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Autonomous adaptation to climate change by shrimp and catfish farmers in Vietnam's Mekong River delta

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Disclaimer

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Intensive shrimp pond, Bac Lieu province, Mekong River delta, Vietnam

Executive Summary

The Mekong River delta of Vietnam supports a thriving aquaculture industry but is exposed to the impacts of climate change. In particular, sea level rise and attendant increased flooding (both coastal and riverine) and coastal salinity intrusion threaten the long-term viability of this important industry. This working paper summarizes an analysis of the economics of aquaculture adaptation in the delta, focusing on the grow-out of two exported aquaculture species—the freshwater striped catfish and the brackish-water tiger shrimp. The analysis was conducted for four pond-based production systems: catfish in the inland and coastal provinces and improved extensive and semi-intensive/intensive shrimp culture.

The approach taken was first to understand the potential impacts of climate change on these systems. Farm-level costs and benefits were then analyzed under scenarios of climate change with autonomous adaptation, and with no climate change. The analysis was done for two time periods, from 2010–2020 (where projections of climate change impacts on input costs and price changes could be made with relative confidence) and from 2021–2050 (where projections become more uncertain).

Results and policy implications

The results suggest that shrimp farmers overall are able to bear the cost of adaptation over a longer time frame than catfish farmers. Indeed, catfish farmers already operate at the brink of economic viability, and climate change decreases even further their expected profitability. This conclusion suggests that major re-structuring of the industry is needed to reduce input costs or transfer profit margins down the value chain to the producers. The high level of capitalization and integration of the catfish industry could be an asset when designing adaptation strategies along the value chain and implementing adaptation cost-sharing mechanisms among different actors in the value chain.

The shrimp industry is more mature and less capitalized and so will remain profitable for longer than catfish under a climate change scenario. Despite its lower profitability compared with the semi-intensive/intensive system, improved extensive shrimp culture is more sustainable, both environmentally and economically, especially for small-scale farmers.

For both species, autonomous adaptation costs borne by farmers can be reduced or offset by planned adaptation measures, such as construction of coastal and river dikes to control floods and intrusion of saline waters into the delta, while providing ancillary benefits to other economic sectors. On the other hand, complete polderization of the delta would reduce opportunities for expanding brackish-water aquaculture. A more thorough integrated assessment of the economics of planned adaptation is needed to examine trade-offs in costs and benefits of adaptation options among sectors.

The study raises policy issues that need to be addressed regarding Vietnam's aquaculture in an increasingly uncertain future. The scale of the aquaculture sector in the Mekong River delta has increased more than fivefold over the last decade. If the industry is of sufficient economic importance nationally, then adaptation plans for climate change in the Mekong River delta need to take into account the potential impacts on aquaculture development trajectories in synergy with fisheries, land use and aquaculture planning, and coastal protection. It is also important to recognize that adaptation to climate change cannot be divorced from the broader processes by which the sector reaches maturity after a period of exceptional growth.

If the industry is to continue to prosper, it will require changes in farming practices, marketing, investment and many other activities. It is therefore important to consider other investments—besides those related directly to adaptation—that are required to ensure that the aquaculture sector is able to respond to both a changing climate and a changing domestic economy and global market. While some of the specific costs of climate change adaptation may be identified for analytical purposes, the reality will be one of continuous change in response to a wide variety of economic, physical and climatic factors in which the specific role of adaptations to a changing climate may be difficult to single out.

Diversification into more ecologically sustainable and diversified production systems will hedge the aquaculture industry against increasing risks to shrimp and catfish farming and the uncertainties brought about by climate change.

Critical issues when estimating costs of adaptation

This study, the first of its kind in the region, raises a number of methodological issues for more detailed economic assessments of climate change impacts and adaptation in the aquaculture industry. These include the following:

1. Modeling of the impact of climate change on growth, production and yield of cultured species is urgently needed to enable better estimation of projected farm yields under different climate change scenarios and management responses.
2. New thinking and approaches are needed to address the constraints of conventional economic analysis tools such as cost-benefit analysis.
3. An interdisciplinary approach, using qualitative and quantitative methods, is needed to better understand farmer preferences, willingness and ability to adapt to climate change.
4. It is pertinent to extend the farm production-level analysis further along the value chain for a broader impact and adaptation assessment.
5. It is also pertinent to embed assessment of climate change impacts into a broader economic assessment of how the aquaculture sector might respond to a changing climate and a changing domestic economy and global market.
6. From a cross-sectoral perspective, it is imperative to adopt a holistic land- and water-use planning approach to explore synergies in adaptation and mitigation strategies between coastal protection, agriculture, aquaculture and fisheries to derive greater co-benefits from these strategies.

Catfish ponds, An Giang province, Mekong River delta, Vietnam

1. Introduction

Aquaculture is one of the fastest-growing animal food-producing sectors in the world. In 2008, aquaculture accounted for 46% of the global food-fish supply, and per capita supply from aquaculture increased from 0.7 kg in 1970 to 7.8 kg in 2008, an average annual growth rate of 6.6% (FAO 2010). In developing countries, the sector contributes significantly to livelihoods and food security, especially in the Asia-Pacific region. In 2006, developing countries accounted for the majority of aquaculture production, with the Asia-Pacific region alone accounting for almost 90% of total aquaculture production (FAO 2009). The Asia-Pacific region has been identified as one of the most vulnerable to climate change, and the potential impacts of climate change will pose significant challenges to aquaculture productivity and dependent livelihoods in the region. Adaptation is urgently needed to foster the resilience of this dynamic sector.

Adaptive strategies can take the form of either processes, actions or outcomes in order to better adjust to, cope with and manage changing conditions (Smit and Wandel 2006). Adaptation mechanisms can be differentiated along several dimensions: by the purposefulness of adaptation (whether the adaptation is planned or unplanned), by the timing of implementation, by spatial and temporal scale, by sector of activity, or by which actors are designing and implementing the mechanisms (Adger et al. 2007; Smit et al. 1999). However, merely identifying a suite of potential adaptation options will not be a sufficient basis for decision making. Better estimates of the benefits and costs of adaptation interventions are needed to guide design and prioritization at the policy level (Heltberg et al. 2009). This study focuses on autonomous adaptation at the farm level and draws implications for planned adaptation to address farm-level issues. We define autonomous adaptation and planned adaptation in Box 1. While households have already responded to localized manifestations of climate variability and emerging climate risks, governments can play a role in enhancing the adaptive capacity of farmers.

The first objective of this paper is to present an economic analysis of the direct costs of implementing a series of adaptation options at the farm level for the aquaculture sector in Vietnam. This is the first study that quantitatively explores the costs of adapting aquaculture to climate change in the Vietnam Mekong River delta for the two main export-oriented species, namely the brackish-water tiger shrimp (*Penaeus monodon*) and the freshwater striped catfish (*Pangasianodon hypophthalmus*). The second objective is to discuss critical issues when undertaking economic analysis of adaptation options in aquaculture and the research gaps that need to be filled in order to support follow-up studies on the economic impact of and adaptation to climate change.

Box 1. Autonomous and planned adaptation.

Autonomous adaptation does not constitute a conscious response to climatic stimuli but is triggered by ecological changes in natural systems and by market or welfare changes in human systems. It is when actors respond ‘spontaneously’ to climate change. In aquatic agricultural systems, autonomous adaptation can include changes in cultivation type and timing or changes in irrigation schemes, for example.

Planned (*policy-driven*) adaptation is the result of a deliberate policy decision to respond to climate change in order to return to, maintain or achieve a desired state and can help reduce or offset the impacts of climate change. While actors at the farm level can make informed and deliberate decisions, unless these strategies are the outcome of a plan by a public agency or government, these decisions are considered autonomous. Examples of planned adaptation would be government investment in research on salinity-resistant crops, changes in land allocation and reforestation policies, subsidies at the farm level for dike construction, or major infrastructure investment such as in sea defenses.

Source: Adapted from EEA (2007); IPCC (2001).

The working paper begins by characterizing the shrimp- and catfish-farming industry in Vietnam in section 2. Section 3 describes assessment methods and an analysis of the potential impacts of climate change on aquaculture in the Mekong River delta. The identification of potential impacts on the four production systems and their implications for farm operations, identified in section 4, are used to formulate adaptation options. In section 5, the estimated costs of autonomous adaptation at the farm level are presented. The policy implications of the results for Vietnam, as well as a discussion of the assessment methods and identification of further research priorities, are discussed in sections 6 and 7.

2. Shrimp and catfish farming in the Mekong River delta of Vietnam

The Mekong River delta of Vietnam supports a thriving aquaculture industry. Its coast and extensive floodplain have been modified by an intricate system of canals, embankments and water-control structures to provide a mosaic of freshwater, brackish-water and marine environments that accommodate diverse aquaculture systems producing a variety of fish, shrimp and mollusk species. The aquaculture industry in the delta is dominated by pond culture of shrimp (mainly the black tiger shrimp, *Penaeus monodon*) and the striped catfish (*Pangasianodon hypophthalmus*). The delta accounted for about 80% of the country's total shrimp production in 2008 and has also increased its share of the country's cultured fish production from 67% in 2005 to an estimated 76% in 2008, mainly due to the expansion of the catfish industry (GSO 2008). Pond culture of brackish-water shrimp accounts for 71% of the total aquaculture area, while freshwater catfish culture dominates production, accounting for 47% of total aquaculture production in the delta (GSO 2008).

The spatial distribution of cultured shrimp and fish production in the delta reflects the geographical separation between the brackish-water environment of the coastal provinces and the freshwater regime of the inland provinces (Figure 1). Culture of catfish started with *Pangasius bocourti* ('Cá Ba Sa' in Vietnamese) in the 1960s using floating cages, but has since been almost completely taken over by culture of the export-oriented striped catfish ('Cá Tra') in earthen ponds sited adjacent to rivers to permit a high level of water exchange. Since 2002, with relaxation of land zoning for catfish production, farms have expanded from the inland provinces towards the coast—as far downstream as the water salinity conditions are tolerable to the riverine catfish—taking advantage of the stronger tidal movement to lower water-pumping costs.

Extensive shrimp grow-out takes place in large coastal ponds relying upon tidal water exchange. These farms are stocked from hatcheries and use limited amounts of fertilizer and artificial feed to promote the natural growth of organisms to feed the shrimp; hence the production system is often recognized as the "improved" extensive type. Semi-intensive or intensive grow-out methods use smaller ponds and higher stocking rates, relying upon water pumps and aeration to maintain water quality and making use of a variety of formulated feedstuffs. The black tiger shrimp is still the dominant species cultured in the delta, although the recent introduction of the Pacific white leg shrimp (*Litopenaeus vannamei*) has seen increased production of this species.

