# 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

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## ABSTRACT

Agricultural systems are increasingly considered complex adaptive systems. They are dependent on the integrated nature of biophysical and social sub-systems, continuously adapt to changing conditions and often display non-linear responses to various drivers of change at multiple scales. This research applied the lens of complex adaptive systems theory to analyze current and historical drivers of change and adaptation pathways of agricultural systems to increased salinity intrusion in coastal areas of the Red River and Mekong deltas in Vietnam since 1975. The analysis is based on 27 in-depth interviews with officials of local and national authorities as well as 198 semi-structured interviews and 11 focus group discussions conducted with farmers along three salinity transects in both deltas in 2015-2016. The results show 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 historic salinity levels recorded in the Mekong Delta 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. Additionally, attention should be drawn to interactions and feedbacks in future changes within and across adaptation pathways in order to prevent further increases in salinity intrusion and lock-in effects in agricultural systems within the deltas.

**Keywords: complex adaptive systems, drivers of change, adaptation pathways, salinity intrusion, Vietnam, lock-in effects**

## 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 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 causes 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.

## 2. Complex adaptive systems, drivers of change and adaptation pathways

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). Internal drivers are driving forces at the local scale and can be identified and measured from the system of analysis. External drivers, in contrast, are distal factors to the system and can be identified by understanding their effects on the internal drivers (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., 2003; Lambin et al., 2001; Mueller 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 enhances 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.

## 3. Study areas

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 1).

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 level of salinity varies spatially. In the RRD, the presence of complex protective infrastructures has reduced the extent and severity of salinity intrusion (Yen et al., 2016). 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 was considered in Nam Dinh province in the RRD (Fig. 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.

**Table 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<br>Brackish and saline water zones: from end of December to end of August | Fresh and brackish water zones: from end of December to June<br>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 | Freshwater zone: Winter-Spring rice from October to | Rice: Chiem (Winter-Spring) rice from end of February to |

| | | | |
|---|---|---|---|
| | mid August; Winter-Spring rice from mid September to end of January<br>Brackish water zone: rice from mid September to end of January; integrated shrimp-crab from February to end of August<br>Saline water zone: extensive and integrated shrimp-crab all year round | end of January; Summer-Autumn rice from June to end of September<br>Brackish water zone: rice from September to mid December; semi-extensive or intensive shrimp from January to end of August<br>Saline water zone: two to four intensive shrimp cycles per year | early June; Mua (wet season) rice from the end of July to early November<br>Rice-vegetable: rice from June to end of September; 1-3 vegetable crops from October to end of April<br>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 $km^2$<br>- Agricultural land: 441 $km^2$<br>- Population : 117,883<br>- Population density: 200 inhabitants $km^{-2}$ | - Total area: 372 $km^2$ (My Xuyen); 473 $km^2$ (Vinh Chau)<br>- Agricultural land: 142 $km^2$ (My Xuyen); 63 $km^2$ (Vinh Chau)<br>- Population: 157,264 (My Xuyen), 165,751 (Vinh Chau)<br>- Population density: 421 inhabitants $km^{-2}$ (My Xuyen), 349 inhabitants $km^{-2}$ (Vinh Chau) | - Total area: 238 $km^2$<br>- Agricultural land: 92 $km^2$<br>- Population: 190,291<br>- 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] GSO An Minh, 2014; GSO Nam Dinh, 2015; GSO Soc Trang, 2013.

