4 Social and Environmental Impact of Rapid Change in the Coastal Zone of Vietnam: an Assessment of Sustainability Issues

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Abstract

Ca Mau Peninsula, which lies at the extreme southern tip of the Mekong Delta in Vietnam, has experienced rapid environmental and socio-economic change, particularly since the 1990s when the *doi moi* (renovation) policy introduced an agenda of agriculture-led growth. The peninsula lies entirely within the zone of saline intrusion, which previously extended up to 50 km inland during the dry season, thus limiting traditional rice production to only one rainy-season crop. To promote the intensification of rice production, a plan was devised to build a series of coastal embankments and tidal sluices to control salinity intrusion. The protected area lying within Bac Lieu Province, which covers approximately 160,000 hectares, is the focus for this discussion.

Data collected on environmental and socio-economic conditions within the protected area during the study period reflect a complex spatial and temporal pattern of impacts. However, the pattern can be seen as a transition between a freshwater environment supporting rice production and a brackish environment supporting shrimp production. The impacts of these changes in environmental management strategies are discussed. A strategy favouring rice production depends on the operation of sluices in such a way that a freshwater environment is maintained. Intensification of the rice production system involves relatively low risk for farmers, but results in relatively low income. On the other hand, shrimp production requires that a brackish environment be maintained and is seen to offer the potential for increased wealth, but at high levels of risk and indebtedness. Currently available evidence of impact cannot easily be extrapolated to assess long-term sustainability.

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Introduction

Ca Mau Peninsula, which lies at the extreme southern tip of the Mekong Delta in Vietnam (Fig. 4.1), has experienced rapid environmental and socio-economic change, particularly since the 1990s when the *doi moi*[1] policy introduced an agenda of agriculture-led growth. The peninsula lies entirely within the zone of saline intrusion, which previously extended up to 50 km inland during the dry season, thus limiting traditional rice production to only one rainy-season crop (June–November). To promote the intensification of rice production, a plan was devised to build a series of coastal embankments and tidal sluices to control salinity intrusion (Tuong *et al*., 2003). The first sluice in this area became operational in 1994 and the zone protected from saltwater intrusion gradually expanded westward as successive sluices were completed (Fig. 4.1). Within the protected area, the duration of freshwater conditions was extended in line with the policy to promote double or triple cropping of rice.

However, as the freshwater zone spread gradually westward, the local economy was undergoing rapid change. Profitability of the rice crop was falling and at the same time aquaculture was experiencing a dramatic boom, fuelled by technical innovations and the high local and export prices of tiger shrimp (*Penaeus monodon*). Traditional extensive systems of shrimp production based on natural recruitment of shrimp larvae were being replaced by semi-intensive monoculture production systems (Hoanh *et al*., 2003). By 1998, tiger shrimp culture was widespread in the western part of the project area (Fig. 4.2).

The expansion of tiger shrimp culture was consistent with the official policy[2] of the central government adopted in 1998, which explicitly encouraged production for export. But shrimp farming in the protected area contradicted the land-use policy of rice intensification in the area. Despite the apparent success and popularity of shrimp farming, tidal sluices continued to be built and the freshwater zone continued to spread westward up to 2000 (Fig. 4.1). When the supply of brackish water required for shrimp production was cut off, many farmers were forced to abandon aquaculture and to convert to less profitable rice farming. Some shrimp farmers resisted and attempted to maintain favourable conditions by blocking secondary canals and pumping brackish water into

their fields, but this created conflict with rice farmers, who depended on fresh water to irrigate their fields. Eventually, in 2001, the original policy emphasizing rice production was revised to accommodate extensive shrimp cultivation in the west while maintaining areas of intensive rice production in the east. Land use adjusted rapidly to this new policy and by 2002 areas of intensive rice production had shrunk back to the freshwater zone in the non-acid soils to the east (Fig. 4.2).

The background to this policy shift within the highly dynamic environmental and socio-economic circumstances of the project area is discussed by Hoanh *et al.* (2003). This shift is significant because it represents a relaxation of centralized planning in order to allow more freedom for private-sector decisions on land use. The pressure that brought about this change can be seen as the rational response by farmers to economic incentives. However, several emerging issues point to the need for continuing scrutiny and regulation of land use (and in particular shrimp farming) to ensure that short-term gain does not result in failure to achieve long-term sustainable development.

The essential requirements for sustainable development can be defined as poverty eradication, changing unsustainable patterns of production and consumption, and protecting

[1] *Doi moi* can be translated as 'renovation' and is commonly used to describe the move from a centrally planned command economy to a market economy with accompanying democratization of social relations.

[2] Decision on the ratification of the programme of developing the export of aquatic products up to 2006; Government Decision no. 21, 1998.