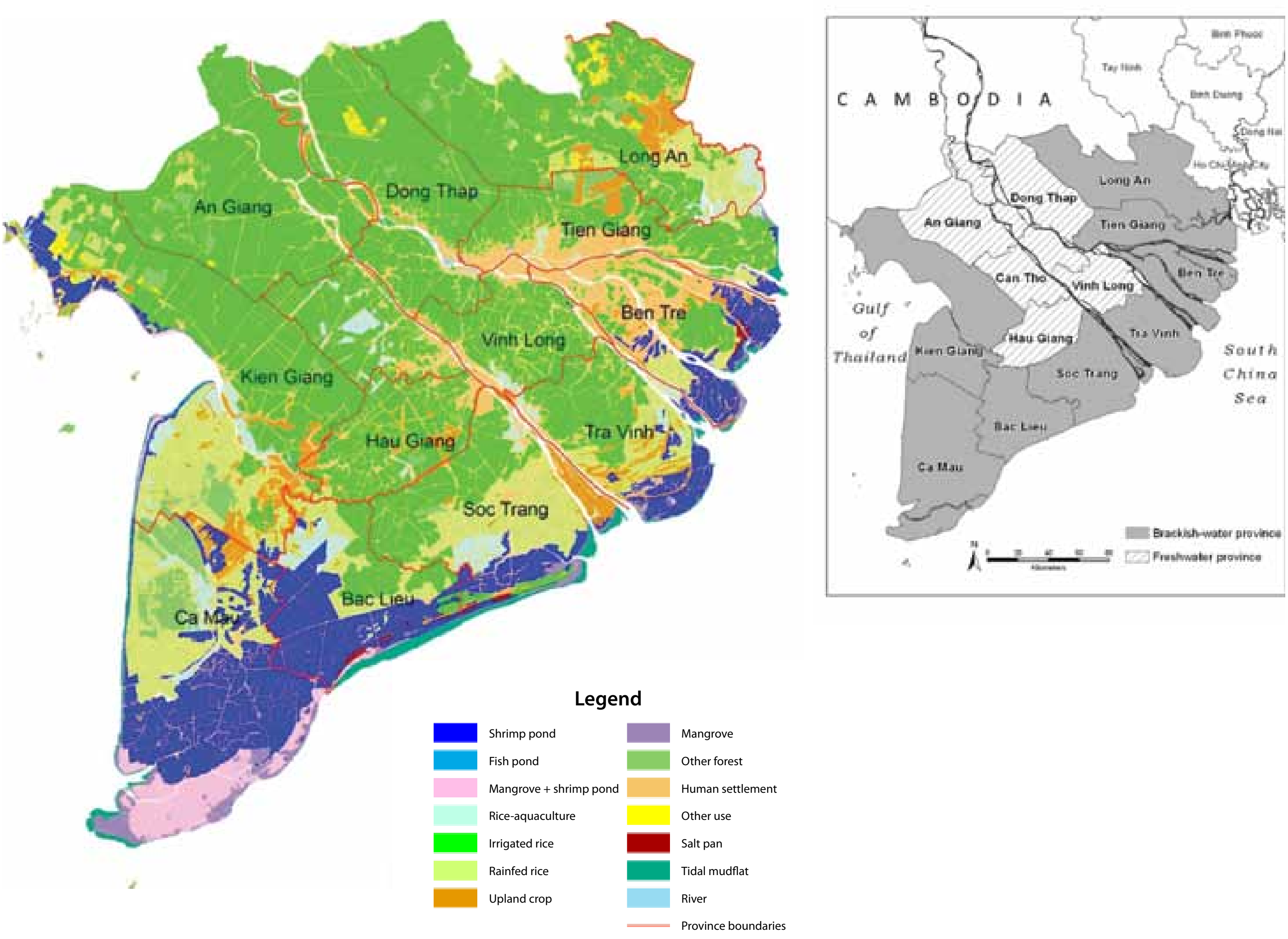

Figure 1. Land use in the Mekong River delta, 2007.
Source: The Sub-National Institute for Agricultural Planning and Projection (Sub-NIAPP), Vietnam.

The export-oriented aquaculture industry in the Southeast Asian region, including Vietnam, is highly dynamic, volatile, and subject to economic boom and bust (Szuster 2003). It is constantly subjected to global fluctuations in demand (and hence price) and international pressure on product quality, production standards and food safety regulations. Vietnamese producers, as well as the government, are highly market-responsive and adapt quickly to changing situations. Climate change impacts constitute an additional driver of change to which they have to adapt. Because most aquaculture systems are situated in riverine and coastal environments, they are highly exposed and vulnerable to the impacts of climate change—not only the direct climatic parameters, such as temperature and rainfall patterns, but particularly sea level rise and consequent flooding and coastal salinity intrusion. Any increase in the intensity and frequency of extreme climatic events such as storms may affect aquaculture production by damaging production assets and transportation infrastructure required for access to markets. These impacts will have significant economic as well as livelihood and social costs to those dependent on the aquaculture industry.

This study focuses on the shrimp and catfish industries, which are the dominant sectors in both production volume and value. For catfish, the analysis focused on the pond culture system, as about 95% of the catfish are now cultured in ponds. For shrimp, the focus was on the black tiger shrimp as the dominant species. Four shrimp-farming systems exist in the Mekong delta (Lam and An 2008):

- *Improved extensive shrimp farming:* Stocking with lower density of *P. monodon* juveniles, typically 1–5 post-larvae (PL) m^{-2}, with resulting yields of 300–500 kg ha^{-1} $crop^{-1}$. This system is more popular in the coastal provinces.
- *Semi-intensive shrimp farming: P. monodon* seed stocked at higher density, typically 10–20 PL m^{-2}, with resulting yields of 1,500–2,000 kg ha^{-1} $crop^{-1}$.
- *Intensive shrimp farming: P. monodon* cultured at densities of 20–40 PL m^{-2}, resulting in yields of 4–9 t ha^{-1} $crop^{-1}$. The semi-intensive and intensive systems are concentrated in Soc Trang, Ben Tre and Tra Vinh provinces.
- *Mixed shrimp farming-mangrove forest:* Shrimp culture is fully reliant on natural seed and food chains; yields are typically 200–350 kg ha^{-1} $year^{-1}$. This system is concentrated in Ca Mau, Ben Tre, Kien Giang and Tra Vinh provinces.

Farming striped catfish in ponds is carried out at intensive scale, with stocking densities of 20–40 fingerlings m^{-2}, with resulting yields of 150–400 t ha^{-1} (Lam and An 2008).

Based on the shrimp and striped catfish industry review above, four production systems were selected for analysis—two for catfish and two for shrimp:

- Catfish (I) – pond culture of striped catfish in the inland provinces of An Giang, Dong Thap, Can Tho and Vinh Long;
- Catfish (C) – pond culture of striped catfish in the coastal provinces of Soc Trang and Ben Tre;
- Shrimp (Ext) – black tiger shrimp cultured at improved extensive scale, mainly in Ca Mau and Bac Lieu provinces; and
- Shrimp (SII) – black tiger shrimp cultured at semi-intensive/intensive scale in most other coastal provinces.

3. Assessment methods

3.1 Identifying impacts of climate change

We used a combination of qualitative and quantitative methods to assess potential bio-physical impacts of climate change on aquaculture. Reviews of the literature and secondary data, combined with consultations with local experts and stakeholders, provided information to determine exposure, sensitivity and potential adaptation options. Sensitivity related mainly to the physiological, biological and ecological responses of farmed species. Exposure related to the main climate and climate-related drivers triggering these responses, such as weather changes, sea level rise and storm surges. In this study, estimates of the extent of aquaculture area affected by salinity intrusion and tidal and riverine flooding are used as specific measures of exposure.

Increases in salinity intrusion and flooding in the Mekong River delta have been modeled by the Sub-Institute for Water Resources Planning (SIWRP) using the Vietnam River Systems and Plain (VRSAP) hydraulic and salinity model, which simulates water flow through the complex network of canals and the salinity control system (stretches of embankments with water-control sluices to protect areas from seawater intrusion) that already exist in many parts of the delta (SIWRP 2009). We did a Geographic Information Systems (GIS) overlay of the VRSAP results for a 50 cm sea level rise (SLR) scenario (provided by SIWRP) with the 2007 land use map for the delta (provided by the Sub-National Institute of Agricultural Planning and Projection) to estimate shrimp and catfish areas that will be affected by increments of maximum salinity during the dry season and maximum flooding during the rainy season.

3.2 Economic analysis of adaptation

Conceptually, the traditional approach to economic analysis of adaptation to climate change involves three steps (Boyd and Hunt 2006). The first step is to establish the projected baseline with no planned adaptation (1: Future Society, Climate Today). Next, estimates are made of the impact of climate change with no adaptation (2: Future Society, Future Climate). Lastly, an estimation is made of the change in climate risks from implementing adaptation policies and measures (3: Adapted Future Society, Future Climate). The impact of climate change on a production system is estimated as the difference between a world with climate change and no adaptation (2), and the projected baseline (1). The effects of adaptation are taken as the difference between a world with climate change and no adaptation (2), and a world with climate change and adaptation (3).

This traditional approach has merit, but its practical usefulness has been challenged. First, it is sometimes difficult to distinguish between impacts of and adaptation to climate change (EEA 2007). For instance, land abandonment due to sea level rise could, and often is, regarded as an impact, but it can also be a seen as a response to climate change (EEA 2007). Second, the focus is on planned adaptation without sufficient consideration of the costs of autonomous adaptation occurring at the farm level. Farmers will, and do, respond to changes in land and water availability, commodity prices, market incentives and climate variability by using different levels and combinations of inputs, altering culture species and production systems, adjusting the height of pond dikes, and increasing water volumes pumped into ponds. All of these constitute autonomous adaptation, where actors respond ‘spontaneously’ to climate change (Adger et al. 2007) and incur incremental capital investment at the farm level. Ignoring autonomous adaptation can lead to a serious overestimation of the impacts of climate change (Tol et al. 1998).

The ‘dumb farmer’ hypothesis is often used to represent the assumption that an impacted agent does not anticipate or respond to changed climate conditions but will continue to act as if nothing has changed. In contrast, it has been argued that most farmers are not completely oblivious but actually do adjust their practices in response to persistent climate changes (the ‘typical farmer’); some use available information on expected climate conditions to proactively adapt to climate change (the ‘smart farmer’), and still others claim perfect knowledge of future climate conditions and face no impediments to the implementation of adaptation measures (the ‘clairvoyant farmer’) (Fussel and Klein 2002). This typology is represented in Figure 2 against different interpretations of the term ‘impact’.

