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Resilience and shifts in agro-ecosystems facing increasing sea-level rise and salinity intrusion in Ben Tre Province, Mekong Delta

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Abstract Coastal areas of the Mekong Delta in Vietnam are increasingly experiencing salinity intrusion in freshwater systems, in part due to climate change induced sea-level rise, compromising agricultural production and domestic water supply. In order to determine which development trajectories could result in resilient agro-ecosystems, a study area in Thanh Phu district, Ben Tre province was selected where the influence of salinity intrusion on agro-ecosystem can be studied along spatial and temporal salinity gradients. The district is divided in three sub-regions: sub-region 3, closest to the coastline, is principally dedicated to brackish-water shrimp farming; more inland, sub-region 2 has a mix of rice-shrimp farming; and further inland, sub-region 1, which is protected from salinity intrusion by a system of dykes, is dedicated principally to rice farming. Household and expert interviews, focus group discussions and a review of policy documents were used to capture historical salinity problems as well as shifts in farming systems. Agricultural activities have changed in the last decades, mainly driven by national-level policies. At present, the development of engineered infrastructures is favoured whereas complementary or alternative solutions to increase the resilience of social-ecological systems with respect to salinity intrusion

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exist. These include regeneration of coastal ecosystems, agronomic measures, upstream flow control and shifts in agro-ecosystems. The latter would increasingly enable farmers to work under the influence of both saline and freshwater systems allowing income diversification. National authorities have an opportunity to change the business as usual mode of tackling water-related problems including extreme events in the Mekong Delta through infrastructure development by looking at these alternative solutions.

1 Introduction

The Intergovernmental Panel on Climate Change (IPCC) SREX report (IPCC 2012:15) has highlighted with high confidence that in the absence of adaptation, "locations currently experiencing adverse impacts such as coastal erosion and inundation will continue to do so in the future due to increasing sea levels". The SREX report further recognises that sea level rise (SLR)-driven salinity intrusion in coastal areas, which is a global problem (Werner et al 2013), can further deteriorate already limited freshwater reserves emphasising the threat this represents for small island states. However, there is no extensive discussion linked to other geographical settings, such as coastal deltas which are highly exposed and vulnerable to SLR because of their typically low elevation (Overeem and Syvitski 2009) and in some cases subsidence (Syvitski et al. 2009). Many deltas worldwide are densely populated and, due to favourable environments, are intensively cultivated. Salinity intrusion could significantly affect agriculture-based livelihoods in these deltas. This is particularly the case in the portion of the Mekong Delta located in Vietnam (hereafter Mekong Delta) which is one of the most vulnerable coastal regions in the world with respect to SLR (Dasgupta et al. 2007) and where several studies have shown that SLR impacts, including inundation, erosion and salinity intrusion into groundwater and surface water, will be important for its coastal agro-ecosystems (Wassmann et al 2004; CIEM et al. 2012).

Although the Mekong Delta is naturally affected by salinity intrusion due to tidal influences, SLR is likely to increase the salinity problem in the future particularly when combined with other factors such as high groundwater extraction rates and changes in river discharge rates and timing due to climate change or upstream dam operations. Dat et al. (2011) predicted that the 2.5 g/L isohaline—used as a benchmark for serious impacts on rice production—could be shifted up to 15 km upstream in the main branches of the river assuming a 20 cm SLR and 38 % reduction in discharge by 2030 when compared with the respective isohaline from 1998 (a year when serious salinity intrusion occurred). The magnitude of salinity level and the duration of high salinity periods in surface water at a particular location are influenced by its distance and connectivity to the river and its distributaries. The latter depends on the canal system and the operation mode of existing salinity-control measures (Nhan et al. 2011).

As salinity intrusion can seriously affect agricultural activities and particularly rice production (Kotera et al. 2008; Chen et al. 2011), many projects have been and still are underway to limit its geographical extent and severity (Hoang et al. 2009), through for example, the construction of dykes and sluice gates. These also allow rice production intensification (double or triple rice systems) compared to a single rainy season crop. However, these measures cause an alteration of the natural, tidal-influenced processes which has some drawbacks (Tuong et al. 2003), including declining water quality due to pollution accumulation when sluice gates are closed (Hoang et al. 2009).

