move from EXTS or IES to INTS or IMS, or from INTS or IES to EXTS if severe losses were incurred in the preceding production cycles.

Based on earlier participatory assessments and information from agents, the following assumptions are made: (i) shifting from IES and INTS to IMS is not possible; (ii) when a farm shifts from extensive to intensive production on part of the farm only, the remaining land is kept as EXTS if the shift is to INTS and the farm is larger than 0.25 ha and if the shift is to IES and the farm is larger 0.5 ha; (iii) shifting away from an IMS system can occur only if the policy framework allows; and (iv) shifts from INTS and IES to EXTS happen in the case of farm bankruptcy or after three consecutive virus outbreaks on a farm. Figure 5.2 presents the possible shifts between farming systems.

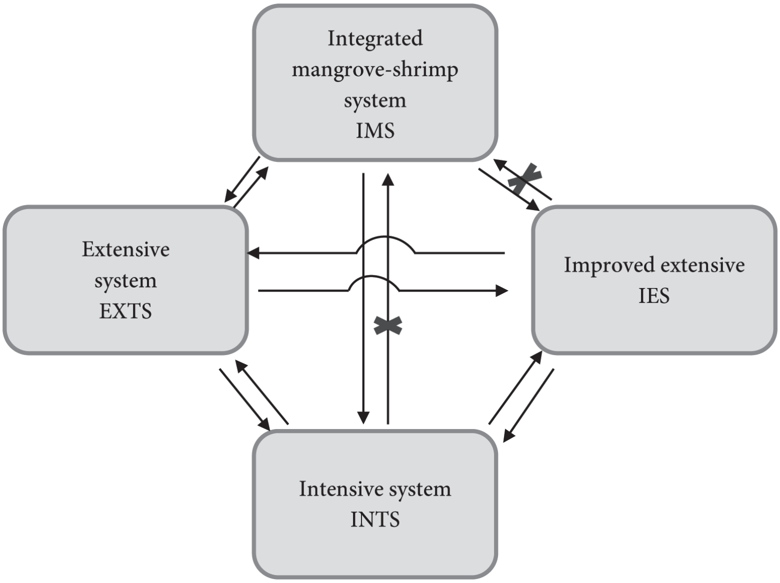

Figure 5.2: Possible shifts of farming system between extensive (EXTS), intensive (INTS) and integrated mangrove-shrimp (IMS). Shifting from intensive (INTS) or improved extensive (IES) to integrated mangrove-shrimp (IMS) is not possible (dark cross)

5.2.2.1 Basic decision-making

Agents' behavior is mainly driven by the desire to maximize profit, influenced by a number of social, financial, physical and policy constraints. These include (i) the agent's investment capacity, including past farming results, access to loans, other economic activities and household expenses; (ii) willingness of an individual agent to shift to another production system; (iii) local policies; (iv) neighboring production systems; and (v) the biophysical characteristics of the plot. Biophysical characteristics are measured as two suitability indexes: one indicating each plot's potential to grow mangrove and one for each plot's potential for intensive shrimp farming. Both suitability indexes are based on annual measures of flood level and water salinity.

In the initialization process (Figure 5.3), socioeconomic-specific characteristics of farmers were drawn from statistical distributions based on census data to create a realistic representation of the agent population. The characteristics observed were (i) area of INTS, plus area of IES in the case of hybrid agents; (ii) household size; (iii) household secondary income; (iv) household bank account balance; (v) maximum loan amount that the household could obtain.

Probabilistic rules were defined for household second income; for the maximum amount a household could borrow; for the balance (debit or credit) of the household bank account; and for crop cost, yield and gross revenue. The rules were based on socioeconomic data from Ha (2012) and additional surveys in the field. They vary according the types of agent (EXTS, IES, INTS, IMS). The rules were calibrated using district-level socioeconomic data and later refined during RPGs with farmers. As the shrimp market is extremely volatile, a market price for shrimp was set at the beginning of each cycle, drawing a uniform distribution defined by a maximum and minimum market price.

After initialization, our model is composed of two phases per cycle. Considerations in the first phase determine whether each agent decides to shift production system. This is followed by a second phase in which each agent implements the decision made.

The initial consideration in the first phase is the type of land title, as this determines whether the agent is allowed to change production system (see Figure 5.3). The second relates to financial capital, which depends in part on whether the farmer decides to take out a loan. Hard thresholds determine the behavioral strategy of an agent. EXTS farmers with enough investment capacity may have the ability to shift part of their farm to an intensive system;

however, the actual decision made will depend on their willingness to do so. The model implements willingness to shift using a probabilistic approach based on data on farmers in the area. Farmers' probability to shift from one system to another is updated according to local conditions (land elevation and water salinity) before being tested. If the test is positive, (part of) the land is converted to INTS, and the next crop has its characteristics. If the test is negative, willingness to shift to IES is tested. The last option is to test willingness to shift to IMS. If none of the tests is positive, the agent continues the same production system.

In the second phase, the agent implements the decision. Again for each agent, the model tests for the presence of diseases, which are a major determinant of shrimp yield. The results of one run indicate the farm's financial gain or loss. In addition to the crop's economic return, other household income, household expenses and loan repayments are taken into account to update the bank account balance. The historical record of virus outbreaks within the farm is also recorded.

In a case of INTS, an agent will continue this system if he/she has enough capital to cover the crop cost and has experienced less than three consecutive crop failures due to disease outbreak. For an IES agent, similar rules apply. An IES or INTS agent with insufficient financial capital to cover operational costs or with successive past failures of their system will convert back to EXTS or abandon shrimp farming. This last option happens only if the farm size is less than 1 ha. IMS and EXTS agents maintain their system even if they have experienced successive crop failures.

At the end of each cycle, the shrimp yield, the area of each production system, the updated bank account balance and the decision made are recorded for each agent, and this information is linked to a GIS file of the study area in which all farms are represented. For the entire study area, the results for each cycle are aggregated. The model includes various parameters that influence agents and their decision making. These include the base probably of shifting from one system to another, policies on organic shrimp farming, payments for ecosystem services, and the influence of neighbors. Because the model is designed to simulate changes over time, economic variables such as market prices are dynamic, to represent fluctuations and development of the market for shrimp. In each cycle the success or failure of the shrimp crop is calculated for each plot-agent and the economic returns of the farm-agent are updated accordingly.

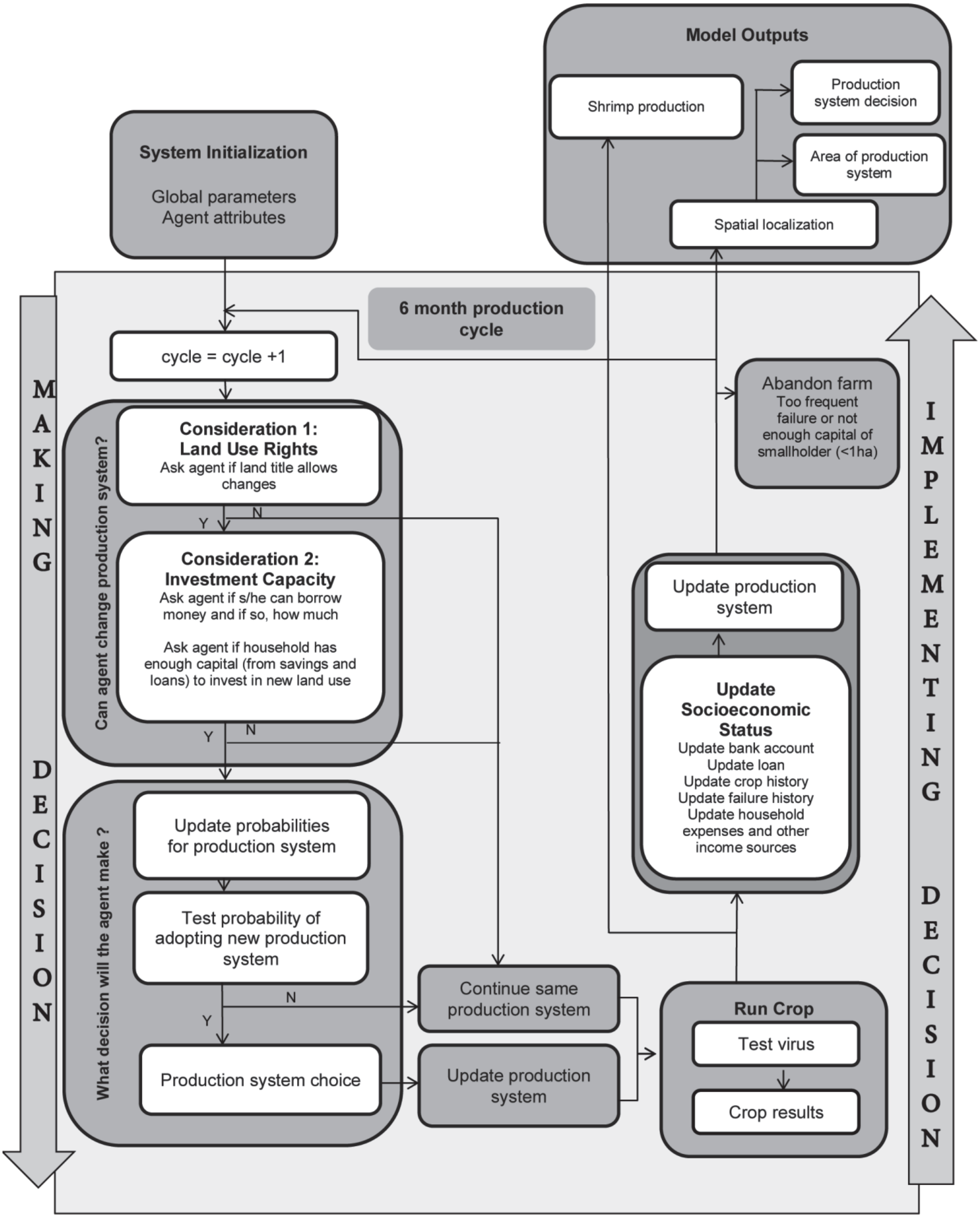

Figure 5.3: Flow chart of the agent-based model (ABM), depicting agents' considerations at each step, the decision made and outcomes of decision implementation

5.2.2.2 Interactions between agents

Interactions between agents are of two types: (i) the direct influence of neighbors on production-system decisions and (ii) the influence of neighboring farms on the risk of a virus outbreak. If the density of intensive or integrated shrimp farms in the neighborhood increases, the probability of an agent shifting to those systems rises, due to the copycat mechanism observed in the Mekong Delta (Nguyen and Ford, 2010). Farmers learn from their neighbors, and they are more willing to adopt a production system if they observe it in successful transformations around them. The model incorporates this with a variable called social influence, which is integrated into the calculation of the probability to shift to INTS, IES or IMS. Details of the calculation are given in Appendix A. In all cases, the effect of social influence was validated and calibrated during consultations with farmers and the RPG. A similar approach was used to estimate the interaction between agents regarding the influence of virus outbreaks.

5.2.2.3 Interaction with the local environment and the market and policy framework

Agents are influenced by a range of contextual variables, especially in relation to market and policy. In some areas, (local) policy influences agents' decisions to develop IES and INTS. Extension services, for example, may promote production intensification. Agents with exposure to these services will exhibit greater willingness to shift to INTS and IES. The model includes this factor as *policy influence*.

Both policy and market factors can be affected by shrimp prices. Furthermore, agents involved in organic production may receive Payment for Ecosystem Services (PES). Accessibility of a premium price for shrimp (*organic influence*) and PES (*PES influence*) modifies agents' willingness to shift to IMS, which is the only production system entitled to such support. All agents are influenced by the local biophysical environment, encapsulated by our suitability indexes for intensification and for growing mangrove.

5.2.3 Design of the Role Playing Game

The RPG centered on a board game in which each player managed one farm with characteristics derived from the CASS model. The RPG followed the sequence from land use decisions to investments and cropping results (see Appendix B for details). As such it mimicked the ABM. The game served to validate and calibrate agent behavioral rules for farmers and to investigate and test famers' decisions within four socio-environmental contexts: 'business as usual', 'neighbor influence' (expansion of intensive or integrated mangrove-shrimp), 'organic' (access to organic value chain and PES) and 'climate change'. 'Business as usual' is the original setting, using the production system parameters obtained from our consultations. In 'neighbor influence', the same production system parameters are used, but 20% of the farms on the board game (but not the players) are either INTS or IMS farms, according to the case being implemented: expansion of intensive or expansion of integrated mangrove-shrimp. After each cycle, the number of these farm types increases. This setting was used to investigate the influence of neighbors. In an 'organic' setting, the farmers who decide to shift to IMS obtain a premium price for their organic production: +10%, corresponding to the ideal premium price in the Vietnamese organic shrimp value chain. In addition, they receive a financial incentive (PES) of US $50 per hectare per year of forest on their farm. For 'climate change', the operational and investment cost as well as the virus risk increase for all farm types (Kam et al., 2010).

For each scenario, the participating farmers played 10 crop cycles and were then asked to share their experiences. The game master asked the players specific questions relating to their decisions in order to fine-tune the model rules and parameters for the probability of shifting and the influence of neighbors.

5.2.4 Scenario and exploration workshops

After calibration and validation of the ABM, workshops were organized with local decision makers and practitioners to develop scenarios for the future of shrimp farming (spanning a timeframe to 2030). The participants were asked to validate a list of drivers influencing shrimp farming in the study area derived from a previous participatory assessment.

In the first phase of the workshops, participants developed scenarios and supplemented these with short narratives explaining the main drivers in the aquaculture sector and the resulting overall changes in production systems and shrimp production. During the second phase, participants quantified some of these changes, as well as the drivers' effects and their impact on model variables such as investments and operational cost of the different production systems, shrimp sale prices, areal expansion of the different production systems, volumes produced and risk of disease outbreak.

The results of the scenario workshops were used to update the model, and the scenarios were run again. The outputs of the model under different scenarios were the following: (i) maps of land use in 2013 and 2030; (ii) estimates of the changes in total shrimp yield and percentages of area under each type of system in the study area and (iii) estimates of shrimp yield per production system. These were presented and discussed at a second workshop, followed by a survey asking individual participants their opinions about the model, the method used and the results presented.

5.2.5 Case study: Dam Doi District

Dam Doi District is part of Ca Mau Province. It encompasses 15 communes with a total area of some 48,000 ha, including 20,447 farms. In the district, we applied our model in eight adjoining communes, both coastal communes with dense mangrove cover and adjacent inland communes with less or no mangrove. Shrimp farming was the dominant land use in all of the communes. The mangrove areas were managed under the Dam Doi Forest Enterprise and included two main zones: (i) a Full Protection Zone of some 3,470 ha along the coastline where no farming activity was allowed and (ii) a Buffer Zone of 7,380 ha where most IMS farms were found. The IMS farmers had a 'Green Land Certificate', which required them to maintain half of their land under mangrove. They therefore did not have the option of implementing a more intensive shrimp production system.

The rest of the study area encompassed more than 37,000 ha of shrimp farm land. EXTS covered most of the area (78%), though IES and INTS were also found, as well as hybrids of these with EXTS (Figure 5.4). Agents varied in their economic and technical characteristics (Table 5.1). INT and IES farms could harvest two crops per year. IES and INTS could be implemented in only one pond on the farm, with the remaining area managed as EXTS. Farmers with IMS production also earned income from sales of timber, crabs, cockle and fish, in addition to shrimp.

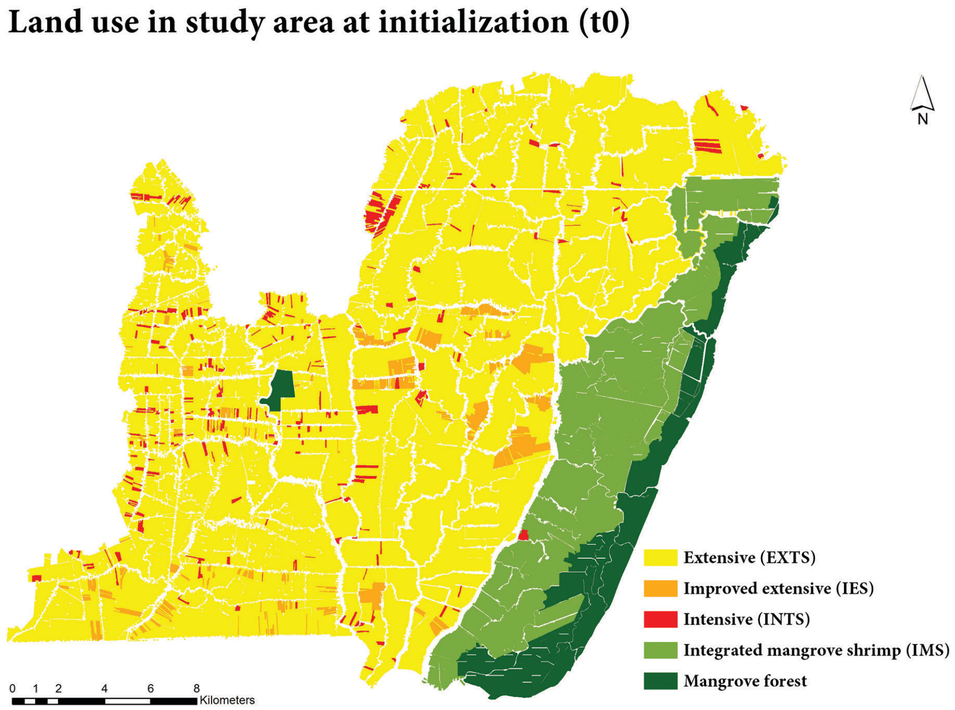

Figure 5.4: Land use in the study area at initialization (time step 0)

5.2.5.1 Suitability indicators

The suitability of land in the study area for the different shrimp farming systems was determined by water level and salinity. These were estimated during eight consultations with local shrimp farmers and authorities. The consultations were structured around a participative mapping process to derive the spatial distribution of land suitable for shrimp farming within each commune. Water level and salinity in the river network were derived using a MIKE-11 model (Dat et al., 2011), which was calibrated and validated to simulate hydrodynamics and saline intrusion over the whole Mekong Delta. The outcomes of the local consultations were combined with the hydrological modeling to produce the suitability index for INTS and IES, and that for IMS (Appendix A). In addition, communes with specific policies to promote development of intensive and improved extensive farms were given a higher value for these production systems in the suitability index. The suitability factor for

INTS and IES farming was valued at between 0.08 and 1.50 (Appendix A). This suitability was then used to calculate the probability of shifting to INTS or IES. The suitability factor for developing IMS was valued between 0.09 and 2.60 (Appendix A).