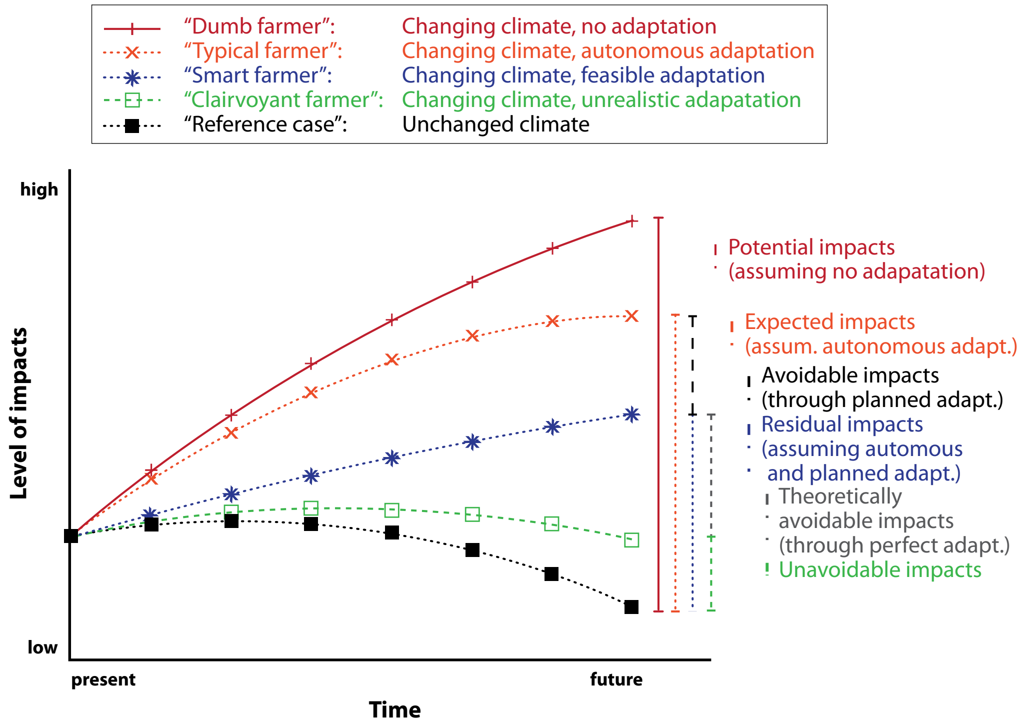

Figure 2. Typology of impacts based on adaptation levels.
Source: Adapted from Fussel and Klein (2002).

3.2.1 *Costs and benefits of farm-level autonomous adaptation*

In this study, we considered Vietnamese fish farmers as 'typical farmers' and calculated the expected impacts of climate change assuming autonomous adaptation. This means that the cost of climate change on aquaculture production at the farm level includes the cost of autonomous adaptation. The approach taken in the economic evaluation was first to conduct farm-level cost-benefit analysis (CBA) for freshwater catfish and brackish-water shrimp in the Mekong River delta under climate change with autonomous adaptation (CC) and non-climate change (NCC) scenarios for the 2010–2050 period. CBA is a conventional bottom-up economic approach for estimating impact and adaptation costs in climate change research and was chosen because it can rely on farm budget data. The main steps in the economic analysis at farm level are shown in Figure 3.

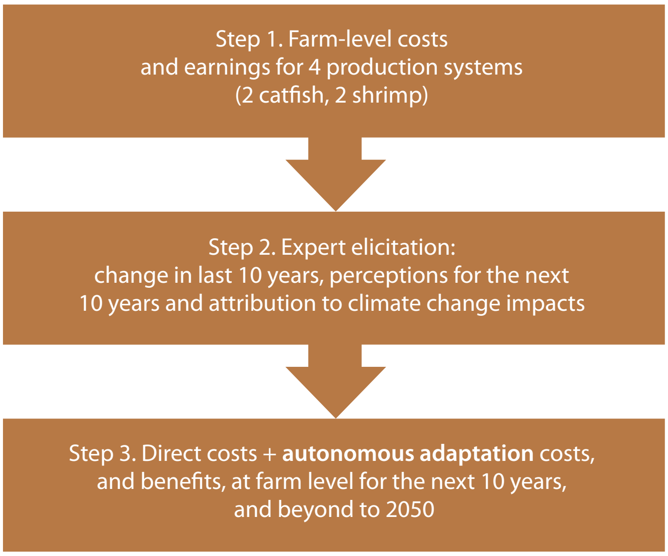

Figure 3. Steps in the farm-level economic analysis of costs and benefits of autonomous adaptation.

The farm-level analysis assessed the net benefits from shrimp and catfish farming grow-out operations. In Step 1, base production budgets for catfish and shrimp operations in the Mekong delta derived from a previous study (Sinh 2008) were compiled to estimate the current (2010) costs and benefits to farm operations. The data used represent means among farms (131 inland catfish farms, 60 coastal catfish farms, 50 extensive/improved extensive shrimp farms, and 50 intensive/semi-intensive shrimp farms) surveyed in the delta in 2008.

In Step 2, interviews were conducted with 13 stakeholders comprising shrimp and catfish farmers, provincial aquaculture staff (who also operate their own shrimp and catfish farms), and local university researchers specializing in aquaculture. The respondents were asked for their perceptions of changes over the last 10 years in farming shrimp and catfish, and the reasons for these changes. The focus was on variable inputs, such as land price, feed use (application rate, price) and seed use (rate, price). The reasons given for the changes were grouped into four categories: technical, market, pond environment and climate change, including climate variability. The respondents were asked to estimate the relative contributions they attributed to each of these four categories. The perceptions of the respondents were also elicited on how the changes in the variable inputs over the


Pelleted feed for catfish, An Giang province, Mekong River delta, Vietnam

past 10 years were foreseen to differ in the next 10 years (i.e., 2010–2020), both in terms of the magnitude and direction of changes. On this basis, these percentages were applied to current (2010) input costs and prices to derive projected values (in real terms) for the next decade to 2020. We assumed costs and prices changed linearly in between the anchor years of 2010 and 2020.

In Step 3, cost-benefit analysis was applied to farm-level production systems. Benefits from farm operations were measured by gross income while considering fixed and variable costs. Under the climate change (CC) scenario, the full value of input costs was used. For the no climate change (NCC) scenario, the percentages of costs due to climate change were omitted. As there was no information on expected changes beyond 2020, a linear extrapolation was used for the period 2021 to 2050, based on the average annual rates of change from 2010–2020.

The method and assumptions used in estimating the different components of benefits and costs in Step 3 are outlined below.

Gross income

Gross income (GR) was calculated as $GR = Y_i \times P_i$,

where Y_i is yield (t ha^{-1}) and P_i is farm-gate price of fish or shrimp;

i = extensive shrimp, semi-intensive/intensive shrimp, coastal

catfish and inland catfish.

Yield: Current yield (2010) was based on information from Sinh (2008) and stakeholder interviews. Depending on the responses of stakeholders, the 2010 yield was linearly increased or decreased to the 2020 level. To extrapolate from 2021 to 2050, the mean annual change (%) from 2010–2020 was applied from 2021 onwards.

Price: The current price of catfish and shrimp was assumed to be VND 17,000 kg^{-1} (the prevailing currency exchange rate at the time of study was VND 19,000 to the USD) and VND 100,300 kg^{-1}, respectively. Based on the opinions of stakeholders and aquaculture experts, who took into consideration the history and relative stability of the catfish and shrimp markets, the price of catfish was assumed to increase 35% between 2010 and 2020 (3% p. a.). Given that catfish is a growing market, it was assumed that catfish price would double from 2021 to 2050 (2.3% p. a.). Shrimp prices were expected to increase by a mean of 15% between 2010 and 2020 (1.4% p. a.). As shrimp is considered to be a more stable market than catfish, it was assumed that shrimp price would increase at the same rate of 1.4% per annum from 2021 to 2050.

Fixed costs

Fixed costs consisted of depreciation of ponds, depreciation of machinery and land taxes. Note that the production budget provided costs in terms of VND ha^{-1} crop^{-1}. These figures were multiplied by the mean number of crops year^{-1} for each type of farming system to provide costs expressed in VND ha^{-1} year^{-1}. Total fixed costs were adjusted to 2020 levels depending on the expected increase—doubling by 2020 for extensive shrimp, coastal catfish and inland catfish, and tripling for semi-intensive/intensive shrimp. Costs were linearly extrapolated from 2021 to 2050 based on the average of the annual rate of change from 2010 to 2020.

Variable costs

Variable costs consisted of feed, dike upgrading, pond preparation, seed, chemicals and drugs, fuel and electricity, harvest and transportation, labour, interest on loans, and miscellaneous items.

Feed cost

Feed cost (C_{feed}) was calculated as $C_{feed} = Y_i \times FCR \times P_{feed}$, where FCR is the feed conversion ratio (quantity of feed required per tonne of fish or shrimp yield), and P_{feed} is the price of feed (VND t^{-1}). The 2010 FCRs for shrimp and fish were linearly increased or decreased to the 2020 level. FCR for extensive shrimp was expected to decline by an average of 10%, while for SII shrimp, inland catfish and coastal catfish FCRs were expected to decline by an average of 5% by 2020. We assumed that FCR levels remained constant from 2021 to 2050. All shrimp and catfish feed prices were expected to increase in the range of 1.5 to 2.5 times by 2020. We assumed a linear increase from 2010 to 2020 prices, and applied the same magnitude of increase from 2010 to 2020 to projected prices from 2021 to 2050.

Dike upgrading

Two aspects of pond dike upgrading were considered. For ponds in areas not impacted by increased flooding due to sea level rise or its associated impact, river flooding in the wet season, the cost of dike upgrading pertains to routine maintenance without need for raising the pond dike. The cost for routine dike maintenance was provided in terms of area (VND ha^{-1}) from the field interviews and adjusted after consultation with local researchers. The cost was expected to increase by 67% for both catfish systems, 17% for extensive shrimp and 75% for semi-intensive shrimp over 10 years. Costs between 2010 and 2020 were linearly increased. The average of the annual rates of change in cost from 2010 to 2020 was then used to extrapolate for the period 2021 to 2050.

For ponds in areas expected to be impacted by increased flooding, the per hectare costs of raising the height of pond dikes (C_{dike_j})

for incremental height increases of j metre (j = 0, 0.5, 1.0, ...) were provided by field interviews and added to the cost for routine dike maintenance.