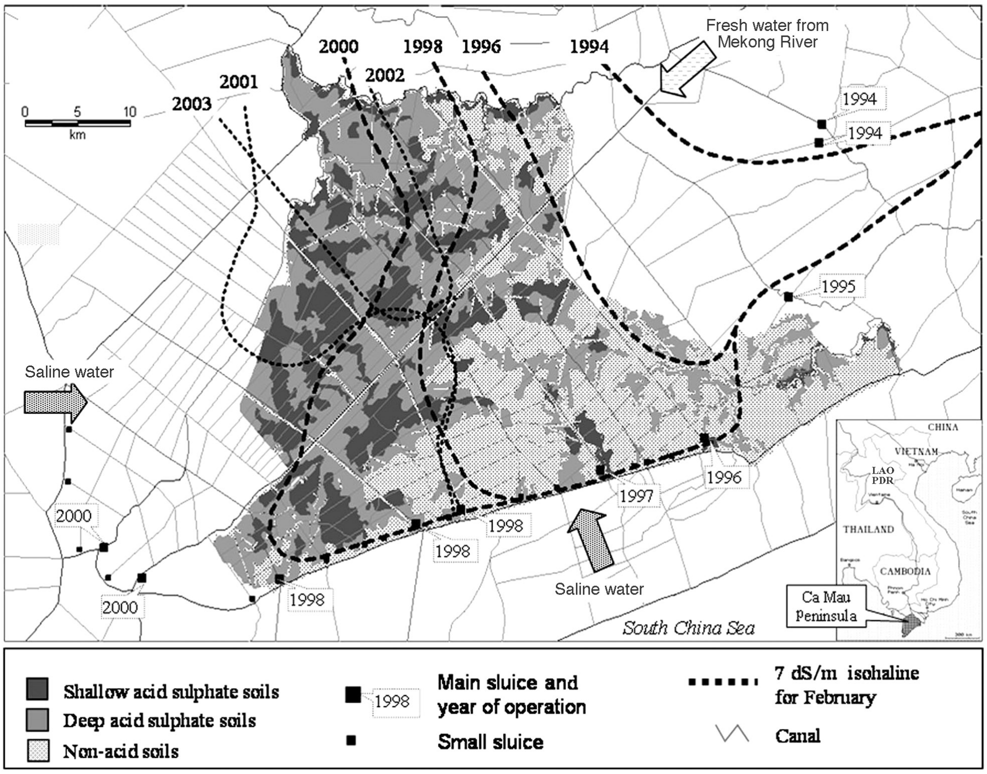

Fig. 4.1. Study area showing extent of saline intrusion at different stages of project development.

and managing the natural resource base (UN, 2002). These objectives need to be understood as mutually supportive and the importance of poverty–environment linkages should be seen as the core of sustainable development strategies. Poor people are predominantly rural and predominantly dependent on natural resources for their livelihoods. They are therefore particularly vulnerable to environmental problems. They need economic growth to escape poverty, but this must be based on the sustainable use of environmental resources. Concern for environmental protection is therefore not seen as being in conflict with concern for human development. The enhancement and maintenance of environmental capital allow for the prudent use of natural resources in the short term while providing for effective protection of the environment in the long term.

The notion of *vulnerability* is critical to understanding the impacts of change. Vulnerability occurs because livelihoods are exposed to stress and are unable to cope with that stress (Adger and Kelly, 2001). Shocks (such as floods and storms) may produce stress when people lose their assets or are forced to dispose of them as a short-term survival strategy. Longer-term adverse trends (such as soil erosion, siltation or acidification) may gradually degrade assets and also create stress. The inherent fragility of poor people's livelihoods limits their adaptive options and makes them generally more vulnerable. Vulnerability therefore relates to both (i) exposure to risk likely to affect livelihood and (ii) weakness of the existing state that limits capacity to cope with the resulting stress.

The rapid expansion of brackish-water shrimp farming in the study area indicated farmers' preference for this production over rice. However, brackish-water shrimp farming elsewhere has been characterized by

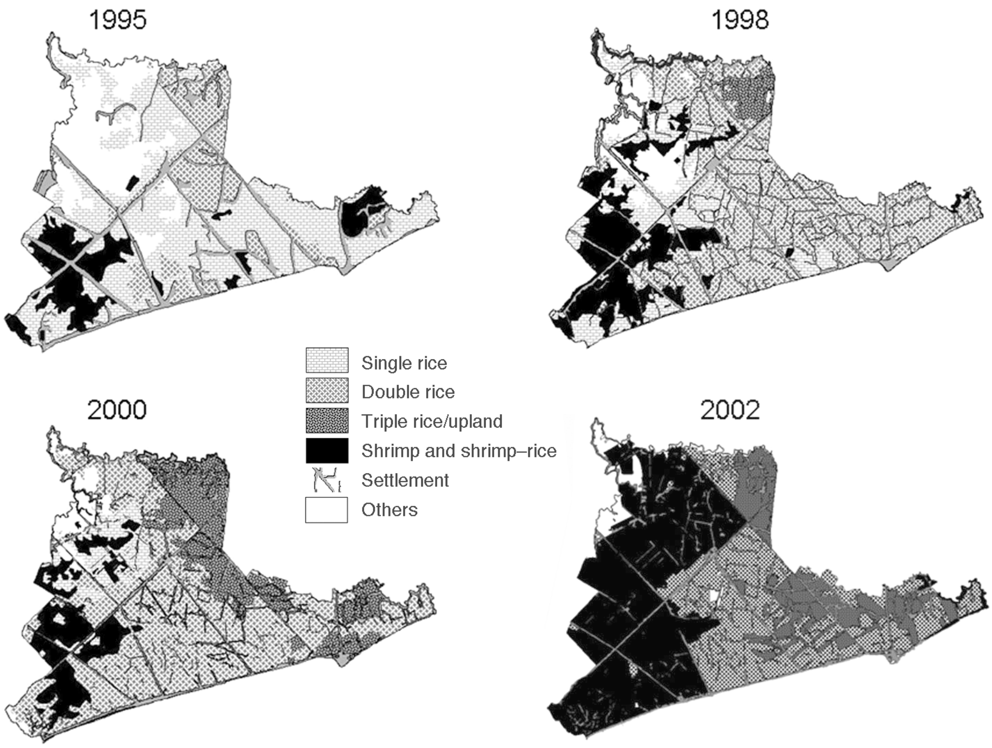

Fig. 4.2. Land-use change in the study area.

recurrent boom-and-bust cycles that cast doubts on its sustainability (Primavera, 1998). Adverse environmental and socio-economic impacts have been widely reported over the past decade (Phillips *et al*., 1993; Beveridge *et al*., 1997; Primavera, 1998; Lebel *et al*., 2002; Shanahan *et al*., 2003). It is important to examine the sustainability of shrimp farming in the study area.