Table 5.1: Main characteristics of agents, means and standard deviations (based on Ha 2012 and consultations with farmers)

	Extensive (EXTS)	*Improved extensive (IES)*	*Intensive (INTS)*	*Integrated mangrove-shrimp (IMS)*
HH expenses (mVND/cycle)	8.5 ± 0.21	8.05 ± 1.46	19.6 ± 1.2	8.5 ± 0.21
HH loans (mVND/cycle)	12.99 ± 3.0	35 ± 5.0	45 ± 7.0	6. 94 ± 2.0
HH second income (mVND/cycle)	4.28 ± 2.50	4.14 ± 22	12.23 ± 6	3.97± 1.8
Land title	Red	Red	Red	Green
Crop cost (mVND/ha/crop)	3.87±1.0	35 ± 7.5	200 ± 75.0	4.78 ± 1.0
Post-larvae /m^2	< 4	3 to 8	15-30	2-3
Risk of severe disease outbreak	16%	40%	50%	10%
Yield (kg/ha/cycle) – successful crop	140 ± 20.9	450 ± 109	3,600 ± 1,045	91.45 ± 13.61
Yield (kg/ha/cycle) – failed crop	37 ± 6.8	44 ± 25.21	1,046 ± 460	45.0 ± 6.8
Share of the total shrimp area	78%	3%	2%	17%
Hybrid system	–	Hybrid IES and EXTS possible	Hybrid INTS and EXTS possible	Hybrid IMS and IES possible*

5.2.5.2 Farm characteristics, decision rules and land use map

Farm economic and structural characteristics (Table 5.1) were defined based on the consultations with farmers in the eight communes in the study area in addition to using data from Ha (2012). Farmers participating in the consultations expressed and refined the rules for decision making, as well as the probability of shifting. Quantitative thresholds for certain rules were averaged over the eight consultations. A land use map of the study area was obtained from the district office. A first step of the participative mapping exercise was to update the map to obtain a 2013 land use map reflecting our typology of agents.

5.2.5.3 Validation and calibration workshops

A series of three validation and calibration workshops were organized with local farmers from three communes within the study area. In total, 25 farmers were invited to these workshops, representing all four types of production system. The workshops included a rapid survey of agent characteristics in order to validate some of the model assumptions and farm characteristics. Workshop participants then conducted an RPG simulating farm decisions. Each participant played a farmer (agent) in the board games, with five to eight farmers playing at each board (Figure 5.5). Farmers' decisions to shift from one system to another were recorded and these records were used to update the ABM probabilities of agents changing from one system to another. The board game furthermore provided insights on the decisions farmers made under various circumstances, as outlined in section 5.2.3

5.2.5.4 Scenario workshop

During the scenario workshop, the model and results of the baseline scenario were presented to 19 participants representing government and nongovernmental organizations involved in mangrove and aquaculture development in the province.

The participants validated a list of drivers influencing shrimp farming in the study area. They also validated and fine-tuned three predetermined scenarios for the future based on this list of drivers. Like the baseline scenario, these scenarios spanned a timeframe to 2030. The scenarios were the following: (i) organic coast with integrated mangrove-shrimp farms, (ii) intensive shrimp farming and diversification of aquaculture and (iii) climate change.

Participants were asked to develop a narrative to go along with the three scenarios, explaining how each driver worked and, in a backcasting exercise, to quantify the parameters and outputs within each scenario and suggest trends in production systems and farmers' behavior.

Figure 5.5: Role playing game (RPG) based on the Coastal Aquaculture Spatial Solutions (CASS) model in which farmers make decisions on whether to retain or to change shrimp production system. The board depicts shrimp farms and canals. Different colors on the board represent different farm types

5.2.5.5 Exploration workshop

At the exploration workshop, which was held two days after the scenario workshop, the results of the different scenarios were presented to the same group of participants and their comments and feedback collected. The outcomes of the different scenarios were discussed in groups, followed by an individual survey asking personal opinions about the model, the method used and the results presented. The findings presented in the results section pertain to the average of 10 independent runs for each scenario, with means and standard deviations of shrimp production and other output variables of the model.

5.3 Results

5.3.1 Validation and calibration

A key remark made at the validation and calibration workshops was that market prices played a central role in shrimp farmers' decisions. When prices are high, farmers tend to take more risk and intensify production. This was then added to the model with a new module including shrimp price fluctuations. Higher shrimp prices were considered to increase farm revenues and thus to increase the capacity of the agent to invest. The participants validated the land suitability factor based on the importance of soil type and land elevation for shifting to INTS and IES. The spatial distribution of suitable land was updated based on additional information acquired during the workshops. The behavior of farmers, for example, regarding loans, proved diverse and difficult to integrate into the model. Some farmers preferred not to borrow, while others took loans in order to invest. The rules regarding loans were modified to provide the option of taking a higher loan to finance a shift to intensive shrimp farming after several successful crops.

The workshop also clearly established a minimum land size (2 ha) required to shift to IMS; below that area farmers would not convert their land to IMS. Additionally, the workshop participants established a new type of agent: the hybrid farm combining IMS and IES. This agent (labeled IMS_IE) was elaborated and integrated into the model under the organic shrimp scenario.

It also became apparent that farmers interpreted the shift to IMS as a modification of their land title, from 'red' to 'green', meaning that they would lose decision power over their farm to government administrators. This explains in part why, in the RPG and in reality, few farmers decide to shift to IMS. Participants furthermore observed that the effects of learning and access to knowledge were missing from the model, as well as the presence of specific and unexpected climate events that could trigger massive losses in shrimp farming. A final missing element was access to infrastructure, such as roads and electricity, which might influence decisions to shift to an intensive system.

5.3.2 Scenarios for shrimp farming

Our baseline scenario represents current policy on shrimp farming in Dam Doi District. The probabilities of shifting from one system to another were based on the initial assessments, with no changes made in hydrological conditions. Increases in costs and prices were based on the local consultations.

The ‘organic coast’ scenario promotes IMS development in the current EXTS farming area. This scenario may materialize if the benefits of mangrove cover increase due to PES, as well as if farms succeed in accessing the organic value chain with its premium prices (+10%), as both increase willingness to shift. Larger IES and EXTS farms become hybrid farms with IMS alongside an IES pond that constitutes about 30% of the total aquaculture area. Income from timber would increase by 50% compared to current IMS with the possibility of selling timber at auction, and access to premium organic prices would increase revenue from shrimp sales. Risk of virus outbreaks is lower in hybrid IMS systems than in IES, due to the presence of mangrove in neighboring ponds.

The ‘intensive shrimp farming and diversification of aquaculture’ scenario represents a future in which policies and investment in infrastructure support expansion of INTS farming. Extension services and the private sector enable this development by dissemination of knowledge. Farmers can borrow larger amounts if they shift to an INTS system, 60 mVND/ha instead of 45 mVND/ha. This doubles the probability that EXTS farmers and IES farmers will shift to INTS, as well as the probability of EXTS shrimp farmers shifting to IES. The risk of disease outbreak increases for all farms due to the expansion of INTS. EXTS farms diversify aquaculture production, adding crab and fish culture in addition to shrimp, thus increasing their revenue by 20%.

In the ‘climate change’ scenario sea-level rise modifies land suitability for intensification. Low-lying lands become less suitable for INTS and IES. The probability of shifting to a more intensive system thus diminishes. Because of higher water levels, investment and operational costs are greater for all systems (fuel, feed and other inputs), but the increase is most significant for INTS farms. Higher temperature and climate hazards slightly increase the risk of virus outbreaks in all shrimp production systems. Values of economic variables supplied by participants were later calibrated in accordance with available literature (Appendix A).

In all scenarios, including the baseline, the average shrimp price increases by 1.4% per year. Shrimp prices, operational costs, investments and economic returns, as defined by the participants within the scenario, were implemented as an constant increase per cycle. In all cases the value at initialization was the same as in the baseline scenario. Future inflation was not factored into the absolute values of operational costs, investment and shrimp market prices.

5.3.3 Outputs of the model

Trends in production differ under the different scenarios. Slight and steady increases in total production are found after 10 cycles in the baseline scenario, while the climate change scenario shows steadily decreasing production (Figure 5.6). In the case of the intensification scenario a rapid increase is, after 6 cycles, followed by a plateau and then a decrease in total production in the last cycles. The total shrimp production expected in the study area in 2030 oscillates between some 5,300 tons per cycle in the climate change scenario to slightly more than 7,800 tons in the organic coast scenario. After an initial increase, the total shrimp production in 2030 in the intensification scenario is expected to decrease steadily in the last 7 cycles due to abandonments (Figure 5.7). The expected production decrease in the intensification scenario up to 2030 compared to the baseline scenario is not significant (less than 1%). The organic coast scenario is expected to produce 2.4% more shrimp than the baseline scenario over this time span. After 30 cycles, total production in the climate change scenario is expected to be 30% lower than the baseline.

The organic coast scenario presents a similar trend to the baseline scenario. Of all the scenarios, the intensification scenario presents the highest variability with the largest standard deviations. Incidence of virus outbreaks, with sudden drops in production, can be seen in all scenarios. Similarly, all scenarios show a drop in production in early cycles due to a model artifact, leading to shifts or abandonment of improved extensive and intensive farms after 3 cycles.

At initialization, production in the baseline scenario is dominated by EXTS (63%), followed by INTS (27%), IES (5%) and IMS (5%). After 30 cycles, in all scenarios but climate change, production is dominated by INTS farms. In the climate change scenario, EXTS systems are still dominant after 30 cycles, with INTS farms representing only 18% of total production, compared to 49% in the intensification scenario. IES farms represent between 13% and 15% of the production across all scenarios. The new IMS_IE system (mixing the integrated and improved extensive systems) created in the organic coast scenario, represents 4% of total production, equivalent to the IMS total.

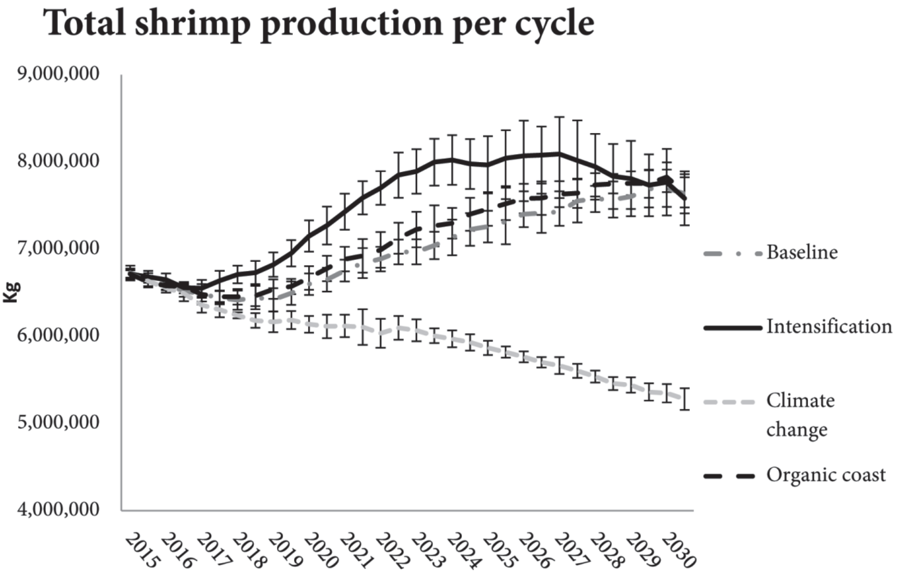

Figure 5.6: Total shrimp production per cycle (2015–2030) in the study area (48,000 ha) according to four scenarios: baseline, climate change, organic coast and intensification (error bars represent standard deviations based on 10 runs of the model)

At initialization (t0) land use in the study area is dominated by EXTS farms (84%) (Figure 5.4). After 30 cycles (t30), EXTS farm area decreases in all scenarios, representing 64%, 67%, 69% and 79% of the area, respectively, in the intensification, organic coast, baseline and climate change scenarios. The IMS area changes slightly, by 1%, across all the scenarios, but in addition to IMS farms, the IMS_IE system represents 5% of the area in the organic coast scenario.

The intensification scenario exacts the highest social cost, as it produces the largest number of shrimp farms abandoned every cycle, gradually increasing to more than 500 farms per cycle, representing a total of up to 4,000 INT and IES farms in the study area (Figure 5.7). Spatial patterns vary between extremes, for example, as represented by the climate change and intensification scenarios (Figure 5.8). In the intensification scenario, INTS and IES farms become concentrated in the central part of the study area and spread along the Buffer Zone, where IMS farms are found.

In the northern and southwest parts of the study area, intensification is less significant, reflecting the lower suitability of these areas for such production systems. Abandoned farms are found mostly in areas with greater intensification.

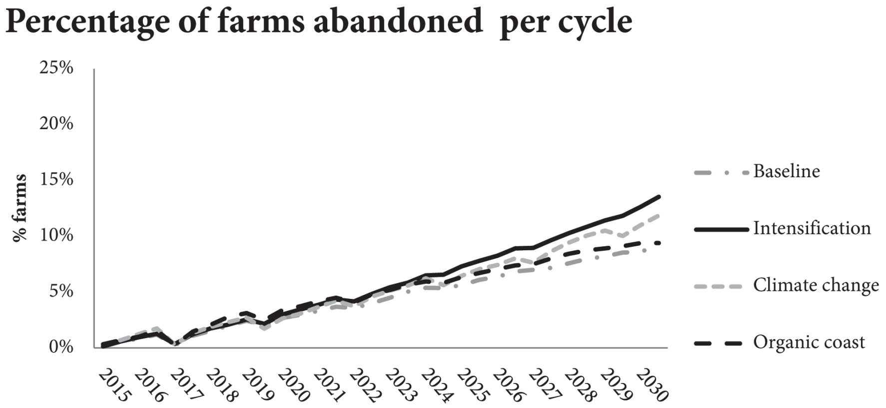

Figure 5.7: Percentage of INT and IES farms abandoned every cycle in the four scenarios: baseline, climate change, organic coast and intensification

In other scenarios, intensification is limited to the most suitable areas. In the organic coast scenario, the hybrid mangrove-shrimp system and the improved extensive shrimp pond (IMS_IE) are found adjacent to IES and INTS farms on the land that is suitable for intensification.

5.3.4 Observations about communication and learning

Farmers found the RPG to be a good learning tool for assessing the risks involved in shrimp farming and for thinking about farm management in the medium term. In their feedback, farmers reported appreciating the lessons they had learned by playing the RPG, as it mimicked the effect of choices over several cropping cycles and helped them to better gauge the risk of virus outbreaks. The significant risk to shrimp farming posed by the climate change scenario prompted a number of farmers to shift to IMS, because it requires less capital than INTS or IES and the risk of virus outbreaks is lower. Decision makers considered this as a possible adaptation measure for the future.

Farmers' interpretation of the land law and their belief that planting mangrove trees on their farms would affect the status of their land title came as a surprise to decision makers, and demonstrated farmers' limited knowledge of the law and regulations. Neither a PES scheme nor an organic value chain existed in the study area. Farmers participating in the RPG therefore had no experience to draw on and only limited understanding of these types of market-based incentives. This lack of knowledge was similarly unanticipated by decision makers, who themselves were aware of a well-developed organic shrimp value chain in Ca Mau Province. Access to higher loans generated the results of the intensification scenario in which more farmers converted to INTS, ultimately leading to reduced total shrimp production by the end of the simulation period. Decision makers noted the relevance of this model output for future land use policies specific to intensification of shrimp farming.

Decision makers acknowledged that use of the ABM helped them to integrate multiple variables into a vision of shrimp farming in 2030. They considered the model realistic and robust, and based on grounded data. Practical and useful information was produced in the design of the scenarios and in their exploration. Decision makers also appreciated the straightforwardness and comparability of the ABM results, which allowed them to anticipate different futures and evaluate risks associated with shrimp farming in the context of climate change and disease outbreaks. Finally, it allowed different policy options to be tested and trade-offs between policies to be quantified.