Seed cost
Seed cost (C_{seed}) was calculated as $C_{seed} = SD \times P_{seed}$,

where SD is the stocking density, given in the number of shrimp post-larvae ha^{-1} or number of fish ha^{-1}, and P_{seed} is the price of seed (VND $piece^{-1}$). Stocking density was expected to decrease for SII shrimp and inland catfish by 2020, while no change was expected for coastal catfish and extensive shrimp. A price of VND 663 $piece^{-1}$ was used for catfish (Phuong et al. 2007). By 2020, seed prices were expected to decrease by an average of 25% and 20% for SII and extensive shrimp, respectively, while prices for coastal and inland catfish were expected to increase by an average of 50% and 10%, respectively. To extrapolate seed cost from 2020 to 2050, the average annual rates of change in seed cost from 2010 to 2020 were applied to each year from 2021 onwards.

Pumping water from the Mekong River for catfish ponds

Chemicals and drugs
Cost of chemicals and drugs (C_{cd}) for catfish was calculated as $C_{cd} = Y_i \times P_{cd}$,

where P_{cd} is the price of chemicals and drugs per tonne of fish (VND t^{-1}). P_{cd} was expected to increase by an average of 2.25 times from 2010 to 2020, after which it was assumed to increase by 50% from 2021 to 2050. The prices in between the anchor years of 2020 and 2050 were linearly increased and so assumed a linear relationship between yield and the amount of chemicals and drugs required. Chemical and drug costs for shrimp were estimated per unit area (VND ha^{-1}) and were expected to increase on average 2.5 times for extensive shrimp and to double for semi-intensive shrimp by 2020. To extrapolate chemical and drug costs from 2021 to 2050, the average of the annual rates of change in cost from 2010 to 2020 was applied to each year from 2021 onwards.

Pond preparation
Cost for pond preparation was estimated per area (VND ha^{-1}) and was expected to increase on average 20% for both catfish systems, 35% for extensive shrimp, and 2.5 times for semi-intensive shrimp. Costs in between 2010 and 2020 were linearly increased. The average of the annual rates of change in cost from 2010 to 2020 was then applied to extrapolate for the period 2021 to 2050.

Fuel and electricity, labour, harvest and transportation, interest on loans, and miscellaneous items
For this group of inputs, the 2010 costs were used for both catfish and shrimp. As with fixed costs, the production budget figures were estimated in terms of VND ha^{-1} $crop^{-1}$ and were converted to VND ha^{-1} $year^{-1}$. For each input, rates of change from 2010 to 2020 are outlined below. To extrapolate from 2021 to 2050, the average of the annual rates of change in cost from 2010 to 2020 was applied to each year from 2021 onwards.

Fuel and electricity: Costs were assumed to increase by 10% by 2020 for extensive shrimp, and 20% for semi-intensive shrimp and both catfish systems. For coastal catfish, adjustments were made for increases in fuel and electricity costs under the 'with CC' scenario to account for increased pumping of water into the ponds when increased water salinity at high tide will offset the advantage of using the tidal fluctuation to save on pumping costs. It was assumed that the fuel and electricity cost for the coastal catfish system would increase to 67% of that for the inland catfish system by 2020, and equal that for the inland catfish system by 2050.

Labor: This was expected to increase on average 75% by 2020 for extensive shrimp and inland catfish, 125% for SII shrimp, and 100% for coastal catfish.

Harvest and transportation, interest on loans, miscellaneous items: No stakeholder information on expected changes to these costs was available. It was therefore assumed that harvest and transportation and miscellaneous costs from 2010 to 2050 would increase by the annual inflation rate. Data on the annual percentage change in inflation for Vietnam from 2010 to 2014 was available from the IMF World Economic Outlook Database.[1] The average of the annual rate change from 2010 to 2014 (7%) was applied for the period 2015 to 2020. It was assumed that interest on loans would increase by 2.5% from 2010 to 2020. This is a conservative estimate given recent rises in commercial interest rates.[2]

In calculating the net benefits from shrimp and catfish grow-out operations, all costs and prices were treated in nominal terms. The flow of yearly net benefits was discounted by a real discount rate (nominal market discount rate minus inflation rate) and summed up to provide the net present value (NPV) of shrimp and catfish farming under CC and NCC scenarios. Based on the commercial bank prime lending rate for Vietnam of 13% per annum for 2010[3] and an inflation rate of 7% per annum,[4] an annual real discount rate of 6% was used for discounting the flows of future costs and benefits.

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[1] *Source*: http://www.imf.org/external/pubs/ft/weo/2012/01/weodata/index.aspx.
[2] *Source*: Vietnam Business Forum, www.vibforum.vcci.com.vn.
[3] *Source*: CIA – The World Factbook: Vietnam. https://www.cia.gov/library/publications/the-world-factbook/geos/vm.html (accessed 10 March 2010).
[4] *Source*: World Economic Outlook Database Oct 2009 report (downloaded from IMF website 10 March 2010).

3.2.2 Offsetting autonomous adaptation costs with planned adaptation measures

While there will be substantial autonomous adaptation at the farm level, farmers could benefit from planned adaptation measures such as external support to increase resilience. We illustrate the consideration of benefits to the aquaculture sector due to planned adaptation measures by determining the extent that costs of farmers' autonomous adaptation could be offset by specific public adaptation actions. We use the case of public investment in constructing river dikes to prevent inland river flooding and sea dikes to prevent tidal intrusion as an example whereby a planned adaptation measure can offset on-farm costs of upgrading dikes and increased costs in electricity and fuel in response to CC-related impacts of increased flooding and salinity intrusion. We then consider that any public investment aimed at reducing salinity intrusion and flooding in the Mekong River delta that matches these costs is likely to benefit the aquaculture sector by reducing or offsetting the costs that farmers would have to bear for autonomous adaptation.

We limited the industry-level analysis to the 2010–2020 period as projected production area estimates were available only until 2020. Pond dikes were assumed to be raised in stages as flood waters increase in depth as a result of gradual sea level rise. The years in which dikes were expected to reach different heights, and hence additional costs for raising dikes would take effect, were set on the assumption of a linear increment of flooding depth with incremental sea level rise over the 2010–2020 period. The industry-level cost incurred by farmers to raise pond dikes in response to incremental increases in flooding depth was calculated for each year as follows:

$\sum \Delta A_{impact\_j} \times C_{dike\_j}$,

where ΔA_{impact_j} is the annual incremental production area impacted by flooding and C_{dike_j} is the per-hectare cost of raising dikes for incremental height increases of j metre (j = 0, 0.5, 1.0, ...). The total current production area that would be impacted by flooding (A_{impact}) and the proportions of pond area subjected to different dike height increases were estimated from GIS overlay of shrimp and catfish aquaculture maps with the SIWRP maps of maximum flooding depth for the 50 cm SLR scenario. We estimated the 2020 impacted areas for each production system by applying an 'area ratio' between the 2020 and 2010 projected production areas provided by the Vietnam Ministry of Agriculture and Rural Development (MARD 2009) and assumed an annual linear increment of affected area over this 10-year period.

In a similar manner, the industry-level cost incurred by farmers on additional electricity and fuel use associated with pumping freshwater into the ponds in response to incremental increases in water salinity was calculated for each year as follows:

$A_{impact} \times C_{elecfuel}$,

where A_{impact} is the annual incremental production area impacted by increased salinity and $C_{elecfuel}$ is the per-hectare additional electricity and fuel cost for water pumping. The per-hectare costs for electricity and fuel were based on local knowledge, while GIS overlay of shrimp and catfish aquaculture maps with the SIWRP maps of maximum water salinity for the 50 cm SLR scenario provided estimates of pond areas affected by increments in salinity due to sea level rise.

4. Potential impacts of climate change on aquaculture in the Mekong River delta

According to the climate change scenarios officially released by the Government of Vietnam for the seven ecological regions of the country (MONRE 2009), the southern region where the Mekong River delta is situated will experience temperature increases of 0.4°C to 1.0°C from 2020–2050, beyond which increases are projected to be more rapid, reaching 1.4°C, 2.0°C and 2.6°C respectively for the three Intergovernmental Panel on Climate Change (IPCC) B1, B2 and A2 Special Report on Emissions Scenarios (SRES). The increases in air temperature would be within the tolerance range of the main cultured species, which is 29.8 ± 1.0°C for shrimp (Duong 2006) and 28–30°C for river catfish (Hargreaves and Tucker 2003). The main effect of temperature rise is increased metabolic rate, which may enhance growth rates provided that feeding is correspondingly increased, hence incurring higher cost but reduced time to grow to the preferred size.


Sampling catfish from pond, An Giang province

Higher air and water temperatures may lead to higher organic decomposition rates, which may lead to fouling of the water, particularly in closed-culture systems such as ponds. Decreased dissolved oxygen may require more aeration, particularly in intensive culture of shrimp, which is more sensitive to reduced oxygenation than catfish. River catfish can better tolerate poor water quality, including high organic matter or low dissolved oxygen levels. Farmers may increase aeration of pond water, but this would incur additional electricity and fuel costs, especially if water exchange is done through pumping. Energy-efficient water aeration, re-circulation systems, increased use of tidal flow and new pond designs (depth, compaction) are other adaptation options that have synergies with mitigation that farmers could undertake. As pond size and volume become smaller during drought, best management practices that include reduced feeding and reducing the number of operational ponds might be useful adaptation options.

Annual rainfall in the Mekong River delta is projected to increase by 0.7% to 1.7% by 2050 and by 1.0% to 4.1% by 2100 (MONRE 2009). The dry seasons, during March–May, are projected to get drier. Projected reductions in rainfall during the dry season due to climate change would be in the range of -7.1% to -9.1% by 2050 and -9.3% to -22.2% by 2100. The wet seasons are projected to get wetter, with rainfall in June–August increasing 0.1% to 2.1% by 2050 and 0.2% to 5.0% by 2100. Disease outbreaks in catfish typically occur at the start of the rainy season and the end of the flood season (Poulsen et al. 2008) and could increase under a scenario of 'wetter wet seasons,' leading to an increased use of antibiotics.

In general, the effects of projected changes in localized rainfall on water availability for aquaculture ponds are not likely to be as significant as those of changes in sea level and upstream hydropower development in the Mekong Basin. Aquaculture ponds are dependent on freshwater supply from rivers and canals, rather than directly from rainfall. Projections of climate-related changes in mean annual flow in the Mekong River range from 5% (Hoanh et al. 2003) to 20% (Eastham et al. 2008). In comparison, 27 planned large hydropower projects in the Mekong are projected to increase dry season flows by 10–50% and decrease wet season flows by 6–16% (Hang and Lennaerts 2008).

Changes to the hydrological cycle accompanying global warming (both over the land and the sea) are expected to be the most significant aspect of climate change to affect the fisheries and aquaculture sector. These include not only changes to air (and sea) temperatures and precipitation patterns, but also changes to sea levels and to monsoon and coastal extreme events, including frequency and magnitude of these climatic events.

