Institut für Lebensmittel- und Ressourcenökonomik

Drivers of change, adaptation and resilience of agricultural systems facing increased salinity intrusion in deltaic coastal areas of Vietnam

Dissertation

zur

Erlangung des Grades

Doktor der Agrarwissenschaften (Dr. agr.)

der Landwirtschaftlichen Fakultät

der Rheinischen Friedrich-Wilhelms-Universität Bonn

von

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aus

Vinh Long, Vietnam

Bonn 2019

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Tag der mündlichen Prüfung: 11.02.2019

Augefertigt mit Genehmigung der Landwirtschaftlichen Fakultät der Universität Bonn

ACKNOWLEDGEMENT

First of all, I would like to thank my supervisors at United Nations University-Institute for Environment and Human Security (UNU-EHS), Prof. Fabrice Renaud and Dr. Zita Sebesvari. They are the main "Driver of Change" of my intellectual growth during the last four years. I am grateful for their continued guidance and support, their patience, and a lot of time they spent on reading and commenting on my writing. I also wish to thank my first supervisor at the University of Bonn, Prof. Karin Holm-Müller, for her scientific advice and encouragement throughout my PhD. I express my gratitude to my field supervisor, Dr. Nguyen Duy Can, for his administrative support and sharing knowledge on the research areas.

I am grateful to the financial support from the Federal Ministry of Education and Research (BMBF), Germany through the Sustainable Adaptation of Coastal Agro-ecosystems to Increased Salinity Intrusion (DeltAdapt) project and Prof. Wulf Amelung for his coordination of the project. I am indebted to farmers and authorities in the research areas who have spent their time to participate and share their thinking and knowledge with me. I wish to thank the research partners in Vietnam, Prof. Guong, Dr. Khoi, Dr. Vien, Mr. Khanh and the soil group at Can Tho University, and Dr. An and Mrs. Van at Vietnam National University of Agriculture for their support during my time in the field. I would also like to thank my two enumerators, Thuy An and Kim Ngan, for their excellent work. I express special thanks to Dr. Linh, Dr. Binh and Dr. Tuan for their valuable advice on my research. I am grateful to Maria for introducing me this PhD project and for her encouragement and support during my PhD.

I have a big thank to my friends and colleagues at UNU-EHS who made my last four years not only research work but full of smiles and fun. I wish to thank my colleagues at the EVES (Environmental Vulnerability & Ecosystem Services) section for a lot of fun time with food, drinks, and "babyfoot". I express my special thanks to Nga, Hoai, Aju, Sari, Gianna, Carl, and many others for the knowledge exchange and the time together at the 27th-floor of the UN building. I would also like to thank my Vietnamese friends in Bonn and Köln for the food and time we shared together.

Finally, I would like to thank my family and Mai Anh for their love and support.

ABSTRACT

This PhD research aimed to examine historical and present drivers of agricultural changes in the Mekong (MKD) and Red River (RRD) deltas in Vietnam since 1975 as well as explore adaptation pathways and resilience of agricultural systems facing increased salinity intrusion in these deltas. The research ultimately used the lens of complex adaptive systems theory to examine interactions and feedbacks in agricultural systems and their drivers of change at multiple levels in deltaic social-ecological systems. In addition, this study applied an adaptation pathway approach to identify various adaptation options and potential lock-ins in agricultural systems and the subjective resilience assessment method to quantify the resilience of agricultural systems in these deltas. Currently, the RRD is protected from salinity intrusion by a concrete sea dyke and sluicegate system. In the MKD, salinity is naturally happening as it is a tide-dominated delta and there are fewer protective structures in place. Case study research was carried out in villages located along salinity gradients in the MKD, and at different distances to sea dykes in the RRD in Vietnam. Empirical data consisted of 27 in-depth interviews with officials of local and national authorities as well as 11 focus group discussions, 198 semi-structured interviews, 226 structured-interviews and 3 role-playing games conducted with farmers in both deltas in 2015-2016.

This study reveals that agricultural systems in the RRD and MKD since the end year of the war in 1975 have experienced considerable changes. The analysis of drivers of change and adaptation pathways shows that a dynamic interplay and feedback of various drivers of change such as policy intervention, farmers' desire for profit maximization, changing salinity conditions, and technological development at different levels of the deltaic social-ecological system have shaped the changes and adaptations in agricultural systems over the last decades. In response to increased salinity intrusion, as exemplified by the highest salinity levels in 90 years which were recorded in the MKD in 2015-2016, various adaptation options have been considered. These include adaptations that would lock-in agricultural production in particular agricultural systems or constrain changes in others, potentially problematic in light of the high uncertainty related to future changes. The study recognizes the need to apply both incremental and transformative changes and select adaptation pathways which allow for continuous change or that are reversible in order to avoid lock-ins and address future challenges.

In addition, this study implemented a subjective resilience assessment method based on farmers' perception of the three resilience components i) the sensitivity of their agricultural

systems to increased salinity intrusion, ii) the capacity to recover from salinity damage, and iii) the capacity to change to other systems if salinity increases in the future. Results from the subjective resilience assessment reveal that none of the agricultural systems received a higher score than the others when considering all three resilience components, implying that an increase in one resilience component by switching agricultural systems would negatively impact others. Improving resilience components (e.g. through policies and interventions, resource allocation and farming system changes) to sustain agricultural production or facilitate transformation to alternative systems when necessary is critically important for agricultural systems facing stress. For a methodological implication, this research emphasizes the need to complement subjective resilience assessment with qualitative data to enhance understandings of drivers of resilience in order to improve components of resilience for agricultural systems in the respective deltas.

In summary, attention should be drawn to interactions and feedbacks in future changes within and across adaptation pathways as well as trade-offs involved in farming system shifts regarding resilience components. Consideration of this could contribute to preventing further increases in salinity intrusion and lock-in effects in agricultural systems in the deltas.

KURZFASSUNG

Das Ziel der Arbeit ist historische und gegenwärtige Treiber für den Wandel der Landwirtschaft im Mekong Delta (MKD) und Red River Delta (RRD) in Vietnam zu identifizieren. Weiterhin sollen Anpassungspfade und die Widerstandsfähigkeit der landwirtschaftlichen Systeme im Hinblick auf die zunehmende Salzanreicherung in den beiden Deltas untersucht werden.

Die Forschung baut auf der komplexen, adaptiven Systemtheorie auf, um Wechselwirkungen und Rückkopplungen in landwirtschaftlichen Systemen zu untersuchen. Der Ansatz zielt darauf ab, ein besseres Verständnis der Treiber des Systemwandels auf mehreren Ebenen im sozial-ökologischen System der Deltaregionen zu erreichen. Darüber hinaus hat diese Studie einen Anpassungspfad-Ansatz angewandt, um verschiedene Anpassungsoptionen und mögliche „*Lock-ins*“ in landwirtschaftlichen Systemen zu identifizieren sowie die Methode der subjektiven Resilienzbewertung verwendet, um die Widerstandsfähigkeit von landwirtschaftlichen Systemen in diesen Deltas zu quantifizieren. Derzeit ist das RRD durch einen Deich und ein Schleusensystem vor dem Eindringen von Salzgehalt geschützt. Im MKD tritt der Salzgehalt natürlich auf, da es sich um ein von den Gezeiten dominiertes Delta handelt und es weniger Schutzstrukturen gibt. Im MKD wurden empirische Erhebungen entlang von Salzgehaltsgradienten durchgeführt. Im RRD lag der Fokus darin, den Einfluss von Deichen auf die landwirtschaftliche Entwicklung zu untersuchen. Die empirischen Daten wurden in den Jahren 2015-2016 erhoben und setzen sich zusammen aus 27 Interviews mit Vertretern von regionalen und überregionalen Behörden, elf Fokusgruppen-Diskussionen, 198 *semi*-strukturierten Interviews, 226 strukturierten Interviews sowie den Auswertungen von Rollenspielen mit Landwirten.

Die Ergebnisse der Studie zeigen, dass sich die landwirtschaftlichen Systeme im RRD und im MKD seit dem Kriegsende 1975 erheblich verändert haben. Die Analyse der Treiber von Veränderungs- und Anpassungspfaden zeigt, dass ein dynamisches Zusammenspiel von verschiedenen Faktoren wie Politikintervention, Gewinnmaximierung der Landwirte, veränderte Salzgehalte und technologische Entwicklung in den letzten Jahrzehnten den Wandel und die Anpassung der landwirtschaftlichen System geprägt haben. Als Reaktion auf die zunehmende Versalzung, wie die seit 90 Jahren in 2015-2016 höchsten gemessenen Salzgehalte im MKD zeigen, wurden verschiedene Anpassungsoptionen in Betracht gezogen. Dazu gehören Anpassungen, die die landwirtschaftliche Produktion in bestimmten

Agrarsystemen einschränken oder Veränderungen in anderen Systemen unterbinden. Angesichts der hohen Unsicherheit im Zusammenhang mit künftigen Veränderungen könnte dies problematisch sein.

Die Studie erkennt die Notwendigkeit an, sowohl inkrementelle als auch transformative Veränderungen vorzunehmen und Anpassungspfade zu wählen, die kontinuierliche Veränderungen ermöglichen oder reversibel sind, um „*Lock-ins*“ zu vermeiden und zukünftige Herausforderungen anzugehen. Darüber hinaus führte diese Studie eine subjektive Methode zur Bewertung der Widerstandsfähigkeit ein, welche basierend auf der Wahrnehmung der Landwirte die drei Komponenten von Widerstandsfähigkeit einschätzt: i) die Sensitivität ihrer landwirtschaftlichen Systeme gegenüber einem erhöhten Salzgehalt, ii) die Fähigkeit sich von den Schäden durch Versalzung zu erholen und iii) die Fähigkeit auf andere Systeme umzusteigen, wenn der Salzgehalt in der Zukunft weiter ansteigen wird. Die Ergebnisse der subjektiven Bewertung von Widerstandsfähigkeit zeigen, dass keines der landwirtschaftlichen Systeme bei der Betrachtung aller drei Komponenten eine höhere Bewertung erhielt als die anderen. Dies zeigt, dass die Erhöhung der Widerstandsfähigkeit gemessen an einer Komponente, beispielsweise durch einen Wechsel der landwirtschaftlichen Systeme, andere Komponenten negativ beeinflussen würde. Die Erhöhung der Widerstandsfähigkeit im Hinblick auf die drei Komponenten (z.B. durch politische Maßnahmen und Interventionen, der gezielte Einsatz von Ressourcen oder Änderungen der Anbausysteme), ist für landwirtschaftliche Systeme, die unter Stress durch Versalzung leiden, von entscheidender Bedeutung, um die Produktion aufrechtzuerhalten oder bei Bedarf die Umstellung auf alternative Systeme zu erleichtern. Die Ergänzung der subjektiven Bewertung der Widerstandsfähigkeit mit qualitativen Daten ist daher entscheidend für das Verständnis der Treiber von Widerstandsfähigkeit, um die Komponenten der Widerstandsfähigkeit für landwirtschaftliche Systeme in den jeweiligen Deltas zu verbessern.

Zusammenfassend ist darauf hinzuweisen, dass Wechselwirkungen und Rückkopplungen bei künftigen Veränderungen innerhalb und zwischen den Anpassungspfaden sowie Kompromisse hinsichtlich der Komponenten der Widerstandsfähigkeit zu berücksichtigen sind. Dies könnte dazu beitragen, eine weitere Erhöhung des Salzgehalts und „*Lock-in*“ Effekte in landwirtschaftlichen Systemen in den Deltas zu verhindern.

TABLE OF CONTENT

ABBREVIATIONS

CAS	Complex Adaptive Systems
DARD	Department of Agriculture and Rural Development
DONRE	Department of Natural Resources and Environment
DPSIR	Driver-Pressure-State-Impact-Response Framework
FGD	Focus Group Discussion
IPAT	Impacts = Population x Affluence x Technology
MA	Millennium Ecosystem Assessment Framework
MARD	Ministry of Agriculture and Rural Development
MKD	Mekong Delta
MONRE	Ministry of Natural Resources and Environment
OARD	Office of Agriculture and Rural Development
ONRE	Office of Natural Resources and Environment
PC	People's Committee
PRA	Participatory Rural Appraisal
RPG	Role-Playing Game
RRD	Red River Delta
SLA	Sustainable Livelihood Framework
VND	Viet Nam Dong (currency)

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

1.1 Research background and rationale

During the dry season of 2015-2016, a severe drought and salinity intrusion struck the Mekong Delta (MKD) in Vietnam. The event was the most severe drought and salinity intrusion in the delta in 90 years. At the end of the event in July 2016, an estimated 244,805 ha of rice of the MKD had been damaged or lost (UNDP, 2016), while 11 out of 13 provinces in the delta had to declare the state of emergency. The event sparked a debate in the media about the reconsideration of salinity intrusion as only a negative hazard and the role of alternative production systems (e.g. brackish aquaculture instead of rice production) in adapting to increased salinity intrusion. As a result of a fall in rice production area after the event and these activities, the national government adjusted the rice area to be maintained at the national level from 3.81 million ha to 3.76 million ha and allowed the conversion of 400,000 ha of rice to aquaculture or upland crops, given that this area could be converted later to rice land (GoV, 2016a). More than one year after the hazard event, a big conference on sustainable and climate-resilient development for the MKD was organized in September 2017, chaired by the national government and comprising various parties from the ministries, local agencies, scientist and international organizations. One of the central ideas that emerged was that sea level rise in general and salinity intrusion in particular is one of the primary threats for agricultural production in the coastal zone of the MKD and strategic, long-term adaptation planning to salinity intrusion is needed (GoV, 2017).

The MKD in the South, together with the Red River Delta (RRD) in the North, are the two largest deltas of Vietnam. These deltaic areas are typically characterized by a dense network of natural and man-made rivers and canals that provide a foundation for diverse agricultural activities (Minh et al., 2010; Tri, 2012). The two deltas play an important role in ensuring food security of the country and beyond, given that these deltas together contribute to 71.2% of the rice, 86.3% of the farmed aquaculture and 64.7% of the fruit production of Vietnam (GSO, 2015; MARD, 2013), as well as the country shares 10.5% of the global rice export quantity in 2013 (FAOSTAT, 2013). Nevertheless, the increase of sea level rise is posing a major threat to agricultural production in these deltas since both the MKD and RRD are low-lying coastal areas (Syvitski and Saito, 2007) and are experiencing subsidence (Dang et al., 2014; Syvitski et al., 2009). Combined with projected sea level rises, these coastal deltas are

some of the most vulnerable deltas globally (Carew-Reid, 2008; Dasgupta et al., 2007). In the coastal areas of these deltas, increasing salinity gradients into freshwater systems that are partly induced by sea level rise threaten agricultural production (Renaud et al., 2015; Wassmann et al., 2004; Yen et al., 2016). During the dry season corresponding to the low flow period of the rivers, the tidal cycles from the sea typically bring salt water further inland through a dense network of rivers and canals (Pruszak et al., 2005; Tuan et al., 2007). In the wet season, increased river flows and rainfall can significantly limit the intrusion of salt water further inland (Minh et al., 2010; Smajgl et al., 2015). Although salinity intrusion is a natural process in the MKD and RRD, the rising sea levels and land subsidence would accelerate the impact of salinity intrusion on agricultural systems in the coastal zones of these deltas (Carew-Reid, 2008; MONRE, 2016; Syvitski et al., 2009).

Among the two deltas, the increased salinity intrusion could impact the MKD more seriously than the RRD due to a tide-dominated environment, a low elevation of the coastal zone and fewer protective infrastructures in place (Pruszak et al., 2005; Renaud and Kuenzer, 2012). In the MKD, salt water could intrude far inland and impact a large area of 2.1 million ha during the dry season (Tuan et al., 2007). In the coastal areas of the RRD, salinity intrusion is controlled by a system of concrete sea and river dykes, sluicegates, and irrigation systems. Nevertheless, salinity intrusion through sluicegate leakage and infiltration of salt water through sea dykes also causes reduction of rice yield and difficulty for irrigation due to a shift of intake gates farther upstream (Dat et al., 2014; Yen et al., 2016).

In the MKD and RRD, biophysical factors such as soil and water systems and agriculture-based livelihoods have co-evolved within dynamic changing conditions (Stewart and Coclanis, 2011; Tessier, 2011). In order to maintain agricultural production in the deltas, various adaptation measures to salinity intrusion have been implemented. The construction of protective infrastructures such as dykes and sluicegates to limit the duration and areas of salinity intrusion for rice cultivation are currently the principal adaptation strategies of the government (GoV, 2012a; Smajgl et al., 2015). Other measures consist in the implementation of adaptive farming techniques such as salt-tolerant crop varieties, adjustment of cropping calendars, and shifting land use patterns to allow agricultural systems adapting to the changing salinity conditions (Aizawa et al., 2009; Minh et al., 2010; Nhan et al., 2010).

Together with the changes in biophysical conditions, agricultural systems in these deltas have evolved with fundamental shifts in the socio-economic and political systems intensively since

Doi Moi (economic and political renovation starting in 1986). The shift from planned to collective and finally to a market-oriented economy with increased liberalization and integration in the global market has brought about major changes in agricultural systems (Sanh et al., 1998; Ut and Kei, 2006). The Doi Moi was widely recognized as the major factor that brought Vietnam from a rice importer country in the early 1980s to the second world rice exporter by 1997 (Käkönen, 2008). The wider and vibrant social-economic and political transformations since Doi Moi are also primary drivers of agricultural changes in the coastal zones of these deltas (van Dijk et al., 2013).

In land use science, the causing mechanisms of land use changes have been predominantly explained by the single-cause mechanisms (Lambin et al., 2001). This simplistic approach does not solve many complex problems related to the complexities of interconnections and feedbacks in land use changes as well as future uncertainty and inevitable changes in land use systems (Bennett et al., 2014). Changes in land use such as in agriculture are influenced by multiple drivers of change and their linkages are sometimes nonlinear and spatially and temporally separated (Berkes et al., 2003a; Geist and Lambin, 2002). Drivers of change would operate diffusely from the systems of analysis and their influence on the agricultural systems by altering one or more local driving factors is hard to establish using the single and linear approach (Millennium Ecosystem Assessment, 2005). Given these complexities, land use in general and agricultural systems in particular are increasingly considered as complex adaptive systems (CAS) which are influenced by multiple drivers of change at different levels of the social-ecological systems, co-evolved with the outside environment and governed by the interaction and feedback between these systems (Lambin et al., 2001).

While improved data availability and models could enhance the projection of land use development, the non-linear relationship between land use changes and their causal mechanisms as well as the emergence of new drivers of change and regime shifts make land use projection and adaptation planning highly uncertain (Mueller et al., 2014). A new approach to adaptation planning has emerged recently that frames a set of future adaptation options as adaptation pathways (Barnett et al., 2014; Butler et al., 2014; Fazey et al., 2015; Haasnoot et al., 2013; Wise et al., 2014). This pathway approach illustrates future adaptation as various adaption options and a sequence of each action over time regarding the capacity to reverse or switch to other measures once the existing action is no longer effective (Haasnoot et al., 2013). This capacity to reverse or switch to other systems could help to prevent the

development of lock-in situations that keep the system in a certain system state (van Staveren and van Tatenhove, 2016). This PhD research therefore aimed to apply the concept of complex adaptive system and adaptation pathway approach for identifying drivers of agricultural changes and adaptation options to salinity intrusion in the MKD and RRD since the end year of the war in 1975.

The complex adaptive system and pathway approaches are closely associated with the concept of social-ecological resilience with relation to alternative system states, threshold and lock-in effects in social-ecological systems. In agricultural systems, the resilience thinking has provided a new insight and approach to the conventional perspective of agricultural management by emphasizing the need to maintain a diversity of future options to adapt to inevitable and often unpredictable changes (Bennett et al., 2014; Walker et al., 2010). Understanding agricultural systems as complex adaptive systems underscores that future changes and uncertainty are inevitable and the systems need to adapt to these constantly changing conditions (Rammel et al., 2007). At the moment, agricultural systems in the RRD and MKD are considerably changing due to the dynamic changing conditions at multiple levels of the deltaic social-ecological systems. The responses of agricultural systems to increased salinity intrusion and various social-economic drivers of change would result in different farming systems. Some of these development pathways in agricultural systems would lock-in specific areas of the deltas in particular production systems due to a difficulty to reverse or constraining further shifts to alternative systems. Thus it is important to examine the resilience to increased salinity intrusion of agricultural systems in the deltas to inform these changes and prevent the development of "path-dependencies".

Resilience concept has been applied in various disciplines of studies and development programs, yet different approaches to operationalize and measure the concept are still being developed (Quinlan et al., 2015). Subjective measurements have been popularly applied to quantify the cognitive aspects of individuals such as well-being, perception and preferences (Armitage et al., 2012; UNEP, 2003), yet the application of subjective measurement of resilience is only now being tested (Clare et al., 2017; Jones and Tanner, 2016; Kien and James, 2013). This study contributes to this ongoing work of operationalizing the resilience concept by implementing a subjective resilience assessment method based on farmers' self-assessment on the sensitivity of their agricultural systems to increased salinity intrusion and

the capacities of the systems to recover after salinity damage and change to alternative systems in the future.

In summary, this PhD research aimed to analyze the historical and present drivers of agricultural changes in the coastal areas of the MKD and RRD since 1975 as well as explore adaptation pathways and resilience of agricultural systems facing increased salinity intrusion in these deltas. The research was undertaken under the framework of the project "Sustainable adaptation of coastal agro-ecosystems to increased salinity intrusion" (DeltAdapt). One of the main goals of this project - of which this PhD research is a part – aimed to explore the drivers and consequences of socio-ecological changes in the coastal areas of the RRD and MKD in the context of increased salinity levels. At present, several salinity-control infrastructures such as sluicegates and sea dykes are to be implemented in the RRD and MKD (GoV, 2012b; Mekong Delta Plan, 2013). Adapting agricultural systems in these deltas to changing salinity conditions requires understanding of the implications from past decisions (Käkönen, 2008). The analyses of historical and present changes in agricultural systems therefore would provide important insights for land use planning and future adaptations. For the MKD, the potential impact of large-scale protective infrastructures planned in this delta would also be inferred from alterations in agricultural systems in the RRD. The analysis of drivers of agricultural changes and adaptation pathways as well as the examination of the resilience of farming systems in the context of increased salinity intrusion thus aimed to provide insights for the management of agricultural systems and land use planning in these and similar coastal deltas. The application of new ways for analyzing drivers of change and adaptation as well as testing of new and alternative resilience assessment methods is important for theoretical and methodological implications as well.

1.2 Research objectives and questions

The objectives of this study are to (1) identify historical and present agricultural changes and their drivers in the RRD and MKD since 1975 through the lens of complex adaptive systems, (2) explore multiple adaptation pathways of agricultural systems to various drivers of change and increased salinity intrusion regarding their potential lock-in effects, and (3) assess the resilience of different agricultural systems facing increased salinity intrusion in the deltas. Detailed questions are formulated as follows in order to guide the research.

i. What were the changes in agricultural systems in the coastal areas of the RRD and MKD since 1975? What were the socio-economic, political and environmental drivers of changes in agricultural practices and how are these changes and drivers operationalized within the complex adaptive system framework?
ii. How can agricultural systems in the deltas adapt to future varying key drivers of change? What are possible adaption pathways of agricultural systems to changing salinity conditions?
iii. How resilient are different agricultural systems that are facing increased salinity intrusion in the coastal zones of the RRD and MKD? How can the resilience concept be operationalized using the subjective resilience assessment method?

1.3 Research boundaries and foci of the dissertation

The research focuses on the analysis of agricultural changes manifested at the local level in the MKD and RRD but accounts for multiple drivers at different levels of the deltaic social-ecological systems. The regional focus of this research is in the agrarian rural areas of the coastal zones in the RRD and MKD which are being exposed to salinity intrusion. The selection of the research areas aimed to capture the heterogeneity of agro-ecosystems and various degrees of salinity intrusion, as well as to explore the diversity of drivers of agricultural changes and multiple potential responses of agricultural systems to these drivers. Three case research areas were located in the coastal zones of both deltas in different agro-ecological zones along the salinity transects in the MKD and at different distances to the sea dykes in the RRD.

1.4 Structure of the dissertation

The dissertation is organized as follows. After this introduction, the next chapter presents the theoretical and conceptual background of the research, including the research concepts, approaches in measuring and assessing the resilience, as well as approaches in analysis of drivers of social-ecological changes and the conceptual framework of the dissertation. The third chapter describes the methodology of the research, consisting of a short introduction of the research sites, the methods applied, the sampling approach and data collection, as well as data analysis. The next chapters present and discuss the main findings of the dissertation, including the context of biophysical and agricultural changes in the deltas (Chapter 4), the role of the state in agricultural changes in the two deltas since 1975 (Chapter 5), a detailed

examination of drivers of agricultural changes and adaptation pathways of agricultural systems to changing key drivers of change and salinity intrusion (Chapter 6), and results from the assessment of resilience of different farming systems (Chapter 7). The last chapter (Chapter 8) highlights the main findings of the dissertation and offers policy recommendations and research outlook.

2. THEORETICAL AND CONCEPTUAL BACKGROUND

2.1 Research concepts

2.1.1 The concept of risk

Risk is a multifaceted concept that has been defined differently amongst disciplines. The concept is commonly described as a function of probability and exposure to losses or a function of hazards and vulnerability (Thywissen, 2006). The first definition of risk focuses solely on the hazards such as the magnitude and frequencies of the events and their potential impacts (Birkmann et al., 2009). This definition thus neglects the social construction of risks and the influence of the pre-conditions of the system or places such as poverty, infrastructure and governance on the loss and damage (Thywissen, 2006). Other scholars (Birkmann et al., 2013; Brooks et al., 2005; Gallopín, 2006; IPCC, 2014, 2012; Turner II et al., 2003) therefore incorporate the notion of vulnerability that comprises not only the components of exposures and sensitivity but also adaptive capacity into risk and hazard analysis. This latter perspective addresses both the social and ecological dimensions of risk and explains why some hazard events turn into disasters for specific areas or particular groups of people, and not for others. From a political-ecology viewpoint, Wisner et al., 2003 explain multiple root causes of being at risk through the lens of diverging social-economic and political conditions, for instance, a lack of access to resources and unequal resource distribution among socio-economic groups. Changes in root causes such as poverty, population growth, and economic restructuring etc. place dynamic pressures differently on certain groups of people that could mediate and transform into unsafe conditions. Once the hazards happen, the social groups that are put in the unsafe situations are most vulnerable to the event effects (Wisner et al., 2003). This explanation is in line with the predominant approach in risk and safety management that separates the risk management into different phases, including the pre-event actions, in-time of crisis management, and post-hazard activities (Birkmann et al., 2013; UN-ISDR, 2015).

Many studies address the risk in the context of natural hazards, yet limited studies consider both technical or natural and societal risk aspects (Schwab et al., 2016). In a broad sense, risks and hazard events could take any forms and can be generated by both biophysical and social processes and also by their interaction and feedbacks (UN-ISDR, 2004). In this study, salinity intrusion is considered as a kind of slow-onset hazards which can generate risks to people in coastal areas (Binh, 2013). These hazard-related risks could be in the direct form of crop

losses, or the degradation of household's adaptive capacity over time due to chronic salinity damage (Binh, 2015). Käkönen (2008) and Miller (2003) argue that salinity intrusion in the MKD, apart from the risk it poses, also offers an opportunity for changes since it allows local farmers shifting from inefficient land use to more profitable farming systems e.g. conversion of double rice in salinity affected areas to upland crops and brackish aquaculture. Risk reduction, in this context, is not the sole driver to take actions in agricultural systems, but also the motivation to take benefits from this chronic hazard. Salinity risks and the pressures and opportunities they created, in this context, act as internal and external driving forces of adaptation in agricultural systems that are interplayed with other pressures. In this study, both risks induced by salinity intrusion and alterations in social and ecological transformation were analyzed as the drivers/motivation of changes and adaptation in agricultural systems.

2.1.2 Coupled social-ecological systems

Social-ecological system is an emerging concept that has been popularly applied in the fields of resilience, vulnerability, robustness, and adaptation (Cumming, 2011). Gallopín et al. (2001) define social-ecological systems as complex systems that comprise both societal and ecological factors in mutual interactions ranging from the household to the planet scales. Berkes & Folke (1998) consider social-ecological systems as nested, multilevel systems in which the social and ecological sub-systems are highly interrelated. In the same manner, Cumming (2011) defines social-ecological systems as fully integrated and complex systems between nature and people. Turner et al. (2003) use the concept of human-environment systems to illustrate the coupled social-ecological systems and their interaction, including the response capacity and systems of feedback to the hazards. Similarly, coupled human and natural systems are defined by Liu et al. (2007) as systems in which the human and natural components interact through reciprocal effects and feedback of spatial and temporal couplings.

The analyses of drivers of change, adaptation and resilience of agricultural systems facing increased salinity intrusion in this research are undertaken within the context of coupled social-ecological systems. Lambin et al. (2001) argue that land-use change processes occur at the interface between human and environmental systems, interacting with both of these systems and with each other by feedbacks, synergistic effects, and other system processes. Recent studies in integrated assessment and comprehensive analysis of environmental problems (Alcamo et al., 2001; Ostrom et al., 2012; Reynolds et al., 2003) have also shown

that assessing drivers of environmental changes demands a multi-scale and multidimensional assessment of the dynamic and interaction of both social and ecological components of the system. Agricultural changes in the MKD and RRD over the last decades have indeed been influenced by various biophysical and social drivers at multiple levels of the deltaic social-ecological systems (Hanh, 2013; Miller, 2014; Renaud et al., 2015). It is thus of particular importance to address the drivers of agricultural changes in the RRD and MKD from both social and ecological perspectives. The definition of Berkes & Folke (1998) is used in this study that the social-ecological system is defined as a nested and multilevel of the coupled social-ecological sub-systems in which the two components are mutually interactive, linked and dependent on each other.

2.1.3 Drivers of change in social-ecological systems

Several typologies of drivers of change have been defined by scholars in the field of social-ecological systems. The Millennium Ecosystem Assessment (MA) defines drivers as any natural or human-induced factors that directly or indirectly cause a change in an ecosystem (Millennium Ecosystem Assessment, 2005). Direct or internal drivers are driving forces that operationalized at the local levels and could be identified and measured through a direct observation of the analyzed systems. Indirect or external drivers, in contrast, are referred to as distal factors at macro levels that influence the ecosystem through direct drivers and could be identified through understanding its effects on the direct drivers (Millennium Ecosystem Assessment, 2005).

Some scholars categorize drivers into proximate and underlying causes that are similar to the concept of direct and indirect drivers (Geist and Lambin, 2002; Lambin et al., 2003). In studying the causes of deforestation in tropical regions, Geist & Lambin (2002) classify causing mechanisms into underlying drivers such as demographic, economic, technological, institutional and policy, and cultural drivers; while other drivers operationalized at the local scale such as infrastructure extension, agricultural expansion, wood extraction are considered as proximate drivers of these changes (Geist et al., 2006). Some scholars further divide the underlying forces into human driving forces and human mitigating forces (Moser, 1996; Turner, 1989). In these classifications, human driving forces are macro drivers such as global environmental changes or factors associated with the human-nature link. These drivers include population and technological changes as well as socio-cultural and socio-economic organizations. Human mitigating forces are drivers that are released as responses to human

driving forces in order to modify or counteract to human driving forces such as regulation, market adjustments, technological innovations, and informal social regulations such as norms and values (Moser, 1996; Turner, 1989).

One of the key issues in the analysis of drivers of change is the consideration of temporal and spatial operation scales of drivers and their cross-scale interaction (Millennium Ecosystem Assessment, 2005). The spatial scales of drivers can be categorized into local, sub-national, national, regional and global scales, while the temporal scale could be classified as very slow, slow, medium, and fast scales (Petschel-Held and Bohensky, 2005). The driving forces at macro scales may change slowly, while the drivers at lower scales would fluctuate rapidly (Walker et al., 2012). It is widely assumed that the drivers at higher scales of the system can impact and cause changes in the slower ones (Britton, 2007; Walker et al., 2012). Nayak & Berkes (2012), however, argue that changes at lower scales could also affect the higher ones, for instance, drivers at the local system can cascade to the national and international levels and cause changes at the higher levels. In the same manner, Pelling (2011) argues that in the field of climate change adaptation, local actions may be potential drivers for policy at the higher level. At a certain point in time and place, some driving forces may dominate each other and cause significant changes in the whole system (Gallopín et al., 1997).

The definition of drivers of change in this research has followed the typology of Millennium Ecosystem Assessment (Millennium Ecosystem Assessment, 2005) that defines drivers of change as any social or environmental factors that cause a change in an ecosystem since this definition can be used in a possible broadest sense.

2.1.4 Adaptation, transformation and adaptation pathways in social-ecological systems

Adaptive capacity, with its manifestation adaptation, is a term from the field of evolutionary biology that illustrates the ability of species to cope with changing environmental conditions to survive and reproduce (Smit and Wandel, 2006). In the social-ecological field, adaptation is applied in a broad sense to represent adjustments in response to/preparation for not only climatic stressors but internal processes such as changes in demography, economics and organizations to moderate harm and exploit beneficial opportunities (IPCC, 2007). Nevertheless, adaptation is not necessary to create a positive outcome and some adaptations may turn into maladaptation or influence adaptation of other social-economic groups or places (Adger and Vincent, 2004; Snorek et al., 2014). Adaptation, in some cases, for example

intensification of production or specification in one resource input in response to growing external pressures, could also degrade the natural capital and reduce the redundancy of potential responses that would erode the system's resilience and adaptive capacity in the longer run (Bennett et al., 2014; Walker et al., 2006).

Adaptation studies commonly address specific questions based on the anatomy "adaptation of what to what", for example, what systems need to adapt to what drivers of change, who or what to adapt, how the adaptation occurred, and how good is the adaptation (Schwab, 2014; Smit et al., 1999). Since the adaptive capacity is socially differentiated (Birkmann, 2011), understanding who can adapt and who cannot, why and how much to adapt, what are the barriers and limits of adaptation for particular groups or geographic areas, and different outcomes of adaptation between various socio-economic groups are increasingly gaining traction in adaptation research. In the field of climate change adaptation, adaptation could be classified into various groups as follows.

Table 2.1. Classification of adaptation in climate change research

Criteria	Classification	References
By actors	Formal (government) and informal (household), public and private adaptation	Birkmann et al., 2010; World Bank, 2010
By form	Structural and non-structural measures, hard and soft measures, coping and adaptation*	McElwee et al., 2010; Turner II et al., 2003
By outcome	Impact and change, risk transfer and risk reduction, adaptation and maladaptation	Birkmann, 2011; Grothmann and Patt, 2005; IPCC, 2007
By spatial scope	Global and local adaptation	Smit et al., 1999
By timing	Reactive (response to) and anticipatory (prepared for)	IPCC, 2012; Nelson et al., 2007; Smit and Wandel, 2006
By both temporal and spatial scope	First and second-ordered adaptation	Birkmann, 2011
By purposes	Autonomous and planned; risk reduction and opportunity seeking	Fankhauser et al., 1999; IPCC, 2012
By process	Adaptation transition and adaptive management	Pelling, 2011; Reed et al., 2013

By degree of adaptation	Resilience/transition/transformation; how much to adapt and cost of each adaptation degree	Pelling, 2011; World Bank, 2010

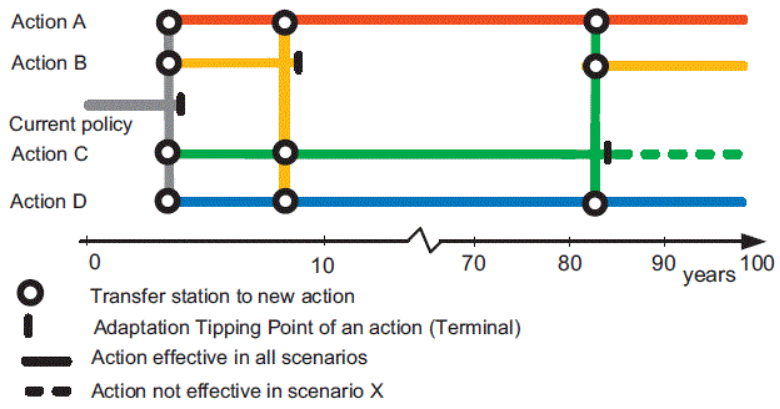
* *Coping and adaptation could also be distinguished by timing* (IPCC, 2012). *Coping refers to short-time actions to maintain the status quo under perturbation, for instance, immediate responses or management of resources after salinity damage to keep the system in place, while adaptation is long-term measures to improve the conditions/change the status quo in response to/prepare for external pressures, even before severe impacts are felt (based on Schwab, 2014; Smit and Wandel, 2006).*

Adaptation is widely considered as a process rather than a single action to achieve a final outcome. Adaptive actions are learning processes and are shaped by both climatic factors and societal issues such as behaviors, norm, and values (Adger, 2016; Reed et al., 2013). According to Pelling (2011), adaptation takes place to enable resilience, transition or transformation of the system. Adaptation, in this case, is an umbrella concept to explain the purposes and degrees of change that adaptation creates. In this point of view, transformation is one pathway of adaptation, apart from resistance and incremental adjustment (Pelling et al., 2015). In resilience literature, there have been calls for a distinction between adaptation and transformation concepts (Wilson and Pearson, 2015). It is argued that adaptation in principle aimed to incrementally change the current systems in order to stay and continue within the same development trajectories, while transformation is profound changes to shift the system into a new qualitative state with different structures and feedbacks (Olsson et al., 2014).

In complex adaptive agricultural systems, the temporal and spatial complexity of the system and a diversity of adaptation options that farmers consider when responding to external drivers are important because more options in terms of responses enhance the adaptive capacity of the systems to future changes (Folke et al., 2004; Gallopín, 2006). These sets of adaptation options have been increasingly framed in the metaphor of adaptation pathways – a decision-oriented planning approach that considers adaptation as a continuous learning process rather than a single action in time (Barnett et al., 2014; Haasnoot et al., 2013). The adaptation pathway approach identifies various adaptation options to drivers of change, their interconnections, and a sequence of each action over time within a wider social-ecological context (Haasnoot, 2013; Wise et al., 2014). A decision-making process based on the pathway approach allows for the identification of potential lock-ins that enable the continuous adaptation of actions to address future changes (Haasnoot et al., 2013). In agricultural

systems, changes and adaptation can navigate the systems along various adaptation pathways allowing possibly for shifts to other systems or to path-dependency that locks the system in specific configurations (Bennett et al., 2014). In addition, adaptations in one pathway could potentially influence changes in other agricultural systems due to the interactions and feedbacks between the systems (Kinzig et al., 2006). In this regard, today's adaptation measures to increased salinity intrusion and changing drivers in agricultural systems are critical not only to maintain agricultural production in the deltas but also should allow for future change and transformation (Pelling, 2011) in order to grasp potential emergent opportunities (Haasnoot, 2013; Schwab, 2014). This study therefore qualitatively examines possible adaptation pathways of the agricultural systems in these deltas with regard to potential lock-in effects.

(a)



(b)

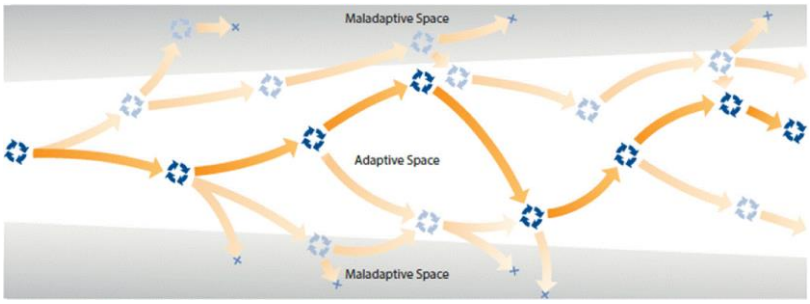


Fig. 2.1. Adaptation pathways with various signposts (a) for shifting to other alternative actions once the existing action is no longer effective (Haasnoot et al., 2013), and adaptive area for adaptation planning (b) (Wise et al., 2014)

2.1.5 Resilience, "path-dependency", and regime shifts in social-ecological systems

Resilience is a concept that has emerged and is being developed from/into various academic disciplines with different meanings and understandings (Alexander, 2013; Folke, 2016). The three predominant perspectives of resilience include engineering resilience, ecological resilience, and social-ecological resilience. The first resilience perspective considers a system to be static and assumes that it should "bounce back" to a steady state condition once the disturbance/perturbation is removed or overcome, for instance, the capacity of an agro-ecosystem or a critical infrastructure to return to its original state after disturbances (Schwab et al., 2016). In ecological and social-ecological resilience, the systems are considered to have multiple basins of attractions and the systems could switch from one functional state to another (Folke, 2016). The capacity to withstand shocks and recover after the perturbations before moving into an alternative state with different structures and feedback is considered as the ecological resilience of the system (Walker et al., 2004). Social-ecological resilience is not only the capacity of the systems to buffer and bounce back but more importantly, the ability to learn from change and create new desirable development pathways under disturbances (Folke, 2016). In this study, resilience is defined as the sensitivity of agricultural systems to increased salinity intrusion and the capacities of the systems to recover from salinity damage and to change to alternative farming systems if salinity intrusion increases before severe impacts are felt (this definition is based on Bennett et al., 2014; Darnhofer, 2014). These three resilience components cover the three core properties of social-ecological resilience. The two first components, the sensitivity to increased salinity intrusion and capacity to change capture the first resilience perspective as capacity of the system to bounce back. The last component, the capacity to change, illustrates the capacity of the system to change and transform to better deal with future challenges (Folke, 2016) (for a detailed explanation of resilience definition in this study, see Chapter 7).

Social-ecological resilience is considered as a progressive and dynamic changing status rather than a final outcome (Folke, 2016). The concept therefore strongly focuses on the adaptive capacity of an ecosystem to deal with changes and uncertainties. The adaptive cycle (Fig. 2.2) introduced by Holling (1986) has been popularly used to understand the dynamic changes of a complex system and its resilience. This adaptive cycle conceptualizes changes as ongoing processes comprising four distinct phases: growth or exploitation (r), conservation (K), collapse or release (Ω), and reorganization (α) (Darnhofer et al., 2016). The fore-loop from

growth to conservation is slow, while the back-loop phase from release to re-organization is fast. These adaptive cycles occur and repeat continually and are connected with a set of nested hierarchical cycles across time and space, which represents a panarchy (Allen et al., 2014). The resilience of the social-ecological system and the form of the adaptive cycles are determined by the cross-scale interaction of slowly changing variables (e.g. climate, nutrients, cultural tradition) and fast-changing variables such as market prices or climatic variation (Folke, 2006).

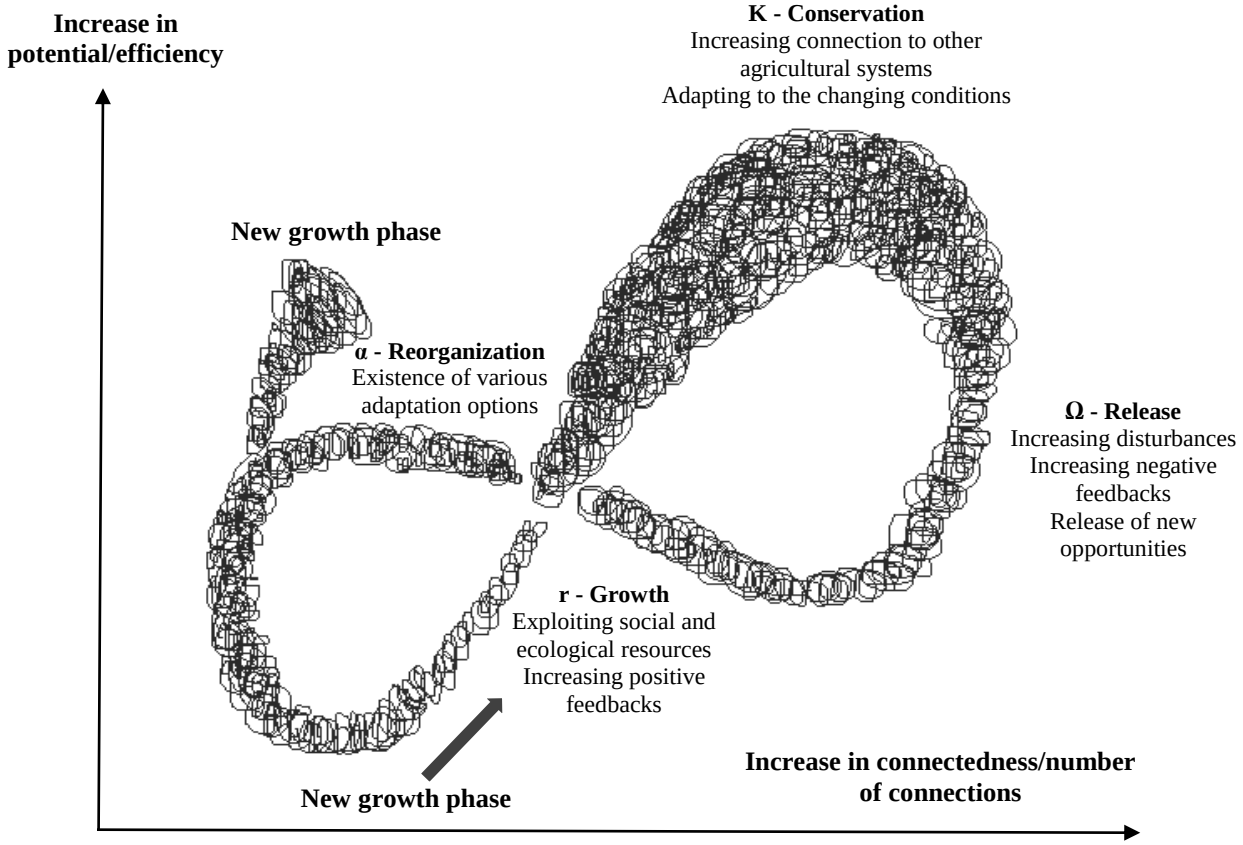


Fig. 2.2. An illustration of complex adaptive cycles (based on Berkes et al., 2003; Darnhofer et al., 2016)

During the first phase from growth to conservation, connectedness and stability are increased and the capital of biomass and nutrients are accumulated. After a long time of growth and conservation, changes increase and the system could (i) reorganize and remain in the same state, or (ii) shift to another regime by changing the feedback loops or scales of the dominant operating processes, but the basin variables are still within the same domain, or (iii) transform

to another new system in which the state variables, feedbacks, and processes are totally different (Abel et al., 2006). The concept of adaptive cycles can help to understand interactions and changes in social-ecological systems of which the changes in the small scale could cascade to the bigger scales, and the large and slow components of the higher hierarchical cycles provide the memory of the past to allow the recovery and reorganizations of smaller and faster ones (Kinzig et al., 2006).