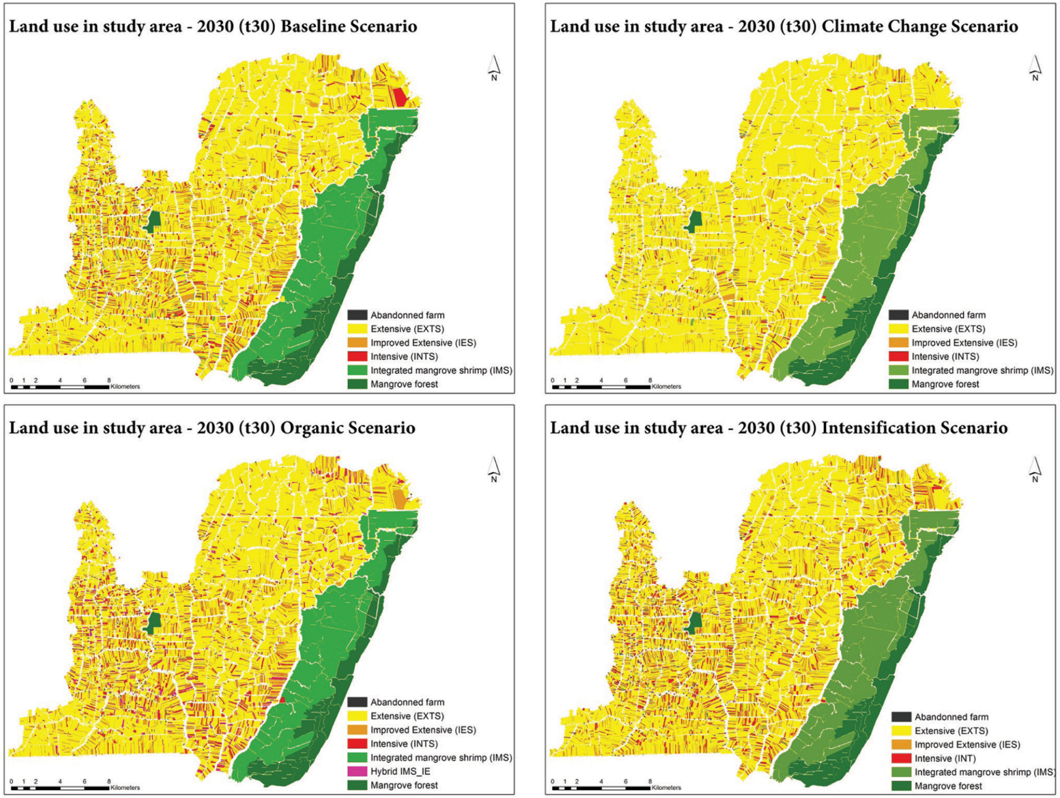

Figure 5.8 : Illustration of land use in the study area according to our four scenarios: baseline, climate change, organic coast and intensification based on a single run of the model

5.3.5 Role playing game delivered more than validation and calibration

The combination of an RPG and actor-based modeling produced a more finely tuned ABM based on grounded evidence (Vilamore et al., 2014; Barreteau et al., 2001; Castella et al., 2005; Etienne, 2003). In our case, several rules and new parameters were identified and confirmed during the RPG and integrated into the ABM, thus providing calibration as well as confirmation that an ABM can provide realistic descriptions of behaviors and social interactions, as postulated by Le Page et al., (2012).

The purpose of the model was not to precisely estimate total production in the study area but to determine how land suitability, water quality, policies and history of the farm and its economic status influence farmers' decisions and how these variables are interrelated. The adequacy and validity of the model owes as much to its acceptance by local farmers, who participated in the consultations and RPG, as to its fair and functional representation of the farm and interactions between the different parameters (Naivinit et al., 2010). We received positive feedback from farmers after the RPG. This supports the idea that the model provided a valid representation of reality and stimulated learning about farm management and about investment strategy and risk.

5.3.6 Local knowledge transfer and adaptive learning

Any model might provide an accurate representation of one stakeholder's views, while, at the same time, being inaccurate (though precise) from a different stakeholder's perspective. Indeed, farmers may make different decisions than those predicted by researchers', practitioners' and decision makers' knowledge (Moss, 2008). We incorporated local knowledge into the decision-making process through a series of consultations. The outcomes of these consultations were used to design and refine the rules of our model and the RPG.

Our analyses produced interesting outputs, such as the increasing number of INTS farms with access to higher loans, the abandonment of intensive farms in the intensification scenario, the changes in spatial patterns in the study area, limited shifts to IMS and the creation of the IMS_IE type of farm. This knowledge was very useful for decision makers, and they remarked on it during the exploration workshop when the outputs of the model were discussed. Differences between the various scenarios could easily be compared and attributed to farmers' behavior and socioeconomic characteristics and to the suitability of the environment. Finally, a clear benefit of this method was the learning it facilitated among decision makers about local practices.

Our approach faces two limitations as well. First, model rules based on outcomes of an RPG are limited by game participants' knowledge and experience. In our model, policy measures such as the PES scheme and the organic value chain had little influence on farmers' behavior, due to the absence of PES schemes and an organic value chain in the study area. Second, there was no feedback loop modifying the decision-making process of the agent, for example, to integrate learning about new policies or the efforts of environmental awareness programs. Although we incorporated local knowledge using several first-order type rules, social interaction and social learning were limited to spatial relationships because (i) the probabilities of choosing the IMS or INTS system increase when more neighbors implement such a system and (ii) the chance of shifting is related to the suitability of soil, water level and salinity. Capacities to learn from past failures and experiences and agents' considering new techniques and policies – like PES – were not included in the model. These adaptive learning behaviors would have been interesting for the climate change scenario, in which shifting local environmental conditions required adaptation of techniques and systems. The utility of the ABM for decision makers would be increased if such a component were added, providing a tool for future policy analysis that captures not only the dynamics of global changes but also the adaptive behaviors of (groups of) agents in the face of these changes (Acosta-Michlik, 2008).

5.3.7 Limitations of the model and approach

The structure of the model and its results were found to be realistic and useful to decision makers. However, feedback from users highlighted the absence of several variables, such as demographic changes (as the area available for farming is diminishing due to increasing population density), coastal erosion, infrastructure and aquaculture services and the choice of shrimp species cultivated. Hence, decision makers would have liked to see more complexity in the model, including additional external drivers of changes within farmers' decision-making processes.

A participatory approach is crucial for decision makers to acquire ownership of the model. This requires time. The period between the scenario workshop and the exploration workshop was too short to integrate all of the modifications and changes resulting from the consultation with farmers and decision makers into the model, and to redesign the model according to the scenario. Moreover, the process would have gained from having an additional workshop for decision makers to play the same RPG developed in collaboration with farmers. The results of the scenario would have been better understood and links between agent scale, landscape and policies better perceived, and they could have been analyzed by type of stakeholder. Doing this might have enabled a more efficient transfer of local knowledge and farmers' viewpoints on production systems to the higher decision making level.

The model of this specific case study underlines the influence of proposed policy measures and of changes in the environmental and economic context on farmers' behaviors and on outcomes at the landscape level. This study, therefore, illustrates the power of the approach for capturing local knowledge and conveying it to the decision-making level. The model and the approach could be improved by including stronger feedback loops, such as adaptive learning of the agent, thus better reflecting agent behaviors. Additionally including policymakers in RPG development would help them to better understand local farmers' knowledge and, as such, facilitate dialogue between these two stakeholder groups, improving the design of the scenarios and the sense of ownership of the model outcomes. Fruitful additional research would include measurement of the results of this approach on farmers' management skills and the effects of the approach on aquaculture planning.

Chapter 6

General discussion and conclusion

6.1 Outline

The objective of this study was to develop an approach that integrates the decision making process of individual shrimp farmers within a decision-support tool to improve planning for shrimp aquaculture in the coastal zone. We used the Mekong Delta as a case to test a new method to develop such an approach and to answer the four research questions elaborated in Chapter 1:

- What is the diversity of shrimp farming in the Mekong Delta and how productive are those systems?
- Is diversification through brackish water polyculture a valid risk management strategy for smallholders?
- What are the drivers for the adoption of diversified and integrated aquaculture practices that restore mangrove cover?
- Can we integrate farmers' knowledge and decision-making processes into a spatially explicit decision support approach for policy makers to explore future aquaculture policies?

Chapter 2, 3, 4 and 5 investigated the research questions through surveys, case studies and Agent Based Modeling. In this last chapter we summarize and discuss the main findings of the thesis, before discussing their implications for shrimp aquaculture and proposing directions for future research.

6.2 Main research findings

6.2.1 Productivity and diversity of shrimp farming in the Mekong Delta

Little is known about the diversity of shrimp production systems in the Mekong Delta and their productivity. Following the boom of the shrimp sector and its expansion further inland traditional shrimp production systems changed. Intensification and diversification processes resulted in diverse production systems varying in productivity. We conducted a survey along a transect across the coastal zone of the Mekong Delta that covers not only the coastline, but also the brackish water areas located further inland. We identified four main production systems i) rice-shrimp system in the alternate fresh/brackish water area, ii) extensive brackish water polyculture, iii) intensive household-based shrimp farms and iv) commercial intensive shrimp farms.

When analyzed for their productivity and economic results, we found that the capital required for extensive and rice–shrimp farms is about 10 times lower compared to intensive family and commercial farms. The efficiency of capital use was significantly higher ($p<0.05$) in extensive and rice-shrimp farms compared to intensive farms, when the farms are not affected by viruses. When considering only disease-free farms, labor productivity reached 15 kg per man per day of work in intensive family farms while it was below 10 kg per man per day of work for both extensive and rice-shrimp farms. Differences in virus occurrence were large and significantly higher ($p<0.05$) in extensive (49% ± 45 of the farm affected) and intensive family-based farms (32 ± 36 %) compared to rice-shrimp (25 ± 36 %) and intensive commercial farms (13± 27%). Both extensive and rice shrimp systems presented an average yield below 250 kg per hectare, which was significantly lower ($p<0.05$) than in intensive farms where production reached in average 6.1 and 4.6 tons for intensive commercial and intensive family farms respectively.

Shrimp capture fisheries and farming are traditional production systems in the Mekong Delta. Description of, and information on, productivity and economic return of the traditional system in this region can be found as far back as the late 19th century (Brière, 1880). From extensive fisheries, the production systems changed to an extensive farming system where wild shrimp post larvae (PL) are trapped in ponds together with other aquatic organisms. In the Mekong Delta, the traditional extensive systems were predominant until the end of the 20th century, sometimes associated with mangrove (Johnston et al., 2000) or in alternate rotation with rice (Be et al., 1999; Brennan et al., 1999; Xuan and Matsui, 1998). In 1997, extensive shrimp farms were still recruiting wild post larvae and only 2% of the farms were stocking the tiger shrimp, *P. monodon* in monoculture. Yields were reported to be between 14 kg/ha and 139 kg/ha and input was limited to occasionally homemade feed (Brennan et al., 1999). Yields were lower than for brackish water polyculture systems, which yield 242 ± 109 kg/ha and 77 ± 13 kg/ha in disease-free farms and disease-affected farms respectively. The low yields recorded in the late 1990s were already related to disease outbreaks, but diversification of production, including high value fish and crab, had yet to be identified as a coping strategy by the farmers. In less than a decade, the farming systems in this coastal province began relying entirely on hatchery-reared post larvae, and the intensive production systems appeared (Be et al., 1999; Brennan et al., 1999).

Compared to extensive systems of similar size found in Bangladesh, shrimp yields are within the same range, with a reported average around 146 kg /ha (Alam et al., 2007) or 204 kg/ha (Islam et al., 2005) with other aquatic species counting for about half of the aquaculture production (Alam et al., 2007). Interestingly, in Bangladesh, the extensive systems do not include the stocking of other high value aquatic species and still rely on wild fish and shrimp trapped in the ponds. In this case, the farmers' strategy relies on low input systems and productivity of the natural ecosystem. This can be seen as a less advanced stage than the brackish water polyculture system in Vietnam, where farmers stock high value species. Meanwhile, in Bangladesh, disease occurrence is high, with 96% of the ponds affected by virus (Alam et al., 2007), which is higher than the disease occurrence reported in Vietnam.

The tiger shrimp, *P. monodon* intensive production systems were also found in Thailand until 2006. They have similar yields to Vietnam, between 4.4 and 4.7 tons/ha (Lebel et al., 2002). However, Thai farms (and the entire sector) shifted from tiger shrimp's (*P. monodon*) culture to the Pacific white shrimp (*Litopenaeus vannamei*), requiring a higher level of intensification. This radical change proved to be successful, at least for the first years, with lower environmental impact and higher productivity and cost effectiveness (Lebel et al., 2010). However, this shift was not within the investment capacity and technological range of all small-scale farmers. Such strategy and conversion of the entire sector to another exotic shrimp species is not achievable in the Mekong Delta without a significant social cost.

Vietnam recently followed a different path based on two species: *P. monodon* and *L. vannamei*. Following the lift of the ban on *L. vannamei* cultivation in 2008, cultivation of the Pacific white shrimp has been expanding fast since 2012. In specific provinces of the Mekong Delta like Soc Trang and Ben Tre, the annual increase of *L. vannamei* production was up to 31% in 2014 (VASEP, 2015). *L. vannamei* was not only produced in intensive *P. monodon* farms but also in new non-planned areas. From less than 2,000 hectares in 2009 the total cultivated area of *L. vannamei* reached 67,000 ha in 2014 in the Mekong Delta. The estimated production in 2014 (245,000 tons), is almost similar to the *P. monodon* production (248,000 tons).

This recent change in the sector was not observed at the time of data collection. It illustrates a new step towards the evolution of the shrimp sector in the Mekong Delta, with a clear dichotomy between large areas of low input, low productivity extensive systems based on *P. monodon*, and limited areas of intensive production system based on *L. vannamei*.

6.2.2 Diversification as risk management strategy

With high occurrences of virus outbreaks, extensive family-based shrimp farms are the ones most at risk. As a result, farmers diversify their aquaculture production with other high value products such as crab and fish (Chapter 2). Is this diversification through brackish water polyculture a valid risk-management strategy for smallholding shrimp farmers?

Diversification is a well-known strategy for smallholders to cope with risks and shocks (Pannell et al., 2000; Hardaker et al., 2004; Heinemann, 2014). In the case of shrimp farming, diversified production systems are usually related to extensive traditional systems where multiple aquatic species are trapped in the pond during water exchanges (Xuan and Matsui, 1998). These systems are now obsolete and the current strategy described in the Mekong Delta is based on stocking specific species, which is an investment choice made by farmers. This thesis further investigated smallholders' strategies to cope with disease risk, focusing on diversification of aquaculture production. A household survey along the coastline of one Mekong Delta province was carried out to understand the relative contribution to the household incomes of other aquaculture species stocked in shrimp ponds. The survey sample (n=92) was stratified in three income classes: poor, medium and better off households.

Shrimp farmers' strategies vary according to their wealth status. Better-off farmers with more land and capital can invest in more intensive production systems or in the culture of a high value fish. Medium income households invest in less intensive systems, with an operational cost 4.7 times lower than better off households. This income group, responding to market demands, targets high value products such as elongated goby and mud crabs, while poor households cannot plan this type of diversification due to limited investment capacity. Poor households base their livelihood strategy on daily catch of fingerlings and juvenile crabs that are later sold to medium and high-income farmers to be raised in their ponds. Natural resources from the mangrove and mudflats are of crucial importance for poor households, who have limited access to land, capital and job opportunities, as they sustain their livelihoods. This study also confirmed (Chapter 2) that with larger investments in intensive ponds, the virus frequency is lower. On average 37% of the better off households were affected by a virus outbreaks compared to the poor and medium income ones where disease incidence is equal or higher than 50% on average. Diversification with crab and fish does not reduce the risk of disease outbreak but provides additional income for family-based aquaculture farms, contributing to almost 50% of the income from aquaculture, and thus being as important as shrimp production for the households' income. This strategy helps medium income households to cope with income shocks from shrimp diseases.

Usually aquaculture is a mean for diversification of farm-based production systems aimed at improving households' livelihoods and wealth (Ellis and Allison, 2004). This type of risk management strategy is common in fresh water aquaculture in Vietnam (Reurd, 2007). It is also a common way to cope with the disease risks faced by extensive smallholder shrimp producers in Indonesia (Hariati et al., 1998), in the Philippines (Stevenson et al., 2007) and in Bangladesh where the value from other wild aquatic species trapped in extensive shrimp ponds represent at least 18% of the farm income (Alam et al., 2007). Shrimp farmers adopt the previously existing traditional farming systems, where natural seeds are trapped in the pond by stocking selected species. The recruitment of wild species is estimated below 0.2 PL/m^2 (Johnston et al., 2002) and too low to provide sufficient income. Additional stocking of high value species is therefore necessary. This diversification strategy is opposite to the common diversification strategy where consumption and households' food security is the main target (Reurd, 2007). This type of diversification found its roots in traditional extensive diversified aquaculture ponds systems to which farmers adapted to respond the local market demands.

This diversification strategy is widely spread among the 500,000 ha of shrimp farming in the Vietnam's Mekong Delta. Extensive shrimp aquaculture systems, and thus the farmers' livelihoods, are dependent on wild crab and fish seeds collected in mangroves and mudflats. Early evidence of declining crab and fish resources based on fishermen's claims was presented in Chapter 3. The widespread adoption of such strategy questions the sustainability of the sector and the livelihood of small-scale producers, representing almost 189,000 tons and 62% of the Mekong Delta shrimp production in 2009. When a significant amount of farm income is derived from species requiring juveniles be sourced from their natural habitat, it is crucial to either provide hatchery reared juvenile and/or sustain and control the natural production and exploitation of this resource in order to support smallholder producers.

6.2.3 What drives the adoption of integrated mangrove-shrimp aquaculture in Vietnam?

The literature and the farmers' reported perceptions suggest that integrated mangrove-shrimp systems can support the restoration of the ecological functions provided by the mangrove forest (Primavera, 2000; Oswin, 2001), contribute to pond ecology (Tendencia, 2012) and support more resilient production systems (Johnston et al., 2000, Ha et al., 2013). These integrated systems are found, for example, in the rehabilitation of abandoned shrimp farms in Thailand (Stevenson, 1997; Troell et al., 2009), in Indonesia (Sukarjo, 1989; Bunting et al., 2013) and in the Philippines' (Primavera, 2000) coastal area. In the Mekong Delta, this type of system exists but is limited to less than 50,000 ha, of which 92% are found in one coastal province. Moreover, this system remains confined to the existing mangrove area, where no other production system is allowed. One can question why this system did not spread elsewhere in the coastal zone and what are the drivers stimulating farmers to adopt integrated mangrove-shrimp systems? Based on literature review, we identify in Chapter 4 a series of farms characteristics (or internal drivers) and drivers external to the farms that influence the farmers' choice of a given production system. We conducted a series of consultations with Vietnamese and international experts to weigh the importance of the external and internal drivers in influencing the shift to, and continuation of, integrated mangrove- shrimp systems.