Figure 4 shows where increments in maximum water salinity under the 50 cm sea level rise scenario are projected to occur during the dry season, assuming no additions to current hydraulic structures (SIWRP 2009). This will affect an estimated 224,600 ha (or 55%) of the shrimp-farming area in the delta. Almost 80% of this area experiences salinity increments of 2 ppt or less in the dry season. Short-term increases in salinity would not directly affect shrimp survival rates if kept within the range of 10–35 ppt, but the tolerance range may be further limited by disease.[5] For most of the other parts of the delta that are already protected from salinity intrusion by existing water control infrastructure, increments in maximum salinity are relatively smaller, not exceeding 1 ppt. Where catfish rearing has expanded towards the coast, in Vinh Long and Ben Tre provinces, ponds may be exposed to slightly higher salinity levels.

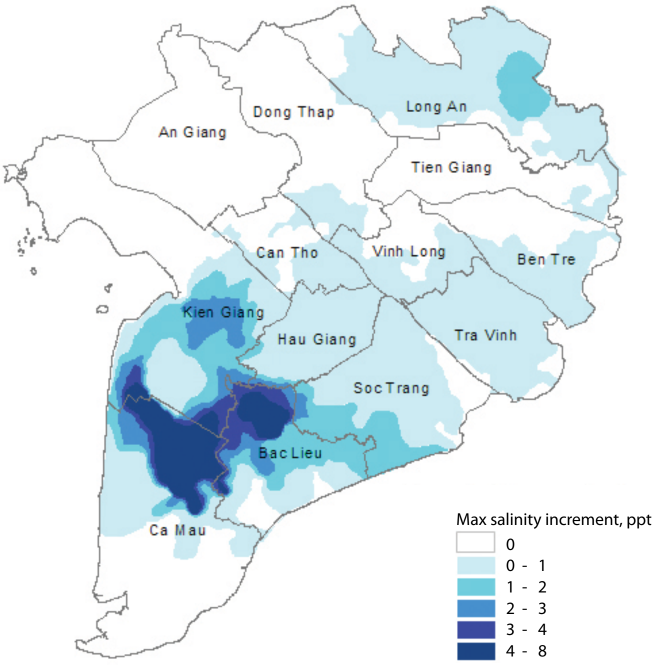

Figure 4. Increment of maximum salinity intrusion (ppt) during the dry season for 50 cm sea level rise scenario.
Source: SIWRP (2009).

The effect of sea level rise on increased flooding will be more widespread throughout the delta (Figure 5), compared with its effect on salinity intrusion. Increased flooding will be felt not only in the coastal areas not protected by sea dikes, but also in the flood-prone inland provinces in the upper delta. The higher tidal ingress due to sea level rise will obstruct river discharge into the sea and exacerbate riverine flooding in these provinces. Figure 5 shows the projected increase in maximum flood levels during the rainy season for a 50 cm sea level rise scenario, superimposed with locations of catfish pond areas in each province. The greatest increments in flooding depth are projected to occur in the An Giang, Dong Thap and Can Tho provinces, which have the largest concentrations of catfish farms in the delta. These provinces already experience floods from the annual discharge of the Mekong River during the rainy season, and catfish farmers have been coping with these seasonal floods by raising the height of pond dikes. The extensive areas of flooding in the coastal provinces are expected to affect large areas of shrimp ponds, even though the water depths from increased flooding are generally lower than in the inland provinces.

The increased water salinity, plus higher evaporation rates from ponds due to elevated air temperature, would also increase pumping of freshwater into the ponds, hence incurring additional electricity and fuel costs in operating the aquaculture farms.

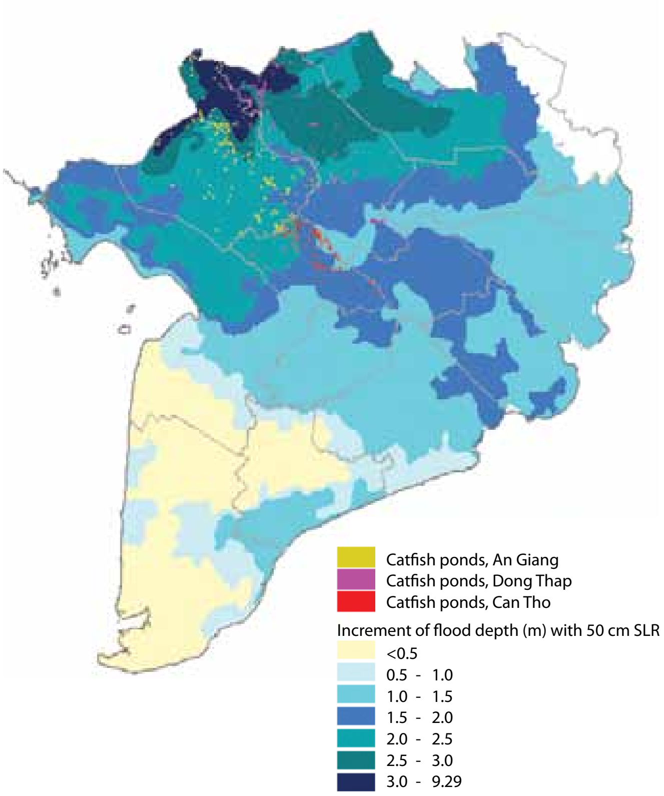

Figure 5. Increment of maximum flood level (m) during the rainy season for 50 cm sea level rise scenario, with location of catfish farms.
Source: SIWRP (2009).

Because of its southerly location, the Mekong River delta is generally spared from the frequent typhoons and tropical storms that hit Vietnam's central and northern coasts. Of the 62 extreme events recorded over the 1989–2008 period,[6] only one major typhoon (Typhoon Linda) hit the southern tip of the Vietnamese coast in 1997 and badly affected the provinces of Bac Lieu and Ca Mau. This typhoon caused as much damage to aquaculture, and twice as much loss of fish and shrimp, as all the 61 other events combined. This shows that a major extreme event hitting the delta, however infrequently, can severely affect Vietnam's aquaculture industry, which is concentrated there. Because fewer models have simulated CC impacts on tropical storms than those simulating temperature and precipitation changes and sea level rise, there is less certainty about the changes in frequency and intensity of tropical storms on a regional basis than for temperature and precipitation changes. The results of one simulation study (Stowasser et al. 2007) suggest that increases in tropical storm frequency are statistically significant in the South China Sea under a scenario of six-fold increase in CO_2 concentration in the atmosphere. Whether the trajectories of tropical storms of the future would shift further south, and therefore affect the Mekong River delta with greater frequency, remains uncertain. The extreme coastal event factor has not been taken into consideration in this study, which focuses on autonomous adaptation by farmers to the gradual impacts of climate change rather than response to and rehabilitation from major disasters.

[5] Interview during inception visit in October 2009 with Dr. Nguyen Van Hao, Director of RIA2, Ho Chi Minh City.
[6] Downloaded from the Natural Disaster Mitigation Partnership (NDMP) website, http://www.ccfsc.org.vn/ndm-p/?ln=en&sid=NDMP.

A summary of the relative importance of environmental changes brought about by climate change impacts for the four aquaculture production systems being studied (Table 1) guided the identification of the major farm operation costs related to adaptation responses that farmers would undertake.

Table 1. Relative importance of environmental changes across production systems.

	Temperature rise	Drier dry season	Wetter wet season	Sea level rise: flooding	Sea level rise salinity intrusion
Catfish – "coastal"	**Low:** catfish ponds are deep, and there is considerable water mixing because of continuous water pumping	**Low:** water supply is through pumping from river; catfish farms are located very near to rivers and major canals	**Medium:** may add to the impact of river flooding	**Medium:** increased water level due to SLR	**High:** due to tidal ingress up the rivers in the dry season
Catfish – inland			**High:** will add to the impact of deep-river flooding	**High:** due to deeper river flooding	**Low:** out of reach of salinity intrusion
Shrimp – improved extensive	**High:** ponds are relatively shallower, with large surface area and limited circulation (aerators not used)	**High:** increased competition for freshwater supply to counteract salinization of pond water due to salinity intrusion	**Medium:** additional water supply for ponds, but increase in wet season rainfall is minimal	**High:** for areas not protected by sea dikes and considering large pond size and longer perimeter	**High:** particularly in areas not protected from salinity intrusion
Shrimp – semi-intensive/intensive	**Medium to high:** depending on amount of organic debris and leftover feed that are subject to decomposition			**Medium:** for areas not protected by sea dikes	

5. Costs of adaptation to climate change impacts

5.1 Costs of autonomous adaptation at farm level

Base production budgets from Sinh (2008) used for cost-benefit analysis of striped catfish and shrimp culture are presented in Tables 2 and 3. Feed constitutes the largest cost in aquaculture production, accounting for 82% and 84% of the variable costs for inland and coastal catfish farms (Table 2) and 53% and 66% of variable costs for semi-intensive/intensive and improved extensive shrimp farms (Table 3), respectively. Seed and bio-chemicals account for the next largest costs for both catfish and shrimp production, with bio-chemicals taking up a high 11% of the variable costs in the semi-intensive/intensive shrimp system.

Table 2. Base production budget for inland and coastal catfish farms.

Input (VND million ha^{-1} crop^{-1})	Inland (N=131)	Coastal (N=62)
Gross Income	4868.9	3738.1
Total Costs	4616.8	3644.7
Total Fixed Costs	20.9	28.3
- Depreciation of ponds	11.6	17.15
- Depreciation of machinery	7.17	8.15
- Land taxes	2.13	3.0
Total Variable Costs	4596.1	3616.4
- Pond preparation	23.6	27.2
- Seed	329.1	263.7
- Feed	3772.5	3051.2
- Chemical and drugs	205.4	152.4
- Dike upgrading	11	4.6
- Fuel and electricity	48.7	7.7
- Harvest and transportation	28.8	25.4
- Labour	39.2	44.7
- Interest on loans	127.4	33.9
- Miscellaneous	10.4	5.6
Net Income	252.1	93.4

Source: Sinh (2008).

Table 3. Base production budget for improved extensive and semi-intensive/intensive (SII) shrimp farms.

Input (VND million ha^{-1} crop^{-1})	Inland (N=50)	Extensive (N=50)
Gross Income	431.1	65.9
Total Costs	193.3	28.8
Total Fixed Costs	13.53	2.94
- Depreciation of ponds	7.58	1.79
- Depreciation of machinery	4.6	0.85
- Land taxes	1.35	0.30
Total Variable Costs	179.77	25.86
- Pond preparation	8.09	2.2
- Seed	9.35	3.13
- Feed	119	13.7
- Chemical and drugs	21	1.88
- Dike upgrading	3.05	0.31
- Fuel and electricity	8.63	1.37
- Harvest and transportation	1.61	0.10
- Labour	6.11	1.45
- Interest on loans	1.41	1.14
- Miscellaneous	1.43	0.58
Net Income	237.8	37.1

Source: Sinh (2008).