In social-ecological resilience, a system can possess multiple equilibriums, or basin of attractions, which determine their "stability landscape" (Gallopín, 2006). The regime shift (Fig. 2.3) is one common forms of the non-linear relationship in the complex adaptive system, in which the system reorganizes into a new system with different structure and function associated with switching of dominant feedbacks when the controlling variables pass a threshold termed tipping point. This change may be triggered by external abrupt, large shocks or by the accumulation of shocks that overwhelm the dominant feedbacks (Mueller et al., 2014). The prediction of a regime shift is difficult since the system may show little changes before the regime shift (Scheffer et al., 2009). Renaud et al. (2010) convey that in the social-ecological system, the threshold would be passed if the system lost their capacity to learn and adapt. The authors suggest that various tipping points should be considered for the social and ecological systems since the social system's components may start to reorganize even the capacity of the ecosystem to provide essential services has not yet totally degraded. In this context, regime shifts in social systems and institutional structures could be induced by "swift change, wide-spread impact, discontinuity'' or by "slow and gradual change, related to lock-in and path dependency" (Garschagen and Kraas, 2011).

From the governance perspective, Walker et al. (2010) argue that when a system is trapped in an undesirable regime and the recovery and configuration to a new system are not possible; then it is necessary to transform the system into a new state with different structures and feedbacks. In the same manner, Garschagen (2011) argues that societal components, for examples, participation, networks, leadership and multilayered institutions could navigate the adaptive cycles and resilience's trajectories into desirable states through pro-active adaptations. The author suggests the need to supplement the adaptive cycle with an additional phase of "precautionary reorganization" that leapfrogs the phase of collapse and undesirable state (Garschagen, 2011). This modified adaptive cycle therefore skips the phase of release of material and resources to go directly into the next phase. This adaptive cycle thus only

happens in certain complex, connected systems of which memory and transfer of knowledge and materials from other scales could provide sufficient matters for reorganization and learning.

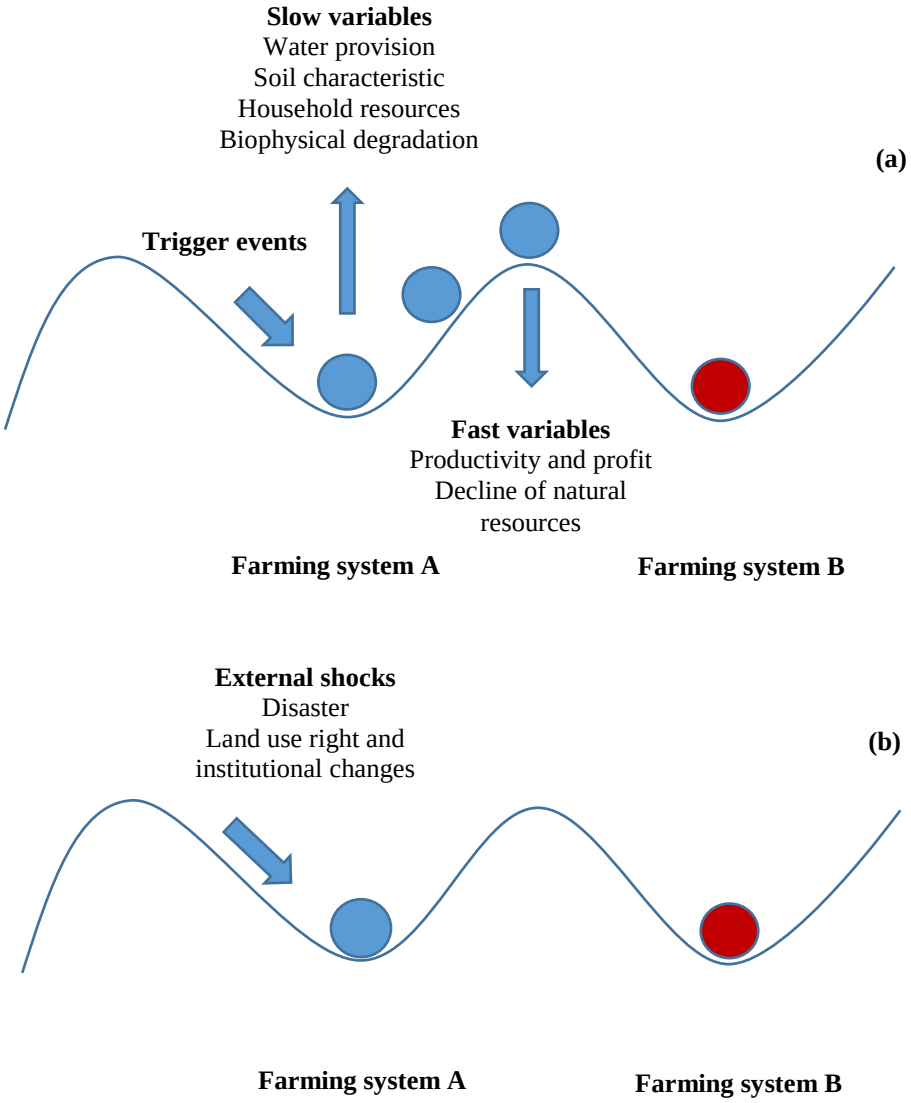


Fig. 2.3. An illustration of regime shifts in land use systems – the state of each land use system is represented by a ball operating within a valley (a "stability landscape", or regime). A regime shift takes place when the system changes into another state with different interactions and feedback (basin of attraction) (illustration based on Mueller et al., 2014)

2.2 Approaches in measuring and assessing resilience

Resilience has become the background and objective for a wide range of studies and development programs, yet ways to operationalize it as a measurable concept are still being developed (Quinlan et al., 2015). In operationalization of the resilience concept, the measurements focus substantially on the use of objective indicators (FSIN 2014, Jones and Tanner 2016). In these measurements, resilience is deconstructed into components or capacities (Ciani and Romano 2014, FAO 2014, FSIN 2014). Social-economic and environmental indicators such as household characteristics, access to loans and social networks, and soil and water characteristics that are assigned to these components or capacities are then obtained and aggregated to construct a resilience index (FSIN 2014). Researchers therefore have to understand factors that characterize the resilience of these systems (Clare et al., 2017). One limitation of this approach is that if the indices are constructed based on these predefined social-ecological characteristics, the discussion and conclusion are likely to follow these initial indicators (Levine, 2014). While qualitative approaches can explore issues that the researchers have not expected, the objective indicator approaches can only quantify what researchers knew about the systems, for instance, after a literature review or pre-test of the questionnaires (Bernard, 2000; Jones and Tanner, 2016). Therefore, these approaches are widely considered as subject to manipulation and circular argument bias since it limits the understanding of which characteristics influence resilience apart from the socio-economic and environmental factors that are used to construct the indexes themselves (Béné, 2013; Clare et al., 2017; Jones and Tanner, 2016). The approach is also difficult to compare across case studies since farmers at particular places and times can rely on different resources to build resilience (Béné, 2013). Other alternatives and complementary approaches to objective resilience measurement such as the quantification of the cost of anticipation, impact and recovery under shocks (Béné, 2013), or the subjective measurements of resilience based on respondents' perception (Clare et al., 2017; Jones and Tanner, 2016; Kien and James, 2013) are being developed. These approaches do not use the direct social-economic and environmental characteristics of the measured units to construct the resilience indexes and can therefore more readily inform on which factors influence resilience (Clare et al., 2017). This study applied the subjective assessment approach to quantify resilience based on the premise that farmers themselves are in the best position to understand the factors that influence the sensitivity and ability to recover and change of their

farming systems, as well as their capacities to influence these resilience components (Jones and Tanner, 2016).

Both subjective and objective measurements of resilience run the risk of a limited system understanding through the collection of what can be easily measured and the simplification of a multidimensional concept into few single indexes (Levine, 2014; Quinlan et al., 2015). There are suggestions that resilience cannot be directly observed and a qualitative assessment of resilience is more useful (Carpenter et al., 2005; Cumming et al., 2005). Resilience can be assessed through the historical profiling of a specific place over time to understand its system dynamics and how it evolved and responded to changes, as illustrated in the practical guides of the well-known Resilience Assessment Workbook (Resilience Alliance, 2010, 2007). This approach requires a comprehensive analysis of the variables that determine the system's functions, as well as cross-scale interactions and feedbacks between the focal scale and other connected systems above and below the focal scale. Alternative approaches are based on the development of local surrogates which are considered resilience-building blocks (see Table 2.2 for a summary of these resilience-building blocks) to assess resilience indirectly (Berkes and Seixas, 2005; Marschke and Berkes, 2006). Qualitative assessments can capture some aspects of a system's resilience that are difficult to quantify such as culture, well-being or social cohesion of households and communities (Maxwell et al., 2015; Quinlan et al., 2015). Against this background, our research supplemented a subjective resilience assessment based on 5-point Likert scales to measure farmers' perception of the resilience components of their systems with qualitative data, allowing for a more holistic understanding of resilience. The complementarity of quantitative measurement with a qualitative assessment of resilience is crucial since it allows for a deep understanding of system dynamics, especially for issues that are embedded in the wider spatial-temporal complexities (Frankenberger and Nelson, 2013; Quinlan et al., 2015). A system-wide analysis for resilience assessment can provide insights into the operation of the systems under stresses and its changes, as well as for understanding the social-ecological settings that should help dictate the management of these complex systems (Biggs et al., 2012).

Table 2.2. Summary of major criteria for resilience assessment

Criteria/Resilience-building blocks	Main themes	References	Examples of local surrogates relevant to resilience of farming systems in the deltas*
Nurture capacity to change and transform to deal with future challenges	Learning	- Learning and experimentation (Biggs et al., 2012)/Learning to live with change and uncertainty (Folke, 2006)/Encourage learning and experimentation (Biggs et al., 2012)/Reflective and shared learning (Cabel and Oelofse, 2012)/Combining different types of knowledge for learning (Folke, 2006)/Learning (Walker et al., 2006)	1) Regulation framework for changing to other systems 2) Rapid response of the farming system to external drivers of change e.g. market prices 3) Rapid adaptation of the farming system to changing salinity levels 4) Potential development of new pathways
	Transformation	- Recognize windows for transformation (Anderies et al., 2006)/Transformation (Walker et al., 2006)/Addressing transformations to global sustainability (Sellberg et al., 2016)	
	Governance	- Embrace adaptive governance (Anderies et al., 2006)//Promote polycentric governance systems (Biggs et al., 2012)	
	Self-organization	- Socially self-organized/Ecologically self-regulated (Cabel and Oelofse, 2012)/Creating opportunity for self-organization towards social-ecological sustainability (Folke, C., Colding, J, and Berkes, 2003)	
	Others	- Innovation variables that relate to the development of novel solutions and responses to change (Cumming et al., 2005)/Broaden participation (Biggs et al., 2012)	
Maintain diversity and redundancy	Diversity	- Maintain diversity and redundancy (Biggs et al., 2012)/Nurturing diversity for resilience (Folke, 2006)/Manage for diversity (Anderies et al., 2006)/Manage for as many potential configurations of social-ecological systems as possible (Anderies et al., 2006)	5) Diversity of adaptation strategies to increased salinity intrusion 6) Diversity of development pathways in response to external drivers of change 7) Income diversification
	Functional redundancy	- Functional and response diversity; Spatial and temporal heterogeneity (Cabel and Oelofse, 2012)/Functional and response diversity (Walker et al., 2006)	
Foster integrated social-ecological systems and complex adaptive systems thinking	Connectivity and interactions	- Manage connectivity (Biggs et al., 2012)/Manage at multiple scales as much as possible (Anderies et al., 2006)/Cross-scale interactions (Walker et al., 2006)/Relationships process or interaction variables that link components (Cumming et al., 2005)/Appropriately connected/Coupled with local natural capital (Cabel and Oelofse, 2012)	8) Close connection with the rivers and canals/Maintain the provision of ecosystem services 9) Reservation of landscape

	Domains and components	- Foster and understanding of social-ecological systems as complex adaptive systems (Biggs et al., 2012; Sellberg et al., 2016)/Ecological vs. social domains (Walker et al., 2006)/Components, objects, agents, entities that make up the system (Cumming et al., 2005)	10) Potential ecological degradation e.g. soil salinization 11) Influence on other farming systems e.g. salinity leakage, interlocking effects
	Slow, fast variables and feedback	- Manage slow variables and feedbacks (Biggs et al., 2012)/Attend to slow variables (Anderies et al., 2006)/Fast and slow variables (Walker et al., 2006)	
	Others	- Recognize that vulnerability cannot be eliminated (Anderies et al., 2006)/Globally autonomous and locally interdependent (Cabel and Oelofse, 2012)/Continuity variables that maintain identity through space and time (Cumming et al., 2005)	
Use of traditional ecological knowledge and social capital	Mental models	- Understand underlying mental models (Anderies et al., 2006)/Mental models (Walker et al., 2006)	12) Use of traditional farming knowledge
	Social capital and safety nets	- Builds human capital (Cabel and Oelofse, 2012)/Social safety net (FSIN, 2014)	13) Social safety nets and mutual help 14) Existence of active cooperatives 15) Low degree of income stratification 16) Historical experience and memory of local people on the farming system 17) Existence of formal support networks e.g. loans, training, farmers' associations, subsidization
Exposure to perturbations and prepare for damage	Exposure	- Exposed to disturbance (Cabel and Oelofse, 2012)	18) Salinity tolerance level of the farming system 19) Exposures to salinity intrusion 20) Access to salinity information

** The local surrogates could be ranked (e.g. based on expert assessment, group discussions, literature review of relevant studies) on the scale: 0 (No observe), 1 (Observe), 2 (Strongly observe) as Marschke and Berkes (2006). The aggregation of the scores of ranking may be applied if necessary.*

2.3 Classical and linear approaches in analysis of drivers of social-ecological changes

For a long time, the reasons for environmental change such as alterations of land use and land cover have been explained by the single and linear causing mechanisms such as population growth that go along the principals of Ricardian and Malthusian theories (Lambin et al., 2001). In the Malthusian theory, population growth is the most important driver of land use changes, both for land use intensification and expansion. This theory considers that each parcel of land possesses a certain capacity to produce food (which increases linearly) and thus can carry a certain population (that grows geometrically) (Lambin, 2012). The Ricardian viewpoint added to the theory of Malthusian that while population growth and land limitation are barriers to agricultural development, this can also bring marginal land into uses since the prices of land use increase (Lambin, 2012). When land is abundant, the most productive land will be used first, leading to land expansion. As population increases and land becomes scarce, the intensification of land use such as increase of labor and input uses will lead to diminishing returns. The optimization view along the theory of Ricardo defines that given a parcel of land, the landowner manages the land to have the highest return. This theory can identify various policy measures on the land allocation choices, yet analyze the land within an isolated marketplace and does not examine the process of land use changes such as intensification and the differences in land use types between urban and rural contexts (Rasmussen, 2013). In contrast to the Malthusian's view, the Boserup's theory focuses on the role of population growth in stimulating technology development and social-economic advances (Rasmussen, 2013). Nevertheless, Lambin et al., (2000) argue that this theory defines land use changes as a "continuum agricultural intensity" and therefore, is difficult to apply for local cases and projection of land use development.

Over the time, more single-cause explanations of environmental change were added such as religion (White, 1967), common property institutions (Mccay and Jentoft, 1998), and capitalism and colonialism (O'Connor, 1988). The IPAT identity (Impacts = Population x Affluence x Technology) that has emerged since the 1970s is one of the first attempts to address drivers of environmental change in a multi-dimensional perspective (Millennium Ecosystem Assessment, 2005). The IPAT formulation is based on the idea that population (P), affluence (A), and technology (T) cause an impact (or change, I) on the environment. Within IPAT, there are multiple human drivers of environmental change in which their effects are multiplicative, drivers are interrelated, and that assessing the impact of these drivers requires

both theory and empirical evidence (Millennium Ecosystem Assessment, 2005). The IPAT identity provides a framework for analyzing driving forces of ecosystem changes and has been widely adopted and refined by many scholars on studies of environmental impact (Dietz and Rosa, 1994; Waggoner and Ausubel, 2002; York et al., 2003). However, the IPAT has also been criticized as too simplistic since the formulation does not take into account the interdependency among its components. This identity is also considered as insufficient for understanding the complex nature of driving forces and their interconnection in ecosystem changes (Lambin et al., 2001).

For those above reasons, calls for research approaches that capture both the socio-economic and biophysical drivers at the local context as well as recognize the role of macro drivers at the global level in environmental change have emerged (Lambin et al., 2001). Several frameworks have been developed and applied to trace the root causes of ecosystem changes through systematic approaches, notably the Driver-Pressure-State-Impact-Response (DPSIR) Framework, the Millennium Ecosystem Assessment (MA) Framework, the Drivers of Change Framework, and the Sustainable Livelihood Framework (SLA) (Table 2.3).

Table 2.3. Summary of conceptual frameworks explicitly addressed drivers of social-ecological changes

Conceptual framework	Content	References
IPAT formulation	Population (P), affluence (A), and technology (T) cause an impact (or change, I)	Waggoner and Ausubel, 2002; York et al., 2003
Driver-Pressure-State-Impact-Response (DPSIR) framework	Driving forces create pressures that impact the states of the systems and lead to responses	Maxim et al., 2009; Ribbe et al., 2013
Millennium Ecosystem Assessment (MA) framework	Direct and indirect drivers cause changes in the ecosystems and then human well-being	UNEP, 2003; Yang et al., 2013
Drivers of Change framework	Institutional settings influence and structure the changes	DFID, 2005
Sustainable livelihood framework (SLA)	An actor-oriented approach; livelihood endowments and context influence livelihood strategies	de Haan, 2012; Ha, 2012; Reed et al., 2013

The DPSIR framework (Fig. 2.4) was developed by the European Environmental Agency (EEA) based on the Pressure-State-Response (PSR) model of OECD (1996) and can offer an operational platform for studying the impact of drivers of change on coupled social-ecological systems. The DPSIR framework is based on an idea that driving forces create pressures on the environment that impact the state of an ecosystem and then cause changes in the system. The conceptual framework is a causal chain, closed loop and illustrates different interconnections between its components. This framework has been widely applied in the analysis of landscape change and river basin and coastal management (Holman et al., 2005; Karageorgis et al., 2006; La Jeunesse et al., 2003), as well as adopted by several organizations in integrated research programs and assessments (EEA, 2005; OECD, 2003; UNEP, 2002).

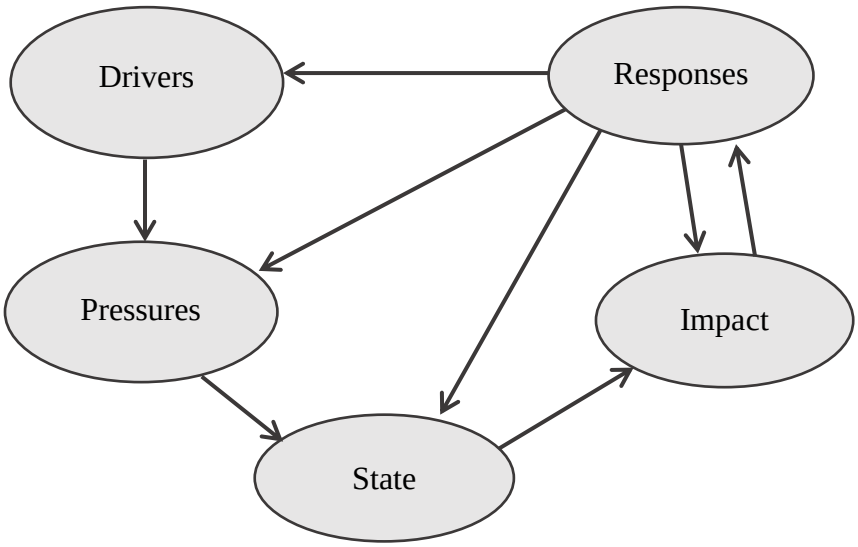


Fig. 2.4. Driver-Pressure-State-Impact-Response (DPSIR) Framework (Source: EEA, 1999)

Although the DPSIR framework is useful in bringing the social and natural fields into the analysis, it has been criticized for lack of support for communicating among researchers in interdisciplinary fields and between researchers and policymakers (Svarstad et al., 2008). There has been called to make a clear definition and provide specific information in five categories of the framework to support policymakers (Maxim et al., 2009). The framework is also considered as simplistic since the ecosystem is far more complex than the only causal and linear relationship, and that the interconnection between categories should be emphasized to

understand their dynamics (EEA, 1999; Maxim et al., 2009). Moreover, the DPSIR framework does not conceptualize the feedback loops and interrelations between indicators in each category (Benini et al., 2010). Another challenge of the DPSIR framework is to distinguish between drivers and pressures indicators. Reis et al. (2012) thus define the drivers as distal drivers, while pressures are considered as intermediate causing of changes in the system state.

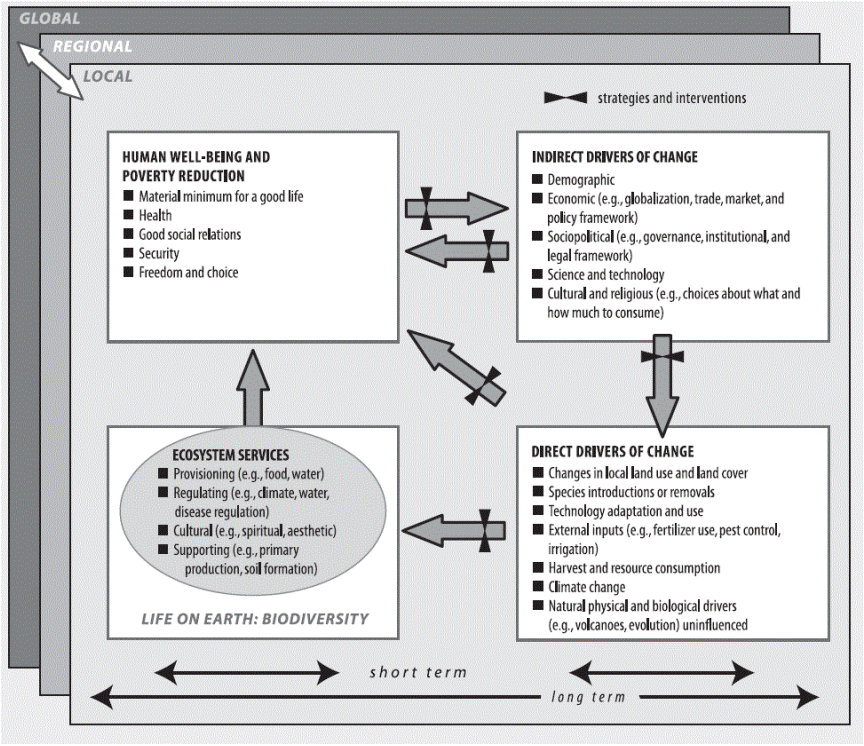


Fig. 2.5. The Millennium Ecosystem Assessment (MA) framework (Millennium Ecosystem Assessment, 2005)

The MA framework (Fig. 2.5) was developed by UNEP since 1998 for the Millennium Ecosystem Assessment which places the drivers of change, ecosystem services, and human well-being at the center of its analysis (Millennium Ecosystem Assessment, 2005). In the MA framework, the complex interactions between ecosystem and human-wellbeing are taken into account by looking both the environmental changes at local, national or global scales and long-term or short-term scales. This multiple-scale approach, therefore, allows the assessment of the interaction of drivers and changes at different levels of analysis (Millennium Ecosystem Assessment, 2005). In the MA framework, the indirect drivers at macro and distal levels can

impact the direct drivers and cause changes in the provision of ecosystem services and then human well-being. The MA framework thus could help to understand the changes and multiple drivers of change in complex social-ecological systems. Carpenter et al. (2009) however suggest that future studies should address and incorporate the quantitative modeling, nonlinear and abrupt changes, and improve assessment and communication of uncertainty into the MA framework (Carpenter et al., 2009).

In order to aid donors to select the right intervention for pro-poor changes, the Department for International Development in the United Kingdom uses the Drivers of Change approach which conceptualizes drivers as institutional or governance factors that operate in a platform of interactions between structural features, institutions, and agents to mediate the livelihood outcome (DFID, 2005). This approach places institutional performance at the center of its analysis and focuses on the formal and informal rules and power structures on the operation for changes. The drivers could be analyzed at six approach levels of "basic country", "medium-term dynamics of change", "Role of external forces", "Link between change and poverty reduction", "Operational implications", and "How to work" (DFID, 2005). The framework emphasizes the importance of context-specific of its components in order to understand drivers of change and necessary aids to be taken for pro-poor orientation. This framework, therefore, focuses on the social changes and neglects the natural processes.

The DPSIR, MA and Drivers of Change frameworks address the social-ecological changes and their drivers at the macro level and therefore, are difficult to grasp the changes at a local scale, for instance, the role of household's adaptive capacity to make a livelihood change (Butler et al., 2014). At the local context, the Sustainable Livelihood Framework (SLA) is particularly relevant to uncover the human-environmental settings and farming system changes since it conceptualizes not only livelihood endowments that households rely on for making livelihood strategies but also the contextual environment that affects the livelihood activities (Fig. 2.6). The SLA framework is based on assumptions that the poor work under a vulnerable context and their livelihood strategies are determined by their tangible and intangible assets such as human, nature, social, physical and financial capitals, as well as their capacity to access to these resources (DFID, 2001). The livelihood decisions and outcome in this context are influenced by both household's adaptive capacities as well as environmental changes such as transformation structures and processes, shocks and trends. The analysis of livelihood capacity therefore could enable to explore the adaptive capacity at the household

level and explain why specific actors decide to switch to certain types of farming systems, for instance, intensive versus extensive shrimp systems within the same village.

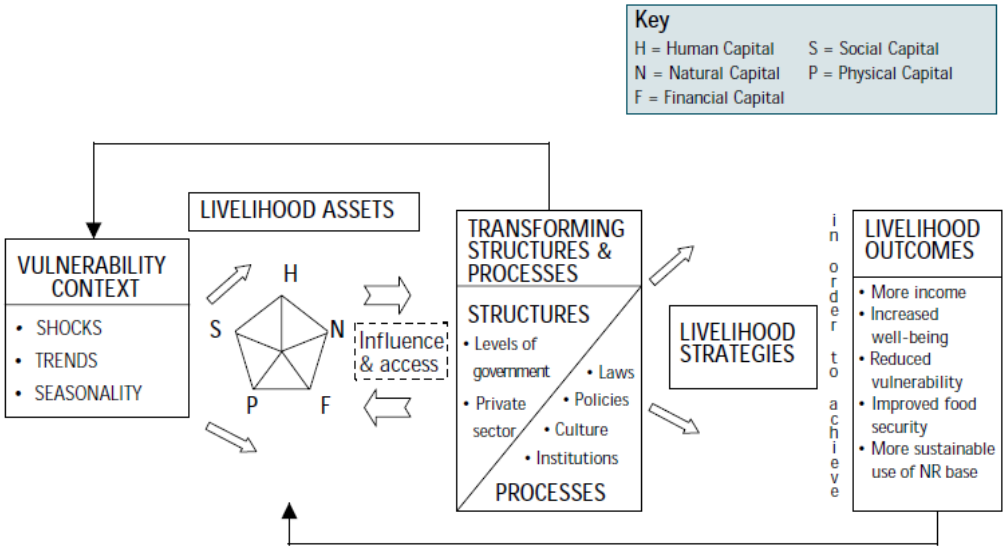


Fig. 2.6. Sustainable Livelihood Framework (SLA) (DFID, 2001b)

This framework, however, addresses the livelihood changes from an actor-oriented perspective and does not consider the macro and distal drivers and their connection with the local driving factors. The livelihood is considered by de Haan (2012) as a moving target, in which the livelihood strategies are changed over time and induced by driving factors from a wider context. In the context of Vietnam, Miller (2014) and Hanh (2013) convey that farming system changes in the MKD and RRD are local responses to environmental, social and political drivers at various scales. Similarly, Ha (2012) argues that many livelihood changes of shrimp farmers and fishers in the coastal areas of the MKD are induced by multiple factors at the household, regional, national and global contexts. In these cases, livelihood strategy is not a one-time event but that is accumulated through preceded activities and influenced by other activities outside the place. In this regard, the SLA cannot capture the spatial and temporal linkages between changes and causing factors outside its analyzed context, for instance, external drivers of agricultural changes at the global and national levels.

2.4 Agricultural systems as complex adaptive systems - A general framework for analyzing drivers of change, adaptation, and resilience of agricultural systems

Due to the complexities of social-ecological systems, there has not yet been a universal theory and conceptual framework to explain their changes. There has been increasing consideration of agricultural systems as complex adaptive systems in which human components such as household resources, farming knowledge and social networks are interlinked with ecological systems (Darnhofer et al., 2009). Stemming from the field of biology, complex adaptive system theory emphasizes the integrated nature of humans and environment, the future uncertainty due to emergence of new system properties and regime shifts, and the adaptability and co-evolution of the systems with the environment (Levin, 1998; Rammel et al., 2007). The concept of complex adaptive systems is used to describe systems that are featured by a close interconnection and feedback between their components. These complex systems are typically influenced by multiple drivers of change at various levels, have multiple scales of interactions and exhibit nonlinear relationships between components and thus unpredictability in terms of predicting their future changes. Thanks to these characteristics, these systems can constantly adapt to changing conditions (Levin, 1998; Rammel et al., 2007). Changes and adaptations in complex adaptive systems are considered as processes of interactions and feedbacks of multiple drivers of change with internal processes of system components at different levels over time (Lambin et al., 2003). These drivers can be endogenous or exogenous factors and operate synergistically to cause a change on the system (Millennium Ecosystem Assessment, 2005). These changes in the ecosystem create feedbacks on drivers at various levels and affect the next interactions of change (Lambin et al., 2003). This makes the investigations of drivers of change and the projection of agricultural trajectories difficult since the changes in agricultural systems and their causal mechanisms are sometimes non-linear and spatially and temporally separated (Mueller et al., 2014; Rammel et al., 2007). Given these complexities, there have been calls for historical examinations of the drivers of change and adaptation in the context of complex, dynamic social-ecological systems for a better understanding of land use development (Berkes et al., 2003b; Lambin et al., 2001; Mueller et al., 2014). This study, therefore, applied the concepts of CAS as a general framework to analyze the historical and present drivers of agricultural changes, adaptation, and resilience of agricultural systems facing increased salinity intrusion in the deltas (Table 2.4).

Table 2.4. Working definitions of the concepts in the dissertation and their focuses

Analyzed concepts	Working definition	Main focuses
Drivers of change	Any social or environmental factors that cause a change in an ecosystem (Millennium Ecosystem Assessment, 2005)	Multiple scales of drivers, cross-scale interaction and feedback, non-linear relationship between drivers and agricultural changes
Adaptation	Adjustments in response to/preparation for changes in climatic stressors and internal processes to moderate harm and exploit beneficial opportunities (IPCC (Intergovernmental Panel on Climate Change), 2007)	Adaptive capacity, proactive changes, incremental and transformative adaptation
Adaptation pathways	Various adaptation options and a sequence of each action over time (Haasnoot et al., 2013)	Multiple responses, lock-in and threshold effects
Subjective resilience	The sensitivity of agricultural systems to increased salinity intrusion, the capacity of the systems to recover from salinity damage, and the capacity to change to alternative farming systems if salinity intrusion increases before severe impacts are felt*	Capacity to deal with future challenges, alternative system states, navigation of resilience trajectories to prevent lock-in and "path-dependencies"
Complex adaptive system	No specific definition**	Close interconnection and feedback between social and ecological systems Complexity, multiple drivers of change Multiple scales of interactions, nonlinear relationship between components, unpredictability Adaptive capacity (Levin, 1998)

** This definition is based on Bennett et al. (2014) and Darnhofer (2014)*

*** Many scholars refrain from defining the complex adaptive systems since a clear definition could limit the understanding of the concept (Levin, 1998). This research follows this trend and identifies complex adaptive systems by their features.*

In this study, a conceptual framework was developed to illustrate and guide the research investigations (Fig. 2.7). This study considers agricultural systems as a function of biophysical factors such as soil and water, farming techniques including cultivars and species uses, and socio-economic factors such as household resources and looks for changes in these factors as responses to drivers of change. These agricultural systems are nested with other agricultural systems at lower and higher scales and are influenced by various internal drivers at the locality as well as external drivers of change at the delta, national, and international

levels. Change and adaptations in agricultural systems are understood in this context as the results and inputs of interactions of external and internal drivers of change and system's components over time. These changes in agricultural systems create feedbacks with drivers of change at various levels and affect the next interactions of change (Lambin et al., 2003). These changes in agricultural systems equate to various adaptation pathways with different abilities to change and transform or pathways that locked-in the systems in one particular system. In this framework, resilience is considered as the results and characteristics of interactions and feedback in agricultural systems that continuously change over time.

In Fig. 2.7, the circles with a number indicate the chapters in the dissertation which explicitly address the components of the conceptual framework. Changes in ecological sub-systems of the framework (e.g. rainfall, temperature and salinity conditions) as well as changes in the social sub-system such as modifications in agricultural systems and alterations in household economic structures are illustrated in Chapter 4 and partly in Chapter 5. Chapter 5 explicitly analyzes changes in the political system as one of the primary external drivers of change as well as their influence on social-sub-system of the framework (e.g. land use rights and transfer of knowledge). Chapter 6 examines the interaction and feedback between external and internal drivers of change and their influence on agricultural changes, as well as explore various adaptation pathways in agricultural systems. Chapter 7 assesses the resilience of agricultural systems as results of adaptation and changes in these complex adaptive systems.

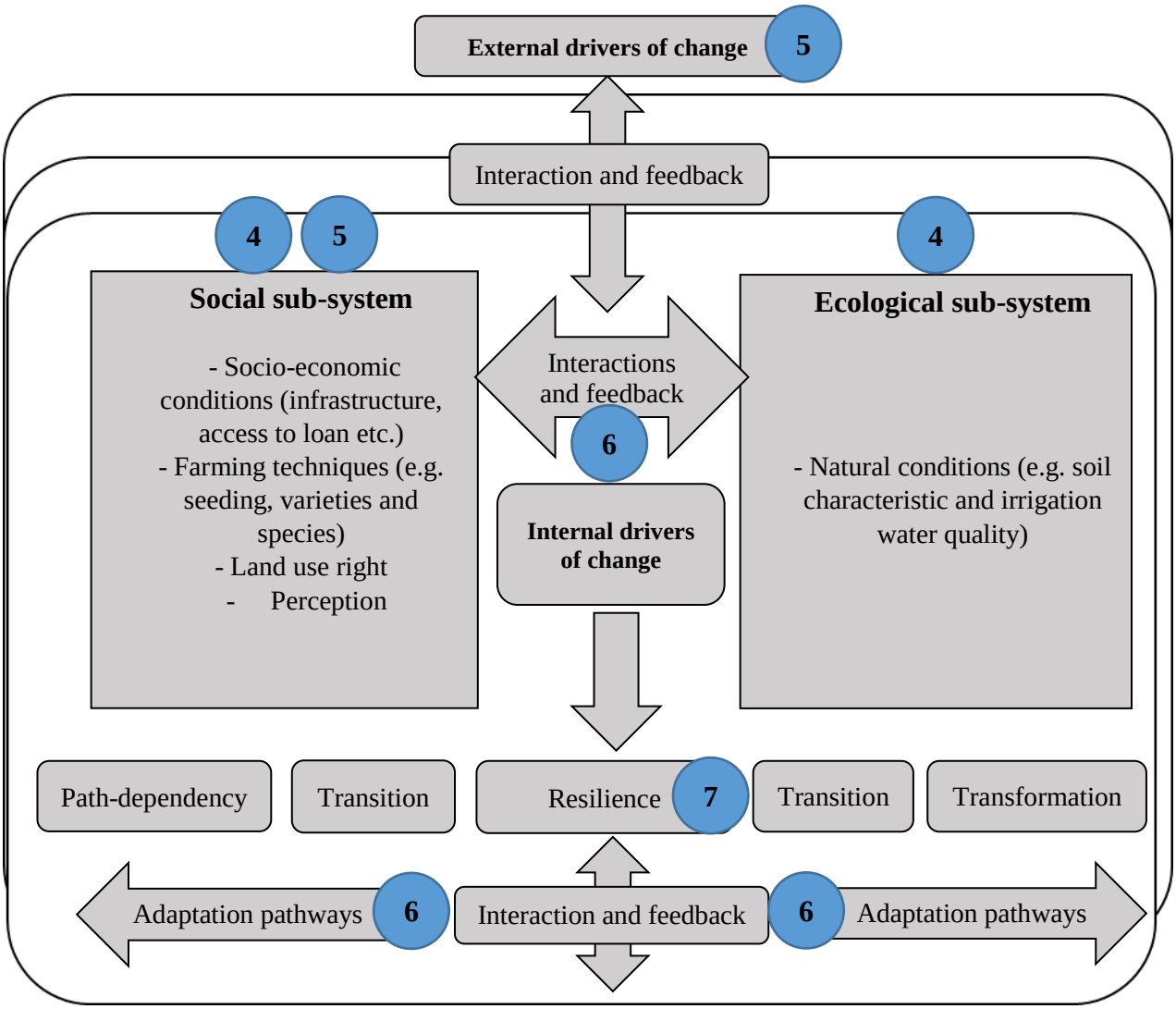


Fig. 2.7. Conceptual framework of the dissertation

3. METHODOLOGY

3.1 Research sites

For the purpose of this research, two case study areas were considered in the MKD in different agro-ecological zones in the provinces Kien Giang and Soc Trang and one case study area, Nam Dinh province, was considered in the RRD (Fig 3.1).

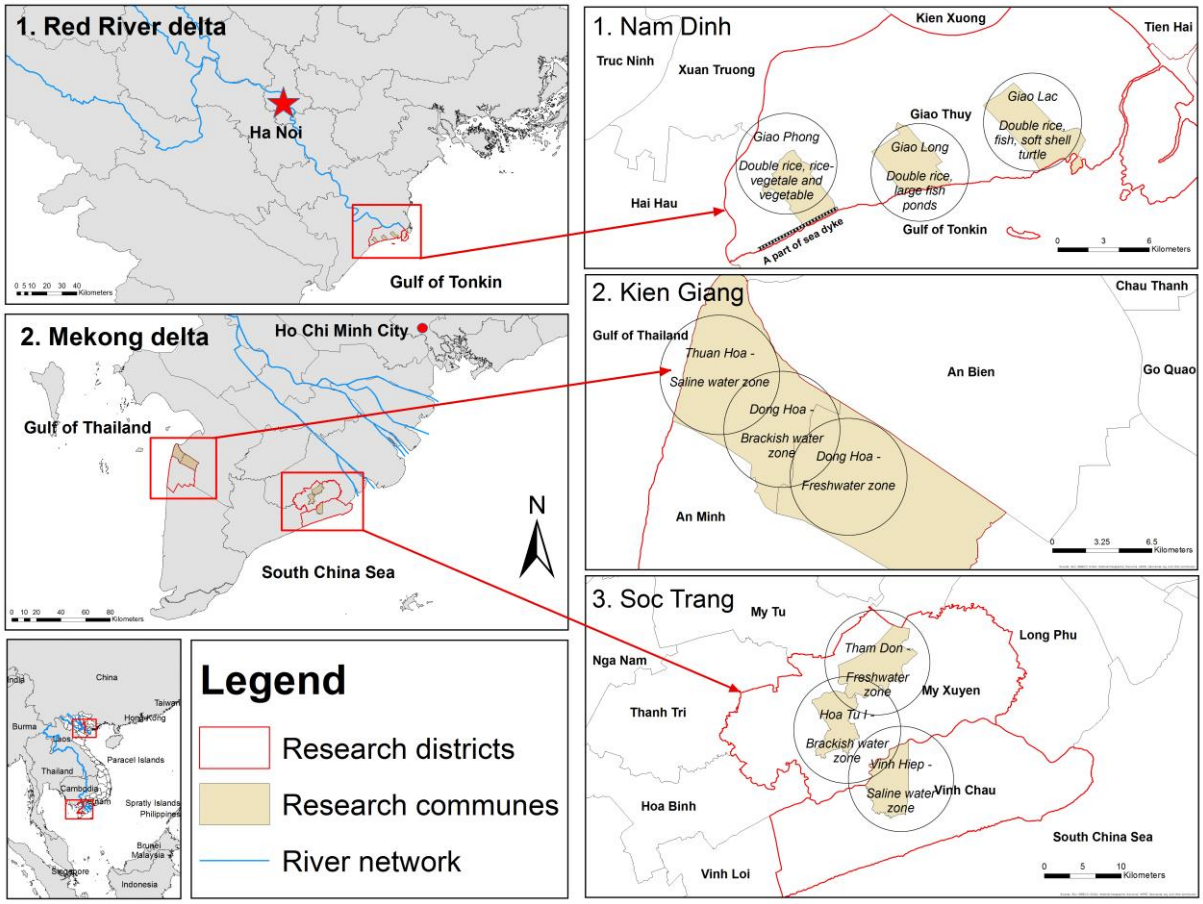


Fig. 3.1. Research sites in the Red River (1) and Mekong (2) deltas with main farming systems indicated

In the MKD, saline water can intrude far inland during the low flow season from December to April and separate the coastal zones into three salinity zones with different agro-ecosystems. During the dry season, salt water can penetrate up to 70 km inland (Tuan et al., 2007), while in some extreme years like the historical salinity event in 2015-2016, the salinity intrusion

could expand to more than 90 km (UNDP, 2016). The area along the coast is largely impacted by saline water the whole year and is considered as the saline water zone, whereas the area which is located far away from the coast and receives sufficient fresh water supply from upstream is the freshwater zone. The area between these zones is affected by saline water several months during the dry season and is characterized by a brackish water environment (Tri, 2012). In this transition zone, duration of saline condition as well as the levels of salinity vary spatially. In the RRD, agricultural systems are less impacted by salinity intrusion when compared to the MKD thanks to the construction of concrete sea dykes and sluicegates, as well as a higher elevation of the coastal zone and a less tide-dominated environment (Cong et al., 2009; Pruszak et al., 2005). The existence of massive protective infrastructure turns the whole delta into a freshwater zone and double rice can be cultivated even in areas very close to the coast. Salinity intrusion however still exists through sluicegate leakages and infiltration of saline water through the sea dykes (Yen et al., 2016).

In order to capture the heterogeneity of drivers of change and diverse trajectories of agricultural systems in the deltas in the context of increased salinity intrusion, the research was carried out in three case study areas located in different agro-ecological and climatic zones and with different degrees of salinity control (Table 3.1). Field research in both areas in the MKD was carried out along a salinity transect: villages principally engaging in double rice cropping (two rice crops per year) in the freshwater zone but with the risk of exposure to salinity intrusion, villages involved principally in rotational rice-shrimp farming (rice was planted during the wet season and shrimp was grown during the dry season) in the brackish water zone, and villages involved in shrimp farming in the saline water zone were considered. In the RRD there were few households that have switched their farming systems from rice production to other farming systems in each village and agricultural changes were heterogeneous among communities. Therefore, villages which have experienced different changes in agricultural systems were selected. The research sites include villages carrying out double rice, rice-vegetable and vegetable cultivation located farthest from the sea dyke (only a few meters from the coast), villages engaged mainly in double rice, fish ponds and softshell turtle farther from the sea dyke, and a village where double rice and large fish ponds were the main farming systems close to the sea dyke. In these villages, double rice was the standard system from which households had changed to the other agricultural systems.

To examine the resilience of different agricultural systems to various degrees of salinity intrusion, case study research was also conducted in villages located along salinity gradients in the MKD and at different distances to the sea dykes in the RRD. These villages were purposely selected from the villages where in-depth interviews, FGDs and semi-structured interviews were carried out for the analysis of drivers of change and adaptation pathways prior to the phase of the resilience assessment (see Fig. 3.2).

Table 3.1. Characteristics of the research areas in the Mekong and Red River deltas

Characteristics	Area (km^2)	Agricultural land (km^2)	Rice production (thousand ton)	Population (thousand persons)	Population density (person/ km^2)	Adult literacy rate (%)	Personal monthly income (thousand Viet Nam Dong)	Poverty rate (%)
Mekong Delta	40,816	2,624	24,267	17,661	433	93	2,798	2.4
Kien Giang	6,349	4,631	4,643	1,761	277	91	2,642	2.7
- An Minh	591	417	123	119	202	n/a	n/a	n/a
Soc Trang	3,312	2,134	2,220	1,311	396	89	1,913	8.7
- My Xuyen	372	142	154	157	421	n/a	n/a	n/a
- Vinh Chau	473	63	14	166	349	n/a	n/a	n/a
Red River Delta	21,260	799	6,579	21,134	994	98	3,610	5.2
Nam Dinh	1,669	914	935	1,851	1,119	98	2,816	3.0
- Giao Thuy	238	92	96	190	800	n/a	n/a	n/a

(Source: GSO, 2015; Kien Giang Statistics Office, 2016; Nam Dinh Statistics Office, 2015; Soc Trang Statistics Office, 2013)

Kien Giang

Kien Giang lies at the side of the Gulf of Thailand. The province has a long coastline of more than 200 km. The saline water from the Gulf of Thailand could intrude further inland in the province through main rivers and canals (e.g. Cai Lon, Cai Be, Giang Thanh, Rach Gia and Rach Soi). Salinity intrusion also occurs in inland areas which share the same borders with Bac Lieu and Ca Mau as saline water from the South China Sea could intrude further inland from the direction of those provinces through Quan Lo-Phung Hiep canal. Highest salinity level usually occurs in March and April (Source: in-depth interviews with local authorities; DARD Kien Giang, 2015). In An Minh district of Kien Giang, the agro-ecological systems include mangrove-shrimp and blood shell cultivation in the area along the coast, next to the extensive shrimp and then rice-shrimp production zones, and the area of double rice further inland. Kien Giang has the largest area of extensive shrimp and rice-shrimp production in the MKD at 85,730 ha, whereby An Minh contributes the largest share of 35,823 ha (DARD Kien Giang, 2015).

Soc Trang

Soc Trang is located at the side of the South China Sea and shares 72 km border with the sea. Salt water can intrude far inland in Soc Trang through the Hau River and its branches (e.g. Saintard and Du Tho rivers) or the My Thanh River. There are systems of sea and river dykes for preventing salinity intrusion along the coast and in Cu Lao Dung Island (DARD Soc Trang, 2015a). My Xuyen district is divided into two agro-ecological zones by a river dyke system, with brackish water zones in the area outside the river dyke, and freshwater zone in the area inside the dyke. Vinh Chau district is exposed to saline water the whole year and is characterized by the saline water zone. The main agro-ecosystems along the salinity transects in Soc Trang comprise intensive shrimp in areas close to the coast, rice-shrimp (i.e. rice is cultivated in the wet season and shrimp is grown during the dry season) and semi-intensive shrimp in the brackish water zone, and double or triple rice, vegetable and freshwater aquaculture in areas further inland.

Nam Dinh

Giao Thuy district in Nam Dinh province is located at the side of the Gulf of Tonkin. The province has 72 km border with the sea, in which Giao Thuy constitutes 32 km. The salt water

could go upstream of the main rivers such as Hong, Day and Ninh Co. The agro-ecosystems of Giao Thuy are divided into two main zones. The area inside the sea dyke is the freshwater zone, while the region outside the sea dykes is entire saline water zone. Major agricultural changes in the district include (i) conversion of rice land to freshwater aquaculture or vegetable in areas inside the dyke and (ii) modification of the existing extensive aquaculture land to intensive saline aquaculture or conversion of salt production land and natural land to saline aquaculture in areas outside the dyke. The research activities in Giao Thuy district were conducted in areas inside the sea dykes since this zone represents a major area of the research district and is the main area for agricultural production. The area outside the sea dykes constitutes a minor proportion of the district. A large majority of the district's population also lives in areas inside the sea dykes (Source: in-depth interviews with local authorities).

3.2 Methodology

This PhD research applied a mix-methods approach consisting of in-depth interviews with authorities at different levels from national to commune levels as well as semi-structured interviews, focus group discussions (FGD), household survey and role-playing games (RPGs) with farmers (see Fig. 3.2). The application of both quantitative and qualitative methods aimed to enhance the research exploration and understanding of the social-ecological complexities at various scales as well as to validate and triangulate the collected data (see Appendices A.1 for procedures of the field research and data collection).

Qualitative methods provided the primary information in this dissertation. According to Mackrell et al. (2009), qualitative methods can offer a deep understanding and advance the observation at different viewpoints of both researchers and participants. The study requires a historical approach to uncover and relate changes in agricultural systems and their drivers at multiple levels over time. Some of these agricultural changes were carried out many years ago, for instance, the change from single rice to double rice in Kien Giang was carried out more than 40 years ago during 1977-1978. Therefore, the application of qualitative methods aimed to provide a deep understanding of the historical and present drivers of change and how the agricultural changes occurred. At the explorative phase of the research, qualitative methods such as in-depth interviews with authorities and local farmers have offered an insight into the context of the social-ecological systems and revealed potential drivers at multiple scales. At the later phases of the field research, qualitative tools such as FGD and semi-

structured interviews with farmers have provided an in-depth understanding of the role of each driver and how the changes had taken place. The relative importance and interaction amongst various drivers of changes at different scales were discussed and clustered, for example, through historical timelines and scoring during the FGDs (see section 3.2.1 for a detailed depiction of the qualitative methods and Appendices A.2 for the guideline of the FGDs).

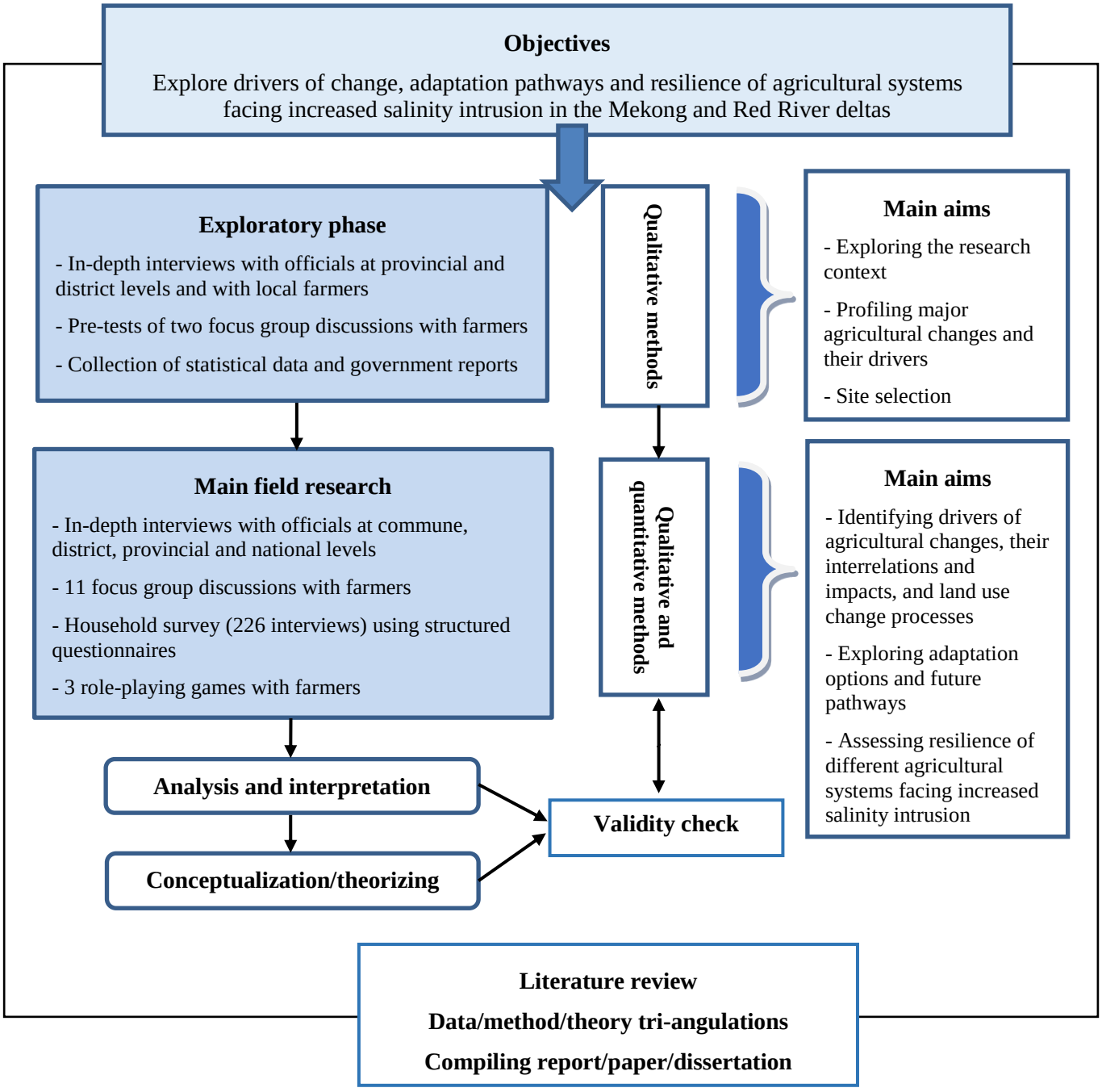


Fig. 3.2. Methodology and data collection processes

Although the qualitative methods can yield rich information, the results are usually considered as contextual and are difficult to generalize to the whole population as well as the application of the method could be influenced by the subjective bias of researchers (Neuman, 2003). The application of quantitative methods was aimed to address these challenges. Various methodologies are applied to assess subjective resilience, varying from household surveys to qualitative approaches such as focus group discussions and in-depth interviews (Levine, 2014; Jones and Tanner, 2016; ODI, 2016). While no single method is able to capture resilience in all contexts, utilizing of a wide range of methods is usually recommended (Frankenberger and Nelson, 2013; FAO, 2014). The subjective assessment of resilience in the MKD was based on a survey of 226 randomly selected households in Kien Giang and Soc Trang from December 2015 to February 2016. In the RRD, the resilience assessment was derived from 118 semi-structured interviews conducted between March and April 2016. This quantitative information was complemented with qualitative data from 80 semi-structured interviews in the MKD as well as 11 FGDs with farmers and 27 in-depth interviews with local and national authorities in both deltas for an understanding of the drivers of resilience (see Table 3.2 and Section 3.2.2). In the resilience assessment in the MKD and RRD, structured and semi-structured interviews offered the main source of information. Qualitative data from FGDs and in-depth interviews with authorities were supplemented to explain the results when necessary.

In addition, three RPGs were conducted at the end of the field research in May 2017. The board game was developed to validate and triangulate the preliminary findings and explore farmers' decisions in response to changing key drivers of change (see Appendices A.3 for a detailed description of the games).

Table 3.2. **Number of interviews, focus group discussions, and role-playing games with farmers per research site**

Number of interviews, focus group discussions, and role-playing games	Kien Giang	Soc Trang	Nam Dinh
Semi-structured interviews	43	37	118
Structured interviews	112	114	n/a
Focus group discussions	4	3	4
Role-playing games	n/a	3	n/a

In addition to empirical data, a collection and review of secondary data such as statistical data on land use changes, land use maps, and relevant government reports related to agricultural changes were also carried out. The policies that were mentioned during the interviewed were then reviewed in order to understand and relate the policies and agricultural changes carried out in the field. The monitoring climatic data on salinity levels, rainfall, temperature, water levels of the rivers over time were also obtained for examining the biophysical changes in the deltas.

3.2.1 Qualitative methods using in-depth and semi-structured interviews and focus group discussions

In each agro-ecosystem along the salinity transects in the MKD and within villages at different distances from the sea dyke in the RRD, interviews with local authorities, FGDs, and semi-structured interviews with farmers were carried out (see Table 3.3). First, in-depth interviews with local authorities of the Department of Agriculture and Rural Development (DARD), the Department of Natural Resources and Environment (DONRE) at provincial and district levels, and staff of the People's Committee at the commune level were conducted. The in-depth interviews aimed to explore the general context of agricultural changes in the research areas and identify various drivers of change at different levels. This was followed by FGDs for which participants (5-16 farmers) were invited to the meetings by village leaders or heads of Farmers' Associations at the commune level based on the criteria of age, location, and wealth to ensure representativeness of diversity in respondents. The main objectives of the FGDs were to identify changes in agricultural systems within the villages and their drivers since 1975, examine the relative importance of the drivers and understand the shifting processes and socio-economic conditions of the communities. During the FGDs, tools of participatory rural appraisal were applied, including (i) resource map and general socio-economic conditions of the village, (ii) cropping calendar, (iii) historical timeline of agricultural systems from 1975, (iv) relative importance of the drivers of major changes, (v) the farming systems of choice if the salinity intrusion or market price change, and (vi) ranking of agricultural production problems in the village. For the interviews, semi-structured questionnaires were applied to gain an understanding of the i) historical development and the drivers of change in agricultural systems at the household level, ii) the economic earnings from agricultural changes based on a 5-point Likert scale assessment, and iii) the perception of households on salinity changes and the desired farming systems. Snowball and purposive

sampling methods were applied to select the interviewees in order to capture the changes at different times in the past, age of the household heads, household location, and wealth. In the MKD, the gate-keepers (hamlet leaders or leaders of Farmers' Association) were asked to select an equal number of households in each wealth category. In the RRD, wealth was not a criterion to select the interviewees due to a small number of households who have changed their farming systems, for example from double rice to fish ponds and softshell turtle in each village. The wealth categorization in both deltas was based on the judgment of the gate-keepers and the researcher's evaluation of household conditions e.g. income, house type, and durable assets after each interview. In the FGDs and interviews, the research focused on the historical development and activities related to agricultural changes. Gender was not a specific criterion for selection of households even though the researcher(s) recognize that this creates a bias in responses. As a vast majority of households in the research areas are headed by males, the majority of the participants in the FGDs and interviewees were male-headed households (see Table 3.3). All stakeholders had the right to participate in the interviews and FGDs or to refuse involvement and no conflicts of interests between participants exist.

In total, 7 FGDs and 80 semi-structured interviews were conducted with farmers in the MKD from September 2015 to February 2016 and 4 FGDs and 118 semi-structured interviews were carried out with farmers in the RRD from March to April 2016. This information was triangulated and supplemented with 27 in-depth interviews with local and national authorities and by secondary data collection from statistics and government reports. The major scale of analysis was agricultural systems at the commune level. However, changes at the household level (e.g. income gain) are also presented. These various scales of analysis aim to illustrate cross-scale interactions and feedbacks of drivers and changes.

Table 3.3. Number and characteristics of interviewed households and number of FGDs in three study areas

Salinity zones/distance to sea dyke and categories of change (in parentheses)	Number of interviewed households according to present farming systems and number of FGDs	Wealth categorization (better-off/ average/ poor households)	Average age of respondents	Average years of schooling of respondents	Average family size	Female-headed households (%)	Households having at least one out-migrated member (%)	Average of total farm size (1,000 m^2)
Kien Giang								
Freshwater zone (from single rice to double rice)	8 rice-rice 1 FGD	3/2/3	64.9	3.6	5.5	12.5	25.0	20.8
Brackish water zone (from rice-fish to rice-shrimp, double rice to rice-shrimp)	19 rice-shrimp 2 FGDs	6/6/7	59.6	4.0	4.4	10.5	15.8	21.5
Saline water zone (from single rice to shrimp, rice-fish to rice-shrimp to mono shrimp)	16 mono shrimp 1 FGD	6/5/5	56.7	5.8	4.1	0.0	20.0	23.4
Soc Trang								
Freshwater zone (from single rice to double rice)	12 rice-rice 1 FGD	4/4/4	54.9	4.2	4.4	16.7	58.3	10.0
Brackish water zone (from rice-*Penaeus merguiensis* to rice-shrimp, from rice-shrimp to mono shrimp)	13 rice-shrimp and shrimp 1 FGD	4/5/4	57.5	5.6	4.6	7.7	23.1	20.0
Saline water zone (from rice-*Penaeus merguiensis* to rice-shrimp, from rice-shrimp to mono shrimp)	12 mono shrimp 1 FGD	3/5/4	54.3	3.1	3.8	16.7	33.3	15.1

Nam Dinh								
Close to sea dyke (from double rice to large fish ponds)	10 fish/12 rice No FGD[a]	9/12/1[b]	51.3	6.7	3.6	4.6	36.4	3.8
Farther from sea dyke (from double rice to fish ponds and soft-shell turtle, soft-shell turtle to fish or vegetable)	12 fish/17 rice 10 soft-shell turtle/4 fish or vegetable/6 rice 2 FGDs	13/22/14[b]	54.5	6.0	3.8	10.2	61.0	2.2
Farthest from sea dyke (from double rice to rice-vegetable, double rice to vegetable, rice-vegetable to vegetable)	15 double rice plus rice-vegetable or vegetable 8 rice-vegetable/14 rice-vegetable plus vegetable 10 vegetable 2 FGDs	11/29/7[b]	56.3	6.9	3.6	6.4	47.2	2.2

[a] *Most large fish pond farmers were residents of inland villages and only temporarily settled in the area for fish farming. Thus FGD was replaced by in-depth interviews with village leaders.*

[b] *Wealth was not a specific criterion in the RRD due to a small number of households who changed the farming systems in each village.*

3.2.2 Quantitative methods using semi-structured and structured interviews

The subjective assessment of resilience was based on farmers' perception of i) the sensitivity of their farming systems to increased salinity intrusion, ii) the capacity of their farming systems to recover from salinity damage and iii) the capacity to change their farming systems to other systems if salinity increases in the future. Following the study of Jones and Tanner (2016), a single question with a 5 point-Likert scale was asked to address each resilience component: (i) To what extent is your farming system impacted if salinity intrusion increases? (ii) In the case of salinity damage, to what extent can you re-engage in your farming system? (iii) To what extent can you alter/convert your farming system to another system if the conditions for production change? The answers consisted of five scales (1) Very little, (2) Little (3) Average (including "neither little nor much", "Do not know exactly", "it depends", "it varies"), (4) Much, (5) Very much severity (for question on the sensitivity to increased salinity intrusion) or ability (for questions on the capacities to recover and to change). Each of

these questions captured one of the three components of social-ecological resilience; sensitivity of agricultural systems to increased salinity intrusion, capacity to recover, and capacity to change to a new system before severe impacts are felt. Elicited answers were noted and transcribed as were the explanations of the choices. For the rice-shrimp system in the MKD, the questions of sensitivity and recovery capacity were asked separately for rice and shrimp farming and then aggregated because rice and shrimp are exposed differently to salinity intrusion. The wealth criteria for the wealth ranking exercises were collected from the FGDs and the ranking of all households in the village was conducted by following small groups of stakeholders (e.g. hamlet leaders, elderly farmers, leaders of farmers' associations at the commune level). In total, 226 households in villages along the salinity gradients were interviewed in the MKD (see Appendix 4 for community characteristics and results of the wealth ranking exercises).

In the RRD, many households have not experienced salinity damage for many years and the assessment of the sensitivity and recovery capacity of their farming systems in the case of increased salinity was difficult. Therefore, the three resilience-related components were only assessed for double rice, fish ponds, soft-shell turtle production and rice-vegetable, the most exposed systems to salinity intrusion. For large fish pond and vegetable systems, only the capacity to change based on the 5-point Likert scale was assessed. Qualitative data from the semi-structured interviews, FGDs, and secondary data were subsequently employed to assess the sensitivity to increased salinity intrusion and the capacity to recover from salinity damage of these farming systems.

3.2.3 Data analysis

Qualitative analysis

Following the field research in Vietnam, the qualitative and quantitative data were digitalized and analyzed comprehensively in Bonn, Germany from June 2016. The qualitative data from the FGDs, RPGs and semi-structured interviews was entered into a word processing software and analyzed qualitatively using the MAXQDA program (VERBI, Berlin, Germany). The analysis followed the grounded theory approach (Neuman, 2003). The questions and answers with similar themes were structured and grouped after the pre-test. The questions however were open-ended and more codes or categories that emerged after the first open coding were generated during the analysis phase. The selective coding was applied at the end to compare

the frequencies of coding between the statements such as the mentioned drivers of change, system of choice, and income gains.

Quantitative analysis

Descriptive statistics (e.g. mean and median) were calculated using STATA (StataCorp LLC, Texas, USA). Socio-economic and ecological characteristics of the agricultural systems were examined and compared in order to explain the differences of resilience-related components among them. Chi-square and Kruskal-Wallis tests for non-normal distributed data were performed for this purpose (Wooldridge, 2010). Wherever the Kruskal-Wallis test found a significant difference, Dunn's tests were performed to find out which specific values of sub-groups are significant from the others (Dinno, 2015). The qualitative data from the FGDs and semi-structured interviews were transcribed and the text was analyzed using the MAXQDA software.

4. A CONTEXT OF BIOPHYSICAL AND AGRICULTURAL CHANGES IN THE MEKONG AND RED RIVER DELTAS IN VIETNAM SINCE 1975

4.1 Introduction

Natural hazards and climatic variations have been intensified in Vietnam over the last decades. During the period 1958-2014, the annual average surface temperature in Vietnam increased by approximately 0.62^{o}C, with the increasing rate at 0.1^{o}C per decade. The sea level rose by 2.45 mm per year. Extreme weather events such as storm, tropical low pressure, drought, and floods have occurred more frequently (MONRE, 2016). At the national scale, the annual rainfall of the country has slightly increased (MONRE, 2016). The average annual rainfall has risen (approximate 6.9-19.8%) in the Southern climate zone and declined (approximate 5.8-12.5%) in the Northern climate zone during 1958-2014. There have been also shifts in the amount of rainfall between the months of the year and increases of the occurrence of abnormal events such as heavy rains in the wet season and abnormal rains during the dry season (MONRE, 2016).

Biophysical conditions in the coastal zones of the MKD, and to a lesser extent in the RRD, have experienced considerable changes during the last decades. These changes were first driven by the human modification of the ecology (e.g. through dyke construction, drainage of acid sulphate soils) for intensive agricultural production and then by alterations in climatic factors (de Araujo Barbosa et al., 2016; Tessier, 2011). This chapter examines changes in biophysical conditions and agricultural production areas in the coastal zones of the RRD and MKD based on the analysis of statistical and secondary data. The first part of this chapter illustrates seasonal variations of rainfall and temperature between the dry and wet seasons, changes in the water levels of the rivers and salinity conditions in the research areas in the recent past, and projected impacts of rising sea levels and salinity intrusion in the coastal zones of the MKD and RRD. The next sections examine the general trend of agricultural development in the deltas and research provinces since 1975 as well as provide an overview of alterations in the economic structure and livelihoods of farming households since Doi Moi in 1986. The last section concludes and highlights the main findings of the chapter.

4.2 Biophysical changes related to salinity intrusion in the coastal areas of the Mekong Delta

The MKD is characterized by a vast low plain area at an elevation of 0-4 m with heterogenous natural conditions, hydraulic infrastructures, and agro-ecosystems (Mekong Delta Plan, 2013). The delta covers an area of 3.97 million ha, of which 2.40 million ha are dedicated to agricultural production (Tri, 2012). The diverse landscapes of the delta can be divided into seven agro-ecological zones, including the Freshwater Alluvial Zone (0.9 million ha), the Ca Mau Peninsula[1] (0.8 million ha), the Coastal Zone (0.6 million ha), the Trans-Bassac Depression (0.6 million ha), the Plain of Reeds (0.5 million ha), the Long Xuyen-Ha Tien Quadrangle (0.4 million ha), and the Hills and Mountains (0.2 million ha) (Sanh et al., 1998). Amongst these zones, the Ca Mau Peninsula and the Coastal Zone are the two agro-ecological zones that are most affected by salinity intrusion (Sanh et al., 1998). The salinity affected areas spread in regions of 0.78 million ha along the coast from the Vam Co River to the Hau River, and 1.26 million ha mainly in the Ca Mau peninsula agro-ecosystem zone and nearby areas in the Trans-Bassac Depression (Sanh et al., 1998; Tuan et al., 2007). The predominant soils in the delta are acid sulfate soil with 1.6 million ha (40% the total area of the delta) mainly in the Plain of Reeds, the Long Xuyen-Ha Tien Quadrangle, and the Ca Mau Peninsula, followed by alluvium soil (ca. 30% total area) in areas along the main rivers, and saline soil (ca. 30% of the delta plain) in the coastal zone (Thinh, 2003; Tuan et al., 2007).

The influence of salinity intrusion varies largely between agro-ecological zones within the MKD due to differences in the natural conditions and existence of protective infrastructures in place. The coastal zone in the eastern part of the MKD is predominantly influenced by the semi-diurnal tidal regime of the South China Sea with an amplitude of 3.5-4.0 m, while the western part of the delta is principally affected by the diurnal regime of the Gulf of Thailand with a lower tidal range between 0.8-1.2 m (Tri, 2012; Tuan et al., 2007). The tidal regimes, together with the rainfall, the hydrological regime of the Mekong River, the temperature, the elevation of the river bed, and the monsoon wind are natural factors that determine the variation of the timing and geographical extent of salinity intrusion in the MKD (Tri, 2012).

[1] The Ca Mau agro-ecological zone is not identical with the common name Ca Mau peninsula. The name Ca Mau peninsula in general refers to the area of 1.6 million ha in the southern side of the Hau River covering the Ca Mau agro-ecosystem zone and parts of the Trans-Bassac Depression, the Freshwater Alluvium Zone, and the Coastal Zone.

In addition to natural factors, human activities at different levels of the delta such as dam construction and irrigation activities as well as the existence of protective infrastructure strongly influence the salinity intrusion in the delta (Tri, 2012). This complexity makes the projection of salinity intrusion trend difficult and the high salinity levels in some abnormal years could cause substantial damages due to a lack of long-term salinity projection for preparedness (Anh, 2017; Binh, 2015).

The monitoring data on rainfall, temperature, water levels of the river and salinity levels in the research areas present little variations over time (see Fig 4.1 to Fig. 4.4). However, there are large fluctuations in those factors between the dry and wet seasons. The following sections examine changes in rainfall patterns, temperature, water levels of the rivers and salinity conditions in the research areas in the recent past.

Seasonal variations of rainfall and temperature in Kien Giang and Soc Trang

The rainfall is one of the most important natural factors affecting the salinity intrusion and farming activities in the MKD (Sam, 2006). Being located in a tropical monsoon climate, the rainfall in the MKD fluctuates largely between the dry and wet seasons. In both provinces Kien Giang and Soc Trang, most of the rainfall was distributed in the wet season from May to November, while there was little rainfall during the dry season from December to April (Fig. 4.1). In the research area in Kien Giang, the rainfall is a vital freshwater resource for farming activities and drinking and cooking purposes[2] since An Minh district is located far away from the Hau River and thus does not receive sufficient freshwater supplies from the river. Rice farmers in An Minh follow the rain to plant their rice from May to the middle of August (Summer-Autumn season), while rice-shrimp farmers rely on the rainfall for leaching salinity from the soils after the shrimp season and start the rice season from the middle of September to the end of January (Source: FGDs).

The rainfall also influences the timing of salinity intrusion which is a key factor determining the salinity damage (Binh, 2015). Interviews with authorities in Soc Trang reveal that the timing of high salinity levels in the province has been shifting earlier, causing damages to the

[2] In the household survey, 87.6% households in Kien Giang and 57.0% households in Soc Trang use rainfall for drinking and cooking purposes during the wet season, while 78.1% households in Kien Giang and 32.5% households in Soc Trang use rainfall for drinking and cooking during the dry season.

Winter-Spring rice at the end of the season. In the salinity event in 2015-2016 in the MKD, high salinity levels happened two months earlier than previous years and caused severe damages on the Winter-Spring rice since there was not sufficient freshwater reserved in the field and canal systems until the rice ripening stage (MARD, 2016). In Soc Trang and Kien Giang, the temperature starts rising in February and gets highest in April at the end of the dry season (Fig. 4.1). A high temperature would accelerate the evaporation (Sam, 2006) and consequently amplify the salinity levels during the typical high salinity period.

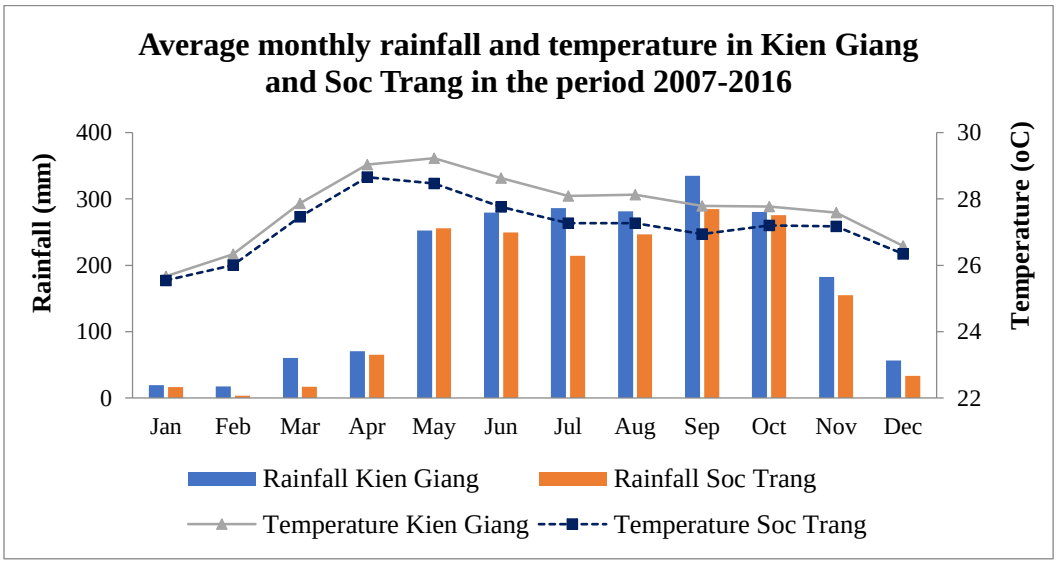


Fig. 4.1. Average monthly rainfall and temperature in Kien Giang and Soc Trang in the period 2007-2016 (Source: NCHMF, 2017)

Changes in water levels of the rivers and salinity conditions in the research areas

The Mekong River and its abundant waters are the foundation of diverse agricultural activities in the MKD. However, the distribution of the river waters varies largely between the dry and wet season, causing flooding in the wet season and water scarcity during the dry season (Renaud and Kuenzer, 2012). In the dry season, the salt water at 4 g l^{-1} – used as a salinity benchmark at which the yield of salinity-intolerant rice varieties would significantly decline (Nhan et al., 2010) - can travel up to 70 km farther upstream of the main rivers (Tuan et al., 2007). During the wet season, the increase of river flows could push the salt water into the proximity of the mouth of the rivers (Hashimoto, 2001). The water levels in the Hau River,

one of the two main distributaries of the Mekong River, at Dai Ngai station in Soc Trang (40 km from the coast) exhibit a slight increase in the period 1985-2009 (Fig. 4.2). This result concurs with the study of Fujihara et al. (2016), which shows increasing trends of water levels in the MKD. The authors argue that these rising water levels in tide-dominated areas were mainly caused by rising sea levels and land subsidence, while the effect of inflow water from upstream areas of the rivers was limited. In addition, the water discharge at the early period of the dry season has been reduced over the last decades due to a decline of water retention in the upper delta, mainly in the Plain of Reed and the Long Xuyen-Ha Tien Quadrangle. The expansion of rice cultivation into these back swamps and flood-prone areas reduced the water storage capacity and lowered the water transfer back to the river channels after the flood season. The alteration of river discharge consequently made the salinity intrusion occur earlier and longer in the coastal areas of the delta (Hashimoto, 2001; Tuan et al., 2007).

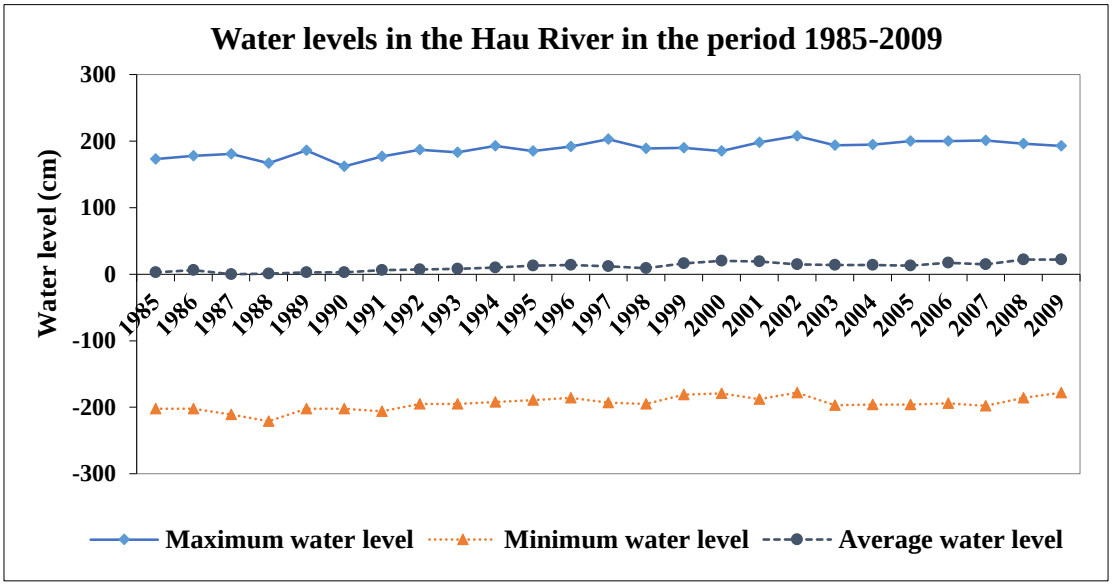


Fig. 4.2. Trends in water levels (maximum water levels at high tides, minimum water levels at low tides, and average water levels) in the Hau River in the period 1985-2009 (Source: DARD Soc Trang, 2015)

The salinity levels in the coastal zone of Kien Giang fluctuate largely between the dry and wet seasons (Fig. 4.3). During the wet season, the salinity levels and geographical extent of salinity intrusion in the province decline significantly since the area receives a large amount of flood water from the Long Xuyen-Ha Tien Quadrangle and Cambodia draining into the sea

through dense drainage systems. In An Minh, salinity intrusion typically starts rising at the end of the Winter-Spring rice, with highest salinity levels usually occurred between March and April (DARD Kien Giang, 2017). During the high salinity period, farmers rely on the reserved water in the field and wait for the rain. An early intrusion of salt water therefore could damage the rice crop due to a lack of water and an increase of oxidation of acid sulfate soils since the research area is strongly impacted by surface acid sulfate and acidic soils (Thinh, 2003).

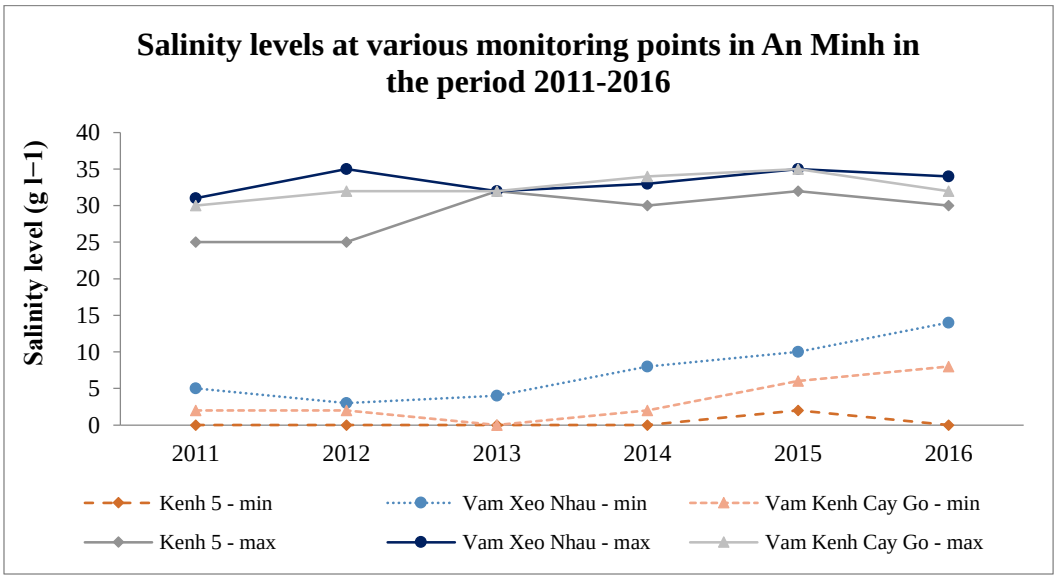


Fig. 4.3. Maximum and minimum salinity levels at various monitoring points in An Minh in the period 2011-2016 (Source: DARD Kien Giang, 2017b)

In Soc Trang, a low river bed and the influence of two tidal cycles per day allow salt water to be distributed far inland and in a large area of the province through a dense network of rivers and canals (DARD Soc Trang, 2015a; Tri, 2012). During the dry season, the area is strongly influenced by the North-East monsoon wind that can bring salt water even further inland (DARD Soc Trang, 2015a). The monitored salinity levels in Soc Trang exhibit a slightly decreasing trend in the period 2000-2014 (Fig. 4.4). This declining trend could be explained by the implementation of several salinity-control projects to improve the fresh water supply and limit the geographical extent of salinity intrusion in the coastal areas of the Ca Mau peninsula since the early 1990s (Hashimoto, 2001; see Chapter 5, section 5.4). A high salinity level in the rivers and canals would be a problem for rice and rice-shrimp systems in Soc

Trang since it prevents water irrigation into the field that consequently leads to increase of the oxidation of acidic soils and release of toxic substances (Aizawa et al., 2009; Leigh et al., 2017). In the saline water zone, increased salinity level in the rivers is not a major problem for shrimp production since farmers usually get the water at the time of suitable salinity levels and recirculate the water for three to four seasons. However, high salinity levels in the rivers would prevent farmers from irrigating river waters to lower the salinity levels in the shrimp ponds in the case of high temperature that leads to an increase of salinity levels in the pond.

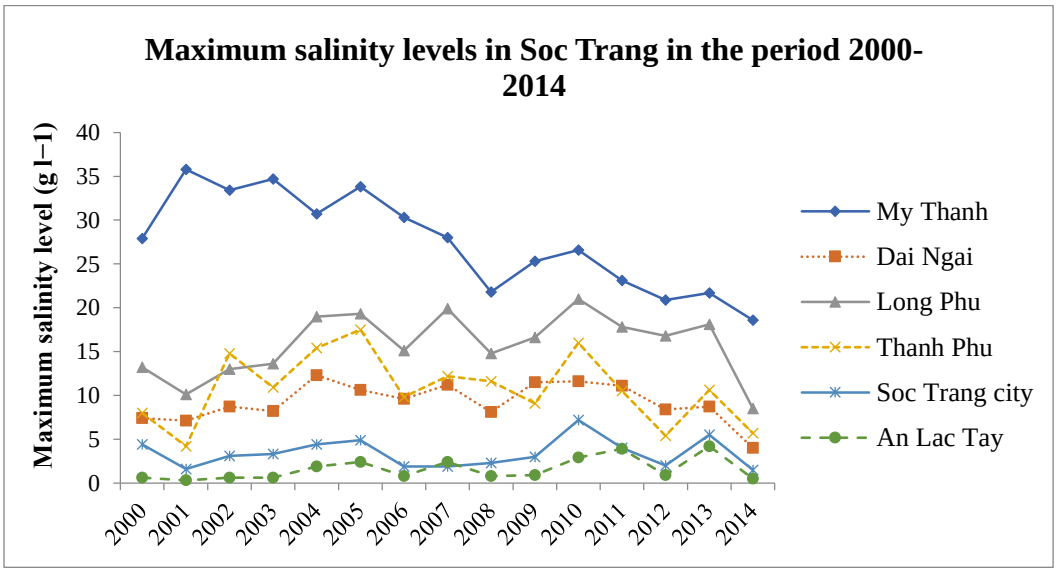


Fig. 4.4. Maximum salinity levels in different monitoring stations in Soc Trang in the period 2000-2014 (Source: DARD Soc Trang, 2015)

4.3 Biophysical changes related to salinity intrusion in the coastal areas of the Red River Delta

The RRD is characterized by a relatively flat topography at lower than 3 m above sea level, with most of the delta plain is lower than 1 m above sea level (Minh et al., 2010; Syvitski and Saito, 2007). Compared to the MKD, the RRD has a smaller catchment basin at approximately 25,000-30,000 km^2 with a steep gradient (Tanabe et al., 2006). The research area in the RRD is influenced by the diurnal tidal regime from the Gulf of Tonkin with a tidal range between 0.5 and 2.5 m (Minh et al., 2010). During the dry season, the salt water at 4 g l^{-1} can intrude up to 40 km upstream of the Red River (Minh et al., 2010). The distance of

salinity intrusion in the delta depends on the river flows, the tidal cycle, and the river morphology (Pruszak et al., 2005).

The RRD has a long tradition of hydraulic development for rice cultivation (Tessier, 2011). The hydraulic development was started more than one thousand years ago in order to protect local people from natural hazards such as flooding and storm surges and to facilitate agriculture production. These protective systems have been continuously developed since then. From 2006, the dyke systems in the RRD have been upgraded thanks to several projects for concreting the sea dyke system from Quang Ninh to Quang Nam and upgrading the river dykes along the main rivers (e.g. Hong and Thai Binh rivers) (GoV, 2006). Thanks to the upgrade of systems of dykes and irrigation, the extent and severity of salinity intrusion have been reduced (Cong et al., 2009). However, the salinity intrusion through sluicegate leakages and salinity infiltrations through sea dykes still existed (Yen et al., 2016). In addition, the increasing salinity intrusion to upstream areas of the rivers would create difficulty for irrigation in the coastal zone as the inlet gates in downstream areas of the rivers are closed and freshwater is irrigated into the fields from intake gates farther upstream (Yen et al., 2016).

Seasonal variations of rainfall and temperature in Nam Dinh

The monitoring rainfall in Nam Dinh exhibits a large fluctuation between the dry and wet seasons during the period 2007-2015 (Fig. 4.5). Most of the rainfall was distributed during April to October, while low rainfall occurred from November to March. Following the first rains, farmers in the research area start the Winter-Spring rice (Vietnamese Chiem rice or Chiem Xuan rice) from the end of February to the early of June, and Mua (wet season) rice from the end of July until the early of November (Source: FGDs). Being located within a subtropical climate, the temperature is Nam Dinh is lower than in the MKD (Fig. 4.5). The temperature starts rising in March and gets highest in June during the middle of the wet season. Thus, the effect of temperature on salinity intrusion in the RRD is lower than the MKD due to a low evaporation rate and a peak of temperature occurs during the period of high river discharge and low salinity levels.

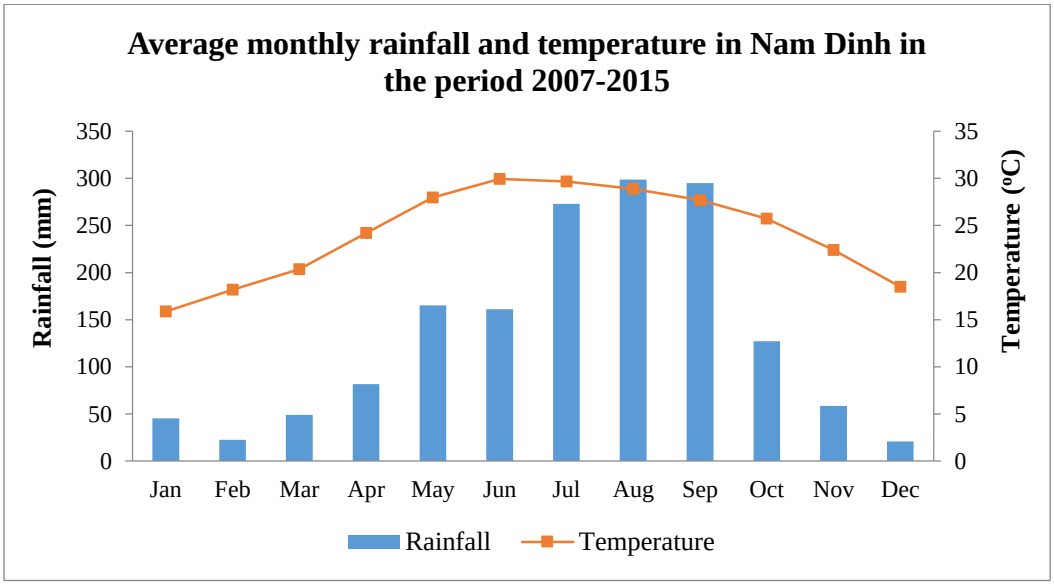


Fig. 4.5. Average monthly rainfall and temperature in Nam Dinh in the period 2007-2015 (Source: NCHMF, 2017)

Changes in water levels of the rivers and salinity conditions in the research area

The research area in the RRD is located close to the Ba Lat mouth which is the main estuary of the Red River. This distributary constitutes 25% of the total amount of the water discharge of the Red River amongst its branches with the highest water discharge at 34×109 m^3 per year (Pruszak et al., 2005). Nevertheless, the amount of water and sediment transport of the Red River has been decreasing (Minh et al., 2010). Coinciding with the distribution of rainfall, the river flow of the Red River varies largely between the dry and wet seasons, with a low discharge at less than 1,000 $m^3 s^{-1}$ in the dry season and a peak of water discharge at 14,000 $m^3 s^{-1}$ in case of flood in the period 1996-2006 (Minh et al., 2010). The water levels of the Red River measured at Giao Thuy during the Winter-Spring season from December to April show little variations in the period 2005-2015 (Fig. 4.6a). The water levels were typically highest in December and lowest in March before rising at the beginning of the wet season in April. In addition to seasonal fluctuation, there is also an unequal distribution of the water budgets across the Red River basin that typically causes freshwater shortages in high elevation areas of the delta (Minh et al., 2010; Pruszak et al., 2005).

Similar to the water levels, the salinity levels measured in Giao Thuy present a very slight fluctuation between years from 2005 to 2015 (Fig. 4.6b). Corresponding to the rainfall and

water discharge, the salinity levels typically increase from December to April during the low flow period of the Red River. The highest salinity level usually occurred in January (DARD Nam Dinh, 2016). A high salinity level during that period could create difficulty for irrigation and affect the Winter-Spring rice at the early stages during which a high amount of irrigation water is needed for land preparation and vegetative growth. The salinity levels also decline substantially when going further upstream of the Red River (see Fig. 4.6b).

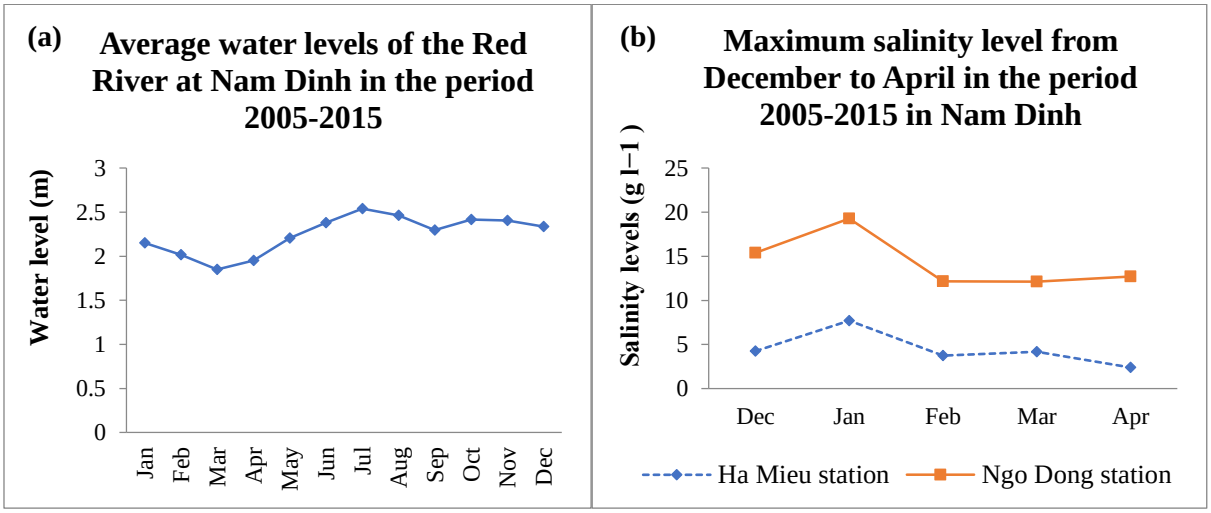


Fig. 4.6. Average water levels (a) of the Red River at Ha Mieu station (26 km from the sea), and salinity levels (b) at Ngo Dong station (17 km from the sea) and Ha Mieu station in the period 2005-2015 in Nam Dinh (Source: DARD Nam Dinh, 2016)

4.4 Projected sea level rises and salinity related risks in the Mekong and Red River deltas

Sea level rise and increased climate variation are likely to accelerate the impact of salinity intrusion in the coastal zones of Vietnam (Arndt et al., 2015; Carew-Reid, 2008; Dasgupta et al., 2007). The increased sea level rise is projected to severely worsen the economy of the country, especially in the coastal zones and when it comes together with cyclone strikes or storm surges by 2050 (Arndt et al., 2015). According to the high greenhouse gas emission scenarios of MONRE, if the sea level increased by 1 m, 38.9% of the MKD would be inundated (MONRE, 2016). In Kien Giang, a 1-m sea level rise would flood 76.9% the province, while in Soc Trang, 50.7% area of the province would be inundated (Fig. 4.7)

(MONRE, 2016). In the RRD, it is projected that the 4 g l^{-1} isohaline would shift to 20 km further inland at the end of this century if the sea level increased by 75 cm, as predicted in the medium greenhouse emission scenario of MONRE (Anh et al., 2014; MONRE, 2009). In the RRD, a 1-m rise of sea level would flood 16.8% the total area of the delta, with Nam Dinh being the most impacted province with 58.0% areas being inundated (MONRE, 2016). However, these projected flooding areas did not account for the existence of sea dykes in the RRD, as well as the potential impact of future implementation of dykes in the MKD. These protective infrastructures would reduce the effect of eustatic sea level rise and flooding areas in the coastal areas of both deltas, but could also potentially contribute to increases in land subsidence and salinity intrusion as feedbacks from the interventions (see Chapter 6 for a discussion of feedbacks in agricultural changes).

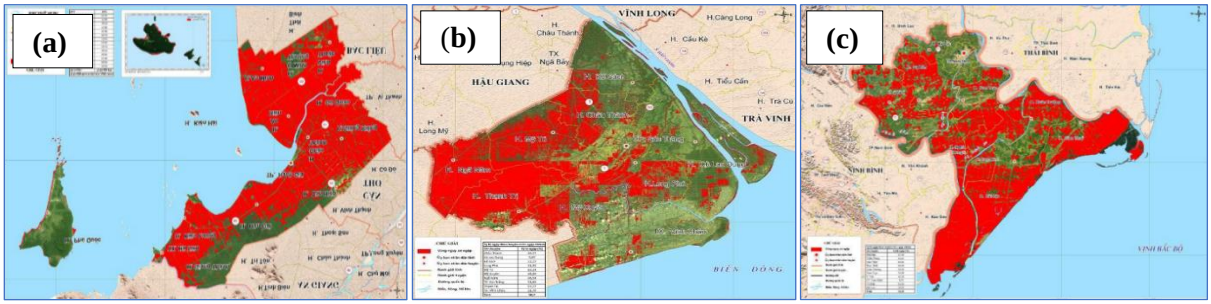


Fig. 4.7. Maps of projected inundation areas (in red) in Kien Giang (a), Soc Trang (b) and Nam Dinh (c) if sea level rise increased by 1 m (Source: MONRE, 2016)

In addition, both the RRD and MKD are at risks of overexploitation of groundwater (Wagner et al., 2012a; World Bank, 2003) and are ongoing subsidence (Dang et al., 2014; Syvitski et al., 2009). In the coastal areas of the deltas, high salinity levels and lack of freshwater supplies have driven the exploitation of groundwater for domestic, industrial and agricultural uses. These first order-responses (Birkmann, 2011) to biophysical hazards could exacerbate the salinity intrusion and create new pressures to the delta systems due to an increased intrusion of salt water into the river channels and aquifers (Rogers et al., 2013), as well as an acceleration of delta' subsidence (Syvitski and Saito, 2007). The latter would be more problematic for the MKD since it is a low-lying delta with high rate of subsidence (Erban et al., 2014).

4.5 Major changes in agricultural systems facing increased salinity intrusion in the Mekong and Red River deltas[3]

4.5.1 Rice intensification and diversification of agricultural systems in the Mekong Delta and research areas

Agricultural development in the MKD since 1975 has followed the trend of rice expansion and intensification from 1975 to the late 1990s, and diversification of rice production to aquaculture and upland crops from the early 2000s onward (Fig. 4.8). The first development stage experienced a rapid expansion and intensification of rice farming system (Sanh et al., 1998). Rice production in the MKD has increased from 4.7 million ton in 1975 to 7 million ton in 1985 and then 13 million ton in 1995 (MARD, 2017). Since 2000, the growth of cultivated rice area (i.e. rice land multiplies with the number of crops per year) in the delta has declined continuously after the central government implemented a new policy that promoted more diverse land uses (Can et al., 2007; GoV, 2000; Käkönen, 2008). This policy together with the increasingly international market demand for shrimp and demographic factors such as population growth and migration to coastal areas for land reclamation have led to a rapid expansion of saline and brackish aquaculture in the coastal zones of the MKD (Joffre et al., 2007; Miller, 2014).

These agricultural development trends are well illustrated in the statistical data. In the coastal provinces[4] of the MKD, aquaculture area increased rapidly from 428,100 ha in 2000 to 728,600 ha in 2015, while the cultivated area of rice remained stable (i.e. from 2,451,000 ha in 2000 to 2,488,400 million ha in 2015) during that period (GSO, 2015b, 2015c). As a result, aquaculture production in the coastal provinces rose from ca. 0.23 million ton in 2000 to ca. 1.36 million ton in 2015 (GSO, 2015c), in which shrimp production contributed the largest share. During 1995-2015, the output of shrimp production in the coastal provinces increased multiple times from 68,593 tons to 509,217 tons (GSO, 2015d). However, the outspread of shrimp diseases (e.g. the White Spot Disease Virus) together with the plummetting of shrimp

[3] The analysis of changes of cultivated areas at the district level was not carried out since the geographical areas of all research districts have been adjusted over the last decades (An Minh in 2007, My Xuyen in 2009, Vinh Chau in 1991, and Giao Thuy in 1997), and thus the analysis of land use changes based on statistical data at the district level would be inaccurate.

[4] Coastal provinces in the MKD consist of eight provinces Long An, Tien Giang, Ben Tre, Tra Vinh, Soc Trang, Bac Lieu, Ca Mau, and Kien Giang that have a border with the sea.

prices in 2008 concomitantly with the rapid increase of rice prices on the international markets resulted in a sharp decline of shrimp farming areas in the MKD during 2005-2008 (Ha, 2012). Although shrimp production continued rising, the increasing trend of cultivated shrimp areas slowed down since 2005 before rising again since 2009 (GSO, 2015d).

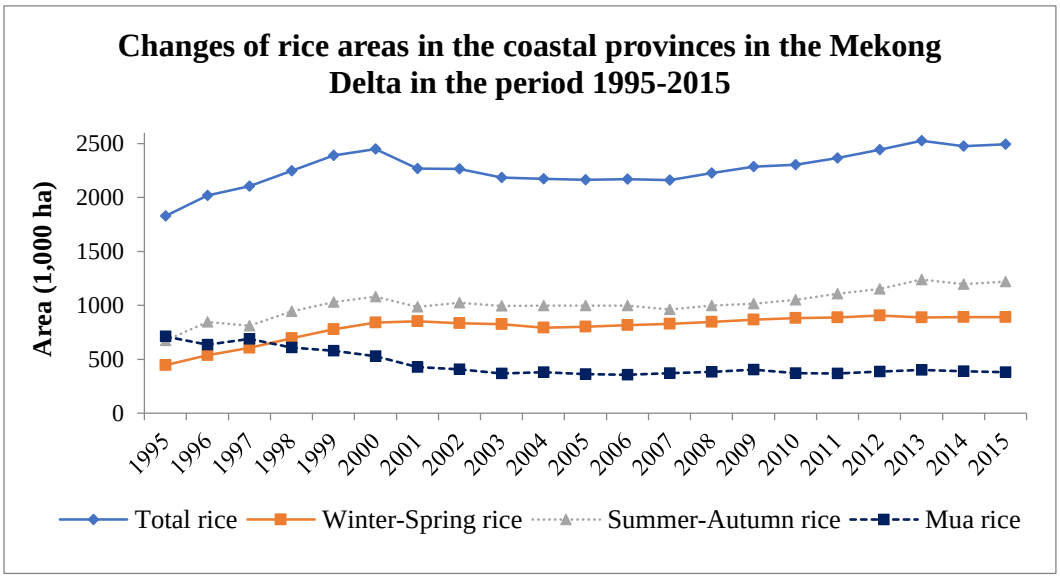


Fig. 4.8. Changes of Winter-Spring, Summer-Autumn, Mua and total rice areas in coastal provinces of the Mekong Delta in the period 1995-2015 (Source: GSO, 2015a)

Rice intensification, rice land expansion, and aquaculture development in Kien Giang

In contrast to other coastal provinces, the total cultivated rice area of Kien Giang continued rising after 2000 (Fig. 4.9). In Kien Giang, in addition to many hydraulic works to prevent salinity intrusion and improve freshwater supply for the coastal zone, several large projects to control flooding in the Long Xuyen-Ha Tien Quadrangle and to reclaim the acid sulfate soils have been carried out in the province over the last decades (Hashimoto, 2001). These land reclamation projects have enabled the expansion of rice land into flood-prone and acid sulfate soil areas and the increase of the cropping number per year (Biggs et al., 2009; Nhan et al., 2015). As partly a result of these projects, the cultivated rice area of the province continuously increased from 380,300 ha in 1995 to 769,500 ha in 2015 due to a growth in both Winter-Spring and Summer-Autumn rice.

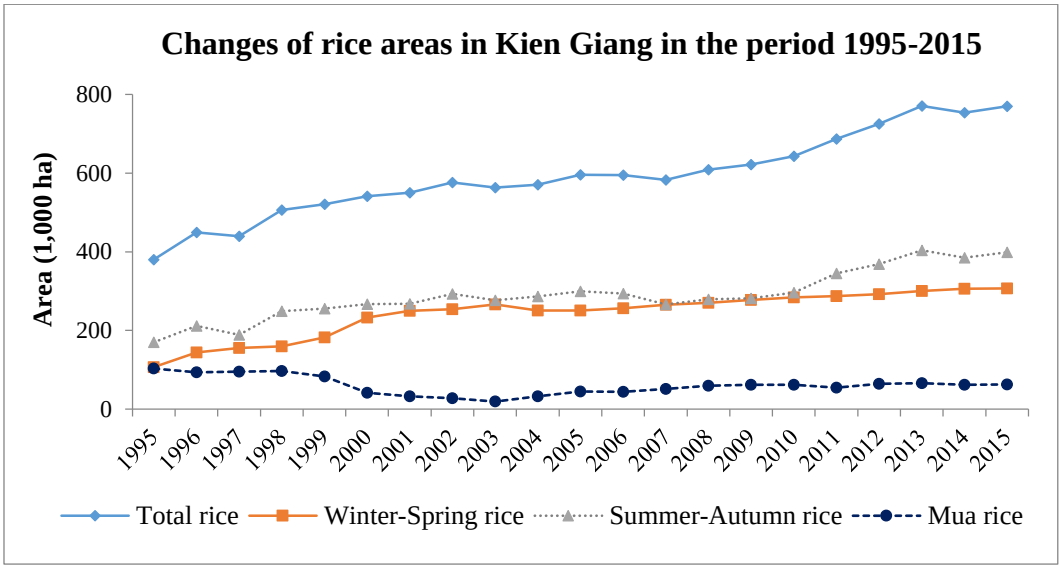


Fig. 4.9. Changes of Winter-Spring, Summer-Autumn, Mua and total rice areas in Kien Giang in the period 1995-2015 (Source: GSO, 2015a)

Since 1999-2000, while the areas of Winter-Autumn and Summer-Autumn rice continued rising, the area of the traditional Mua (rain-fed) rice of the province has been declining (Fig. 4.9). In contrast, the area of aquaculture land in Kien Giang increased rapidly from 34,600 ha in 2000 to 136,200 ha in 2015 (GSO, 2015c). The most growing sectors were extensive and improved extensive shrimp and integrated systems of aquaculture-rice crop or aquaculture-garden (Table 4.1).

Table 4.1. Aquaculture changes from 2002 to 2012 in Kien Giang

Area (ha)	2002	2006	2007	2008	2009	2010	2011	2012
Shrimp (intensive, extensive, integrated rice-shrimp)	38,000	72,736	78,620	81,255	78,426	81,726	84,571	87,123
Fish (net fish, fish-rice field, fish-garden)	10,993	11,333	15,142	20,209	31,754	31,970	15,274	13,768
Other aquatic species (e.g. crab, clam)	752	2,561	10,073	7,687	9,634	5,195	13,095	7,082
Total	49,745	82,966	103,835	109,151	119,814	118,891	112,939	108,024

(Source: DARD Kien Giang, 2015)

Rice intensification and the rapid growth of shrimp production in Soc Trang

Rice intensification has taken place in Soc Trang later than for other provinces in the MKD (Sanh et al., 1998) during the early 1990s after several salinity-control and irrigation systems to prevent salinity intrusion and improve freshwater supply for the coastal zone of the Ca Mau Peninsula were carried out in the province (see Table 5.3, Chapter 5). The total cultivated rice area in the province increased from 275,600 ha in 1995 to 370,400 ha in 2000 (Fig. 4.10) (GSO, 2015b). The expansion of cultivated rice area during this period resulted from the increase of Winter-Spring and Summer-Autumn rice, while the area of Mua (rain-fed) rice of the province declined continuously from 132,600 ha in 1995 to 28,600 ha in 2015 (Fig. 4.10) (GSO, 2015b). Together with Ca Mau and Bac Lieu, Soc Trang is considered as one of the typical coastal provinces in the MKD that have rapidly transformed the agricultural landscape in areas along the coast from rice cultivation to dominantly shrimp production (Can, 2011). Aquaculture systems in Soc Trang also involved in the intensification of stocking densities and input use and diversification of aquatic species such as changes from black tiger shrimp to white leg shrimp and other aquatic species such as mudskipper and *Lates calcarifer* (Can, 2011; Joffre, 2015).

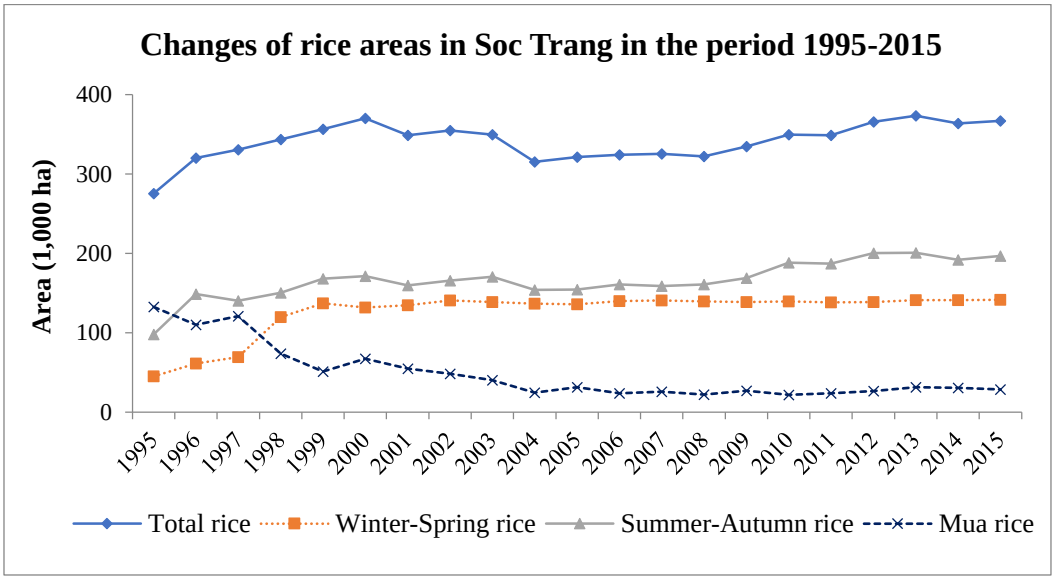


Fig. 4.10. Changes of Winter-Spring, Summer-Autumn, Mua and total rice areas in Soc Trang in the period 1995-2015 (Source: GSO, 2015a)

4.5.2 Stability of rice land and diversification of agricultural systems in the Red River Delta and research areas

In contrast to the MKD, agricultural land in the RRD during the last decades has not varied rapidly (Fig. 4.11). The agricultural land in the RRD increased from 662,185 ha in 1985 to 799,000 ha in 2015, mainly due to the expansion of arable land (GSO, 2015a; Khanh, 2012). However, the cultivated rice area in the RRD has stabilized since the reunification of the country in 1975, with a slight increase from 1,060,500 ha in 1976 to 1,110,900 ha in 2015 (GSO, 2015b; Khanh, 2012).

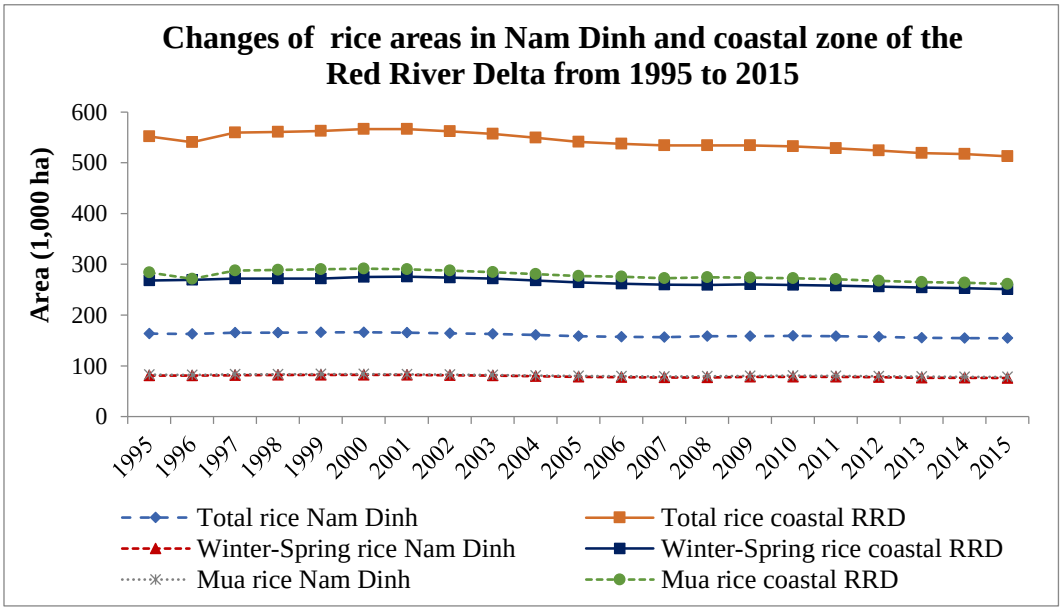


Fig. 4.11. Changes of Winter-Spring, Mua and total rice areas in Nam Dinh and coastal provinces[5] of the Red River Delta in the period 1995-2015 (Source: GSO, 2015a)

The intensification of rice production in the RRD, for example, changes in local rice varieties to modern and hybrid rice varieties and an increase of input use, has also observed since the early 1990s (Hanh, 2013). Local farmers have also diversified their agricultural production systems since the mid-1980s and more so since the early 1990s by converting their rice land to fish ponds, fruit orchards, vegetable, and increasing the share of livestock farming (Hanh,

[5] Coastal provinces in the RRD consist of six provinces Nam Dinh, Thai Binh, Hai Phong, Ninh Binh and Quang Ninh that have a border with the sea.

2013). In the coastal provinces of the delta, aquaculture land increased from 43,000 ha in 1995 to 72,000 ha in 2013, while rice area continuously declined from 552,000 ha to 519,300 ha during that period (GSO, 2015b, 2015c).

In Nam Dinh, the areas of both Winter-Spring and Mua rice have slightly declined over time since 2000 (Fig. 4.11). In a reversing trend, aquaculture land of the province has increased from 9,500 ha in 1995 to 11,600 ha in 2000 and 15,500 ha in 2016 (GSO, 2015c). Similar to the MKD, an acceleration of conversion to aquaculture since the early 2000s would be explained by the release of the policy for agricultural restructuring in 2000 (GoV, 2000) that allowed farmers to convert ineffective rice land to other farming systems such as freshwater aquaculture and vegetable crops.

4.5.3 Agrarian livelihood changes in the Mekong and Red River deltas since Doi Moi in 1986

In addition to on-farm changes, the economic structure and livelihoods of farming households in both deltas have fundamentally altered towards diversification of income sources since the early 1990s after the country followed the processes of socio-political transformation since Doi Moi (Tuan, 2010). Agrarian livelihoods in the coastal provinces in the RRD and MKD since then have been intensively influenced by the dynamic processes of industrialization and urbanization within the deltas and big cities nearby (e.g. Ha Noi and Hai Phong in the North and Can Tho and Ho Chi Minh City in the South) (Garschagen et al., 2012; van Dijk et al., 2013). During the 1990s, economic growth was maintained at 10% per year, whereby industry and service sectors achieved a vibrant development at 14-18% per year (Tuan, 2010). The shares of the agricultural sector in the economy have declined continuously from ca. 38.1% in 1986 to ca. 16.0% in 2016 (GSO, 2017). The socio-economic transition has led to changes in the household economic portfolios, with an increase of the shares of income from wage and non-farm activities and a decline of on-farm income (Garschagen et al., 2012; Ha, 2016). Agricultural labors have increasingly migrated to the big cities to seek off-farm jobs in the industrial and service sectors (Anh et al., 2003; Garschagen et al., 2012; Tuan, 2010). All research provinces had net migration rates in 2015, with -9.1‰ in Kien Giang, followed by 5.4‰ in Soc Trang and -3.4‰ in Nam Dinh. In contrast, the major destinations of the migrants such as Ha Noi and Ho Chi Minh City had positive net migration rates by 0.6‰ and 4.6‰ respectively (GSO, 2015e). This response to environmental stressors and social-economic transitions would influence the adaptation strategies to salinity intrusion in the

deltas in different dimensions. On one hand, a flow of remittances would contribute to lift the migrant-sending households out of poverty (Duc et al., 2015) and thus could boost the capacity to recover after salinity damage and provide investment capital for shifting to new systems. However, some studies conducted in Vietnam have also pointed out that a move of the prime labor force (e.g. young and high education people) would leave behind the rural economy with a lack of productive labor force for agricultural activities and climate change adaptation (Anh, 1998; Schwab, 2014).

4.6 Conclusions

This chapter examines changes in biophysical conditions related to salinity intrusion, general changes in the agricultural systems, and alterations in the household economic structure in the RRD and MKD during the last decades. The river water and rainfall are the vital resources for agricultural activities in both deltas. However, unequal distribution of rainfall between the dry and wet season, seasonal fluctuation of water discharges of the river, and timing of high temperature have resulted in an increase of salinity intrusion during the dry season in these deltas. The salinity intrusion in the research areas varies largely between years and the salinity trend is hard to predict due to the influence of a variety of natural and human factors. At the country and delta levels, the projected eustatic sea level rise is likely to accelerate the impact of salinity intrusion in the coastal zones due to an increased intrusion of saline water further inland.

Agricultural development in the MKD since 1975 has evolved in the process of intensification until the late 1990s and then diversification of farming systems since 2000. In the RRD, agricultural systems have only slightly changed since the early 1990s. These changes in agricultural systems in the deltas reflect a strong influence of the state. The next chapter will explicitly examine alterations in policies and legal framework related to agricultural systems and their influence by illustrating different roles of the state in agricultural changes in the RRD and MKD since 1975.

5. THE ROLE OF THE STATE IN AGRICULTURAL CHANGES IN THE MEKONG AND RED RIVER DELTAS IN VIETNAM SINCE 1975

5.1 Introduction

Governance system is a key factor in social-ecological systems (Biggs et al., 2012; Brondizio et al., 2016; Harrison, 2003) that operates in closely associated with other components such as resource units, resource systems, and users (Ostrom, 2009). Ecosystem changes caused by the interaction of these factors in turn create feedbacks with the resource management system and other subsystems at various levels (Ostrom, 2009). Numerous studies worldwide have highlighted that the state-driven governance in general and the government policies in particular is one of the main drivers of land use changes (Bezák and Mitchley, 2014; Hang et al., 2016; Mueller et al., 2014). Several empirical studies (Clement and Amezaga, 2008; Hanh, 2013; Renaud et al., 2015; Tran et al., 2018) carried out in Vietnam also point out the role of policies and legal framework as the primary drivers of change in land use and agricultural systems. However, there are limited empirical studies that examine the role of institutional and legal frameworks in land use change processes as well as how these systems are influenced by feedback from dynamic changing conditions at the locality. In the context of Vietnam, several studies on the institutional analysis in the fields of water and land use changes (Ha and Bush, 2010; Linh, 2015; Sikor, 2004; Waibel, 2010) consider regulation framework and policies and their practices as both the top-down interventions and results of the interplay and arrangements between the state and local actors, in which the state is a strong party. Changes in agricultural systems in the RRD and MKD in Vietnam since 1975 indeed reflect a strong influence of the agricultural policies and legal framework, with new policies released as triggers of farming system changes as well as feedback from changing conditions locally.

By adopting Evans' (1995) idea of different roles of the state as policing and promotion, this chapter aimed to examine various roles of the state in agricultural changes in the RRD and MKD in Vietnam since 1975. The study did not seek to examine the institutional design, performance or interplay as "rules of the game" (North, 1990), but aimed to provide an insight of the influence of policies and legal frameworks on agricultural development in the two deltas since the end year of the war in 1975. Specifically, the study described alterations on the three crucial governmental instruments of agricultural governance, including policies and planning, land use tenure, and infrastructure development and government support. These

governmental involvements and modifications in policies and legal framework illustrate various roles of the state as a primary regulator or a facilitator and organizer in the process of agricultural changes in the deltas.

5.2 Methodology

The analysis of this chapter was based on 27 in-depth interviews with local and national authorities, 198 semi-structured interviews and 11 FGDs with local farmers conducted in 2015-2016 as well as a collection and review of the literature and relevant government reports. These interviews and FGDs were carried out in three case studies in the MKD and RRD for the purpose of exploring drivers of agricultural changes in the MKD and RRD since 1975. In order to explore the historical and present drivers of change and adaptation in agricultural systems along salinity transects in the MKD and RRD, in-depth interviews with national authorities of MARD and MONRE and with local authorities at provincial, district, and commune levels were conducted in Kien Giang and Soc Trang provinces in the MKD and Nam Dinh province in the RRD. The consultations at the local level consist of interviews with authorities of DARD and DONRE at the provincial and district levels, as well as with staff of the People's Committee at the commune level. The analysis of alterations in policies and legal framework was conducted mainly at the national and delta levels. The influence of these policy instruments on agricultural systems in the research areas was illustrated by farmers and authorities' perceptions and their responses to the state intervention. The policies and legal frameworks that were mentioned during the in-depth interviews with authorities and semi-structured interviews and FGDs with farmers were reviewed in order to uncover and relate changes in agricultural systems to the policies at various governance levels. This empirical data was complemented with a literature review on policies and legal changes related to agricultural systems in the RRD and MKD since 1975.

5.3 The role of the state in agricultural changes in the Mekong and Red River deltas in Vietnam since 1975

5.3.1 The state as a regulator - Policies and land use planning in agricultural management in the Mekong and Red River deltas

The RRD and MKD over the last decades have been subjected to fundamental socio-political changes. Many of these changes took place in the land use structure, which has been mainly

induced by national policies. During the period late 1975-early 1980s, land in the RRD was collectivized under the state-owned farms, while agricultural activities in the MKD were principally organized as individual farming systems (MacAulay et al., 2007). Land use in both deltas during that time was planned by the government at provincial and district levels under the guidance of the Ministry of Planning and Investment and the National Institute for Agricultural Planning and Projection (Trung et al., 2006). Since Doi Moi in 1986, land use decisions were transferred to farmers. Within the vibrant processes of socio-economic transformation during the late 1970s-early 1980s (before and during Doi Moi), substantial adjustments in land use management were carried out, with a shift from the collectivization to decollectionzation and then decentralization in the agricultural management structure. Agricultural management decisions since then were relocated significantly to the provincial level (Fritzen, 2002).

These changes in the institutional framework of the state since 1975 were facilitated by a system of guidelines, directives and regulations at different scales to guide and enforce the land use policies (Table 5.1) (Ho and McPherson, 2010). The national policies regarding land use have created a legal framework for the design and formulation of numerous policies at lower administrative levels (Huong, 2016). By looking at the coastal areas of the two deltas, many shifts in agricultural systems have been observed after the release of these policies such as the rapid conversion from double rice and rice-shrimp to shrimp in the MKD after the agricultural restructuring policy in 2000, and the change from double rice to aquaculture in Nam Dinh in the RRD after the land allocation policy in 1992 (Table 5.1).

Table 5.1. Major land use policies implemented in the research areas in the Mekong and Red River deltas since 1975

Year	Policy	Content	Reference
1977	n/a	Secretary of the Communist Party suggested the change from single to double rice to ensure the food security of the district	FGD in An Minh
1981	Khoan 100 (100-CT/TW)	Farmers receive the inputs from the government, take care the farming activities and submit the quota output to the government	Semi-structured interviews and FGD in Giao Thuy
1986	Introduction of Doi Moi	A process of economic and political reforms - change to market-oriented mechanisms	Semi-structured interviews and FGDs in both deltas
1988	Khoan 10 (10-NQ/TW)	Farmers take all responsibility for the investment and farming activities. Many services were started	Semi-structured interviews in Nam Dinh
1992	Pretest of the Land Law 1993 in Nam Dinh	Land allocation to farmers	In-depth interview with hamlet leaders in Giao Thuy
1993	Khoan 10-Round 2 (64-CP)	Land allocation for a period of 20 years for rice land	FGD in Giao Thuy
2000	09/2000/NQ-CP	Agricultural restructuring policy for changing ineffective land use to aquaculture and upland crops	In-depth interviews with authorities, semi-structured interviews with farmers in both deltas
2002	2932/QĐ-UB	The district asked the provincial level for approval in economic structural change in 2001; the province approved the request and a detailed planning of shrimp farming of An Minh was released in 2002	In-depth interviews with district and commune authorities in An Minh
2002-2003	n/a	A policy/plan of the province for changing areas along the coast to freshwater fish	In-depth interviews with provincial and district authorities in Nam Dinh
2003	2072/QĐ-UB	Review, adjust and plan for agriculture, forestry, and aquaculture in the province in the period 2001-2010	In-depth interviews with district authorities in An Minh
2003	1351/QĐ-UB	Interest rate policy for investment in agricultural machines in the period 2003-2005	In-depth interviews with district authorities in An Minh

2004	2124/QĐ-UB	Loan policy for investment in agricultural machines in period 2009-2010	In-depth interviews with district authorities in An Minh
2010	1690/QĐ-TTg	Strategies for the development of aquaculture and fisheries until 2020	Interview with authorities of Ministry of Agriculture and Rural Development (MARD)-General Department of Aquaculture
2010	NĐ 41/2010	Loan policy for agricultural and rural development	In-depth interviews with district authorities in An Minh
2012	Regulation 42 (42/2012/NĐ-CP)	Policy to protect rice land and ensure 3.8 million ha rice of Vietnam	In-depth interviews with provincial authorities in Kien Giang
2012	n/a	The district agreed on the idea to develop *Scripus littoralis*-shrimp-crab farming to improve the environment of shrimp ponds.	In-depth interviews with district authorities in An Minh
2013	2760/QĐ-BNN-TCTS	Plan for restructuring aquaculture and fishery until 2020. The general trend is to promote aquaculture and rice-shrimp production	Interview with authorities of MARD-General Department of Aquaculture
2013	1445/QĐ-TTg	General development planning of aquaculture and fishery	Interview with authorities of MARD-General Department of Aquaculture
2014	1105/QĐ-UBND	General planning of Kien Giang for aquaculture development until 2020. A plan to change the area along the coast to mono shrimp production and revert some inside area in An Minh to rice-fish	In-depth interviews with provincial authorities in Kien Giang
2015	5528/QĐ-BNN-TCTS	Planning of shrimp farming until 2020, vision to 2030 in the Mekong Delta	Interview with authorities of MARD-General Department of Aquaculture

(Source: in-depth interviews with local and national authorities, FGDs, semi-structured interviews)

One general orientation in agricultural development from 1975 until the late 1990s was the prioritization of rice production for ensuring food security after the war and then for supporting export (Garschagen et al., 2012). At the provincial and district levels, specific number of ha (quota) of rice land to be maintained are set annually and detailed land use planning (eg. 5-10 years agricultural planning) has been carried out at provincial and district levels to ensure the "rice-first" policy (Garschagen et al., 2012). As mentioned by the provincial authorities in Kien Giang:

"The district manages the activities [in agriculture]. The district gives the responsibility to lower levels. Regulations to prevent the changes in land use and farming system exist, but the government cannot fine the farmers. There is Regulation 42 to ensure the 3.8 million ha rice. For Kien Giang, it has to keep the rice areas from now to 2020 for at least 370-380,000. Among them, 329,000 ha are double rice, and around 50-60,000 ha are single rice crop".

(Source: in-depth interview with provincial authorities in Kien Giang, date 04/02/2015)

Since 2000, the policy for restructuring and diversification of the agricultural sector was then implemented by the state nationwide (GoV, 2000). Thus, regardless of the switching to crop diversification since the beginning 2000s, the central policy and common practices since the 1975 until late 1990s have maintained the favour toward rice domination. In fact, it is not uncommon to witness provincial and district cadres struggling at the ambivalent stand between rice prioritization and crop diversification. In addition, although the restructuring policy in 2000 allows the diversification of land use, the choice of farming systems is dependent on specific land use planning that already sets the area of each type of crop (Garschagen et al., 2012; Tien et al., 2006). Farmers can still decide for the varieties of rice or fruits to cultivate for each land use category. However, a conversion from double rice to other land use categories such as aquaculture is not allowed (GoV, 2012). Such policy structure has had an influence on the decision of farmers towards their farming system. Farmers express their discontent on the restriction:

"The government does not allow the change. 99% households want to change to Hoe (*Styphnolobium japonicum* (L.) Schott)*, vegetable, Dinh Lang* (*Polyscias fruticose*)*, and VAC [integrated garden-pond-animal shed system]. The area does not lack water, but the rice diseases are high. Yellow snail and grass are high. We have to spray [pesticides] many times per season. Rat and seabirds [the village is close to the Giao Thuy Ramsar] also destroy rice".*

(FGD with farmers – Giao Thuy district, date 23/03/2016)

Although there is a dominant top-down approach towards land use planning, the upward flows of information and opinion from local to higher administrative levels exist. In the field of water and irrigation management in Vietnam, Linh (2015) demonstrates that a dense

network of formal and informal systems from national to hamlet level allows a dynamic flow of information and feedback between different governance levels. Similarly, Vasavakul (2006) argues that land use planning in Vietnam, in theory, begins at the commune level. As mentioned by the district authorities in An Minh: *"There has plan use planning for An Minh District until 2020, and each region is planned for specific farming systems already. The planning is based on the suggestion from the commune level. The office also organizes meetings with communes to collect their recommendations"* (Source: in-depth interview with district authorities in Kien Giang, date 05/02/2015).

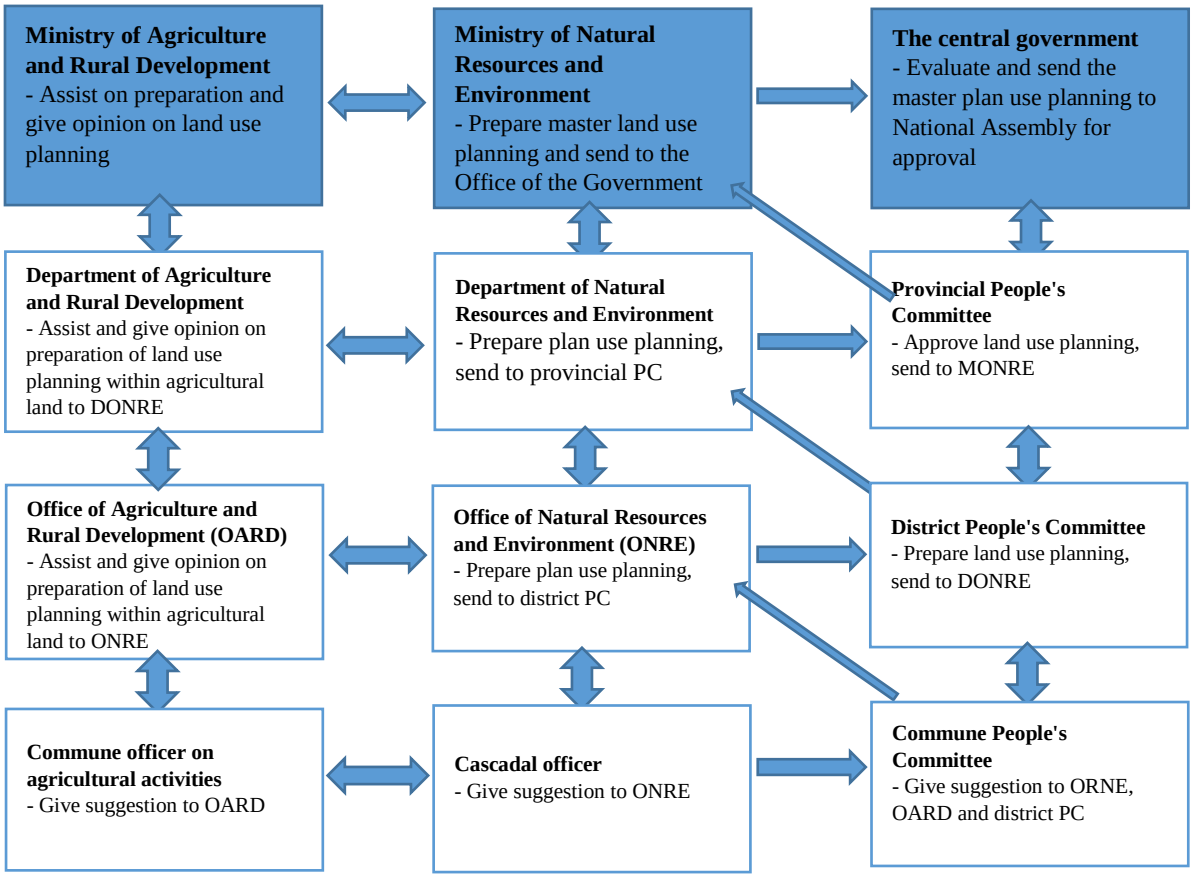


Fig. 5.1. Procedures of land use planning related to agriculture land in Vietnam (Source: based on Han, 2012; in-depth interviews with authorities)

The information flows in land use planning are depicted in Fig. 5.1. At the national level, the National Assembly approves the amount of each land use type to be maintained every 5-year period and the land use management schemes under the Land Law. The Ministry of

Agriculture and Rural Development (MARD), Ministry of Natural Resource and Environment (MONRE), and their lower administrative levels take principal responsibilities to manage the agricultural land. The MONRE and its lower administrative levels prepare the land use planning in collaboration with other government agencies and manage the land use types in general, while MARD and its lower administrative agencies take responsibility for the management of agricultural land such as agricultural, aquaculture and forest land (Fig. 5.1). The People's Committees (PC) at the provincial and district levels contribute to the land use planning via its functioning agencies (e.g. DARD and DONRE) and thus are able to make decisions on the planning (Wells-dang et al., 2016).

The rigidity of a policy in the agricultural sector in Vietnam is subjected to diversity and flexibility, depending on locality. In terms of the "rice-first" policies, to some extent bottom-up influence towards shifting away from rice domination also exists. Indeed, the change from double rice to rice-shrimp in Kien Giang was initiated by local farmers and commune authorities. The district government then asked the provincial level for an approval (GoV, 2002). As stated by the commune authorities in An Minh:

"At the beginning, it was written in the Red Book [certificate of land use right] that their land is used for double rice. Later farmers asked for a conversion, and the People's Committee had to agree. The change to rice-shrimp has helped to improve people livelihood, while double rice provided only quite enough profit. Salinity intrusion was not serious that farmers could not farm rice, but double rice could not generate too much benefit. Farmers can get only 15 million Viet Nam Dong (VND) for 1 ha of double rice, while 1 ha of rice-shrimp can generate 30-40 million VND".

(Source: in-depth interview with commune authorities in Kien Giang, date 05/02/2015)

In some research communes in the RRD (e.g. Giao Long and Giao Xuan communes in Giao Thuy District), the government planned small areas along the sea and river dykes to be aquaculture area and allowed the exchange of double rice in the inland areas to get the communal land along the sea and river dykes for large fish pond cultivation. The conversion from double rice to aquaculture in those communes is prohibited. However, in nearby communes where no area has been dedicated to aquaculture, some farmers have converted

double rice to fish ponds, and the action was tolerated by the local authorities to a certain extent.

The special cases of Kien Giang and communes in Giao Thuy denote the room of maneuver that Vietnamese structure of policy implementation possesses when it comes to agricultural policy. Other institutional studies in agriculture and irrigation systems (Hang et al., 2016; Sikor, 2004; Waibel, 2010) conducted in Vietnam have also pointed out cases of deviation between the implementation of national legislation and policies at the local level. In the context of water governance in Vietnam, some scholars (Benedikter, 2014; Linh, 2015) consider this kind of variation through a concept of "everyday politics" (Kerkvliet, 2005), in which the local actors play a role in influencing the higher administrative decisions through deviation or ignorance the will or orders from the state. The variation of policy implementation in the research areas could be explained by either a nature of encouraging more than forcing in the context of agricultural policy implementation, a relaxation on policy implementation at the locality, or a toleration of legalizing-fence breaking practices at a certain extent by the government (Heberer, 2005).

5.3.2 The state as a regulator - Land use rights and a relaxation to control of land use systems in the Mekong and Red River deltas

Land property rights have been considered as the most institutional factor that framed social and economic relations (FAO, 1994). In the RRD and MKD, many changes were carried out after the relaxation of the state on the control of land use rights that reintroduced the market incentives to farmers (Ravallion, 2008). Since the 1980s until 2016, there have been six significant adjustments in the legal framework related to land use rights, with the release of the Land Law in 1987, the Land Law in 1993, the Land Law in 1998, the Land Law in 2001, the Land Law in 2003, and the Land Law in 2013[6]. Each turn of the Land Law change marks a strategic effort of the state in managing the resources within the contemporary context of changes and transformation.

From the 1950s until 1981, land use system in the North of Vietnam was managed under the central planning and cooperative systems. In 1981, with the introduction of the contract

[6] The Land Law 1998 and 2001 are revisions of the Land Law 1993; and the Land Law 2008 is the revision of the Land Law 2003. The name Land Law is used for both the original land law and their revisions.

system known as Khoan 100 (see Table 5.1), land was given to cooperatives and then allocated to individual households with a contract. The households then received the input, carried out the assigned farming activities and submitted the quota output to the cooperatives according to the recorded labor hours on the communal land (FAO, 1994; GoV, 1981; Toan and Lakshmi, 2008). The implementation of Khoan 100 has created positive effects on the agricultural sector, and rice production of the country has increased by approximate 6.3% during 1981-1985 after a long period of stagnation (MacAulay et al., 2007). Since 1981 and more so since the beginning of Doi Moi in 1986, agricultural systems have evolved in significant changes in the economic structure and the role of individual farmers as a basic unit of agricultural production was increasingly recognized (MacAulay et al., 2007). The Land Law 1987 (GoV, 1987), the first land law since Doi Moi, established the private use of the allocated land and after the launch of the resolution known as Khoan 10 in 1988, farmers were titled the rice land for a period of ca. 15 years (GoV, 1988). In 1989, the policy for market liberation was released and since then, the economy shifted into market-orientated mechanisms and the private trade of agricultural products was officially recognized (GoV, 1989; Minot and Goletti, 2000).

The subsequent Land Law 1993 marked a significant change in land use tenure when rice farmers were entitled a land use right for a period of 20 years and land rights were made tradable (GoV, 1993; Taylor, 2007). This land law has been considered as "a cornerstone of new rural policy" of Vietnam (Sikor, 2004). The policy was widely perceived by farmers in the research area in Nam Dinh as Khoan 10-Round 2 in refer to Khoan 10-Round 1, the crucial land use policy of Doi Moi initiated in 1988 mentioned above (Table 5.1). The Land Law in 1993 was the main driver of agricultural intensification and diversification since the 1990s in the RRD (Hanh, 2013). There is evidence of the effects of changes of land use rights in the Land Law 1993 on crop choices and household labor allocation, in which provinces that experienced rapid land use change processes presented a higher proportion of multiple-year crops and a higher non-farm labor force (Toan and Lakshmi, 2008). The Land Law in 1998, 2001, 2003 and 2013 (GoV, 2013a, 2003, 1998) were further steps toward increasing the marketization of land use rights, the amount of land farmers can possess and the period of land titling (to 50 years for agricultural land in the latest Land Law 2013). The decollectivization in agriculture systems and the liberation of land use rights and market were major triggers of numerous agricultural changes (Ravallion, 2008). Land productivity has

been increased substantially, and land use changes were taken place nationwide afterward (Fig. 5.2).

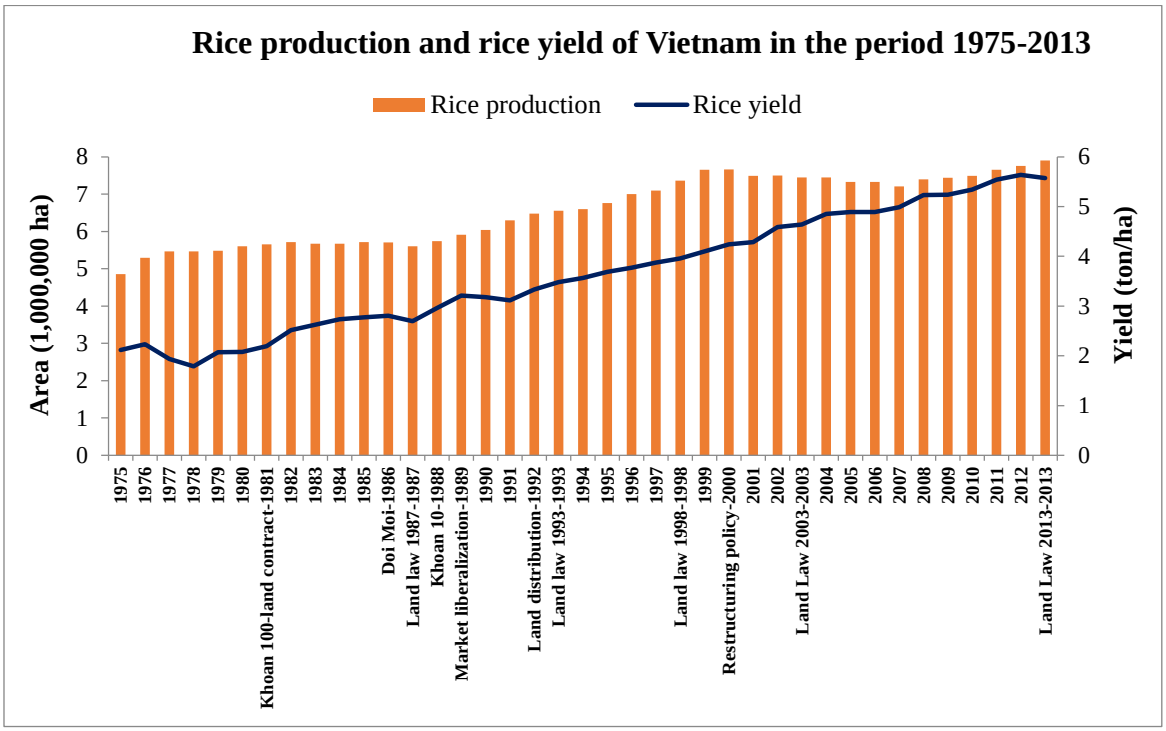


Fig. 5.2. Rice production and rice yield of Vietnam with relation to major land use policies in the period 1975-2013 (Source: FAOSTAT, 2016)

Differences in historical development regarding the land allocation and regulatory framework between the RRD and MKD also explain the variation in agricultural diversification between the two deltas. Farmers in the RRD have involved in a collective and state-dominated farming system for several decades until Doi Moi in 1986. In 1992, Nam Dinh was one of the first provinces that were selected for the pre-test of the land allocation one year before the Land Law 1993[7] and since then, farmers can own the rice land for 20 years (MacAulay et al., 2007). In the MKD, the land allocation was less dramatically as in the RRD and many farmers in the

[7] The land allocation was carried out one year after the seventh 5-year meeting of the Communist's Party in 1991 that confirmed the continuity of the pathway of Doi Moi. While some scholars (Sikor, 2004; Toan and Lakshmi, 2008) consider the land allocation as part of the Land Law 2003, this land allocation has been mentioned in the Vietnamese literature as a result of several resolutions (e.g. GoV, 1991) of the above meeting. The intensive hydraulic construction in the MKD since the early 1990s has also been attributed to these resolutions.

South resisted the collectivization (i.e. less than 6% of farmers in the MKD belonged to the agricultural cooperatives) and land allocation (Anh, 2012; FAO, 1994; MacAulay et al., 2007; Toan and Lakshmi, 2008). Farmers in the MKD thus remained primary decision makers on their farming activities, whereas the land preparation and irrigation works were taken by the production collectives or solidarity production groups (Benedikter, 2014). These disparities lead to the fact that farmers in the RRD usually depend on the community for the change of farming system. In addition, after multiple periods of land allocation, the farm size in the RRD is small and the land plots are fragmented (Table 5.2) (MacAulay et al., 2007; Tuan, 2010). In the semi-structured interviews with farmers in the RRD, dependence on community decisions, small farm size, and far-from-home land were usually mentioned as reasons to refuse to shift away from double rice in addition to the government regulations.

Table 5.2. Characteristics of agricultural land in the Mekong and Red River deltas

Region/provinces	Land/household (m^2)	Number of plots	Largest plot (m^2)	Distance from the house (m)	Smallest plot	Distance from the house (m)
Vietnam	10,140	5	4,830	1,200	2,250	900
Mekong delta	18,260	2	10,000	1,700	5,290	1,000
Red River delta	2,370	8	600	1,200	150	700
Nam Dinh	2,370	5	1,077	1,016	169	220

(Source: Tuan, 2010)

5.3.3 The state as a facilitator and organizer - Infrastructure development and government support for agricultural changes in the Mekong Delta

In the MKD, the irrigation development since 1975 has suited to the land use planning and the state development orientation in order to achieve these development and political objectives. The hydraulic works together with the government training and support in the MKD reflect the role of the state as a facilitator and organizer that creates or facilitates the favourable conditions for agricultural changes.

Before 1975, the irrigation systems in the MKD were mainly aimed for the purpose of intensive rice production in areas closed to the main rivers and in alluvial soils, while the areas classified as heavy acid sulfate and saline soils in principal were kept untouched (Hashimoto, 2001; MARD, 2017). The irrigation development few years after the country reunification in 1975 was considered as a continuity of the previous works on the modification of the ecological system, with many canals and waterways being dug by the collective labor forces (e.g. farmers, soldiers and hydraulic engineers) to improve freshwater supplies for rice cultivation (Benedikter, 2014; Biggs et al., 2009; Käkönen, 2008). These hydraulic works were considered as efforts to find and adopt a suitable pathway for irrigation development in the MKD after the war, based on the technocratic ideology transferred from the North of Vietnam, previous studies from international organizations, and results from research groups sent to the field by the Ministry of Irrigation (Benedikter, 2014; Käkönen, 2008; MARD, 2017).

From 1975, irrigation development also began to support the expansion of rice land into marginal areas of high acid sulfate and saline soils in the Plain of Reeds, the Long Xuyen-Ha Tien Quadrangle and the Coastal Zone. Many large projects for improved freshwater supplies and drainage of acid sulfate soils have been constructed in the MKD during the period 1975-late 1980s that influenced the river flows and salinity conditions in the research areas. These works include the dredging of Vinh Te canal and construction of dams e.g.Tra Su and Tha La to control flooding from the direction of Cambodia (1978-1981), excavation of canals to connect the Hau River and Rach Gia River (1981-1984), and numerous canals to supply fresh water from the Hau River to the western part of the MKD (MARD, 2018). These hydraulic works were mainly carried out in the upstream areas or within Kien Giang to control flooding and channel the river waters to areas where were impacted by water shortage or acid sulfate soils. Since the early 1990s, hydraulic infrastructure development has focused on dyke and sluicegate constructions in the coastal areas for salinity control in order to expand the freshwater area for rice cultivation and increase cropping number (Evers and Benedikter, 2009). This infrastructure development was strongly associated with the “rice-first” policy to protect freshwater zones from salinity intrusion and to turn the brackish water areas into freshwater zones for rice monoculture (Käkönen, 2008). The notable work of this orientation is the Quan Lo-Phung Hiep project (1992-2001) to turn brackish water areas of Soc Trang, Bac Lieu, Ca Mau and Kien Giang in the Ca Mau Peninsula into freshwater zones (World Bank, 1999).

In the research areas in Kien Giang, numerous smaller projects have been conducted since 1975 that have modified the salinity conditions locally (Table 5.3). These works consisted of the excavation of canals to improve the freshwater supplies in an attempt to amend the acid sulfate soils for the purpose of double rice cultivation few years after the end year of war in 1975, and the construction of dykes to separate the areas of shrimp and rice-fish areas to protect rice-fish production from salinity intrusion. In Soc Trang, there were several large-scale projects to improve the irrigation systems and to control salinity intensively since the early 1990s (Table 5.3). These hydraulic works in Soc Trang were part of the massive plan to turn the Ca Mau peninsula into a freshwater zone for the purpose of rice production mentioned above.

Table 5.3. Major projects for salinity intrusion control and improved freshwater supplies in the research areas in Kien Giang and Soc Trang

Years of implementation	Projects	Location	Project description
Kien Giang			
Since 1976	Excavation of canals	An Minh district	Excavation of canals to improve the freshwater supply for double rice cultivation, more intensively after the establishment of the agricultural cooperative in 1980
1984-1986	Construction of Canh Nong dyke	An Minh district	Excavation of canals and building of dykes to separate the inside and outside the dyke for rice and shrimp production
1994	Upgrade of Canh Nong dyke	An Minh district	Upgrade of the Canh Nong dyke, construction of four sluicegates to separate the rice-fish and shrimp zones
2009	Construction of Quoc Phong dyke	Along the coastal line of Kien Giang	Construction of sea dyke and sluicegates along the coast to protect the inland area from salinity intrusion, storms and coastline erosion
2011	Construction and upgrade of dykes and roads on dykes in An Bien and An Minh	An Minh and An Bien districts	Construction and upgrade of dykes and roads on dykes in An Bien and An Minh

Soc Trang			
1993-1994 to 2003-2004	Long Phu-Tiep Nhat project	Long Phu and Tran De districts in Soc Trang	Construction of river dykes and sluicegates, excavation of canals to improve freshwater supplies for double rice production
1992 to 2001	Quan Lo – Phung Hiep project	Nga Nam, Thanh Tri, My Tu districts in Soc Trang (works conducted in Soc Trang)	Construction of sluicegates to prevent salinity intrusion, excavation of canals to improved freshwater supplies for double and triple rice crops
1993-1994 to 2003	Ba Rinh-Ta Liem project	My Tu district in Soc Trang	Construction of dyke and sluicegates, excavation of canals and dredging of existing canals, installation of pumping stations to supply fresh water for double and triple rice crops
1995	Construction of dyke in My Xuyen	My Xuyen district	Construction of a dyke to protect the inland area from salinity intrusion for double rice production
2009-2010	Construction of a series of separating sluicegates	Soc Trang, Bac Lieu	Construction of sluicegates to control salinity intrusion from the direction of Bac Lieu province

(Source: in-depth interviews with local authorities, FGDs)

Following these large-scale projects, the agro-ecosystems in the coastal areas of the MKD were fundamentally altered (Can, 2011). According to Evers & Benedikter (2009), at the end of the 1990s, "much of the delta's territory had been transformed into a hydraulic landscape under human control". Local people subsequently have sought to adapt their traditional and river-based livelihoods to the changing conditions by switching the farming practices and shifting their agricultural systems.

In addition to infrastructure development, other supporting activities were implemented to enact the rice-first policy or the land use planning such as training, loan, and guidelines. Apart from formal intervention instruments, the state also has a strong ability to mobilize the mass organizations (e.g. Farmer's Association, Women Union) to promote and support the successful implementation of land use policies (Benedikter, 2014). In Soc Trang, in order to promote rice-shrimp production, supporting projects such as "sweet rice-clean shrimp" (Vietnamese "Gao Thom Tom Sach") and rice-shrimp collaborative groups were also established. These supports play a role as a trigger of agricultural changes (e.g. training for new farming knowledge and low-interest loans for the conversion), or facilitator (e.g.

subsidies and supporting projects) after the changes have been taken place. Farmers in the FGDs in An Minh mentioned the government supports in the change to the rice-shrimp system:

"At the time of change in 2001, the government had training on how to choose the shrimp stocks, pond preparation and water treatment, measurement of pH and salinity levels. The government provided loans to convert [rice fields, rice-fish fields] to the ponds, but this amount of money was not enough since the government only gave the money for the excavation. Farmers needed more money to buy lime. At the time of change in 1997, there was no training since the transportation was not good. The road was not upgraded. There was also no communication device. Later the government provided a loan at 2 million VND per ha through Vietnam Bank for Agriculture and Rural Development".

(Source: FGD with farmers - An Minh district, date 29/10/2015)

In the field of water governance, the state also plays a role as an organizer on the use and share of water resources between provinces and farmers' groups. In coastal areas of the delta, conflicts on water management between rice and shrimp production systems and between "only-rice" initiative and diversification of farming systems have emerged since the late 1990s (Can Tho newspaper, 2013; Käkönen, 2008; Lao Dong newspaper, 2012; Nhan et al., 2007; Sai Gon Giai Phong newspaper, 2008). Few months after the release of the agricultural restructuring policy in September 2000, the central government agreed for changing ca. 500,000 ha rice land in the MKD to brackish and saline aquaculture at the end of the year (GoV, 2000b). Since then, the plan to turn the Ca Mau peninsula to freshwater zone was terminated and irrigation development turned to support the diversification of agricultural systems and aquaculture in the coastal areas. Since 2010, the development of brackish aquaculture demanded a separation of irrigation systems to prevent water-sharing conflicts between rice and shrimp production. Sluicegates and small dykes were then constructed in the coastal areas to separate the fresh and saline water zones (MARD, 2017). A picture of water sharing and conflict was described in the below quotation:

"In 2007, Bac Lieu planned the regions which share the same border with Soc Trang to be rice (above part of the province) and shrimp (below part of the province) farming. Then, the sluicegates in Bac Lieu were opened to get salt water for shrimp cultivation. The salt water penetrated further inland to Soc Trang through Quan Lo-Phung Hiep canal. In 2008-2009, the salt water from Bac Lieu traveled very far inland to Nga Nam town of Soc Trang and created heavy damage for rice cultivation there. Then Soc Trang has asked MARD to establish a group to manage the water sharing between the two provinces. The team was then established, including provinces Bac Lieu, Soc Trang, and Ca Mau. These provinces came to an agreement that the salinity level of 4 g l^{-1} measured at Ninh Quoi corner [in Bac Lieu] is considered as the threshold for closing the sluicegates in Bac Lieu. However, farmers in Bac Lieu usually got salt water at 25-27 g l^{-1} and consequently, the salinity levels in Ninh Quoi corner were sometimes at 15-20 g l^{-1}. In 2009-2010, a project to separate fresh and saltwater regions between Soc Trang and Bac Lieu was implemented. Sixty-seven sluicegates have been installed in both provinces".

(Source: in-depth interview with provincial authorities in Soc Trang, date 09/02/2015)

5.4 Conclusions

As a result of decades of social-economic, political and environmental transformation, agricultural systems in the coastal areas of the RRD and MKD deltas in Vietnam have undergone considerable changes. Many agricultural policies that have been implemented nationwide have provided a legal framework for the promulgation of other policies at the local level to support the policy implementation such as land use planning and construction of hydraulic infrastructures. Numerous changes in agricultural systems were the direct responses to changes in policies and property rights or indirect responses to the government intervention after the social-ecological conditions that favour the shift of agricultural systems have been made by the government (e.g. through dyke construction, loans, and training). These changes in farming systems then generated feedbacks with the governance system at various levels and new policies were promulgated as responses to these changes. The policies and legal frameworks as well as infrastructure development, on one hand, have enabled the intensification and diversification of agricultural systems in the deltas, while concomitantly can constrain the shift to other systems at the local levels and can create water-sharing conflicts between farming systems. A flexibility of land use changes for learning new farming

systems and taking feedback from local changes into agricultural management system is crucial to limit these drawbacks. In addition, understanding cross-scale interactions and feedback in agricultural changes are necessary to prevent the development of "path-dependencies" and lock-in effects between agricultural changes. The next chapter will tackle these issues by identifying multiple-scale drivers of change, their potential interactions and feedback in shaping agricultural systems in the case study areas since the end year of the war in 1975, as well as explore various adaptation pathways through the lens of complex adaptive systems and adaptation pathways.

6. DRIVERS OF CHANGE AND ADAPTATION PATHWAYS OF AGRICULTURAL SYSTEMS FACING INCREASED SALINITY INTRUSION IN COASTAL AREAS OF THE MEKONG AND RED RIVER DELTAS IN VIETNAM[8]

6.1 Introduction

Coastal deltas are usually highly populated and productive agricultural areas due to the rich provision of ecosystem services contributing to economic value (Syvitski and Saito, 2007). Global deltaic coastal zones are facing dynamic changes mainly driven by sea level rise and human activities that modify deltas' catchment characteristics such as deforestation, large-scale hydraulic development and land use conversion (Syvitski et al., 2005). These changes in land use can impact the stability of the coastal zones and global and regional climates through alteration of carbon cycles, soil degradation, declines of biodiversity, and changes in the provision of ecosystem services (de Araujo Barbosa et al., 2016; Lambin et al., 2006).

The Mekong and Red River deltas in Vietnam are examples of dynamically changing deltas where an interaction of natural forces such as flooding and tidal influences and human efforts to control water resources have shaped a large diversity of agricultural landscapes. The two deltas are currently agricultural hotspots of Vietnam, contributing 71% of the rice production, 86% of the farmed aquaculture and 65% of the fruit production of the country (GSO, 2015; MARD, 2013). Being low-lying coastal areas (Syvitski and Saito, 2007) with ongoing subsidence (Dang et al., 2014; Syvitski et al., 2009), these deltas are some of the most vulnerable deltas to sea level rise globally (Carew-Reid, 2008; Dasgupta et al., 2007). In the coastal areas of these deltas, salinity intrusion - which is only partially induced by sea level rise - is a major threat to agricultural production. The Red River Delta (RRD) today is protected from salinity intrusion by a system of concrete sea and river dykes, sluicegates and pumping stations (Hien et al., 2010). In the Mekong Delta (MKD), salinity intrusion is naturally happening as it is a tide-dominated delta and there are fewer protective infrastructures in place (Renaud and Kuenzer, 2012). During the dry season, corresponding also to low river discharges, tides from the South China Sea and the Gulf of Thailand

[8] This chapter is based on the paper: Tu, M.N, Renaud, F.G, Sebesvari, Z. (2019). Drivers of change and adaptation pathways of agricultural systems facing increased salinity intrusion in coastal areas of the Mekong and Red River deltas in Vietnam. Environmental Science and Policy, 92, 331-348.

typically bring salt water far inland and impact approximately 1.8 million ha in the delta, of which 1.3 million ha are affected by salinity levels above 5 g l^{-1} (Carew-Reid, 2008; MRC, 2011; Tri, 2012). In the dry season of 2015-2016, which was characterized by a strong El Nino effect, salt water intruded more than 90 km inland and caused heavy crop losses and damages in 11 out of 13 provinces in the MKD (CGIAR, 2016). In total, an estimated two million people lost their income from agricultural production, while two million people also experienced shortages in drinking and domestic water supplies due to the drought and increased salinity intrusion (UNDP, 2016).

Local farmers have learned to adapt to typical seasonal changes in salinity levels for generations, for instance by cultivating various crops at different times of the year and along the salinity transects. Many salinity-control structures such as dykes, sluicegates and irrigation infrastructures have also been intensively developed in the MKD in the recent past to limit the salinity-affected areas and improve freshwater supplies for intensive rice production (Renaud et al., 2015). This infrastructure development was embedded within other policies, for instance, the "rice first" policy to ensure national food security (GoV, 2012a; Käkönen, 2008). After the historical salinity event in 2015-2016, the national government decided to reduce the rice land area to be maintained from 3.81 million ha to 3.76 million ha by 2020 (GoV, 2016a). Of this new total, 400,000 ha of rice land that is considered ineffective for rice production could be converted to more profitable crops, given that this area could be reverted later to rice land (GoV, 2016a). This rice area target is then assigned to lower administrative levels (e.g. provincial and district levels) to dictate land use management. During the last decades, agricultural systems in the deltas were subjected to fundamental changes in the national political systems. This is especially true since Doi Moi in 1986, when the country switched its political-economic orientation first from centrally planned, to collective, and finally to a market-oriented economy with increased liberalization and integration globally. Many changes in agricultural systems such as shifts from rice monoculture to aquaculture and upland crops were induced by the releases of new agricultural policies and the relaxation of the state control over the agricultural sector (Käkönen, 2008; Ut and Kei, 2006).

Against this background, agricultural changes in these deltas have been influenced by various drivers - defined here as any social or environmental factors that cause changes in the systems (Millennium Ecosystem Assessment, 2005) - at multiple scales of the deltaic social-ecological systems. Changes (in response to social-political drivers of change) and adaptation (to salinity

intrusion) of agricultural systems could alter these deltaic social-ecological systems, modify the distribution of risks within them, and lock specific areas of the deltas into particular agricultural systems (Käkönen, 2008; Miller, 2014). At present, several salinity-control infrastructures such as sluicegates and sea dykes are to be implemented in the RRD and MKD (GoV, 2012b; Mekong Delta Plan, 2013). The analyses of past decisions regarding agricultural systems in the deltas can provide important information on implications for land use planning and decision making (Käkönen, 2008). For the MKD, the potential impact of large-scale protective infrastructures that are planned could be partly inferred from the situation in the RRD. This study aims to analyze current and historical drivers of agricultural changes in coastal areas of the Red River and Mekong deltas since the end of the war in 1975 and explore future development and adaptation options to increased salinity intrusion. A historical analysis of drivers of changes and their interactions and feedbacks in shaping agricultural systems and adaptation in these deltas enhances our understanding of the management of complex agricultural systems and provides insights for adaptation planning both in these and other similar coastal deltas.

The paper is structured as follows: Section 2 introduces the theoretical background of the paper. Sections 3 and 4 provide a detailed description of the research areas and methodology. Section 5 presents the historical changes in the two deltas since 1975, the drivers and feedback processes in changing agricultural systems. Section 6 discusses the role of drivers of change and their influences on agricultural systems. Section 7 presents different adaptation pathways of agricultural systems to changing drivers and salinity intrusion. The last section discusses adaptation barriers in terms of agricultural changes, provides some conclusions and the implications of the research.

6.2 Complex adaptive systems, drivers of change and adaptation pathways (These theories and concepts are mentioned in Section 2.1.3, Section 2.1.4 and Section 2.4; Chapter 2 Theoretical and conceptual background)

6.3 Study areas (A detailed description of research sites is mentioned in Section 3.1, Chapter 3 Methodology)

Table 6.1. Characteristics of research sites

Research sites	An Minh district – Kien Giang province (MKD)	My Xuyen and Vinh Chau districts – Soc Trang province (MKD)	Giao Thuy district – Nam Dinh province (RRD)
Tidal regime	Diurnal tides from the Gulf of Thailand	Semi-diurnal tides from the South China Sea	Diurnal tides from the Gulf of Tonkin
Salinity control	No protection against salinity intrusion	Partial protection to control salinity intrusion by river dykes, embankments, and sluicegates	Protection against salinity intrusion by sea and river dykes, sluicegates, and pumping stations
Climate	Tropical monsoon climate	Tropical monsoon climate	Humid subtropical climate
Agro-eco zone categorization[a]	Gulf of Thailand coastal zone	Ca Mau peninsula zone	Coastal agro-ecological zone
Soil characteristics[b]	Acid sulfate soil	Saline and acid sulfate soils	Saline and alluvial soils (in double rice villages), sandy soil (in rice-vegetable and vegetable villages)
Salinity periods[c]	Freshwater zone: between January and May Brackish and saline water zones: from end of December to end of August	Fresh and brackish water zones: from end of December to June Saline water zone: salinity is highest in March and April and lowest in November	Salinity intrusion increases from December to April. The average salinity levels between December and April during 2000-2015 were 14.3 g l^{-1} and 4.5 g l^{-1} at distances of 17 km and 26 km to the sea, respectively (DARD Nam Dinh, 2016)
Cropping calendar[d]	Freshwater zone: Summer-Autumn rice from May to mid August; Winter-Spring rice from mid September to end of January Brackish water zone: rice from mid September to end of January; integrated shrimp-crab from February to end of August Saline water zone: extensive and integrated shrimp-crab all year round	Freshwater zone: Winter-Spring rice from October to end of January; Summer-Autumn rice from June to end of September Brackish water zone: rice from September to mid December; semi-extensive or intensive shrimp from January to end of August Saline water zone: two to four intensive shrimp cycles per year	Rice: Chiem (Winter-Spring) rice from end of February to early June; Mua (wet season) rice from the end of July to early November Rice-vegetable: rice from June to end of September; 1-3 vegetable crops from October to end of April Vegetable, fish and softshell turtle: all year round. Fish is usually harvested after one year. Freshwater turtle is harvested after 2-3 years

General characteristics[e]	- Total area: 591 km^2 - Agricultural land: 441 km^2 - Population : 117,883 - Population density: 200 inhabitants km^{-2}	- Total area: 372 km^2 (My Xuyen); 473 km^2 (Vinh Chau) - Agricultural land: 142 km^2 (My Xuyen); 63 km^2 (Vinh Chau) - Population: 157,264 (My Xuyen), 165,751 (Vinh Chau) - Population density: 421 inhabitants km^{-2} (My Xuyen), 349 inhabitants km^{-2} (Vinh Chau)	- Total area: 238 km^2 - Agricultural land: 92 km^2 - Population: 190,291 - Population density: 800 inhabitants km^{-2}

Source: [a] Liem et al., 1990; Tri, 2012 [b] Sanh et al., 1998; Trang and Thanh, 2012; [c] DARD Nam Dinh, 2016 and FGDs; [d] FGDs; [e] An Minh Statistics Office, 2014; Nam Dinh Statistics Office, 2015; Soc Trang Statistics Office, 2013.

6.4. Methodology (A detailed description of methods is mentioned in Section 3.2, Chapter 3 Methodology)

6.5 Historical development of agricultural systems in coastal areas of deltas

6.5.1 Rice intensification in the freshwater zone in the Mekong Delta

Agricultural changes in the freshwater zone in the MKD since 1975 have been closely linked to hydraulic development for the purpose of rice intensification. Since the country's reunification in 1975, significant investments have been made to construct dykes, sluicegates, and irrigation infrastructure to protect the inside areas from saline water and for improved freshwater supply for intensive rice production (Sanh et al., 1998; Ut and Kei, 2006). These hydraulic works together with the introduction of new farming techniques and high-yielding rice varieties from inland areas where farming communities were involved earlier in double systems and mechanization in land preparation have enabled farmers to plant a second rice crop in the dry season.

In 1975, the freshwater zone in Kien Giang was characterized by a large surface area of strong acid sulfate soils. Farmers cultivated transplanted rice in the wet season and fish throughout the entire year. Between 1976 and 1980, the government sent tractors to the district and established an agricultural cooperative to reclaim marginal areas. Thanks to mechanization for land preparation, the development of irrigation infrastructure and the adoption of high-yielding rice varieties from inland regions, farmers started to cultivate double rice. Changes

from local rice varieties e.g. Trang Tep, Trang Lun, Lun Can, and Mot Bui Mua to high-yielding rice varieties such as IR 42, T54 and to short cycle varieties such as OM 576, OM 6976, OM 5451, OM 6976, OM 2517 has continuously taken place since then. Since 2003, farmers in the freshwater zone have continuously converted their double rice to a rice-shrimp system. In order to prevent saline water leakages from rice-shrimp fields and continue with double rice production, farmers built a small dyke within the so-called "large field model" and established a double rice cooperative. From 2013, farmers have exploited groundwater resources for the cultivation of vegetables e.g. watermelon and Galia melon as a third crop.

Table 6.2. Main changes in agricultural systems in the freshwater zones in Kien Giang and Soc Trang

Major changes	**Years of change**	**Scoring of listed drivers in FGDs (distribution of 25 points)**	**Most frequently mentioned drivers in the interviews (in order of mention; drivers that were mentioned in FGDs are shown in bold)**
Kien Giang			
Single rice to double rice	1977-1980	Policy intervention (12 points), low profit of single rice (9 points), mechanization (4 points)	**Mechanization**, **policy intervention**, imitation of farmers from inland regions, imitation of farmers from the village, availability of new rice varieties
Double rice to double rice plus vegetable	From 2013-now	n/a	Profit maximization, low rice prices, imitation of farmers in other regions
Soc Trang			
Single rice to double rice	1994-2007	Dyke construction (8 points), canal excavation (5 points), mechanization (5 points), training (3 points), government support (2 points), suitability (2 points)	**Dyke construction**, **tractors**, **canal excavation**, new rice varieties, higher profit, imitation of other farmers from the village, imitation of other farmers from other villages
Double rice to double rice plus vegetable	From 2013-now	n/a	Profit maximization, low rice price, imitation of farmers in other regions

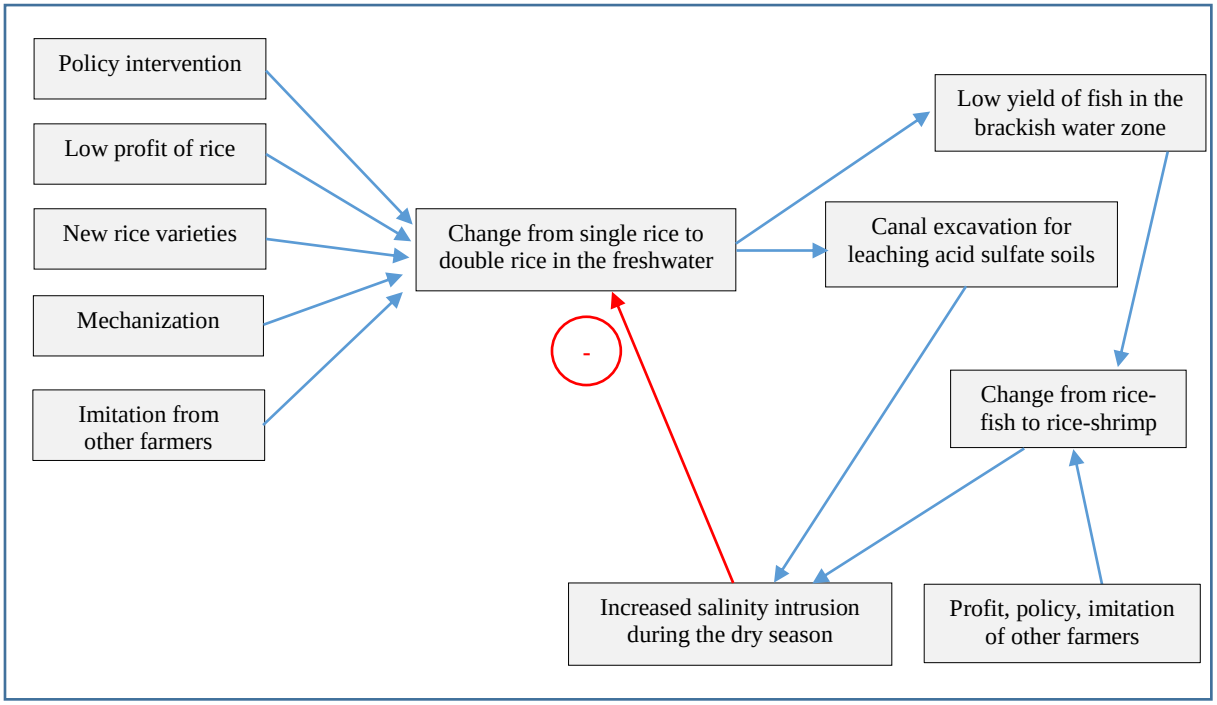
Rice intensification only started in Soc Trang during the mid-1990s. Between 1994 and 1995, the government constructed a dyke to protect the inland area from salinity intrusion and excavated canals to supply fresh water for double rice cultivation. Several years after the construction of the dyke, thanks to the improvement of soil quality, the introduction of farm

machinery for land preparation, new rice varieties from inland villages, and government training, farmers started to farm double rice. Since then, farmers have continuously switched from local rice varieties such as 42, Than Nong Do, Trang Tep, Trang Hoa Binh, Duoi Trau, Bong Dua to high-yielding rice varieties and then to salt tolerant and short cycle varieties such as OM 576, ST5, OM 4900 and hybrid rice C10. Farmers also cultivated vegetables for several years after the canal excavation thanks to an increased freshwater supply and raised tilapia since 2000 and dairy cows since 2003.

The change to double rice was successful in improving farmers' incomes, e.g. 6 out of 8 interviewed farmers in Kien Giang and 4 out of 12 farmers in Soc Trang stated that their income had very much increased, and the remaining farmers in both provinces described their income as slightly increased or stagnant. In the interviews, ca. 38% of farmers in Kien Giang and 75% of rice farmers in Soc Trang considered double rice as the best system for their villages. Other systems that were considered as the best system include rice-shrimp and double rice-vegetable in Kien Giang and triple rice and double rice-vegetable crops in Soc Trang.

However, major hydraulic works for intensive rice production and changes in agricultural systems have generated many environmental drawbacks. The drainage of acid sulfate soil has caused acidification in the canals and rivers (Minh et al., 1997). The modification of the river network has reduced the sediment and nutrient transport and prevented the distribution of these fertile materials on rice fields (Tuong et al., 2003). In Soc Trang, these biophysical changes led to a decline in aquatic populations and impacted the livelihoods of farmers in the brackish water zone, based on the collection of natural aquatic species such as banana prawn (*Penaeus merguiensis)* and mudskipper (amphibious fish of the *Gobiidae* family). Farmers in the brackish water zone then shifted to a rice-black tiger shrimp (*Penaeus monodon*) system. The change to rice-black tiger shrimp, in turn, generated a negative feedback (buffering the change) to the double rice system in the freshwater zone as saline water was pumped into the fields and intruded farther inland (Fig. 6.1b). In Kien Giang, in order to cultivate two rice crops per year, many canals were excavated to get the fresh water from rivers to leach the acid sulfate soils. These canal networks have also enabled salt water to penetrate farther inland in the dry season (Fig. 6.1a) (Tuan et al., 2007).

(a) Kien Giang



(b) Soc Trang

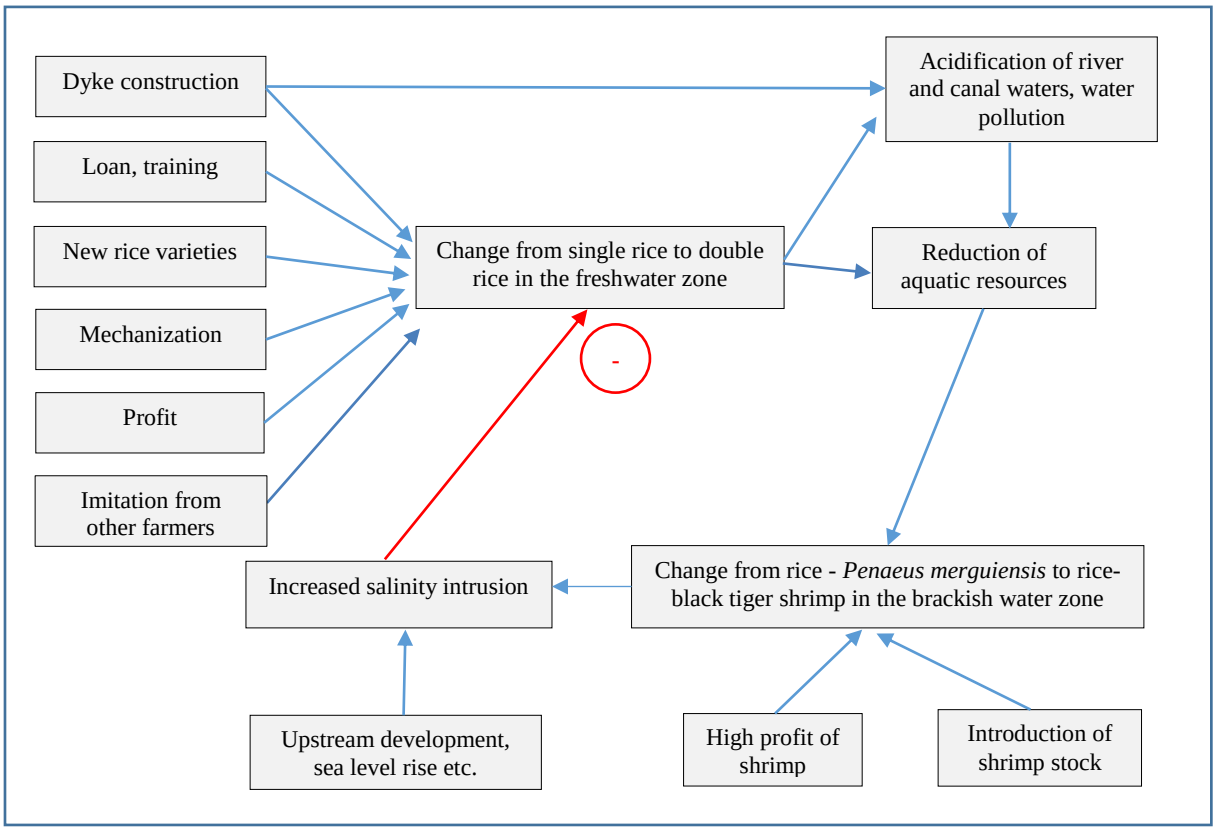


Fig. 6.1. Drivers of change (blue arrows) and negative feedback loops (red arrows) in changes from single rice to double rice in Kien Giang (a) and Soc Trang (b)

6.5.2 Diversification of agricultural systems in the brackish water zone in the Mekong Delta

In the brackish water zone, farmers have made use of the brackish water environment during the dry season by switching from the collection of naturally-occurring aquatic species or cultivation of fish to semi-extensive or extensive shrimp production systems.

In 1975, farmers in the brackish water zone in Kien Giang planted rainfed rice in the wet season and raised fish all year round. From 1997 to 2001, farmers in the inland area of the brackish water zone imitated farmers in the freshwater zone to change from a rice-fish to a double rice system. From 2001, the area close to the coast was planned by the government as a rice-shrimp zone and farmers were provided with low-interest loans and training for rice-shrimp farming. Beginning with the conversion to rice-shrimp in 2001, farmers from inland areas followed farmers from areas close to the coast and continuously converted double rice to rotational rice-shrimp systems. At first, the government forced farmers in this inland area to practice a double rice cultivation system, however, the saline water leakage from shrimp ponds gradually damaged the rice crop and farmers increasingly converted their double rice to rice-shrimp systems (Fig. 6.3a). From 2003, the government organized meetings with farmers to ask them for their preferred farming systems and permitted the conversion if more than 60% of farmers in the communities preferred rice-shrimp cultivation. As a consequence of this consultation, a large area of the freshwater zone in the district was transformed into rice-shrimp and the area of the dry season rice decreased continuously from 11,505 ha in 2002 to 102 ha in 2015 (An Minh Statistics Office, 2004; Annual report of Dong Hoa Commune, 2015).

Table 6.3. Main changes in agricultural systems in the brackish water zones in Kien Giang and Soc Trang

Major changes	Years of change	Scoring of listed drivers in FGDs (distribution of 25 points)	Most frequently mentioned drivers in the interviews (in order of mention; drivers that were mentioned in FGDs are shown in bold)
Kien Giang			
Rice-fish to double rice	1976-1995	Mechanization (13 points), imitation of farmers from other regions (12 points)	**Mechanization**, profit maximization, **imitation of farmers from inland regions**, imitation of farmers from the village, government intervention, improvement of irrigation
Rice-fish to rice-black tiger shrimp	2001-2002	Profit maximization (14 points), policy intervention (7 points), imitation of farmers from the village (4 points)	**Government planning**, **profit**, **imitation of farmers from the village**, continuous income generation of shrimp
Double rice to rice-black tiger shrimp	From 2003-now	Profit maximization (7 points), imitation of farmers from the village (5 points), saline water leakage from other fields, participation in seminar, low productivity and profit of Summer-Autumn rice (all 3 points)	**Profit maximization**, government intervention, **less profit from rice**, **saline water soaking from surround shrimp ponds**, imitation of farmers from other regions
Soc Trang			
Rice-*Penaeus merguiensis* to rice-black tiger shrimp	1980s-1995	High profit from shrimp and reduction of natural shrimp (25 points)	Imitation of farmers from other regions, imitation of farmers from the village, government intervention, **profit maximization**, introduction of shrimp stocks
Rice-black tiger shrimp to rice-white leg shrimp (*Litopenaeus vannamei*)	From 2012-now	White leg shrimps were easy to raise at the beginning (10 points), price of black tiger shrimp was low while price of white leg shrimp was high (5 points), white leg shrimp has shorter cycle than black tiger shrimp (5 points), black tiger shrimp displays slow growth (5 points)	**Profit maximization**, **failure of black tiger shrimp**

In the brackish water zone in Soc Trang, farmers cultivated transplanted rice in the wet season and collected naturally-occurring aquatic species e.g. banana prawn and mudskipper during the dry season until the early 1980s because the brackish environment favoured a growth of abundant aquatic species. In the early 1980s, black tiger shrimp was introduced to the area by farmers in the saline water zone of the province and from the South Central coast of Vietnam

and some farmers then started to raise black tiger shrimp during the dry season. In the late 1990s, due to a high profit from shrimp cultivation and a decline of natural aquatic species, most farmers have changed from rice-*Penaeus merguiensis* to a rotational rice-black tiger shrimp system. At the beginning, rice-shrimp systems typically had a platform in the middle for rice and a ditch around the platform for shrimp. Since 2012, farmers removed the platform and excavated the pond deeper to change to white leg shrimp (*Litopenaeus vannamei*) (Fig. 6.2). The pond excavation allowed farmers to increase the stocking density, but rice could not be cultivated if the pond was too deep for tidal drainage (Fig. 6.3b). In the interviews, ca. 64% of farmers cultivated both black tiger and white leg shrimps, while the rest raised only white leg shrimps. Since the shift to white leg shrimp, farmers also made use of the pond bank to farm grass for livestock farming, added fish in the rice field to diversify income sources, and cultured new aquatic species e.g. sea bass and brackish prawn.

Fig. 6.2. A rice-shrimp field with a maintained platform in the middle for rice and a ditch around the platform for shrimp (left), and a rice-shrimp field without platform (right)

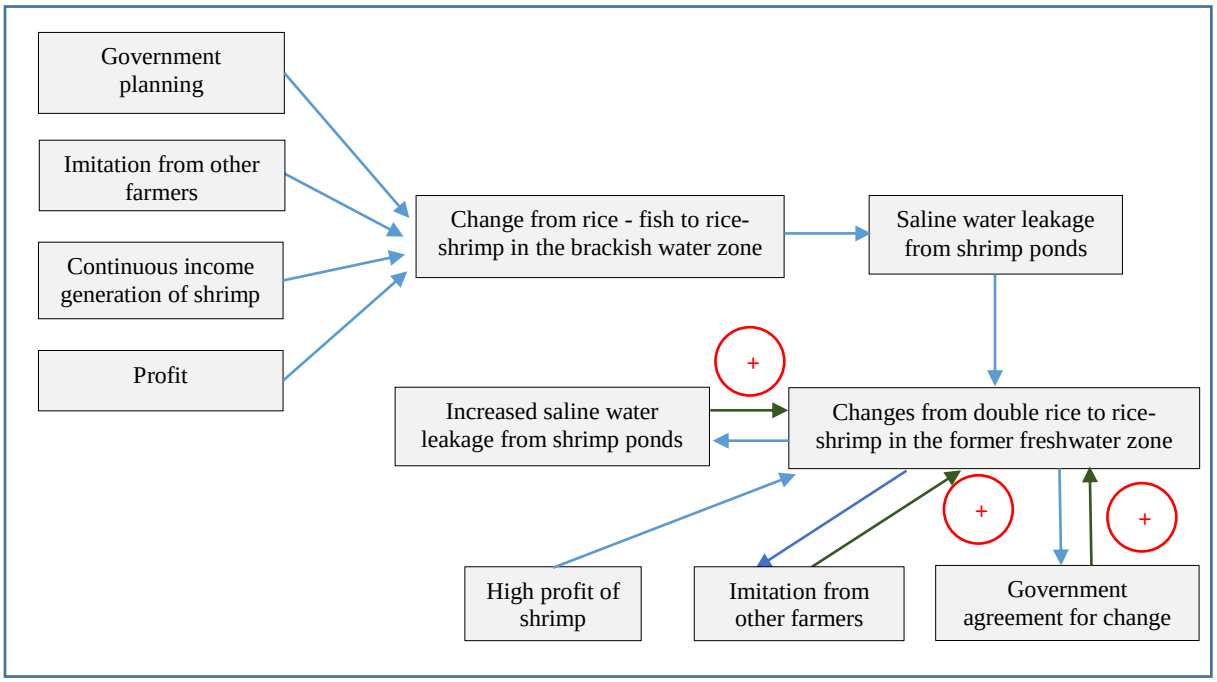
The shift to rice-shrimp has generated a significant source of income in the dry season for farmers. In the interviews, 12 out of 17 rice-shrimp farmers in Kien Giang and 7 out of 12 respondents in Soc Trang stated that their income had very much increased, while the rest saw their earnings slightly increase. The adoption of white leg shrimp in Soc Trang also created a high income for farmers - 7 out of 10 farmers stated that their income was very much increased or slightly increased. However, this system was usually considered also a high-risk endeavor due to potential total failures in production (Joffre, 2015). In the interviews, two

farmers stated that their income was the same, and the last farmer had seen a slight decrease in income.

Changes to rice-shrimp in the brackish water zone have also forced farmers to practice farming systems that they did not prefer. In Kien Giang, farmers who did not wish to engage in a rice-shrimp system had to follow the community to convert double rice to rice-shrimp system since saline water was allowed into the entire area for shrimp farming in the dry season. In the interviews, 12 out of 18 farmers stated that rice-shrimp was the best farming system for their villages, while others said that double rice, double rice plus vegetable, or rice-fish were the best farming systems.

In the MKD, there have been different preferences in the choices of production and water use before 2000. In the late 1990s, while large hydraulic works were under-developed to turn large areas of the Ca Mau peninsula into the freshwater zone for intensive rice production, farmers had different preferred farming systems and tried to access saline water for shrimp cultivation (Käkönen, 2008). This tension has resulted in the release of the new policy for diversification of farming systems in 2000 (GoV, 2000). This policy allowed farmers to change the low productivity rice land to aquaculture or upland crops that have in turn led to rapid shifts in farming systems in the coastal zones in both deltas.

(a) Kien Giang



(b) Soc Trang

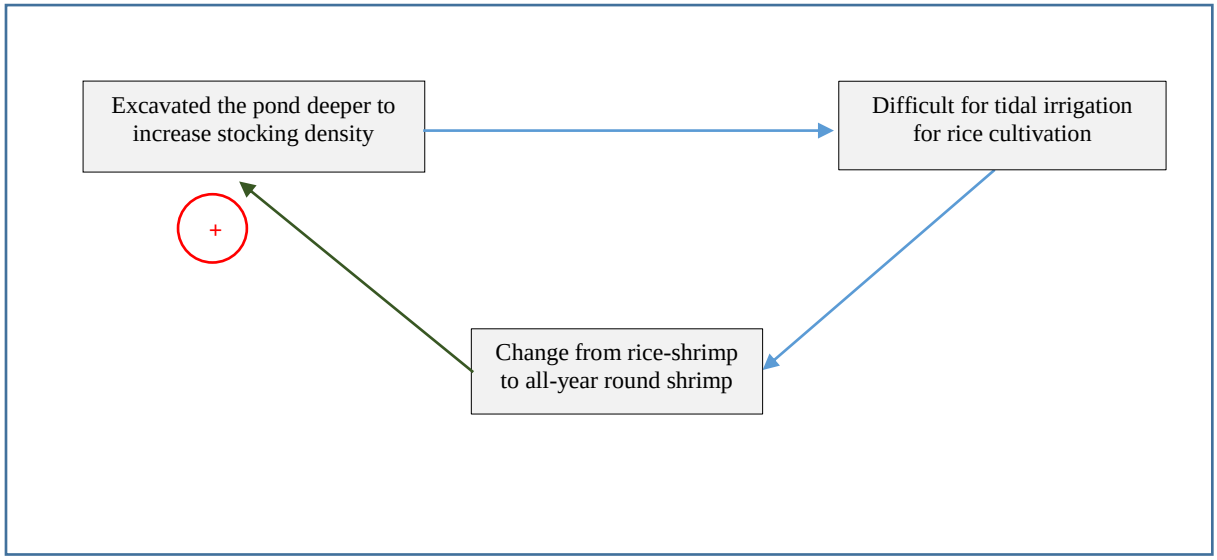


Fig. 6.3. Drivers of change (blue arrows) and positive (amplifies the change) feedback loops (green arrows) in changes from double rice to rice-shrimp in Kien Giang (a) and from rice-shrimp to all-year round shrimp in Soc Trang (b)

6.5.3 Shifting to year-round shrimp cultivation and integrated farming systems in the saline water zone in the Mekong Delta

In the saline water zone, farmers have switched from a rainfed rice system in the wet season and fallow land during the dry season or rice-shrimp to year-round shrimp cultivation. Since the conversion of rice or rice-shrimp fields to mono shrimp required a complete shift of the ecological system and a large amount of investment and new farming knowledge, these changes were mainly planned and facilitated by the government e.g. through low-interest loans and training.

In 1975, farmers in the saline water zone in Kien Giang cultivated local rice varieties e.g. Mong Chim and Mot Bui Mua in the wet season from August to December and harvested the rice before the onset of high salinity levels. From the 1980s, with the introduction of policy for shifting to extensive shrimp and low-interest loans, farmers excavated the field and changed to shrimp farming. In the overlapping area between the saline and brackish water zones, farmers followed a rice-shrimp system before shifting to mono shrimp in 2002. A few years after the conversion to rice-shrimp, farmers gradually dropped the rice crop due to the high profit and continuous income generation of mono shrimp and low rice productivity. As a

consequence, the soil was increasingly salinized as saline water was kept in the pond all-year round and rice could not be cultivated anymore (Fig. 6.4a). To provide shelter and natural feeding for shrimp, farmers started to farm the wetland plant Co Nang (*Scirpus littoralis*).

Table 6.4. Main changes in agricultural systems in the saline water zones in Kien Giang and Soc Trang

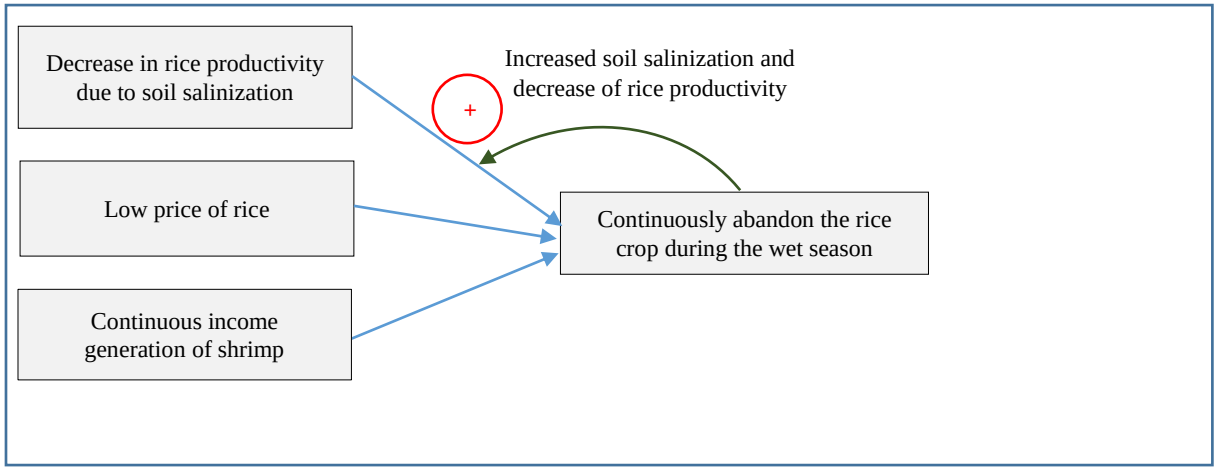
Major changes	Years of change	Scoring of listed drivers in FGDs (distribution of 25 points)	Most frequently mentioned drivers in the interviews (in order of mention; drivers that were mentioned in FGDs are shown in bold)
Kien Giang			
Single local rice to extensive black tiger shrimp	1980-1987	Government planning (25 points)	**Government planning**, soil and water salinity, high profit of shrimp
Rice-fish to rice-black tiger shrimp	2000-2004	Policy (9 points), damages by yellow snail (6 points), profit maximization (4 points), low price and yield of fish (3 points), low price and yield of rice (3 points)	**Policy**, **profit maximization**, imitation of farmers from the village, continuous income generation of shrimp
Continuously stop rice cropping	From 2002-now	Soil salinization (25 points)	**Soil salinization**, decrease in rice productivity, low price of rice
Soc Trang			
Rice-*Penaeus merguiensis* to rice-black tiger shrimp	1990-1999	Follow other farmers from the village, profit maximization (25 points)	**Profit**, maintain of shelter and rice straw for shrimp, government intervention, introduction of shrimp stocks from other regions, reduction of natural shrimp
Rice-shrimp to semi-intensive black tiger shrimp	1995-2006	Profit maximization (11 points), government planning (7 points), loans (7 points)	Deep pond, **profit maximization**, saltwater intrusion from surrounding shrimp ponds, imitation of other farmers from the village, **loans from the government**, low rice productivity
Black tiger shrimp to white leg shrimp	From 2012-now	Black tiger shrimp has a long and risky rearing cycle compared to white leg shrimp (17 points), black tiger shrimp displays slow growth (6 points), white leg shrimp is easy to raise in the first few years (2 points)	Imitation of other farmers in the village, profit maximization, **short rearing cycle of white leg shrimp**, imitation of other farmers from other regions

In the saline water zone in Soc Trang, farmers planted a single rice crop in the wet season until 1996. From 1996-1997, some groups of farmers went to Bac Lieu province to buy shrimp stocks and excavated a ditch around the field to stock shrimp after the rice season. Since 2001, the government planned the region as a shrimp area and provided low-interest loans for the conversion to semi-intensive black tiger shrimp. Since 2012, white leg shrimp was introduced to the region by farmers in areas near the coast and farmers in the village then switched to this shrimp species. In the interviews, ca. 46% of farmers raised both black tiger and white leg shrimp as a way of risk management, while the rest cultivated only white leg shrimp. Several years after the switch to white leg shrimp, farmers also began to raise animals and farm vegetables on the pond banks during the wet season to diversify income sources and reduce the risk of income loss from shrimp failures.

By switching to extensive shrimp, all farmers in the interviews have seen an increase of income e.g. 60% of respondents in Kien Giang and 50% of respondents in Soc Trang stated that their income had very much increased, and the rest of respondents that income had slightly increased. The adoption of the white leg shrimp system, however, did not create benefits for all farmers. In the interviews, 8 out of 12 farmers said that their income had very much increased or slightly increased, 3 farmers reported no income gain and the last household had experienced a slight decrease in income after the switch to white leg shrimp.

In the saline water zone of Soc Trang, failures of the mono shrimp system forced farmers to try reverting back to rice-based systems, but the rice was destroyed by salinized soil and saline water from surrounding shrimp ponds (Fig. 6.4b). In the interviews, 5 out of 16 farmers in Kien Giang and 7 out of 12 farmers in Soc Trang said that rice-shrimp is the best farming system for their villages, while the rest stated that mono shrimp, rice-fish or clam is the best system.

(a) Kien Giang



(b) Soc Trang

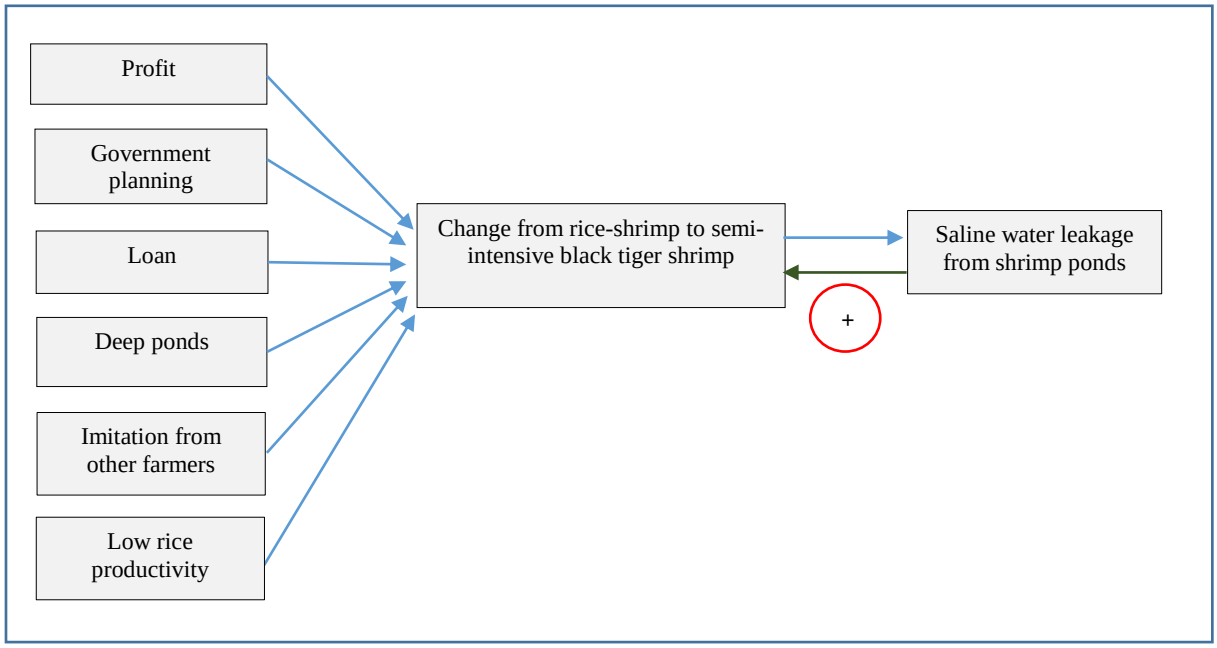


Fig. 6.4. Drivers of change (blue arrows) and positive feedback loops (green arrows) in continuous abandonment of the rice crop in Kien Giang (a) and in the change from rice-shrimp to semi-intensive shrimp in Soc Trang (b)

6.5.4 Sea dyke and infrastructure development for water control in the Red River Delta

The agricultural systems in the RRD are highly dependent on hydraulic infrastructures such as the construction of a complex system of sea and river dykes, sluicegates, polders, and irrigation systems. In the research area, double rice crop is the predominant system. Farmers

in the district also converted a part of their rice fields to freshwater fish and softshell turtle, rice-vegetable and vegetable production. These conversions are principally the result of government policies and planning. Many changes in agricultural systems were observed following Doi Moi in 1986 and intensively after 1992 with the policy for land allocation (GoV, 1993) that redistributed and granted land rights to farmers for 20 years as pretested in Nam Dinh. In all changes and especially in the shifts to vegetable and large fish ponds, most farmers reported a large increase in income compared to double rice production.

In 1975, local farmers farmed double rice and rice-vegetable crops in the villages farthest from the coast. From 1977 and particularly since Doi Moi in 1986, farmers in these villages have continuously converted double rice to rice-vegetable and then from rice-vegetable to all-year round vegetable. In the same period in the rice-vegetable system, farmers have also consistently changed from local rice-sweet potato rotation to systems of modern rice-multiple vegetable crops e.g. nut and German and Dutch potatoes.

In the villages located in the middle of the study region, farmers cultivated only double rice until 1992. Since the land allocation policy in 1992 that aimed to redistribute the land to households under the new Land Law (GoV, 2003) and more so after the government gave permission for the conversion of double rice to aquaculture in 2003, farmers started the conversion of rice fields to fish ponds or softshell turtle. Since 2008, due to the pollution of water and diseases of softshell turtle, and the lack of an output market and natural feeding sources, some farmers switched from softshell turtle to fish or filled the ponds with soil to farm the Japanese pagoda tree (Vietnamese Hoe; *Styphnolobium japonicum (L.) Schott*) and Ming aralia (Vietnamese Dinh Lang; *Polyscias fruticose*). In 2011, a new species of softshell turtle from southern Vietnam was introduced and farmers returned to softshell turtle farming. In recent years, farmers in the middle villages have also cultivated vegetables e.g. chili as the winter crop.

In the villages along the sea dyke, farmers cultivated double rice until the early 1990s. Since the land allocation in 1992, farmers have been able to exchange their rice fields in the village to get the land along the sea dyke for fish farming or keep their rice land in the village and get a five-year land contract with the commune for fish farming. In 2007, the government gave permission for the conversion of double rice to large fish ponds up to 200 m from the sea dyke. Rice farmers in the village then began excavating the rice fields further inland for fish farming.

Table 6.5. Main changes in agricultural systems in Nam Dinh

Major changes	Years of change	Drivers in FGDs in order of ranking	Most frequently mentioned drivers in the interviews (in order of mention; drivers that were mentioned in FGDs are shown in bold)
Double rice to rice-vegetable or only vegetable	1977-2012, accelerating in 1986 and 2005	Profit maximization, free land use rights	**Profit maximization**, low productivity and low price of rice, lack of water for rice
Local rice-sweet potatoes to modern rice- multiple vegetable crops	1986-2012	Technology, "Khoan 10" (policy for land distribution to households), profit maximization, diversification of variety	**Profit maximization**, **change in land use rights**
Change of rice varieties	From 1990s-now	Technology development, "Khoan 10", profit maximization, diversification of variety	**New rice varieties from Thai Binh province and China**, deterioration of local rice varieties, **new rice varieties delivered by the cooperative**, **change in land use rights**
Double rice to soft-shell turtle	1992-2008	Imitation of farmers from other regions, high output market of soft-shell turtle, profit maximization	Low productivity and price of rice, **higher profit of softshell turtle**, policy, rat infestations, rice damage
Double rice to fish ponds	1993-2014	Profit maximization, rat infestation, high costs of input for rice	**Profit maximization**, **rat infestations**, low productivity and price of rice, policy, **high effort for rice cultivation**
Double rice to large fish pond	1995-2010	n/a	Government planning, high profit of large fish pond
Rice-vegetable to only vegetable	From 2005-now	First village: Profit maximization, high input cost for rice cultivation Second village: Profit maximization, soil suitability, lack of water for rice, occurrence of sulfuric acid and salinity during drought	**Profit maximization**, short cycle vegetable, **high input cost for rice cultivation**, rice diseases

In the double rice system in all villages, farmers have continuously changed from local rice varieties such as Nong Nghiep 8, Di Truyen, Moc Tuyen varieties to hybrid and short cycle varieties such as Tap Giao, PC, and Bac Thom since the early 1990s after the right to freedom

in land was granted in conjunction with the rapid development of modern rice varieties. In the lowland areas along the sea dyke, farmers have adopted rice varieties that can tolerate variations in water levels and acidic conditions resulting from submerged water conditions, necessary because these areas usually suffer flooding during the operation of irrigation systems. In the rice-vegetable systems, rice is only planted during the time of heavy rain from July to October, thus short cycle varieties e.g. QR and QN2 are mainly used to save time for vegetable farming.

Although the sea and river dykes in the RRD are successful in protecting agricultural production from water-related hazards, these structures also separate the inside area from the outside environment (Adger et al., 2001). A lack of water and nutrient-rich sediment exchange with the main rivers requires a large supply of fertilizers to maintain soil fertility (Luu et al., 2012). In the RRD, agrochemicals were applied intensively to control the widespread occurrence of rice pests, rats, and yellow snails (Hoai et al., 2011; Thuy et al., 2012). In addition, a lack of provision of essential ecosystem services from outside environments has hampered the development of new farming systems e.g. due to the lack of natural feeding for the softshell turtle. Finally, sea and river dykes also generated new risks to agricultural systems. Rice farmers in the area along the sea dyke, in addition to the salinity intrusion, also experience flooding due to the operation of irrigation and sluicegate systems. Since these communities are located downstream of irrigation and drainage systems and are at lower elevations than upstream villages, they are often flooded once irrigation takes place. In contrast, in high-elevation villages such as double rice-vegetable villages, a lack of irrigation water is one of the main production constraints. These problems are some of the factors driving conversions from double rice to vegetable and large fish ponds in the research areas.

6.6 Drivers of changes in agricultural systems in both deltas

The changes in agricultural systems since 1975 in both deltas were driven by a dynamic interplay of various drivers at multiple scales, notably national and provincial policy interventions, farmers' desire for profit maximization, technology development and uptake, drivers at the basin and delta scales such as dam construction and mangrove deforestation, and at the local level environmental degradation. The interacting changes of external drivers at the macro level have impacted the internal drivers at the local level and altered the integrated nature of the social-ecological system e.g. improvement of soil and water quality and farmers' knowledge has caused changes in agricultural systems (Fig. 6.5). These changes, in turn,

create a feedback with the drivers of change at various scales and generate new drivers and increased salinity intrusion in the deltas.

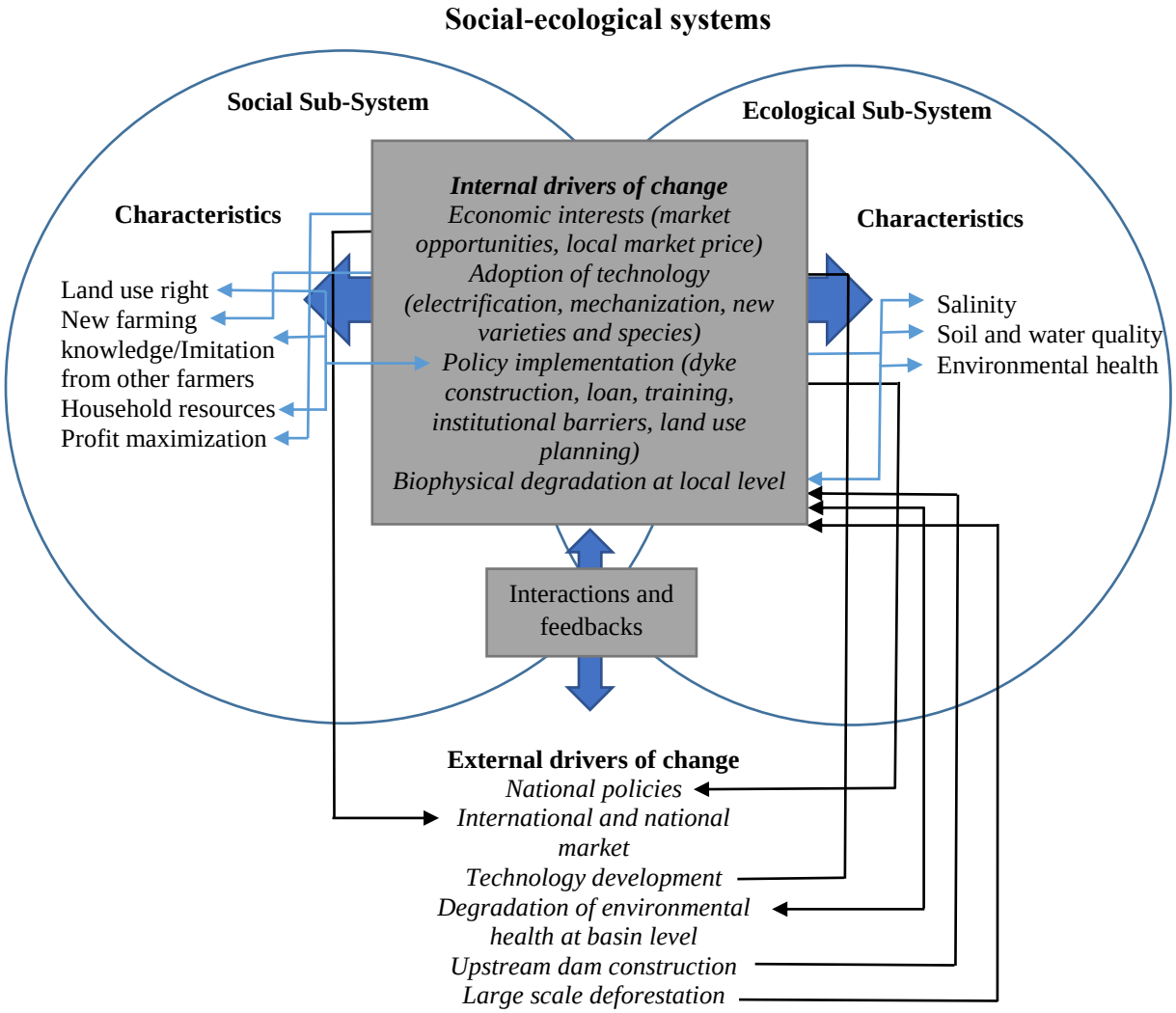


Fig. 6.5. Drivers of change and their interactions and feedbacks in agricultural systems in the deltas. The black arrows illustrate the influence of external drivers on the internal drivers (one-way arrow) or the mutual interactions and feedback between external and internal drivers (two-way arrows). The blue arrows represent the mutual influences of internal drivers of change and characteristics of the system (based on the results of the focus group discussions and household and expert interviews)

Government intervention

Government intervention is a critical factor in the agricultural changes observed since 1975. Government-led actions included construction of hydraulic infrastructure, development of new rice varieties, the drafting of policies and regulations, availability of loans and subsidies,

development of training and guidelines, and changes in land use planning. Since 1975 and more so after Doi Moi in 1986, a series of agricultural policies were implemented that have fundamentally changed the farming systems towards commercial farming systems, enabled land use rights, and increased the links to other non-state sectors by liberalization of input and output markets (Marsh et al., 2007; Ni et al., 2003; Sanh et al., 1998; Ut and Kei, 2006). Many shifts in the agricultural systems were carried out after suitable farming conditions were created through hydraulic constructions or the release of new policies e.g. after the land allocation in 1992 in the RRD and the policy for agricultural restructuring in 2000 at the national level (GoV, 2000, 1993). This agricultural restructuring policy in 2000 introduced more flexibility in land use choices that allowed a conversion of marginal rice land to other systems such as vegetable crops and brackish aquaculture (GoV, 2000). In the MKD, shifts to rice-shrimp and mono shrimp were mainly planned and facilitated by the government e.g. through low-interest loans and training since these conversions demanded a modification of the ecological system and a large investment and new farming knowledge. In the shift to the rice-shrimp system, nearly 60% of respondents in Kien Giang and 67% of interviewed farmers in Soc Trang have asked for a loan, while in the change to mono shrimp in Soc Trang, ca. 42% of farmers have asked for government loans.

In the coastal areas of the deltas, policy interventions have had a primary role and greatly shaped the agriculture trajectories, but the state regulations have also hampered opportunities for changes to other farming systems. The system state in the freshwater zone is principally locked-in by institutional barriers that restrict shifting from double rice to other systems e.g. aquaculture. The food security policy mandates that specific areas for rice cultivation have to be maintained and each province has to keep the assigned area; e.g. Kien Giang, Soc Trang and Nam Dinh were assigned to conserve 382,829; 138,000 and 76,307 ha rice land until 2020, respectively (GoV, 2016b, 2016c, 2013). Therefore, farmers in the freshwater zone have fewer options to respond to external drivers than those in the brackish and saline water zones due to these regulatory barriers.

Profit maximization and market drivers

Economic considerations and market incentives played an important role in terms of diversification of farming systems. Many conversions from double rice or rice-shrimp production to saline aquaculture in the MKD were driven by the high profit of shrimp

production. In the MKD, the increase of shrimp prices since 2000 on global markets has led to the rapid transformation of rice fields to shrimp ponds (Can, 2011), while a rapid increase in rice price on the international market during 2007-2008 resulted in a reversed trend (FAO, 2010). In the RRD, shifts from double rice to aquaculture and vegetable were mainly induced by profit maximization interests. Recent developments in the agricultural systems e.g. integrated farming systems in the brackish and saline water zones in the MKD corresponded to adaptation strategies of increased connectivity of the systems to the global market in order to diversify the income sources and buffer the high volatility to fluctuation of market prices (de Araujo Barbosa et al., 2016).

Technology changes

The development and adoption of new technologies such as the introduction of high-yielding rice varieties, mechanization in land preparation or production electrification were one of the main factors driving the intensification and modernization of agricultural systems in both deltas. These modern technologies have enabled farmers to increase the yield and number of crops per year and expand rice production into less-favoured areas such as soils classified as strong acid sulphate or saline soils (Ut and Kei, 2006). The high adoption rate of these intensive farming methods is usually attributed to the results of the Green Revolution in the 1960s and has been rapidly enhanced since Doi Moi thanks to a large investment in technology research (Devienne, 2006; Ut and Kei, 2006).

Degradation of environmental quality, dam construction, and mangrove deforestation

Being located downstream of a large transboundary river, agricultural systems in both deltas also suffer from accumulated effects of human interventions along the rivers and their catchments (Renaud and Kuenzer, 2012). The construction of a series of hydropower dams in upstream areas of the deltas has disrupted the complex ecological characteristics of the rivers through a decline in the sediment loads, alteration of natural flood pulse, and blockage of fish migration (Kummu and Varis, 2007; Manh et al., 2015; Vinh et al., 2014). Within the delta, the construction of embankments and dyke systems to control flooding in the upper part of the MKD for intensive rice production during 1997-2000 has significantly limited the flood water retention in those areas. These developments lead to changes in hydrology causing earlier - right at the end of Winter-Spring rice season - saline water intrusion from the sea as well as a

lower biological productivity of the river water due to the trapping of sediments and nutrients (Kummu and Varis, 2007; Miller, 2014). These changes have contributed to a decline in aquatic populations and affected the aquatic resource-based livelihoods of farmers in downstream communities, especially the poorest groups (Käkönen, 2008). Along the coastline of the MKD, the expansion of aquaculture and agricultural activities has resulted in a decline of the mangrove forest coverage (Joffre, 2015). These mangrove losses could aggravate salinity intrusion because of a reduced shoreline buffer capacity against storm surge, coastline erosions, and sea level rise (Gedan et al., 2011).

At the regional and delta levels, increases in temperature and prevalence of heat waves also cause problems for farming systems in the deltas (MONRE, 2012). In the brackish and saline water zones of the MKD, high temperatures cause a rise in salinity levels in shrimp ponds and irrigation canals. In this case, farmers need to rely on reserved freshwater sources or exploit groundwater resources to reduce the high salinity levels. The latter contributes to increased salinity intrusion since an overexploitation of groundwater leads to increased land subsidence (Shrestha et al., 2016; Wagner et al., 2012b).

Changes in agricultural systems were also influenced by changing factors at the local level, for example, by the high population of yellow snail (a rice pest) in the case of conversion to rice-shrimp in Kien Giang, or the water pollution and lack of natural feeding in the receding of the softshell turtle in Nam Dinh. These biophysical changes were possibly a result of the dysfunction or a lack of material transfers between the agricultural system and the natural river and wetland ecosystem of the deltas and river basin, for instance, due to the alteration of floodwater from the upstream area in the MKD or the lack of provision of essential ecosystem services in the case of Nam Dinh.

6.7 Adaptation pathways of agricultural systems in the Red River and Mekong deltas

6.7.1 Diversification and shifting farming systems in the Mekong Delta

In addition to governmental interventions, changing salinity conditions and market prices are two key factors driving changes and adaptation in the agricultural systems. Based on farmers' considerations of responses to changing salinity conditions, market prices and examination of past and present changes and adaptation in agricultural systems, the researcher(s) synthesized various adaptation pathways (Fig. 6.6). Responses of agricultural systems to these external drivers consist of various degrees of incremental (adjustments to changing outside conditions

in order to stay in the same systems) and transformative changes (fundamental alterations to shift to a new system). These adaptations have potential drawbacks and some would constrain further shifts to other systems or be difficult to reverse due to positive system feedbacks. These adaptation actions could also influence changes in other agricultural systems in different places (Fig. 6.7).

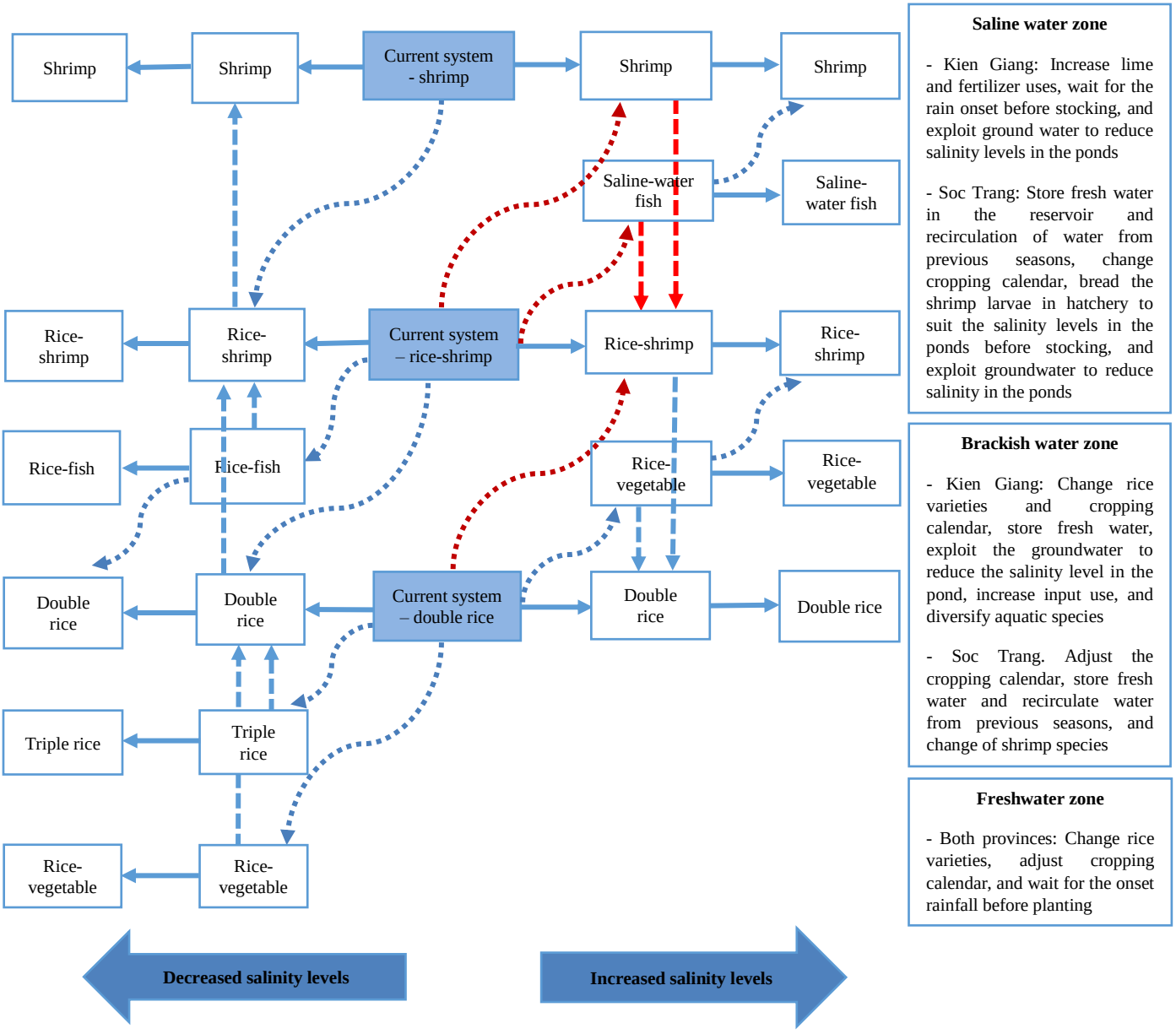


Fig. 6.6. Adaptation pathways in different salinity zones in the MKD to changing salinity conditions based on results of FGDs, and expert and household interviews. Blue dashed arrow curves: pathways to other agricultural systems; red dashed arrow curves: pathways with potential lock-ins; blue dashed lines: reversing the system is easy; red dashed lines: reversing is difficult; in boxes: incremental adaptations to increased salinity intrusion.

Freshwater zone

An increased salinity intrusion would significantly affect rice production in the current freshwater zone (Smajgl et al., 2015) and lead to major shifts to brackish aquaculture. In the case of increased salinity intrusion, the implementation of protective infrastructure is crucial to maintain rice production (Smajgl et al., 2015). During the interviews, 5 out of 8 farmers in Kien Giang and 8 out of 12 farmers in Soc Trang said that they would shift to rice-shrimp and rice-vegetable if salinity increased, while the rest preferred to maintain double rice. In the case of decreased salinity, 6 out of 8 farmers in Kien Giang and 5 out of 12 farmers in Soc Trang mentioned continuing with double rice cultivation. Alternatives include double rice plus vegetable and triple rice.

When considering a decrease of rice prices, 5 out of 8 farmers in Kien Giang and 5 out of 12 farmers in Soc Trang stated that they would continue cultivation of double rice, whereas other farmers preferred to change to rice-shrimp, wished to see the situation unfold before taking a decision, or preferred to change to double rice plus vegetable or to single rice-vegetable crops. In contrast, 4 out of 6 farmers in Kien Giang and 6 out of 11 farmers in Soc Trang stated that they would continue with the cultivation of double rice, while others preferred triple rice if the rice price was to increase.

In the freshwater zone, one pathway would be a shift to a rice-shrimp production system if salinity increased. This option requires profound changes in the incentive of prioritizing double rice to a rice-shrimp system. There is evidence that rice-shrimp production would not cause long-term soil salinization (Leigh et al., 2017; Preston and Clayton, 2003). However, the modified landscape and irrigation schemes would be a barrier to reverse the system and the area would likely continue with brackish aquaculture following a widespread commitment to rice-shrimp. One of the possible problems with this shift is a limitation of the freshwater resource that would impact domestic water consumption (Renaud et al., 2015) and constrain the diversification of freshwater-based agriculture e.g. integrated rice-animal husbandry or fruits. A decline of freshwater supply would potentially increase salinity intrusion and create a positive feedback for changing to mono shrimp or saline water fish in the brackish water zone (Fig. 6.7).

The cultivation of double rice plus vegetable or single rice-vegetable crops is an alternative option which would diversify income sources of farmers and allow for other farming systems to evolve if the salinity gradients increased (Dat et al., 2010). This pathway also allows for

shifts to rice-fish or even triple rice if the fresh water supply is increased in the future, for instance, due to the completion of the two planned massive estuary sluicegates in Cai Lon and Cai Be Rivers in Kien Giang (Smajgl et al., 2015) and the implementation of irrigation projects to provide freshwater for the coastal zones in the MKD such as the irrigation planning for the MKD until 2020 (GoV, 2012). A potential problem would be land subsidence and lowering of groundwater tables if groundwater is over-exploited for vegetable farming, which could exacerbate salinity intrusion in the longer run (Shrestha et al., 2016; Wagner et al., 2012a). The cultivation of triple rice would consequently degrade the environmental health and aquatic resources (Käkönen, 2008), initiating a negative feedback to other systems. As observed in the collapse of rice-fish and rice-*Penaeus merguiensis* systems in the brackish water zone due to the shift to double rice in the freshwater zone before, a drainage of acid sulfate soil and dyke construction for double rice production would cause a reduction of aquatic resources and negatively affect the development to rice-fish or any other natural feeding-based systems in the brackish water zone if the area follows that pathway (Fig. 6.7).

Brackish water zone

In the brackish water zone, an increased salinity intrusion would have a smaller effect on agricultural production than in the freshwater area thanks to the adaptation of rice and shrimp systems to seasonal changes in salinity conditions. During the interviews, 11 out of 19 farmers in Kien Giang and 6 out of 12 respondents in Soc Trang said that they would maintain rice-shrimp systems if salinity increased, while others considered shifting to mono shrimp and saline-water fish production. In the case of decreased salinity, most farmers preferred to continue with the rice-shrimp system. For shrimp production, a low salinity level would reduce the growth and feed conversion efficiency of shrimp (Ye et al., 2009). A conversion to double rice or rice-fish would be considered for areas which have engaged with double rice or rice-fish before in Kien Giang given a decrease in salinity intrusion. In Soc Trang, the conversion from rice-shrimp to double rice was not a considered option. Local farmers in the brackish water zone in Soc Trang have only cultivated a single rice crop in the past and not engaged with double rice production as the area does not have a freshwater supply during the dry season due to the heavy salinity intrusion via a dense canal and river network (DARD Soc Trang, 2015a). A shift to double rice or rice-fish in the brackish water zone would also positively influence changes to triple rice or double rice plus vegetable in the freshwater zone

due to a decline of salinity intrusion and saline water leakage from rice-shrimp fields (Fig. 6.7).

In Kien Giang there is little evidence that the local farmers will change their rice-shrimp farming if shrimp prices were to vary. In contrast, 7 out of 12 farmers in Soc Trang would consider cultivation of mono shrimp if shrimp prices increased and 6 out of 12 farmers would prefer rice-shrimp production if shrimp prices decreased.

In the brackish water zone, a potential outcome would be a replacement of rice cropping during the wet season by shrimp production that would pose several environmental drawbacks (Thuy and Ford, 2010). The shift to year-round shrimp cultivation would convert the area into the saline water zone and reverting back to rice-shrimp systems would be difficult due to soil salinization as well as deep shrimp ponds, which would need to be filled (Tho et al., 2008; Thuy and Ford, 2010). There are only very few production systems possible once the soil is salinized e.g. shrimp-*Eleocharis* (a sedge plant) in Kien Giang that provides less productivity and income than rice-shrimp. The shift to mono shrimp would increase saline intrusion further since saline water would be pumped into the ponds and kept all-year round (Fig. 6.7). This would reinforce the change to brackish aquaculture in the current freshwater zone due to a shift of freshwater environment to increasingly brackish water conditions. Recognizing the drawbacks of shrimp monoculture, the local governments in Kien Giang and Soc Trang are trying to prevent the total abandonment of rice by e.g. the establishment of rice-shrimp cooperatives and supporting projects, and setting specific areas of rice to be maintained annually (Annual report of My Tu I commune, 2016).

Saline water zone

In the saline water zone, farmers have only little choice in terms of farming systems. Shrimp systems can endure relatively high levels of salinity depending on the shrimp species. The optimal growth rate is obtained at salinity levels less than 15 g l^{-1} for white leg shrimp and 35 g l^{-1} for black tiger shrimp (FAO, 2004; Ye et al., 2009). In the case of increased salinity levels, a switch from white leg shrimp to black tiger shrimp (or other shrimp species which can survive at higher salinity levels) combined with incremental adaptation measures such as preservation of freshwater in the reservoir would be an option if farmers want to continue with shrimp production. In the case of decreased salinity, reversing back to rice-shrimp cultivation would be considered if the region receives an improved freshwater supply, for

instance, due to the change to double rice in the current brackish water zone (Fig. 6.7). In the interviews, the majority of farmers in both provinces stated that they would continue with mono shrimp if salinity increased. When considering a decrease of salinity levels, ca. 33% of farmers in Kien Giang and 50% of farmers in Soc Trang expressed a desire to shift back to a rice-shrimp system, while others preferred to maintain mono shrimp.

In the saline water zone, an increase or decrease of shrimp prices would significantly affect the stocking intensity. In Kien Giang, farmers mentioned that they would reduce the stocking frequency if the shrimp price decreased. In Soc Trang, five out of nine farmers considered increasing stocking density if shrimp prices increased, while most farmers said that they would reduce the stocking density and the number of operational ponds if the shrimp price decreased.

There are several concerns on the ecological and livelihood sustainability of intensive shrimp production such as a breakout of shrimp diseases, bankruptcy and out-migration due to production failures (Joffre, 2015; Thuy and Ford, 2010). Several measures have been proposed and applied in the saline water zone to limit these problems e.g. the development of integrated farming systems, the introduction of new aquatic species, the reduction of stocking intensity, and wetland rehabilitation (Can, 2016; Hagenvoort and Tri, 2013). Some of these measures such as wetland rehabilitation and the development of integrated farming systems would have effects outside the salinity zone since these measures would also buffer the high salinity intrusion in the brackish and freshwater zones (Gedan et al., 2011). The ripple effects from these changes would create a positive feedback for the shifts to farming systems that need lower salinity conditions in the inland areas (e.g. from double to triple rice in the freshwater zone, or from semi-intensive shrimp to rice-shrimp in the brackish water zone).

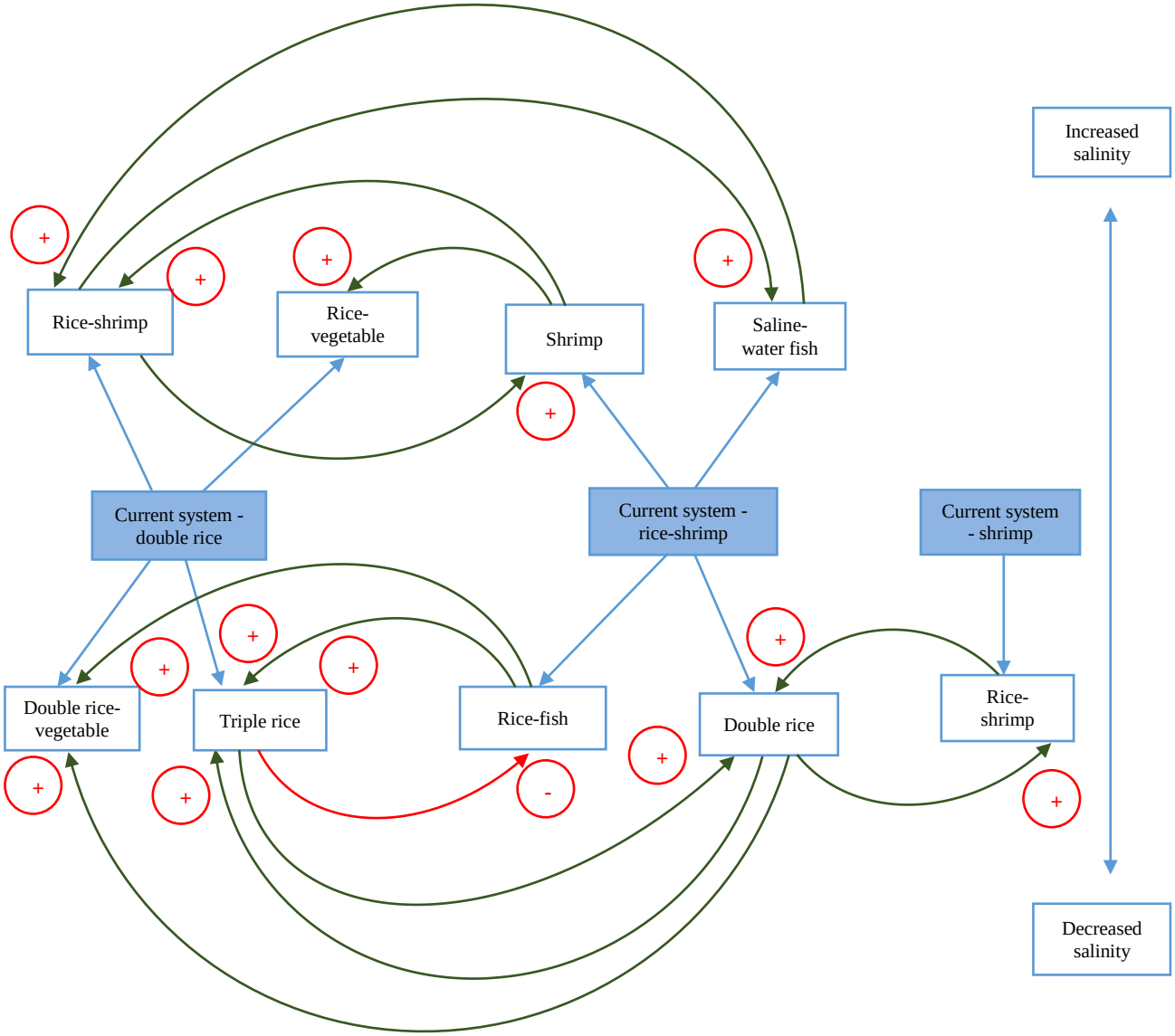


Fig. 6.7. Potential interactions and positive feedback (green arrows) and negative feedback (red arrow) between adaptation pathways (blue arrows) (based on previous interactions and feedback in agricultural changes)

6.7.2 Continuing on the present path and incremental adaptations in the Red River Delta

In the RRD, adaptation options to increased salinity intrusion are principally based on the upgrading of the sea and river dykes, sluicegates, and irrigation infrastructure. Other adaptation measures are mainly incremental changes to sustain the current agricultural systems e.g. adjustment of varieties and cropping calendar, increase of fertilizer and lime uses, management of water intake and practicing water exchange to flush out the salt water,

replanting of mangrove forest along the sea dyke and conversion of small areas of marginal rice land along the sea and river dykes to aquaculture and integrated farming systems of garden-pond-animal shed.

In the inland villages furthest from the coast, salinity is not a problem for vegetable farming at the present time due to the high elevation of the land. Rice-vegetable and vegetable farmers mentioned that they would raise their fields using the sand of the Red River if salinity increased. In rice-vegetable farming, rice price fluctuations would not greatly affect the rice cultivation because rice is mainly used for household consumption and vegetables cannot grow well during the wet season due to storms, heavy rains, and flooding. During the interviews, most rice-vegetable and vegetable farmers stated that they would change the vegetable crops if the vegetable prices decreased, and none of the farmers would like to shift the vegetable system to other farming systems given the high profit of vegetable production.

In the middle villages, all fish and softshell turtle farmers mentioned cultivation of fish and softshell turtle production or changes of fish species if salinity increased or market price decreased. In contrast, 18 out of 48 farmers in the interviews stated that they would like to convert their rice field to a fish, vegetable or garden-pond-animal shed system or to fruits if salinity increased.

In the area along the sea dyke, fish farmers would consider switching to brackish shrimp or fish given an increase in salinity as well as changing the fish species and raising livestock to diversify their income sources if the fish price decreased. In double rice systems, a majority of farmers stated that they would maintain double rice and increase livestock farming and only a few farmers would consider adopting fish farming if salinity increased or rice price decreased.

Regardless of the farming system, a majority of farmers in the RRD stated that they would continue their current farming systems even after two consecutive crop losses, while others considered finding off-farm jobs, migrating to the cities, shifting their farming system if allowed, and doing fishing. In all villages, 46 out of 118 households have at least one member who migrated out of the district and 61 out of 118 households have off-farm jobs such as in handicrafts, fishing, and small-scale business. Compared to the MKD, 23 out of 80 households in the semi-structured interviews have at least one member permanently migrating out of the district and 26 out of 80 households have off-farm income. These measures are considered by several authors (Adger et al., 2002a; Cole et al., 2015; Dun, 2011) as an adaptation of marginal groups in the research areas to environmental stressors and

undermining natural resources, or a way to gain access to non-farm income for the better-educated households which in turn creates a feedback with the resource use strategies and adaptation in agricultural systems.

6.8 Discussion and conclusions

Agricultural systems in the RRD and MKD over the last decades have changed considerably, shaped by dynamic interplays and feedbacks of various drivers of change at multiple scales. Many of these changes were initiated at the national level through national target plans and policies (Renaud et al., 2015; Smajgl et al., 2015). At present, 3.76 million ha of agricultural land of Vietnam - of which a major part are located in the MKD and RRD - are dedicated to rice production in order to achieve ca. 41-43 million tons of rice by 2020 (GoV, 2016a, 2012c). From an institutional perspective, a change in land use types is more flexible in the coastal areas than in the inland areas since the fertile land in the inland areas is strictly managed for double or triple rice systems in order to attain these production targets. In the RRD, a shift away from double rice is generally prohibited since the whole area inside the sea dyke is principally dedicated to intensive rice production. Another barrier is the financial requirement for change, especially for land use systems' shifts to rice-shrimp and shrimp aquaculture in the MKD since the investment costs for these systems are much higher than rice production (Can, 2016). Thus financial support (e.g. low-interest loans) is critical to allow a wide range of farmers to enact these transformations (Renaud et al., 2015). The last barrier is household motivation to change, which, as recognized in the MKD, is linked to education and skills, farmers' desire for change, assistance for conversion, and food security at the household level (Smajgl et al., 2015). At present, several ongoing developments such as land consolidation, reduction of sediment loads due to upstream development, and increased migration to big cities would fundamentally alter the future social-ecological environment and its capacity for change. This study could only qualitatively analyze the trajectories and thresholds of potential changes and follow up research on quantifying these dynamics is necessary to better understand trajectories of agricultural systems in the deltas.

This case study illustrated that several challenges agricultural systems currently face such as increased salinity intrusion or declines in aquatic resources are consequences from modifications and increasing human control over the deltaic ecosystem for the purpose of intensive rice production. A departure from massive interventions (taming of nature) towards an adapted agricultural production with the natural and dynamically changing ecological

conditions of the deltas therefore would maintain the natural capital and keep adaptation options open in the future. These have implications for the long-term planning such as the Mekong Delta Plan (Mekong Delta Plan, 2013). This plan proposes a variety of land use options for different hydrological zones in the MKD under various scenarios of social-economic development and changing climates. However, the implementation of many hard adaptation strategies such as hydraulic construction as proposed in the plan would destabilize the ecological system and create many challenges as already experienced in the deltas today. These structural measures could also lock-in specific areas in the coastal zone in particular agricultural system configurations. In the context of dynamically changing social-ecological conditions in the deltas, new external drivers and adaptation options will emerge. Adaptation measures in agricultural systems therefore need to be flexible in order to address future opportunities and challenges. Thus it is necessary to apply both incremental and transformative changes and favour adaptation pathways which allow for adjustments or reversion to avoid lock-in effects. In addition, understanding interactions and feedback in future changes within and across adaptation pathways is critical for the management of agricultural changes in these deltas.

7. SUBJECTIVE RESILIENCE ASSESSMENT OF AGRICULTURAL SYSTEMS FACING INCREASED SALINITY INTRUSION IN DELTAIC COASTAL AREAS OF VIETNAM[9]

7.1 Introduction

The worst drought and salinity intrusion in 90 years took place during the dry season of 2015-2016 in Vietnam with substantial impacts on agricultural production in the country (UNDP, 2016). An estimated two million people experienced income loss, while millions of people suffered from a lack of drinking and domestic water supplies (UNDP, 2016). In the Mekong Delta (MKD) where 11 out of 13 provinces had to declare a state of emergency, increased drought and salinity intrusion caused heavy crop losses and infrastructure damages (CGIAR, 2016). This increase in salinity intrusion was partially attributed to the strong El Niño event which caused a rise in temperature and significant changes in rainfall patterns and river flows regionally. However, other factors influenced the severity of salinity intrusion in the delta, including a lack of long-term projection of salinity trends for salinity preparedness, a decline of river flows and water storage capacity due to the construction of upstream dams and reservoirs, and deficiencies in the effectiveness of response measures locally such as irrigation management and salinity monitoring (Anh, 2017; CGIAR, 2016). In the coastal areas of the Red River Delta (RRD) which is the second largest delta of Vietnam, salinity intrusion also negatively impacts rice yields and poses challenges to irrigation due to the necessary shift of irrigation intake gates farther upstream (Dat et al., 2014; Yen et al., 2016). A further increase in salinity intrusion is predicted for both the Mekong and Red River deltas due to the alteration of rainfall patterns, changing river flows and sea level rise (Carew-Reid, 2008; Dat et al., 2010; Hien et al., 2010). In addition, anthropogenic activities such as dam construction on the respective river systems and groundwater extraction locally have the potential to further accelerate the impact of salinity intrusion on the delta systems (Hai and Lee, 2015; Wagner et al., 2012b).

The Red River and Mekong deltas are the main agricultural production areas of Vietnam as these coastal deltas support a large diversity of agricultural systems and contribute 71.2% of

[9] This chapter is based on the paper "Resilience of agricultural systems facing increased salinity intrusion in deltaic coastal areas of Vietnam", by Nguyen Minh Tu, Fabrice G. Renaud, Zita Sebesvari, and Nguyen Duy Can. The paper was resubmitted to Ecology and Society for a second review.

the rice, 86.3% of the farmed aquaculture and 64.7% of the fruit production of the country (GSO, 2015a; MARD, 2013). The two deltas are historically managed in different ways in terms of addressing salinity intrusion and other natural hazards to maintain agricultural production (Renaud and Kuenzer, 2012). In the MKD, which is largely influenced by tides, farmers have adapted to the seasonal changing salinity conditions by adopting different farming systems along salinity gradients (e.g. cultivation of two or three rice crops per year in the freshwater zone and implementation of rotational rice-aquaculture, all-year round aquaculture, and upland crops in the brackish and saline water zones close to the coast). In the RRD, which has a higher topography and less tide-dominated environment than the MKD, agricultural production is principally protected from salinity intrusion by a system of sea dykes and sluicegates developed over the last thousand years (Tessier, 2011). In the MKD, several salinity-control structures such as sluicegate and river dykes were also established in the coastal zone of the delta in the recent past (Käkönen, 2008; Tuan et al., 2007). These protective infrastructures in both deltas are principally aimed to extend the salt-free period and limit the areas of salinity intrusion for intensive rice production. Currently, the central government has dedicated 3.76 million ha of agricultural land of the country to rice production in order to secure national food security and increase export (GoV, 2016a; Smajgl et al., 2015).

Against the background of increased salinity intrusion, agricultural systems in the RRD and MKD have been increasingly influenced by social-ecological processes at and beyond the delta level. In the basins of both deltas, several dams and reservoirs have been constructed or are planned (MRC, 2011; Vinh et al., 2014). These engineered structures have reduced the sediment loads and altered the hydrological regimes of the rivers that consequently caused significant difficulties for agricultural production in the deltas (Kummu and Varis, 2007; Vinh et al., 2014). From an institutional perspective, many changes in agricultural systems in the deltas over the last decades were driven by national policies. Other major socio-economic drivers include increasing migration and integration of farming systems to global markets, which has accelerated since the Doi Moi (economic and political renovation starting in 1986) (Tu et al., submitted). As results of these processes, agricultural systems in the deltas have changed considerably towards intensification, for example by increasing annual crop production and input use, and diversification of rice production with more aquaculture and upland crops (Käkönen, 2008; van Dijk et al., 2013). These adaptation processes in agricultural systems to changing deltaic social-ecological conditions could lock-in some areas

of the deltas to particular production systems, making shifts to alternative systems or reversing to the original farming systems complicated if not impossible. Examining the sensitivity of agricultural systems to increased salinity intrusion and the capacities to recover from salinity damage and shift to other farming systems when necessary is particularly important for informing the management of such changes and in particular avoiding the development of path dependency (Bennett et al., 2014).

Resilience is a concept that is popularly used to illustrate capacities of systems to absorb disturbances and recover from damages to persist within the same trajectory, as well as the ability to change and transform to a new system state (Carpenter et al., 2001; Folke, 2016). The concept has emerged and is being developed from/into various academic disciplines with different meanings and understandings (Alexander, 2013; Folke, 2016). The first resilience perspective considers a system to be static and assumes that it should "bounce back" to normality/a steady state condition once the disturbance/perturbation is removed or overcome, for instance, the capacity of an agro-ecosystem or critical infrastructure to return to its original state after disturbances (Carpenter et al., 2001; Schwab et al., 2016). This "engineering perspective" of resilience focuses on the reduction of exposure/sensitivity of systems to disturbances so that they stay in the same regime. This perspective can be considered as a flipside of vulnerability (Chelleri et al., 2015). In ecological and social-ecological resilience, the systems are considered to have multiple basins of attractions and are able to switch from one functional state to another (Folke, 2016). The capacity to withstand shocks and recover after the perturbations before moving into an alternative state with different structures and feedbacks is considered the ecological resilience of the system (Walker et al., 2004). Social-ecological resilience is not only the capacity of the systems to buffer and bounce back, but more importantly, the ability to learn from change and create new desirable development pathways under disturbances (Folke, 2016; Nelson et al., 2007).

In agricultural management, the resilience concept has offered a new approach to the conventional farm management that addresses not only the capacity of the farming system to maintain functionality under shocks but also adds the value of proactive changes and transformation into new systems to address future challenges and take advantage of opportunities that arise (Darnhofer, 2014; Nelson et al., 2007). The latter perspective of resilience emphasizes the need to maintain natural capital, redundancy, and flexibility of systems for future adaptation (Bennett et al., 2014; Walker et al., 2010). Management for

resilient agriculture thus requires an understanding of which farming practices to implement in order to maintain the existing system, and when and how to adapt and transform into alternative systems when necessary (Bennett et al., 2014). Despite the widespread application of the concept in various disciplines, resilience has been popularly used as a concept for understanding and managing change, while few studies have attempted to assess and measure resilience in practice (Kien and James, 2013; ODI, 2016). This study therefore aimed to operationalize the resilience concept by assessing the resilience of different agricultural systems in the Mekong and Red River deltas to increased salinity levels based on farmers' perspectives as well as to characterize factors that influence the resilience of these systems.

Although there is variation among disciplines, resilience definitions share similarities in key elements such as types of disturbances, system/unit of analysis, pre-event action, damage limitation, and managing change (ODI, 2016). For example, Kien and James (2013) defined the resilience of households in the MKD to floods as comprising three components: (i) the confidence in securing basic consumptions such as food and income during floods and recovering after the event, (ii) the confidence in securing homes, and (iii) interests in learning and practicing new flood-based farming practices. Resilience is defined by Bennett et al. (2014) and Darnhofer (2014) as the ability of farming systems to buffer shocks and persist, and the capacities to adapt and transform to new systems. Following these definitions, this study defined resilience of agricultural systems to increased salinity intrusion as an interplay of three components. The first component is the sensitivity of the system to increased salinity, indicating how the current farming system would be impacted if salinity increased in the future. The second component relates to the recovery capacity, reflecting the ability of the system to recover after salinity damage in case of increased salinity intrusion (both spatially and temporarily as well as in intensity). The third component is the capacity to change, illustrating the ability of the system to change to alternative farming systems if salinity were to increase even before severe impacts are felt. The first two components - the sensitivity to increased salinity intrusion and the capacity to recover - capture the first resilience perspective in terms of the ability of a system to absorb/buffer shocks and recover after disturbances to persist within the same regime. The last component, the capacity to change, reflects the capacity of the system to change its fundamental attributes to move to a new regime/system state in order to better address future challenges (Chelleri et al., 2015; Folke, 2016).

7.2 Approaches in measuring and assessing resilience (These approaches are mentioned in Section 2.2, Chapter 2 Theoretical and conceptual background)

7.3 Research areas and methodology

7.3.1 Research areas (A detailed description of research sites is mentioned in Section 3.1, Chapter 3 Methodology)

7.3.2 Methodology (A detailed description of methods is mentioned in Section 3.2, Chapter 3 Methodology)

Table 7.1. Characteristics of the interviewed households in the structured (MKD) and semi-structured interviews (RRD)

Explanation		Mean and median (Standard deviations and interquartile ranges in parentheses)		
	Mean/ median	Kien Giang (MKD)	Soc Trang (MKD)	Nam Dinh (RRD)
Number of interviewed households and wealth categories (poor-average-better off) [a]		112 (28-58-19)	114 (41-42-31)	118 (n/a) [a]
Age of the household head (years)	Mean	52.2 (12.83)	50.8 (10.38)	54.6 (9.90)
Education of the household heads (1: No schooling; 2: Primary school, 3: Secondary school; 4: High school; 5: Higher education e.g. university, college, vocational degrees)	Median	3 (2-3)	2 (2-3)	3 (2-3)
Percentage of male-headed households (%)	Mean	86.7 (0.34)	83.3 (0.37)	92.4 (0.27)
House size in square meters	Mean	116 (53.56)	97 (72.18)	86 (53.37)
Percentage of households who are able to access the house by motorbike in both seasons (%)	Mean	80.0 (0.40)	76.3 (0.43)	96.6 (0.18)
Percentage of households that have off-farm income (%) [b]	Mean	41.9 (0.50)	45.6 (0.50)	51.7 (0.50)
Percentage of households that have other on-farm income (%) [c]	Mean	28.8 (0.46)	18.8 (0.39)	37.7 (0.49)

Percentage of households that receive remittances (%)	Mean	10.8	17.1	36.4
		(0.31)	(0.38)	(0.74)
Number of household members	Mean	4.2	4.6	3.7
		(1.43)	(1.56)	(0.29)
Farm size in ha (including all different fields, also of other farming systems)	Mean	2.32	1.75	0.25
		(1.99)	(1.64)	(1.20)

[a] *The wealth categorization was based on the wealth ranking exercises (see section Methodology). No wealth ranking exercise was conducted in the RRD due to a small number of households who have changed farming systems in each village. Change of farming systems was a main criterion for the selection of respondents in the RRD in order to explore the drivers of agricultural changes*

[b] *Off-farm income consists of income sources from hired labor jobs, government jobs, small-scale businesses, fishing, etc. and excludes the remittances or income of members who do not permanently stay in the house*

[c] *Other on-farm income includes income sources from livestock, other cropping systems or aquaculture besides the income from the main system*

7.4 Results

7.4.1 Resilience of agricultural systems to increased salinity intrusion in the Mekong Delta

The results from the resilience assessment (Table 7.2) reveal that the double rice system was perceived as the most sensitive system to salinity, followed by the rice-shrimp and shrimp systems. In contrast, the rice system was perceived as the system with the best recovery capacity after being affected by salinity, while the shrimp and rice-shrimp systems can recover least easily. Rice farmers also perceived a higher capacity to change their farming system, followed by rice-shrimp and shrimp system farmers. However, differences among the farming systems were only statistically significant in relation to the households' perceived capacity to recover ($p<0.05$; Kruskal-Wallis test). The following sections present the sensitivity of agricultural systems to increased salinity intrusion and the capacities to recover from salinity damage and change to other systems if salinity increases in the future. The factors that characterize these resilience components were examined based on the qualitative data from the FGDs and in-depth interviews with farmers and authorities.

Table 7.2. Median values of resilience-related components of agricultural systems for the interviewed farmers in the Mekong Delta (interquartile ranges in parentheses)

Farming systems	Sensitivity [a]	Capacity to recover [b]	Capacity to change [c]
Rice	2.5 (2.0-3.0)	4.0 ^{a} (2.5-4.5)	3.0 (2.0-4.0)
Rice-shrimp	2.0 (2.0-4.0)	3.0 ^{b} (2.0-4.0)	2.0 (2.0-4.0)
Shrimp	2.0 (1.5-3.0)	3.0 (2.0-4.0)	2.5 (2.0-4.0)

The values in the table represent a "1-5 Likert scale" standing for: very little (1) to very much (5) severity (for the question on the sensitivity to increased salinity intrusion) or ability (for questions on the capacities to recover and to change)

No significant difference between farming systems on the sensitivity and capacity to change, significant difference between farming systems on the capacity to recover (p-value<0.05, Kruskal-Wallis test). The median values with different superscripts are significantly different (p-value<0.05, Dunn's test)

[a] *Median value of the first question on expected salinity impact if salinity intrusion increases; lower value is better*

[b] *Median value of the second question on the capacity to recover after salinity damage; higher value is better*

[c] *Median value of the third question on the capacity to change if the conditions of production change; higher value is better*

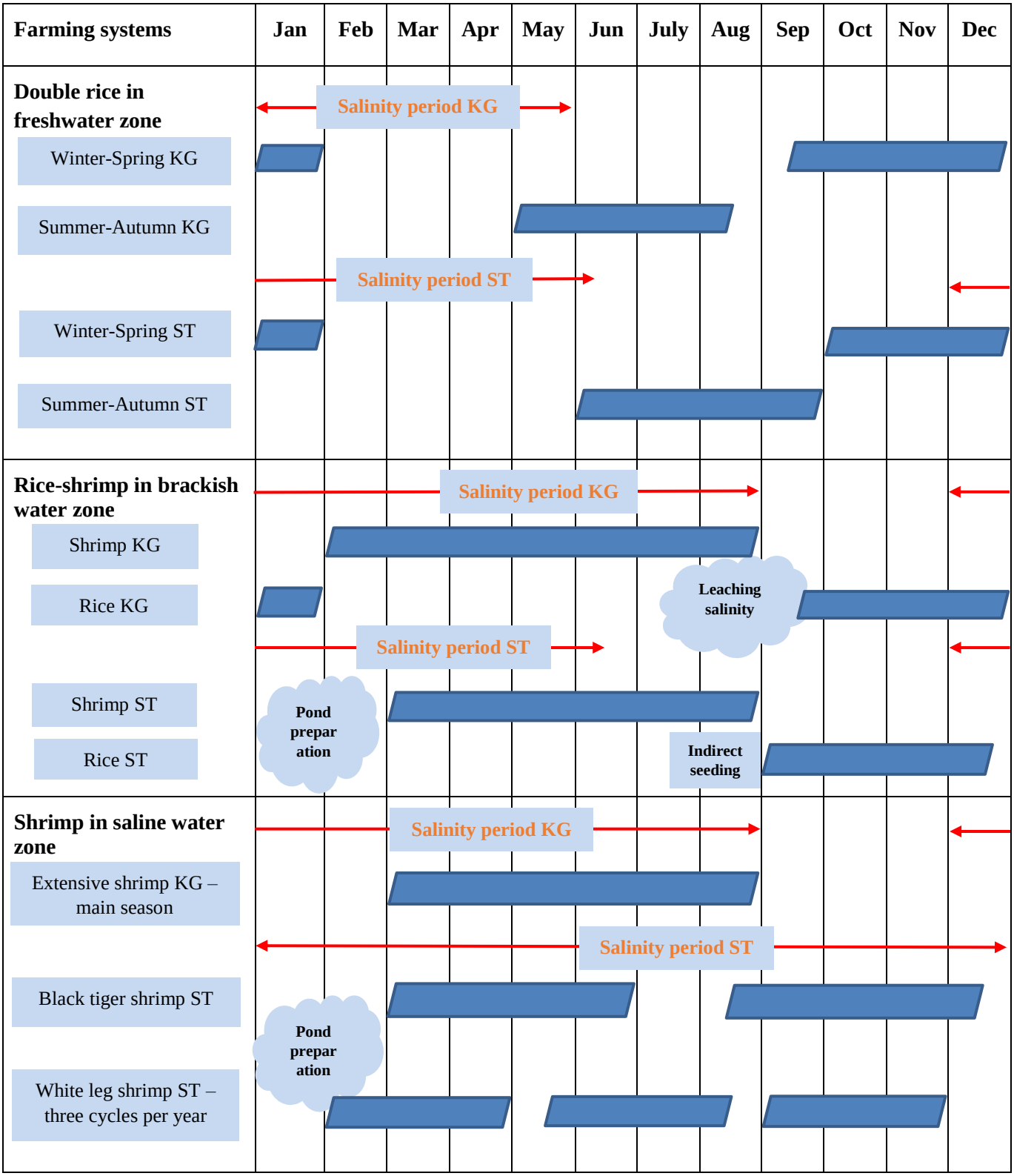
Sensitivity of agricultural systems to increased salinity intrusion

Results from the structured-interviews indicated that nearly 43% of rice farmers, 68% of rice-shrimp farmers and 53% of shrimp farmers assumed that salinity intrusion would increase in the next decade. In the MKD, increased salinity intrusion would cause more impact on rice production than rice-shrimp and shrimp systems. Rice is a saline sensitive crop and yields can significantly decline at salinity levels above 3 g l^{-1} even for some salt-tolerant varieties (Smajgl et al., 2015). Shrimp systems can endure relatively high levels of salinity depending on the shrimp species. The optimal growth rate is obtained at salinity levels less than 15 g l^{-1} for white leg shrimp and 35 g l^{-1} for black tiger shrimp (FAO, 2004; Ye et al., 2009). The rice-shrimp system is typically less affected by salinity intrusion than double rice thanks to the adaptation of rice and shrimp systems to seasonal changes in salinity conditions (see Table 7.3). Prolonged salinity intrusion, however, can shorten the necessary time for leaching salinity after the shrimp season and before the rice season, damaging rice during its crucial development stage due to the remaining salinity content in the soil (Leigh et al., 2017; Nhan et al., 2010).

In the freshwater zone of the research areas, salinity intrusion usually affects the double rice system during the vegetative period of the Winter-Spring season, the latter lasting from September to January in Kien Giang and from October to January in Soc Trang (Table 7.3). In the semi-structured interviews, rice-shrimp farmers often cultivated salt-tolerant rice varieties, while double rice farmers mainly adopted short cycle varieties to be able to harvest the rice before the onset of salinity intrusion. Thus, if salinity intrusion begins to affect the rice crop, the damage is more serious for double rice systems due to a lower salinity tolerance of short cycle rice varieties and the fact that a salinity stress at the vegetative stage causes more harm than during other growth stages (Asch and Wopereis, 2001).

The occurrence of a high content of sulfate and high acidity in the soil is another factor contributing to the high sensitivity of the rice system to increased salinity intrusion. In the MKD, there is evidence that the water acidity rather than salinity affects the rice cropping in areas inside the dyke (Aizawa et al., 2009). During the period of high salinity levels, the sluicegates will be closed to prevent saline water from entering, leading to a lack of freshwater supply and thus falling water levels in the paddy fields (Aizawa et al., 2009; Nhan et al., 2007). The oxidation of acid sulfate soils and the release of toxic substances due to the increased exposure to oxygen damage rice production (Aizawa et al., 2009; Nhan et al., 2007). In the structured and semi-structured interviews, rice-shrimp farmers usually mentioned a reduction of acidity thanks to the use of lime for pond preparation and treatment in-between the rice and shrimp seasons and during the shrimp season (see also Leigh et al., 2017). As evidenced from the structured-interviews, the largest field/pond of rice-shrimp and shrimp systems has a lower acid sulfate soil than double rice systems (p-value $p<0.01$, Kruskal-Wallis test).

Table 7.3. Cropping calendars in Kien Giang and Soc Trang



(KG: Kien Giang; ST: Soc Trang)

Capacity to recover from salinity damage

In the structured-interviews, the rice-shrimp system was perceived to be the least able to recover once affected, while the double rice and shrimp systems were deemed to be able to recover more easily ($p<0.05$; Kruskal-Wallis test). One explanation is that rice-shrimp farmers in Kien Giang rely on rainfall for leaching salinity from the soil after the shrimp season. If the rice-shrimp system experiences damages from salinity, farmers need to wait for the onset of the rain to wash out the salinity and replant. Rice-shrimp farmers in Soc Trang have better access to the fresh water from the adjacent Hau River to eliminate salinity from the soil. However, the increased salinity levels in the river at the end of the rice season could damage the rice crop in Soc Trang, especially when replanting (see Table 7.3). Other explanations are linked to the low capacities farmers have to recover after salinity damage of the rice-shrimp systems as explained in the interviews e.g. lower access to loans and lower off-farm income sources compared to double rice and shrimp systems (all significant at p-value<0.01, Chi-square test). Rice farmers in the freshwater zone can access government loans due to the government policies to promote rice production (GoV, 2012a), while commercial shrimp farmers in the saline water zone generally can easily access loans from input sellers and traders (Ha, 2012; Joffre, 2015). In the freshwater zone, many farmers have off-farm jobs as hired laborers and workers thanks to being closer to the district's center, whereas in the saline water zone, farmers have more opportunities for hired labor jobs in commercial shrimp farms and fishing.

Capacity to change to other agricultural systems

The measurement of perceived capacity to change (Table 7.2) shows no statistical difference between systems (p-value $p<0.01$, Kruskal-Wallis test). In the interviews and FGDs, the shrimp system often demonstrated the least capacity to change since there is no clear pathway the shrimp system could move towards apart from reversing to a rice-shrimp system. There is evidence that the reversion to rice-shrimp systems would also be difficult due to the modified landforms that need to be refilled and as a result of soil salinization from practicing intensive shrimp cultivation (Tho et al., 2008; Thuy and Ford, 2010). Double rice and rice-shrimp systems have more opportunities to change trajectories if salinity increases (e.g. to rice-

shrimp or rice-vegetable crops for double rice systems and mono shrimp for the rice-shrimp systems).

The capacity of double rice systems to change is largely affected by government regulations. At the national level, 3.76 million ha of rice have to be maintained until 2020 to ensure food security and each province has to maintain an assigned rice land area (GoV, 2016a). In 2000, the central government implemented a restructuring policy that introduced greater flexibility and allowed the diversification of marginal rice land use to other systems such as vegetable crops and brackish aquaculture (GoV, 2000a). Nevertheless, the choice of farming system is bound to specific land use planning that stipulates the area for each type of crop (Garschagen et al., 2012; Tien et al., 2006). Farmers can decide which varieties of rice or fruits to cultivate for each assigned land use category. However, a total conversion from double rice to other farming systems such as aquaculture is not encouraged (GoV, 2012a). Given this institutional impediment for shifting away from double rice production, the rice system usually has fewer possibilities for changing to alternative systems when compared to rice-shrimp production.

7.4.2 Resilience of agricultural systems to increased salinity intrusion in the Red River Delta

Sensitivity of agricultural systems to increased salinity intrusion and capacity to recover from salinity damage

In all villages, most farmers assumed that salinity intrusion would decline in the next decade thanks to the continuous upgrade of sea dykes, sluicegates, and irrigation infrastructures. In the RRD, rice is the most salinity affected system (Table 7.4) since it is exposed directly and regularly to water from the Red River. The main sources of salinity intrusion are through sluicegate leakage and salinity infiltration through sea dykes (Yen et al., 2016). Soft-shell turtle and fish production systems are only very slightly affected by an increase in salinity intrusion since these systems are less exposed to saline water due to a less regular exchange with river water (Dat et al., 2014). The increased salinity intrusion also has a low impact on vegetable and rice-vegetable crops since these systems are irrigated with groundwater. Salinity intrusion in groundwater was reported during the interviews but not considered serious at that time. However, since some rice-vegetable and vegetable fields were converted from salt production fields in the past, salinity does become a problem during droughts as sub-soil layers still contain relatively high levels of salt. For the large fish pond system along

the sea dyke, salinity leakage through sea dyke exists but is not serious for fish farming. Vegetable crops, fish, and soft-shell turtle also have a lower sensitivity to salinity when compared to rice (FAO, 2002).

Table 7.4. Median values of perceived sensitivity of agricultural systems to increased salinity intrusion and recovery capacity for the interviewed farmers in the Red River Delta (interquartile ranges in parentheses)

Perceived components	Double rice	Rice-vegetable	Vegetable	Fish pond	Soft-shell turtle	Large fish pond
Sensitivity [a]	1.0 (1.0-2.0)	1.0 (1.0-1.0)	n/a	2.0 (1.0-4.0)	2.0 (1.0-2.0)	n/a
Capacity to recover [a]	4.0 (3.0-5.0)	4.0 (2.0-5.0)	n/a	4.0 (2.5-4.5)	4.0 (2.0-4.0)	n/a

[a] *The values in the table represent a "1-5 Likert scale" standing for: very much (1) to very little (5) severity (for question on the sensitivity to increased salinity intrusion) or ability (for questions on the capacities to recover and to change). No statistical test was performed due to the small sample size or lack of answers for some farming groups*

Farmers in all farming systems perceived a high capacity to recover from salinity damage (Table 7.4). During the interviews, rice farmers mentioned that they would replant the rice crop by washing out the salinity and increasing fertilizer use to compensate for the damage. Rice-vegetable and vegetable systems can also recover easily from salinity damage since farmers can switch the vegetable crops. For fish pond, soft-shell turtle and large fish pond systems, farmers usually mentioned the use of lime and fertilizers to lower the salinity in the ponds before returning to farming activities.

Capacity to change to other agricultural systems

Regardless of the farming system, a majority of farmers in the interviews stated that they would continue their current farming systems even if they suffered two consecutive crop losses. In the interviews, when asked for a self-assessment of the capacity to change, fish pond, large fish pond, and double rice farmers noted low capacities to change, while rice-vegetable, vegetable, and soft-shell turtle farmers rated a higher capacity to shift to other systems (Table 7.5). Fish pond and large fish pond systems are usually difficult to convert back to double rice or other systems due to excavation of land and a high financial capital

requirement to fill the pond. Similar to the MKD, the institutional settings that favor rice production impede shifts from double rice systems to alternative systems (GoV, 2012a). For rice-vegetable and vegetable, farmers can easily change their systems to fruits, bonsai, rice, and flowers. During the interviews, soft-shell turtle farmers also perceived a high capacity to shift to other systems such as fish, integrated garden-pond-animal shed systems, and vegetable.

Table 7.5. Median values of perceived capacity to change of agricultural systems by the interviewed farmers in the Red River Delta (interquartile ranges in parentheses)

	Double rice	Vegetable	Rice-vegetable	Fish pond	Soft-shell turtle	Large fish pond
Perceived capacity to change	3.0 [a] (2.0-4.0)	4.5 [b] (4.0-5.0)	4.0 (3.0-5.0)	2.5 [a] (2.0-4.0)	4.0 (3.0-5.0)	2.0 [a] (2.0-4.0)

The values in the table represent a "1-5 Likert scale" standing for: very little (1) to very much (5) ability. Significant difference of perceived capacity to change between farming systems ($p<0.05$, Kruskal-Wallis test). The median values with different superscript are significantly different (p-value<0.05, Dunn's test)

7.5 Discussion and conclusions

7.5.1 Factors that characterize resilience components of agricultural systems in the deltas

Sensitivity of agricultural systems to increased salinity

The existence of protective infrastructure is a key factor shaping differences in resilience to salinity of farming systems between the two deltas, especially the sensitivity to increased salinity intrusion. In the RRD, the system of concrete sea dykes and sluicegates makes the entire area a freshwater zone. Agricultural systems generally have a low exposure and sensitivity to salinity intrusion and high recovery capacity but have a low capacity to change to other systems. In the MKD, agricultural systems are more exposed to salinity due to a close connection between farming systems and the surrounding environment. Rice-shrimp and shrimp systems in the MKD are less sensitive to increased salinity intrusion thanks to the higher salt tolerance level of shrimp and an adaptation of rice and shrimp farming systems to seasonal fluctuation in salinity conditions.

In both deltas, the uptake of salt-tolerant rice varieties is a factor lowering the sensitivity of the system to salinity (Table 7.6). There is some evidence that at a salinity threshold below 3 ppt, rice production in the MKD would be maintained if sensitive rice varieties were replaced by salt-tolerant rice varieties (Smajgl et al., 2015). In the MKD, an early seasonal occurrence of salinity intrusion can significantly affect the rice crop. Thus rice farmers have attempted to shorten the rice growing cycle (e.g by adopting short cycle rice varieties and transplanted rice) to harvest the rice crop before the onset of saline conditions. In order to improve their performance, these agronomic measures are usually applied together with additional strategies such as adjustment in cropping calendar, agro-chemical application and soil preparation, and irrigation management (Nhan et al., 2010).

Another factor that can influence the sensitivity and coping capacity of farming systems to salinity intrusion is the use and communication of salinity measurements or information by farmers. In the MKD, rice-shrimp and shrimp farmers generally use salinity information for their farming activities more often than rice farmers and therefore can react more quickly when salinity levels start rising. In the semi-structured interviews, rice farmers mentioned that they received information on salinity from television, rice-shrimp farmers, and from the operators of pumping stations or sluicegates. In the brackish water zone, a majority of rice-shrimp farmers (e.g. 7 out of 11 farmers in Kien Giang and 8 out of 12 farmers in Soc Trang) measured the salinity, while others received information from other rice-shrimp farmers, shrimp stock sellers, and television. In the saline water zone in both provinces, most farmers measured the salinity levels before pumping the water into the ponds. This salinity information, however, was acquired only when the saline water had already entered the canals. In the RRD, salinity monitoring and operation of sluicegates and pumping stations - which are managed by a state irrigation company - are also important factors for preventing salinity damage. Monitoring and long-term projections of salinity levels would build resilience in all agricultural systems in both deltas by enhancing their adaptive capacity to confront changes and increase the preparedness of farmers facing increased salinity intrusion (Adger et al., 2005; Renaud et al., 2015).

Capacity of agricultural systems to recover after salinity damage

Financial capital is an important factor contributing to the capacity to recover from salinity damage of many farming systems in the deltas. For rice-shrimp and shrimp systems in the

MKD, the recovery is largely based on capital investment since the investment for rice-shrimp and shrimp cultivation is much higher than for the double rice system (Can, 2016; Joffre et al., 2007; Thuy and Ford, 2010). In the semi-structured interviews, farmers mentioned that they usually harvest their shrimp immediately if they experience evidence of failure to partially regain the invested capital. This can be done for 2-2.5 month-old black tiger shrimp and 1-1.5 month-old white leg shrimp. This capital is therefore important for the investment in the next season. In the RRD, investment capital is usually required for increasing input uses to recover from the salinity damage.

In the RRD, most farmers perceived that their farming systems can recover easily. This high ranking of the recovery capacity of agricultural systems in the RRD, however, might be influenced by farmers' perception of mild salinity intrusion episodes as experienced in the past, when farmers could easily flush out salinity from rice fields and increase the use of inputs to compensate for the damage to rice, fish and soft-shell turtle production (Dat et al., 2014). Thus the perceived capacity to recover of these systems would be lower if salinity intrusion increases and such coping measures will no longer be effective for a full recovery of the systems following salinity damage.

Support from other farmers and the government is another factor that enhances the recovery capacity of agricultural systems, especially during times of crisis. At present, the government has policies to promote double rice production, and rice farmers can receive a subsidy of 50,000 VND (approximately 2.5 USD) per 0.1 ha in case of salinity damage (GoV, 2012a). In the structured interviews in the MKD, rice and shrimp farmers have reported a higher probability of receiving help from other farmers and the government, while rice-shrimp farmers reported a lower ability to receive this kind of support (see Appendix 5). In all villages in the RRD, farmers mentioned receiving high levels of support from other farmers (e.g. loans, direct help), and except for the vegetable production, farmers reported low government support e.g. subsidies, loans (see Appendix 5). One explanation of low perceived government support in the RRD is that farms are typically smaller (Tuan, 2010), limiting the accessibility of subsidies and loans for farmers.

Capacity of agricultural systems to change to other systems

At present, the rice system in both deltas is locked-in by the "rice-first" policy that favors rice production and discourages shifting to alternative systems (GoV, 2012a). This comes hand in hand with the development of infrastructure built to limit salinity intrusion and boost irrigation capacity, infrastructure that then requires a return on investment, thus also contributing to the lock-in effect. Another constraining factor regarding the capacity to change is linked to the biophysical characteristics of the land/pond. In the MKD, soil salinization and land modification from practicing shrimp farming and rice-intensive shrimp systems in Soc Trang (Table 7.6) need technical solutions to remedy and investments to re-fill the ponds. These are the main factors preventing the reversion and change to other systems of shrimp and rice-intensive shrimp systems (Thuy and Ford, 2010). Investment capital to fill the pond is also a barrier to reverse or to shift to other systems for fish and soft-shell turtle systems in the RRD.

Table 7.6. Factors that characterize the resilience components of agricultural systems

	Rice (MKD)	**Rice-shrimp (MKD)**	**Shrimp (MKD)**	**Rice (RRD)**	**Rice-vegetable, vegetable, fish pond, soft-shell turtle and large fish pond systems (RRD)**
Factors that increase/decrease the sensitivity to increased salinity	- Low salt-tolerance level of rice varieties (increase) - Salinity damage during the sensitive time of the rice crop (increase) - High acid sulfate soils (increase) - Limited use of salinity information (increase)	- Application of salt-tolerant rice varieties (decrease) - Regular use of salinity information (decrease)	- High salt-tolerance level of shrimp (decrease) - Low exposure to the river waters by water recycling (decrease) - Regular use of salinity information (decrease)	- Low salt-tolerance level of rice varieties (increase) - Management of sluicegate operation and water intake (decrease)	- High salt-tolerance levels of vegetable crops, fish and soft-shell turtle (decrease) - Less regular exchange with the river waters (decrease)

Factors that increase/decrease the capacity to recover	- High support from the government and neighbors (increase) - High access to loans (increase) - High off-farm income (increase)	- Availability of freshwater supplies for leaching salinity after salinity damage (increase) - High investment capital requirement (decrease) - Low access to loans (decrease) - Low off-farm income (decrease) - Low support from the government and neighbors (decrease)	- High investment capital requirement (decrease) - High access to loans (increase) - High off-farm income (increase) - High support from the government and neighbors (increase)	- Availability of irrigation water for washing salinity (increase) - Availability of investment capital for an increase of input use (e.g. fertilizer) (increase) - High neighbor help (increase) - Low access to loans and subsidies (decrease)	- Availability of investment capital for an increase of input use (e.g. fertilizer) (increase) - High loans and subsidies for vegetable production (increase) - High neighbor help (increase)
Factors that decrease the capacity to change	- Inflexible regulatory framework for change	- Land modification. A too deep excavation of the fields for shrimp farming causes difficulty for rice cultivation in the wet season and locks-in the system in shrimp production	- Soil salinization - Difficulty of reversion of the modified landform from shrimp ponds to other systems	- Inflexible regulatory framework for change	- Investment capital requirement to fill the land (for fish and soft-shell turtle)

7.5.2 Resilience trade-offs in agricultural shifts and navigation of resilience components in the context of increased salinity intrusion

The assessment of resilience according to the criteria of the sensitivity of agricultural systems to increased salinity intrusion and capacities to recover and change resulted in none of the agricultural systems being ranked first in all resilience components. This finding implies that a shift from one system to another to reduce the sensitivity or improve capacities to recover or change would impact other resilience components negatively. For example, a change from double rice to rice-shrimp would reduce the sensitivity to salinity intrusion and increase the capacity to change but decrease the recovery capacity of the system. Similarly, a change from rice-shrimp to shrimp can reduce the sensitivity and increase the capacity to recover but decrease the capacity to change in the future (Fig. 7.1). Similarly, a shift from double rice to

fish in the RRD can limit the sensitivity to salinity intrusion. However this comes at the expense of capacities to recover and to change to other systems when necessary.

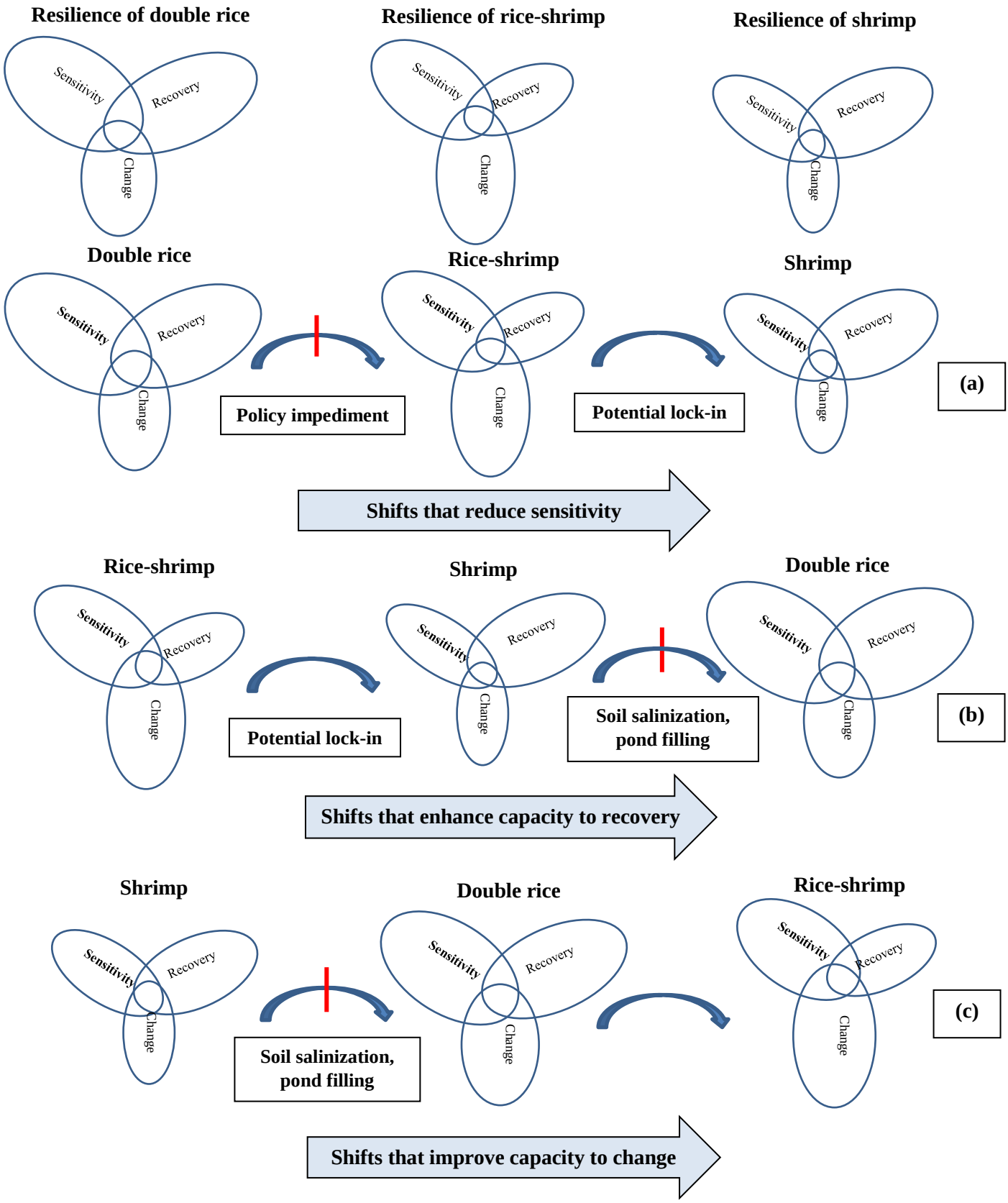


Fig. 7.1. Resilience and changes in resilience factors by shifting agricultural systems in the Mekong Delta (the bigger the propeller, the higher the sensitivity, recovery, or ability to change of agricultural systems). The shift from one system to another will help to reduce the sensitivity of the system to salinity intrusion (case a), increase the capacity to recover (case b), or improve the capacity to change (case c). These shifts consequently increase the sensitivity (case b and c: from shrimp to double rice), reduce the capacity to recover (case a and c: from double rice to rice-shrimp), or degrade the capacity to change (case a: from double rice to rice-shrimp; case b: from rice-shrimp to shrimp). The red blocks indicate shifts that are either very difficult or not currently possible.

Agricultural management for reducing sensitivity to salinity intrusion

Under a specific salinity level, agricultural systems can buffer salinity without changing their structures and feedbacks (Darnhofer, 2014). The implementation of adaptive farming technologies such as salt-tolerant rice varieties, adjustment of the cropping calendar, or control of irrigation and water intake would be effective to prevent salinity damage on rice and rice-shrimp systems (Table 7.6) (Nhan et al., 2010; Renaud et al., 2015). Additional solutions could be the development of early warning systems and awareness raising on salinity intrusion to reduce the exposure of the systems to high salinity events. Structural adaptation measures such as the construction of protective infrastructures and improvement of irrigation networks as well as an application of ecosystem-based adaptation measures such as mangrove reforestation and wetland rehabilitation could also limit the magnitude of salinity intrusion (Renaud et al., 2015; Smajgl et al., 2015). One of the risks of structural measures is the modification of the hazard exposure and the focus on one resilience component that may degrade other resilience components and the overall resilience in the longer run due to a decline of biodiversity, functional redundancy, and spatial variation (Adger et al., 2005; Biggs et al., 2012).

Agricultural management for enhancing recovery capacity after salinity damage

An alternative solution is to improve the recovery capacity to keep the systems in place and quickly recover from salinity damage. For instance, the diversification of income sources would be one such measure. In the MKD, farmers in the freshwater zone have integrated double rice with vegetables, while farmers in the brackish and saline water zones have diversified rice-shrimp and shrimp systems with livestock to buffer yield losses. Additional measures could be considered at higher levels beyond farm management such as subsidization

for salinity damages, crop insurance to pool risk, and generation of off-farm income. Since Doi Moi in 1986, the economic structure and livelihoods of farming households in both deltas have altered fundamentally towards diversification of income sources, with an increase in the share of income from wage and non-farm activities and a decline of on-farm income (Garschagen et al., 2012; Ha, 2016; Tuan, 2010). At the national level, the shares of the agricultural sector in the economy have declined continuously from ca. 38.1% in 1986 to ca. 16.0% in 2016 (GSO, 2017). Agricultural labors in the deltas have increasingly migrated to the big cities to work in the industrial and service sectors (Anh et al., 2003; Garschagen et al., 2012; Tuan, 2010). In the research areas of the RRD, many interviewed households have off-farm income and receive remittances from family members in addition to the on-farm income. In all villages, ca. 39% of households had at least one member who permanently migrated out of the district and ca. 52% of households had off-farm jobs such as making handicrafts, fishing, and operating small-scale businesses. In the MKD, ca. 29% of households responding to the semi-structured interviews had at least one member permanently migrating out of the district and ca. 33% of households had off-farm income. This could be considered as contributing adaptation measures to salinity intrusion and other natural hazards that influence the resilience of the farming systems in the research areas (Adger et al., 2002b; Dat et al., 2014; Dun, 2011), even if they were initially put in place for boosting income and livelihoods.

These incremental adaptations for buffering the consequences and enhancing the recovery capacity from salinity damage do not necessarily change the qualitative state of the system (IPCC, 2014; Schwab et al., 2016). If higher salinity levels materialize in the long-term, these measures may not be effective at helping the system to fully recover from damages (Binh, 2015). The increased external pressures, in particular salinity intrusion and the changing internal agricultural structures and feedbacks, will slowly push the agricultural systems over a threshold towards undesirable states (Bennett et al., 2014; Mueller et al., 2014). The change of system states in this case does not necessarily take place after the salinity level has reached its thresholds, but even earlier than this point after the household's adaptive capacity for adaptation to salinity has been degraded. This could be a result of a poverty trap in an increasingly threatened system by salinity intrusion and undermining social-economic capitals for adaptation (Binh, 2015).

Agricultural management for improving capacity to change

Another option would be the shift to new systems with lower sensitivity to salinity intrusion or higher recovery capacity from salinity damage before severe impacts are felt (see Fig. 7.1). During the interviews in the saline water zone in Kien Giang, shrimp farmers mentioned the discontinuity of income from monthly shrimp harvesting during the rice season in cases where rice-shrimp production was reverted to. In the RRD, many farmers wish to change their double rice systems to aquaculture if policies allowed them to do so. These agricultural transformations may be disruptive and thus require an introduction of a flexible regulatory framework for changes and outside supports (e.g. loans and training) for trying and learning new farming practices and systems. The shift from one system to another, for instance, from double rice to fish pond and soft-shell turtle in the RRD would also degrade other resilience components, in particular the capacities to recover and to change. A shift from rice-shrimp to shrimp in the brackish water zone in the MKD would lock the system into shrimp production, constraining further shifts to other systems (Tho et al., 2008; Thuy and Ford, 2010). In the face of changing social-ecological conditions in the deltas that will pose more opportunities and challenges, the shifts that allow the reversion or transformation to other systems to address future developments should be favored as opposed to shifts that may lock-in agricultural systems to path-dependencies and hinder future changes (Renaud et al., 2015). Some integrated farming systems such as single or double rice combined with vegetable, coconut or rice-extensive aquaculture in the MKD, and integrated rice-garden-animal shed systems or rice-vegetable in the RRD would diversify farmers' income sources which could contribute to buffer salinity-induced damages and create opportunities for further innovation. The conversion to these systems does not require substantial land modification and thus would keep the natural capital and future options relatively intact and also be accepted to some extent by the government.

7.5.3 Limitations and insights from subjective assessment of resilience

There are some limitations in subjective assessment of resilience in this study. The first bias could be linked to the framing of the questions by researchers and the way respondents perceived them. In this regard, there might be discrepancies in farmers' perception on different components of resilience. For example, in the assessment of the capacity to recover from salinity damage, rice-shrimp farmers could think about recovery in the next season,

while rice farmers might refer to recovery within the same season. This difference in farmers' perception is also relevant for the assessment of the sensitivity of agricultural systems since farmers may think of different salinity levels depending on their past experiences. A second potential drawback is the fact that marginal groups might give a higher value on the Likert-scale than they actually feel (Jones and Samman, 2016), or deviations in cultural norms between different ethnic groups (e.g. Kinh and Khmer), regions (e.g. between the Mekong and Red River deltas) or gender might influence the answers from respondents. A careful design and pre-testing of the elicited questions has been suggested for the subjective measurement of resilience to limit both the researchers and respondent's biases (Clare et al., 2017; Jones and Tanner, 2016). In this study, an extensive questionnaire pre-test and an application of both the scoring and the explanation for the selection were carried out to reduce these biases.

In addition, agricultural systems in the deltas are currently exposed to multiple social and environmental stressors from water-related hazards, social-economic transitions and market volatility (Cong et al., 2009; de Araujo Barbosa et al., 2016). Responses of agricultural systems to these stressors would influence the resilience of the systems to salinity intrusion and other stressors in different dimensions. For instance, increased migration and remittances could contribute to lifting the migrant-sending households out of poverty (Duc et al., 2015) and thus boost their capacity to recover from salinity damage and provide investment capital for shifting to new systems. However, a move of the prime labor force (e.g. young and highly educated people) would lead to a lack of productive labor force for agricultural activities and climate change adaptation (Anh, 1998). While the study aimed to assess the resilience of farming systems to salinity intrusion as a specific environmental stressor, other multiple shocks and trends within and beyond the delta level could influence the general resilience of these systems. Thus a highly resilient system to salinity would be less resilient to other stressors, for example a market fluctuation or an epidemic. A specified resilience assessment as presented in this study therefore would limit the social-ecological understanding of resilience as the ability of systems to transform to alternative system states to deal with new and unpredictable stressors (Chelleri et al., 2015; Nelson et al., 2007; O'Connell et al., 2015).

Similar to the study of Jones and Samman, (2016), this study did not find a strong association of household characteristics such as wealth, education, age of household heads, and group membership on subjective resilience-related components. There were also no significant

differences between farming systems in the MKD with relation to household's perceived sensitivity of their systems to increased salinity intrusion and perceived capacity to change. There are some explanations and implications of this result: (i) the application of subjective resilience assessment using a single question for each component was not enough to capture the resilience of agricultural systems. To date, there has not been a standard resilience approach to validate the resilience assessment and measurement and to compare between subjective and objective measurements of resilience (Clare et al., 2017). In this regard, complementing subjective resilience assessment with qualitative data e.g. from FGDs and in-depth interviews provides a more holistic understanding of resilience and its determinants; (ii) the socioeconomic characteristics of households were not important in determining the subjective resilience of farmers. Therefore, we may need to include more variables related to the ecological component of the farming system such as soil or irrigation characteristics to test for the associations; and (iii) the application of the 5-point Likert scale may not yield comparable results of resilience since farmers are limited in terms of responses. An application of more evaluation scales (e.g. 7-point Likert scales or higher) in the elicited questions such as in Clare et al., (2017) therefore could be considered. In addition, supplementing qualitative information from FGDs and in-depth interviews could offer insights into resilience and would allow for a comparison of resilience between agricultural systems and communities. In this study, the qualitative information was useful to explore the drivers of resilience as well as to explain potential differences in resilience components between farming systems. This enabled the identification or confirmation of the differences in resilience components where the statistical analysis was not applicable or was not able to reveal significant differences between systems.

8. CONCLUSION AND OUTLOOK

8.1 Main research findings

8.1.1 Multiple drivers of change and adaptation pathways in agricultural systems facing salinity intrusion in the Mekong and Red River Deltas

Agricultural systems in the Mekong and Red River deltas over the last decades have experienced considerable changes. Being located at low-lying coastal areas with ongoing subsidence, both the MKD and RRD are facing significant adverse effects of relative sea level rise and salinity intrusion (Syvitski et al., 2009; Wassmann et al., 2004). Various studies (Aizawa et al., 2009; Dat et al., 2014; Ngoc, 2013) carried out in the research areas emphasize the impacts of climate change and rising sea levels as one of the main drivers of agricultural changes in these deltas. However, few studies assessed the ripple effects of natural hazards such as salinity intrusion on the farming systems and feedback mechanisms between them. The linkages between salinity intrusion and agricultural systems in these deltas are reciprocal since changes in farming systems due to salinity intrusion create feedbacks that aggravate the salinity problem (Chapter 6). In difference from the simple and linear approaches that are predominantly applied in analyses of causing mechanisms of land use changes, this research considers agricultural systems as complex adaptive systems and emphasizes that changes in these systems are results of interactions and feedbacks of multiple drivers of change at and beyond the delta level.

The first objective of this study was to explore historical and present drivers of agricultural changes in the MKD and RRD since 1975. The empirical findings (Chapter 6) reveal that changes in agricultural systems over the last decades in these deltas were shaped by the interactions and feedbacks of various drivers of change (e.g. national policies, farmers' desire for higher profit, changes in biophysical and salinity conditions, and development and adoption of advanced farming techniques) across various spatial and temporal scales. Some of these drivers such as national policies, dam construction at upstream areas of the deltas, and global market prices operate diffusely from agricultural systems. These external drivers influence internal drivers at the local level and caused changes in the farming systems. Amongst those drivers, government policies are the major drivers of many changes in agricultural systems in the deltas. Policies would be classified as an external driver when it is considered at the national scale. At the local level, the implementation and processes of

policies are internal processes. Several alterations in government policies and political ideologies such as the Doi Moi starting in 1986, the land allocation since 1992 in the RRD, and the policy for agricultural restructuring in 2000 (Chapter 5) were political factors that strongly shaped the current farming systems in the deltas. Policies and government interventions also influenced other drivers of change. For instance, changes in policies toward a market-oriented economy have reintroduced the market incentives to farmers. Dyke construction and excavation of irrigation canals by the government in order to favour rice production were some of the main factors contributing to environmental degradation (Huu, 2011). High-yielding rice varieties and new farming techniques were also introduced to farmers and facilitated via government extension agencies (Ut and Kei, 2006). At the local level, a variation of drivers exists. These include biophysical degradation due to dam construction and excavation of irrigation systems, adoption of new farming techniques, modern crop varieties and aquatic species, lack of supplies of ecosystem services, and farmers' interest in profit maximization of their farming activities. These internal drivers are influenced by external drivers at various scales and their changes create feedbacks with external drivers that in turn become the new drivers and positively or negatively affect agricultural development.

The research identified and discussed interactions and feedback mechanisms in agricultural changes (Chapter 6) that would contribute to further increases in salinity intrusion and agricultural changes. For instance, in the change from double rice to rice-shrimp production in Kien Giang, saline water leakage from the converted rice-shrimp fields damaged the rice crop and reinforced the shift to mono shrimp. In Soc Trang, a change from single to double rice in the freshwater zone resulted in a decline of aquatic resources that contributed to a shift from a collection of aquatic species to shrimp production during the dry season in the brackish water zone. These changes consequently exacerbated salinity intrusion further inland and negatively affected the development of the rice system in the freshwater zone. There were also feedbacks in the agricultural management system, for instance in An Minh the policies were released in response to agricultural changes locally. The local administration asked the higher administrative government at the provincial level for an agreement for change and got approval after the conversions had already been carried out in the district. The policy for change then created a positive feedback with the ongoing shifts and the conversion was cascaded to the larger scale. An important implication from the analysis of drivers and feedback mechanisms in agricultural changes is that these interactions and feedbacks could

increase salinity intrusion further and negatively impact agricultural changes at other places that need to be carefully considered in agricultural planning. This is relevant for both the MKD and RRD and other similar coastal deltas where agricultural systems and the ecology are highly complex and interconnected.

Based on the analyses of past and present changes in agricultural systems, as well as potential responses of farmers to changing drivers and salinity conditions, the second objective of this research aimed to explore trajectories and various adaptation options of agricultural systems facing salinity intrusion (Chapter 6). The study adopted an adaptation pathway approach to determine which specific agricultural systems farmers are likely to shift to with a hypothetical salinity intrusion or market price change, their capacity to reverse or to shift to other systems, as well as potential interactions and feedbacks between these future changes. The analyses reveal multiple adaptation pathways (e.g. from double rice to rice-shrimp system, rice-vegetable crops, or from rice-shrimp to shrimp production) in response to changing market prices and salinity levels within each salinity gradient. Apart from these two drivers, agricultural systems in the research areas are also influenced by other social-ecological processes at the delta and national levels. Dam construction at the upstream areas of the deltas that could alter the river flows and sediment loads (Kummu and Varis, 2007; Manh et al., 2015; Vinh et al., 2014), increased migration to big cities (Chapter 4), changes in land use policies (for example, the recent policy for climate change adaptation for the MKD released in 2017; GoV, 2017) are other biophysical and socio-economic drivers that would alter the future conditions and barriers of adaptation. An inclusion of all these drivers into adaptation pathway exploration requires multiple hypotheticals and considerations by farmers in the interviews and FGDs and makes the analyses complicated. Therefore, only the two mentioned key drivers were asked for future considerations in the interviews and FGDs with farmers.

The study also assessed the reversibility of each adaptation process and the potential influences of each change on other agro-ecosystem (Chapter 6) based on a literature review of relevant studies and data generated during the FGD and interviews. Reversibility is not only a feature to address future uncertainty, but this criterion concurs with many other government policies related to land use. Several policies considered the reversibility an important criterion for land use shifts. For example, the government decision on adjustment of rice land in 2016 (Chapter 1) stipulated that the conversion of 400,000 ha rice land to another system is allowed only if this area could be reverted later to rice land (GoV, 2016a). Results from the analyses

of adaptation pathways show that changes in agricultural systems, for instance from rice-shrimp to all-year-round shrimp, would lock-in the system within one production system or constrain shifts in other agricultural systems due to cross-scale interactions and feedbacks between these changes. In the context of the deltas, many hard adaptation structures such as dyke construction together with the fixed land use planning favouring rice production are inflexible to address future changes. Thus shifts to agricultural systems which allow for a continuous adjustment to avoid lock-ins and prevent the development of "path-dependencies" should be advocated.

In addition, the relative importance of drivers varies between agro-eco zones and drivers are also different amongst places and stakeholders. Therefore, not all farmers within communities would follow the same pathways. A fixed and single adaptation pathway may generate opportunities for some groups of farmers, and lock-in others in pathways that are undesirable for them (Käkönen, 2008). Given the heterogeneity of agricultural landscapes in the deltas, no pathway could fulfill wishes of all stakeholders. It is thus important to embrace site-specific adaptation measures and a diversity of adaptation pathways for various agro-eco zones and groups of farmers. Additionally, supports (e.g. low-interest loans, training, and subsidies) are necessary for marginalized groups to enact the adaptation actions or where new risks are generated due to adaptation at other places to improve the equality for all resource users (Adger, 1999; Renaud et al., 2015; Wisner et al., 2003).

8.1.2 Resilience of agricultural systems facing increased salinity intrusion in the Mekong and Red River Deltas

This study contributes to the development of alternative approaches for assessing resilience by developing and testing a subjective resilience assessment method. Based on a literature review and information from the previous phase of the research that aimed to identify drivers of agricultural changes, the resilience of agricultural systems to increased salinity intrusion was defined as comprising three components (i) the sensitivity of agricultural systems to increased salinity intrusion, (ii) the capacity to recover after salinity damage, and (iii) the capacity to change to other systems (Chapter 2 and 7). The resilience assessment of agricultural systems facing increased salinity intrusion in the MKD and RRD (Chapter 7) reveals that none of the systems has the highest scores in all resilience components. This result implies that a shift from one system to another to improve a particular resilience component would degrade the others. Management for resilient agriculture thus demands an

appropriate allocation of available resources to improve specific resilience components at appropriate time and place. This is to increase the ability of the farming systems to absorb the salinity and to recover after the damage to persist in the same system under a certain coping range, as well as to transform the systems into a new state when necessary. The most important implication from the implementation of the resilience concept is the necessity to promote the flexibility and diversification of agricultural systems in order to prevent the development of "path-dependencies" that would hinder future changes. Adaptation to increased salinity intrusion should be considered as a learning process (Abel et al., 2016; Haasnoot et al., 2013; Reed et al., 2013), and land use and adaptation planning should give room for learning and trying new farming systems, as well as for facilitating adjustment of resilience components when necessary.

The study initially aimed to identify the best farming system in terms of resilience for different groups of farmers within various salinity transects based on an indicator-based approach. This analysis aimed to identify the "best" adaptation pathway for each social-economic group (e.g. different wealth and educational groups) that, in combination with the drivers of change identified in Chapter 6, could provide important information for land use shifts. However, the statistical analyses did not reveal a significant difference between groups of farmers with relation to their perception on resilience components. It is important to stress that resilience is considered as dynamic rather than a final outcome to be achieved (Darnhofer, 2014). Therefore, a measurement and comparison of resilience indexes could provide misleading information for the management of these complex systems since the measured resilience metrics could change rapidly (Clare et al., 2017; Levine, 2014). Moreover, given the heterogeneity of the research sites, the measurements of resilience of different farming systems for different groups of farmers would not provide a meaningful information in term of shifting farming systems. Farmers at different time and place could rely on different resources to build resilience and a quantification of resilience is hard to generalize to the whole group or the entire salinity zone (Levine, 2014). Therefore, the management of resilience components to suit the changing salinity conditions was a more feasible approach.

8.1.3 Should the Mekong Delta be intensively dyked?

Salinity intrusion is currently less severe in the RRD than in the MKD, partly thanks to the construction of a system of concrete sea dykes and sluicegates. At the moment, there are

scientific and public debates on whether a system of sea dykes should be built in the MKD (Danh, 2012; Smajgl et al., 2015). The Mekong Delta Plan (see Chapter 6), while calling for "no-regret measures" in adapting to rising sea levels in the MKD, also introduced options of construction of sea dykes and sluicegates in the coastal zones of the delta (Mekong Delta Plan, 2013). After the historic salinity event in 2015-206, calls for a more technical approach in adapting agricultural systems in the MKD to salinity intrusion also emerged in the media. Should sophisticated dyke and sluicegate systems be built in the MKD? Could the agricultural systems in the MKD adapt to a more hydraulic-dominated landscape as existing in the RRD? And would an implementation of massive engineered infrastructures bring a prospering or undesirable delta system?

Apart from salinity intrusion, there are other aspects to consider in response to increased rising sea levels and salinity problem in the MKD. The Mekong and Red River deltas are different in geographical conditions (Chapter 4), socio-economic settings and historical development (Chapter 5) that differentiate the impacts and adaptations to salinity intrusion between the two deltas. Unlike the RRD, the MKD is a young, low-lying delta which relies on supply of sediments to slow subsidence, which is currently happening at an average rate of 1.6 cm per year (Erban et al., 2014; Syvitski et al., 2009). The RRD has a higher elevation than the MKD and thus would be less seriously impacted by increased eustatic sea level rise and land subsidence (MONRE, 2016). Several studies (Anthony et al., 2015; Kummu and Varis, 2007; Manh et al., 2015) indicate that the construction of dams and infrastructure in the MKD has reduced sedimentations and caused rapid erosion in the coastal zone of the delta. A decline of surface water supplies due to hydraulic works would introduce additional problems such as overexploitation of groundwater that exacerbates land subsidence (Erban et al., 2014). Thus the effects of a more intensive application of dykes and protective infrastructures on the sedimentation, water use and delta subsidence need to be assessed comprehensively.

From an environmental perspective, an installation of structural defenses such as sea dykes, sluicegates and water control lines in large areas of the coastal zone would cause fundamental social-ecological changes and block some specific areas in the coastal zone with outside environments. Farmers in the MKD rely on sediments and river water for replenishing soils and washing pollutants and salinity out of the fields (Sanh et al., 1998). Canals and waterways play a vital role for transportation in the delta that would be constrained by hydraulic construction. Tidal irrigation is currently popular in the MKD thanks to a large tidal

fluctuation and a close connection of farming systems to the rivers and canals. Changes in these features due to infrastructure construction would impact the irrigation system and the ecological diversity in the coastal zone and bring many drawbacks as already known in the freshwater zone today under the dyke systems e.g. declines of provision of essential ecosystem services, increase of production costs, or degradation of the product quality (Berg et al., 2016; Renaud et al., 2014; Sebesvari et al., 2012). A reduction of biodiversity and disruption of ecological baseline would also reduce the resilience of agricultural systems to future changes (Chapter 7). These consequences such as increased use of inputs to maintain soil fertility and high production costs were already observed in the RRD (Kono and Tuan, 1995; Young et al., 2002). Additionally, first evidence from analyses of pesticide concentrations in soils and sediments in the RRD reveals that a dyke system could alter the spatial distribution and the fate of pesticides in areas inside the sea dyke and serve as a sink for pesticide accumulation (Braun et. al., accepted). The authors thus called for a proper operation of sluicegates and adjustment of cropping calendar in order to limit the transportation of pesticides to the marine environment and mangrove systems.

Other factors are related to the adaptive capacity of local people to the changing social-ecological conditions. Investment capitals and household behaviors are adaptation barriers that would hamper the conversion - the latter case is critical if farmers have another preference of farming systems (Smajgl et al., 2015). Additionally, poor farmers in the MKD rely on natural resources (e.g. inland and near-shore fishing, mangrove exploitation) for their livelihoods (Käkönen, 2008; Miller, 2014). Past interventions in agricultural systems such as dyke construction and drainage of acid sulfate soils for intensive agriculture have resulted in a decline of these common pool resources that negatively affected the income of the poorest groups (Käkönen, 2008; Minh et al., 1997). Finally, the conversion to an intensive hydraulic landscape would alter the traditional culture of local farmers in the MKD which is strongly linked to the Mekong River and its waters (Linh, 2015). Such adaptation costs and consequences of engineered infrastructures should be thoroughly evaluated before the delta goes further with this technological pathway. These include the costs for maintaining and upgrading the dyke system, as well as the impacts if the system partially or fully fails to protect the farming systems and increased migration as a part of the interventions.

In summary, due to the complex and interconnected nature of the delta system, any interventions in agricultural systems in the coastal zone would have effects across various

scales. The interactions and feedbacks from these interventions would create negative impacts locally and at other places and lock-in some areas in specific development pathway (Chapter 6) that need to be well understood before massive alterations are implemented in the delta. In this regard, this study concurs with other studies (Renaud et al., 2015; Smajgl et al., 2015) that concluded that a combination of both structural and non-structural measures should be considered (Chapter 7). Non-structural measures such as development of salinity-tolerant varieties, adjustment in cropping calendar, wetland rehabilitation, and shifting land uses (e.g. from double rice to rice-aquaculture) could be sufficient if the salinity intrusion is limited. Structural measures would be installed in areas where salinity intrusion would degrade the long-term adaptive capacity of the systems/areas to salinity problem. A combination of these measures would keep the farming system continuously adapting to the changing salinity conditions and allow the conversion to other systems if salinity intrusion passes the thresholds for coping, or when opportunities for transformation emerge in the future.

8.2 Reflections on the analyses of drivers of change, adaptation pathways, and resilience of agricultural systems facing increased salinity intrusion

8.2.1 The contributions of complex adaptive systems concept and adaptation pathway to analyzing drivers of change and adaptation

In this study, the complex adaptive systems concept provides an overarching framework to explore the drivers of change and adaptation in agricultural systems. The consideration of agricultural systems as complex adaptive systems highlights the interconnections between farming activities and ecology factors. Adopting a complexity perspective has helped to identify negative and positive feedback mechanisms in agricultural changes and explore more drivers of change that are difficult to reveal using the classical and linear approaches. A complexity perspective also allowed the identification of non-linear relationship in agricultural changes, as well as cross-scale interactions between these systems. In this regard, this study concurs with several other studies, for example Miller (2014) and Käkönen (2008) that agricultural changes, at least in the MKD, are results of multiple drivers within and outside of the deltas and have a path-dependency with agricultural decisions in the past. Changes in agricultural systems in the deltas are processes that are influenced and have effects outside of the local level. Thus assessing the drivers of agricultural changes requires

analyses at both various and across scales. An assessment of the systems in isolation within a specific time or place is not sufficient for understanding changes in agricultural systems.

Adaptation pathway is a new approach for exploring various future adaptation options in the context of high uncertainty (Wise et al., 2014). The adaptation pathway approach is not a prediction of future, but an identification of possible future states under "what if" hypotheticals (e.g. what will happen if the salinity conditions change). Most of the scenario approaches, including the Mekong Delta Plan (Mekong Delta Plan, 2013), are based on some plausible possible futures in order to identify the interventions to get to the possible future of choice. Given the unpredictability and the influence of various drivers of change, the anticipation of the future using the scenarios and modeling is highly questioned (Haasnoot et al., 2013). In order to maintain flexibility and robustness of adaptation measures in the face of changes, adaptation and scenario planning require approaches that take into account the high level of uncertainty and a need for flexibility of adaptation measures (Haasnoot, 2013). In this context, the adaptation pathway approach is relevant for long-term delta planning and management because it can help to identify "lock-ins" of adaptation measures and thus accounts for a high uncertainty and multiple future states related to non-linear relationship, unpredictable changes and regime shifts of deltaic social-ecological systems.

Methodologically, the analyses of drivers of change and adaptation pathways were based on a qualitative approach that includes a series of in-depth interviews with authorities, as well as focus group discussions, role-playing games and semi-structured interviews with farmers. The role of quantitative data is not emphasised in this analysis. Quantitative approaches such as surveys cannot capture the changing processes in agricultural system that have taken place many years before. In addition, these approaches cannot necessarily provide detailed answers on future adaptation under hypotheticals of changing drivers. Additionally, a quantification of all drivers of change and their effects on agricultural systems is difficult if not impossible due to cross-scale interactions of drivers and agricultural systems as well a separation between the causes and effects in agricultural changes (Geist et al., 2006; Lambin et al., 2001). Agricultural changes at the local level were results of interplays of various drivers at different scales and these changes created interconnections and feedbacks with other agricultural systems spatially and temporally. Thus the causing mechanisms and potential adaptation pathways in these complex adaptive agricultural systems could only be observed and qualitatively assessed through analysis of multiple sources of information.

8.2.2 Insights from the implementation of subjective resilience assessment method and implications for future research

The resilience concept has been developed within various schools of thought and is currently being applied in different fields outside ecology. The concept has been used as a new approach and thinking for the management of resources in the face of change and uncertainty. For example, the concept has been adopted in management of critical infrastructures to better prepare for breakdowns under extreme events (Schwab et al., 2016), and for management of farming systems under multiple shocks and trends (Darnhofer et al., 2016). However, the concept still serves as a means to understand and manage change, while few studies attempt to operationalize resilience in practice. A standard approach for quantifying resilience is still lacking in literature. Resilience is a concept with different meanings and covers many aspects. Thus assessing or quantifying resilience requires cross-scale analyses of complex, highly connected systems and interdisciplinary perspectives (Sellberg et al., 2015). In this regard, approaches that combine different methodologies and sources of information are useful to uncover multiple aspects of resilience (Levine, 2014). The empirical findings of this study (Chapter 7) emphasize that it is critically important to supplement the subjective resilience assessment with qualitative data to enhance holistic understandings of system dynamics. Social-ecological resilience is a concept related to CAS (Folke, 2016; Nelson et al., 2007). The concept contains multi-dimensional notions related to system dynamics, regime shifts, feedback loops and interconnection across time and places. Many of these characteristics of the systems can only be indirectly observed through understanding system dynamics and how the systems responded to changes (Levine, 2014; Nelson et al., 2007). Supplementing qualitative data therefore can offer insights into resilience and their determinants that would provide practical implications for improving the resilience of the analyzed systems.

8.2.3 Limitations in the application of the concepts and of the research

In this study, the complex adaptive systems concept has offered an appropriate means for exploring drivers of change and adaptation pathways through a landscape and systematic approach. The concept is useful for large-scale and cross-scale analysis of change. However, at the local level, the complex adaptive system concept does not provide a framework for exploring household's adaptive capacity and decision-making processes. An inclusion of other frameworks to examine household and intra-household capacities and decision-making

processes is necessary to complement the approach. In this regard, there is one research question that was raised at the beginning of the research but was not addressed within the data and the frameworks of this study. This research question aimed to identify "winners" and "losers" of adaptation processes by examining who could change their farming systems and who could not. In the case of the conversion from double rice to rice-shrimp in Kien Giang, few farmers refused to shift their double rice to rice-shrimp production and then dropped their farming activities and pursued non-farm jobs. In order to provide implications for adaptation planning and decision making, it is worth to understand diverging adaptation preferences between stakeholders (Snorek et al., 2014) and variations in adaptation outcomes between various farmer groups. Actor-oriented and in-depth qualitative approaches such as life-event and livelihood history analyses with specified samples would enable to achieve these objectives.

Adaptation pathway is an useful approach to identify flexible and robust measures that are reversible or changeable and effective even when future conditions change. The flexibility of adaptation measures should be considered an important criterion in adaptation evaluation given the high uncertainty of future changes (Barnett et al., 2014; Schwab, 2014). However, an evaluation and selection of future options solely based on the reversibility or changeability could lead to favour flexible but low effective measures (e.g. in terms of economic benefits) and neglect high effective but irreversible or unchangeable measures. The adaptation options and pathways as illustrated in this study will be constantly changing. Some adaptation pathways would not be possible anymore or the social-ecological thresholds and conditions for change in one system would be altered due to changes in other systems (Chapter 6). Given the constantly changing social-ecological conditions in the deltas, the delay of adaptation strategies would cause difficulties for later implementation, for example, through expansion of population into planning areas. Thus the evaluation and selection of adaptation options should be considered together with other criteria that value to authorities and local farmers (e.g. food security, preferences, environmental impact, cost-benefit analysis) rather than the sole assessment of lock-in effects. A complementary and practical approach for adoption and evaluation of adaptation pathway would be an identification of future pathways that are preferred or not referred to by different stakeholders, as well as the events that trigger the pathways (Barnett et al., 2014). Then stakeholders would select the pathways they prefer based on multiple-criteria analyses and implement necessary interventions to prevent the undesirable future system states from happening.

In the analysis of drivers of agricultural change (Chapter 6), the study has identified major processes at the regional and delta levels such as mangrove deforestation, impacts of dam construction, and migration and assessed how these factors have affected the research areas based on relevant studies. However, only the major processes that came out during the interviews with authorities, farmers and fieldwork were taken into account. Other less important processes that were not of direct concern (or not mentioned by local authorities and farmers) in the research areas were not considered. Additionally, in the assessment of adaptation pathways, reversibility is a relative term that was assessed through information generated from interviews with authorities, farmers, and through the review of other studies that assessed the capacity to revert of the same system. A system-wide analysis of reversibility is difficult due to a lack of data on soil and water characteristics, as well as socio-economic settings.

There are several limitations in assessing resilience of agricultural systems in this research. These limitations are linked to the specific focus of resilience assessment on one stressor, the measurement scale in the resilience elicited questions (e.g. an application of a higher scale assessment than a 5-point Likert should be considered), and an inevitable bias in the questionnaire and interview approaches. These limitations were discussed in detail in section 7.5.2, Chapter 7: Limitations and insights from subjective assessment of resilience.

8.3 Research outlook

At present, the adaptation pathway approach has been used as a technological framework to explore potential adaptation options and the capacity to reverse or to shift to other measures when the future conditions change within the same adaptation spaces – illustrated as various clustered adaptation pathways that depart from the same original systems at specific places. There is no exploration of interactions of changes across adaptation pathways spatially and temporally in which adaptation actions in one pathway within an adaptation space would influence changes of other pathways in different spaces. These changes and interactions would take place far away from each other. Taking the MKD as an example, some adaptation actions such as a shift from single or double rice to triple rice in the upstream area of the delta (all possible pathways from single or double rice to other systems in the upstream area are considered within an adaptation space) have altered the flooding conditions and water flows of the Mekong River (Duong et al., 2016; Triet et al., 2017). These changes consequently impacted the water use, salinity conditions and subsequently farming activities and

adaptations in the coastal areas (another adaptation space). Thus an adaptation action within an adaptation space would have interactions and impacts on others at different places or time. Moreover, although this study has identified the interactions and feedbacks within and across scales, a quantification or detailed assessment of their interconnections and feedbacks was not addressed. The identification of these features as presented in this study would serve as a background to develop further quantitative or modeling approaches to quantify or assess specific interactions and potential feedbacks. A careful assessment of these features in agricultural shifts would provide important implications for preventing the interlocking effects between farming system changes.

In the resilience field, there has not been a standard approach to quantify the resilience of households or ecosystems. The subjective resilience assessment method could be a supplementary approach to quantify the resilience of these systems. However, the subjective resilience assessment would be difficult for comparison of resilience of different farming systems or between social-economic groups. Future studies should explore the possibilities of comparison of subjective resilience assessment as well as the predictive ability of subjective resilience in relation to objective outcome and well-being (Clare et al., 2017). Longitudinal studies that use the time-series data to compare the resilience assessment results before and after the events (e.g. shocks, hazards or project interventions) would be an approach to validate the method. Additionally, an explicit examination of the role of subjective resilience as well as each resilience component on intended or future adaptation strategies would be a promising approach to link subjective resilience to objective outcome and well-being.

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APPENDICES

Appendix 1. Procedures of the field research and data collection

In the first phase of the PhD research project from December 2014 to January 2015, a literature review of relevant studies was carried out and a first draft of research proposal was developed. This was followed by a scoping study in Vietnam from January to the end of March 2015 in order to explore the research context, collect available secondary data and conduct exploratory interviews with local officials and farmers. Visits to government agencies in four coastal provinces (Ben Tre, Tra Vinh, Soc Trang, and Kien Giang) were organized in the MKD. In-depth interviews with officials of the Department of Agricultural and Rural Development (DARD) and the Department of Natural Resources and Environment (DONRE) at provincial and district levels were subsequently conducted in Kien Giang and Soc Trang provinces in the MKD. In addition, in-depth interviews with staff of the People's Committee at the commune level as well as two pre-testing FGDs with farmers were organized in My Xuyen District of Soc Trang and An Minh District of Kien Giang. In the RRD, in-depth interviews with staff of the Office of Agriculture and Rural Development (OARD), the Office of Natural Resources and Environment (ONRE), hamlet leaders and farmers were undertaken in four coastal districts, consisting of Giao Thuy District in Nam Dinh, Tien Hai and Thai Thuy districts in Thai Binh, and Vinh Bao District in Hai Phong. In total, 20 government offices were visited and 2 FGDs were conducted in the MKD, whereas interviews with staff of 8 government agencies, 9 hamlet leaders, and 8 individual farmers were carried out in the RRD. Visits to the General Statistical Office and the Statistical Publishing House in Hanoi were also organized to collect the statistical data. This information was then analyzed and a detailed proposal was developed in Bonn from February to August 2015.

The main field research started from August 2015 and lasted until May 2016. The field research began with in-depth interviews with local authorities and village leaders. Following the in-depth interviews, FGDs with local farmers were carried out. Subsequently, semi-structured interviews with farmers were conducted. In the RRD, interviews with authorities of DARD and DONRE were conducted after the semi-structured interviews and FGDs with farmers. In total, 80 semi-interviews were conducted in the MKD, whereas 118 semi-interviews were carried out in the RRD. In the MKD, a survey of 226 households was also conducted after the semi-structured interviews. Moreover, in-depth interviews with national officials of the Ministry of Agricultural and Rural Development and the Ministry of Natural

Resources and Environment were conducted in May 2016 after finishing all FGDs and household surveys in both deltas. Finally, three role-playing games (RPG) with farmers were carried out at the end of the field research in May 2017 to validate the preliminary results and explore farmers' decisions in response to changing key drivers of change.

Appendix 2. PRA guidelines

These guidelines were developed based on the tools of participatory rural appraisal (PRA) methods to guide the FGDs processes. Some less important questions (e.g. distribution of points for the rate and consequences of change, VEEN diagram) in this guideline were skipped or simplified depending on the situations (e.g. remaining time, applicability) during the FGDs.

Table A.1 PRA guidelines

Tools and objectives	Description
Participatory mapping	- Participants are asked to draw a sketch of their village, then for information about main features, rivers, areas of rice fields, rice-shrimp fields and shrimp ponds etc.
Depiction and assessment of socio-economic situation	- Which kinds of livelihood activities are taking place in the village, how are the educational and infrastructural status (wealth, road, electricity, school, sanitation and health services etc.) of the village? - Local criteria of wealth categories (for the wealth ranking later with the village leaders and elderly people).
Seasonal timeline	- Participants are asked to indicate the time frame of their seasons and information on cropping patterns, time of planting and harvesting, time of high and low salinity levels (a table indicating 12 months was prepared beforehand).
Historical timeline	- Participants are asked to recall important years in terms of farming system changes since 1975. - Pick up the major changes for further discussion below.
- Drivers of change	- What were the reasons for this change?
- Capacity for change - Social driver	- How did people finance this shift? What were necessary assets or things for this change? Who could change their system and who could not? Who has changed and failed? Who has changed and got success?

- Political driver	- Did the government allow or encourage this change? Were there any policies proposed at that time and years before regarding land use and agro-ecosystem changes? Were there any programs (e.g. agricultural training, loans or dyke constructions) that were implemented at that time or years before that influenced the farming system changes? - Which organizations have involved in this farming system shift (using Veen diagram if applicable)?
- Biophysical driver	- Which field plots could be changed? Which plots could not be changed? - How were the salinity conditions at the time of this change and years before? - How has the salinity conditions (salinity level and duration) changed over time?
- Technological driver	- Were there any training, varieties or technologies that were introduced at the time of change or years before which can help to better cope with salinity?
- Economic driver	- How were the market price of rice, shrimp and alternative products at the time of change and years before?
- Relative importance of drivers	- Scoring the importance of the listed drivers on the farming system change. Deliver 25 points (buttons) to farmers and ask them to distribute to the listed drivers.
- Rate of change	- How has this farming system changed over time? Pick up the farming system and the begin year, then allocate 10 points (buttons) and ask the participants to distribute to each 5-year interval.
- Consequences of change	- Participants' judgment of whether income had improved or worsened over time? Pick up the farming system and the begin year, then allocate 10 points (buttons) and ask the participants to distribute to each 5-year interval.
Constraints of agricultural production - Problem ranking	- Which are the constraints for agricultural productions in the village? - Ranking these identified problems.
Strengths-Weaknesses-Opportunities-Threats Analysis (SWOT) analysis	- Which are the strengths, weaknesses, opportunities, and threats of the main farming systems in the village?
Scenarios	- How will the farming system change when the identified drivers change? Write the answers on the cards. - Which is the best farming system for your village? - How will the household's assets be affected by this change?

Appendix 3. Role-playing games (RPGs) with farmers

Three RPGs were conducted in two villages (Hoa De and Hoa Truc villages) in Hoa Tu I commune, My Xuyen district, Soc Trang province (Table A. 2). These communes are located in the brackish water zone which comprises different farming systems: rice-shrimp, shrimp monoculture (black tiger shrimp and white leg shrimp), and rice monoculture. Therefore, this transition zone could illustrate the tradeoffs involved in farmer's land-use choices. One group of female farmers who own excavated platform in the rice-shrimp field, one group of male farmers who own the maintained platform in the rice-shrimp field, and one group of male farmers who have the excavated platform in their rice-shrimp field were organized (Table A.2).

Table A.2. Investment costs and revenues of rice-shrimp systems estimated by players and observers in the role-playing games in Soc Trang

Group characteristics	Characteristics of a typical pond size of 2,000 m^2	White leg shrimp (million VND)	Black tiger shrimp (million VND)	Rice (in rice-shrimp) (million VND
Male group, own excavated platform	Average investment	65	65	2.3
	Good harvest (high/normal/low price)	108/90/70	300/200/150	7/6.5/5.5
Male group, own maintained platform	Average investment	55	75	3
	Good harvest (high/normal/low price)	130/115/95	300/180/120	11/10/8
Female group, own excavated platform	Average investment	70	35	5
	Good harvest (high/normal/low price)	135/120/80	150/100/80	7/6.5/6

[a] *The original rice-shrimp system contains a platform for rice and a small ditch around the field for shrimp. To increase stocking density, some farmers have removed this platform.*

The design of these RPGs took benefits from the games developed by Pardoe (2016), as well as fruitful discussions with researchers of the Mekong Development Research Institute (Can Tho University) who have been applying the RPGs in the MKD. However, the RPGs failed to mimic farmers' decision-making processes in the research areas. It was partly because the factors that influenced the farming decisions were far more complex than what the games could capture. Moreover, constrains in the organizations of the games and the time limits for

each game (which lasted around 1.5-2 hours each) resulted in an unreliability of results in terms of choices under future conditions as mimicked in the games. Nevertheless, these RPGs have provided useful information regarding farming activities and farmers' considerations and could play a role as a validity check of the overall results of the research.

- **Key components**

- Key components comprise different production seasons (rice season, shrimp season), market price, and the risk of failure since the interactions between these drivers were found to be the key driving factors of agricultural changes (apart from the political factors and neighbor's influence that are hard to include).

- The production systems comprised rice production, shrimp production (black tiger shrimp, white leg shrimp) and abandoned land (in case the player wants to leave the ponds abandoned).

- The market price was designed to be a random element (low, normal and high market prices).

- The risk of failure was also designed to be a random element but had different weights between rice and shrimp. There were three failure cards over six good cards for shrimp and one failure card over five good cards for rice. Thus the probability of getting a failure was 0.5 for shrimp and 0.2 for rice. The risk of shrimp failure would take place the whole year if the player raised shrimp in both dry and wet seasons. The risk of rice failure only happened in the wet season since farmers in the areas only farm rice in the wet season.

- The household capacity was also not specifically included. Each player at the beginning of the game threw the dice for their initial capital (farm plots). Therefore, each player would have different farming assets and pathways to manage their farms.

- **Participants**

- Each group consisted of three players (one farmer as one player) and other farmers as observers

- One game master (the PhD researcher) who explained and monitored the game.

- One game assistant who helped to calculate the costs and profits for players and to take note during the game.

- **Rules of the role-playing games**

At the beginning of the game, each player threw the dice to determine the number of their plots (1, 2 or 3 plots). The typical size of a plot was 2,000 m^2. Each player thus managed 1, 2 or 3 plots (ponds). The process of the game was to move around the calendar from January to December (see Fig. A.1). Different colored stickers were used to represent different production systems as well as to note farming activities. The player placed stickers on each row for their decisions (thus there were cases that three stickers were placed on one row for the player who had three plots). At the beginning of the growing season, one player decided which production system he/she wants to cultivate for his/her ponds first, then to other players. After two years, the number of rice and shrimp seasons and the total profits of each player were calculated.

Fig. A.1 Picture of a role-playing game with farmers in Hoa De village, My Xuyen district

The players freely decided which production system (rice or shrimp) and shrimp species (black tiger shrimp or white leg shrimp) to cultivate for each plot. The raising duration of white leg shrimp and black tiger shrimp are usually three and five months respectively in case there is no failure during the raising period. The duration of rice is four months. However, the players will determine the time of harvest due to their risk perception.

At the end of the growing season, each player received different amounts of money for high, normal and low market price as mentioned at the beginning of the game. The players drew the card each month to determine the risk of failure for each plot during the shrimp season. If the risk of failure happens in the first two months for black tiger shrimp and the first month for white leg shrimp, the player will earn no revenue. From the third month for black tiger shrimp

and the second month for white leg shrimp, if the player got a failure, he/she would decide to harvest their shrimp and throw the dice to determine the market price. For black tiger shrimp, the revenues were around 60% and 80% for the third and fourth month respectively compared to the full revenues at the normal harvest time. For white leg shrimp, the revenue was usually 50% for the second month compared to the revenue at harvest. However, the players and observers determined these amounts of money in the games. If the player got a failure during the growing season, he/she then could decide the time (month) for the next cropping season. For rice, the player would receive 10 and 8 million VND for normal and high salinity if the rice price was high. They would receive 9 and 7 million VND for normal and high salinity if the rice price was normal and 8 and 6 million VND for normal and high salinity if the rice price was low (as mentioned at the beginning of the game). For the rice production, the players threw the dice for the market price and drawn the card for the salinity level only one time during the whole season. These amounts of money were also determined by the players and observers.

Initially, the investment costs were designed to be conditional as the minimum investment cost required for the selection of each production system and the ability to take a loan as in reality. However, the game was simplified after the pretests. There was no limitation of the times of loan taking. However, the players were asked to specify the source of the loan and the possibility of borrowing the loan in reality after the production failure.

The game was continued for two years (two dry seasons and two wet seasons) and after that, the total amount of revenues was calculated. The player did not seek to achieve the highest profit but to play the game as they do farming activities in reality. Thus there were no winners and losers. The players could have discussions and help each other to make decisions. The players have been asked for explanations about their choices, their perception, and strategies in applying the farming activities during the game. Therefore, the most important information was from the discussions and decisions during the game rather than the final results of the RPGs.

- **Summary of results**

Following general conclusions would be drawn during the RPGs.

- Rice-shrimp farmers who have excavated platform tend to apply the only shrimp production. In contrast, rice-shrimp farmers who have maintained platform kept the rice crop.

- High profit from shrimp production was the main reason to keep shrimp production, whereas improving environmental conditions of shrimp ponds was the main reason to maintain the rice crop.
- The duration of the shrimp season was an important factor to maintain the rice crop. Without experiencing a failure, farmers tend to maintain shrimp production even it overlaps into the rice season.
- After several shrimp failures, farmers tend to use the ponds for natural fishes or reduce the stocking density.
- The investment capital is important to determine the timing of the next shrimp season and the stocking density.
- The financial support from other farmers who achieved the farming success was an important safety net to buffer the shrimp failures.
- With three plots, farmers tend to diversify the shrimp species.
- Stocking at different times of the year is a strategy to reduce failures and disease outspread.

Appendix 4. Community characteristics and results of the wealth ranking exercises in the research areas in the Mekong Delta

Table A.3 Community characteristics and results of the wealth ranking exercises in the research areas in the Mekong Delta

Research sites	Kien Giang			Soc Trang		
	Freshwater zone (Bay Xang II village)	Brackish water zone (Bay Xang I village)	Saline water zone (Ban A village)	Freshwater zone (Tra Bet village)	Brackish water zone (Hoa De village)	Saline water zone (Tan Lap village)
Number of households that were listed by the hamlet leaders for the ranking exercises/total households*	44/267	458/638	212/466	443/468	272/285	306/322
Wealth ratios in the ranking exercises (poor/average/rich households; percentages in parentheses)	8/22/14 (18/50/32)	63/256/139 (14/56/30)	21/163/28 (10/77/13)	110/307/26 (25/69/6)	27/146/99 (10/54/36)	42/192/72 (14/63/23)

General characteristics of the villages	Agricultural land: 757 ha (102 ha of double rice, 655 ha of rice-shrimp) Road: 100% can travel in both seasons Public electricity: nearly 100% households Poor**: 17 Near-poor: 23	Agricultural land: 812 ha of rice-shrimp Road: can travel in both seasons only in main roads School: one elementary, one kindergarten Poor: n/a Near-poor: n/a	Agricultural land: 510 ha, mostly extensive shrimp Road: can travel in both seasons only at one side of the canal; the other side is mud road Public electricity: 95% households (around 40% are shared with others) School: one elementary school, one kindergarten Poor: 35 Near-poor: 64	Agricultural land: 597 ha (150 ha of rice-shrimp outside the dyke, 231.8 ha of double rice and 33 ha of vegetable inside the dyke) Road: can travel in both seasons School: one elementary, two kindergartens Public electricity: 98% households (including sharing with others) Poor: 89 Near-poor: 59	Agricultural land: 350 ha of rice-shrimp and semi-intensive shrimp Road: there have still mud roads in inside areas Public electricity: 100% Poor: 12 Near-poor: 20	Agricultural land: 450 ha of semi-/intensive shrimp Road: can travel in both seasons Public electricity: 100% School: one elementary school, one kindergarten (in the very close to/nearby village) Poor: 18 Near-poor: 57
Summary of general criteria for the wealth ranking exercises	- Poor: landless, having debt, low education, unstable jobs, sickness, daily labor jobs, living in thatched houses (except single and young families) - Average: having 3-4 ha in saline water zone and 1, 2 or 3 ha in the freshwater zone, achieving secondary education - Rich: having more than 7 ha, high education, having relatives abroad, doing stocking and business activities, doing clam production (in saline water zone)			- Poor: landless or having less than 1 or 2 Cong (ca. 0.1 or 0.2 ha), living in social houses, thatched houses, having many years of shrimp failures (in saline water zone), low education, daily labor, unstable jobs - Average: having 1-2 ha, good houses, having motorbikes - Rich: having more than 2 ha, having good economic condition, doing business, having concrete houses, having good motorbikes, wearing gold, achieving farming success for several years (in saline water zone)		

** The numbers of households in the ranking exercises are lower than the actual numbers of household in each village due to out-migration, missing in listing the households, etc. In the freshwater zone in Kien Giang, there were only 44 households who were cultivating double rice and therefore the ranking exercise was only taken for these households. In the saline water zone of Kien Giang, many households located along the coast and close to the mangrove forest are migrants and were not listed by the hamlet leader.*

*** Number of poor and near-poor households with certificates according to the government classification* (*Source: in-depth interviews with hamlet leaders, FGDs).*

Appendix 5. Median values of perceived support received from other farmers and the government for the interviewed farmers in the Mekong (Table A.2) and Red River (Table A.4) Deltas (interquartile ranges in parentheses)

Table A.4. Median values of perceived support received from other farmers and the government for the interviewed farmers in the Mekong Delta (interquartile ranges in parentheses)

Farming systems	Support from other farmers	Support from the government
Rice	3.0 (2.0-4.0)	4.0 ^{a} (2.0-4.0)
Rice-shrimp	2.0 (1.5-4.0)	3.0 ^{b} (2.0-4.0)
Shrimp	3.0 (2.0-4.0)	4.0 ^{a} (2.0-4.0)

The values in the table represent a "1-5 Likert scale" standing for: very little (1) to very much (5) support. No significant difference of support from other farmers between farming systems (p-value<0.05, Kruskal-Wallis test), significant difference of support from the government between farming systems (p-value<0.05, Kruskal-Wallis test). The median values with different superscripts are significantly different (p-value<0.05, Dunn's test)

Table A.5. Median values of perceived support from other farmers and the government for the interviewed farmers in the Red River Delta (interquartile ranges in parentheses)

Perceived support from	Double rice	Rice-vegetable	Vegetable	Fish pond	Soft-shell turtle	Large fish pond
Other farmers	4.0 (2.0-4.0)	3.5 (2.0-4.0)	3.5 (2.0-5.0)	4.0 (2.0-4.0)	4.0 (4.0-5.0)	4.0 (2.0-4.0)
Government	2.0 (2.0-3.0)	2.0 (2.0-3.0)	3.5 (2.0-4.0)	2.0 (1.0-2.5)	2.5 (1.0-3.0)	1.5 (1.0-2.0)

The values in the table represent a "1-5 Likert scale" standing for: very little (1) to very much (5) support. No significant difference of perceived supports from other farmers and the government between farming systems (p<0.05, Kruskal-Wallis test)

PUBLICATIONS AND PRESENTATIONS

SCIENTIFIC PAPERS (CORRESPONDING TO CHAPTER 6 AND 7)

1/ Tu, M.N, Renaud, F.G, Sebesvari, Z. (2019). Drivers of change and adaptation pathways of agricultural systems facing increased salinity intrusion in coastal areas of the Mekong and Red River deltas in Vietnam. Environmental Science and Policy, 92, 331-348.

2/ Tu, M.N, Renaud, F.G, Sebesvari, Z., Can, D.N (resubmitted). Subjective measurement of resilience of agricultural facing increased salinity intrusion in deltaic coastal areas of Vietnam. Ecology and Society.

INTERNATIONAL CONFERENCES

1/ Nguyen Minh Tu, Zita Sebesvari, Fabrice Renaud (2016). Complex adaptive systems – A framework for understanding drivers of change and adaptation in agricultural systems in coastal deltas of Vietnam. Oral presentation. Resilience 2017 - Resilience Frontiers for Global Sustainability Conference. 20-23 August 2017. Stockholm, Sweden.

2/ Nguyen Minh Tu, Zita Sebesvari, Fabrice Renaud (2016). Resilience of agricultural systems facing increased salinity intrusion in deltaic coastal areas of Vietnam. Poster presentation. Tropentag 2017- Future Agriculture: Social-ecological transitions and bio-cultural shifts. 20-22 September 2017. Bonn, Germany.