One of the characteristics of the study area is the presence of extensive deposits of acid sulphate soils (ASS), particularly in the western part. These soils develop as a result of the drainage of parent materials that are rich in pyrite (FeS_2), as occurs with the reclamation of brackish-water intertidal swamps. ASS are characterized by low pH (< 4), which results from the oxidation of reduced S- and Fe-bearing compounds producing acid via a number of possible chemical and biochemical pathways (Dent, 1986). The acid released in this way reacts with clay minerals to produce soil–water solutions containing high concentrations of aluminium and iron. Reclamation of ASS for agricultural use depends on leaching these toxic substances out of the root zone and has been reported to create severe acidification of the aquatic environment in Indonesia (Klepper *et al*., 1990) and Australia (Wilson *et al*., 1999) as well as in Vietnam (Minh *et al*., 1997b). The acid pollution and associated changes in water chemistry can have severe impacts on fish populations (Callinan *et al*., 1993), which are not confined to the reclaimed area. The impact on estuarine ecosystems has been reported by Sammut *et al*. (1996) and Wilson *et al*. (1999) for Australia, where mass mortalities of fish have been recorded as a result of episodic acidification, and there is also evidence of chronic long-term effects on estuarine and coastal ecosystems.

The conflict between agricultural production and environmental protection poses a question of the sustainability of development of ASS within the study area. Leachate from reclaimed ASS in the Mekong Delta shows marked peak acidity and Al concentration at the start of the rainy season (Minh *et al*., 1997a, Tuong *et al*., 1998), which may create shocks for the aquatic resources and *vulnerability* for the landless poor who depend a great deal on fisheries for their livelihood.

Objectives of This Study

Given the nature of the deltaic environment, strategies for both land use and water management have been equally influential in determining the nature and extent of recent environmental changes in Ca Mau Peninsula. The pre-2000 strategies, favouring rice monoculture, can be criticized (with the benefit of hindsight) for suffering from the same faults identified by Hori (2000) in a review of development planning throughout the lower Mekong basin. They failed to recognize the diversity of livelihoods of the population and did not give adequate consideration to environmental impact. The study reported here was therefore conducted between 1999 and 2003 to investigate the likely sustainability of development as it affects that part of the newly protected area lying within Bac Lieu Province (approximately 160,000 ha).

Sustainability is a multidimensional concept that is measured by reference to multiple indicators selected to represent environmental, social and economic aspects. However, it is clear that two critical issues against which recent change in Bac Lieu Province should be judged are:

- environmental sustainability, which is achieved when the productivity of the natural resource base (i.e. environmental capital) is conserved or enhanced; and
- livelihood sustainability, which is achieved when households respond and adapt to change without becoming more vulnerable.

The objective of this paper is therefore to present an assessment of the sustainability of the development, with a particular focus on:

- the state of the environment and natural resources within the project area; and
- socio-economic conditions and the relationship between livelihoods and natural resources within the project area.

Short-term Assessment of Project Impact

Social impact: method of assessment

In recognition of the importance of livelihood sustainability, one of the work packages within the study focused on social impact assessment, that is, *assessing changes in farmers' livelihoods and farmers' resource-use strategies in coping with changes brought about by salinity intrusion protection.*

The initial activity under this work package was to establish a framework for social differentiation so that the poor could be identified as a distinct stakeholder group in order to permit an appraisal of environment–poverty linkages and any differential impact of environmental change on them. The framework adopted was based on participatory wealth-ranking exercises.

At an early stage in the project (in 2000), a quantitative survey was conducted in 14 hamlets representing different hydrological, soil and land-use regimes (Tuong *et al*., 2003). This survey provided data required to characterize the baseline condition in terms of asset and production profiles for 350 representative households across four wealth categories. This was followed by an in-depth qualitative survey that used standard participatory rural appraisal (PRA) tools in interviews with key informants to improve understanding livelihood strategies and to help identify the key issues affecting poor people (Chambers, 1997).

Follow-up surveys were conducted toward the end of the project (in 2003) to provide data for an assessment of short-term livelihood impacts. A combination of quantitative and qualitative surveys was again adopted within seven of the original 14 hamlets, where all households previously included in the baseline study were resurveyed. The key indicators used to measure changes in livelihoods are summarized in Table 4.1. These indicators provide some insight into the short-term impact of environmental change within the project area based on quantitative data for 1999 to 2003, which can be extended back to 1994 on the basis of insights derived from the PRA. However, the prediction of future livelihood trajectories of different stakeholders is more problematic.

Environmental impact: method of assessment

In recognition of the importance of environmental sustainability, another of the work packages within the study focused on environmental impact analysis, that is, *characterizing the changes in soil and water quality and resource use brought about by salinity protection interventions.*

The initial activity under this work package was the collection and compilation of data from existing soil and land-use maps and the water quality monitoring network in the area. Subsequently, the activities involved the actual soil and water quality monitoring carried out by the study team. By bringing these data into a GIS for spatial data management, integration and visualization, it was possible to establish an idea of the baseline condition (Kam *et al.*, Chapter 15, this volume). It also provided a means of linking the monitoring activity to modelling work based on the VRSAP[3] hydraulic model (Hoanh *et al.*, 2001, 2003).