The consultations revealed that only extensive shrimp farmers could shift to an integrated system. Integrated systems cannot recover the investment made during intensification and thus intensive farmers do not consider such transition as an economically sound option. Experts pointed out the importance of the ecological function of the mangrove forest to reduce economic losses from disease and to improve the pond's water quality, in choosing such systems. External drivers that constrain the shift to integrated systems are related to the regulatory framework and to the functioning of the value chains. Drivers in the current context, limit the financial performance of integrated mangrove- shrimp systems. The framework regulating the forest's benefits sharing, where State representatives control the selling price of timber and other costs related to forest management, disadvantage farmers.

As a result the financial return of forest exploitation is low and does not incentivize farmers to plant mangrove. Drivers such as access to an organic value chain, complying with quality standards and receiving a premium price are currently undermined by the organization of the value chains. Delays in payment, limited premium price and its skewed distribution over the value chain, limit the incentive to shift to an integrated mangrove-shrimp system.

Profitability of the system is crucial in driving the farmers' shift to integrated mangrove-shrimp production. Bosma et al., (2014) show that in the Mekong Delta the net income of integrated systems under the current rules is sufficient to sustain farmers' livelihood only when the farm area is above 4 ha, this usually represents a large piece of land in Vietnam. Meanwhile integrated systems can compete, on a longer time scale (15-20 years), in economic terms to extensive systems without mangrove, when the regulatory framework is not limiting benefits from timber (Ha et al., 2014). Supporting the conversion of extensive systems to integrated mangrove-shrimp system will require a regulatory framework that supports the economic resilience of the farm households. Recent policies to support the shift to integrated a mangrove-shrimp system, such as the development of an organic value chain or the scheme for Payment for Ecosystem Services (PES) are either not efficient (Ha et al., 2012) or not yet in place in the Mekong Delta (Mc Nallly et al., 2011).

To achieve economic efficiency, one option for farmers would be the intensification of shrimp culture within the integrated system. This is a farm model where the mangrove stand is connected to the wider ecological system and a more intensive shrimp culture is developed in a separate pond. This option could provide sufficient incentive to farmers by achieving their income target in a small area, while on the other hand providing ecosystem services through the mangrove stand. In this case connectivity between forest and aquatic systems can be improved, ensuring a more regular flooding of the mangrove. Developing policies and a regulatory framework that support such shift from extensive to integrated mangrove-shrimp farm will certainly provide the farmers with an incentive based on the economic return. This option could interest smallholder farmers.

6.2.4 A spatially explicit decision support to explore future shrimp aquaculture policies

The last research question concerned the integration of farmers' knowledge and decision-making process into a spatially explicit decision-support approach to test future aquaculture policies with decision makers. Chapter 5 presents a new approach that enables decision makers to quantify the trade-off between different future policies, within a participatory process combining Role Playing Games (RPGs), Agent Based Modeling and Scenario building. The methodology is tested to explore future scenarios for shrimp farming in one coastal district.

Consultations with farmers and RPGs were used to collect local knowledge and to calibrate the spatially explicit Agent Based Model (ABM). This model was later used under four different scenarios built by the decision makers. Results showed that policies supporting intensification are not sustainable within a 15 years' time frame and have the highest social cost, with the largest number of abandoned farms among all the tested scenarios. The model outcome indicated that without adaptation measures, climate change will threaten aquaculture production due to higher costs of production. Tested policies to support organic shrimp culture and integrated mangrove-shrimp farming are not strong enough to induce a shift to integrated mangrove-shrimp systems. The model provides spatially explicit outputs and clear patterns of intensification are identified in areas prone to intensification due to local policies and land suitability.

The approach used to build the model in iterative consultation with farmers identified knowledge gaps of farmers regarding the organic value chain and the payment for ecosystem services policy. It also provided decision makers with insight about farmers' perception and decision-making process. Knowledge gaps where conveyed to decision makers through the model, during the exploration of model outputs. In addition, farmers found the use of RPGs useful to learn about farm management and confirmed that the model was a valid representation of the reality. As mentioned by Schmitt and Brugère, (2013), robustness of the model will be improved by wider involvement of stakeholders and ease the implementation of policy measures resulting from the research findings.

6.3 Is the shrimp aquaculture sector a complex adaptive system and can we model it?

The complexity of the shrimp production sector where human behaviors interact, adapt and change under the influence of economic and bio-physical drivers can be considered a Complex Adaptive System (CAS). '*CASs are open systems in which different elements interact dynamically to exchange information, self-organize and create many different feedback loops, relationships between causes and effects are nonlinear, and the systems as a whole have emergent properties that cannot be understood by reference to the component parts'* (Barnes et al., 2003 cited by Grus et al., 2010). CASs are characterized by features and behaviors. In Table 6.1, we identify key features and behaviors of the shrimp aquaculture sector in the Mekong Delta and in the Agent Based Model (ABM) developed in the Chapter 5: the Coastal Aquaculture Spatial Solution model.

The shrimp sector, as it is in the Mekong Delta, presents most of the characteristics of a Complex Adaptive System. The sector outputs are difficult to predict, open to external influence and have a strong capacity to adapt to shocks and changes. Small events, like disease outbreaks in a pond, or external factors like changes in international market prices, can lead to tremendous changes within the system. An obvious example are the virus outbreaks that led to more than a 50% drop of the production in 1994 or more recently when the new non-viral disease, APHN, hit more than 80% of the farms in the Mekong Delta. A change in the regulation, like the possibility to convert rice fields into shrimp ponds led to the expansion of shrimp ponds with more than 350,000 ha within 12 years. CASs are considered systems with limited central control. Even when policy makers in the Mekong Delta want to increase the area with intensive farms or spread organic farming, like in Ca Mau (Ha, 2012), change in policy does not achieve the objectives and the farmers' decision remains under the influence of a multitude of internal and external factors.

Feedback loops are important characteristics of CAS and are found at multiple levels in the case of shrimp farming. Primary order feedback loops include, for example, the direct feedback from a farmer's decision on land use and production system, access to knowledge and introduction of new technology. An example of feedback loop in the case of change in production system can be illustrated by the change in nutrient loads due to intensification (Thakur and Lin, 2003; Anh et al., 2010), leading to the deterioration of local water quality conditions. Secondary order feedback loops relate to long-term effects of national and international policies, market price fluctuations and changes in consumer demand that act as external driver on the system and its agents. For example, the introduction of a quality standard with a specific value chain and premium prices leads to changes in the sector at the level of production systems in order to comply with specific standards such as organic product or Good Management Practices.

The Agent Based Model (ABM) created in this thesis includes different features and behaviors of CAS (Table 6.1) with the farm as the basic component. As presented in Chapter 5, the model results are not constant, results vary due to slight changes of initial parameters, and emerging patterns can be identified from the aggregation of individual behaviors. The model includes similar features and behaviors to the shrimp sector, but the relationship between its components or agents and the socio-ecological system are simplified. Feedback loops are limited and the agent's decision-making is based on stochastic rules.

In the ABM, the agent does not learn from failure (or success), neither from extension services and private sector trainings, or learning about new policies and associated awareness campaign. Behavioral models have been used in Agent Based Modeling (Jagger et al., 2000; Ziervogel et al., 2005). This approach assumes that cognitive strategies of farmers will depend on their characteristics, social network and past experiences, where risk assessment and how farmers reach their decision is complex and modified by external variables not merely based on the economic dimension. The agents' response to external drivers and the farmers' adaptive learning can be modeled using i) a mental memory map where the agents remember their farms' results from previous years and ii) mental maps that represent their social network (Acosta–Michlik and Espaldon, 2008). Using more detailed farmers' decision-making processes will enable more complex and detailed primary and secondary feedback loops regarding past experiences and policy changes (Vilamor et al., 2014; Scholz, 2011). For example, the influence of the organic value chain on farmers' decision to comply with these standards will be more important through time, once farmers gradually learn about the policies through their social networks.

These feedback loops are not developed in the current Coastal Aquaculture Spatial Solution model and could be improved in the future to capture the complexity of the farmers' decision-making process and the interaction between farmers and the wider social-ecological system. It will provide a better understanding of how external drivers influence individual

Table 6.1: Features and behavioral characteristic of Complex Adaptive Systems (adapted from Grus et al., 2010; van der Lei et al., 2009).

CAS features and behaviors	*Mekong Delta shrimp sector*	*Coastal Aquaculture Spatial Solution model*
Features		
Component	Farm and farmers sharing water resources, linked by social and economic networks.	Farms managed by farmers. Neighboring farms influence each other.
Path dependency	Path dependency exists with intensive ponds that cannot be converted to extensive ponds due to high switching costs.	Intensive ponds cannot revert to extensive or integrated mangrove-shrimp systems.
Openness	The sector is open to hydrological changes, and open to the world market's demand influencing the price of shrimp. The sector also includes actors other than farmers: the supply and marketing chain, including consumers.	Change in policies or shrimp prices and variables external to the system influence the system. But limited external influence in the model of value chain functions.
Unpredictability	Impossible to predict production, price of shrimp, and diseases leading to low yields.	The system is based on individual decisions of agents, and small changes of policy create a cascade of events and generate un-expected results.
Scale independence	No.	No.
Behaviors		
Adaptability	Strong adaptability to market (prices), bio-physical condition, diseases and technological changes.	Adaptability of the agent to disease, flood level, neighbor influence and, to a lesser extent, market price changes.
Self-Organization	Self-organization observed at local level with farmers organization and clustering, and advocacy to change policies and regulation.	No. The structure of the components is fixed.
Nonlinear behavior	Influence by multiple drivers and variables that make the predictability of future paths difficult. Emergence of new properties when all farmers follow similar paths, leading to a tipping point in the system such as disease outbreaks.	External and internal factors affect yield, farm's economic results and the farmer's decision in a nonlinear way with a probabilistic model. Cascading effects of failure and abandoned farms after widespread intensification.
Feedback loop mechanism	Strong adaptive learning from the sector illustrated by changes of production in case of: heavy disease impact, reaction to international market price, extension services and other sources of knowledge. Strong adaptive learning of farmers to cope with risk and uncertainty.	Limited to positive (influence of neighbors) and negative (concentration of intensive farm affecting disease frequency) feedback loops.

decision-making and lead to the emergence of un-expected and un-predicted trade off and patterns at the landscape scale.

Looking at the shrimp sector as a Complex Adaptive System implies that the sector cannot be only managed by a central authority that designs policies to achieve planned targets. Complex Adaptive Systems can be seen has ‘having their own will’, reacting to, and being influenced by, multiple variables. Influencing the shrimp sector requires more than just policies and planning; it requires direct influencing of its agents and their behavior. Therefore, knowledge transfer and the agents’ adaptive learning are important to influence the behavior of the system in order to, to in turn achieve specific goals. Another way to strengthen knowledge transfer between components of the system is by creating innovation platforms to address current sector issues and to support not only the technological aspects of the innovation process, but also its social, organizational and institutional ones (Boogaard et al., 2013). Innovation platforms foster collaborations and exchange between stakeholders of the sector. Such tool is more likely to enhance the adaptive capacity of the system components. The shrimp sector is an open system and inputs from outside are difficult to control or predict. Un-planned events will always occur and strengthening the system’s adaptive capacity is the only way to avoid significant negative and un-wanted new emergent properties within the system in reaction to unpredictable and un-planned events.

6.4 New tool to address the shrimp sector’s productivity and sustainability challenge

6.4.1 Relevance to the sector

The world’s population is expected to reach an estimated 9.3 billion by 2050 (United Nations, 2009), which means an increase in food demand of 1.1% per year during the 2007-2050 period (Alexandratos and Bruinsma, 2012). A recent study by the World Bank (2013) estimates that by 2030 aquaculture will provide almost two thirds of global fish consumption. This trend is driven by the demand from the emerging middle class, mostly in Asia, where the region’s fish consumption will grow by 30% by 2030. Within this projection, shrimp is one of the main aquaculture commodities. Shrimp aquaculture production is expected to grow from 3.4 million tons in 2008 to 8.06 million tons in 2030 and it is expected to contribute up to 9%

of total aquaculture production by 2030 (7% in 2008), of which 39% will be sourced in South East Asia (27% in 2008). With more than 39% of the world's shrimp aquaculture production concentrated in Asia, it is predicted that a generalized disease outbreak in this region would severely hit the world shrimp market. These figures highlight the challenges ahead, whereby shrimp production needs to increase to support food provision and local economic growth without depleting productive natural resources and damaging the natural environment. Shrimp aquaculture is expected to contribute significantly to global food production and thus requires planning to reach this goal.

The approach developed in this thesis supports the idea that a change toward a more sustainable sector can be achieved by modifying existing extensive production systems and integrating mangrove stands within shrimp farms. Only farmers, influenced by a multitude of drivers, can make the decision leading to this change. Some of the drivers are shaped by decision makers who design policies for regulating the sector. By engaging decision makers and farmers in an approach that facilitates interaction between them and provides visual and quantifiable trade-offs between tested policies, the proposed approach in this thesis supports the development of shrimp aquaculture planning.

Considering the trends and projections detailed above, we are convinced that the shrimp sector will continue to grow. Existing production areas will certainly intensify to meet the increasing demand and thus require better planning. The question remains whether integrated mangrove shrimp farming will ever be able to meet this growing demand. Some opinion makers, therefore, argue that intensification is the only path to food security. This argument is supported by the increasing pressure on suitable land for coastal aquaculture (Klinger and Naylor, 2012). New conversion of large areas into extensive or integrated mangrove-shrimp systems is unlikely to take place. In this thesis, we do not claim that the expected contribution of shrimp farming in achieving food security can be achieved by converting all farms to integrated mangrove-shrimp systems. However, in areas where smallholder extensive shrimp farming systems are dominant, conversion of all farms into intensive systems is unrealistic, risky and will not necessarily achieve the desirable production target while also imposing a high social and environmental cost. We argue that intensification is not for all, and that supporting the conversion of extensive systems into integrated mangrove-shrimp systems can support, through its ecological function, intensification of farms within the same landscape, while providing smallholders with economically and ecologically sustainable production systems. Integrated production systems will contribute less to the total volume of shrimp production compared to intensive systems, but the social costs associated with disease outbreaks will be lower for the local government. The question whether such a balanced landscape between intensive production systems and integrated-mangrove shrimp systems can achieve future production targets, cannot be answered yet. However, we hypothesize that a resilient sector, integrating both integrated and intensive systems within its landscape, can achieve more ambitious production targets, is better able to adapt to changes, can innovate and perhaps move toward sustainable intensification.

The case study was carried out in the Mekong Delta, where the sector is predominantly based on smallholders practicing extensive production systems. The demand for a more sustainable sector is also highly relevant from a societal point of view. The sector's development contributes to the livelihood of farmers and households working within the value chain. These specific aspects of the Mekong Delta's shrimp sector raise questions about the applicability of this approach in other countries. Below, we discuss the wider applicability and relevance of the proposed approach in four different shrimp-producing regions: Bangladesh, India, Thailand, and Ecuador.

6.4.2 Applicability and adaptability to other contexts

Bangladesh, Ecuador, Thailand and India, are four significant shrimp producing countries, each with specific characteristics and components (Table 6.2). On one hand, Thailand is based on intensive *L. vannamei* farms fuelled by technology and high quality inputs (Lebel et al., 2010). At the opposite end of the spectrum, Bangladesh and specifically the South-Western part of the shrimp belt, is based on extensive systems with limited access to knowledge, technology and capital to invest (Paul and Vogl, 2011). Roughly halfway along the continuum is Ecuador, where shrimp production systems based on *L. vannamei*, both extensive and vertically integrated farms, using high level of inputs and high stocking are found (Wurmann et al., 2004). This dichotomy within the sector has recently also been developed in the Mekong Delta and in India. The shrimp sector is divided into two main sub-sectors: on the one hand extensive *P. monodon* production systems, which are improved and operated by smallholders, and on the other hand a rapid increase of intensive *L. vannamei* farms (Manoj and Vasudevan, 2009; FAO, 2015; VASEP, 2015).

Table 6.2: Comparison of area, production and main features of shrimp aquaculture in Thailand, Ecuador, Bangladesh, India and Mekong Delta (Vietnam). Area and production data for the Mekong Delta are mostly for 2014 (VASEP, 2015) with some cases for 2013 (FAO, 2015).

	Bangladesh	*India*	*Ecuador*	*Thailand*	*Mekong Delta (Vietnam)*
Main Shrimp species cultivated	*P. monodon*	*P. monodon* and *L. vannamei*	*L. vannamei*	*L. vannamei*	*P. monodon* and *L. vannamei*
Annual production ('000 tons)	57	270	281	609	493
P. monodon / L. vannamei		(123/147*)			(248/245)
Area of production ('000 ha)	244	115	190	80	604
P. monodon / L. vannamei		(93/22)			(537/67)
Intensity of the dominant production systems	Low input, smallholders	Low input, smallholders + Intensive commercial farms	Medium to high input + Intensive commercial farms	Intensive smallholder and commercial farms	Low input, smallholder + Intensive smallholder
Average productivity (tons/ha)	0.23	2.34	1.47	7.61	0.81
P. monodon / L. vannamei		(1.3/6.6)			(0.46/3.65)
Level to knowledge and service industry	Low	Low/ High	Medium to high	High	Low – medium/ High

In these four countries shrimp farming development was detrimental to mangrove forest development (Hamilton, 2013; Paul and Vogl, 2011; Barbier and Cox, 2002). Shrimp production systems are facing high risks of disease outbreaks illustrated by several cases of disease outbreaks in the past that significantly reduced the country's annual production. (Alam et al., 2007; Lighter, 2011; Umesh et al., 2010; Wurmann et al., 2004). The main differences found between these countries are (i) the species cultivated, *P. monodon* in Bangladesh, mix of both shrimp species in the Mekong Delta and in India and a sector based only on *L. vannamei* in both Thailand and Ecuador, and (ii) the intensity of production, with a gradient from low input brackish water polyculture systems found in Bangladesh (Paul and Vogl, 2011) to intensive systems supported by a well-developed service industry in Thailand (Lebel et al., 2002). An indicator of the level of intensification, e.g., the average yield of shrimp farms per hectare illustrate this gradient, with Thailand as the most productive country, followed by India and Ecuador with average productivities at 2.34 tons per ha and 1.47 tons per ha respectively. The Mekong Delta and Bangladesh have an average yield below 1 ton per ha.

