Estimating the Value of Improvements in Environmental Quality Due to Changes in Sluice Gate Operations in Bac Lieu Province, Vietnam

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A Report submitted to the

Standing Panel on Impact Assessment of the CGIAR

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Executive Summary

Rice farming and shrimp production drive the economy of the lower Mekong Delta in Vietnam. In areas with good soils, and water of appropriate quality, these activities enhance food security and generate substantial income for landowners and laborers. However the issue of water quality has complicated efforts to expand rice farming and shrimp production in the region, as rice farmers require low-salinity water, while shrimp producers need brackish water.

The salinity of water in the streams and channels that form the Delta's irrigation and transportation network is influenced by the discharge of fresh water from the Mekong River and tidal influences from the East and West Seas. In the early 1990s, in an effort to boost rice production, the Bac Lieu provincial government began building sluices to regulate the inflow of saline water during the dry season. Over time, with the increasing price of shrimp, many shrimp producers advocated removing the sluices to allow more brackish water into the region's waterways. The provincial government asked a group of international researchers to assist in designing a sluice operation plan that would enable rice farmers and shrimp producers to receive water with the desired levels of salinity in designated portions of the Delta.

Results of hydrological analysis were combined with an understanding of the region's soils, in developing a revised management plan for the sluices. The eastern portion of the region was designated for fresh water rice production, while the western portion was designated for brackish water shrimp production. The center portion would become a zone of mixed fresh water and brackish water, in which a combination of rice farming and shrimp production would be possible. The new management plan and the corresponding zonal designations were well received by rice farmers and shrimp producers.

In addition to enabling greater production of rice and shrimp in the region, the revised management plan likely impacted the flora and fauna that are found within and near the region's waterways. Many residents obtain value from the flora and fauna, either directly through household consumption, or indirectly through the amenities they receive without consumption. In both cases, the values are not described by market prices or revealed in monetary transactions. Yet the values might be substantial, and they might be helpful in justifying the cost of implementing the revised sluice management program.

We have endeavored in this study to estimate the non-market values that might be attributed to changes in the sluice gate operations. Such an effort is somewhat challenging in a region in which most residents have not thought previously about assigning monetary values to the amenities they receive from natural resources. In addition, it is challenging to estimate the impacts of such a policy intervention after it has been implemented, and absent an *a priori* design for gathering information ideally suited for such a study.

A secondary goal of our study is to determine the changes in non-market values that might have been generated as a result of the International Water Management Institute's (IWMI) involvement in the project to design an alternative sluice management program. That objective also is somewhat challenging, as IWMI was not the only organization involved in the project.

Scientists from other international research centers and national organizations also participated. In addition, from a technical perspective, the change in sluice gate operations was not the only change underway in the region. Shrimp production was increasing over time, and expanding into areas with acid sulfate soils that require special treatment to enable and sustain productivity. The increased use of lime by shrimp producers to control acidity likely impacted water quality in some portions of the Delta. We note also the difficulty of separating the possibly continuing impacts on flora and fauna due to sluice gate construction in the late 1990s, from the impacts of changes in sluice gate operations.

While acknowledging the challenges of estimating and attributing the changes in non-market values due to revising the sluice gate operations, we think it is helpful to examine those values, and to consider them as upper bound estimates of the actual, attributable project benefits. We find, for example, that the average willingness to pay for continuation of sluice gate operations, expressed by survey participants in three villages, ranges from $39 to $73 per household per year. The average proportions of those estimates attributable to changes in flora and fauna range from 12% to 18% in the three villages. Applying these proportions, the estimated willingness to pay for changes in flora and fauna range from about $6 to $10 per household per year, or from 0.3% to 0.4% of annual household income.

While estimating non-market values is not an exact science, particularly in areas where it is difficult to determine precisely how a policy action influences environmental quality, we view our results as plausible. Households obtain value from several species of flora and fauna in the region, while some species reduce yields or raise the cost of rice production. The net value obtained from the changes in flora and fauna will reflect a blending of benefits and costs.

We calculate the aggregate value of the environmental improvement by multiplying our estimates of non-market values per household by the numbers of household in each of our sample villages. There are about 2,000 households in each village, and the estimated average annual willingness to pay for continued sluice gate operations is $8.31 per household. Hence the residents in the three villages might be willing to contribute almost $50,000 per year to continue receiving the non-market values they obtain through beneficial changes in flora and fauna. Residents in other villages in the region likely obtain non-market benefits, also, such that the full non-market value might be closer to $200,000 per year.

This value likely exceeds the incremental cost of closing and opening the gates according to the modified schedule developed by IWMI researchers and their partners. The large cost of constructing the gates is not pertinent in our analysis, because the gates were already in place when the research began. The market and non-market values generated by modifying gate operations need only to offset the incremental costs of opening and closing the gates according to a different schedule.

In sum, we conclude that the sluice gate operation program has been successful in allowing rice and shrimp farmers to conduct their activities in a coordinated fashion, and also in generating non-market values for households that benefit from observed changes in the abundance of several flora and fauna species. The attribution of these benefits can be shared by IWMI, other international research centers, and national organizations.

1. Background

Rice and shrimp production are major sources of economic activity that create exportable goods and generate foreign exchange, while also sustaining the livelihoods of many residents in Vietnam's Mekong Delta. Production of rice and shrimp has increased substantially in the region in recent years. Rice production has increased from about 12.5 million tons in 1995 to 19.2 million tons in 2005, while farmed shrimp production has increased from 47,000 tons to 270,000 tons during the same period (Sakamoto *et al*., 2009). Today about 80% of the rice exported from Vietnam and 80% of the country's farmed shrimp are produced in the Mekong Delta.

The rapid development of rice and shrimp production has generated competition for limited land and water resources, and created conflict regarding water quality. Rice producers require fresh water supplies from the Mekong River and non-saline soils to achieve desirable yields and sustain productivity over time. Shrimp producers require saline water inflow from the South China Sea to provide the level of salinity needed in their ponds (Hoanh *et al*., 2009). They must also discharge low-quality water from their ponds when production cycles are complete. The salinity of water in the Delta varies in the dry and wet seasons as a function of rainfall and of the volume of water flowing southward in the Mekong River.

The focus of our study is Vietnam's Bac Lieu province on the Ca Mau Peninsula (Fig. 1), which is the southern tip of the Mekong Delta. In an effort to stimulate dry season rice production in the region, the Vietnamese government installed ten water control sluices during 1994 through 2000 (Hoanh *et al*., 2003) to prevent the inflow of saline water during periods of low flow in the Mekong River. The program has enabled many rice farmers to produce three crops of rice per year, but it has reduced the supply of saline water available to shrimp producers.

During the time that sluices were being installed to promote rice production, the international price of rice fell sharply, while the local and export prices of tiger shrimp rose substantially. These changes in relative prices motivated farmers to expand their production of shrimp in semi-intensive and intensive aquaculture operations (Hoanh *et al*., 2003). This development created a notable conflict between rice farmers and shrimp farmers regarding the operation of sluices to control the inflow of saline water. Shrimp farmers prefer water with salinity of 10 dS m^{-1} or greater, while the upper limit of salinity for successful rice production is 7 dS m^{-1} (Hoanh *et al*., 2003).

Soils in the eastern portion of Bac Lieu province are largely alluvial and non-acidic (Fig. 1), while shallow and deep acid sulfate soils characterize the western portion (Gowing *et al*., 2006). The central portion of the province has a mixture of alluvial and acidic soils. The alluvial soils, covering about half of the provincial area, are well suited for rice or shrimp production, provided that water of the desired salinity level is available. The acid sulfate soils, covering the other half of the provincial area, are not suitable for rice production, but can be used for shrimp production, provided that shrimp farmers apply lime to maintain acidity within an acceptable range.

The effort to support more intensive rice production in Bac Lieu province by operating sluice gates to control saline water inflows, and the unexpected expansion of shrimp production, likely contributed to an increase in acidity in local waterways. The underlying sources of the increased acidity are the acid-sulfate soils found largely in the western and central portions of the lower Mekong Delta. When those soils are disturbed in ways that allow oxidation to occur, sulfuric acid is produced and large amounts of iron and aluminum are mobilized (Minh *et al*., 1997; Thomas *et al*., 2003; Kawahigashi *et al*., 2008). When the oxidized soils are then leached by rainfall or canal water, the acid and the toxic iron and aluminum enter local waterways, with potentially harmful impacts on fish.

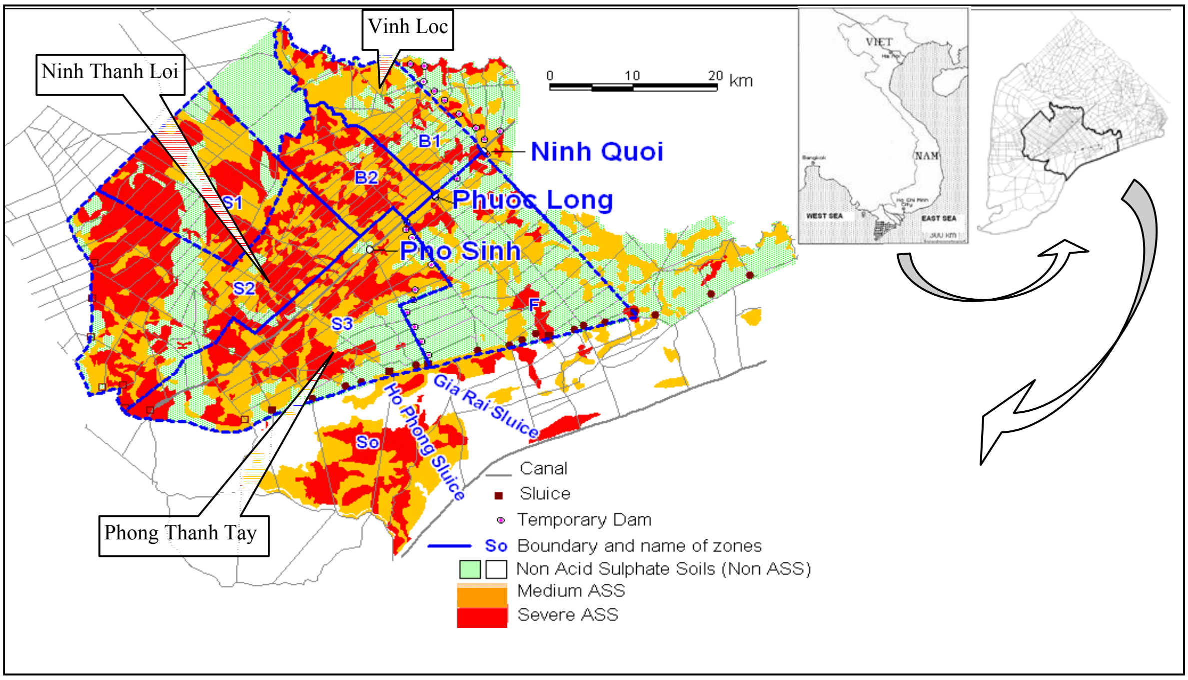

Figure 1. The study area with its soil types and dense canal network

At the field and farm level, there are two ways in which the acid-sulfate soils are exposed to oxidation conditions in the lower Mekong Delta (Tuong *et al*., 2003): (i) restricting tidal inflows by operating the sluices to optimize rice production lowers the water table, thus allowing increased oxidation of acid sulfate soils; and (ii) when shrimp farmers convert low-lying lands in the region with acid sulfate soils, they pile soil material (from the sulfidic and pyretic sub-horizons) on the new shrimp field embankments. Acidity develops when these materials oxidize upon exposure and drying.

At the water system control level, canal excavation and dredging disturb acid sulfate soils and bring sulfuric and sulfidic materials to the surface of canal embankments. Acidity develops upon oxidation and drying. Surface runoff and seepage flow across canal embankments are the primary sources of acid pollution in areas with acid sulfate soils (Phong, 2009).

The amount of acidity in surface runoff and seepage from canal and shrimp field embankments varies with the characteristics of the acid sulfate soils, the time that has elapsed since dredging or excavation, and with rainfall patterns. Severely acidic soils and those that have been disturbed most recently generate more acidity than moderately acid soils or those that were disturbed several years ago. Generally, surface runoff and seepage with the highest acidity are observed within two to three years after dredging or excavation. In addition the acidity in seepage gradually decreases over time as canal embankments become compacted with vehicle traffic and as shrimp field embankments become saturated as farmers attempt to minimize water loss from their shrimp fields (Phong, 2009).

In all cases, the oxidation occurs primarily in the dry season, while the increase in acidity is noticed at the beginning of the wet season, when rainfall moves the iron and aluminum into local waterways. Shrimp farmers control acidity in their ponds by applying lime. Yet the increased acidity in local waterways can be harmful to fish and can reduce aquatic biodiversity. The primary source of increased acidity in Bac Lieu province is the leaching of shrimp pond embankments in the western portion of the province (Tuong *et al*. 2003).

In 2001, the conflict between rice farmers and shrimp producers regarding the impacts of sluice gate operations on the salinity of their water supplies reached a level that motivated government intervention (Hoanh *et al*., 2003). A request was made for advice on operating the sluice gates to maintain freshwater in some portions of Bac Lieu province and saline water in other portions. The goal was to accommodate the needs of both rice farmers and shrimp producers. In collaboration with the national planning agencies researchers from the International Water Management Institute (IWMI) and other CGIAR centers analyzed alternative sluice operation programs and generated recommendations that were adopted by local authorities. Sluice gate operations were modified in accordance with those recommendations from 2001 onward (Hoanh *et al*., 2003). The research that generated the recommendations was supported, in part, by the U.K. Department for International Development. Subsequent research, conducted while the program was being implemented, was supported by the CGIAR Comprehensive Assessment of Water Management in Agriculture (Molden, 2007) and the Projects PN 10 and PN 25 of the Challenge Program on Water and Food (Dung *et al*., 2009).