The soil map published by IRMC[4] in 1999 at a scale of 1:50,000 provided a baseline for monitoring soil changes. Initial fieldwork was undertaken (in 2000) to verify the predictive value of the soil map at selected locations based on the previously defined sampling zones. It was found to be satisfactory, but some areas mapped in 1998 as *potential* acid sulphate soils had already developed into *actual* acid sulphate soils. A soil monitoring programme was established as part of this work package, which included intensive surveys of acidity release.

Data on water quality are subject to much more temporal variability than are soil data, and therefore presented a greater sampling problem. Data on salinity, pH and Al3+ from 26 locations throughout the study area were collected from 1993 to 2000, but the frequency of observations was inconsistent. A follow-up water monitoring programme was established in 2001, which included more intensive roving surveys. The aim of these activities was to provide data on short-term changes and a basis for predicting longer-term impact on soil and water quality. Particular concerns were:

- the presence of extensive deposits of acid sulphate soils (ASS) that provide a source of acidity likely to affect water quality; and
- the impact of water quality change (acidity and/or salinity) on the productivity of fisheries.

Table 4.1. Key indicators of livelihood impact.

Livelihood asset	Investigate changes in
Natural	Land ownership; total size of landholding; number of land parcels; cropping patterns; rice production; non-rice crop production; aquaculture production (shrimp and other); capture fisheries catch and seasonality, including destination of catch (home consumption or sale)
Financial	Total net HH income; contribution to total HH income from rice, shrimp, other aquaculture, livestock, employment, capture fisheries; remittances from relatives and other funds
Physical	Access to TV, radio, rowing boat, motorboat, tiller/pump/thresher
Human	Workers available per HH; age of HH head; % of female-headed HH; main occupation of HH heads

HH, household.

[3] VRSAP, Vietnam River System and Plains model.
[4] IRMC, Integrated Resource Mapping Center.

Use of the VRSAP model allowed for spatial analysis across the whole of the protected area for the period 1993–2003, but downstream impacts in the surrounding coastal zone may also be significant and these were not monitored. To analyse environmental sustainability, it is necessary to consider both wider and longer-term impacts.

Evidence of short-term impact

Data collected on environmental and socioeconomic conditions within the protected area during the study period should be seen in the context of rapid change occurring at that time, which resulted in a complex spatial and temporal pattern of impacts. However, the key characteristic is the transition between a freshwater environment supporting rice production and a brackish environment supporting shrimp production as summarized in Figure 4.3.

A strategy favouring rice production depends on the operation of sluices in such a way that a freshwater environment is maintained. Intensification of the rice production system involves relatively low risk for farmers, but results in relatively low income. On the other hand, shrimp production requires that a brackish environment be maintained and is seen to offer the potential for increased wealth, but at high levels of risk and indebtedness.

Within the extensive areas of ASS, rice production is seriously constrained by soil conditions, but low profitability precludes the adoption of measures to ameliorate the problem. However, there is evidence that more land is brought into use after conversion to shrimp production. Inputs of lime are widely used to ameliorate acidity within the shrimp ponds, although release of acidity into the wider environment still occurs.

Other impacts on natural resources and consequently on livelihoods can also be identified. The freshwater environment favours higher production of fruits and vegetables from home gardens, and of livestock for sale and consumption, than is possible in the brackish environment. On the other hand, by sustaining freshwater conditions, the catch of wild fish from open-access canals is seen to decline.

These impacts on productivity of the natural resource base result in knock-on effects on livelihoods, but the nature of these secondary impacts varies depending on the livelihood strategy adopted by a particular

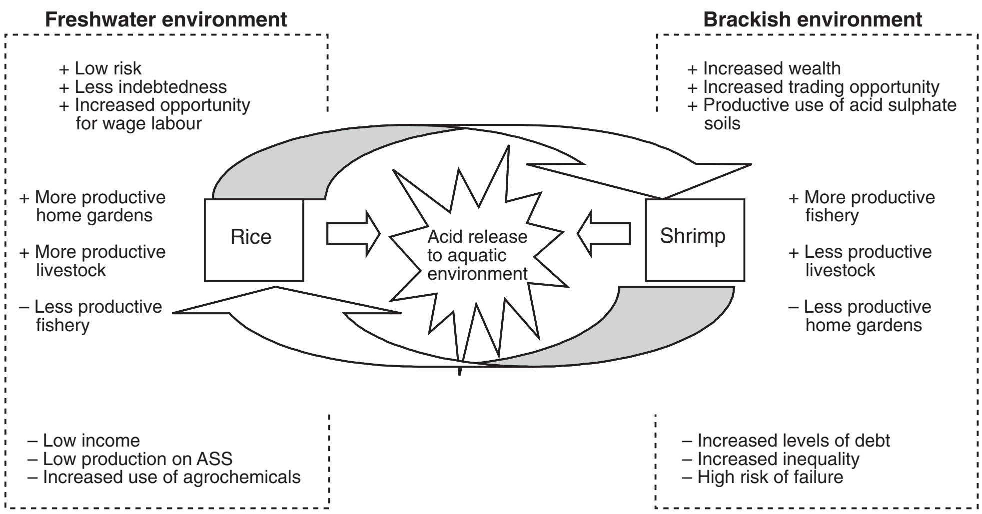

Fig. 4.3. Impacts of alternative environmental management strategies within the protected area.

household (Table 4.2). Households classified as 'very poor' were identified in five of the 14 hamlets and represent 7% of all households. They exhibit a very high proportion of functionally landless and depend on selling labour. They find more employment opportunities in rice areas than in shrimp areas. Households classified as 'poor' exist in all hamlets and represent 34% of the total population. They have some land and may benefit from conversion to shrimp production, but their asset base is low and the associated risk makes them very vulnerable to indebtedness. 'Average' and 'rich' households represent, respectively, 37% and 21% of the total.