Differing from Thailand's shrimp sector, in the Mekong Delta (Vietnam), India, Bangladesh and, to a lower extent in Ecuador, the smallholder low input systems are a significant contributor to the total country production and represent thousands of farmers with limited investment capacity. Economic sustainability of these systems is necessary to avoid social problems and contribute to economic growth of the coastal areas. However, the same industrial model of the Thai shrimp industry, based only on intensive farms, cannot be replicated in all the other countries, where most shrimp farmers have poor access to capital, knowledge and a limited secondary service industry.

Even with access to the resources needed to achieve a conversion to intensive farms, this shift of production system in large production areas such as the Mekong Delta, Bangladesh or Andhra Pradesh in India is probably not desirable from an environmental and economic sustainability point of view. The conversion of most of the existing extensive systems into intensive farms will have a heavy impact on local aquatic ecosystems (Anh et al., 2010) and will increase the risk of disease outbreak and thus of a massive drop in production. A recent AHPN outbreak in Thailand showed that even an intensive *L. vannamei* production system, supported by a strong and organized service industry, is not immune to diseases and can be significantly damaged.

Other options for the growth and development of the shrimp sector are needed so that smallholder shrimp farmers can sustain their livelihood. Using an approach that focuses the debate and the design of policies sensitive to farmers and their decision-making might provide a useful and applicable solution. In Bangladesh and for regions in the Mekong Delta, India or Ecuador, where smallholder extensive farms are the dominant systems, a similar approach with participatory modeling, Agent Based Model and involvement of decision makers to evaluate new policies, is relevant. Testing policies to promote integrated systems in areas where aquaculture significantly contributed to the loss of mangrove, like in Ecuador (Hamilton, 2013), will be of high interest to planners and international agencies that promote coastal protection and reforestation of mangrove. For countries like Thailand, where the sector is based on intensive systems, or in the case of intensive commercial farms in Ecuador, India or Mekong Delta, the Agent Based Model developed in this thesis is less relevant. Farms are already intensified and shifts to other types of shrimp culture systems with integration of mangrove are less likely to happen. Risk management is based on bio-security's control measures. In such context, the approach and the Agent Based Model could be adjusted to test other options. An example is the deployment and adoption of standard practices such as Good Management Practices or the rehabilitation of abandoned ponds through integrated mangrove-shrimp systems (Schmitt and Brugère, 2013; Stevenson, 1997; Troell, 2009).

The approach involving farmers and decision makers is valid and will support the debate to shape new policies for developing a sector. For example in Thailand, Ecuador, and more recently in the Mekong Delta and India where commercial intensive farms are providing an important share of the total country production, this participatory approach could be used to test policy measure such as Payment for Ecosystem Service (PES). Within a new regulatory framework that will support such policy, commercial farms will have to pay for the conservation and rehabilitation of mangrove stands by extensive farmers. The PES approach was found promising in Thailand (Schmitt and Brugère, 2013) but not yet tested with the different stakeholders in the sector. Therefore, to be applicable in countries and regions were the sector is more advanced and based on intensive production systems, other stakeholders groups need to be integrated, such as commercial farms and private sector to i) modify the Agent Based Model and integrated new type of agents and ii) involve powerful economic agents in scenario development and enhancing dialogue between decision maker and farmers (or entrepreneurs and investors in the case of intensive commercial farms).

In all cases adapting the approach will require an update of the model as shrimp farm characteristics and farmers' decisions will be different in a new location. Additionally, the required parameters to characterize agents and the detailed spatial data of ponds and farms in the study area, makes the development of the approach data intensive and time consuming.

6.4.3 Improving the model

Farmer's (agents') decision-making is central to the Agent Based Model developed in Chapter 5. In this model, agents' decisions were based on probabilities that were inferred from consultations and Role Playing Games with farmers. Other models use different methods to simulate agents' decisions. For example a Bayesian Belief Network (BBN) (Baran et al., 2006, Schmitt and Brugère, 2013), or a fuzzy logic approach (Bosma et al., 2007) could be used to support the integration of more complex feedback loops in the decision making.

The fuzzy rule base consists of "*if-then*" propositions and deals with linguistic values, and is therefore appropriate to model farmer's decision taking (Jang et al., 1997). BBN models are based on probabilistic relationships between variables (Castelletti and Soncini-Sessal, 2007) and can incorporate both quantitative and qualitative information. While modeling farmer's decisions with fuzzy logic was found technically complex to develop (Bosma et al., 2007), BBN uses a relatively simple approach based on expert consultations. In the model developed in this thesis, an agent's decision is based on baseline probabilities that are modified by bio-physical environment, policies and neighbor's influence, but interactions between those external drivers are not specifically taken into account. Neither the relationship between farm characteristics and external drivers and how these interactions influence farmers' decisions are taken into account. More complex interactions between external variables and farmers' decisions could be elaborated by integrating a BBN within the Coastal Aquaculture Spatial Solution model.

6.5 Further research

The finding of this study could provide material and hypotheses for future research looking at developing a more resilient aquaculture sector in the coastal zone. Future research could integrate the spatial component of having a larger mangrove cover to support the shrimp aquaculture sector. Further research could address specific issues regarding:

- Epidemiology: a study comparing virus/bacteria occurrence, and pond-to-pond transmission between farms (including integrated mangrove-shrimp farms) will contribute to a better knowledge of risks and a better understanding of the spatial spread of disease agents between farms;
- The spatial dimension of mangrove ecosystem services provided by mangroves to aquaculture systems could be quatified. Examples are nursery, water filtration and so on. It will support aquaculture planning by understanding the relationship between mangrove cover and its associated services;

- Social learning and how the combination of RPGs and ABM can enhance farmer's knowledge and management capacity and how effective this tool is in terms of improving farmer's management capacity is still largely unknown. Research about the benefit of creating a dialogue platform such as the RPGs will also indicate if such approach is beneficial to decision makers in their understanding of the sector.

6.6 Conclusions

This thesis aimed at developing an approach that integrates individual shrimp farmers' decision making in a decision support tool to better plan shrimp aquaculture. This objective was translated in four research questions.

The following conclusions can be drawn from this thesis:

- Intensification of shrimp farming in the Mekong Delta is not sustainable for smallholder farms;
- Diversification of aquaculture production in the Mekong Delta is the main strategy used by small-scale producers to cope with disease risk;
- Diversification of aquaculture based on wild seeds sourced in the mangrove is not sustainable because dependent on habitat and on the mangrove forest's nursery function.
- Drivers promoting the adoption of diversified and integrated aquaculture practices that restore mangrove cover are related to the governance and regulatory framework that shape the economic benefits of this integrated production system;
- Gaming tools are useful to support a modeling process, involve stakeholders, and can be used as a learning tool to support the farmers' adaptive capacity;
- Combining ABM and participatory tools and processes facilitate knowledge-sharing between stakeholder groups such as decision makers and farmers.

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Appendixes

Appendix A: Overview of the design, concepts, and relevant details of the Coastal Aquaculture Spatial Solutions (CASS) Model

A.1. Overview

A.1.1. Purpose

The aim of the agent-based model Coastal Aquaculture Spatial Solutions (CASS) is to create a simulation tool for the analysis of land use change and (shrimp) farmers' decision-making under the influence of social, policy, economic, and bio-physical drivers (Figure A.1). The agent-based model is parameterized with empirical data and calibrated through role-playing games. The model also uses a GIS (Geographical Information System)-based cadastral map and outputs of hydrological modeling to estimate spatial suitability of plots for different shrimp production systems.

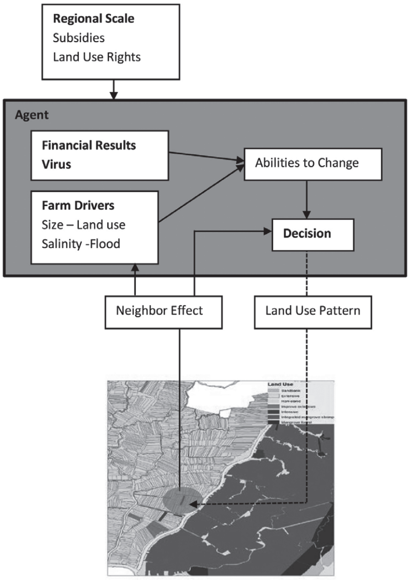

Figure A.1. Interaction between farmer (agent), external drivers, and neighbors in land use decision-making

The aim of the model is to i) explore policies for coastal aquaculture management, ii) investigate future production results of shrimp farming based on different policies, economic settings and bio-physical context, iii) integrate new drivers influencing farmer's decision at the farm level and understand their impact at a larger scale (commune and district) on spatial land use changes. This spatially explicit agent based model aims to be a decision making support tool for policy makers and planners. Using such a tool may support their discussion about coastal aquaculture planning.

State Variables and Scales

Coastal Aquaculture Spatial Solutions (CASS) was developed in Gama 6.0 (Grignard et al., 2013). The model is based on the cadastral map of eight (8) communes in Dam Doi district, a coastal district of Ca Mau Province in the Mekong Delta, Vietnam. The cadastral map is composed of more than 20,000 plots, each plot representing one shrimp farm or one forest plot. Two types of entities are found: farms and plots. Agents represent farmers that manage their plots and each farm is composed of one single plot. The attributes of farms and plots are given in Tables A.1 and A.2.

Table A.1. Attributes of farm entities

Farm Attribute	*Description*
Number of plots	Number of plots in the farm (equal to 1).
Total land area	The area of the farm, loaded from the GIS file.
Household size	Household size randomly determined based on a Gaussian distribution (5±1.7).
Household expense	Household expense to sustain farm family living: the amount relates to the household size, the crop revenue, and the production system.
Maximum loan	Maximum loan an agent can borrow, correlated to the land size and production system type.
Available loan	Amount of loan available to the agent, based on previous loans contracted and the maximum loan.
Household loan	Current loan contracted by the agent.
Household loan history	Records loans contracted by the household in the past cycle.
Household bank account	Summarizes the current savings and loans of the agent, including the different revenues, costs, and loans involved.
Probability to shift	Probability for agent to shift to a specific production system. This is updated at each cycle and for each production system if the agent has enough capital to make the shift. The updated probability integrates bio-physical and social actors.
Household's 2nd income	Represents the revenue of the household from activities other than shrimp farming, randomly determined on a Gaussian distribution and varies according to production system.
PES	Payment for Ecosystem Services, or the amount of subsidies received when farmers plant mangrove trees in their farm.

Table A.2: Attribute of plot entities

Plot Attribute	*Description*
Id_plot	Plot ID loaded from GIS file.
Land use certificate	Describes the type of land title of the plot – Green or Red – which determines the possibility to modify land use (Red) or not (Green).
Production system	Production system of the plot. Four types are possible: Extensive (EXTS), Improved Extensive (IES), Intensive (INTS), and Integrated Mangrove-Shrimp System (IMS), as well as a mixed system, IMS_IE.
Social influence	Influence of the neighboring farm on future land use regarding shifting to INTS or IMS system.
Failure rate	Risk of virus and loss of crop. The risk varies according to production system.
Failure history	Records the number of crop failures in the past. A high number of consecutive failures in an INTS production system triggers change towards EXTS production system or the abandonment of the plot.
Land use history	Records the number of cycles with the same land use. Agents applying INTS and IMS cannot change production systems after one production cycle, even if they incur loss.
Crop yield	The yield is based on a Gaussian distribution for each type of production system and is randomly determined for each agent in each cycle. The yield of the crop is determined by the presence or absence of virus.
Crop cost	Crop cost determines the operational cost of the crop per hectare for each production system based on a Gaussian distribution and randomly determined for each agent in each cycle.
Crop revenue	Represents the economic results of the farm based on the yield and selling price minus the operational cost.
Plot suitability for mangrove	The suitability factor is between 0 and 2 and corresponds to the suitability of the area for planting mangrove and developing an Integrated Mangrove-Shrimp system. The suitability is based on water salinity during the year and flood level (mean monthly water level).
Plot suitability for INT and IE systems	The suitability factor is between 0 and 2 and corresponds to the suitability of the area for developing Intensive and Improved Extensive shrimp farming systems based on water salinity during the year and flood level (mean monthly water level).
Policy IE	Corresponds to the influence of government policy to promote the Improved Extensive system in specific locations. The factor ranges between 1 and 1.6 and influences the probability to shift to an Improved Extensive system.
Ie_factor ext_factor Int_factor	Plots may not be fully converted into Intensive or Improved Extensive system. This factor (a random number between 0.3 and 1) is multiplied to the plot area to determine the INTS area or IES area of the plot, which is further managed as an EXTS system.

Table A.3.Attributes and descriptions of global variables used in the CASS model (mVND: Million Vietnam Dong)

Attribute	*Description*
Minimum investment	Lowest investment required to shift from EXTS to IMS (13.3 mVND/ha).
Chance for higher loan	Probability to get a loan that is higher than usual (20%) for IES, EXTS and IMS farms.
Fail factor	Minimum amount of capital required to continue INTS or IES farming, expressed as a percentage of the crop cost (20% of the operational crop cost).
Investment cost of INTS/EXTS/IMS system	Amount required transforming the pond into a new production system, including the cost of equipment. Investment cost is provided per hectare: INT (165 mVND /ha); IE (90 mVND /ha); IMS (12 mVND /ha).
Social distance	The distance corresponding to the radius around a plot center used to calculate the influence of neighbors on the possible change to INT (500m) or IMS (1,000m).
Base probability to shift	The base level of the probability for a farmer to shift from one system to another. It includes all the different possibilities to shift. Those probabilities are based on local trends and are calibrated during focus group discussion and role-playing.
PES influence	Factor, depending on local policy (subsidies), that increases the probability to shift to IMS.
Organic premium	Percentage of premium price added to the shrimp' selling price if the organic standards are applied (10%).
Organic influence	Factor, depending on local policy (organic premium), that increases the probability to shift to IMS.
Policy influence	Factor, depending on local policy to focus extension service in certain area, that increases the probability to shift to INTS or IES.
Price fluctuation	Shrimp price is randomly determined every cycle, between a lower and upper boundary.
Intensification Ratio	Ratio of Intensive shrimp area / Total shrimp area.
Virus outbreak	Probability to have a virus outbreak in the region, which increases with the level of intensification of the farm. This probability is updated before every cycle and determines the level of risk for the run.
Additional risk	A 30% increased risk for all farms during one cycle of a disease outbreak due to virus. This risk depends on probability of a virus outbreak, and translates to the cyclic appearance of new disease agents or of more virulent varieties of existing viruses or bacteria.

A plot is characterized by its type of production system, area, suitability for each type of land use, potential yield, risk of virus, and economic characteristics (operational cost). Four production systems are possible: Extensive (EXTS), Improved Extensive (IES), Intensive (INTS) and Integrated Mangrove-Shrimp System (IMS). Plot agents also can be hybrid plots with an Intensive system area and an Extensive system area (or Improved Extensive and Extensive) within the same plot.

The model includes also global variables that influence agents and their decision-making. The list of global variables is given in Table A.3.

Since the model is designed to simulate changes across time, economic variables such as market prices are dynamic enough so as to represent fluctuations and developments in the shrimp market. The increases in shrimp price, operational cost, investment cost, and returns defined by the participants within the scenario are transformed into an increment per cycle, and are added to the variable cost for every new cycle (Table A.4). Those increment values are derived from literature (Kam et al., 2010) and workshops with experts of the shrimp sector in Ca Mau.

Table A.4: Increment of model variables per cycle

Variable	*Increment*
Price	+ 1.4% per cycle
Minimum investment	+ 0.63 mVND /haper cycle
Investment cost of Intensive/Improved Extensive/Integrated Mangrove-Shrimp Systems	INTS: + 1.66 mVND /ha per cycle
	IES : + 0.65 mVND /ha per cycle
	IMS : + 0.27 mVND /ha per cycle
Crop cost: Intensive/Improved Extensive/Integrated Mangrove-Shrimp / Extensive Systems	INTS: + 3.33 mVND /ha per cycle
	IES : + 0.57 mVND /ha per cycle
	IMS : + 0.16 mVND /ha per cycle
	EXT : + 0.10 mVND /ha per cycle
Failure rate: Intensive/Improved Extensive/Integrated Mangrove-Shrimp / Extensive Systems	INTS: + 0.27% cycle
	IES : + 0.27% cycle
	IMS : + 0.17% cycle
	EXTS : + 0.17% cycle

One time step (or cycle) corresponds to 6 months (1 shrimp crop). At each step, success or failure of the shrimp crop is calculated for each plot (agent) and the economic results of the farm agent are updated accordingly. Farm agent characteristics and spatial representation of the farms and plots are based on local and current situation of shrimp farming in Dam Doi district and from empirical data collected during an on-farm survey (Ha, 2012) completed with focus group discussion and role playing with farmers. Plot suitability for developing an IMS farm and an INTS farm is derived from hydrological modeling of the flood and water salinity (Dat et al., 2011) and translated into a suitability index.

A.1.2. Process Overview and Scheduling

At every time step, the 'Farm Plot' agents carry out the process in the following order (Figure A.2):

1. Check the land title of the plot (Decision 1). If land title is 'Green', the agent keeps the same production system; if land title is 'Red', the agent estimates its capital for investment (checks its bank account);
2. Check the bank account of the farm agent and see if this is above the minimum threshold (minimum bank account) to invest in another production system;
3. Check the bank account of the farm and see if this is above the investment needed to convert to an Intensive farm. If not, a similar check is done for Improved Extensive (medium threshold) and Integrated Mangrove-Shrimp (lowest threshold) farm, in this order;

In case the land title is Green or the bank account of the farm is lower than any threshold (Decision 2), the 'Farm Plot' agent keeps its current production system ('No Change') and 'runs a crop cycle' through the following steps: a) Test the crop for presence of virus, and b) Calculate yield and economic results accordingly before updating its bank account, including loan reimbursement, secondary income, and household expenses.