Modifying the sluice gate operations to manage the inflow of saline water into the lower Mekong Delta has altered the acidity profile in the region by changing the volume and quality of water in the canal system and by influencing production decisions at the farm and field level:

1. At the field and farm level

a. Allowing additional saline water in the region provided suitable conditions for converting fallow lands in the acid sulfate soils area into shrimp fields. Those conditions, in addition to the high market price of shrimp, encouraged farmers to construct new shrimp fields. The farmers compacted their shrimp field embankments and applied lime to neutralize acidity in the water. Later, through informal community agreements, they minimized the leaching of acid into the canal system to prevent damage to neighboring shrimp fields.

b. The modified sluice gate operations allowed a higher tidal water level in the region, thus supporting higher groundwater levels and higher surface water levels in farm fields. These conditions minimized the oxidation of pyrites and limited the movement of jarosites from deep soil layers to the surface via capillary action.

2. At the water system control level

a. The higher tidal water level limited the movement of acidic water from the area with acid sulfate soils (in the western portion of the province) to production areas in the eastern and southern portions.

b. In addition to the dilution effect of fresh water, the higher inflows of saline water increased the water pH, through its buffering capacity (Phong, 2009).

The revised procedures for operating the sluice gates have been successful in supporting both rice farming and shrimp production. Rice yields increased in three of four intervention zones in the Bac Lieu province between 2000 and 2006 (Khiem and Hossain, 2010). Shrimp yields increased in two of three intervention zones between 2000 and 2003, while declining somewhat in those zones in 2006. Livelihoods improved in all four intervention zones between 2000 and 2006, due partly to higher revenues earned in rice and shrimp production and from the sale of livestock. Shrimp production became an important source of income for many farm households with the re-introduction of saline water in some zones (Can *et al*., 2010).

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2. Objectives

Our primary goal in this study is to estimate the non-market value of improvements in water quality made possible by changing the sluice gate operations to support shrimp and rice production in Bac Lieu Province. We focus on changes in flora and fauna that provide benefits to households in the region. Some species of plants and animals have increased in abundance with the changes in water quality, while others have declined. We interview household members to determine the net effects of changes in flora and fauna from their perspective. We inquire also about how much the households would be willing to pay to ensure that the modified sluice gate operations are continued. We ask households also to describe the portion of that value they would attribute to changes in flora and fauna, rather than improvements in rice and shrimp production.

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3. Modeling the effects of changes in sluice gate operations on salinity and acidity

3.1. Hydrological characteristics and water quality issues in the study region

The Ca Mau peninsula is a largely flat, deltaic region, with elevation less than 1.5 m. Two seasons are distinguished in the peninsula: the rainy (or wet) season from May to mid-November, and the dry season from mid-November to April. About 90% of the annual rainfall (1,800 mm) is received in the rainy season. During the dry season, fresh water availability for irrigation is a major constraint to rice production. The solar radiation available for photosynthesis is more abundant during the dry season, such that rice yields in the dry season generally are higher than in the wet season, provided that sufficient water is available.

Hydrology in the peninsula is governed by the flow of the Mekong River and tidal influence from the East and West Seas. The average flow in the Mekong River is about 14,000 $m^3 s^{-1}$, arising largely from runoff during the monsoonal rainfall season, over a large basin (approximately 795,000 km^2). The seasonal distribution pattern includes a flood season from June to December, with a peak in September, and a low flow season from January to May, with the lowest average discharge in April (2,340 $m^3 s^{-1}$). During the 1900s, many canals were constructed on the peninsula to provide transport routes and support irrigation systems. The canals intersect and connect with the natural rivers (Fig. 1), thus providing many routes for both fresh water supply and drainage. The canals also allow salt-water intrusion throughout the peninsula. From January through June, much of the water in most canals is too saline for use in agriculture.

The hydrologic characteristics of the East and West Seas (known also as the South China Sea and the Gulf of Thailand) are notably different, in terms of tidal amplitude (3.0 m v. 0.7 m), highest tide level (1.6 m v. 1.0 m), and salinity (50 dS/m v. 39 dS/m) at the main river mouths. During the dry season, the difference in tidal regimes drives the flow of water from the East Sea to the West Sea, across the region (Fig. 1). During the early part of the rainy season, the acidity of water in the canals declines from normal values (pH about 6 to 7) to a pH less than 4, under the influence of acidic water flushed from the acid sulfate soils.

The peninsula is a highly modified environment. While soil type is a primary determinant of viable agricultural production systems, water conditions are critical in selecting profitable cropping calendars. Key conditions include water availability, represented by water levels in the canals, and water salinity and acidity. Rice and shrimp production currently are the primary agricultural activities on the Ca Mau peninsula. Rice production has increased from 0.8 million tonnes per year in 1990 to 1.3 million tonnes in 2000. Shrimp aquaculture and fishery production in the region involve three primary activities: the raising of brackish water shrimp (the most important economic product) and fresh water prawns, and the raising and capture of fish. Many farmers engage in a mixed agriculture-aquaculture production system, in which shrimp and rice are produced in rotation. Many farmers raise shrimp in ditches placed around rice fields, while others strengthen the field bunds after the rice harvest to raise shrimp in the flooded basins.

Salt-water intrusion from the East and West Seas occurs through four primary rivers: the My Thanh, Ganh Hao, Cai Lon, and Ong Doc. The movement of salt into the region renders water quality unsuitable for irrigation on most portions of the Ca Mau peninsula during January through June. Successful development of agriculture in the region could not have occurred without protection from salt-water intrusion, especially from the East Sea, via the My Thanh and Ganh Hao Rivers (Sonntag & McNamee, 1989). A water control system was developed in three phases: 1) the planning phase (1989–1991), 2) the feasibility analysis phase (1991–1992), and 3) the implementation phase (1993 to present).

Given their different production requirements pertaining to salinity, rice and shrimp producers have long expressed differing viewpoints regarding coordinated efforts to manage water quality on the Ca Mau peninsula. By 2001, the conflict between rice and shrimp producers had become so acute that public officials modified their policy of emphasizing rice production (Hoanh et al., 2003). The provincial government essentially implemented a zoning program in which officials declared some portions of the peninsula as suitable for shrimp production, some portions suitable for rice production, and other portions suitable for either activity (Fig. 1).

The separation of proposed land uses matches closely the distribution of saline and fresh water in the region. Shrimp cultivation is promoted in the saline water area in the western portion of the peninsula (Zones S1, S2, and S3), while paddy rice upland rice systems are supported in the fresh water area of the eastern portion (Zone F). The combination of shrimp and rice production is promoted in the buffer zones between the western and eastern portions (Table 1).

Table 1. Zoning by water conditions and land uses on the Ca Mau Peninsula

Zone	Location	Soil types	Water conditions	Land use
F	Near the East Sea, but protected from salinity intrusion	No acid sulfate soils	Fresh water	Agriculture: rice and upland crops
B1	Far from both the East and West Seas	Slightly acid sulfate soils	Buffer zone: low salinity – low acidity	Rice and shrimp-rice
B2	Far from both the East and West Seas	Medium to severe acid sulfate soils	Buffer zone: low salinity – medium acidity	Rice and shrimp-rice
S1	Far from the East Sea, but near West Sea	Severe acid sulfate soils	Saline zone: high salinity and high acidity	Mostly shrimp cultivation
S2	Between the East and West Seas	Severe to medium acid sulfate soils	Saline zone: high salinity – high acidity	Mostly shrimp cultivation, with some rice plots
S3	Adjacent to the Ho Phong and Gia Rai sluices at the East Sea	Severe to medium acid sulfate soils	Saline zone: high salinity – low acidity	Shrimp cultivation, with rice plots near zone F
So	Near the East Sea	Largely no acid sulfate soils, with some plots of acid sulfate soils	Saline zone: high salinity – some plots with low acidity	Shrimp with some rice plots

The management of saline and fresh water on the peninsula is accomplished by operating a system of 12 large sluices, and many small ones, constructed along national Highway No. 1, which runs along the eastern edge of the study area (Fig. 1). Several temporary dams also are included in the set of investments made to manage water in the region. The two largest sluices have three gates through which water can pass or be blocked. The Ho Phong (HP) sluice is 24 m wide, while the Gia Rai (GR) sluice is 22.5 m wide. Fresh water for rice and upland crops in the northeastern zone of the study area is diverted from the Mekong River and delivered through the main canal (QLPH).

3.2. The effects of changes in sluice gate operations on salinity and acidity

Fig. 2 depicts measurements of acidity and salinity at several stations that comprise a network for monitoring water quality on the Ca Mau peninsula. The data, which were collected during 1999 through 2006, describe acidity and salinity conditions during the dry and rainy seasons, before and after 2001.

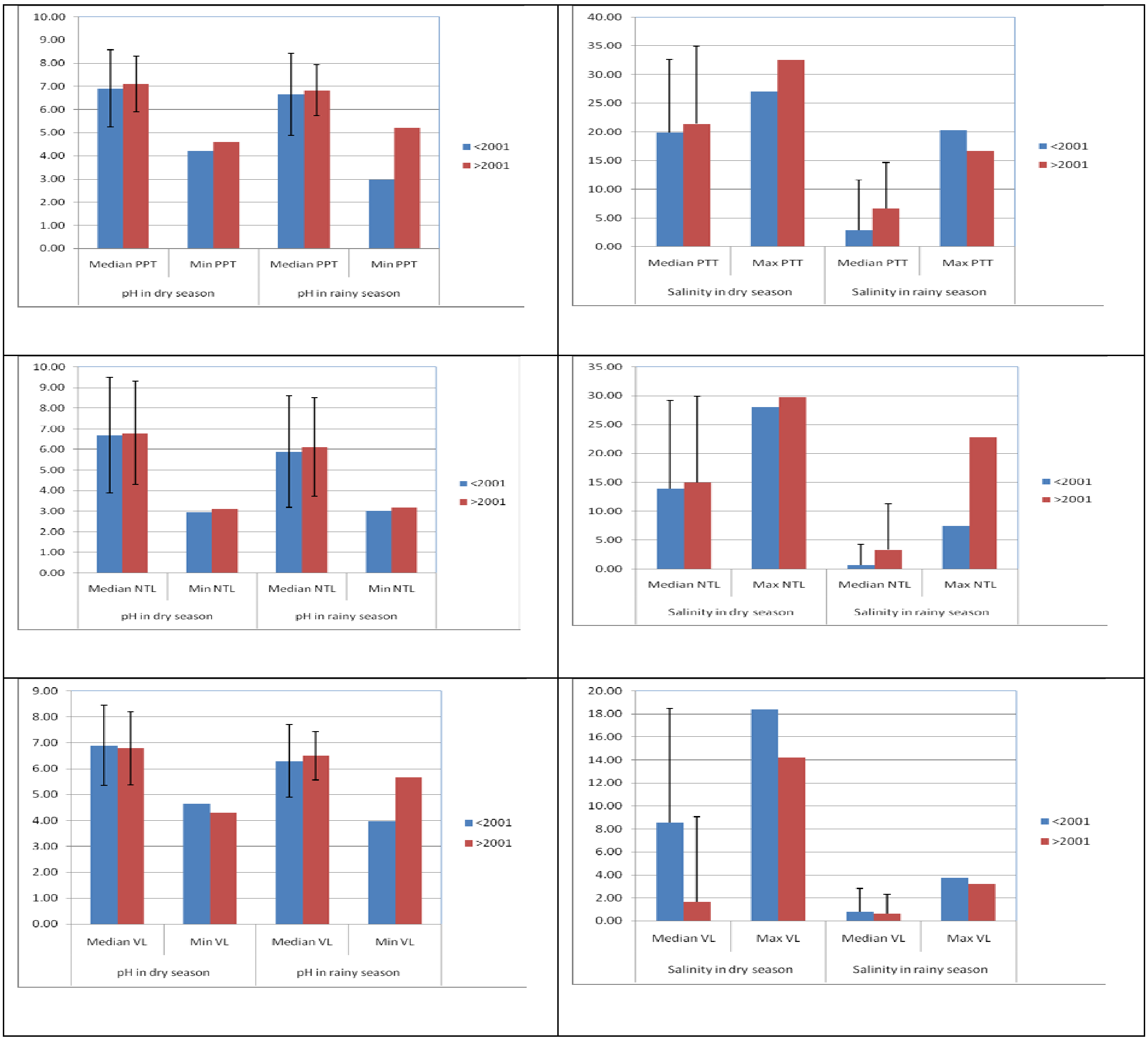

Figure 2. The averages of measured pH (left) and salinity (right, in g/l) in the dry season (Jan. to June) and in the rainy season (July to Dec.) at Phong Thanh Tay (PTT), Ninh Thanh Loi (NTL) and Vinh Loc (VL).

Notes:
- Data were collected during 1999 through 2006.
- The blue bars indicate the averages of pH or salinity before 2001, while the red bars indicate the average values during and after 2001.

Comparison of the measured acidity (pH) and salinity before and after 2001 (Fig. 2) suggests that:

- Salinity declines with increasing distance from the HP and GR sluices. Salinity is highest at PTT, medium at NTL and lowest at VL.