Long-term Assessment of Sustainability

Shrimp production

Probably the most frequently voiced concern over shrimp farming is the degradation of coastal wetland ecosystems and in particular the loss of mangrove forests. Over the last 50 years, Vietnam has lost a large proportion of its original mangrove cover through various pressures, but during the last decade the principal threat was reported as shrimp aquaculture (Shanahan *et al*., 2003). Critics have pointed to the adverse consequences of conversion of mangroves to shrimp ponds on aquatic resources and habitat and forest product, and the increased vulnerability to storms and typhoons in Thailand, the Philippines, Indonesia and Bangladesh, as well as in Vietnam. However, this criticism does not apply to the particular circumstances of the study area, where the expansion of shrimp aquaculture has occurred on land previously cleared for agriculture.

Salinization of soil and water is another major concern associated with shrimp aquaculture, particularly where shrimp ponds have expanded into rice land (Flaherty *et al*., 1999). Shrimp production requires brackish water and its import into non-saline areas affects neighbouring rice fields and degrades water used for both agricultural and domestic needs. Again, when applied to the particular circumstances of the study area, this criticism is not valid. Salinity intrusion is a natural seasonal phenomenon within the area, which can now be managed using the recently constructed tidal sluices, and soil salinity cannot be attributed to shrimp production. There is evidence (Tran *et al*., 1999) that salt leaching from shrimp ponds into adjacent rice fields can be significant, but no long-term buildup of salts is apparent in sequential shrimp–rice production systems (Brennan *et al*., 2002; Phong *et al*., 2003). This problem can be managed by appropriate zoning and the adoption of appropriate production systems.

Other environmental impacts are closely linked to the level of intensity of the shrimp production system. In this respect, there is a marked contrast between Vietnam and other major producer countries, such as Thailand, where the 'industrialization' of shrimp aquaculture has resulted in much higher intensities (Lebel *et al*., 2002), as reflected in Table 4.3. As production becomes more intensive, economic viability becomes dependent on high levels of feed, pesticides and antibiotics

Table 4.2. Livelihood strategies.

Wealth category	Landholding (ha)[a]	Landless (%)	Livelihood strategy
Very poor (*n* = 24)	0.6	21	Mainly off-farm employment; capture fishery important; no home garden
Poor (*n* = 120)	1.3	18	50% income from own farm; also off-farm employment and fishing
Average (*n* = 131)	2.0	9	80% income from own farm
Rich (*n* = 75)	2.9	3	90% income from own farm

[a]Landholding is mean area per household available for productive use.

in order to achieve high postlarval survival rates and high growth rates. Water exchange then releases contaminated pond effluents into the wider environment. The same receiving waters generally serve as intake water for neighbouring shrimp farms and water-borne disease agents spread rapidly from farm to farm, thus encouraging the greater use of antibiotics.

Within the study area, production systems are at relatively low intensity (as also reported by Lebel *et al*., 2002), with lime and seed (postlarvae) as the main purchased inputs. The low quality of hatchery-reared seed is a major constraint contributing to the spread of disease, high risk of failure and pressure to increase the use of antibiotics. Under present circumstances, pollution is not a major concern and the release of acidity is a more significant impact; however, there is clear evidence from elsewhere that highly intensive systems are not sustainable.

Shrimp aquaculture has been encouraged by the government of Vietnam to help raise the standard of living of rural communities. Perceived benefits include job creation during pond construction, income generation for shrimp farmers, increased trading opportunities and employment in aquaculture services (seed supply, other inputs, processing, marketing) and increased foreign exchange earnings. The potential to generate wealth undoubtedly exists, yet shrimp aquaculture has been responsible for the deterioration of livelihoods and promotion of poverty in many countries. Drawing on a series of case studies undertaken in Vietnam, Adger and Kelly (2001) concluded that poorer households are most vulnerable because (i) they are likely to depend on a narrower range of resources and income sources and (ii) the loss of common property management rights represents a serious erosion of their ability to cope. They found evidence of benefits from an increase in overall wealth, but increased inequality.

The high risk associated with the enterprise exposes poor people to financial ruin and landlessness. The vast majority of shrimp farmers must borrow money to pay for pond construction and purchase inputs. When the enterprise is successful, profits can be high, allowing them to pay off their debts quickly. However, the risk of failure is also high; Lebel *et al*. (2002) report a 70% rate, Shanahan *et al*. (2003) report a 70–80% rate and a survey in the study area indicates a similar risk of failure. Failure leads to spiralling indebtedness and eventually to landlessness (as reported also by Luttrell, Chapter 2, this volume), although there is as yet no direct evidence that this has occurred within the study area. Relatively poor farmers are more likely to fail, but, if their neighbours have converted from rice to shrimp farming, they have no alternative.