On current trends, catfish farming faces an uncertain future if gross revenues are not able to keep pace with the expected increase in input costs even in the absence of climate change impacts. Only the most efficient and adaptable farmers will survive such a squeeze on farming margins, which are currently in the range of 3% to 5%. The additional costs of adapting to climate change will intensify this squeeze, hastening the onset of net losses. As suggested in Figure 6 for the 2010–2020 period, coastal catfish farms are barely meeting their costs, with net income becoming negative within five years under the climate change (CC) scenario. For the 2010–2020 period, the NPV is 104% higher under the NCC scenario. This means that for a coastal catfish farmer, responding to climate change results in a discounted net income that is VND 4.7 billion ha^{-1} lower over the 2010–2020 period. Overall, the CBA shows that many coastal catfish farmers may soon find it unprofitable to remain in the sector, and only those who can find innovative ways to substantially reduce their input costs will be able to survive in the long term.

For inland catfish farms, NPV for the 2010–2020 period is positive under the NCC scenario, while under CC, NPV is negative. The difference between the CC and NCC scenarios is larger for coastal catfish, with NCC NPV being around 100% higher than CC NPV for the 2010–2020 period. Under the CC scenario, inland catfish operations will become unprofitable within six years (by 2015), and continue on a declining trend to 2020. Despite a positive NPV, net benefits under the NCC scenario remain positive only until 2018, and then progressively decline. The optimistic NPV may be due to high discounting, which puts more weight on positive net benefits in the near future.

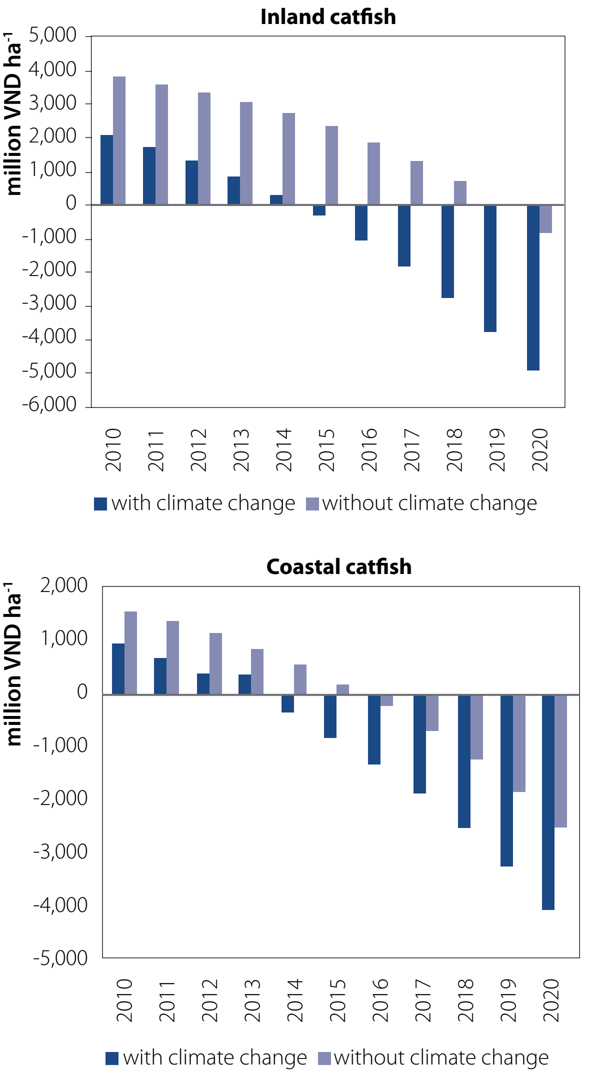

Figure 6. Net farm income for catfish under climate change and no climate change scenarios for the next decade to 2020.

Current trends for shrimp production are not as unfavourable as those for catfish farming, with margins of 123% and 129% for semi-intensive/intensive and improved extensive farms, respectively. The impacts of climate change would lead to a further reduction of profitability. As suggested in Figure 7 for the 2010–2020 period, net income for improved extensive shrimp is positive, but progressively declines under the CC scenario. Similarly, net income under NCC would also decline but at a slower rate than under CC for the 2010–2020 period. NPV for improved extensive shrimp farming for 2010–2020 is positive under CC for 2010–2020. This means that responding to climate change leads to a discounted net income that is VND 51.6 million ha^{-1} lower from 2010–2020.

For semi-intensive and intensive shrimp farming under the CC scenario, net income remains positive but at a declining rate. Under the NCC scenario, net income does not decline as fast. NPV under both CC and NCC scenarios is positive for the 2010–2020 period, with NCC NPV being 22% higher than CC NPV for the 2010–2020 period. This amounts to discounted net income that is VND 403.7 million ha^{-1} lower over the 2010–2020 period due to responding to climate change.

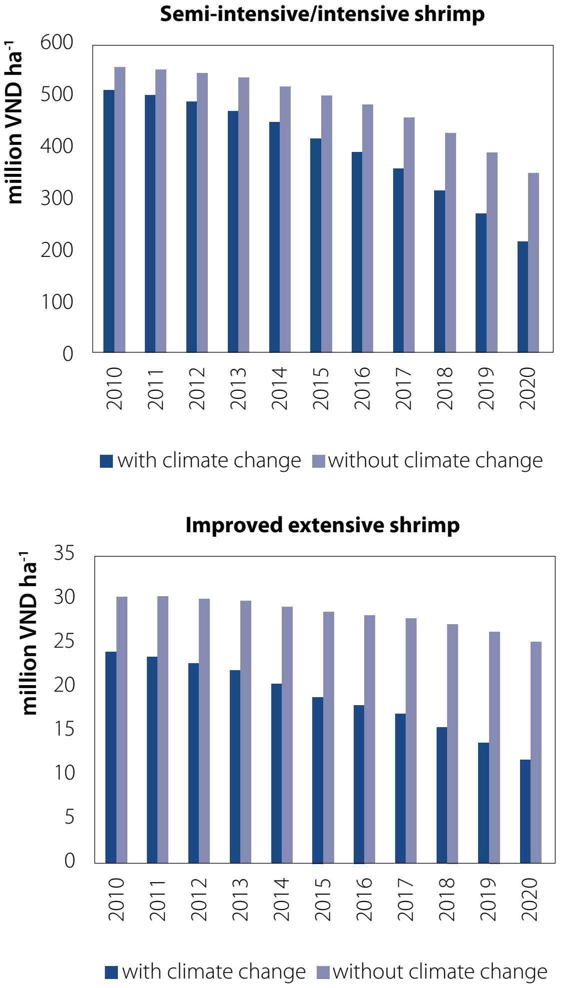

Figure 7. Net farm income for black tiger shrimp under climate change and no climate change scenarios for the next decade to 2020.

The results depicted in Figures 6 and 7 provide a baseline for assessing (a) the net impact of climate change on future profitability, and (b) the viability of various options for autonomous and planned adaptation to offset the impact of climate change. The baselines for the next decade to 2020 reflect general perceptions and assumptions about changes to the catfish and shrimp sectors in the near future based on trends over the past decade.

For the period after 2020, the baseline relies upon simple extrapolation of long-term trends; hence, further reductions in net income due to climate change impacts are likely to happen, as indicated in Figure 8 comparing 2020 and 2050 net incomes for catfish and shrimp aquaculture. In reality, demand for seafood, input prices and other costs of production are very uncertain. Thus, the only relevance of the baseline is to provide a starting point for the analysis of climate change and implications for adaptation and response.

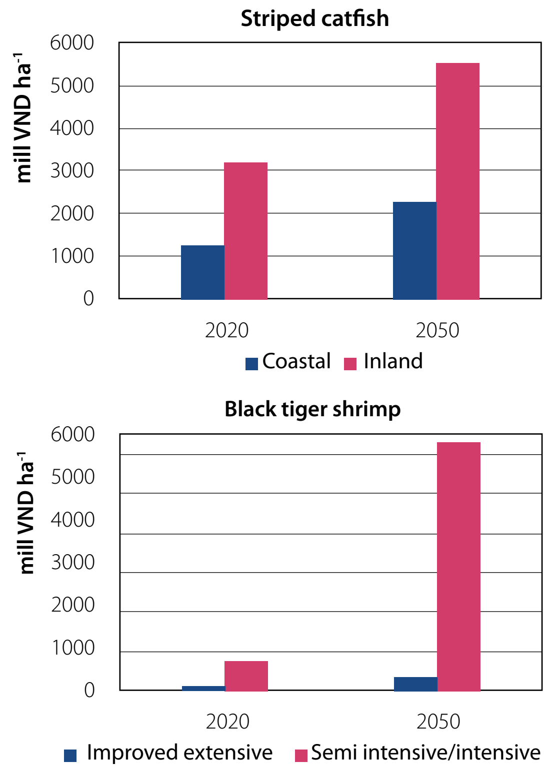

Figure 8. Reduction in net farm income from catfish and shrimp farming due to climate change without adaptation.

5.2 Potential benefits from planned adaptation measures to prevent flooding and salinity intrusion

In the absence of government intervention to construct or raise sea and river dikes for preventing flooding and salinity intrusion due to sea level rise, it is likely that the shrimp industry, being the most extensive in area coverage, will experience the highest increase in autonomous adaptation costs, particularly to floods. Figure 9 depicts the escalating costs for raising pond dikes for the 2010–2020 period. This cost is marginally higher for the semi-intensive/intensive shrimp sector compared with the improved extensive shrimp sector, which has a larger area coverage but also larger pond sizes and hence lower perimeters of pond dikes affected. Even though the catfish farms are subjected to deeper flooding depths, particularly in the inland provinces, the cost of raising pond dikes at the industry level is lower than for the shrimp sector because of the much lower area coverage of catfish ponds operating at highly intensive scale.

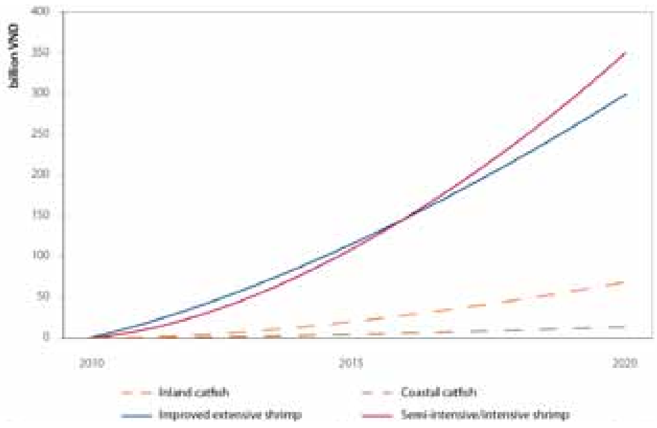

Figure 9. Autonomous adaptation cost for upgrading dikes of catfish and shrimp ponds at industry level for the Mekong River delta, 2010–2020.