- The effect of “sluice opening” from 2001 is shown clearly by the salinity increase at locations in the study area near the HP and GR sluices, particularly during the rainy season. At locations further from the sluices, the effects on salinity are unclear (VL).

- The salinity of canal water causes higher acidity (lower pH) in the dry season than in the rainy season (Phong, 2009).

- There is no significant difference in acidity during the dry season, before and after 2001. However, the average value of the minimum pH during the rainy season has increased since 2001, when officials began operating the sluices to allow the inflow of saline water.

- There is a significant difference between the minimum pH at NTL and the other two sites, due to the impacts of acid sulfate soils and the low volumes of canal water at NTL.

- The strong influence of sea water flowing into the study area through the sluices gates along the East Sea is reflected in the large differences between the maximum and median salinity, and the notable variation in salinity at all three sites.

3.3. Operating the sluice gates also for acidity control

Salinity control was the primary objective of the sluice operators during the early years of the program to manage saline water intake. Managing salinity was a challenge for both the operators and many farmers, who were not familiar with the new water regime. The water monitoring network was expanded in 2003 by increasing the density of stations. From 2005, the sluices have been operating smoothly and farmers have adapted their cropping systems to the new salinity regime. Having achieved successful salinity management, provincial authorities then turned to the challenge of controlling acidity. The goal of sluice gate operations was expanded to include the control of both acidity and salinity.

With the expanded mandate of controlling both acidity and salinity, came the need for better analytical tools to simulate the impacts of sluice gate operations. Lacking the detailed observations needed to describe those impacts for a range of operational decisions, a model was needed to simulate the likely impacts of alternative strategies on water quality conditions. The Vietnam River Systems and Plains model (VRSAP), which includes a scheme of the entire Ca Mau Peninsula was developed at the Sub-Institute for Water Resources Planning (SIWRP, former name of the Southern Institute for Water Resources Planning), Vietnam, to simulate hydrologic conditions in the Mekong Delta for selected water management scenarios (Khue, 1986). That work was part of the salinity intrusion studies funded by the Australian Government, through the Interim Mekong River Committee.

The VRSAP model was developed with high technical standards (Halcrow, 2001), and has been used in many studies (ESSA et al., 1992; NEDECO, 1992; Dong, 2000; KOICA & KARICO, 2000). VRSAP is a numerical model using Saint-Venant equations to solve flow and mass transport problems in a complex network of interconnecting open channels. The model applies the concepts of advection and dispersion (Harleman, 1971), and uses the implicit finite difference scheme (Delft Hydraulics, 1989; Jin & Fread, 1997) to compute water levels, salinity, and acidity for each node and field. The model also calculates the discharge for each segment.

Water interchange between segments and the land area is simulated within VRSAP by defining parcels of land (fields) bounded by channel segments, and by indicating the nature of flow between them, either controlled or uncontrolled by structures. A sluice, as a structure, can be operated in various ways, including: 1) completely closed, 2) opened partially to allow one direction of flow, or 3) opened fully to allow both in-flows and out-flows.

The VRSAP model was enhanced by including new options that enable the simulation of sluice gate operations, with particular emphasis on the movement of saline water through the peninsula, and the pumping of water from canals for shrimp production. A new acidity module was developed by Phong (2009) to simulate acid propagation and estimate acidity loads in the canal network. The module was calibrated using acidity data obtained from the water quality monitoring network for 2003, and verified with data for 2005.

We have used the enhanced VRSAP model to examine water management options for matching the salinity requirements in different land use zones, while minimizing acidity impacts in the study area. In particular, we have examined salinity and acidity variations in the canal network during the dry season and at the beginning of rainy season in each of two scenarios:

Scenario A: Closing all three sluices, and

Scenario B: Operating the Ho Phong (HP) and Gia Rai (GR) sluices to control salinity and acidity.

In scenario A, saline water from the East Sea is taken into the study area during the dry season (December to May) by operating the HP and GR sluices for intake of saline water on the first four days of each month, as in 2003. The sluices are closed in June, which marks the beginning of the rainy season, when acidic water would normally drain away from the area with acid sulfate soils. As shown in Figure 3, the acid propagation in this scenario causes a slight reduction of acidity with the inflow of highly saline water from the East Sea, while a large area of severe acidity (water pH < 5) spreads into the fresh water area (zone F) and in the western portion of the study area (zones S1, B1 and B2). Two small areas of severe acidity appear also in zone S3 and zone S2, downstream of QLPH. Elsewhere, water quality is improved, as indicated by pH values greater than 5.5.

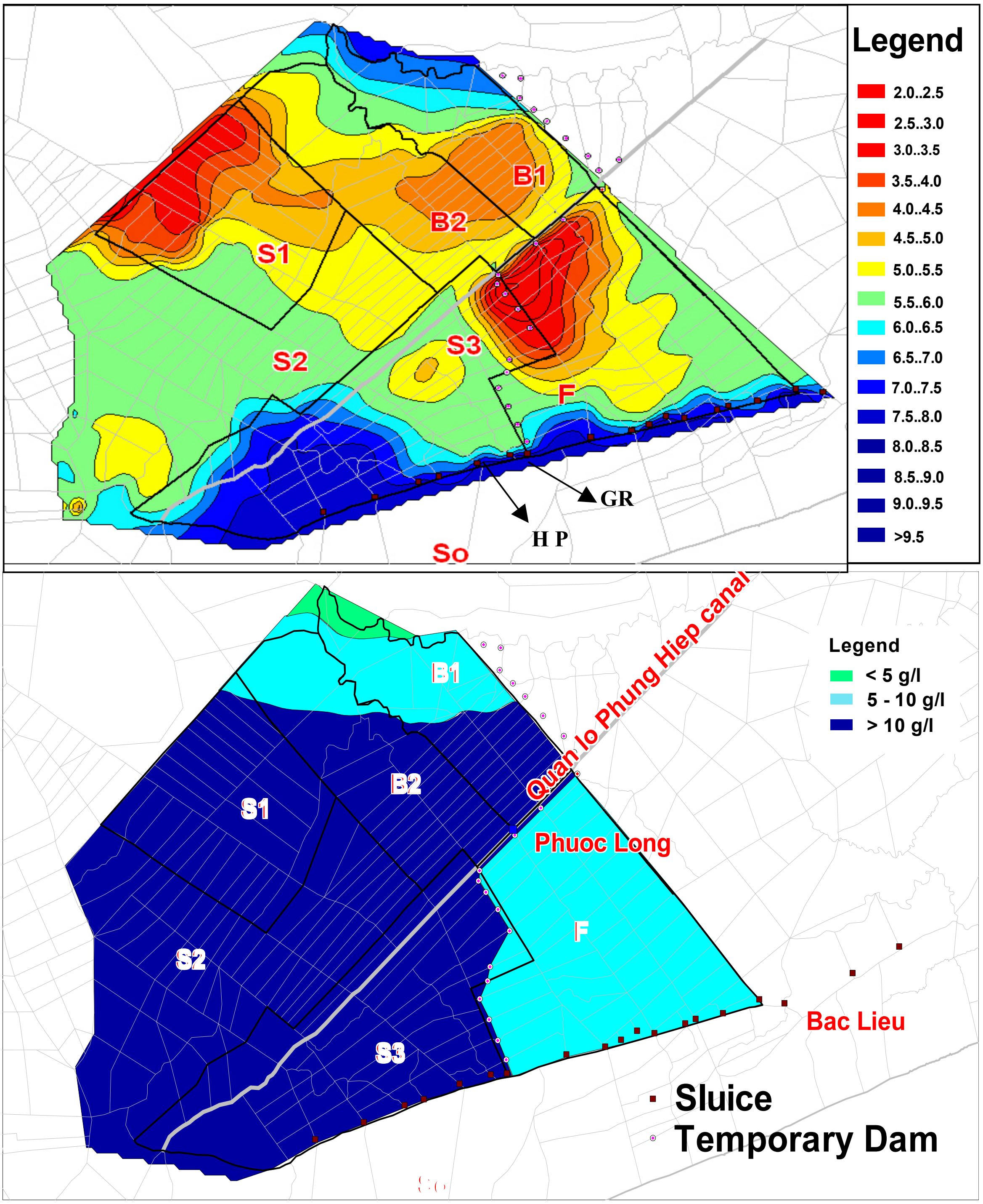

Figure 3. Simulation of water acidity (pH) and salinity on 30 June 2003, under Scenario A, in which the Ho Phong and Gia Rai sluices are closed in June

In Scenario B, the HP and GR sluices are opened for intake of saline water on the first four days of each month during the dry season (December through May), and also in June. This allows more saline water into the study area, thus creating a larger area with low acidity (Figure 5). Compared to Scenario A, lower acidity canal water (pH > 7) expands into a larger area around the QLPH canal, including zones S2, S3, and portions of zones S1, B1 and B2. In Scenario B, a larger volume of saline water is stored in the study area, with the buffering effect of reducing acidity and maintaining the water pH at a high level for about two weeks, until the next intake of saline water.

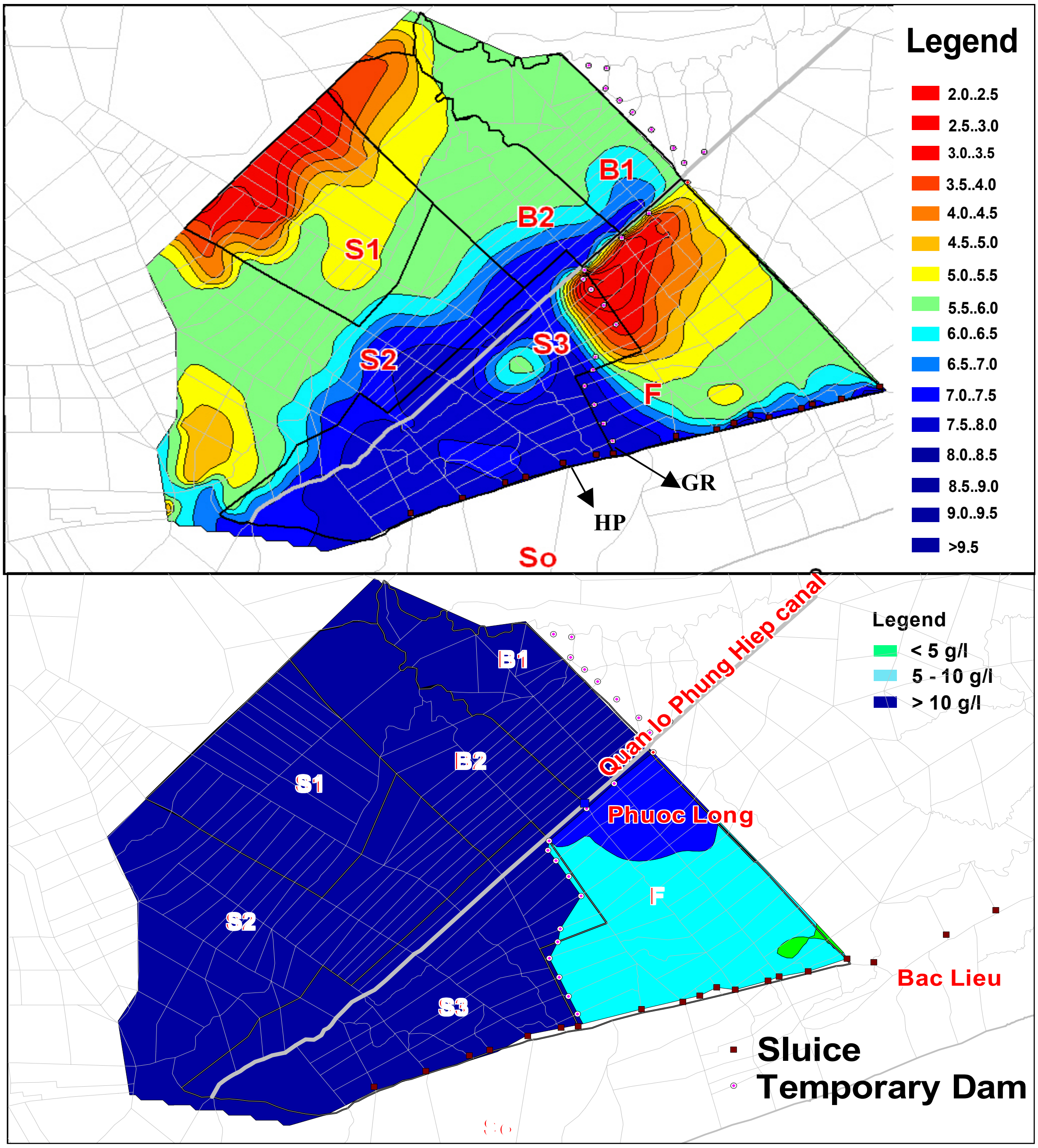

Figure 4. Simulation of water pH on 30 June 2003, under Scenario B, in which the Ho Phong and Gia Rai sluices are operated in June.

However, when saline water is taken in continuously for four days in June, the tidal influence from the East Sea pushes the saline water deeper into the QLPH canal, thus allowing salinity to intrude deeper into the fresh water zone (Figure 4 and Table 2). Regarding acidity control, although the area with acidic water (pH < 5) in zone S1 is smaller, some of this water could be pushed to zones B1 and B2, and the surrounding provinces on the northwest side of the Bac Lieu peninsula.