Landless households depend on selling labour, but evidence from elsewhere (Lebel *et al*., 2002; Shanahan *et al*., 2003) supports findings within the study area that shrimp farming creates fewer employment opportunities than rice farming. Environmental

Table 4.3. Comparative characteristics of typical shrimp farms (adapted from Lebel et al., 2002).

Item	Study area	Ca Mau/Bac Lieu	Western Thailand	Eastern Thailand
Mean pond size (ha)	2.0	2.6	0.6	0.5
Stocking rate (per m^2)	2–3	4.8	55	66
Survival rate (%)	na[a]	11	59	51
Use of feed (% farms)	0	14	100	99
Mean production (kg/crop/ha)	150	185	4760	4460

[a]na, not available.

degradation combined with enclosure of open-access areas affects the livelihoods of poor people (particularly landless households) and adversely affects food security. Where shrimp ponds are developed on land reclaimed from open-access mangrove forest there is a particular concern, but within the study area this is not the case. However, an indirect impact on common property resources still exists because of the change in water quality and its effect on the productivity of the fishery in the canals.

Reclamation of acid sulphate soils

The conflict between agricultural production and environmental protection is the core problem and assessment of the sustainability of development of ASS within the study area leads to the question: Can the land be managed to maintain agricultural productivity while minimizing downstream impacts, or should it be returned to wetlands (Tuong *et al*., 1998)? This requires considering processes that generate acidity (i.e. pollution source) and processes that spread acidity (i.e. pollution transport).

Figure 4.4 presents a schematic comparison of acid pollution processes in rice fields and shrimp ponds. During the dry season, the availability of brackish water allows for the filling of shrimp ponds that are limed to ameliorate the effects of acidity, but rice fields on ASS are likely to remain fallow. Shrimp ponds may lose some water to the surrounding canals via seepage (Fig. 4.4a). During the wet season, rice cropping depends on collecting direct rainfall, but can continue after the end of the monsoon by irrigating. In addition to leaching and flushing of rice fields, leaching of acidity from embankments also occurred (Fig. 4.4b).

Data collected from the study showed that the pH of the canal water in the ASS area of the study site was as low as 3 at the end of May and beginning of June, depending on the rainfall (Tuong *et al*., 2003), but was approximately 7 in the dry season. High pH in the dry season suggests that shrimp ponds do not generate high acid pollution loads. This could also be attributed to the salinity of the brackish water in the dry season, which has high buffering capacity.

Very low pH at the beginning of the rainy season indicates that leaching and flushing of rice fields and leaching of embankments represent an environmental hazard. Evidence collected during the study indicates that the embankments of the shrimp ponds were a major source of acidity, which flushes directly into the wider environment at the start of the monsoon. This was supported by Minh *et al*. (1997a, b), who reported that acidic loading from raised beds in ASS (for growing upland crops such as sugarcane and yam) was eight times higher than that from rice fields. The formation of embankments was similar to that of raised beds and involves the excavation of acidic materials and putting them on the embankments/raised beds. The materials oxidized during the dry season. The acidity is mobilized by rainfall. The pollution is most problematic at the beginning of the rainy season because the high loading coincides with low river discharge for dilution. Though the study did not quantify the impact of acidic pollution on fishery resources, farmers in our surveys confirmed that the diversity of fishery resources declined during the period of high acidity. Those poor farmers who relied on capture fishery also reported low catches during this period.

Acid generation from rice fields is more controllable in that it depends largely on managed flushing prior to planting and therefore depends on the timing of the cropping season. An integrated rice–shrimp system – rice cropping in the rainy season and shrimp raising in the dry season – would allow good prospects for control over acid pollution from rice fields. However, acidity release from the embankments and consequential impact on water chemistry are likely to remain a problem for many years and it is important that the operation of tidal sluices does not exacerbate the problem. These sluices may reduce neutralization by tidal inflows of estuarine water, which would otherwise occur naturally. Estimated rates of acid production and export from ASS in Australia have been reported as 100–300 kg H_2SO_4/ha/year (Sammut *et al*.,