4. If the bank account is above one of the thresholds (for INTS, IES, or IMS), the agent updates his probability (with influence of policies, and suitability) to shift to this system before testing its probability;

5 a) If the tests are successful, the agent calculates the area of each production system in case of a hybrid plot (plot with two production systems such as EXTS and INTS);

b) If the tests are not successful ('No Change') the agent may test the probability to shift to a less intensive system such as IE or IMS;

6 The agent makes the investment for the crop, tests for presence of virus, and calculates yield and economic results of the production systems before updating his bank account with data on loan reimbursement, secondary income, and household expenses.

A.2. Design Concepts

A.2.1. Basic Principles

The CASS integrates social and ecological dimensions. The social behaviors of the agent in the system are based on the principle that agents aim to maximize their profit. Social behavior is based on the 1) agent's investment capacity that includes his past farming results, access to loan, other economic activities, and living expenses; 2) probability of the agent to change to another production system; 3) influence of local policies on this decision; 4) influence of neighbors' land use on this decision, and 5) biophysical characteristics of the plot under different production systems. The biophysical environment of the model includes a suitability index for each plot to grow mangrove and a suitability index for intensive shrimp farming. Both suitability indices are based on flood level and water salinity during the year.

A.2.2. Emergence

Interactions of the agents are of two types: 1) influence of the neighbors on land use decision, and 2) influence of the neighboring farms on the risk of virus. When the density of Intensive or Integrated shrimp farms increases in the neighborhood, the agent increases his probability to shift to those systems due to a copycat mechanism observed in the Mekong Delta (Nguyen and Ford, 2010). For each farm, increased density of intensive shrimp farms increases the risk of virus outbreak increases as follows:

$$\text{Virus outbreak probability} = 0.05 + e^{(2X\ \text{Total INTS farm area/ Total shrimp farming area})}$$

A.2.3. Adaptation

Agents want to maximize their profit. The decision about land use depends first on the financial capital. Hard thresholds determine the behavioral strategy an agent uses. In Intensive systems, an agent with enough financial capacity will continue the same production system if: 1) he is successful, and 2) he has enough capital to cover the crop cost, and 3) he has experienced less than three consecutive crop failures due to virus outbreak. In Improved Extensive systems, similar rules are used, but in case the agent is successful and reaches the threshold to invest in Intensive farming, the agent will test the probability of investing in a more intensive and profitable system. The probability to invest in intensive ponds will depend on the neighbors' influence, the local policy, and plot suitability.

An Improved Extensive or Intensive agent without enough financial capacity to cover his operational cost or with successive past failures of his system will go back to the Extensive system or will abandon shrimp farming. This last option is taken only by smalls-sized Intensive agents (<1ha). Agents with hybrid farms (having both Intensive + Extensive pond or Improved Extensive + Extensive pond) stop their Intensive or Improved extensive pond if they experience successive failures or do not have enough financial resources to cover the operational cost.

Integrated mangrove-shrimp and Extensive agents will keep their system even if they experience crop failure.

A.2.4. Fitness and Objectives

The goal of agents is to intensify their production toward Improved Extensive and Intensive systems. At each step, agents owning Red land title are able to change systems and test if they have enough capital to invest in more intensive production systems to maximize their profit.

A.2.5. Learning and Prediction

Agents do not learn or adjust their decision-making rules. They do not predict the results of their decision.

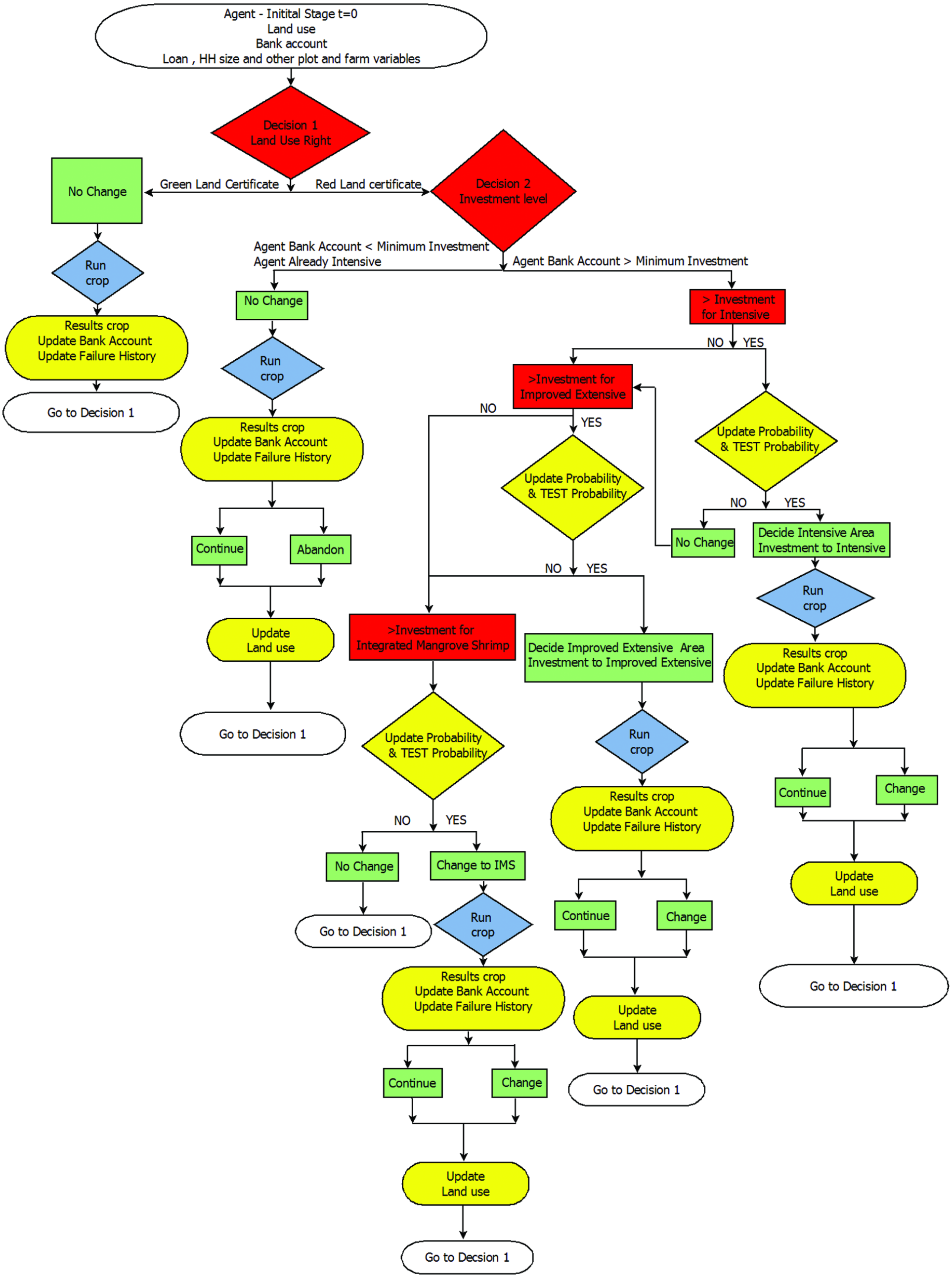

Figure A.2: Agents' decision tree

A.2.6. Sensing (factors influencing agents)

An agent senses a range of variable values from other agents:

- Relative land use choices of their peers, in the case of Intensive and Integrated Mangrove-Shrimp systems. These two land use types indicate the probability of agents to copy each other's production systems.
- Influence of increasing area of Intensive farms because this increases the risk of virus outbreak in neighboring farms.

An agent senses a range of variables from the Global agent. Those variables are related to market and policy:

- Agents sense the influence of local policy to develop Improved Extensive shrimp plots in certain areas. This value is loaded from the GIS file and corresponds to specific areas in the district where local authorities intensify efforts to push for Improved Extensive shrimp farming. This is spatially translated by an increase of the Policy IE factor to 1.6 for plots 750 m around existing clusters of Improved Extensive plots.
- Agents sense the influence of national and regional policy on the development of an organic shrimp value chain and payment for ecosystem service. Those policies increase the probability for Extensive farmers to shift toward an Integrated Mangrove-Shrimp system due to two factors: PES influence and Organic influence calibrated during role playing.

An agent senses a range of variables from the local environment. Flood level and salinity are converted into suitability value for Intensive and Integrated Mangrove-Shrimp systems.

Suitability for Intensive and Improved Extensive Systems

The Flood suitability for Intensive and Improved Extensive systems is set between 0.4 (mean flood level is 1.4 masl) and 1.4 (mean flood level is 0.3 masl). Communes with a specific policy for developing Intensive and Improved Extensive farms have suitability for those systems increased by +0.2. A similar factor was developed regarding suitability to salinity level. Both flood and salinity and local policy factor have been aggregated to create the suitability index for Intensive shrimp farming. The suitability factor for Intensive shrimp farming is between 0.08 and 1.5.

Suitability for Integrated Mangrove-Shrimp System

A similar type of factor for Flood impact has been created for Integrated Mangrove-Shrimp farming. This suitability factor integrates mean flood level, mean water salinity, and local policy. Finally, the suitability factor for Integrated Mangrove-Shrimp farming is between 0.09 and 2.6.

Climate Change – Sea Level Rise Impact

Scenarios can take into account sea level rise and the increased level of flood. For plots of lowest elevation in the study area, a climate change factor was introduced to reduce the suitability of

Intensive shrimp farming(-0.4). This factor will be used when the probability to shift to Intensive and Improved Extensive systems are updated.

A.2.7. Interaction

Besides the interaction between agents explained earlier in terms of copycat behaviors and the influence of Intensive shrimp farms on overall risk of disease outbreak, the model considers no other specific interaction between agents.

A.2.8. Stochasticity

In the initialization process, some variables of agents are set randomly to create a heterogeneous population. Those variables are: 1) the Intensive and Improved Extensive areas in the case of hybrid agents; 2) household size; 3) household secondary income; 4) household bank account, and 5) maximum loan. The functions to determine household second income, maximum loan, and household's bank account vary according to the type of agent (Extensive, Improved Extensive, Intensive or Integrated Mangrove-Shrimp). Each uses a different Gaussian distribution. The values are set based on an average value and a standard deviation. The data are sourced from Ha (2012) and additional surveys in the study area.

During the simulation, more agent variables are set randomly at each cycle. Those variables are: 1) household second income; 2) maximum loan; 3) crop cost; and 4) crop yield.

Stochasticity is also found in the global variable selling price of shrimp. The shrimp market is extremely volatile, and is therefore reset at every cycle. At the beginning of each cycle the program (Table A.5) randomly assigns a price between an upper and lower value.

A.2.9. Collectives

There are no collectives in the model. Agents are individuals, with individual decisions within to make on their plot/pond and farm, and no sort of collective farming is developed in the model.

A.2.10. Observation

The graphic user interface provides several types of graphs and maps enabling the modeler to follow the dynamics of the model. The map updates the land use of each farm every cycle. The graph provides visual representation of variables such as: 1) total shrimp production per cycle; 2) production for each type of system; 3) total shrimp area and total area per type of production system; 4) number of farms that are abandoned or Intensive and Improved Extensive agents who have moved back to an Extensive system, and 5) yield per type of production system. The graphic user interface also allows the modeler to modify several agents and global parameters.

A.3. Details

A.3.1. Initialization

At the initialization stage of the model, the static variables are assigned values. The global and agent's variables are set to default values that can be changed by users. The GIS cadastral map of the study area is loaded. From this GIS layer, plots and farm agents are created with their associated variables: production system, area, land use certificate, plot suitability for intensive and mangrove farming, and the influence of local policy on improve extensive farming.

Also at initiation, farm and plot agents are assigned random values for some variable (See Stochasticity). All variables of farm and plot agents production associated with production systems and socio-economy are given values either from random distribution or loaded from the GIS file (See Tables A.1 and A.2 on all the variables of the agent).

A.3.2. Input Data

External sources were used to prepare the model database:

- The GIS cadastral map was developed by the local authorities, digitized, and updated by the model developer;
- The socio-economic data on the production systems were sourced from Ha (2012) and updated during consultations and role-playing with farmers;
- The baseline probabilities to shift were computed from local trends in shrimp farming and calibrated during the role plays;
- The land suitability for integrated mangrove-shrimp and intensive shrimp farms was derived from the hydrological modeling of the Mekong Delta applied to the study area. The water level and salinity concentration along the river network in the Dam Doi district, Ca Mau province were simulated with the Mike 11 model (Dat et al. 2011). This calibrated and validated model simulates the hydrodynamics and the salinity intrusion over the whole delta of the Mekong. Compared with the actual measured salinity and water levels, the simulated ones followed the measured trend and were within an acceptable range of differences. In fact, the study area was close to the downstream boundary conditions of the applied hydrodynamics model (i.e., the measured tidal regimes).

A.3.3. Sub Models

The sequence of events happening during a cycle or when an agent shifts to Intensive farming is listed in Table A.5 below.

Table A.5: Sequence of actions and reflexes during a cycle

Reflex/Action	*Entity*
Reflex	
Update Price	Global environment
Update virus outbreak	Global environment
Master Rule for testing probability to change to INT	
Determine loan and available loan	Farm
Check land use title	Plot
Check minimum bank account	
Check for Hybrid (ratio of INTS and EXTS plot size)	Plot
Check INT economic threshold	Farm
Update probability to shift to INTS	Plot
Test probability	Plot
Once the production system is decided	
Run crop	
Test for virus	Plot
Update failure history	Plot
Calculate yield and economic return	Plot
Update secondary income and expense	Farm
Update bank account and loans	Farm
Update land use	Plot

A.4.4. Master Rule

The master rule is the main reflex of the model and the backbone of every step or cycle. It applies to every agent and determines a series of actions as follows:

- Determine the Available loan accessible to farm agent;
- Update the cost of the next crop;
- Check if the Land use title is Red (Decision 1 in Figure A.2):
    - Check if the Bank account is above the minimum threshold;
    - If the farm agent does not have an Intensive plot, the plot agent checks for the option of a Hybrid farm and determines the areas for Intensive and Extensive production in case it becomes a hybrid Intensive plot:
        - Based on the Intensive area stochastically determined, the plot agent calculates the cost of investment and the cost of one crop necessary to shit to Intensive production;
        - This cost of investment and crop cost is compared with the Household bank account and the Available loan.

        - If the Bank account + Available loan are above the investment + crop cost, the agent updates the probability to shift to Intensive farming and tests this probability.
    - If the agent has only an Extensive plot and does not have sufficient capital to invest in an Intensive plot, a similar process is done for Improved Extensive farming. The agent checks the option for a Hybrid farm to determine the areas for Improved Extensive and Extensive system in case the plot becomes Improved Extensive.
        - Based on the Improved Extensive area stochastically determined, the plot agent calculates the cost of investment and the cost of the crop necessary to shift to Improved Extensive farming
        - This cost of investment + crop cost is compared with the Household bank account and the Available loan.
        - If the Bank account + Available loan are above the investment cost, the agent updates the probability to shift to Improved Extensive and tests this probability.

    - If the agent has only an Extensive plot and does not have sufficient capital to invest in Improved Extensive farming, he updates the probability to shift to Integrated Mangrove-Shrimp and tests this probability.

Updating Probability

The probability to shift to Intensive, Improved Extensive and Integrated Mangrove-Shrimp can be updated. Updating the probability to shift to Intensive plots is done as follows:

- The base probability to shift to Intensive is loaded from the global variable and varies according to the agent's original land use (Extensive, Improved Extensive, Integrated Mangrove-Shrimp);
- The social influence of neighbors is calculated:
    - Calculate the number of Intensive plots within a 500m radius and generate a ratio between number of Intensive plots/ total number plots if number of Intensive plots is >0;
    - Calculate the social influence for Intensive using this formula: $1+ (0.6 \times (1- (e^{6X \text{ intensive plots/ total number plots}}))$
    - If the number of Intensive plots is = 0, the social Influence Intensive = 0.8;
- The plot suitability for intensive farming is sourced from the GIS file and included in the plot. agent's calculations
- The updated probability is calculated as follows :
    - Probability to shift to Intensive = base probability X social Influence Intensive X plot suitability for intensive

Testing Probability to Shift

Once the probability has been updated, the agent tests its probability.

- If the test result is positive, the agent does the following actions:

        - Update the area of Intensive and Extensive plots (see Check Hybrid);
        - Update the his Bank account by withdrawing the investment and crop cost required for Intensive farming on the pre-determined area;
            - If after the update, the bank account is negative, the agent contracts a loan within range of what is available and the bank account is updated as well as the amount loaned.
            - If the bank account is positive, no loan is contracted.

- If the test is negative, the agent will check if he can invest in an improved extensive plot and follow a similar type of procedure by updating the probability and testing the probability to shift to Improved extensive.

Checking Intensive for Hybrid

To estimate the investment cost needed to develop an Intensive plot, the agent stochastically determines first the areas for the Intensive and the Extensive ponds. Only agents with a small pond area (less than 0.25 ha) converts their pond to Intensive entirely.

- If the total pond area is between 0.25 and 1 ha, the agent chooses randomly a factor between 0.33 and 1. This factor will be the ratio of the intensive pond area to the total area.
- If the total pond area is between 1ha and 2 ha, the agent chooses randomly a factor between 0.4 and 1. This factor will be the ratio of intensive pond area to the total area.
- If the total pond area is above 2 ha, the pond agent chooses randomly a factor between 0.3 and 1. This factor will be the ratio of intensive pond area to the total area.

The ratio will be used to calculate the intensive pond area. If the agent decides to invest in an Intensive shrimp pond, the he will use the area decided during this process.

A similar process is followed to decide the pond area of Improved extensive (Check Hybrid for IE), but with slightly different ratios.