At the industry level, the inland catfish and shrimp pond systems will face substantial increases in water pumping costs. (Figure 10 shows the escalating costs for electricity and fuel for the 2010–2020 period.) In the case of catfish farms, the increased pumping cost is to lift water from the river to the ponds over the heightened dikes, while in the case of the shrimp farms it is to increase the addition of freshwater to overcome higher salinity, particularly in the dry season. The pumping costs for coastal catfish farms are lower on the whole because of the small size of the subsector, as well as the advantage of using tidal water heights to lift water from the lower reaches of the rivers.

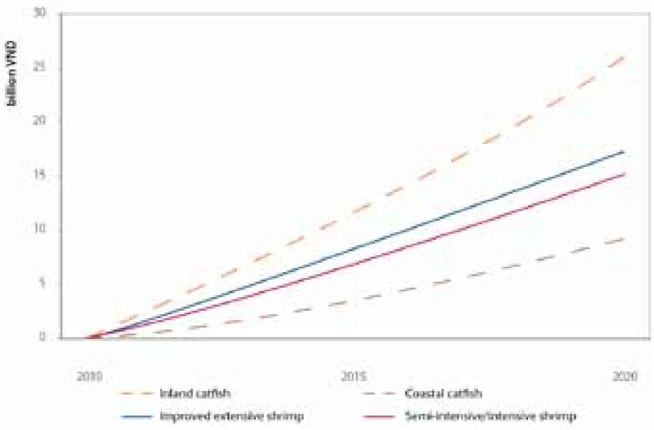

Figure 10. Autonomous adaptation costs for water pumping for catfish and shrimp ponds, 2010-2020.

For all production systems, about USD 172 million will be spent for dike upgrading and USD 18 million for increased costs in electricity and fuel due to climate change, for a total of USD 191 million over the 10-year period 2010–2020 (Table 4). This amount is the minimum planned adaptation cost needed to maintain the same net income as achieved with autonomous adaptation.

Shrimp farmer and shrimp pond, Bac Lieu Pheng province

Catching shrimp in a rice-shrimp field, Bac Lieu province, Mekong River delta, Vietnam

Table 4. Industry-level costs of autonomous adaptation for raising pond dikes and pumping water for catfish and shrimp ponds, 2010–2020.

	Autonomous adaptation costs (mil USD) for		
	Dike upgrading	Water pumping	Total
Inland catfish	14.6	7.1	21.7
Coastal catfish	3.0	2.3	5.3
Improved extensive shrimp	75.3	4.8	80.1
Semi-intensive/intensive shrimp	79.5	4.1	83.6
Total	172.3	18.4	190.7

By comparison, the value from shrimp and catfish exports attributable to the Mekong River delta was USD 2.7 billion in 2008 (Table 5). The total autonomous adaptation costs for raising pond dikes and pumping water for catfish and shrimp farms at industry level over the period 2010–2020 would constitute 0.7% of the total export value over this 10-year period, based conservatively on the 2008 export value as the annual estimate.

Table 5. Economic importance of shrimp and catfish as export commodities for Vietnam.

2008 export value of shrimp and catfish	million USD
Vietnam export value of shrimp[a]	1,625
Vietnam export value of catfish[a]	1,453
Mekong River delta share of shrimp export value[b]	1,300
Mekong River delta share of catfish export value[c]	1,424
Mekong River delta share of shrimp and catfish export value	2,724

Source:

[a] Phuong (2010).

[b] On the basis that the Mekong River delta accounts for 80% of Vietnam's shrimp export value (General Statistical Office of Vietnam, http://www.gso.gov.vn/default_en.aspx?tabid=469&idmid=3).

[c] On the basis that the Mekong River delta accounts for 98% of Vietnam's catfish export value (General Statistical Office of Vietnam). According to the catfish development plan titled 'Development plan for production and consumption of tra catfish in the Mekong river delta by 2010, vision 2020,' approved by the Vietnam Ministry of Agriculture and Rural Development (VNA-14/11/08; http://xttmnew.agroviet.gov.vn/loadasp/tn/en/tn-spec-nodate-detail.asp?tn=tn&id=94031), the catfish export value is targeted to reach USD 1.85 billion by 2020.'

Considering the economic importance of the aquaculture industry for Vietnam (accounting for 7% of the national GDP in 2008; GSO 2008), planned adaptation measures that can offset such nominal costs of autonomous adaptation would bring relief to farmers, particularly the high number of shrimp farmers who operate on low capitalization.

Infrastructure and policies aiming at reducing salinity intrusion and floods, such as sea defenses, better land use planning and coastal forest protection, will also have ancillary benefits to other sectors, such as agriculture. This might significantly increase the gross benefit of planned adaptation versus autonomous adaptation in the Mekong River delta.


Loading harvested catfish onto boat for transport to processing factory, Hau Giang province, Mekong River delta, Vietnam

6. Estimated adaptation costs: policy implications in the Mekong River delta

6.1 Farm-level autonomous adaptation

The CBA shows that even without climate change, the catfish grow-out sector faces an uncertain future given the current trend of low profit margins due to high operating costs. Macro-economic trends and demands from import markets for increasingly stringent quality standards have had significant impacts on catfish production. Farmers operate on the brink of economic feasibility, with rates of unsuccessful farms (those with negative net income) being highly variable over time, depending on external drivers. For instance, because of good market conditions in 2007 and the beginning of 2008, the rates of unsuccessful farms in 2007–2008 were, respectively, 11.6% and 5.4% of grow-out farmers in inland and coastal areas, compared to 20–30% the previous year (Sinh and Hien 2010). There has been a recent move towards vertical integration of operations across the value chain, whereby fish-processing companies acquire their own production facilities or negotiate with larger-scale farmers to attain greater efficiency, higher profit margins and better quality control for compliance with international standards for export products. This move tends to further squeeze out the small-scale producers (Bosma et al. 2009). Khiem et al. (2010) report on a recent initiative to support small-scale farmers to upgrade their production practices and engage in developing cooperative production groups (horizontal contractualization) designed to improve their capacity to negotiate sale contracts with processing companies (vertical co tractualization) and reduce costs associated with complying with international standards. If faced with further viability challenges, the catfish industry is likely to continue restructuring.

Climate change is only one of the drivers affecting the catfish industry, but its impact will have a compounding effect at the farm level, with the additional costs of adaptation further reducing profit margins. In this context, increasing the overall resilience of the sector to change and promoting 'no-regret' strategies, which will increase margins and enable operators to underwrite the costs of adaptation, are warranted. 'No-regret' strategies seek to build a general resilience that does not depend overmuch on detailed climate projections (Heltberg et al. 2009). One such strategy is through improved feed conversion ratios—obtained by research into feed formulation—and reduction of feed costs, along with adoption of better management practices. Another strategy may be to increase the margins enjoyed by farmers rather than retailers in importing countries and export processing companies, recognizing the importance of maintaining the position of the large number of small farmers and transferring benefits from a globally-integrated production system to the rural communities in the delta. Similarly, the cost of adaptation at the farm level could be transferred across the value chain. Both of these options could happen either on the initiative of actors higher up the value chain, as a market response to maintain the supply to meet growth in demand, or else by government intervention or community-driven measures.

It is worth noting that factors other than expected profitability can influence adaptation decision making at the farm level. Such drivers include the availability of technology, financial constraints, risk aversion and cultural considerations, access to government programs, and livelihood opportunities available in other sectors (Belliveau et al. 2006; Nielsen and Reenberg 2010). In this context, planned adaption led by the government or the private sector can play a significant role in increasing profitability, especially considering the high level of integration and capitalization of the catfish industry.

The results point to a greater adaptive capacity of shrimp farms compared with catfish farms. Having had a longer history than catfish farming in the Mekong River delta, the shrimp industry is relatively better established and more stable. Shrimp farmers are likely to produce positive net benefits for a longer period than catfish operators due to lower total costs relative to gross income, especially in the case of the improved extensive shrimp system. Producing shrimp at the improved extensive scale is marginally less profitable but requires less capital outlay and has a lower impact on the environment, so it may be more sustainable for small-scale farmers and the environment in the long term.

In the Mekong River delta, the area under improved extensive shrimp culture is nine times that of semi-intensive/intensive

Unloading catfish from the hold of a transport boat

shrimp (Lai 2009). A significant number of farmers depend on this production system, with its low level of capitalization, for their livelihoods. Their socioeconomic profile is generally lower compared with farmers operating other production systems. Additionally, many shrimp farmers who invested in semi-intensive shrimp farming have reverted to improved extensive shrimp farming practices (Joffre and Truong 2009). This suggests that the improved extensive shrimp sector as a whole merits greater attention in terms of responding to climate change impacts and adaptation, as the pay-offs in sustaining the viability of this sector and maintaining its substantial contribution to the aquaculture industry are high.

Reducing electricity and fuel use as an adaptation strategy for semi-intensive and intensive shrimp culture, as well as catfish pond culture, also provides benefits in terms of greenhouse gas mitigation. Aquaculture operators can decrease direct and indirect fossil fuel use on the farm through reduced and more energy-efficient machinery use, local sourcing of inputs, improved command and control processes, use of low-carbon and/or recycled building materials, and reduced use of inorganic fertilizers and pesticides (Bunting et al. 2009). The synergies between low-carbon footprint aquaculture guided by the government and autonomous adaptation warrant further investigation.

There are also other possible strategies as part of a larger response to climate change. Technical improvements such as specific pathogen-free shrimp brood-stock technology will help reduce disease risks that might increase with climate change impacts (De Silva and Soto 2009). A combination of selective breeding programs and changes in farming practices should permit the farming of catfish species that can tolerate higher levels of salinity, or the replacement altogether of the river catfish with other salinity-tolerant species. Unlike the staple crops and livestock, aquatic species and production systems for freshwater and brackish-water aquaculture are diverse, fitting into different agro-ecologies ranging from purely aquacultural activities to integrated production within rice and mangrove environments. Reducing the high dependence on the shrimp and catfish industries and diversifying into more ecologically-oriented and diversified production systems can also hedge the aquaculture industry against the increasing risks and uncertainties brought about by climate change.

Bringing unloaded catfish to the processing factory

6.2 Implications for planned adaptation

While the adoption of different species and the modification of farming practices will fall to those responsible for managing aquaculture operations, planned adaptation options such as genetics selection and breeding programs fall within the mandate of the government. The impetus for diversification needs to be driven by policy that is integral to the country's development plan for fisheries and aquaculture, which must include the broader sustainability issues facing the sector.