Table 2. Areas of saline water intrusion in two scenarios, A: The HP and GR sluices are closed in June, and B: The HP and GR sluices are opened in June

	Scenario A		Scenario B	
Salinity level (g/l)	Area (ha)	Proportion of area (%)	Area (ha)	Proportion of area (%)
< 5	2,578	1.0	600	0.5
5 -10	56,425	26.0	33,150	15.0
> 10	161,147	73.0	186,400	84.5
Acidity (pH)	Area (ha)	Proportion of area (%)	Area (ha)	Proportion of area (%)
< 5	41,650	18.9	38,500	17.5
5- 7	157,000	71.3	126,500	57.5
> 7	21,500	9.8	55,150	25.1
Total area (ha)	220,150			

In summary, operating the HP and GR sluices in June reduces the acidity of canal water in the study area. Model results show also that more frequent intake of saline water is more effective in improving the acidity condition, due to the increase of alkalinity in the canal water. However, the analysis reveals also a trade-off in water quality management – moving acidity out of the study area might degrade water quality on the West Sea side of the Ca Mau peninsula.

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4. Estimating Environmental Values in a Survey of Residents

Given the primary goal of our study – to estimate the non-market value of improvements in environmental quality – we endeavored first to determine how changes in sluice gate operations might impact flora and fauna in selected areas of the Ca Mau peninsula. If plants and animals in the region provide amenity values to residents, and if sluice gate operations modify water quality in ways that influence the health or abundance of some species, then sluice gate operations might impact the values that residents obtain. The impacts might be positive for some species and negative for others, and some impacts might be very challenging to quantify. However, it seemed reasonable to embark upon a path of inquiry that focuses on impacts involving flora and fauna. This approach enabled us to engage residents in discussions of non-market values in a way that made sense to them, given their notable knowledge of flora and fauna in the region.

4.1. Participatory Rapid Appraisal

Prior to developing a survey instrument to assess environmental values, we met with many villagers, and with rice and shrimp farmers in the region, to gain insight regarding which species of flora and fauna we should include in our analysis. We also conducted a participatory rapid appraisal involving households in our three study areas, Phong Thanh Tay (PTT) in zone S3, Ninh Thanh Loi (NTL) in zone S2, and Vinh Loc (VL) in zone B1 (Figure 5).

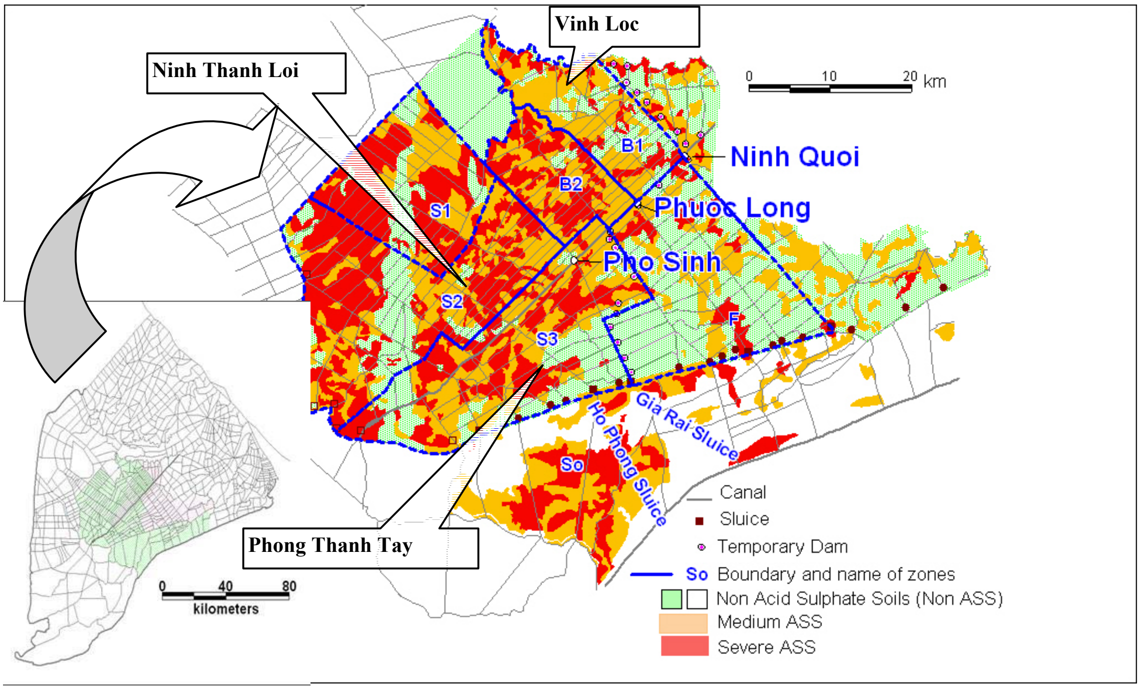

Figure 5. The study area with its dense canal network and soil types

Each PRA session involved from 5 to 11 families (Table 3). We asked the residents to list the species they consider to be most important, and to describe any changes they have observed in the salinity or acidity of soil and water resources during the previous ten years. We sought also their insight and guidance regarding the best method for asking residents about the monetary value of changes in the condition of flora and fauna over time. The PRA sessions were constructive and quite helpful. Many residents understood our interest in water quality conditions in the region and they appreciated the opportunity to assist in the research process.

Table 3. Locations and Characteristics of the Participatory Rapid Appraisal

Locations	Characteristics	Participants
Hamlet 2 Phong Thanh Tay (PTT)	Medium soil acidity, high salinity intake, and high flow in canal	Eleven persons attended, including one vice chairman of the village people's committee and one hamlet leader
Chu Chot Ninh Thanh Loi village (NTL)	High acidity, high salinity, with low flow in canals	Five people attended, including one fishery engineer and one hamlet leader
Vinh Thanh Vinh Loc village (VL)	Less acidity and less salinity in canals	Ten people attended, including one hamlet leader

4.1.1 Observed changes in soil acidity

We asked participants to describe any changes they have observed in soil acidity and water salinity during the previous ten years. We expect that changes in soil acidity are due largely to changes in water management that include higher irrigation flows due to changes in the sluice gate operations. Soil acidity in the region is impacted also by the lime that shrimp farmers apply to reduce the acidity of soil and water in their ponds. We do not expect residents to distinguish between changes in acidity due to changes in water management or changes in lime applications. As shown Figures 6 through 8, PRA participants in all three villages report observing a decline in soil acidity from 2000 to 2010.

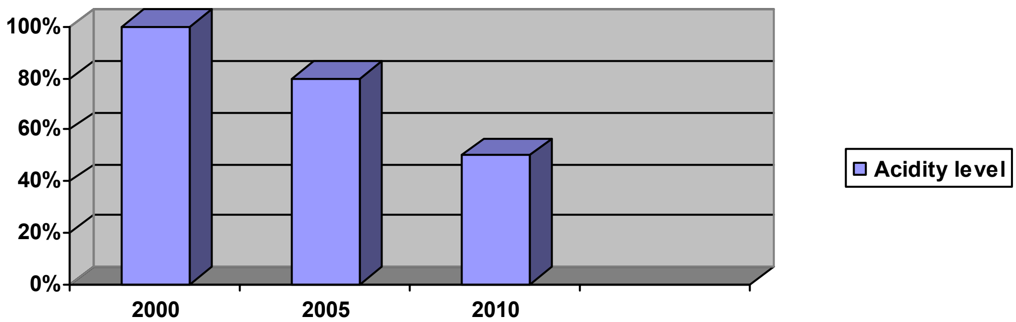

Figure 6. Soil acidity has declined during the previous ten years, as perceived by PRA participants in Hamlet 2, Phong Thanh Tay village, Gia Rai district, Bac Lieu province.

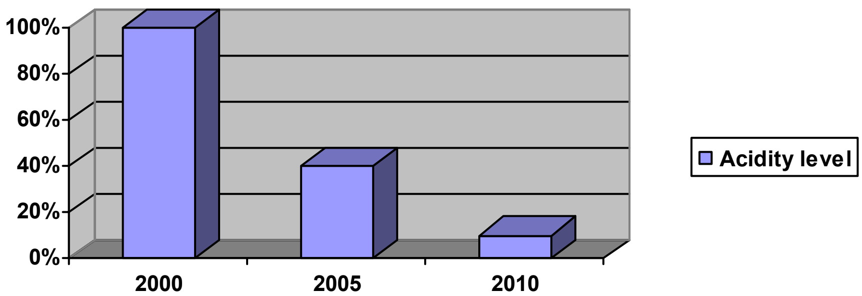

Figure 7. Soil acidity has declined during the previous ten years, as perceived by PRA participants in Chu Chot Hamlet, Ninh Thanh Loi village, Hong Dan district, Bac Lieu province.

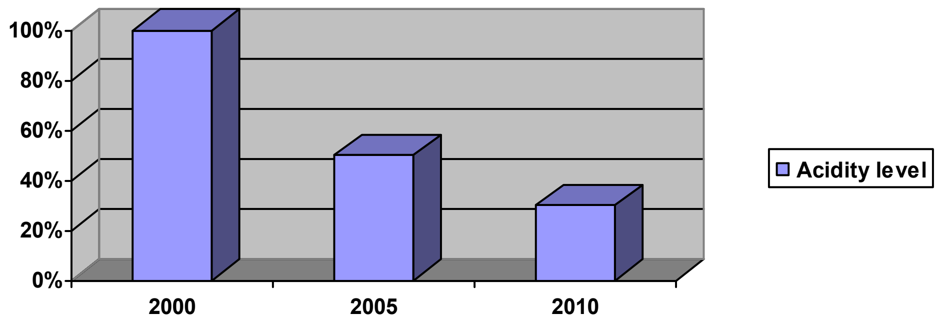

Figure 8. Soil acidity has declined during the previous last ten years, as perceived by PRA participants in Vinh Thanh Hamlet, Vinh Loc village, Hong Dan district, Bac Lieu province.

4.1.2. Observed changes in water salinity

Prior to the year 2000, farmland in the Bac Lieu Province was largely protected from saline water intrusion, for the benefit of rice producers who wished to produce crops throughout the year. Water salinity likely has changed substantially since 2000, particularly during the dry season, given that the sluice gates have been operated to provide saline water for shrimp culture during that season. Table 4 describes water salinity during the peak shrimp production period of February and March, as reported by participants in the PRA in three villages.

Table 4. Water salinity during February and March, as perceived by PRA participants in three study areas, in parts per million

Study Area	2000	2005	2010
Hamlet 2, Phong Than Tay (PTT)	20,000	25,000	25,000
Chu Chot Hamlet (NTL)	28,000	28,000	28,000
Vinh Thanh Hamlet, Vinh Loc (VL)	< 12,000	12,000	12,000

Residents of PTT and VL have observed an increase in water salinity during February and March between 2000 and 2005, while residents of NTL have not observed any changes in salinity, over time.

4.1.3 Observed changes in flora, and suggested methods for estimating monetary values

As noted above, we asked PRA participants to describe any changes in flora and fauna they have observed during the previous ten years. We asked them also to provide insight and guidance regarding the best ways to estimate monetary values associated with those changes. Tables 5 through 7 depict summaries of the results we obtained from PRA participants, pertaining to changes in flora. Tables 8 through 10 depict similar information for fauna.

Table 5. Observed changes in flora, and suggested methods for estimating monetary values in Hamlet 2, Phong Thanh Tay village, Gia Rai district

Flora species	Due to acidity	Due to salinity	Proposed estimation method
Rhizophora mucronata lamk (Đưng, increased)	X	X	These species are available in shrimp fields. The value could be estimated by changes in labor costs to remove them before the shrimp crop is started.
Scirpus littoralis Schrab.. (Năng tượng, increased)	X		
Seaweed (Rong, increased)	X		
Saltwater grass (Cỏ nước mặn, increase)		X	
Pluchea pteropoda hemslly (Lức, increased)	Available before 2000		These species are available in common areas, yet they serve no productive purpose. Willingness to Pay (WTP) and Willingness to Accept (WTA) might be used to determine if the species are valued by individual respondents.
Nipa (Dừa nước, decreased)	Due to smaller tidal magnitude		
Eleocharis atropurpurea (Năng kim, decreased)	X	X	These species are available in shrimp fields. Availability varies among fields. Without these species, shrimp yields would decline by 10%.
Eleocharis dulcis (Năng khía, decreased)	X	X	

Table 6. Observed changes in flora, and suggested methods for estimating monetary values in Chu Chot Hamlet, Ninh Thanh Loi village, Hong Dan district

<table>
<tr><th>Flora species</th><th>Due to acidity</th><th>Due to salinity</th><th>Proposed estimation method</th></tr>
<tr><td>Eleocharis atropurpurea
(Năng kim, disappeared)</td><td>X</td><td></td><td rowspan="3">These species are available in shrimp fields. The value could be estimated by changes in labor costs to remove them before the shrimp crop is started.</td></tr>
<tr><td>Acrostichum aureum L
(Ráng, new emerged)</td><td></td><td>X</td></tr>
<tr><td>Leptochloa chinensis
(Cỏ đuôi phụng, increased)</td><td>X</td><td></td></tr>
<tr><td>Saltwater grass
(Cỏ nước mặn, increased)</td><td></td><td>X</td><td rowspan="7">These species are available in shrimp fields, and they can be used as traditional medicine. One could estimate their value by examining the money residents periodically contribute to the local medical point in the village. Contributions are made as donations when residents obtain medicine.</td></tr>
<tr><td>Panicum repens
(Cỏ ống, increased)</td><td></td><td>X</td></tr>
<tr><td>Pluchea pteropoda hemslly
(Lức, increased)</td><td></td><td>X</td></tr>
<tr><td>Selaginella Tamariscina Spring
(Cỏ chân vịt, decreased)</td><td></td><td>X</td></tr>
<tr><td>Eclipta alba Hassk
(Cỏ mực, decreased)</td><td></td><td>X</td></tr>
<tr><td>Echinochloa crus - galli (L.) Beauv.
(Cỏ lồng vực, decreased)</td><td></td><td>X</td></tr>
<tr><td>Rush (Cyperraceae trialatus (Boeck.)Kern.)
(Lác 3 cạnh, disappeared)</td><td>X</td><td></td></tr>
</table>