Running Crop

Run crop action is set by the plot agent. It determines the revenue from the crop for every cycle. The action is slightly different according to the production system. In Improved Extensive plots the action is as follows:

- The agent checks if the area for Improved Extensive farming is not null and if the production system is Improved Extensive (=2);
    - The failure rate is updated using the failure rate of Improved extensive system + additional risk;
        - The agent tests the probability if the crop is a success or a failure;
            - If the crops is a failure, the agent updates the failure history of the plot (+1), and calculates the yield, gross revenue, and crop revenue.
            - if the crop is a success, the agent sets the failure history to 0, and calculates the yield, gross revenue, and crop revenue

The yield is determined randomly based on an average yield and a standard deviation for this specific production system. The gross revenue is equal to the yield x area cultivated x price (failed or success).The crop revenue is equal to the gross revenue minus the crop cost.

Updating Secondary Income and Expense

At every cycle the farm agent updates the Secondary income of the household (income not derived from shrimp farming activity) as well as the Household expenses. Both expenses and secondary income depend on the production system of the agent. An agent followingan Intensive production system will have expenses and secondary incomes different than an agent with an Extensive production system. To update secondary income and expenses, the agent

- Checks the type of production system
    - Assigns randomly a secondary income, based on an average and standard deviation specific for each type of production system;
    - If the crop revenue is positive, the expense is calculated as :
        - a fraction of the crop revenue + correlation of the expense and the household size;
    - If the crop revenue is negative the expense is calculated as:
        - the correlation of the expense and the household size.

Updating the Bank Account

At the end of the cycle, the agent will update the bank account, taking into account the yield of the crop, the expenses, the secondary income and the debts, as follow:

- Updated bank account = previous bank account + crop revenue+ secondary income – expense.

If the bank account is negative, then the agent will contract a loan. The amount loaned depends on the loan availability for each agent (See Determining Loan). Agent will contract a loan to have a bank account equal to zero.

If the bank account is positive, the agent will reimburse his loan, partially or totally but will always keep their bank account equal to or above 0.

Updating Failure History

Updating the failure history concerns only Intensive and Improved Extensive agents. When the failure history is above 3 or the bank account is less than 20% of the crop operational cost, the agent makes the following decisions:

- If agent has a total plot area of <1 ha, he abandons the plot, and crops and area parameters are set to 0;
- If the agent has a total plot area > 1 ha, he changes production systems and goes back to the Extensive pond, converting the entire plot area to Extensive. Land use history parameter is set to 0.

The improved Extensive agent does not abandon, but only converts to the Extensive system.

A.4.5. Actions

Determining Loan

At every cycle each agent, before testing the different possibilities of production systems, will determine the amount of money he can borrow. The agent will first determine the Maximum loan he can take out by testing if he can contract a 'normal loan' or a 'higher loan'. This is decided by a probability test; an agent has a 20% chance to contract a 'higher loan'.

- If the agent contracts a 'normal loan', the Maximum loan he can contract varies according to the production system of the plot. An Intensive agent can borrow a higher amount than an Extensive agent. The amount is randomly attributed based on an average loan and a standard deviation multiplied by the plot area (loans are proportional to the total area).
- In the case of a 'higher loan', the amount loaned is higher than usual for Extensive, Integrated Mangrove-Shrimp and Improved Extensive agents, and corresponds to the average loan and standard deviation of the Intensive agent.

The Maximum loan calculated during this action will be used to determine the available loan at the beginning of the cycle. The Available loan is equal to the maximum loan minus the household loan (or the current debts of the household).

Land Use History

After every cycle, land use is counted for abandoned plots, Intensive, and Integrated Mangrove-Shrimp plots. Thus, the number of cycles with the same production system is recorded.

Past Changes

Actions related to Past changes use the Land use history of the plot to decide whether or not Intensive plots or Integrated Mangrove-Shrimp plots are allowed to change systems. In fact, once agents decide to shift to an Integrated Mangrove-Shrimp system, they have to stay in this system for the next 20 cycles (or steps) to be allowed to harvest their timber. Thus, when the Land use history is 19 or lower, the probability to shift to another system = 0.

A similar rule is defined for Intensive plots, but the number of cycles agents have to follow this system is equal to 2.

Reflexes

At every cycle the model operates a series of reflexes that define the global variable.

The reflex 'price' determines the farm gate price of shrimp, both from a successful and a failed crop. Both prices are set randomly within a lower and upper boundary.

The reflex 'disease outbreak' of the model determines if there is a significant disease outbreak in a cycle that affects the entire region by testing this probability. If realized, this probability, set to 5%, will increase the risk of a virus outbreak in all production system by 30%.

‘Check abandonment’ corresponds to the re-initialization of plots that have been abandoned. After being abandoned, a plot stays abandoned for 4 cycles. After this period a new agent is initialized and the plot follows an intensive production system, and the value of the parameters are set accordingly.

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Appendix B: Board Game Setting and Rules

The objective of the board game is to validate shrimp farmers' or agents behavior and decision-making under various settings and to calibrate specific variables of the model, such as probability to shift from one system to another. This game will also be used to estimate the influence of neighbors on an agent's decision. It attempts to quantify the copycat mechanism in the probability to shift to Intensive (INTS), or to Integrated Mangrove-Shrimp (IMS) as well as the effect of policies such as payment for ecosystem services and access to organic premium price.

B.1. The Board game

B.1.1. Setting

Each game engages the following players:

- 5 to 8 farmers;
- 1 game master who will explain and monitor the games and decision;
- 1 banker/facilitator who will manage the bank accounts of the participating farmers and help them calculate costs and returns

Four types of farming systems are possible, namely, Extensive (EXTS), Improved Extensive (IES), Intensive (INTS), and Integrated Mangrove-Shrimp (IMS). Hybrid types between EXTS + IES and EXTS + INTS also are possible.

The board game (Figure B.1) involves two water-provisioning canals along which are located 60 shrimp farms of different sizes. Each agent (or player) plays operator of one of those farms with its economic characteristics and specific farm area, and decides on its production system according to its financial possibilities and willingness of the bank to loan money. The farm next to a player's farm can be any type – EXTS, IES, INTS or IMS –and these are identified using stickers of different colors that represent the type of farming system. The game includes farms of different sizes.

B.1.2. Initialization

All farmers start as Extensive farmers, with different farm sizes.

	Board 1 - # players Extensive IMS famers	*Board 2 - # players IES and INT farmers*
Small (1 ha)*	1 to 2	2
Medium (2 ha)	1 to 2	2
Large (4 ha)	1 to 2	2

**participant will be assigned to a farm of a specific land area*

At the start of the game, each farmer will receive:

- An initial amount corresponding to the Crop cost per hectare: 4 mVND/ha (a farmer with 4 ha will receive: 4 x4 = 16 mVND)
- An amount of savings per household; this amount of saving is random and each player (farmer) will roll the two 10-faced dice to calculate his savings (between 2 and 20 mVND per household).

Adding the crop cost and the savings gives the amount of money in the bank account of each player.

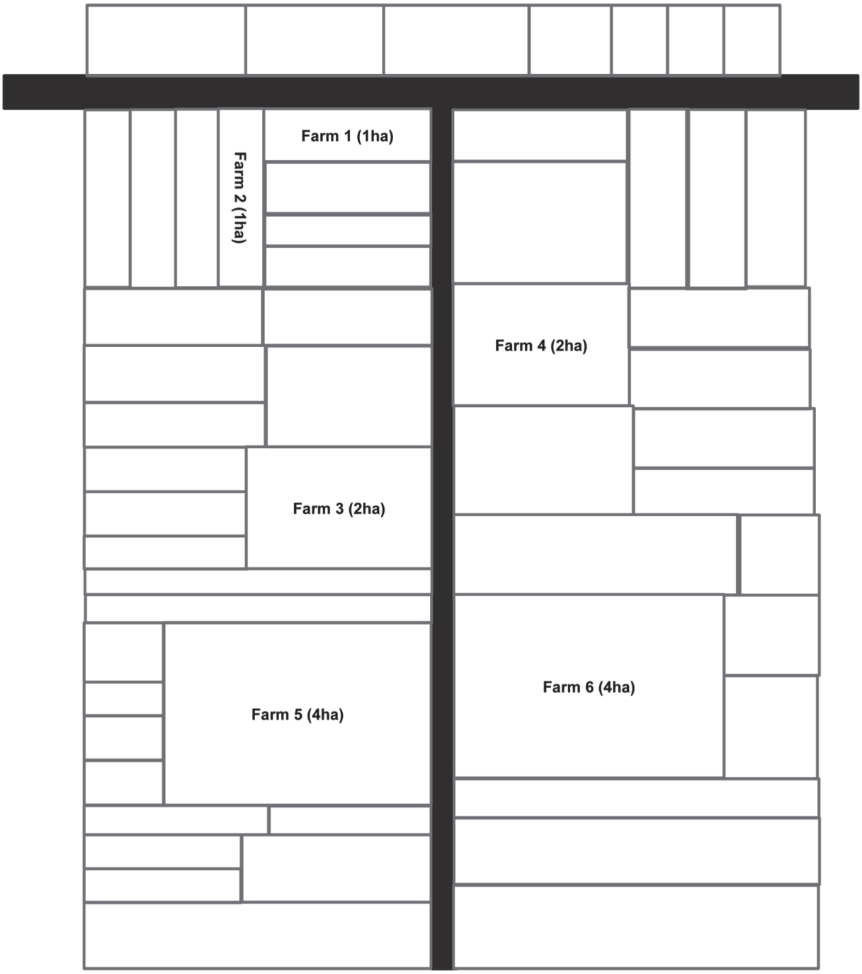

Figure B.1: The board game representing farms surrounded by dikes and gathered around two main canals. The production system followed by each farm is indicated by colored paper, each color representing a different system.

B.1.3. Cycles

1. At the beginning of each cycle, the game master throws the dice to see if there is a virus outbreak in the region. Farmers should not know the results until they make their decision regarding their production system. The risk is about 5%. If the dice throw gives 5% or below, the risk of having a virus in the farmer's pond is increased by 30%. For example, the risk for Extensive farming is normally 16%. In case of a virus outbreak the risk becomes 46%.
2. Each farmer receives the loan he wants to contract. The amount is proportional to the land size (40 mVND /ha).
3. Each farmer decides on the system he wants to follow based on his investment capacity. If a farmer decides to follow a hybrid system, he decides on the area for each production system and indicates it on the board with paper of a specific color (one color is assigned to 1 production system). Based on the farmer's decision, area of each production system (EXTS, IES, INTS, or IMS), land use decision, loan amount, and investment can be recorded on the recording sheet.
4. Each farmer runs the crop:
   - He throws the dice to see if there's a virus effect on his farm (see risk for the different farming systems in Table B.1). The Extensive farmer runs a 16% risk. Dice results of below or equal to 16% = virus; above 16% = no virus.
   - With 'hybrid' farms (farms combining 2 systems, e.g., 1 INT and 1 EXT pond) the risk for virus will be calculated for both systems.
   - Farmer calculates the economic results of the crop based on the economic Net Revenue of each production system. For example, a successfull (no virus) farmer with a 2-ha farm: 1 ha EXT and 1 ha IE will indicated a Net Revenue of 50 + 6 = 56 mVND;
   - He updates his bank account based on results of the crop:
   - He pays the investment if an investment was done in a new system. For example, to convert 1 ha from EXT to IE costs 35 mVND);
   - He decides to pay back or not pay back the loan.

The_Banker/Helper (one member of the Team) will verify and update the bank account of the farmers (Figure B.2). The records of results and farmers' behavior are categorized in the following entries:

1. Amount of loan taken;
2. Initial bank account – bank balance at the beginning of the cycle, after taking out a loan;
3. Farming system decision – shift to another system (partial or entire area), continue or stop operating some ponds;
4. Investment – amount spent on specific production systems
5. Results of the crop;
6. Presence of virus
7. Loan reimbursement.

The process needs to be done with each of the farmers, and 10 cycles should be done as baseline.

B.2. Scenarios Tested

B.2.1. Assessing the influence of neighbors

Intensification along the canal

As game master, reset the game with all the players starting as EXTS, but with 20% of the neighbors as INTS. After each cycle, more and more neighbors are shifting to INTS or IES. Change the color of the neighboring farm from EXTS to IES and INTS (2-3 farms per cycle).

1. Run 10 cycles to see the difference in probability of shifting to IES and INTS compared with the baseline;
2. Discuss the differences with the players and ask: Does the fact that neighbors are intensifying change the decision of the player compared with the baseline?

Figure B.2: Left photo, a farmer calculates his revenue under the supervision of the game master(to his left, standing); right photo, a farmer (2nd from right)throws the dice to test the presence of virus in his pond.

Integrated mangrove-shrimp system

Reset the game with all the players starting as EXTS, but with 20% of the neighbors as IMS. After each cycle, more and more neighbors are shifting to IMS. Change the color of the neighboring farm from EXTS to IMS (2-3 farms per cycle).

1. Run 10 cycles to see the difference in probability to shift to IMS compared to baseline;
2. Discuss the differences with the players and ask: Does the fact that neighbors are shifting to IMS change the decision ofthe player compared with the baseline?

B.2.2. Test scenario for organic shrimp

Reset the game with all the farms being EXT and explain the rules on additional revenue if they shift to IMS with a premium price due to the presence of an Organic value chain (+10% of revenue) and Payment for ecosystem service (0.5 mVND /ha per cycle). Now all the farmers are EXT shrimp farmers, surrounded by EXT neighbors.

1. Run 10 cycles to see the difference in probability to shift to IMS compared with the baseline;
2. Discuss the differences and ask: Does the fact that Organic value chain ad PES are available change the decision of the player compared with the baseline?

B.2.3.Climate change

Reset the game with all the players starting as EXT. Explain the new rules with new economic characteristics. Costs of production are increasing:

- Shrimp price increase by 1.4% per annum;
- EXTS production cost increase 24% by 2020;
- IES production cost will increase 50% by 2020;
- INTS production cost will increase 100% by 2020.

Cost of shifting to INTS and IES will increase due to the higher cost of dike upgrading in 15 years: 86 mVND /ha for IES and INTS.

Virus virulence will increase due to increased temperature, salinity, and climate-related hazards. We assume that the risk of failure for all farmers will increase about 10%.

1. Run 10 cycles;
2. Discuss the differences with the players and ask: Does the fact that cost and risk are increasing change the decision of the player compared with the baseline?

Table B.1:Table of reminders on system characteristics

	Extensive *EXTS*	*Improved Extensive* *IES*	*Intensive* *INTS*	*Integrated Mangrove-Shrimp* *IMS*
Loan	Open – but maximum Threshold : 45 mVND /ha			
Crop cost (mVND /ha)	4	30	200	5
Investment (mVND /ha)		35	150	12
Risk of Virus	16%	40%	50%	10%
Crop Net Revenue Fail (mVND /ha per cycle)	-2	-30	-200	-1
Crop Net Revenue Success (mVND /ha per cycle)	6	50	250	6
Crop Net Revenue Success with Organic certification				7
Economic Threshold to shift (mVND /ha) – Investment		65	350	17

Shifting system: Economic Threshold includes Investment in Equipment and Pond + the Cost of the crop.

Loan can be contracted at the beginning of each cycle only if reimbursed at the end of the previous cycle

Summaries

Summary

Coastal zones support the livelihoods of millions around the world. Deltas especially have undergone rapid transformations in the last decades, with increasing population and an intensification of the uses of natural resources. In South East Asia, a significant driver of change in coastal zones is the spread of shrimp aquaculture. While providing options for economic development, shrimp farming is usually associated with environmental degradation, drives the conversion of mangrove forest into ponds and represents a highly risky and poorly resilient production system for local livelihoods. Risk of disease is an important characteristic of shrimp production systems. Shrimp diseases are numerous and the risk of disease outbreak in ponds cannot be fully controlled by farmers. Disease outbreaks result in economic losses for farmers, sometimes leading to bankruptcy. Outbreaks have the potential of decimating the production of large regions, jeopardizing an entire sector and the local economy.

Various types of shrimp production systems, ranging from intensive to integrated mangrove-shrimp, are found within the coastal zone. Each of these systems has its own specificity regarding economic cost and return, and risk toward disease outbreak and related economic losses. Intensive systems based on technical knowledge, high level of inputs and requiring high investments can provide high and quick returns, but are risky. Extensive systems are less productive, accessible to smallholders and considered risky production systems for farmers. The expansion of both intensive and extensive systems along the coast was possible at the expense of mangrove ecosystems. One type of extensive systems, the integrated mangrove-shrimp system, where 40 % to 60% of the farm area is covered with mangrove, is considered less risky and more resilient than other production systems. Integrated mangrove-shrimp systems can contribute to the restoration of the mangrove cover and its associated ecological functions within the coastal zone.

The combination of the different production systems shape the coastal landscape and influence the future of the shrimp aquaculture sector. The farmers' choice to follow one production system or the other is crucial in planning shrimp aquaculture. It depends on various drivers such as bio-physical characteristics, economic aspects or drivers related to the local or international regulatory framework. Understanding how these drivers influence the decisions of shrimp farmers is a key to planning for the future of the shrimp aquaculture sector.

The overall objective of this thesis is to develop an approach that integrates the decision-making of individual shrimp farmers in a decision support tool to better plan shrimp aquaculture, using Vietnam's Mekong Delta as a case. This objective was translated into 4 research questions: i) What is the extent of the diversity of shrimp farming in the Mekong Delta and how productive are the production systems? ii) Is diversification through brackish water polyculture an effective risk-management strategy for smallholders? iii) What are the drivers for the adoption of diversified and integrated aquaculture practices that restore mangrove cover? iv) Can we integrate farmers' knowledge and decision-making processes into a spatially explicit decision support approach for policy makers to test future aquaculture policies? The study was based on extensive fieldwork in different shrimp farming communities throughout the Mekong Delta and consultations with national and international expert panels to finally produce and test a new approach to investigate future scenarios of shrimp farming that combine modeling and participatory tools with stakeholders.