Refridgerated trucks transporting processed catfish for export, An Giang province, Mekong River delta, Vietnam

Infrastructure and policies aimed at reducing salinity intrusion and flooding, such as sea defenses, better land planning and coastal forest protection will have ancillary benefits to other sectors, such as agriculture. This approach would significantly increase the gross benefit of planned adaptation versus autonomous adaptation in the Mekong River delta.

Coastal protection has received considerable attention in the Mekong River delta due to its high exposure to extreme events and sea level rise. Increased salinity in the delta can affect not only catfish farming, but also rice and other agricultural crops. As demonstrated in section 5.2, dike construction to mitigate river and coastal flooding and salinity intrusion can offset farmers' autonomous adaptation costs of heightening pond dikes and water pumping. It will also provide benefits to agriculture and other sectors. Indeed, the total benefits of such a government-led program, including its ancillary and distributional aspects, would encompass multiple economic sectors, including protection of lives and property.

On the other hand, further development of coastal protection infrastructure would remove opportunities for more areas subjected to increased salinity intrusion to be converted and used for brackish-water aquaculture. From GIS analysis conducted in this study, an estimated 190,000 ha presently in rice and rice-aquaculture areas are likely to experience increased salinity (above the 4 ppt threshold for rice) during the dry season for a 50 cm sea level rise scenario. Adopting an ecosystem services approach to assessing climate change impacts and evaluating adaptation options would ensure that the value of fish production is put in the context of other ecosystem services that are affected by climate change, and would help identify the multiple benefits from certain types of adaptation response, such as the co-benefits of mangrove-aquaculture systems for coastal protection.

In computing the additional costs for raising pond dikes, we assumed a linear increment of flooding depth with incremental sea level rise. This does not take into account possible impacts of increases in extreme events induced by climate change. There remains uncertainty concerning climate change impacts on coastal extreme events, on which topic there has been little study or modeling. Aquaculture installations, being mainly located in the coastal zone, are highly exposed and therefore particularly vulnerable to such disasters, for which gradual autonomous adaptation measures will be inadequate. Investing in disaster response and risk reduction to cope with rare events is a costly proactive investment in the short term, especially in a context of such high uncertainty, but might be necessary to avoid larger damage. In this context, more research on modeling the frequency and intensity of future coastal extreme events, as well as exploring with policy makers necessary responses to different scenarios (including the occurrence of rare but highly damaging events), is warranted. In addition, the feasibility of risk-transfer mechanisms, such as social protection, insurance and micro-finance should be investigated.

7. The cost of climate change adaptation at the farm level: exploring approaches and setting research priorities

In this section, we discuss some of the assumptions and limitations of our methodological approach. We then highlight some approaches that can tackle some of the challenges presented. The aim is not to produce an extensive review of alternative methods available to prioritize and identify the costs and benefits of climate change adaptation, but rather to identify promising approaches that could be used at the farm level. Finally, we identify critical knowledge gaps that can frame future research priorities.

7.1 Reflections on the assessment methods used

7.1.1 Expert elicitation in lieu of predictive models

The economic analysis of farm-level autonomous adaptation was based on expert elicitation. The estimates provided served as proxies in the absence of predictive models on the actual impacts of climate change on fish performance and yields. While this is a valid approach (Moss and Schneider 2000), use of fish-growth models simulating how climate changes (e.g., temperature, rainfall, hydrological regimes) impact productivity and projected yield changes would reduce the uncertainty surrounding the results and provide an independent crosscheck. However, models coupling climate change and aquaculture production and yields are not yet available. Given the current status of quantitative modeling in the aquaculture sector in relation to climate change impacts and adaptation, the three-step framework combining qualitative and quantitative methods developed in this study is a useful approach to tackling uncertainty and lack of predictive climate/biological models.

The study depended on expert consultations to get stakeholders' perceptions of economic impacts of climate change on shrimp and catfish aquaculture at the farm level. The perceived impacts measured by percent of changes in production costs were matched with farm-level costs and benefits to estimate costs and benefits under the climate change and no climate change scenarios. Systematic errors might occur when applying the perceived impacts of climate change reported by interviewed stakeholders to cost and benefit data derived from Sinh (2008). The likely errors from this step can be minimized by gathering cost and benefit data and stakeholders' perceptions on impacts of climate change in follow-up survey studies, and/or by using a sub-sample through re-call and longitudinal surveys.

7.1.2 Uncertainty and non-linearity

Like all economic studies of climate change adaptation, our study is subject to substantial uncertainty surrounding the impacts of future climate change, changes in input and output of commodity prices, and changes in production technologies and other factors. For instance, the analysis was based on the assumption of a linear increase in farm-gate prices for catfish and shrimp. Future market changes were not included in the computation of net benefits, even though the latter are extremely sensitive to the farm-gate price of fish and shrimp. Similarly, technological advances will impact cost structures, and international trade policies may change demand for Vietnam's aquaculture products. A scenario-based approach will be useful to capture uncertainties and the dynamism and non-linearity of catfish and shrimp production systems (Boaventura and Fischmann 2008).

7.1.3 Homogenous farm population assumption

By using base production data aggregated for all farm sizes, we assume homogenous farm adaptation behaviour and economic rationality in decision making. As pointed out by Scrieciu et al. (in press), when discussing the current limitations of climate economics, the assumption that farmers are fully rational economic agents disconnected from their social environments is limiting, especially in the light of "considerable experimental evidence that has shown the relevance of social norms in people's decision making and the context-specific heterogeneity of their preferences" (Scrieciu et al. in press: 8).

Research on the patterns and processes of technology adoption in agricultural systems in the last decade has shown that factors such as farm location, household characteristics, access to technology and financing, and cultural norms can determine adoption rates (see, for instance, Adesina and Forson 1995; Dercon and Christiaensen 2011; Warriner and Moul 1992). Recent work on autonomous adaptation to climate change shows that similar factors affect the choice and adoption of adaptation options (see, for instance, Deressa et al. 2009). A portfolio of qualitative and quantitative approaches will be needed to shed light on the factors influencing farmers' decisions to adapt to perceived climate changes, particularly in the data-sparse context common to many developing countries.

7.1.4 Data source and sampling frame

Estimated costs and benefits for catfish and shrimp farm operations were based on the work of Sinh (2008). Sample sizes were small, and hence statistics on gross income and production costs from these samples might not be representative of complex shrimp and catfish farming systems in the Mekong delta. Furthermore, the catfish and shrimp farming industry in Vietnam has been subjected to rapid transformation, including the vertical integration of farm production and the dominance of large-scale producers. This shortcoming could be resolved by using time series of information combined with cross-sectional panel data to account for the fast growth and heterogeneity of the industry. This approach may provide better inferences than those based on survey data from one reference year.

7.2 Moving the methodological framework forward

A range of economic methods could have been used to estimate the impacts of climate change and the costs of adaptation (e.g., statistical/econometric modeling approaches, Mendelsohn et al. 1994; Seo and Mendelsohn 2008). Ricardian economic modeling can be considered as a top-down approach for calculating changes in farmers' welfare under climate change (Watkiss et al. 2010). This method aims to estimate the long-run economic impact of climate change on agricultural land value and equates this to costs of autonomous adaptation to climate change once adaptation to the new climate has taken place (Hertel and Rosch 2010). The use of Ricardian economics at the farm level will demand higher levels of complexity and data requirements. Statistical/econometric approaches rely on time series and secondary data to estimate statistical relationships between aquaculture production and climate change variables. Conventional economic approaches for investigating climate change impacts and adaptation, such as Ricardian models, are now being complemented by a new generation of choice models that can model crop/livestock choice and irrigation choice using a multinomial probability setting.

Choice modeling approaches allow researchers to examine determinants of adaptation decision making by stakeholders. Under multidimensional and multi-scale contexts of climate change impacts and adaptation, the choice modeling approach (binary and multinomial choice models) has been used to study adaptation decisions made by involved stakeholders and factors driving them to make such decisions (see, for instance, Seo et al. 2010; Seo and Mendelsohn 2008).

Similarly, new generations of cost-benefit analysis tools are being developed. Currently, a promising participatory cost-benefit framework called Social Return on Investment (SROI) is being piloted by the CGIAR's Climate Change Agriculture and Food Security research program. The SROI is a cost-benefit analysis tool for choosing climate change adaptation options that reflect the interests of priority stakeholders along the agricultural supply chain.

Finally, tools and methods used in impact assessment studies related to the adoption of new technologies in agricultural systems could be used in climate change research. The Minimum-Data Tradeoff Analysis Model[7] (TOA-MD) uses a statistical description of a heterogeneous farm population to simulate the adoption and impacts of a new technology or a change in environmental conditions (Antle 2011). Following Claessens et al. (2011), the TOA-MD can be used to analyze and compare three scenarios, as follows: a) farmers operate current farming systems (system 1) with base climate; b) farmers operate current farming systems (system 1) with *perturbed* climate; and c) farmers shift to or adopt an alternative farming system (system 2) under *perturbed* climate. The model is able to test different adaptation strategies and analyze their economic feasibility as well as their effect on net losses ('benefit' of adaptation). This process is referred to as an ex-ante evaluation of adaptation strategies.

7.3 Knowledge gap and research priorities

Assessing the economic cost of the impacts of climate change and adaptation at the farm level in aquaculture remains an uncharted research area. From this study, we identify several knowledge gaps and their accompanying research priorities, listed in Table 6 below, to be considered in framing a future research agenda.

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[7] http://tradeoffs.oregonstate.edu/minimum-data-info.

Table 6. Identified knowledge gaps and research priorities

Knowledge gap	Research priority
Modeling research to understand the impact of climate change on growth, production and yield of cultured species is not established	Develop coupled climate change and aquaculture growth and production models Refine expert elicitation methodologies to use in lieu of predictive models when necessary
There is a high level of uncertainty concerning climate change impacts on coastal extreme events	More research on modeling future extreme events (both frequency and intensity)
There is limited knowledge on responses of aquaculture to input market prices and output prices and trends; this uncertainty limits the usefulness of cost-benefit analysis for adaptation planning	Use scenario analysis to manage uncertainty related to future socioeconomic trends; scenarios can be combined with supply and demand model simulation at the sub-national or national scale
Farmers' preferences, willingness and ability to adapt to climate change remain unstudied	Inclusion in an assessment method portfolio of qualitative and quantitative approaches shedding light on the factors influencing farmers' decisions to adapt to perceived climate changes
There is limited understanding on how climate change adaptations among economic sectors and natural resource uses complement and conflict with one other, as well as what the potential co-benefit of adaptation and mitigation strategies might be	Conduct cross-sectoral cost-benefit analysis integrating aquaculture as one component Conduct cost-benefit analysis from an ecosystem service perspective

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