Table 7. Observed changes in flora, and suggested methods for estimating monetary values in Vinh Thanh Hamlet, Vinh Loc village, Hong Dan district

Flora species	Due to acidity	Due to salinity	Proposed estimated method
Panicum repens (Cỏ ống, increased)		X	These species are available in shrimp fields, and they can be used as traditional medicine. One could estimate their value by examining the money residents periodically contribute to the local medical point in the village. Contributions are made as donations when residents obtain medicine.
Pluchea pteropoda hemslly (Lức, increased)		X	
Eleocharis atropurpurea (Năng kim, decreased)		X	These species are available in shrimp fields. The value could be estimated by changes in labor costs to remove them before the shrimp crop is started.
Leptochloa chinensis (Cỏ đuôi phụng, increased)	X		
Seaweed (Rong, increased)	X		
Water spinach *(Ipomoea aquatica Forssk.)* (Rau muống, increased)	X		
Cây đủa bếp (increased)		X	
Acrostichum aureum L (Ráng, decreased)		X	
Rhizophora mucronata lamk (Đưng, decreased)			
Nipa (Dừa nước, decreased)		X	800,000 VND per 1000m^2 per year
Rush *(Cyperraceae trialatus (Boeck.)Kern.)* (Lác, decreased)		X	10,000,000VND per 1000m^2 per year

4.1.4. Observed changes in fauna, and suggested methods for estimating monetary values

Table 8. Observed changes in flora and suggested methods for estimating monetary values in Hamlet 2, Phong Thanh Tay village, Gia Rai district

Fauna species	Due to acidity	Due to salinity	Proposed estimated method
Rat (Chuột, decreased)		X	These species are priced in the local market, as they are either consumed by residents or used as food for fish and other animals.
Enhydris enhydris (Rắn bong súng, increased)	X		
Naja kaouthia (Rắn hổ, decreased)		X	
Homalopis buccata (Rắn trun, decreased)		X	
Mystus planiceps (Cá chốt, decreased)		X	
Lates calcarifer (Cá chẻm, increased)		X	
Tilapia (Cá phi, increased)		X	
Mullet (Cá đối, increased)		X	
Goby fish (Cá bong cát, increased)		X	
Snake head fish (Cá lóc, decreased)		X	
Perch fish (Cá rô, decreased)		X	
Trichogaster pectoralis (Cá sặc, decreased)		X	
Crab (Cua biển, decreased)		X	
Golden snail (ốc bưu vàng, decreased)		X	
Metapenaeus ensis (Tép bạc đất, decreased)		X	
Vắt (decreased)		X	These species can be valued using Willingness to Pay or Willingness to Accept.
Leech (Đĩa, decreased)		X	

Table 9. Observed changes in flora and suggested methods for estimating monetary values in Chu Chot Hamlet, Ninh Thanh Loi village, Hong Dan district

Fauna species	Due to acidity	Due to salinity	Proposed estimated method
Mullet (Cá đối, decreased)	Due to smaller tidal magnitude		These species are priced in the local market, as they are either consumed by residents or used as food for fish and other animals.
Crab (Cua biển, decreased)			
Metapenaeus ensis (Tép bạc, decreased)			
Metapenaeus spp. (Tép đất, decreased)			
Mystus planiceps (Cá chốt, unchanged)		X	
Snake head fish (Cá lóc, decreased)		X	
Perch fish (Cá rô, decreased)		X	
Tilapia (Cá phi, increased)		X	
Rat (Chuột, decreased)		X	
Snake (Rắn, decreased)		X	
Enhydris enhydris (Rắn bong súng, increased)		X	
Bird (Chim, increased)		X	
Cat fish (Cá trê, decreased)		X	
Eel (Lươn, decreased)		X	

Table 10. Observed changes in flora and suggested methods for estimating monetary values in Vinh Thanh Hamlet, Vinh Loc village, Hong Dan district

Fauna species	Due to acidity	Due to salinity	Proposed estimated method
Mosquito (Muỗi, increased)			These species can be valued using Willingness to Pay or Willingness to Accept.
Toad (Cóc, decreased)			
Đĩa (decreased)		X	
Snake (Rắn, decreased)	Due to catching		These species are priced in the local market, as they are either consumed by residents or used as food for fish and other animals.
Rat (Chuột, increased)			
Golden snail (ốc bưu vàng, increased)			
Feshwater crab (Cua đồng, decreased)		X	
Frog (ếch, decreased)		X	
Tree-frog (Nhái, decreased)		X	
Eel (Lươn, decreased)		X	
Tilapia (Cá phi, increased)		X	
Snakehead fish (Cá lóc, decreased)	Due to excessive harvesting		
Cat fish (Cá trê vàng, decreased)	X		
Tortoise (Rùa, decreased)	Due to excessive harvesting		

4.1.5 Observed changes in production, services, and other livelihood activities

Changes in soil and water salinity and acidity can impact the livelihood activities of residents in deltaic regions, such as the Ca Mau peninsula. With this in mind, we asked PRA participants to describe any changes they have observed over time in production, services, and other components of their livelihood activities.

The production systems in medium and high acidity locations, such as Chu Chot Hamlet (NTL) and Hamlet 2 (PPT), have changed substantially from low-yield rice production throughout the year, to a system in which farmers generate two or three shrimp crops, while still producing also some rice. Higher salinity water also enables some farmers to cultivate crabs. Fruit tree production has declined, as most trees cannot tolerate higher water salinity during the dry season. Residents also have described changes in the incidence of some animal diseases, which might be influenced partly by the changes in salinity. The production of several traditional handicrafts has been reduced, while some services, such as the preparation and repair of agricultural machinery, have been developed in the region, in response to an increase in metal corrosion as the production environment has become more saline.

In Vinh Loc village (VL), where there is less acidity and more fresh water, the production systems have adjusted to accommodate a balance between rice and shrimp production in the wet and dry seasons. Other aquatic species that tolerate both saline and fresh water conditions have been cultured. In addition, other small business, such as noodle making and grocery sales have increased in rural areas.

In sum, the changes in environmental conditions brought about by changes in sluice gate operations have modified livelihood opportunities on the Ca Mau Peninsula in severable notable ways. We have attempted to capture some of those changes, and the associated economic values, in our survey of residents in three study areas.

4.2. Survey of Households in Bac Lieu Province

After summarizing the information we obtained from the PRA sessions, we designed a questionnaire for gathering information describing the monetary values of changes in the health and abundance of flora and fauna over time, in response to changes in sluice gate operations. We tested the questionnaire in several villages, made appropriate revisions, and set about developing a sampling framework. Given our understanding of how soil and water conditions vary with distance from the sluice gates, and also with distance along an irrigation canal, we chose to interview residents in each of our three study areas who live and farm at different distances from a canal. We chose also to interview residents with small (less than 1 ha), medium (1 to 3 ha), and large (greater than 3 ha) farm sizes. We worked with each village leader to select 40 households representing a cross-section of farm sizes and distance to an irrigation canal. Thus, our sample includes 120 households that were not selected at random.

Five interviewers were present during each household interview. Our local guide was not present, as all of the interviewers were Vietnamese, thus eliminating the need for supervision by a local representative. The interviewers invested about two hours of time with each household. The residents understood the purpose of our study and they seemed comfortable with most of the questions. Perhaps the most challenging questions were those in which we asked directly about the monetary value residents would be willing to pay, to ensure that the sluice gates continue operating in the future.

4.2.1. Summary statistics

We surveyed 120 farm households in three villages: Phong Thanh Tay (PPT) in zone S3, Ninh Thanh Loi (NTL) in zone S2 and Vinh Loc (VL) in zone B1 (the locations depicted in Fig. 5). Although not selected at random, we consider the characteristics of our survey participants to be representative of households throughout the region. The average age of household heads in our sample is about 46 years, and is similar in the three villages (Table 11). The household heads have a medium education level of the first year in secondary school in the 12-class system in Vietnam, which includes primary (grades 1 to 5), secondary (grades 6 to 9), and high school (grades 10 to 12).

As noted above, we chose households, in part, according to the distance of their primary field from an irrigation canal. In our sample, the average distance from a primary field to a canal is 356 m. About 80% of the primary fields are within 500 m of a canal, while 12% are within 1,000m, and 8% are located farther than 1,000m from an irrigation canal.

All of the households we interviewed have been in the region for many years. The average residence time is greater than 38 years. Hence, many household members have had the opportunity to observe changes in flora and fauna in their fields during 2000 to 2010.

Table 11. Summary statistics describing survey respondents and their household characteristics, by village

Village	PPT		NTL		VL		All Obs.	
Characteristic	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Age of household head (years)	44.4	14.5	46.5	14.1	47.7	10.1	46.2	13.0
Education (class)	5.1	2.7	5.9	2.6	6.9	2.9	6.0	2.8
Distance from main field to canal (m)	305	554	564	759	199	306	356	586
Settlement period (years)	34.2	16.3	41.8	17.9	39.7	16.1	38.6	16.9

About 26% of our survey respondents are female, with proportions ranging from 12.5% in VL to 37.5% in PPT (Table 12). Although we did not have a target for the proportion of female respondents, we include gender as a potential explanatory variable in our analysis of environmental valuation.

Table 12: Gender information of survey participants, by village

Village	PPT		NTL		VL		All Obs.	
Gender	Freq.	(%)	Freq.	(%)	Freq.	(%)	Freq.	(%)
Female	15	37.5	11	27.5	5	12.5	31	25.8
Male	25	62.5	29	72.5	35	87.5	89	74.2
Total	40	100.0	40	100.0	40	100.0	120	100.0

Table 13. Change of household members and labour force over last ten years by village, in persons per household

Information	PPT		NTL		VL		Total	
	Mean	Std. Dev	Mean	Std. Dev	Mean	Std. Dev	Mean	Std. Dev
Member in 2000	5.4	2.3	5.1	1.5	5.0	1.8	5.2	1.9
Member in 2009	4.7	1.5	4.8	1.3	4.2	1.1	4.5	1.3
Labour in 2000	4.0	2.3	3.6	1.4	3.0	1.5	3.5	1.8
Labour in 2009	3.6	1.7	3.2	1.5	2.9	1.0	3.2	1.4

Household size and labor force participation have declined somewhat in the three villages, since 2000 (Table 13). The primary reason for these changes is the separation of children from their families.

Table 14. Changes in land use between 2000 and 2009, by village, in hectares per household

	PPT		NTL		VL		Total	
	Mean	Std. Dev	Mean	Std. Dev	Mean	Std. Dev	Mean	Std. Dev
Total land 2000	3.01	2.75	2.54	1.66	2.50	1.65	2.68	2.08
Total land 2009	2.89	2.68	2.56	1.55	2.48	1.66	2.64	2.02
Garden 2000	0.21	0.36	0.30	0.47	0.20	0.24	0.24	0.37
Garden 2009	0.22	0.36	0.32	0.48	0.20	0.24	0.25	0.38
Rice-shrimp 2000	2.24	2.31	1.83	1.49	1.90	1.43	1.99	1.78
Rice-shrimp 2009	2.08	2.18	1.84	1.41	1.85	1.45	1.92	1.71
Dike 2000	0.49	0.53	0.38	0.32	0.40	0.35	0.42	0.41
Dike 2009	0.57	0.62	0.38	0.32	0.43	0.35	0.46	0.45
Fallow 2000	0.08	0.47	0.03	0.16	0.00	0.00	0.03	0.29
Fallow 2009	0.02	0.09	0.03	0.16	0.00	0.00	0.01	0.11

The average size of farms also has decreased somewhat, due to the division of farmland among children (Table 14, Figure 9). The increase in dike area (in PPT) is due partly to sedimentation that has occurred after opening the sluice gates. Saline water from the East Sea carries more sediment than fresh water from upstream.