Chapter 2 contributes to our knowledge of the diversity of shrimp production systems in the Mekong Delta's Bac Lieu Province. Four main production systems are identified: i) intensive commercial; ii) intensive family farms; iii) brackish water polyculture farms and iv) rice-shrimp farms. Intensive farms (both commercial and family-based) are both more productive and more labor-productive than extensive rice-shrimp and brackish polyculture farms. Commercial farms are able to respond to disease risks by investing in technological inputs, meanwhile intensive family farms are most at risk of, and most affected by, disease outbreaks. They are not able to invest in appropriate technology to reduce virus occurrence. Households with limited investment capacity diversify their aquaculture production with other high value aquatic animals or adapt their production system to the local seasonal environment, by developing alternate rice-shrimp systems. The strategy adopted by some farmers to diversify pond production does not minimize the virus risk, but provides different sources of income to the households.

Chapter 3 analyzes farmers' strategies related to diversification to cope with the risk of shrimp farming. The case study in Soc Trang Province show that strategies are linked to the wealth of the aquaculture farmers who employ them. Intensification of the production, with investment in technology, reduces the virus risk; however such strategy is not affordable to medium-income farmers and found only in better-off households. The medium-income farmers do not diversify their production to reduce the risk of virus, but to significantly diversify their income portfolio and cope with income losses due to virus outbreaks within their shrimp production system. Aquaculture production other than shrimp contributes up to 50% of the aquaculture income. This diversification responds to the local market demand for crabs and fish and is enabled by the development of a supply chain of fish and crab juveniles. The juveniles and fingerlings are collected from mud flats and mangrove forest by the poorest households. This diversification strategy is dependent on the mangrove cover and the role of its habitat for crabs and fish. The widespread adoption of this strategy questions the sector's long-term sustainability, in particular as the mangroves are being destroyed

Integrated mangrove-shrimp systems are known to be less risky and more resilient to shocks than other shrimp production systems. However those integrated systems are not widespread and are limited to less than 5,000 ha in the Mekong Delta. In Chapter 4, drivers (both external and internal to the farm) that pressure or coerce farmers to shift from an extensive to an integrated mangrove-shrimp system or to maintain such system are identified from the literature. Two panels of international and Vietnamese experts were consulted to validate this list of drivers and to weight their importance in the farmers' decision whether to shift to an integrated mangrove-shrimp system. Consultations with experts highlighted the importance of the mangrove's ecological function to improve the pond's water quality and reduce the risk of disease outbreak related to the farmers' decision to shift toward integrated systems. On the other hand, the current regulatory framework and value chain's functionality constrain the shift to integrated mangrove-shrimp by limiting its financial profit. The regulatory framework determines a benefit from timber production that is not favorable to farmers while the resulting economic benefit from forest production is low. An organic value chain is present in the Mekong Delta and accessible to integrated mangrove-shrimp farmers that comply with certification standards. However, the current value chain's functioning characterized by delays in payments and limited premium prices do not incentivize farmers to shift to integrated mangrove-shrimp systems. To facilitate the expansion of such a production system, we recommend i) to modify arrangements within the value chain and promote transparent and equitable transactions, ii) identify and amend conflicting regulations for forest exploitation and iii) enable landscape-scale governance of mangrove and shrimp culture.

Chapter 5 proposes a new approach to investigate the tradeoff of shrimp aquaculture scenarios by combining Role Playing Games (RPGs), Agent Based Modeling and Scenario building. This approach is tested in Dam Doi District in the Mekong Delta where a series of consultations and RPGs with farmers supported the development and calibration of an Agent Based Model (ABM). The model was later used with local policy makers to investigate the trade-offs of three different future scenarios for aquaculture by 2030. The results showed that intensification of the production is not sustainable and has a high social cost. Without adequate adaptation measures, climate change will significantly affect aquaculture production with higher disease risk and increased production costs. Tested policies for supporting the spread of integrated mangrove-shrimp systems are not strong enough to influence farmers' decision toward the deployment of integrated systems. The approach used was found to be an interesting strategy to bring local farmers' knowledge to the attention of local decision makers. In addition, farmers described the use of RPG as interesting educational material for them to learn farm and risk management.

In the last chapter (Chapter 6), the main findings of the thesis are discussed in the broader context of shrimp aquaculture development. The shrimp aquaculture sector is analyzed as a complex adaptive system to identify and discuss the implications for future shrimp aquaculture planning. The applicability of the Agent Based Model to other contexts and shrimp producing countries is discussed. This research contributed to the overall knowledge of the shrimp sector in the Mekong Delta, a region among the ones with the highest produced volume in the world. This research provides an overview of technical and socio-economic processes within the sector, focusing on smallholder producers and highlights linkages between aquaculture development and natural resources. This study provided new inputs to the emerging field of complex adaptive systems, and the use and application of Agent Based Models by developing such a model with stakeholders and applying it within a participatory process in a coastal district of the Mekong Delta.

Further research is needed on i) the spatial dimension of mangrove ecosystem services provided by mangrove to aquaculture systems, ii) virus transmission and virulence in order to understand the spatial spread of this disease agents between farms and the risk for on-farm outbreaks. Finally, a future line of research could investigate the benefits of the combination of RPGs and ABM on the farmers' knowledge and management capacity.

Samenvatting

Wereldwijd zijn kustzones de basis van levensonderhoud voor miljoenen mensen. De laatste decennia zijn met name delta's getransformeerd als gevolg van bevolkingstoename en intensiever gebruik van natuurlijke hulpbronnen. De opkomst van garnalen cultuur was en is een belangrijke drijver van deze veranderingen in Zuid Oost Azië. Terwijl het economische ontwikkeling beoogt, gaat de teelt van garnalen gepaard met milieu degradatie ten gevolge van de vernietiging van mangrove bossen en met hoge risico's voor de aantasting van de veerkracht van de lokale bevolking. Het risico op ziekte is groot in vrijwel alle garnalen teelt systemen omdat er veel ziektes zijn en de boeren niet alle risico factoren kunnen beheersen. Ziekte uitbraken leiden tot financiële verliezen voor boeren, soms zelfs tot bankroet, en kunnen de productie van een regio decimeren, en de gehele sector en lokale economie in gevaar brengen.

De productie systemen in de kustzone variëren van intensieve garnalen monocultuur tot gemengde mangrove-garnaal systemen. Elk van deze systemen hebben hun specifieke economische kosten en opbrengsten, en risico's v.w.b. ziekte uitbraken en gerelateerde economische verliezen. Intensieve systemen gebaseerd op technische kennis en een hoog niveau van duurzame en operationele investeringen kunnen snel veel geld opbrengen, maar zijn riskant. Extensieve systemen zijn minder productief, toegankelijk voor kleine boeren en tevens riskant. Zowel de verspreiding van intensieve als extensieve systemen langs de kust ging ten kosten van mangrove ecosystemen. Een type van de extensieve systemen: het gemengde mangrove-garnaal systeem, waarin 40 % tot 60% van het bedrijfsareaal is begroeid met mangrove, is veerkrachtiger en minder riskant dan de andere productie systemen. Gemengde mangrove-garnaal systemen kunnen bijdragen aan het herstel van de mangrove bedekking en de gerelateerde ecologische functies voor de kustzone. De combinatie van de verschillende productie systemen heeft het kustlandschap gevormd en bepaald mede de toekomst van garnalen aquaculture sector. Voor deze toekomst en in de planning van de sector is de keuze van de boeren voor het ene of het andere productie systeem cruciaal. Deze keuze hangt af van verschillende factoren zoals de biofysische karakteristieken, de financiële aspecten, en het lokale of internationale regulerende raamwerk. Begrip van de invloed van deze factoren op de beslissing van de garnalentelers is een sleutel tot een goede planning van deze sector.

Het algemene doel van deze thesis is het ontwikkelen van een nieuwe aanpak die de beslissingen van individuele garnalentelers meeneemt in de planning van de garnalen aquaculture. Het onderzoek gebruikt de Mekong Delta, Vietnam als een case. Dit doel is vertaald in vier onderzoeksvragen:

i) Wat is de diversiteit van de garnalen teelt in de Mekong Delta en hoe productief zijn deze productie systemen?
ii) Is diversificatie door brakwater polycultuur een goede risico management strategie voor kleine boeren?
iii) Wat zijn de factoren die de adoptie stimuleren van gediversifieerde en gemengde aquaculture systemen die de mangrove bedekking bevorderen?
iv) Kunnen we de kennis en het beslissingsproces van boeren meenemen in een ruimtelijk expliciet hulpmiddel dat beleidsmakers kunnen gebruiken om de toekomstige effecten van politieke maatregelen te testen?

Om deze vragen te beantwoorden is uitgebreid veldonderzoek gedaan binnen verschillende gemeenschappen van garnalentelers in drie provincies van de Mekong Delta, en zijn panels van nationale en internationale expert geraadpleegd. Met behulp van de verzamelde gegevens is een nieuw hulpmiddel gemaakt dat modeleren en stakeholders raadpleging combineert. Dit hulpmiddel is getest door middel van het onderzoeken van de effecten van meerdere toekomst scenario's voor de garnalen teelt.

Na de inleiding in hoofdstuk 1, analyseerde hoofdstuk 2 de diversiteit van de garnaal productie systemen in de provincie Bac Lieu. Vier garnaal productie systemen domineerden: i) intensieve commerciële bedrijven, ii) intensieve gezinsbedrijven, iii) brakwater polycultuur en iv) gemengde rijst-garnaal bedrijven. Zowel de intensive commerciële als wel de gezinsbedrijven hebben een hogere opbrengst en een hogere arbeidsproductiviteit dan de extensieve rijst-garnalen en brakwater polycultuur bedrijven. Commerciële bedrijven investeren in nieuwe technologie om het ziekterisico te verminderen terwijl intensieve gezinsbedrijven, die een hoger risico lopen op ziekte uitbraken, deze investeringen niet adequaat kunnen doen. Gezinnen met een nog beperktere investeringscapaciteit kiezen ervoor om hun aquaculture productie te diversifiëren met andere hoogwaardige aquatische producten, of passen zich aan de seizoenen aan door afwisselend rijst en garnalen te produceren. In termen van bedrijfsstrategie betekent deze laatste diversificatie niet het minimaliseren van risico maar het verschaffen van een andere bron van inkomsten aan het gezin.

Hoofdstuk 3 analyseert de bedrijfsstrategieën die door middel van diversificatie proberen om de risico's van de garnaalteelt op te vangen. Het bedrijfsonderzoek in de provincie Soc Trang toonde aan dat de strategie van een garnalenteler afhangt van hun kapitaalkracht. Intensivering van de garnaalproductie door middel van technologie wordt gedaan door de meer welvarende gezinnen en verminderd het risico op ziektes ten gevolge van virussen. Gezinnen met een gemiddeld inkomen kunnen zich de intensivering van de productie doormiddel van technologie niet veroorloven. Deze laatsten verminderen het risico en ondervangen het verlies aan inkomen door hun inkomensbronnen van de aquacultuur te diversifiëren. Andere aquaculture producten dan garnaal dragen 50% bij aan het inkomen uit de aquaculture. Deze diversiering beantwoord tevens aan de lokale vraag naar krabben, schelpdieren en vis en is mogelijk dankzij de ontwikkeling van de bevoorrading van juveniele vis en krab. Deze laatsten worden verzameld op de modderplaten en in de mangrove bossen door de armere gezinnen. Deze strategie van diversiering is afhankelijk van het habitat die mangrove bossen bieden aan vissen, schaal- en schelpdieren. De duurzaamheid van deze strategie wordt ondermijnd door de vernietiging van de mangrove bossen.

Gemengde mangrove-garnaal systemen zijn minder riskant en hebben een betere veerkracht dan andere garnalen productie systemen. Echter deze gemengde systemen zijn niet wijdverspreid en hun areaal in de Mekong Delta is minder dan 5,000 ha. Hoofdstuk 4, beschrijft de factoren binnen en buiten het bedrijf die boeren stimuleren om te veranderen van een extensief naar de gemengd bedrijfssysteem of om hiermee door te gaan. Internationale en Vietnamese experts werden geraadpleegd om deze factoren te valideren en om het belang hiervan in de beslissing van boeren te wegen. De oordelen van de expertpanels benadrukken het belang van de ecologische rol van mangrove bossen bij het verbeteren van de waterkwaliteit in de vijvers en voor het verminderen van ziekte risico's, bij de beslissing van boeren om te switchen naar een dergelijk gemengde systemen. Daarnaast beperkt het huidige raamwerk van regelingen en het functioneren van de keten het financiële gewin en dus de switch naar gemengde mangrove-garnaal systemen. De huidige regeling rondom het beheer en de exploitatie van de mangrove resulteren in een lage winst van de houtproductie voor de boeren. Onder bepaalde voorwaarden kunnen deze gemengde bedrijven een biologische certificering krijgen, maar de huidige organisatie van deze keten resulteren in afroming en late betaling van de prijspremie door de andere ketenpartijen. Voor het bevorderen van deze gemengde productie systemen bevelen wij aan om i) de regels binnen de biologische garnalen keten aan te passen zodat de prijspremie transparant en gelijkwaardig verdeeld wordt, ii) het beheer van de mangrove bossen en de garnaal bedrijven op landschapsniveau te bevorderen, en iii) de tegenstrijdige bepalingen voor hout exploitatie te wijzigen.

Hoofdstuk 5 presenteert een methode van planning die rollenspellen en een "Agent Based" Model (ABM) combineert om de effecten te schatten van bepaalde scenario's van de ontwikkeling van garnalenteelt. Deze methode is getest in Dam Doi district in de provincie Ca Mau. Een serie raadplegingen van, en rollenspellen met boeren ondersteunde de ontwikkeling en kalibratie van het ABM. Daarna werd het model gebruikt met lokale beleidsmakers om de na- en voordelen van drie toekomst scenario's voor aquaculture tot 2030 te analyseren. De resultaten laten zien dat intensivering van de garnalen teelt niet duurzaam is en hoge sociale kosten heeft. Zonder adaptatie zal klimaat verandering de productie van de aquaculture aantasten ten gevolge van hogere ziekte risico's en productie kosten. De geteste beleidsmaatregelen om de gemengde mangrove-garnaal systemen te bevorderen zijn niet sterk genoeg om de boeren te overtuigen van het belang van een verandering.

De gebruikte methoden waren nuttig om de kennis en meningen van lokale boeren onder de aandacht te brengen van lokale beleidsmakers. Bovendien erkenden de boeren dat rollenspellen hen inzichten verschafte in de gevolgen (risico's) van bedrijfs-management. Rollenspellen kunnen dus van belang zijn voor de educatie van boeren.

Het laatste hoofdstuk (6) bediscussieerd de belangrijkste bevindingen van de thesis in een bredere context. Als eerste analyseer ik de ontwikkeling van garnalen aquaculture als een complex adaptief system, en identificeer en bediscussieer de implicaties voor de planning van de garnalen aquaculture. Daarna bediscussieer ik de toepassing van het ABM in andere contexten en andere garnaal producerende landen.

Het onderzoek gepresenteerd in deze thesis draagt bij aan de kennis van de garnaalsector in de Mekong Delta, die één van de grotere bijdragers is aan de wereld garnalen productie. De thesis geeft een overzicht van de technische en socio-economische processen in de sector vooral voor kleine boeren en de relatie van de ontwikkeling van de sector met de natuurlijke hulpbronnen. Deze studie geeft nieuwe inzichten in het opkomende onderzoeksveld van complexe adaptieve systemen, en in het gebruik van ABM door het ontwikkelen hiervan in overleg met de stakeholders en het toepassen in een participatief proces voor een district in de kustzone van de Mekong Delta.

Het is aan te bevelen om verder onderzoek te doen naar (i) de ruimtelijke dimensie van de ecosysteem diensten van mangrove van belang voor de aquaculture, en (ii) de virus transmissie en virulentie, om de verspreiding van het ziektes tussen bedrijven en de risico's op ziekte uitbraken op gemengde bedrijven beter te in te schatten. Tenslotte is het van belang onderzoek te doen naar (iii) de effecten van het gebruik van rollenspellen en van de combinatie van rollenspellen en ABM op de kennis en management van boeren.

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About the author

Olivier Joffre was born in Marseille (France), on the 28th of October 1975. He attended high school in Aix en Provence before obtaining a Bachelor's degree in biology from Université de Provence (Marseille) in 1995. He moved to Montpellier to pursue undergraduate studies (Licence and Maitrise) in Cellular Biology and Physiology at Montpelier II University. In 1997-1998 he completed a Master's of Agronomic Sciences degree, with a specialization in Modeling and Systemic Approach which was concluded by an internship at CIRAD (Montpellier, France) to research roots and bacteria interactions for nitrogen fixation in beans. After this experience, he specialized in Rural Development in Tropical Countries with a Master of Tropical Rural Development at the Ecole Superieure d'Agronomie Tropicale (ESAT, currently IRC) and was conferred the title of 'Ingenieur Agronome' (Agronomist) in 2000. Throughout his career, he carried out several research projects in developing countries, with a first internship in the Philippines (1999) with the Peri-urban Vegetable Project, and later with the DELTAS project in Vietnam's Mekong Delta in 2000. This was his first encounter with Vietnamese culture, the Mekong Delta and shrimp farming.

After graduation, Olivier managed a rural development project in Northeast Burundi for Action Contre la Faim. In 2005, he became a consultant for WorldFish focusing on Bangladesh and Vietnam's Mekong Delta. Olivier has since continued to work on aquaculture development and coastal zone management in the Mekong Delta holding several posts with different organizations (GiZ, USAID or WorldFish). Since 2008, he has been based in Phnom Penh, Cambodia, where he conducts research and provides technical expertise to development projects on fisheries, aquaculture and rural development within the Lower Mekong Basins (Vietnam, Cambodia, Lao PDR and Myanmar) commissioned by multilateral and bilateral organizations (FAO, UNOPS, GiZ USAID) and research institutes (WorldFish, IWMI). In 2012, Oliver started a PhD program at Wageningen University within the Aquaculture and Fishery Group, while pursuing his career as an independent consultant in the Mekong Region.

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