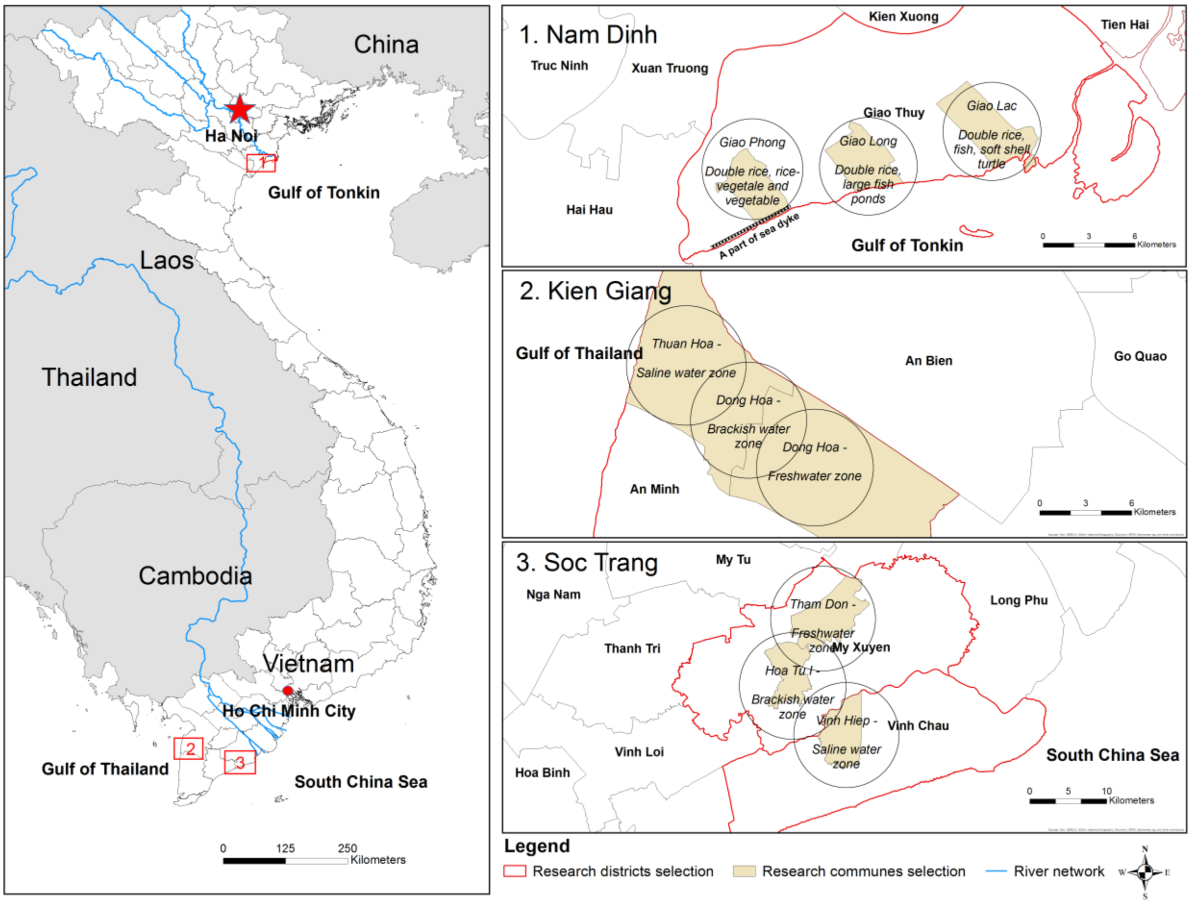



**Fig. 1. Study areas**

## 4. Methodology

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, focus group discussions (FGDs), and semi-structured interviews with farmers were carried out (see Table 2). 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, we focused on the historical development and activities related to agricultural changes. Gender was not a specific criterion for selection of households even though we 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 2). 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. Data was entered into a word processing software and analyzed qualitatively using the MAXQDA program. The data analysis followed the grounded theory approach (Neuman, 2003). The questions and answers with similar themes were structured and grouped after the pre-test, while new codes for emerging categories and sub-categories were generated during the data analysis phase. The selective coding was applied at the end to compare the frequencies of coding such as the mentioned drivers of change, system of choice, and income gains. 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 2**

**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 | 8 rice-rice | 3/2/3 | 64.9 | 3.6 | 5.5 | 12.5 | 25.0 | 20.8 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| (from single rice to double rice) | 1 FGD | | | | | | | |
| Brackish water zone (from rice-fish to rice-shrimp, double rice to rice-shrimp) | 19 rice-shrimp<br>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<br>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<br>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<br>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<br>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<br>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<br>10 soft-shell turtle/4 fish or vegetable/6 rice<br>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<br>8 rice-vegetable/14 rice-vegetable plus vegetable<br>10 vegetable<br>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.*

## 5. Historical development of agricultural systems in coastal areas of deltas

### 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 3**

**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 other 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** | | | |