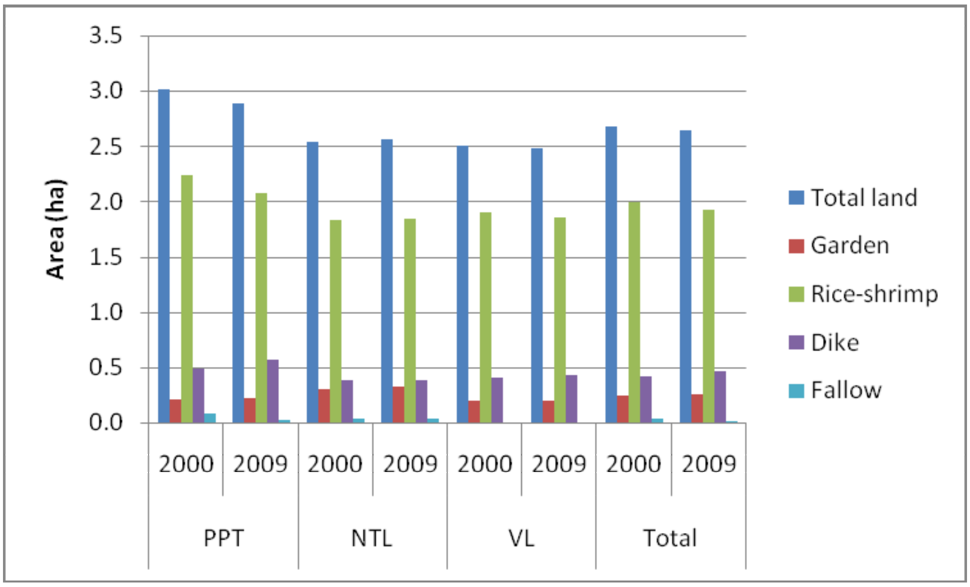

Figure 9. Changes in land use between 2000 and 2009, by village

4.2.2 Observed changes in environmental conditions

We asked survey participants to report their perceptions of any changes in environmental conditions between 2000 and 2009. Observations vary among villages and across seasons. For example, in all three villages, many residents report higher levels of salinity in irrigation canals during the dry season, and lower levels of salinity during the rainy season (Figure 10). These observations are consistent with expectations, given that the sluice gates are opened during the dry season to allow saline water inflows from the East Sea.

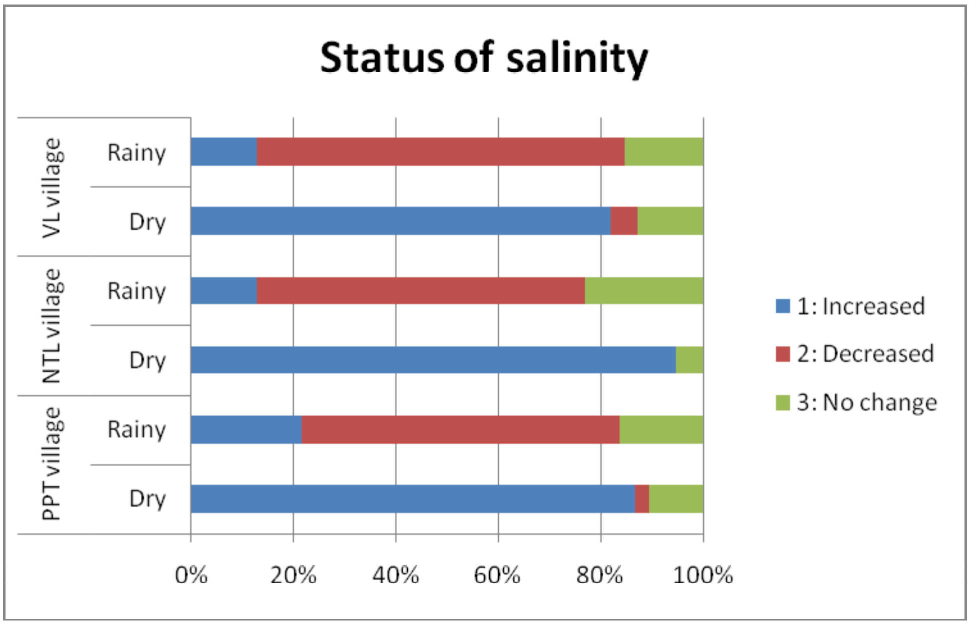

Figure 10: Status of salinity by village and season

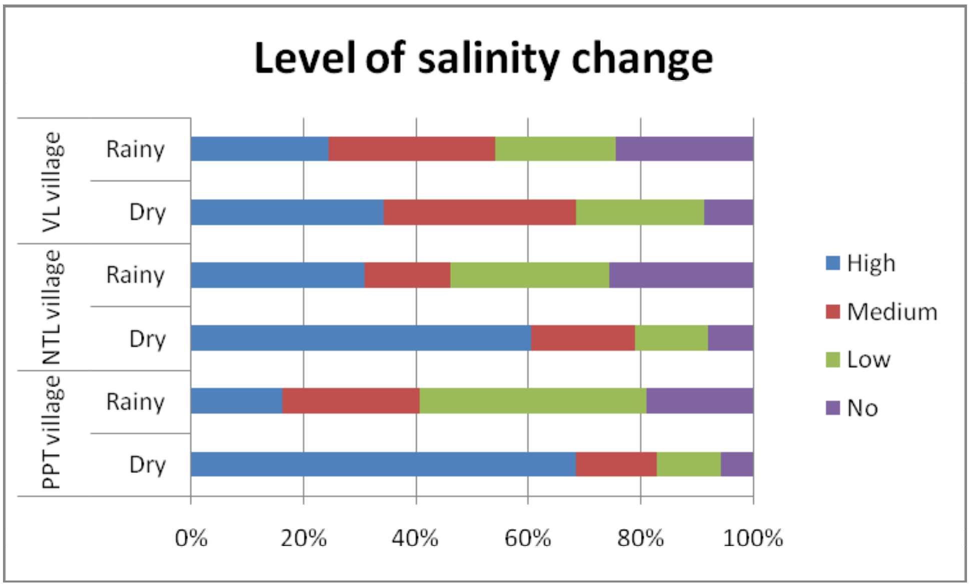

Figure 11. Level of salinity change by village and season

We asked participants to describe also the degree of changes they have observed in environmental conditions. More than 60% of participants in PPT and NTL report a substantial change in salinity during the dry season, with residents in PPT reflecting a slightly higher frequency than residents in NTL (Figure 11). These observations are consistent with expectations, given that PPT is located very near the Gia Rai and Ho Phong sluice gates, while NTL is located somewhat further away. Fewer than 40% of participants in VL, which is located farthest from the sluice gates, report a large change in salinity during the dry season.

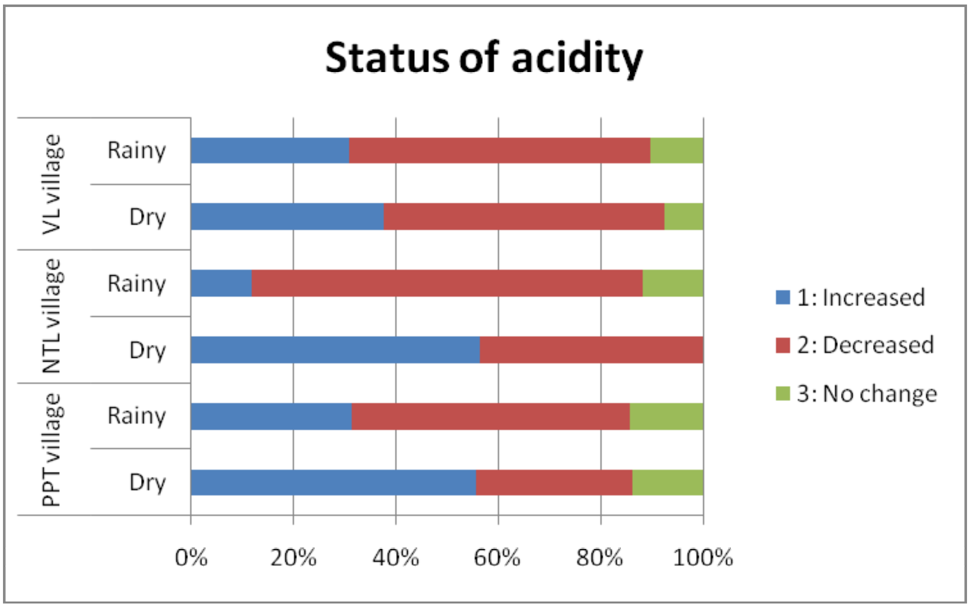

Figure 12. Status of soil acidity by village and season

More than half the participants in each village report a decrease in acidity during the rainy season, while many report an increase in acidity during the dry season (Figure 12). The frequencies of responses reporting an increase in acidity during the dry season are greater in

PPT and NTL than in VL, as expected, given the locations of each village with regard to the sluice gates.

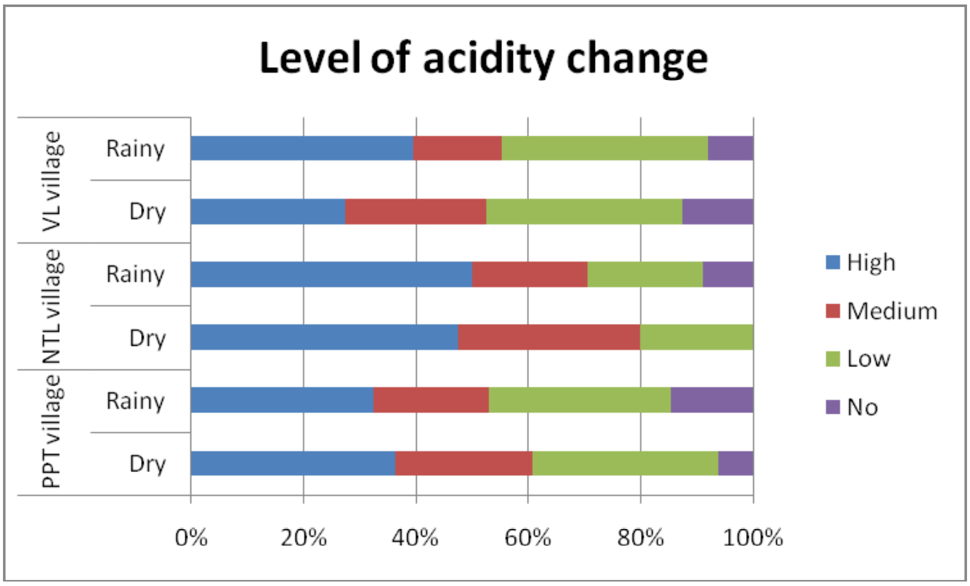

Figure 13. Level of acidity change by village and season

The most notable changes in acidity were observed in the dry season by residents of NTL (Figure 13).

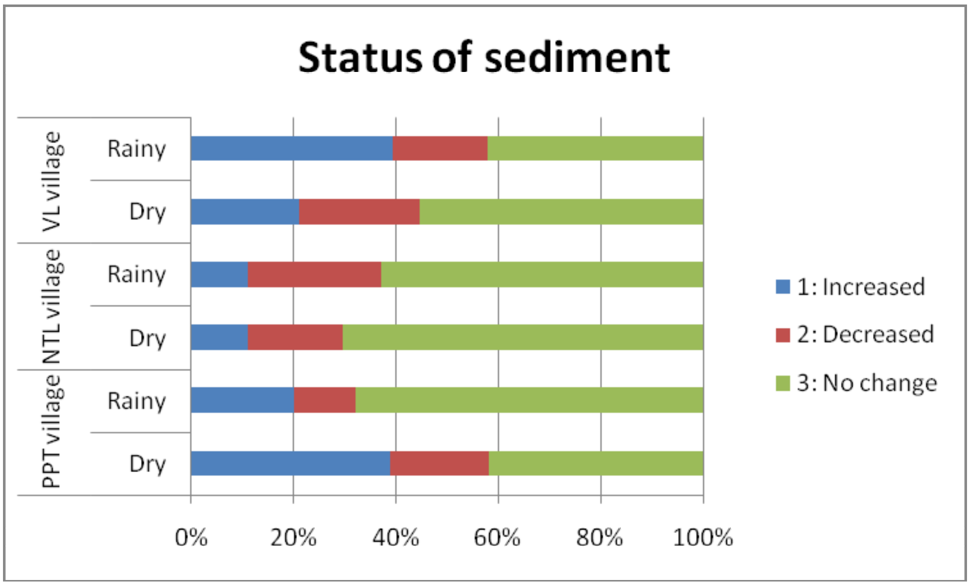

Figure 14. Status of sediment by village and season

Many survey respondents report no change in sediment conditions between 2000 and 2009 (Figure 14). However, about 40% of participants in VL report an increase in sediment during the rainy season, while 40% of participants in PPT report an increase during the dry season.

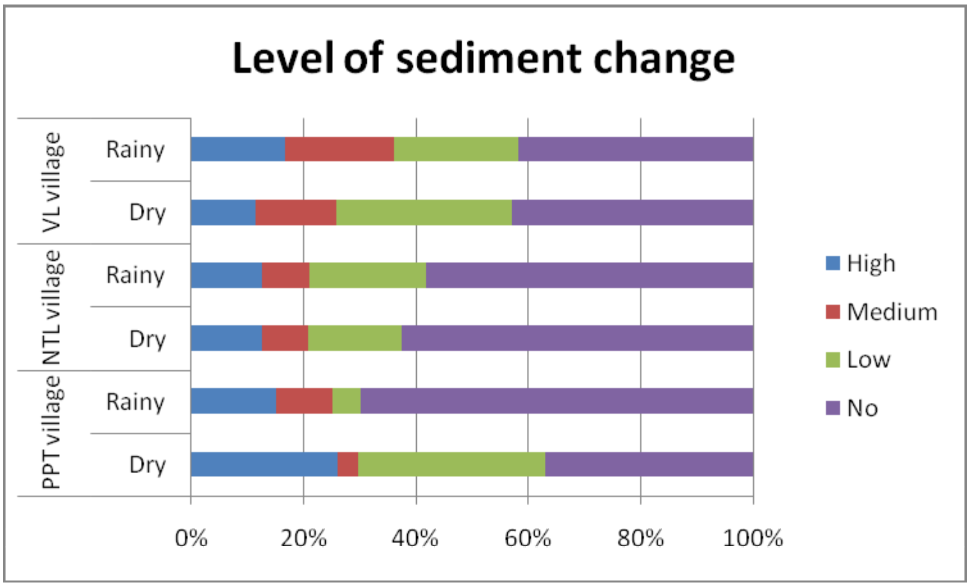

Figure 15. Level of sediment change by village and season

Participants in PPT report a slightly higher intensity of change in sediment conditions than participants in VL, although most participants in all villages report little to no intensity of change (Figure 15).