From a biophysical perspective, increased salinity intrusion implies a shift from a freshwater environment to a brackish environment with consequences to water-related ecosystems and the services they provide. Terrestrial ecosystems, such as agricultural systems, are affected through soil salinisation and the reduction in freshwater availability for irrigation. This in turn has implications on social systems as farmers have to adapt to an alternating or permanent brackish environment and communities have to deal with increased shortages in freshwater resources for domestic use. Various options exist in terms of adaptation to increased salinity intrusion, ranging from purely engineered approaches (which are favoured by authorities for now—see Käkönen 2008; GoV 2012) to shifts in agro-ecosystems. These strategies, when taken separately, equate to different development pathways, leading to different social and ecological environments directly affecting peoples' livelihoods (Käkönen 2008; Royal HaskoningDHV et al. 2013). It is therefore important to understand to which extent coastal social-ecological systems (SES) in the Mekong Delta have adapted and can adapt to increased salinity levels and to which extent these adaptation strategies increase the resilience of these SES (see Garschagen 2010). Resilience is defined here as a system's capacity to absorb a spectrum of shocks or perturbations and still retain and further develop the same fundamental structure, functioning and feedbacks (Chapin et al. 2009) and the degree to which the system can learn and innovate (Folke 2006).

Using a case study area from the Mekong Delta, our main objective was to determine how rural population can adapt to increased salinity intrusion in the future and what changes, if any, are required in current agricultural and aquaculture practices for this adaptation process. We investigated historical changes of agro-ecosystems in a district particularly affected by salinity intrusion to understand under which circumstances changes in agro-ecosystems had taken place in order to identify potential effective systems and policy measures for future adaptation and increased SES resilience which could also be relevant for other densely populated, agricultural deltas globally.

2 Methods

Surveys consisting of household questionnaires, interviews with authorities and focus group discussions (FGD) were carried out in the region in 2011. The analysis of empirical data was complemented by secondary data from reports of Thanh Phu district and statistical data from the General Statistics Office of Vietnam. The household questionnaire captured information on (i) general structure of the household, (ii) a description of current farming systems including fertilisers and pesticide use, (iii) historical changes in farming systems, (iv) income and investments, (v) water resources for the household and for irrigation, (vi) salinity problems, and (vii) farmers' risk perception. A total of 74 household interviews were conducted with more interviews carried out in SR1 and SR2 as compared to SR3 because SR3 had more homogeneous agro-ecosystems and has always been influenced by saline water (Table 1). Criteria for household selection were location (i.e. the sub-region and distance from freshwater protection dyke), type of farming systems (e.g. rice-rice, rice-extensive-shrimp), and income level. Household surveys were complemented with a series of focus group discussions (Electronic Supplementary Material, Table S1). Finally, expert interviews with representatives of the provincial authorities from the Department of Agriculture and Rural Development and Department of Natural Resources and Environment and the Meteorological Centre were carried out to discuss national policies and their implementation at the provincial and district levels.

3 Study area and salinity intrusion

The research focused on Ben Tre province (Fig. 1), a region of the Mekong Delta which has seen many transformations in its landscape and which is particularly exposed to SLR with up to 50 % of the province potentially inundated with a 1 m SLR (MONRE 2009). Thanh Phu district in southern Ben Tre province was selected for this study as it is a coastal district characterised by low elevations (mostly <2 m above mean sea level), and it has the highest

Table 1 Areas where household surveys were carried out, main farming systems and income levels (adapted from Lindener 2012)

	Commune	Typical farming system	Number of households	Income level [poor/middle/wealthy]	Date of survey
SR1	Tan Phong	rice-rice	20	7/7/6	23–27/May 2011
	Hoa Loi	rice-rice	9	3/3/3	
SR2	An Thanh	rice-rice	9	3/3/3	30/May–3/June 2011
	An Thanh	rice-shrimp	21	7/7/7	
	An Dien	rice-shrimp	9	3/2/4	
SR3	Giao Thanh	intensive shrimp	3	wealthy	6–10/June 2011
	Giao Thanh	extensive shrimp-rice	3	wealthy	

level of poverty of the province (WB 2011). The main livelihood is generated through agriculture (various crops, but it is one of the main rice production area of the province) and aquaculture. In 2010 agricultural and aquaculture products contributed 59 % of the Thanh Phu district income (Thanh Phu MPSED 2010). Mangrove forests cover an area of 2,500 ha while an area of 1,000 ha consisting of a sedimentation area of the river is used for clam cultivation (Thanh Phu general report 2010). According to our FGD and household interviews, the number of people migrating to cities for job opportunities has increased and almost all households have at least one of their family members working in urban centers.