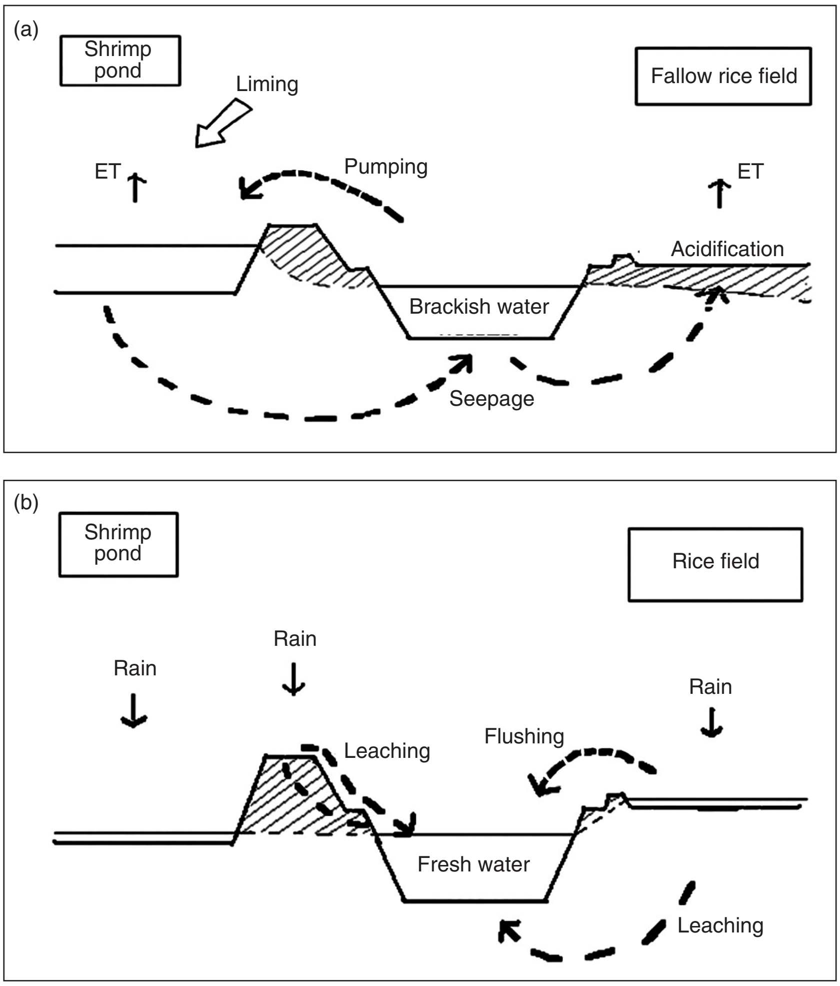

Fig. 4.4. Acid pollution processes in reclaimed acid sulphate soils in the dry season (a) and wet season (b). ET, evapotranspiration.

1996; Wilson *et al.*, 1999). Accumulation behind sluices during sluice closure, followed by sudden release as slug flow into the downstream receiving water, can be catastrophic.

Conclusions

It is clear that conditions are highly dynamic and livelihood strategies have adapted to economic, technological and policy change. But are they sustainable? The concept of sustainability requires a long-term perspective, but currently available evidence is short-term and inconclusive. The concept is also multidimensional and demands consideration of trade-offs among environmental, social and economic impacts, but information is incomplete. The analysis presented here is therefore a tentative attempt to extrapolate from what has been learned during the study by drawing upon experience elsewhere. The analysis has focused on environmental sustainability and livelihood sustainability. In making this assessment, particular consideration has been given to two critical issues that are likely to have a dominant impact on sustainability: shrimp aquaculture and the reclamation of acid sulphate soils.

Within the study area, systems of shrimp production are currently at relatively low intensity. Consequently, the environmental impact from shrimp production is not a major concern and the release of acidity from the reclamation of ASS is more significant. However, social impact is still an issue because of concern for the high risk of mass mortality from diseases and increased inequality. Effective dissemination of good practice, together with improved quality control of hatchery-reared postlarvae, can be expected to reduce the high risk associated with shrimp production. However, long-term sustainability will depend on limiting intensification and concerted action among all stakeholders to adopt integrated management of the environment.

The original development strategy, which promoted intensive rice production throughout the protected area, was rejected by many local stakeholders. Intensification of the rice production system involves relatively low risk for farmers, but results in relatively low income. Within the extensive areas of ASS, rice production is seriously constrained by soil conditions, and low profitability precludes the adoption of measures to ameliorate the problem. Consequently, there is a clear preference among many landholders to produce shrimp in this environment. Inputs of lime are widely used to ameliorate acidity within shrimp ponds and the acid pollution problem consequently decreases, but some release of acidity into the wider environment still occurs. Within the designated freshwater zone on non-acid soils, the current strategy of double-cropped rice appears to be favoured by local stakeholders and no major sustainability concerns have been identified. Elsewhere, an integrated rice–shrimp system offers the best prospects for balanced and sustainable development.

Fish have always been abundant and are considered as a commodity, like water and air, that will always be there, but there is evidence that changes within the protected area have had an impact on fishery resources. The tidal sluices have a direct impact by acting as a barrier to fish migration and an important indirect impact by controlling upstream tidal influence and salinity levels. Their impact on water quality is exacerbated by the accumulation of acid water leached from reclaimed ASS. The acid pollution and associated changes in water chemistry (e.g. high concentration of dissolved aluminium) can be expected to affect the aquatic ecosystem both within the protected area and in the downstream estuarine receiving waters. Evidence from Australia of chronic long-term effects of acid pollution on estuarine and coastal ecosystems provoked White *et al*. (1996) to raise concerns about likely adverse impacts of constructing tidal sluices. This study confirms their analysis and highlights the important connection between environmental and social impacts.

References

Adger, W.N. and Kelly, P.M. (2001) Social vulnerability and resilence. In: Adger, W.N., Kelly, P.M. and Nguyen Huu Ninh (eds). *Living with Environmental Change*. Routledge, London and New York.

Beveridge, M., Phillips, M.J. and Macintosh, D.J. (1997) Aquaculture and the environment: the supply of and demand for environmental goods and services by Asian aquaculture and implications for sustainability. *Aquaculture Research* 28, 797–807.

Brennan, D., Preston, N., Clayton, H. and Be, T.T. (2002) *An Evaluation of Rice–Shrimp Farming Systems in the Mekong Delta*. Report prepared under the World Bank, NACA, WWF and FAO Consortium Program on Shrimp Farming and the Environment, 10 pp.

Callinan, R.B., Fraser, G.C. and Melville, M.D. (1993) Seasonally recurrent fish mortalities and ulcerative disease outbreaks associated with acid sulphate soils in Australian estuaries. In: Dent, D.L and van Mesvoort, M.E.F. (eds) *Selected Papers from the Ho Chi Minh City Symposium on Acid Sulphate Soils.* Pub. 53, ILRI, Wageningen, Netherlands.

Chambers, R. (1997) *Whose Reality Counts?* Intermediate Technology Publications, London, 297 pp.

Dent, D. (1986) *Acid Sulphate Soils: a Baseline for Research and Development*. Pub. 39, ILRI, Wageningen, Netherlands, 204 pp.

Flaherty, M., Vandergeest, P. and Miller, P. (1999) Rice paddy or shrimp pond: tough decisions in rural Thailand. *World Development* 27(12), 2045–2060.

Hoanh, C.T., Tuong, T.P., Kam, S.P., Phong, N.D., Ngoc, N.V. and. Lehmann, E. (2001) Using GIS-linked hydraulic model for managing water quality conflict for shrimp and rice production in the Mekong River Delta, Vietnam. In: Ghassemi, F., Post, D., Sivapalan, M. and Vertessy, R. (eds) *Proceedings of MODSIM 2001*, International Congress on Modelling and Simulation, Canberra, Australia, 10–13 December 2001. Volume 1: *Natural Systems (Part One)*, pp. 221–226.

Hoanh, C.T., Tuong, T.P., Gallop, K.M., Gowing, J.W., Kam, S.P., Khiem, N.T. and Phong, N.D. (2003) Livelihood impacts of water policy change: evidence from a coastal area of the Mekong River delta. *Water Policy* 5, 475–488.

Hori, H. (2000) *The Mekong: its Development and Environment.* United Nations University Press, Tokyo and New York.

Klepper, O., Hatta, G. and Chairuddin, G. (1990) Environmental impacts of the reclamation of acid sulphate soils in Indonesia. *IARD Journal* 12(2), 29–34.

Lebel, L., Tri, N.H. and Saengnoree, A. (2002) Industrial transformation and shrimp aquaculture in Thailand and Vietnam: pathways to ecological, social and economic sustainability? *Ambio* 31(4), 311–323.

Minh, L.Q., Tuong, T.P., van Mensvoort, M.E.F. and Bouma, J. (1997a) Tillage and water management for riceland productivity in acid sulfate soils of the Mekong delta, Vietnam. *Soil and Tillage Research* 42(1), 1–14.

Minh, L.Q., Tuong, T.P., van Mensvoort, M.E.F and Bouma, J. (1997b) Contamination of surface water as affected by land use in acid sulfate soils in the Mekong delta, Vietnam. *Agriculture, Ecosystems and Environment* 61(1), 16–27.

Phillips, M.J., Lin, C.K. and Beveridge, M. (1993) Shrimp culture and the environment: lessons from the world's most rapidly expanding warmwater aquaculture sector. In: Pullin R.S.V., Rosenthal, H. and Maclean, J.L. (eds) *Environment and Aquaculture in Developing Countries*. ICLARM, Manila, Philippines, pp. 171–197.

Phong, N.D., My, V., Nang, N.D., Tuong. T.P., Phuoc. T.N. and Trung. N.H. (2003) Salinity dynamics and its implication on cropping patterns and rice performance in shrimp–rice system in My Xuyen and Gia Rai. In: Preston, N. and Clayton, H. (eds) *Rice–Shrimp Farming in the Mekong Delta: Biological and Socioeconomic Issues*. ACIAR Technical Reports No. 52e, pp. 70–88.

Primavera, J.H. (1998) Tropical shrimp farming and its sustainability. In: De Silva, S.S. (ed.) *Tropical Mariculture.* Academic Press, London, pp. 257–289.

Sammut, J., White, I. and Melville, M.D. (1996) Acidification of an estuarine tributary in Eastern Australia due to drainage of acid sulfate soils. *Marine & Freshwater Research* 47, 669–684.

Shanahan, M., Thornton, C., Trent, S. and Williams, J. (2003) *Risky Business: Vietnamese Shrimp Aquaculture Impacts and Investments.* Environmental Justice Foundation, London, 42 pp.

Tran, T.B., Dung, L.C. and Brennan, D.C. (1999) Environmental costs of shrimp culture in rice growing regions of the Mekong Delta. *Aquaculture Economics and Management* 3, 31–43.

Tuong, T.P., Minh, L.Q., Ni, D.V. and van Mensvoort, M.E.F. (1998) Reducing acid pollution from reclaimed acid sulphate soils: experiences from the Mekong delta, Vietnam. In: Pereira, L.S. and Gowing, J.W. (eds) *Water and the Environment: Innovation Issues in Irrigation and Drainage.* E. & F.N. Spon, London, pp. 75–83.

Tuong T.P., Kam, S.P., Hoanh, C.T., Dung, L.C., Khiem, N.T., Barr, J.J.F. and Ben, D.C. (2003) Impact of seawater intrusion control on environment, land use strategies and household incomes in a coastal area. *Paddy and Water Environment* 1, 65–73.

UN (United Nations) (2002) *Report of the World Summit on Sustainable Development*. United Nations, New York, 173 pp.

White, I., Melville, M.D. and Sammut, J. (1996) Possible impacts of saline water intrusion floodgates in Vietnam's lower Mekong delta. In: Weizel, V. (ed.) *Proceedings of Seminar on Environment and Development in Vietnam*, Australian National University, Canberra. 6–7 December, 1996. Available at <http://coombs.anu.edu.au/~vern/env_dev/papers/PAP07.DOC>

Wilson, B.P., White, I. and Melville, M.D. (1999) Floodplain hydrology, acid discharge and change in water quality associated with a drained acid sulfate soil. *Marine and Freshwater Research* 50, 149–157.