4.2.3 Estimating the willingness to pay for environmental impacts

Evaluating changes in the condition of flora and fauna is more challenging than evaluating changes in soil and water salinity, acidity, and sediment. In the case of soil and water, the implications of changes in quality for production of rice and shrimp are largely well known and direct. For example, an increase in water salinity is harmful to rice production, but beneficial for shrimp production. Acidity is generally harmful to both activities.

Determining the impacts of changes in soil and water quality is more challenging in the case of flora and fauna, as the pathway toward imposing harm or generating benefit is often indirect and the net result is not always clear. For example, suppose higher salinity reduces the viability of an animal species that is known to damage rice yields, yet also is consumed directly by poor households to supplement their food supply. Whether higher salinity generates a net harm or net benefit in this case will depend on the relative implications for harmful and beneficial effects. If most residents place a higher value on rice yields than direct consumption of the species, an increase in salinity might generate a net benefit. However, if most residents place a higher value on direct consumption of the species than on rice production, higher salinity might reduce net benefits.

Another example involves a plant species that has medicinal value, but also interferes with rice or shrimp production. Some residents might consider an increase in the species to be beneficial, while others might consider an increase to be harmful. The net effect will depend on the relative importance of each consideration within a community or region.

Given this challenge, we chose not to base our estimates of environmental values on information pertaining to individual species of flora and fauna. Rather, we chose to ask residents how much they would be willing to pay to ensure that the sluice gates continue operating in the manner that enables the inflow of saline water during the dry season. We asked residents also to estimate the proportion of their willingness to pay that we should attribute to environmental benefits (changes in flora and fauna), rather than values generated in the production of rice, shrimp, or other similar activities.

The responses we obtained from residents seem plausible, even though the residents likely have not been asked previously to estimate their willingness to pay for environment quality in a contingent valuation setting. The average estimates of willingness to pay for continuation of sluice gate operations ranges from $39 per household, per year in PPT to $73 per household, per year in NTL (Table 15). Participants in VL report a willingness to pay of $54 per household, per year.

The average proportions of willingness to pay that should be attributed to changes in flora and fauna are somewhat similar in the three villages. The proportions range from 12% in NTL to 18% in VL, such that the aggregate proportion of the willingness to pay is 15% (Table 15). Using these proportions, the estimated average willingness to pay for environmental quality (changes in flora and fauna) ranges from $5.56 per household, per year in PPT to $9.68 per household, per year in VL. The estimated aggregate value for the region is $8.31 per household, per year. The estimates of willingness to pay for changes in flora and fauna represent from 0.3% to 0.4% of annual household income in the three villages.

Table 15. Willingness to pay to maintain sluice gate operations, and the proportion attributed to changes in flora and fauna, in US Dollar per household, per year

Village	PPT		NTL		VL		Aggregate	
	Mean	Std. Dev	Mean	Std. Dev	Mean	Std. Dev	Mean	Std. Dev
Total WTP to continue sluice gate operations	39.08	45.76	73.38	97.33	53.77	37.86	55.41	66.78
Proportion of WTP due to changes in flora and fauna (%)	15	22	12	18	18	15	15	18
WTP attributed to changes in flora and fauna	5.86		8.81		9.68		8.31	
Average annual income per household in 2009	1,692		2,974		2,615		2,462	
WTP for changes in flora and fauna, as a proportion of annual income (%)	0.3		0.3		0.4		0.3	

5. Conclusions

Provincial officials in Bac Lieu Province have successfully modified the operation of several sluice gates to accommodate both rice and shrimp production in the region. By opening the gates during the dry season, saline water enters the system of canals and streams, much to the benefit of households raising shrimp. Closing the sluices during the wet season enables households to produce rice, using water of lower salinity. Success has been achieved also by establishing a system of zoning in which rice and shrimp production are promoted in selected portions of the province. The zoning program complements the sluice gate operations, thus enabling water managers to achieve a better balance between the demands and supplies of saline and fresh water, both spatially and across seasons.

Researchers at the International Water Management Institute, in conjunction with national partners and scientists from other international centers, developed the simulation model that has been used to examine the potential implications of alternative sluice gate management strategies. The model has been used also to design the zoning program that divides rice and shrimp production areas, so that each set of producers can obtain water deliveries that match their production requirements. To the extent that provincial officials have relied on IWMI's modeling efforts, the Institute's researchers have contributed to a meaningful public policy program that generates notable values for residents of Bac Lieu Province.

The values generated by the sluice gate program include market and non-market components. Shrimp and rice producers obtain higher yields and have greater opportunities to expand and intensify their activities when they are assured of receiving water with the appropriate quality parameters. The values arising from higher yields and greater opportunities can be estimated using price information available in local and international markets. While the market values likely are substantial, they are not the focus of this study. Rather, we have estimated the non-market values associated with changes in flora and fauna made possible by modifying sluice gate operations according to the IWMI recommendations.

We have estimated the average household willingness to pay to ensure continuation of sluice gate operations, and the portion of that willingness to pay that might be attributed to changes in flora and fauna. Our aggregate estimate of $8.31 per household, per year, represents about 0.3% of annual household income. While estimating non-market values is not an exact science, particularly in areas where it is difficult to determine precisely how a policy action influences environmental quality, we view our results as plausible. Households obtain value from several species of flora and fauna in the region, while some species reduce yields or raise the cost of rice production. The net value obtained from the changes in flora and fauna that occur due to changes in sluice gate operations will reflect a blending of benefits and costs.

We can calculate the aggregate value of the environmental improvement by multiplying our estimates of non-market values per household by the numbers of household in each of our sample villages. There are about 2,000 households in each village, and the estimated average annual willingness to pay for continued sluice gate operations is $8.31 per household. Hence the residents in the three villages might be willing to contribute almost $50,000 per year to continue receiving the non-market values they obtain through beneficial changes in flora and fauna. Residents in other villages in the region likely obtain non-market benefits, also, such that the full non-market value might be closer to $200,000 per year.

This values we have estimated likely exceed the incremental cost of closing and opening the gates according to the modified schedule developed by IWMI researchers and their partners. The large cost of constructing the gates is not pertinent in our analysis, because the gates were already in place when the research began. The market and non-market values generated by modifying gate operations need only to offset the incremental costs of opening and closing the gates according to a different schedule. It is likely that those costs are not substantial.

In sum, we conclude that the sluice gate operation program has been successful in allowing rice and shrimp farmers to conduct their activities in a coordinated fashion, and also in generating non-market values for households that benefit from observed changes in the abundance of several flora and fauna species.

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6. References

Can, N.D., N.T. Khiem, M. Hossain and T.P. Tuong (2010). Farmers' Assessment of Resource Management and Farm Level Technological Interventions in the Mekong Delta, Vietnam. In: C.T. Hoanh, B. Szuster, S.P. Kam, A. Noble, A.M. Ismail (eds.) Tropical Deltas and Coastal Zones Communities, Environment and Food Production at the Land-Water Interface. Comprehensive Assessment of Water Management in Agriculture (CA) Series No. 9. UK: CABI Publishing.

Delft Hydraulics (1989). SAFLOW Manual: A Program to Calculate One-Dimensional Channel Flow Including Salinity. Delft Hydraulics, Delft, The Netherlands.

Dong, T. D. (2000). VRSAP model and its applications. In Proceedings of the Workshop On Hydrologic and Environmental

Modelling in the Mekong Basin. Al-soufi, R. W. (ed.). Technical Support Division, Mekong River Commission, Phnom Penh, Cambodia.

Dung, L.C., C.T. Hoanh, C. Le Page, F. Bousquet and N. Gajaseni, 2009. Facilitating dialogue between aquaculture and agriculture: lessons from role-playing games with farmers in the Mekong Delta, Vietnam. Water Policy, Special Issues on Trade-off and synergies in water management across scales. Water Policy 11(Suppl. 1), 80–93.

ESSA Ltd, Stothert, Pegasus, Ward & Associates, and IEM, Inc (1992). Water Control Project for the Quan Lo Phung Hiep Area, Mekong Delta, Vietnam: A Pre-Feasibility Study (Executive Report). Prepared by ESSA Environmental and Social System Analysts Ltd, Vancouver, B.C., Canada, for Ministry of Water Resources, Socialist Republic of Vietnam.

Gowing, J.W., T.P. Tuong, C.T. Hoanh, N.T. Khiem, 2006. Social and environmental impact of rapid change in the coastal zone of Vietnam: an assessment of sustainability issues. In: Hoanh, C.T., T.P. Tuong, J.W. Gowing and B. Hardy (eds), 2006. Environment and livelihoods in tropical coastal zones: Managing agriculture-fishery-aquaculture conflicts. Book No.2 of CA Series (Comprehensive Assessment of CGIAR), CABI Publishing, UK.

Halcrow Group Ltd (2001). Working Paper No. 4 – Review of Available Models. Water Utilisation Project Component A: Development of Basin Modelling Package and Knowledge Base (WUP-A). Mekong River Commission, Phnom Penh, Cambodia.

Harleman, D. R. F. (1971). One-Dimensional Model; Estuarine Modeling: an Assessment. TRACOR, Inc, New York, NY, USA.

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 changes: evidence from a coastal area of the Mekong River Delta. Journal of Water Policy, Issue 5, Volume 5 (2003), 475-488.

Hoanh, C.T., Phong, N.D., Gowing, J.W., Tuong, T.P., Ngoc, N.V., Hien, N.X. (2009). Hudraulic and water quality modeling: a tool for managing land use conflicts in inland coastal zones. Water Policy 11(Suppl. 1), 106-120.

Jin, M. & Fread, D. L. (1997). Dynamic flood routing with explicit and implicit numerical solution schemes. Journal of Hydraulic Engineering, ASCE, 123(3), 166–173.

Kawahigashi, M., Do, N.M., Nguyen, V.B., Sumida, H., 2008. Effects of drying on the release of solutes from acid sulfate soils distributed in the Mekong Delta, Vietnam. Soil Science and Plant Nutrition 54(4), 495-506.

Khiem, N.T. and M. Hossain (2010). Dynamics of Livelihoods and Resource Use Strategies in Different Ecosystems of the Coastal Zones of Bac Lieu Province, Vietnam. In: C.T. Hoanh, B. Szuster, S.P. Kam, A. Noble, A.M. Ismail (eds.) Tropical Deltas and Coastal Zones Communities, Environment and Food Production at the Land-Water Interface. Comprehensive Assessment of Water Management in Agriculture (CA) Series No. 9. UK: CABI Publishing.

Khue, N. N. (1986). Modelling of Tidal Propagation And Salinity Intrusion in the Mekong Main Estuarine System. Technical paper of Mekong Delta Salinity Intrusion Studies, Phase II. Mekong Secretariat, Interim Mekong River Committee, Bangkok.

KOICA & KARICO (2000). Flood control planning for development of the Mekong Delta (basinwide): Final Report, Volume 1, Main Report. Korea Water Resources Corporation and Korea Agricultural and Rural Infrastructure Corporation. Mekong River Commission, Phnom Penh, Cambodia.

Minh, L.Q., Tuong, T.P., van Mensvoort, M.E.F., Bouma, J., 1997. Contamination of surface water as affected by land use in acid sulfate soils in the Mekong River Delta, Vietnam. Agriculture, Ecosystems and Environment 61(1), 19-27.

Molden, D. (ed) (2007) Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture, Earthscan, London, UK, and International Water Management Institute (IWMI), Colombo, Sri Lanka

NEDECO (1992). Thematic Study on Management of Water Resources, Hydraulic Modelling. Vol. 4. State Planning Committee-Government of Vietnam, World Bank, Mekong Secretariat, United Nations Development Programme (UNDP), Bangkok, Thailand, Mekong Delta Master Plan Project (VIE/87/031).

Phong, N.D., 2009. Modelling of canal water acidity due to acid sulphate soils. a case study of the Camau peninsula, Mekong Delta, Vietnam. PhD Thesis. Department of Civil and Environmental Engineering, University of Melbourne, Australia.

Sakamoto, T., V.P. Cao, A. Kotera, K.D. Nguyen, M. Yokozawa (2009). Analysis of rapid expansion of inland aquaculture and triple rice-cropping areas in a coastal area of the Vietnamese Mekong Delta using MODIS time-series imagery. Landscape and Urban Planning, 92(1), 34-46.

Sonntag, N. C. & McNamee, P. J. (1989). Eco-development planning for the Quan Lo Phung Hiep area of the Ca Mau Peninsula. Final report by ESSA Environmental and Social Systems Analysts Ltd for Mekong Secretariat, Vietnam.

Thomas, B.P., R.W. Fitzpatrick, R.H. Merry, W.S. Hicks (2003). Coastal Acid Sulfate Soil Management Guidelines, Barker Inlet, SA. Acid Sulfate Soil Technical Manual (version 1.2). Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia.

Tuong, T.P., Kam, S.P., Hoanh, C.T., Dung, L.C., Khiem, N.T., Barr, J., and Ben, D.C. (2003). Impact of salinity protection on environment, farmer's resource-use strategies and livelihood in a coastal area.. Paddy Water Environment (2003) 1 : 65-73.