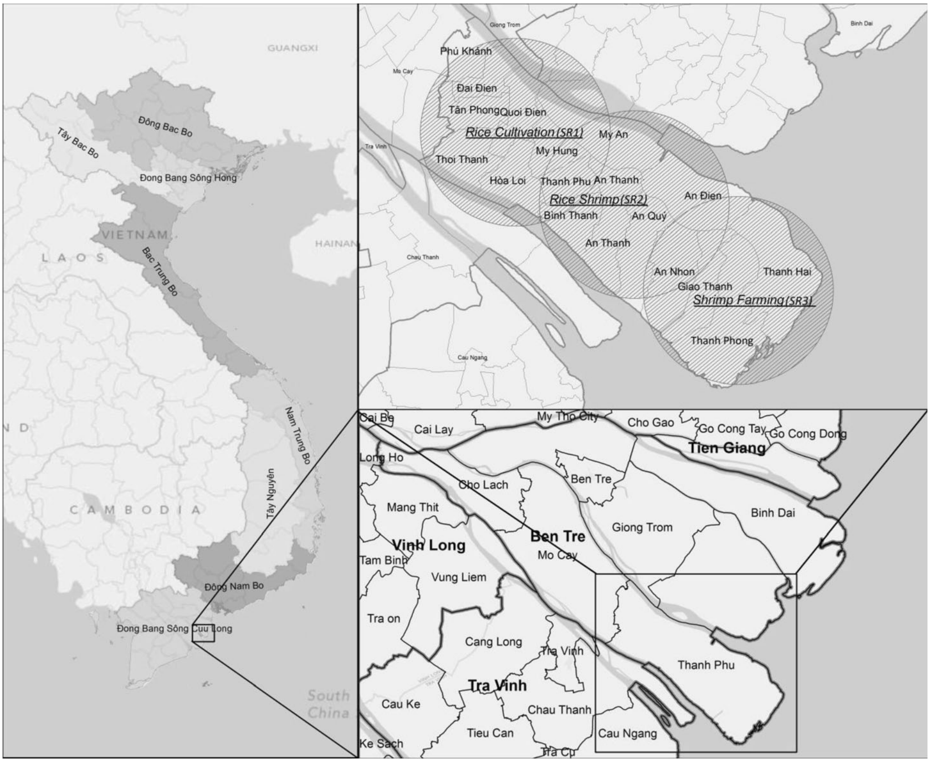

Fig. 1 Study areas in Ben Tre Province of the Mekong Delta, Vietnam

The district is subdivided into three sub-regions with different degrees of exposure to salinity intrusion (Fig. 1). Sub-region 1 (SR1) is the furthest removed from the coastline. A dyke was built between 1990 and 1996 to protect most of SR1 against salinity intrusion thus allowing the intensification of rice production. Surveys in SR1 were conducted in Tan Phong and Hoa Loi communes (see Table 2). Twenty percent of the commune area lies outside the dyke along the Co Chien River. Only one rice crop per season is possible there while a double cropping system can be implemented inside the dyke.

Sub-region 3 (SR3) is directly at the coast and is highly exposed to salinity intrusion and to other coastal hazards. The dominant system in SR3 is shrimp cultivation. Household interviews were conducted in Giao Thanh commune, where extensive shrimp and rice-extensive shrimp cultivation dominate (Table 2). As the water in certain areas of the sub-region is not saline enough for a second shrimp cycle, farmers grow salt resistant transplanted rice in the short time frame of freshwater availability between June and September.

Table 2 General characteristics of surveyed areas in Than Phu district, Ben Tre province

Region	Surveyed communes	Commune area and landuse[1]	Water-related infrastructure & innovation[2]	Number of crops[2]
SR1	Tan Phong	Total area 1,440 ha Population 9,285 Rice 485 ha Yield 4 t/ha Coconut[3] 620 ha Sugarcane 25 ha	• Dyke • Short term rice varieties	• 2–3 rice crops
	Hoa Loi	Total area 2,019 ha Population 9,230 Rice 610 ha Coconut 450 ha Sugarcane 370 ha		• 1–2 rice crops
SR2	An Thanh	Total area 868 ha Population 4,000 Rice 564 ha (transplanted 487 ha) Shrimp 476 ha Coconuts 74 ha	• Short term rice varieties • Information on cropping calendar and salinity level	• 1–2 rice crops • 1 shrimp season
	An Dien	Total area 4,300 ha Population 5,443 Rice-shrimp 700 ha Intensive shrimp 180 ha Extensive shrimp 120 ha		
SR3	Giao Thanh	Total area 1,943 ha Population 6,116 Rice-shrimp 308 ha with rice yield of 3.5 t/ha Intensive shrimp 71 ha with yield of 4–5 t/ha Extensive shrimp 1,342 ha with yield of 250 kg/ha Vegetables 28 ha	• Since 2007: new salt resistant rice variety	• 1 rice crop • 1–3 shrimp seasons

[1] Source: An Thanh commune report (2010), An Dien commune report (2010), Giao Thanh commune report (2010), respectively

[2] Own survey data

[3] Coconuts are often grown as a single fruit crop or planted on the embankments of rice fields or shrimp ponds as an income diversification strategy. Partial conversion from rice to coconut production is occasionally tolerated by local authorities

Sub-region 2 (SR2) is located between SR1 and SR3 and the agriculture/aquaculture systems have to be able to cope with seasonal changes in saline conditions: a predominant system is typically a combination of shrimp cultivation in the dry season and a rice crop during the rainy season. Extensive shrimp cultivation, which is the dominant type in the SR2, starts around December to January and the rearing cycle takes four to five months. The interviews were carried out in An Thanh and An Dien communes (Table 2).

Saline water can affect the province through intrusion via the Dai, Ham Luong and Co Chien estuaries (WB 2011). Salinity intrusion starts in December in SR2 with the beginning of the dry season while it occurs one month later in the region of SR1, which is located further inland. Due to recent overall increasing salinity levels and an extension of the period when high salinity levels predominate, salinity intrusion reached further inland in recent years. The duration of the saline influenced period was estimated by farmers at 6 months in SR2 and 3 month in the region of SR1. With salinity intrusion occurring earlier in the season, rice production in unprotected areas is increasingly threatened. Farmers in the three sub-regions have indicated that salinity intrusion has increased significantly since the 2000s (Electronic Supplementary Material, Figure S1).

Salinity intrusion also seriously affects domestic water supply. The province experiences drinking water shortages during the dry season, with Thanh Phu being one of the most affected districts (WB 2011). In the rural areas, rain water is usually stored in ceramic jars or cement tanks and can supply an average household for about 4–6 months during the dry season. Rich farmers can build big tanks to store enough water for both cooking and drinking purposes while poor farmers can store water for drinking only and have to resort to ground water or/and surface water for cooking and washing. Most interviewed farmers and experts mentioned that increased salinity intrusion will strongly affect the drinking water sources in the future (see also WB 2011).

4 Shifts in agro-ecosystems

4.1 Historical changes

Results from official statistics, focus group discussions and household interviews indicated that land use in Thanh Phu has changed considerably in the last 30 years (Electronic Supplementary Material Figure S2, Table 3). A few decades ago, the whole district was characterised by low agricultural productivity during the rainy season and the exploitation of natural stocks of shrimps or clams during the dry season. Some farmers also grew coconut trees or engaged in off-shore fishing, but these activities tended to generate only limited income. After the national unification in 1975, the government encouraged farmers to reclaim new land in mountainous or coastal areas for farming through the policies on the establishment of new economic regions (QD-95 CP, dated 27/3/1980). During the period 1975–1986 many farmers migrated to the coastal zone of the district to establish new farms, but poverty remained a critical issue. With the Doi Moi (economic reform program starting in 1986), Vietnam gradually changed from being a rice importing to a rice exporting country. Subsequently, with the implementation of various development policies together with the lift of the US embargo on Vietnam and higher prices for rice and aquaculture products, the economy of Vietnam became more market-oriented. In 1997, a freshwater protection dyke was built in Thanh Phu district which aimed at improving freshwater supply for intensive rice production in an area of more than 6,500 ha. With this project, the district was divided into the three sub-regions discussed above and agricultural and aquaculture production evolved further.

Table 3 Changes in land use in Thanh Phu district

Sub regions	Major changes	Year	Reasons for changes
SR1 Freshwater area	Single rice crop—local varieties and one shrimp harvest in natural environment	<1997	Seasonal salinity intrusion, no-embankment
	Changing from single to double rice crop (modern rice and local varieties)	1997–2000	Policies for agriculture and aquaculture development (Directive 20-CT/TW dated 22/9/1997) freshwater dyke construction, improved irrigation and transport systems
	Double rice crop (modern and local rice varieties), triple rice crop (around 100 ha), coconut and vegetables	Since 2000	Complete embankment and sluice gates, farmers individual decisions
SR2 Brackish water area	One local rice crop—natural shrimp stock	<1995	Abundant natural shrimp stock and seasonal water resources
	Local rice variety—extensive shrimp	1995–2000	Decrease in natural shrimp resource, government development policies
	Local rice variety—extensive and intensive shrimp cultivation in some areas	2000–2006	High market price, Decision 09 on Aquaculture Development (09/2000/NQ-CP dated 15/06/2000), support in infrastructure (irrigation, electricity and transportation) and techniques (new species, training, workshops)
	Back to the previous rice-extensive shrimp production in some cases	2009-now	Shrimp diseases, water pollution, lack of financial assets
SR3 Muddy swamps	Mangrove forest and exploitation of natural clam and mussel	<1985	Abundant natural clam broodstock
	Natural clam managed by cooperatives	1985–1995	Reduction in natural clam broodstock, cooperative management
	Clam cultivation starts	1995	Exploited local clam broodstock
	Clam cultivation (dominant)	2005–now	Provision of clam broodstock from other regions
SR3 Brackish water area	Fallow land, mangroves and water coconut dominant, exploitation of natural resource	<1980	
	Forest—more natural shrimp stock exploitation, water coconut dominant, fallow land	1980–1990	Government policies on land use and the management of fallow land and forest
	Forest—natural shrimp managed by contracted farmers	1990–1995	Policy for individual household management
	Less forest—extensive shrimp cultivation	1995	Decrease in natural shrimp stock, good market price
	Less forest area, intensive shrimp cultivation	2000	Provincial planning, national policies, embankment
	Rice and intensive shrimp production	2000–2005	Good shrimp harvest and high market price
	Rice-extensive shrimp production and intensive shrimp production	2008–now	Shrimp disease problems, higher rice price

In the area inside the dyke (SR1), irrigation systems were constructed and renovated. Farmers were provided with modern rice varieties and training on new farming techniques was organised. Mechanisation of agriculture was also encouraged. Within a few years following the construction of the dyke, SR1 changed from single to double rice cropping; in 2011, 63 % of households interviewed in SR1 practiced double rice cropping and 8 % a triple rice cropping. However, not all farmers in SR1 benefited from the construction of the dyke as rice fields located in depressions were adversely affected by acidification linked to the presence of acid-sulfate soils and poor drainage. In addition, in some communes such as Hoa Loi, farmers have limited access to water resources because their farms are located far away from sluice gates and experience poor yields during the spring-summer crop. Finally, fields which lie inside the dyke but in the transition zone with SR2 experience salinity intrusion due to inadequate operation and poor maintenance of the sluice gates. Many farmers in SR1 close to the dyke border are currently constrained to produce rice on specific numbers of ha as per government plans but because of increased salinity intrusion, achieve poor rice yields in the dry season. Increasingly, some farmers in SR1 are diversifying their production systems by e.g. planting coconut trees (Table 2).

The poorest area of the district is SR2 where farmers are entirely dependent on changing natural conditions for rice and shrimp production and where farm size is typically small, limiting the capacity to invest. Since 1996, farmers in SR2 changed from one rice crop and natural shrimp stock exploitation to a rice-extensive shrimp system which has improved income generation. Shrimp farming was introduced in An Dien commune by farmers from Ca Mau province in 2000. During the following years (2000–2005) the entire production was shrimp-based because of high market prices and demand for shrimp export. From 2006 on, multiple factors such as poor water management, the requirement for high capital investment, unstable market prices and shrimp diseases, meant that many farmers experienced economic losses and shifted back to rice-extensive shrimp production systems which generate less income but are more stable and require lower investments.

SR3 is a recently opened area to settlement, linked to the migration of farmers which was facilitated by various national policies. The coastal area is mostly managed by the Forest Protection Management Board and is also under military control as it is a coastal border. The remaining area of more than 12,500 ha is mostly for aquaculture production, including clam cultivation, intensive-shrimp (dominant), rice-extensive shrimp and vegetables in sandy soil. Before 2000, farmers exploited natural stocks of aquatic organisms such as clams or mussels which led to over-exploitation of the resources. In 1996, the release of the "Law of Cooperative" enabled farmers to form cooperatives for specific production purposes, which resulted in better control and exploitation of the natural resources. As a relatively newly settled area, farm size is larger than in the other two sub-regions and farmers have the ability to invest more resources for intensive shrimp production and can build permanent private embankments, allowing them to produce both transplanted rice and shrimps.

In addition to intensification and changes in agricultural systems, farmers also adopted new rice varieties across the subregions, principally in the 2000s. Modern, short-cycle varieties (e.g. OM6162, MTL499, OM6904, OM6955, OM7222) were developed to increase grain quality, resistance to pests and diseases and/or environmental stress such as salinity. In saline environments, the duration of one crop cycle is critical. As salinity intrusion tends to occur earlier in the year, farmers have to resort to shorter cycle varieties. Results from our surveys showed that modern or traditional rice varieties were used in equal amounts during the rainy season in single crop systems of SR1 whereas in SR2, 76 % of the interviewed farmers used only modern varieties. In double cropping systems, modern varieties were typically used for the summer-autumn season and traditional ones during the rainy season. If a third crop is grown during the winter-spring season, this is done with a modern variety. Seeding techniques have also changed partially. To save time, direct seeding is now predominant for the first crop of a double cropping system whereas transplanting is used principally for the second crop (for traditional varieties) or in equal share with direct seeding when only one rice crop is grown.

4.2 Drivers of change

Irrespective of the sub-region, a large proportion of the respondents considered that shifts in their agricultural practices were inspired by other farmers (e.g. in SR1 40 % of the respondents), through their own initiative e.g. after conditions were made more favourable through dyke construction (27 % in SR1), or were encouraged by government agencies (23 % in SR1). The fact that farmers rely principally on neighbours to access new information and knowledge holds for other shifts in production systems, such as aquaculture (SR2 and SR3). However, when farmers were directly asked about their participation in governmental-sponsored activities, the majority of farmers indicated that these were important.

Government intervention is one of the key drivers of change in agro-ecosystems in the region but it also restricts shifts in agro-ecosystems in some cases. A large amount of governmental investments took place in the district to build the freshwater dyke. The local government regularly makes plans for the development of the district and sets the targets for socio-economic, environment and health development (e.g. Thanh Phu MPSED 2010). For the agricultural sector, land use, cropping systems and yields to be achieved are planed and the respective local departments have to follow the plan closely. Farmers can decide which crop varieties to cultivate but they cannot unilaterally change the land use pattern.

Another driver of change is market forces. The high market price for aquaculture products in the late 1990s drove aquaculture production toward intensification, but price collapses also had the reverse effect. Another example concerns coconut production whereby in recent years, price of coconuts increased rapidly leading many farmers in SR1 to amend their production systems to include coconut production even if they are not officially allowed to do this. This action has beneficial outcomes in terms of income diversification but the local government continues to try to enforce rice production (FGD result; Thanh Phu MPSED 2010).

5 Towards more resilient agro-ecosystems

Farmers in Thanh Phu estimated that farming in the future would become increasingly difficult. Results from our surveys indicated that 29 % of the respondents had no knowledge as to whether they were already affected or might be affected in future by climate change but 47 % claimed to have observed effects on their farming activities. Only 1 % of the farmers were of the opinion that there would be no effects from climate change and 23 % stated that although they had not experienced any effects yet, they would be affected in the future. The main perceived threat by the interviewed farmers was salinity intrusion, followed by rice pests (Electronic Supplementary Material Table S2). All participants in (i) our FGDs and (ii) interviews with authorities perceived salinity as the most important hazard to agricultural and aquaculture activities (see also Bergqvist et al. 2012).

Many adaptation options to SLR and salinity intrusion exist for the district in order to increase the resilience of SESs (Table 4). No single solution will satisfy all farmers and combinations of options need to be considered. Measures consist in (i) lowering salinity levels through coastal engineered infrastructures as is already implemented and planned by the authorities; ecological engineering such as densification of coastal vegetation to protect areas

Table 4 Advantages, shortcomings and contribution to resilience of selected approaches to address salinity intrusion

Options to address salinity intrusion	Effectiveness of the approach for salinity intrusion control	Effects on agro-ecosystems	Effects on domestic freshwater supply	Environmental externalities	Social consequences	Contribution to resilience
Infrastructure development (dykes, sluice gates, sea walls, etc.)	Can limit salinity intrusion only if well operated and maintained and can reduce inundation	Freshwater-based systems (e.g. rice) can be maintained or intensified (particularly in SR2 and SR3)	Can contribute to preserve supply of freshwater	In the absence of crop rotation, increasing use of agrichemicals. Generation of pollution within and outside the protected system. Negative impacts on aquatic life, especially fish movement. Altered discharge and sedimentation patterns	Could result in a poverty trap for some rice farmers if no diversification is possible. Loss of income for farmers currently involved in brackish water aquaculture potentially leading to social tensions	Little diversification so fragile system in case of severe pest outbreaks or failure to control salinity. This would impact directly on livelihoods. Loss of capacity to adapt to other environmental changes and to innovate if farmers persist with one single production system
Ecosystem-based approaches (e.g. mangroves)	Limited to protecting coastal fringes from erosion (SR3) and buffering against extreme coastal events. Increased lifespan of engineered structures when placed behind mangroves	Some land would need to be converted back to natural vegetation in SR3. Increase in biodiversity	Would contribute to protect freshwater resources during extreme events in coastal areas	No direct externalities	Some farms in SR3 would need to be relocated. Provision of additional resources for livelihoods	Resilience would be increased as the buffering effect of vegetation would limit the chances of damages along the coast and further inland
Upstream river flow regulation	Can effectively limit salinity intrusion when well managed	Current agroecosystems can be maintained and rice intensification possible. Reduction in extent of brackish water systems if low flows well managed	Can contribute to the preservation of the supply of freshwater resources	Important externalities in areas directly affected by dam construction. Alteration of sediment and nutrient flows as well as water discharge	Reduced stress on agricultural system would be beneficial as long as this is accompanied by livelihood diversification	Resilience could increase but for the most part, the region would be dependent on water management decisions taken upstream which could be problematic

Table 4 (continued)

Options to address salinity intrusion	Effectiveness of the approach for salinity intrusion control	Effects on agro-ecosystems	Effects on domestic freshwater supply	Environmental externalities	Social consequences	Contribution to resilience
Agronomic approaches	No effect	Short cycle varieties would allow for continued rice cultivation in the dry season. Development of further rice salinity tolerant varieties could be outpaced by increased salinity intrusion	Will not protect freshwater supply	No direct externalities, with the exception of increased pollution by agrichemicals with continuous intensive rice cultivation	Preserve current system in short term but failure of system in the longer term is possible (e.g. pest outbreaks) with potential severe consequences on livelihoods	Adapting rice to salinity without further crop diversification, salinity will compromise rice production eventually
Shifts in agroecosyst-ems	No effects as saline environments could be required for new agro-ecosystem	Continued modification of agro-ecosystems with an emphasis on e.g. rice-shrimp systems. Improved water man-agement practice need-ed. Possibly abandon rice production in all sub-regions in the lon-ger term	Will not protect freshwater supply	Increase in salinity intrusion further inland	Can allow to develop livelihoods adapted to both freshwater and brackish water systems, leading to diversification of agricultural production	Increased resilience as agricultural systems adapted to the environmental circumstances. More opportunities to innovate would exist

directly on the coast; upstream control of the Mekong River flows to increase low flows during the dry season; excavation of canals around fields to store rain water during the rainy season to flash out salinity as well as for irrigation purposes in the dry season; (ii) adapting to existing saline environments (see also Nhan et al 2012) such as adoption of saline-tolerant crops or crop varieties; shifts of production systems to brackish water aquaculture or combined crop-aquaculture systems; and improving early warning systems. Accompanying measures include technical training, in particular when shifting to crop-aquaculture and brackish aquaculture systems; and policies for increasing support to farmers to enable them to invest in new farming systems (see Garschagen et al. 2012). Some of these solutions can lead to different development pathways (see also Royal HaskoningDHV et al. 2013) and would result in different system resilience to environmental changes (Table 4).

To control salinity levels, the first option is to develop further coastal infrastructure to prevent salinity intrusion and inundation. This approach is linked to national policies aiming at maximising rice production to ensure self-sufficiency and export earnings (Käkönen 2008). The development of these infrastructures brings both advantages (agricultural intensification, protection from some hydro-meteorological hazards and from inundation) and disadvantages (destruction of natural ecosystems, pollution, soil erosion and conflicts) (Nhan et al. 2007). They are also costly to build and maintain and pose a risk to rice production in case of poor operation and maintenance (Table 4). They can trap farmers into rice production with limited opportunities to diversify or innovate and can lead to conflicts when, for example, farmers were already involved in brackish water aquaculture (Käkönen 2008; Hoanh et al. 2012). In Thanh Phu, some of the farmers interviewed in SR1 were interested in shifting their production to brackish water aquaculture during the dry season to increase income. However, they are not allowed to pump brackish water into the dyke-protected area, as this would affect rice production of other farmers. A potential consequence is that some farmers could be trapped into poverty (e.g. Coclanis and Stewart 2011).

Ecosystems such as coastal vegetation including mangroves can also play a role in limiting salinity intrusion by reducing coastal erosion rates and buffering against coastal storm surges (Gedan et al. 2011). The preservation of these ecosystems is critical for many other factors, including the protection of biodiversity, the provision of livelihoods and the protection of inland infrastructure (Table 4; see also ISPONRE (2013)). In the past four decades, mangrove forest area in the region fluctuated significantly from 4,732 ha in 1976, to 1,110 ha in 1990, and since 2000, the area of mangrove has increased due to governmental and international reforestation programs (Thanh Phu General Report 1984, 1990, 2000 and 2010).

Other solutions can be considered outside the province itself. For example, new dams along the Mekong River and its tributaries are currently critically discussed and can generate both advantages and constraints to communities in the delta. One potential advantage is increased low flows during the dry season; however evidence that this has happened with existing dams is controversial (Kuenzer et al. 2012). Negative impacts of dams such as limiting nutrient and sediment fluxes to the delta, as well as social and economic impacts where they are built could negate any advantages linked to increased low flows. However, should these dams be built, the Vietnamese government could require, during consultations and negotiations, the maintenance or an increase in low flows during the dry season.

In order to adapt to current and future salinity levels, an option is to increase the salinity tolerance of crops or shorten their growing cycle. Such rice varieties have already been developed and research in this direction continues. Other adaptation strategies include rice transplantation and the development of small-scale irrigation structures to flush salinity more effectively. However, in the longer term, with increased salinity intrusion, salinity tolerance limits could be reached before new cultivars are developed (Table 4).

Another option consists in the continuous adaptation of current agro-ecosystems to future salinity intrusion. This adaptation would be considered as a large scale pre-emptive action that could increase SES resilience. Such an approach would consist in accepting increased salinisation but keeping agricultural-based economic activities in the region through integrated rice (or other crop)-shrimp farming. As discussed above, this is not a new approach (Lan 2011; Nhan et al. 2012), as it is implemented in various areas including SR2, but rather it needs to be further enhanced through training and policy changes. There is a window of opportunity that can be capitalised upon from an institutional point of view to increase the adaptability of the current system to an existing threat which will be aggravated in the future (Garschagen 2010). Some rice cultivation would be possible during the rainy season, therefore integration of rice (or other crops) and aquaculture, and in particular with extensive aquaculture production systems, could prove optimal. This would introduce greater flexibility in production systems allowing diversification of income, risk reduction in terms of crop failure and market price fluctuations, as well as opportunities to learn and innovate (Table 4). One of the main drawbacks for the region would be the long-term reduction of available freshwater supply for domestic purposes, which is obviously not negligible and which would require the set-up of alternative sources of freshwater for the communities. Another risk would be to abandon rice production altogether and to focus solely on intensive shrimp production which could prove unsustainable in the long run from an environmental perspective (Guong and Hoa 2012) and could lead to complete SES shifts if land and water resources are irremediably altered (Lan 2011) or prices collapse. To accompany such transformations, training and government policies need to be adapted to satisfy the needs of the poorest farmers to ensure they are not left out (Käkönen 2008). Examples of such interventions are compensation (payments for ecosystem services when dealing with coastal vegetation), low interest loan or crop insurance. In addition, effective adaptation approaches also require better cooperation between government agencies and hierarchies as well as with other stakeholders (Garschagen et al. 2012; Renaud and Kuenzer 2012). The roles of each agency should be defined clearly to avoid overlapping tasks and competition, while maximizing resource use.

Finally, it is also necessary to develop an effective and accessible early warning system. Currently, salinity intrusion is monitored by the provincial Centre of Hydrology and Meteorology. This information is not directly and instantly accessed by the local authority or farmers.

6 Conclusions

Farmers in the Mekong Delta and other deltas globally face the prospect of increased salinity intrusion and other climate change related extremes. Adaptation mechanisms which enhance the resilience of agro-ecosystems need to be advocated. Solutions to addressing salinity intrusion, as discussed above, are not mutually exclusive and a combination of these is required to address the diverse needs of SESs. Government policies and their applications play a critical role. There is therefore an opportunity to set up more flexible institutions dealing with land use planning and agricultural production in the Mekong Delta. Protecting rice production areas at all costs might satisfy national rice production goals but eventually could lead to very vulnerable production systems. An alternative is to give more freedom of choice to the farmers as to which production system to engage with while supporting the poorest to adapt. Integrated, rice (or other crop)-extensive aquaculture production has been identified as a promising system which is likely to be more resilient to future environmental changes as it is adapted to both fresh and brackish water environments, allows for income diversification, has relatively limited impact on the environment and is not reliant upon costly infrastructures.

Resources for such approaches could be acquired through savings made by not systematically developing expensive (to build and maintain) infrastructures. Shifts in agro-ecosystems (IPCC 2012), or the adoption of other measures discussed here should be accompanied by (i) more flexible governmental institutions which provide a favourable environment for innovation, and (ii) increased farmers' awareness of the causes of the problem and potential solutions.

By impacting environmental resources and the capacity of ecosystems to provide services, salinity intrusion will increasingly affect SESs in coastal areas globally. As it is a "creeping" process, salinity intrusion does not systematically get the same level of attention outside impacted areas as other, climate change related, hydro-climatic hazards, yet the consequences could be dramatic for affected systems. In the absence of adaptation, salinity intrusion will slowly affect the freshwater and terrestrial ecosystems of exposed landscapes, contributing to a slow erosion of freshwater, agriculture-based livelihoods and of the availability of freshwater for domestic purposes, leading to increased poverty, health concerns, and potential displacement of populations. Many highly populated deltas are currently threatened by environmental change and anthropogenic factors (Syvitski et al. 2009; Kuenzer and Renaud 2012; Renaud et al. 2013), including salinity intrusion. Specific adaptation measures such as the ones discussed for the Mekong Delta cannot systematically be exported to another delta environment due to different geophysical, social, economic, cultural and political settings. However, the general principles discussed here, i.e. adapting agro-ecosystems to more saline environments, developing crop varieties that are more tolerant to salinity, limiting salinity intrusion or optimising river flows and sediment transport upstream through infrastructure development and management, restoring previously degraded coastal ecosystems, and institutional and governance issues, are relevant to most agricultural deltas and should be considered by development planners. Addressing these options systematically could be one of the components of a proposed global delta sustainability initiative (Foufoula-Georgiou 2013).

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