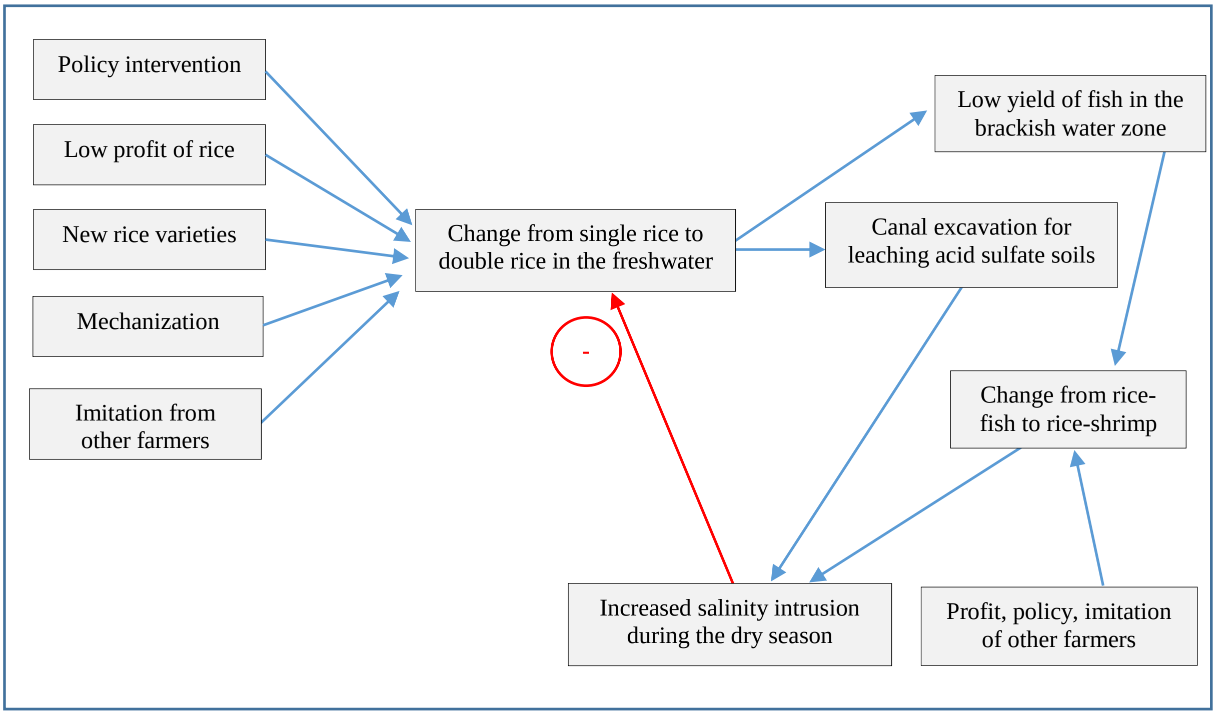
| | | | |
|---|---|---|---|
| Single rice to double rice | 1994-2007 | Dyke construction (8 points), canal excavation (5 points), mechanization (5 points), training (3 points), government support (2 points), suitability (2 points) | **Dyke construction**, **tractors**, **canal excavation**, new rice 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. 2b). 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. 2a) (Tuan et al., 2007).

**(a) Kien Giang**




**(b) Soc Trang**

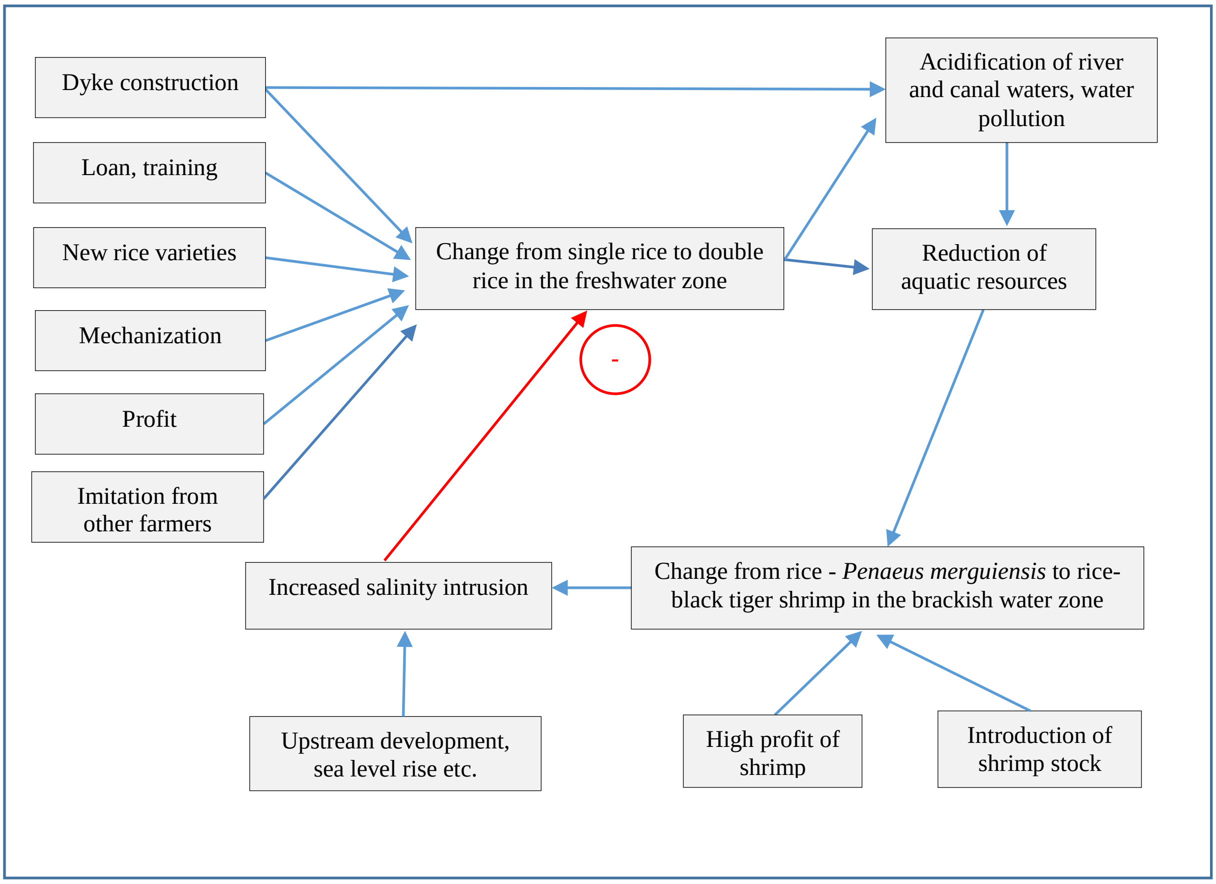



**Fig. 2. Drivers of change (blue arrows) and negative feedback loops (red arrows) in changes from single rice to double rice in Kien Giang (a) and Soc Trang (b)**

### 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. 4a). 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 4**

**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 other 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 other farmers from the village (4 points) | **Government planning**, **profit**, **imitation of other 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 | **Profit maximization**, government intervention, **less profit from rice**, **saline water soaking from surround shrimp ponds**, imitation of farmers from other regions |

| | | | |
|---|---|---|---|
| | | Summer-Autumn rice (all 3 points) | |
| **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 other 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. 3). 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. 4b). 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.

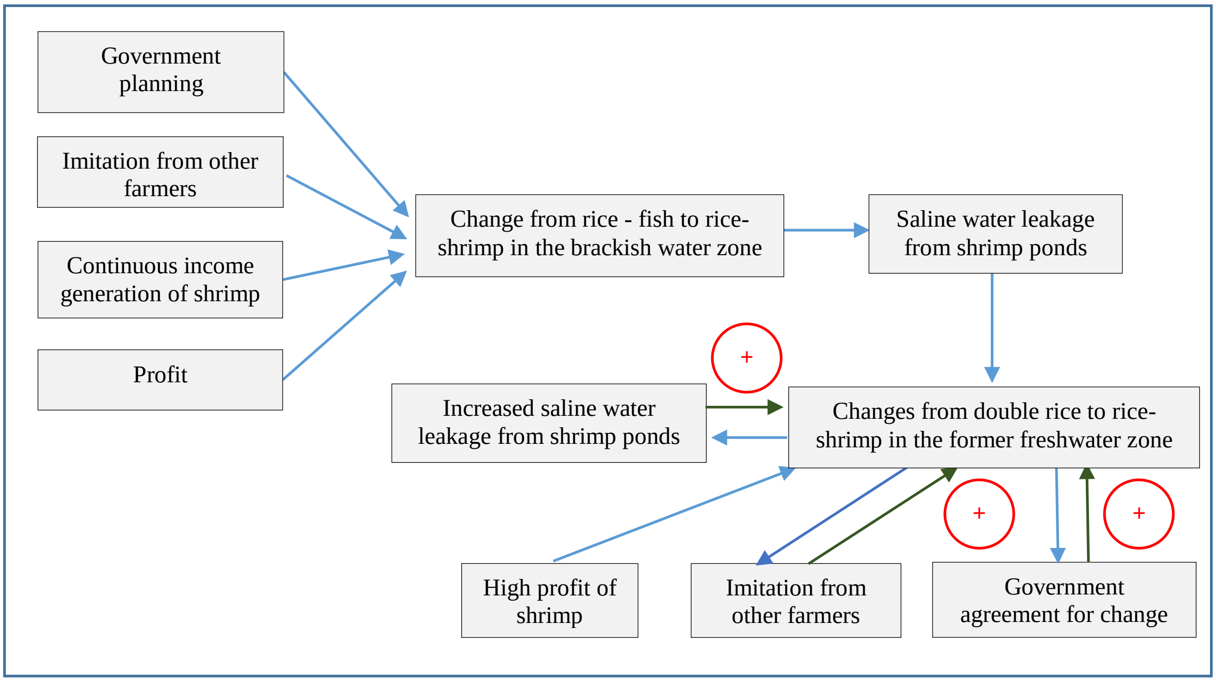
**Fig. 3. A rice-shrimp field with a maintained platform in the middle for rice and a ditch around the platform for shrimp (left), and a rice-shrimp field without platform (right)**

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**

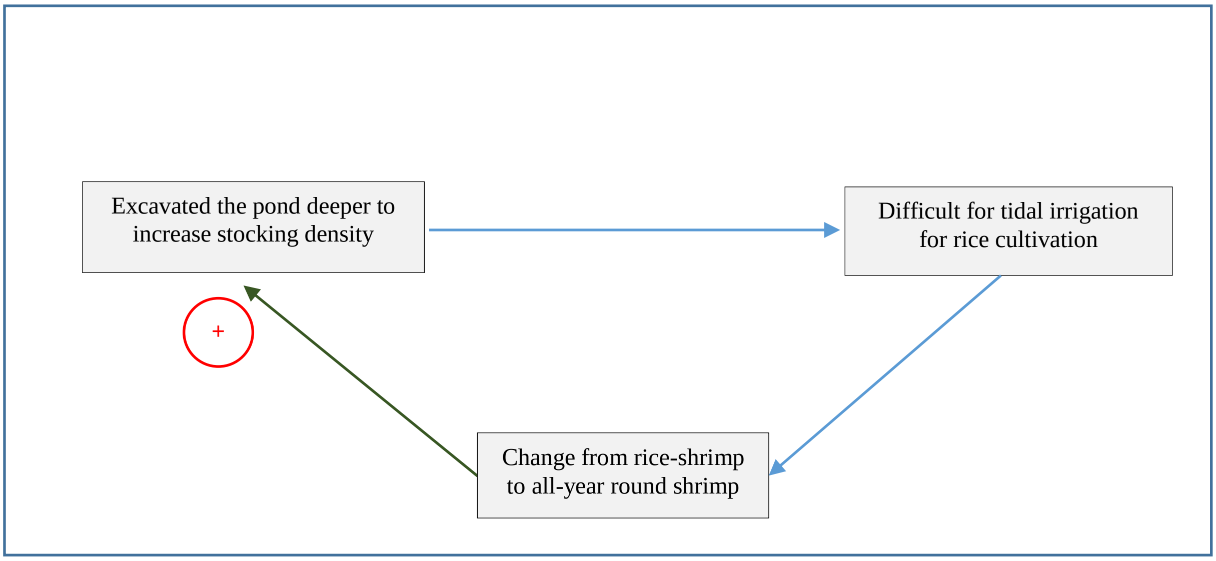



**Fig. 4. Drivers of change (blue arrows) and positive (amplifies the change) feedback loops (green arrows) in changes from double rice to rice-shrimp in Kien Giang (a) and from rice-shrimp to all-year round shrimp in Soc Trang (b)**

### 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. 5a). To provide shelter and natural feeding for shrimp, farmers started to farm the wetland plant Co Nang (*Scirpus littoralis*).

**Table 5**

**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 other 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 | Imitation of other farmers in the village, profit maximization, **short** |

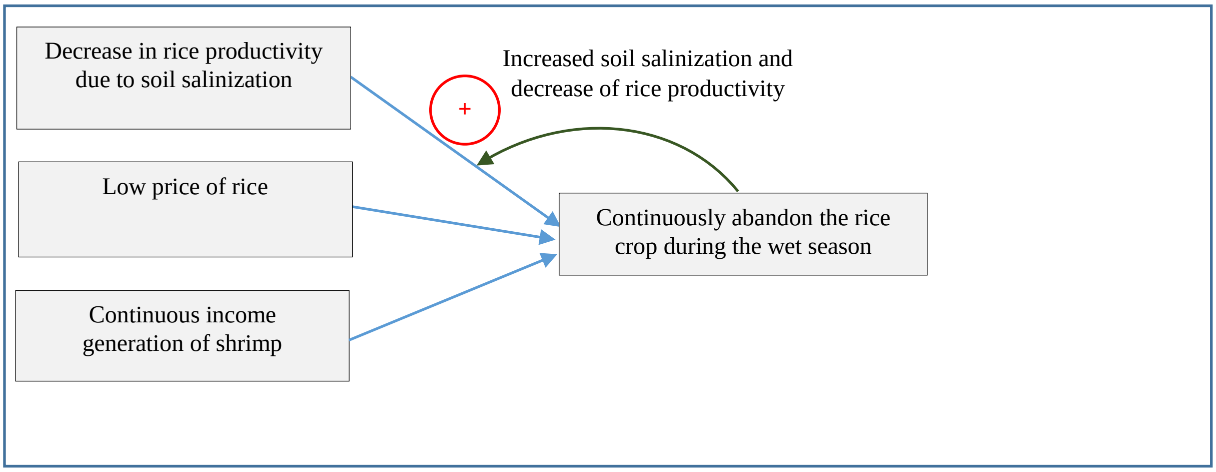
| | | |
|---|---|---|
| | shrimp (17 points), black tiger shrimp displays slow growth (6 points), white leg shrimp is easy to raise in the first few years (2 points) | **rearing cycle of white leg shrimp**, imitation of other farmers from other regions |

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. 5b). 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**

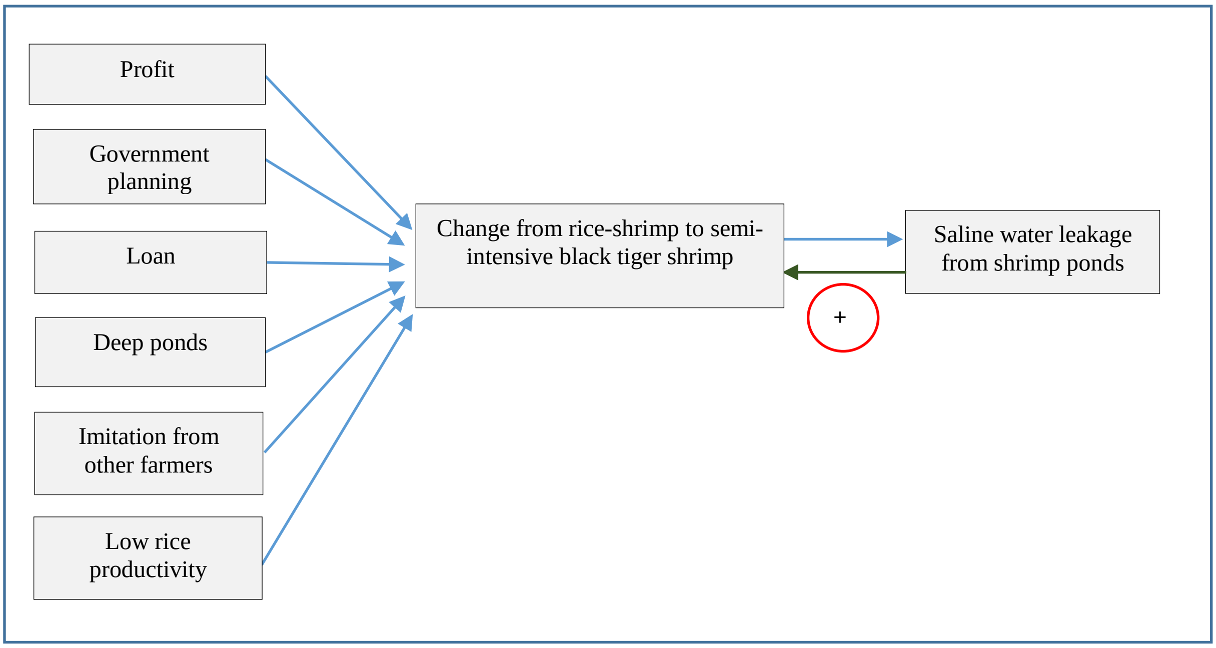



**Fig. 5. Drivers of change (blue arrows) and positive feedback loops (green arrows) in continuous abandonment of the rice crop in Kien Giang (a) and in the change from rice-shrimp to semi-intensive shrimp in Soc Trang (b)**

## 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.

**Table 6**

**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<br>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 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.

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. 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). 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.

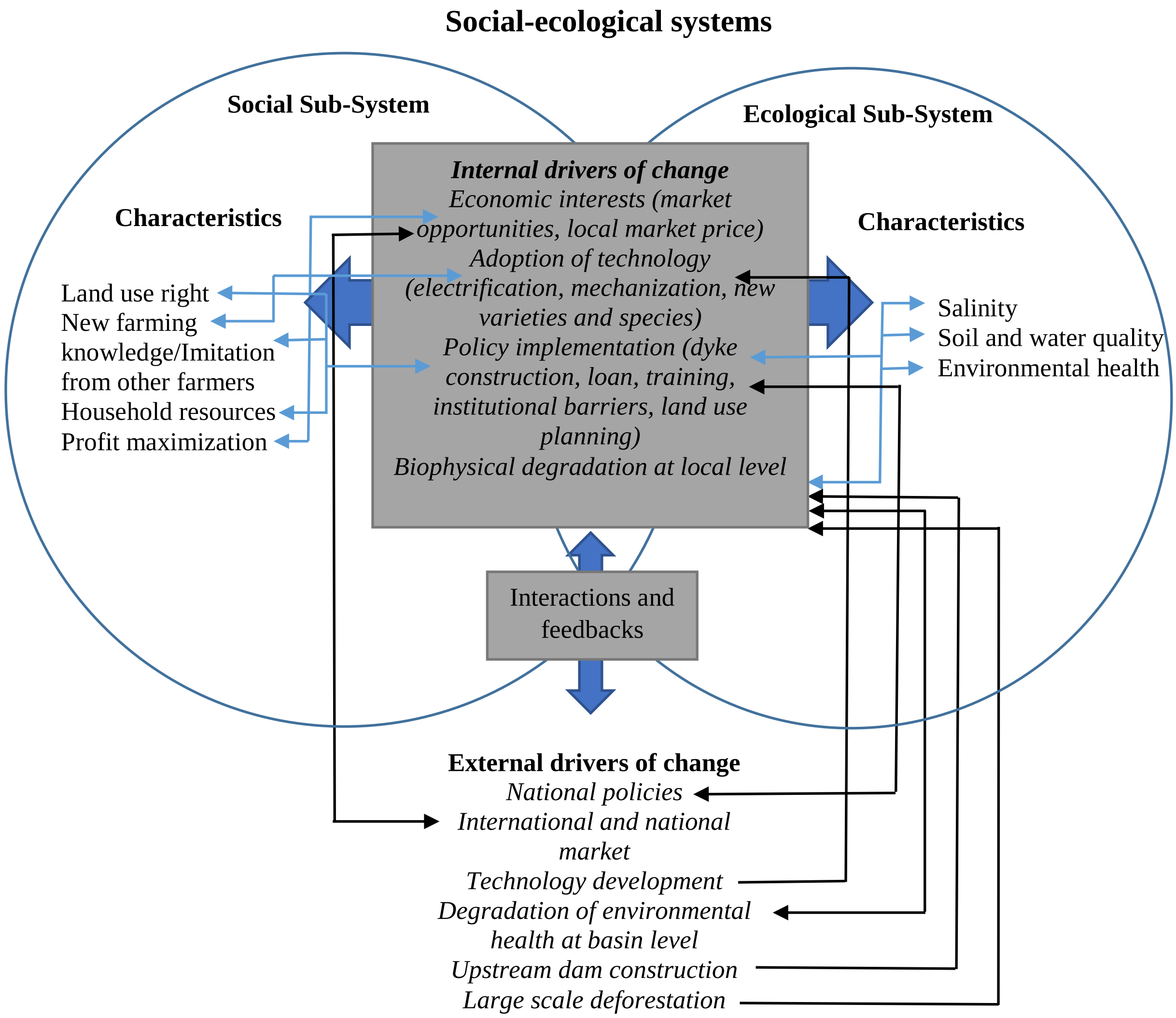



**Fig. 6. Drivers of change and their interactions and feedbacks in agricultural systems in the deltas. The black arrows illustrate the influence of external drivers on the internal drivers (one-**

**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.

## 7. Adaptation pathways of agricultural systems in the Red River and Mekong deltas

### 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, we synthesized various adaptation pathways (Fig. 7). 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. 8).

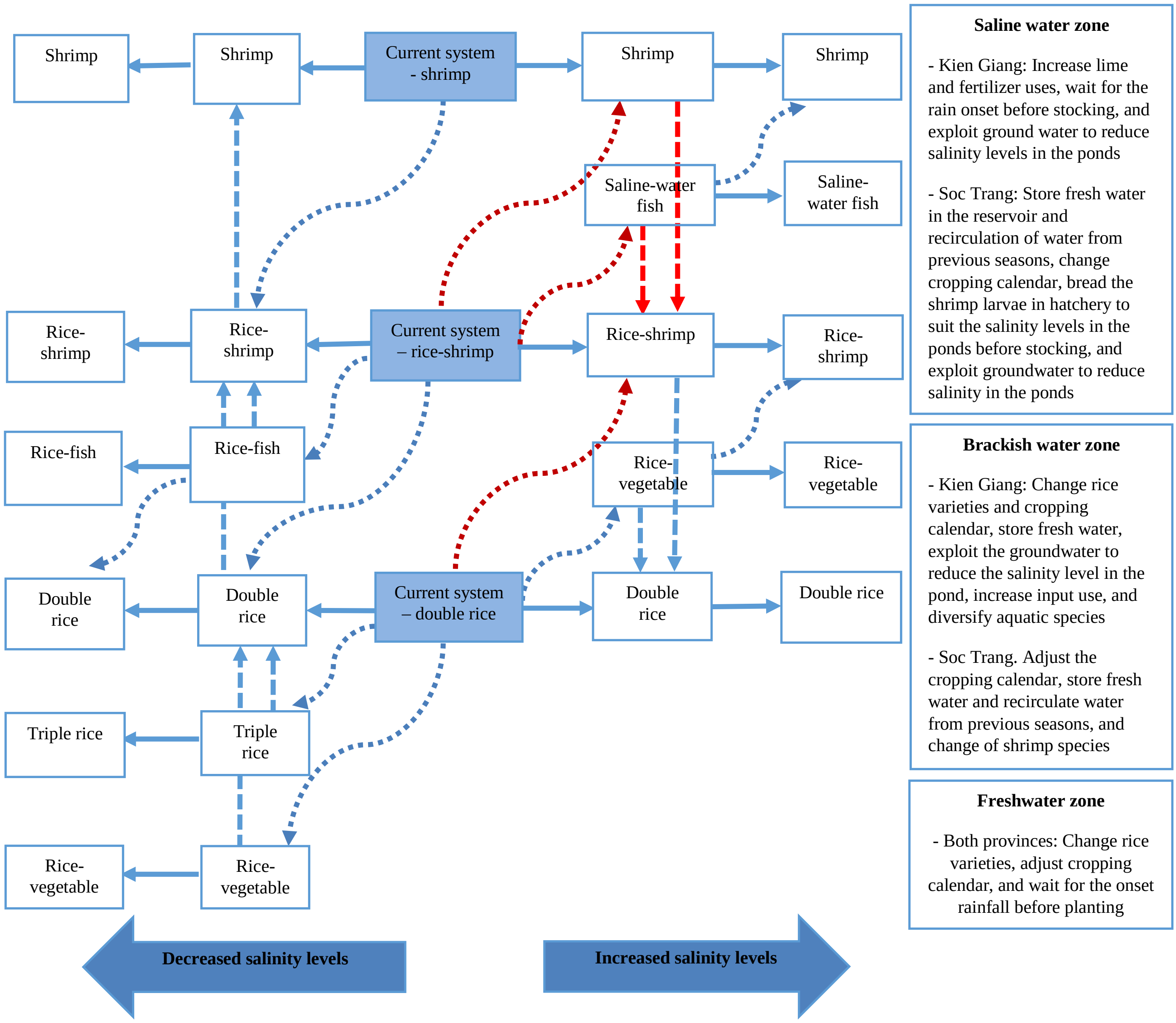



**Fig. 7. Adaptation pathways in different salinity zones in the MKD to changing salinity conditions based on results of FGDs, and expert and household interviews. Blue dashed arrow curves: pathways to other agricultural systems; red dashed arrow curves: pathways with potential lock-ins; blue dashed 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. 8).

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. 8).

## 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, 2015). 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. 8).

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. 8). 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. 8). 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).

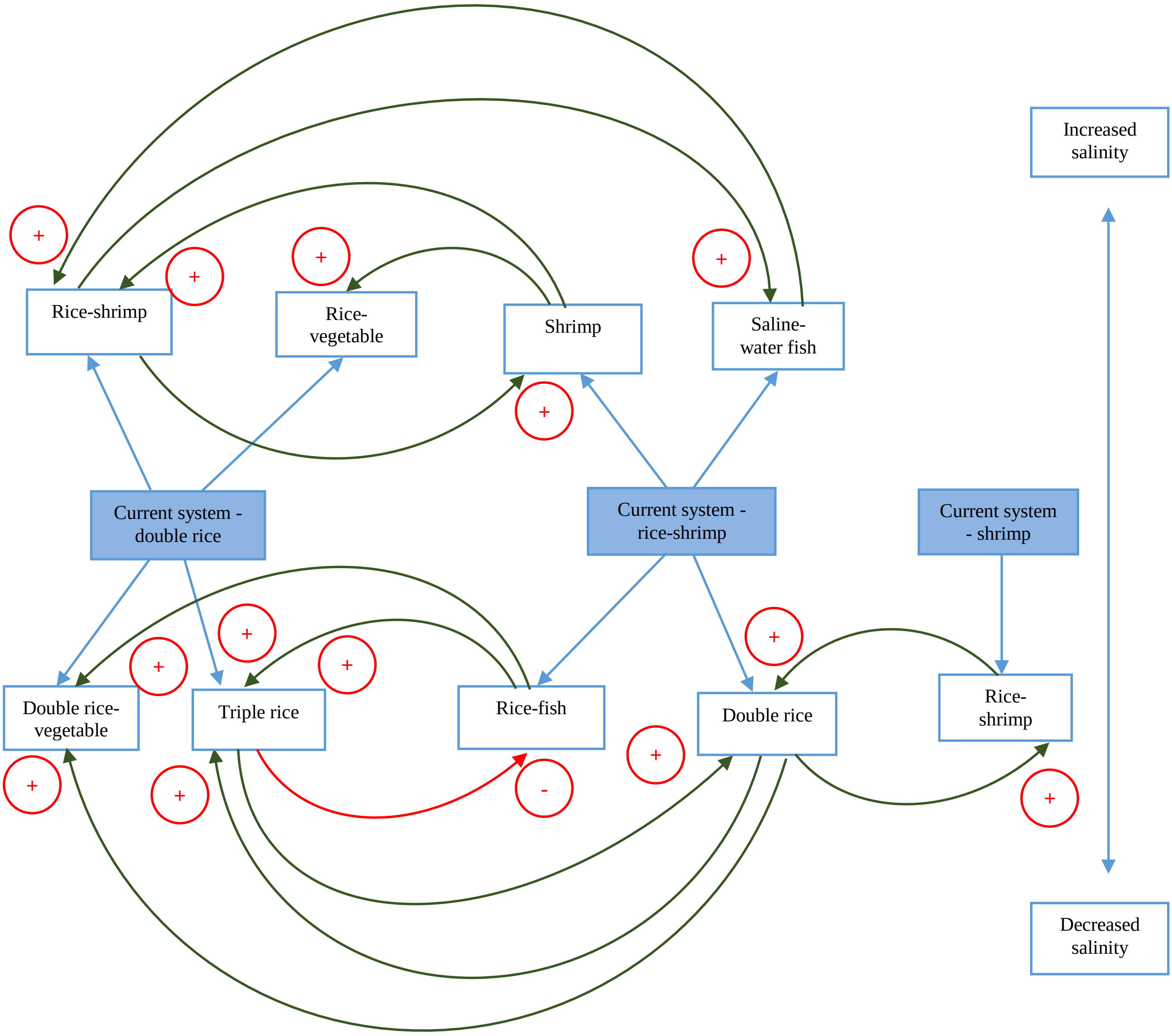


**Fig. 8 Potential interactions and positive feedback (green arrows) and negative feedback (red arrow) between adaptation pathways (blue arrows) (based on previous interactions and feedback in agricultural changes)**

### 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., 2002; 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.

## 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.

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