7. Appendix: The Household Interview Questionnaire

Estimating the Value of Improvements in Environmental Quality Due to Changes in Sluice Gate Operations in Bac Lieu Province, Vietnam

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Study Objective

Our goal in this study is to describe the impacts of changes in sluice gate operations on environmental parameters. These parameters include water quality in local waterways and the viability of fish and other aquatic animals in the lower Mekong Delta. We will first examine the relationship between sluice gate operations and changes in environmental parameters using a combination of empirical information and analytical modeling. We will then assign values to the changes in environmental quality using information from stakeholders and methods developed within the field of economics for the purpose of estimating non-market values.

Survey Narrative – This must be read precisely to each survey participant.

Some time ago, the Provincial Government began operating sluice gates differently, to modify the salinity and acidity of waterways in this portion of the Mekong Delta. One goal of the program is to enable better production of shrimp and rice by improving water quality.

It is possible that the changes in sluice gate operations, and the resulting changes in water quality, have also created better conditions for native plants and animals in the region. If native plants and animals prefer lower salinity levels and less acidity, then some species might be doing better with the changes in sluice gate operations.

The goal of our study is to determine if the changes in sluice gate operations have influenced native plants and animals in ways that generate environmental benefits. The benefits might include greater diversity in plant and animal species, and healthier conditions for the wildlife that depend on native plants.

As part of our work, we seek your input regarding any changes in native plants and animals you have observed in recent years. We will ask you also to help us in placing values on the changes in the numbers and diversity of plants and animals in the region.

The most important characteristics or your answers in this survey are <u>honesty and accuracy</u>. There are no right or wrong answers. Please be sure to describe your actual, accurate perceptions of changes in water quality, and in plants and animals. If you have not perceived any changes, please tell us that quite honestly!

HOUSEHOLD INTERVIEW FORM

Date of interview:____

Interviewer name:____

Respondent name:__________________________________Gender: ☐ M ☐ F

Age of respondent: ____________ Schooled years of respondent:_____________ (0-16)

Home address: Hamlet____________; Village:___________________;
District:___________________

Distance from your house to the nearest canal: _________________(m)

Distance from your field to nearest canal: ______________ (m)

How long have you settled in this location? _______________ (year)

PART 1: HOUSEHOLD INFORMATION

1. Family member

Information	Unit	Year 2000	Year 2009
Total family member			
Total family labor (>16 yrs - <60yrs)			
Reasons for change in family members			
Reasons for change of family labor			

2. Land and its distribution in 2 two points of time

Land used type	**Unit**	**Year 2000**	**Year 2009**	**Reason for change(*)**
(1) Homestead	Ha			
(2) Rice land	Ha			
(3) Shrimp land	Ha			
(4) Dike	Ha			
(5) Fallow land	Ha			
(6) Other land	Ha			
Total land	Ha			

*(*): **1**: since acidity reduced, it was able to convert to other production purpose; **2**: since salinity supplied, it was able to convert to other production purpose; **3**: due to local policy/plan; **4**: other (specified)*

3. Please describe any changes in the proportions of livelihood activities that have occurred within your household during the last ten years, using the following table. Please consider the proportional contribution to income or food security in your household. Please begin by considering your current livelihood activities and then describing how those activities have changed since the year 2000.

Livelihood Activity	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Notable events										
Total income										
Rice production (% or dong)										
Shrimp production (% or dong)										
Other activities (% or dong):										
Sum must be 100%	100	100	100	100	100	100	100	100	100	100

4. Please describe, in very general terms, any changes you have observed in water quality since 2001. Please select from the terms in table below

	Salinity	Acidity	Sediment
In Dry season			
+ Status (0: no observation; 1: increase; 2: decrease; 3: same)			
+ Intensity of change: (0: no observation; 1: none; 2: small; 3: moderate; 4:substantial)			
In Wet season			
+ Status (0: no observation; 1: increase; 2: decrease; 3: same)			
+ Intensity of change: (0: no observation; 1: none; 2: small; 3: moderate; 4:substantial)			

PART 2: VALUATION OF FLORA CHANGE

5. List of all flora species available in family land in two times and method used for valuation

No.	Flora species	Available in land used type(@) and area in 2000 (ha)	Available in land used type(@) and area in 2009 (ha)	Reason for change(*)	Signi-ficance of the species to human life (+/_)	Method proposed for valuation(#) *(if the awnser is WTP/WTA pls go to question 6)*	Value of the flora species for 2009 area (VND) *(do not apply for those with WTP/WTA method)*
1	Đưng *(Rhizophora mucronata lamk)*						
2	Năng tượng *(Scirpus littoralis Schrab..)*						
3	Rong (Seaweed)						
4	Cỏ n. mặn (Saltwater weed)						
5	Lức *(Pluchea pteropoda hemslly)*						
6	Dừa nước (Nipa)						
7	Năng kim *(Eleocharis atropurpurea)*						
8	Năng khía *(Eleocharis dulcis)*						
9	Cỏ đuôi phụng *(Leptochloa chinensis)*						
10	Cỏ ống *(Panicum repens)*						
11	Ráng *(Acrostichum aureum L)*						
12	Cỏ chân vịt *(Selaginella Tamariscina Spring)*						
13	Cỏ mực *(Eclipta alba Hassk)*						
14	Cỏ lồng vực *(Echinochloa crus - galli (L.) Beauv.)*						
15	Lác 3 cạnh (Rush-*Cyperraceae*						

	trialatus (Boeck.)Kern.)						
16	Đưng *(Rhizophora mucronata lamk)*						
17	Rau muống (Water spinach)						

(@): using the code of land used type in 1st column in table 3 above
(*): (1): due to acidity; (2) due to salinity; (3) due to less tidal variation; (4) due to human action; (5) other (specified)
(#): (1) labor cost to remove; (2) effect shrimp yield; (3) use as medicine valued by charity money; (4) replacement price; (5) WTP; (6) WTA; (7) other (specified)

6. Value estimation for those in table 4 with proposed method of WTP and WTA

Code of flora species (use the same number that was used in table 4 above)	Explain why to use WTP/WTA method	Final value determined by WTP/WTA for area changed between 2000 and 2009 indicated in table 5 above (VND)

PART 3: VALUATION OF FAUNA CHANGE

7. List of all natural fauna species available in family use in two times and method used for valuation

No.	Fauna species	Quantity catched (or consumed) in 2000 (kg)	Quantity catched (or consumed) in 2009 (kg)	Reason for change(*)	Significant of the species to human life (+/_)	Method proposed for valuation(#) *(if the awnser is WTP/WTA pls go to question 8)*	Value of the fauna species for 2009 (VND/year) *(do not apply for those with WTP/WTA method)*
1	Chuột (rat)						
2	Rắn bông súng *(Enhydris enhydris)*						
3	Rắn hổ *(Naja kaouthia)*						
4	Rắn trun *(Homalopis buccata)*						
5	Cá chốt (*Mystus planiceps)*						
6	Cá chẽm (*Lates calcarifer)*						
7	Cá phi (Tilapia)						
8	Cá đối (Mullet)						
9	Cá bống (Goby fish)						
10	Cá lóc (Snakehead fish)						
11	Cá rô (Perch fish)						
12	Cá sặc (*Trichogaster pectoralis)*						
13	Cá trê (cat fish)						
14	Lươn (eel)						
15	Cua đồng (freshwater crab)						

16	Cua biển (Crab)						
17	OBV (Golden snail)						
18	Tép bạc (*Metapenaeus ensis)*						
19	Chim (bird)						
20	Muỗi (mosquito)						
21	Cóc (toad)						
22	Ếch (frog)						
23	Nh□i						
24	Rùa (tortoise)						
25	Chồn (fox)						
26	Đĩa (leech)						

(*): (1): due to acidity; (2) due to salinity; (3) due to chemical; (4) due to human action; (5) other (specified)
(#): (1) buy at local market; (2) sell at local market; (3) self-catch and consumed with local market price; (4) replacement price; (5) WTP; (6) WTA; (7) other (specified)

8. Value estimation for those in table 6 with proposed method of WTP and WTA

Code of fauna species (use the same number that was used in table 6 above)	Explain why to use WTP/WTA method	Final value determined for quantity changed between 2000 and 2010 indicated in table 7 above (VND/year)

PART 4: CHANGE OF LIVELIHOOD DUE TO CHANGE OF ENVIRONMENT

9. Change in on-farm production

9.1 Rice production

Item	Unit	In 2000	In 2009
Area practiced	Ha		
Number of crop	Crop/year		
Average yield	Ton/ha/crop		
Output price	VND/kg		
Total cost	VND/ha		
Net benefit	VND/ha		

9.2 Shrimp production

Item	Unit	In 2000	In 2009
Area practiced	Ha		
Number of crop	Crop/year		
Average yield	Kg/ha/crop		
Output price	VND/kg		
Total cost	VND/ha		
Net benefit	VND/ha		

9.3 Fish production

Item	Unit	In 2000	In 2009
Area practiced	Ha		
Number of crop	Crop/year		
Average yield	Kg/ha/crop		
Output price	VND/kg		

Total cost	VND/ha		
Net benefit	VND/ha		

9.4 Pig production

Item	Unit	In 2000	In 2009
Number of head	Head/year		
Total prodction	Kg/year		
Output price	VND/kg		
Total cost	VND/ha		
Net benefit	VND/ha		

9.5 Chicken/Duck production

Item	Unit	In 2000	In 2009
Number of head	Head/year		
Total production	Kg/year		
Output price	VND/kg		
Total cost	VND/ha		
Net benefit	VND/ha		

9.6 Fruit production

Item	Unit	In 2000	In 2009
Names of major fruits			
Total production	Kg/year		
Output price	VND/kg		
Total cost	VND/ha		
Net benefit	VND/ha		

9.7 Vegetable production

Item	Unit	In 2000	In 2009
Name of major vegetables			
Total production	Kg/year		
Output price	VND/kg		
Total cost	VND/ha		
Net benefit	VND/ha		

9.8 Handicraft business

Name of Job	Number of persons involved	Net benefit earned in 2000 (VND)	Net benefit earned in 2009 (VND)

10 Change in health care for diseae related to water quality change

Disease name	Status of disease (+/_)	Cost of health care in 2000 (VND/year)	Cost of health care in 2009 (VND/year)

11 Sale and home use of agriculture & aquaculture products produced at farm in current year

Product	Total product in 2009 (ton)	Sold products (ton)	Home used (ton)
Rice			
Shrimp			
Fish			
Pig			
Chicken			
Duck			
Fruit			
Vegetables			
Others			

12 Change in boat travel cost due to dike system built during last 10 years within the village?

- Number of times per month that you have to pay for the boat carrying service when you go through?

- Cost of per payment? _________________ (VND)

13 Change of machine repair costs

Machine/Asset	Quantity (2000)	Quantity (2010)	Cost of repairs in 2000 (VND/year)	Cost of repairs in 2009 (VND/year)
Agricultural machines				
Electric pumps				
Motorbike				
Motor boat				
Other (please specify)				

14 Other changes to be added by respondent

PART 5: GENERAL ECONOMIC ASSESSMENT

15 Whether or not your household uses plants and animals in the natural environment, you might or might not gain pleasure from changes in the health and abundance of plants and animals. Hence, we ask you to consider the following questions

A. Given your observations of any changes in the health and abundance of plants in the natural environment, do you perceive any values or costs, due to those changes?

_____ Yes   _____ No

If "Yes," please explain the types of values or costs you perceive.

B. Given your observations of any changes in the health and abundance of animals in the natural environment, do you perceive any values or costs, due to those changes?

_____ Yes   _____ No

If "Yes," please explain the types of values or costs you perceive.

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16 Suppose the Provincial Government is considering the possibility of ending its program of modifying sluice gate operations to improve water quality in the region, due to the cost of maintaining the program. If the sluice gate program is ended, water quality will return to the conditions observed previously, before the program was implemented.

Suppose also that the Provincial Government is willing to continue the sluice gate program if households in the region are willing to contribute to the cost of operating and maintaining the gates. All households would be asked to contribute the same amount per year.

Please consider the following payment possibilities from the perspective of your household.

A. The maximum amount that my household would be willing to pay to ensure that the modified sluice gate operations are continued is the following.

$0.00 per month _____

$1.00 per month _____

$2.00 per month _____

$3.00 per month _____

$4.00 per month	_____
$6.00 per month	_____
$8.00 per month	_____
$10.00 per month	_____
$_____ per month	_____

B. If your response, above, is greater than zero, please indicate the proportion of the payment amount that you would attribute to the benefits you receive through: 1) the water quality impacts on rice or fish production, 2) the water quality impacts on other livelihood activities, and 3) the values you obtain by harvesting plants or animals in the natural environment, and 4) the non-monetary values you perceive by knowing that the health and abundance of plants and animals have been improved.

My household's maximum payment, from above, is: $_____ per month.

17 I consider that this amount reflects the following distribution of benefits from improvements in water quality:

Impacts	Proportional Allocation
1. The water quality impacts on rice or fish production	______%
2. The water quality impacts on other livelihood activities	______%
3. The values we obtain by harvesting plants or animals in the natural environment	______%
4. The non-monetary values we perceive by knowing that the health and abundance of plants and animals have been improved.	______%

Please note: The sum of these proportions must be 100%

16. Thank you very much for answering these questions. I appreciate your time and effort in considering the questions very much.

Before we end the survey, are there any other characteristics or concerns regarding the changes in sluice gate operations that you think we should consider in our work?

If so, please feel free to let me know these additional characteristics or concerns. Thank you very much.

Additional characteristics or concerns: