A Decision Tree Analysis to Support Potential Climate Change Adaptations of Striped Catfish (*Pangasianodon hypophthalmus* Sauvage) Farming in the Mekong Delta, Vietnam

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Summary

*This study uses the decision tree framework to analyse possible climate change impact adaptation options for pangasius (*Pangasianodon hypopthalmus *Sauvage) farming in the Mekong Delta. Here we present the risks for impacts and the farmers' autonomous and planned public adaptation by using primary and secondary data. The latter studies showed that a proportion of the pangasius farms located in the coastal provinces will be affected by salinity intrusion in the dry season. Options to adapt to this are: modify pangasius farming practice, stock other species or stock saline-tolerant pangasius. With research and extension support, farmers can further improve their already adapted practice to deal with salinity or use water recirculation systems for prolonged nursery rearing. A breeding program for saline-tolerant striped catfish requires a medium-to long-term investment (0.4 % of the production cost) from government and/or private company. Pangasius farms in up- and mid-stream regions and in coastal areas, which are not located within upgraded government dyke-protected areas, will be affected by flooding at the end of each rainy season. This implies an increased cost for dykes to about 0.34% and 0.25% of the total variable costs for one harvest per ha in the up- and mid-stream regions, and in the downstream region, respectively.*

Résumé

Une analyse en arbre de décision pour soutenir l'adaptation aux changements climatiques de l'aquaculture de poisson chat au Mekong Delta, Vietnam

*Cette étude a analysé les options d'daptation aux impacts des changements climatiques de l'aquaculture du poisson-chat (*Pangasianodon hypopthalmus *Sauvage) dans le Delta du Mekong à l'aide d'un arbre de décision. Basé sur des données originales et des données issues de la littérature et de bases de données, l'article présente les risques et les options d'adaptation aux changements climatiques en distinguant les adaptations autonomes par les pisciculteurs et celles planifiées par le secteur public. Les données originales montrent qu'une partie des étangs de pangasius situés dans les provinces côtières sera affectée par les intrusions salines pendant la saison sèche. Les options d'adaptation à cette contrainte sont: modifier les pratiques d'élevage, changer les espèces, ou élever des pangasius tolérants à la salinité. Soutenus par la recherche et les services de vulgarisation, les pisciculteurs pourront améliorer davantage leur pratique actuelle d'adaptation, en rallongeant la période d'alevinage, en utilisant des systèmes de recyclage de l'eau. Un programme de sélection d'une race de pangasius tolérante à la salinité demande un investissement à moyen terme, de 0,4 % des coûts de production de la part du gouvernement et/ou d'entreprises privées. Les pisciculteurs de pangasius dans les régions en amont et en zones côtières et qui ne se trouvent pas à l'intérieur des zones protégées contre les inondations par des digues, seront affectés par des inondations à la fin de chaque saison des pluies. Ceci implique un accroissement du coût pour rehausser les digues des bassins de production, représentant 0,34% et 0,25% du total des coûts variables pour une récolte et par hectare, respectivement dans des régions en amont et pour les régions côtières.*

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Introduction

Originating in the Mekong Delta, striped catfish (*Pangasianodon hypophthalmus* Sauvage) farming is acknowledged to be one of the most successful aquaculture developments in the world (8). The industry started on fattening of river catfish (*Pangasius bocourti*) in the upstream part of the two main branches of the Mekong River flowing through the provinces of An Giang, Dong Thap, and Can Tho (Figure 1).

However, land-based farmers gradually overtook the sector by culturing striped catfish in ponds after the artificial propagation of this fish was developed and successfully disseminated (5, 29, 34).

Thereafter, the industry expanded more downstream to Vinh Long, Tra Vinh, Soc Trang and Ben Tre provinces (Figure 1). At present the farming sector includes independent small-scale farmers and enterprises, both delivering their fish to processing companies, as well as vertically integrated holdings having their own feed-mills, ponds, and processing facilities. In 2012 and 2013, the sector produced 1.19 million tons of fish in a pond area of 5600 ha and exported the processed Pangasius mainly in the form of fillet valued at 1.7 billion USD to over 142 countries (41).

Vietnam, particularly the Mekong Delta, is likely to encounter adverse impacts of climate change (7), for example, Vietnam ranked as one among the top five countries that is mostly affected by rising sea levels. Studies used sea level rise scenarios to explore impacts on the infrastructure of the Mekong Delta (17), rice cropping areas (21, 42) and current Pangasius farming locations in the Delta (Figure 1). These studies show that Pangasius farms in upstream and middle-stream regions will encounter longer flood periods; thus, higher risks of flooding, while downstream farms will be affected by higher salinity levels and a longer period of salinity intrusion (1). Projecting the impact of climate change on the profitability of Pangasius farmers, Kam *et al.* (20) found that the short-term benefits of the inland Pangasius farms remain positive when climate change is ignored but benefits soon disappear when climate change impacts are considered.

Coastal Pangasius farms will even be more affected by climate change when projected benefits are predicted to be halved (20). Therefore, making decisions on adaptation strategies is urgent in order to counteract the negative impacts of climate change in this important Vietnamese aquaculture sector that sustains over 170,000 employment opportunities among the rural poor (8). While reviewing the impacts of and possible adaptation to climate change in developed and developing economies, Nath and Behera (28) indicated that adaptation also could enhance the resilience against increasing influences of climate change. Adaptation can refer to natural or socio-economic systems, can be reactive or anticipatory based on timing, and can be autonomous or planned depending on the degree of spontaneity (38). Frankhauser *et al.* (14) adopted the definition of autonomous adaptation first defined by Carter et al. (6) as "natural or spontaneous adjustments in the face of a changing climate" and consequently defined planned adaptation as "requires conscious intervention".

The Ministry of Agriculture and Rural Development (MARD) of Vietnam has established the action plan for adaptation of agriculture and rural development for the period 2008-2020. The action plan focuses on ensuring the safety of residents, stability of agriculture production and food security, and safety of dykes, levees and infrastructure.

In order to achieve these objectives, five main tasks were implemented:

(1) Conduct a communication and information program;

(2) Develop human resources and conduct adaptation studies;

(3) Develop a policy system;

(4) Promote international cooperation;

(5) Establish priority adaptation activities (26).

The implementation addressed the impacts of climate change on fisheries and aquaculture nationally (16), but did not yet result in regional adaptation plans for this sector.

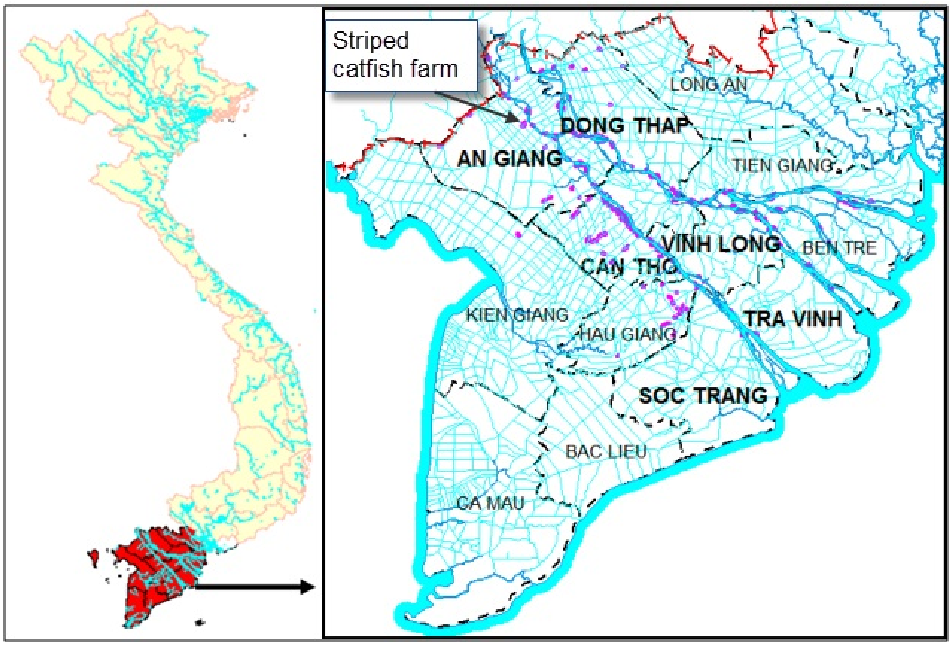

Figure 1: The administrative map of the Mekong Delta with locations of the Pangasius farms [Adapted from Ai (1)].

Anh *et al.* (2) observed that adaptation measures by Pangasius farmers focused on changing their farming practices or their cultured species, in some cases with financial and technical support from private, government and research agencies. Nath and Behera (28) noted that government and civil society play a crucial role in enabling efficient adaptation methods. The adaptation strategies for Pangasius farming, therefore, should combine both autonomous and planned adaptation at private and public levels. According to Smit *et al.* (38), the cost and benefit estimation is an important aspect in the evaluation of adaptation and provides support to recommendations of the most appropriate adaptation. Kam *et al.* (20) analysed the cost of autonomous farmers' adaptation; their analysis showed that the cost can be reduced by planned public adaptation measures.

This paper aims to analyse the adaptation measures that may diminish the climate change impacts for the Pangasius farming sector in the Mekong Delta by using the decision tree framework. After describing the analytical framework, the paper summarises the climate change impacts requiring responses before analysing the options for adaptation. Subsequently the options for both autonomous and planned adaptations were inputted into a decision tree framework in order to facilitate adequate policy making. The cost of the adaptation for the sector and the impact on the cost-efficiency at the level of the Pangasius farmers will be considered before concluding.

Analytical framework

Suitable adaptation strategies are best decided through a decision-making process. Such a process is defined as the systematic analysis of a problem (i.e. cause-effect-response chain) using appropriate data and the final choice of effective solutions (24).

Data

This study used both primary and secondary data. Primary data were collected from our previous studies on climate change impacts on Pangasius farming (1, 2, 3). Primary data on the cost of a Pangasius breeding program were acquired from an expert and complemented with secondary data. Secondary data were collected from the scientific and professional literature and statistical reports from the Vietnamese government and aquaculture organisations. The cost of autonomous adaptation was collected from several studies (20), and included measures, such as dyke enforcement.

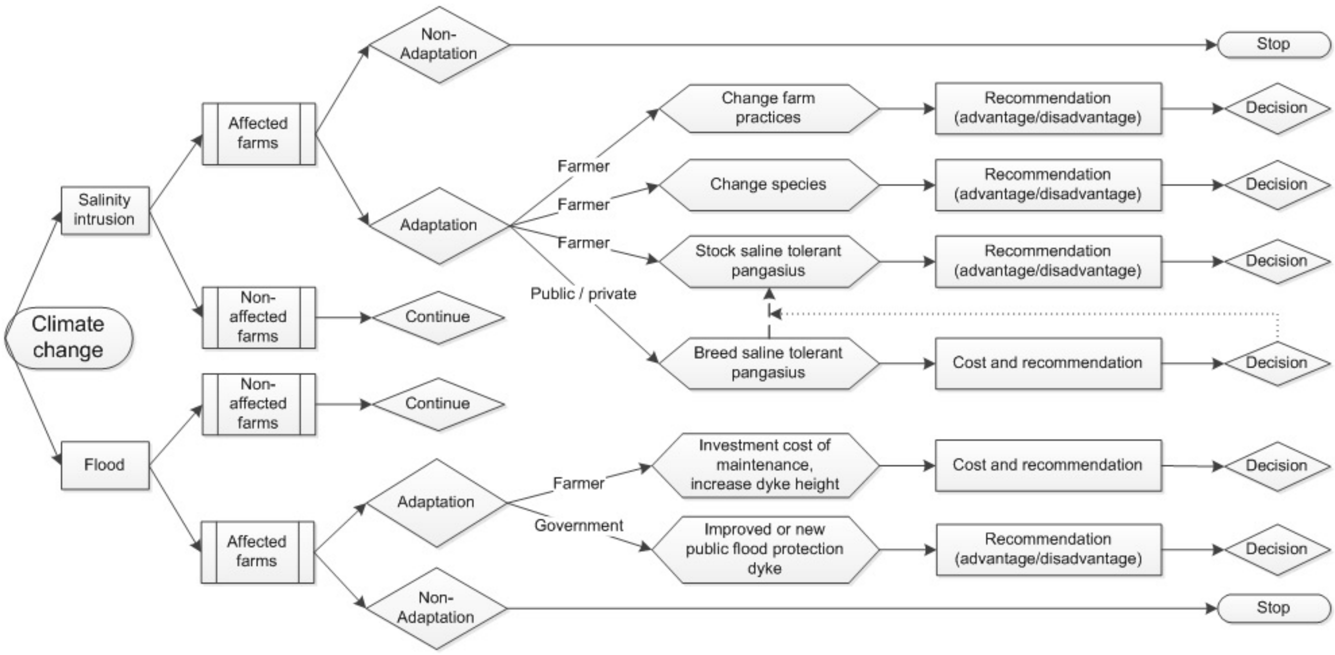

Figure 2: The decision tree framework used for the decision-making process of adaptation choices with events.

Decision tree framework

Decision-making is a process of problem analysis and solution design, implementation and monitoring. All steps involve decisions which can alter the systems and thus require visiting earlier steps; the inherent feedback loops make the process recursive (15). To support policy-making, the present study developed a simple rule-based decision support tree (Fig. 2). A decision tree is a decision support tool that uses a tree-like schematic representation or a model of the possible consequences of specific decisions, and the plausible interactions thereof.

To develop the decision tree, we elucidated the reasons and the recommendations for decision-making at the various nodes of the decision tree following the three steps below:

- Identify the problems (event nodes) and the specific decisions to be made (decision nodes).
- Build the structure of the decisions and its consequences, like a tree with the roots and the branches.
- Clarify the cost (disadvantages / trade-offs) and benefit (advantages / synergies) of each alternative decision in order to determine the most favourable decision.

In the present case, the event nodes represent a problem (e.g. salinity intrusion) requiring an assessment (will it affect my farm or not?), and then a decision (adapt or not?); upon the choice to adapt follows an analysis of options for adaptation. Each option (e.g. change of species) requires an analysis of the cost (disadvantage / trade-off) and benefits (advantage/ synergy) before a decision to apply could follow. If the decision is negative then the decision-maker may analyse another option making the process recursive (feedback loop), and finally enabling a decision to adapt or not to adapt.

Climate change impacts

Climate change may affect the Pangasius farming sector in the Mekong Delta mainly through flooding and salinity intrusion. However the impact varies according to the locations.

Flooding

Induced by sea level rise, flooding in the Mekong Delta of Vietnam is likely to worsen in the long term (17) as floods will arrive earlier and persist longer (42). According to Anh *et al.* (1), sea level rise (SLR) scenarios of +50 to +75 cm will cause an additional expansion of flooding in the upstream provinces of An Giang, Dong Thap and Can Tho, and increase the inundated areas in the coastal provinces of Soc Trang, TraVinh and Ben Tre (see Figure 1).

Under a SLR +50cm scenario, Kam *et al.* (20) predicted the greatest increments in flooding depth will occur in An Giang, Dong Thap and Can Tho provinces, where the largest concentration of Pangasius farms is found. Anh *et al.* (1) calculated that Pangasius farms in all provinces have to deal with a 2-m-flood level in case of the SLR +50 cm scenario. Fifty-five percent of the interviewed Pangasius farmers in upstream provinces was concerned about flooding caused by climate change, and estimated their economic losses at 10% to 100% of their current income. According to these farmers, their cost for disease treatment of the stock would increase up to 300% due to such hazardous flooding (2).

The Pangasius farmers in the affected areas have to choose between either stopping the farming operations, or increasing the height of pond dykes as an autonomous adaptive measure. Pangasius farms located in areas protected from flooding by flood protection dykes constructed by the government can benefit from the planned adaptation.

Salinity intrusion

All Pangasius farms located in the south western area of the TraVinh province and most farms in the Ben Tre and Soc Trang provinces in the Mekong Delta are already subjected to diurnal fluctuations of up to 4% salinity level. The periods of this salinity threat, however, are likely to become longer; the majority of the interviewed farmers (93%) in the downstream region were concerned about salinity intrusion induced by sea level rise (1, 2).

The yield of Pangasius farms located in the downstream region was significantly lower than that in the other regions. Farmers could not stock Pangasius fingerling in months with high salinity, thereby reducing cropping period of Pangasius culture in these provinces (34).

To deal with this problem, the Pangasius farming sector has to either adapt or discontinue farming of Pangasius. Adaptation may be autonomous at farm level through, for instance, changing pond practice or shifting to farming other species that have high salinity tolerance (i.e. an euryhaline species). Planned adaptation, on the other hand, such as shifting to a salinity-resistant strain of Pangasius requires the involvement of other stakeholders.

Options for adaptation

There are five adaptation options that we discuss here for Pangasius farmers. These are:

(i) Changing Pangasius farming practice (e.g., extending the nursing period of Pangasius fingerlings);
(ii) Shifting to other species that have high salinity tolerance;
(iii) Breeding salinity-tolerant Pangasius;
(iv) Increasing the height of farmers' pond dykes
(v) Increasing the height of the public flood protection dykes.

Changing Pangasius farming practice

Some Pangasius farmers in the coastal area can extend the nursing period of Pangasius fingerlings to reduce the grow-out period in ponds during the months of high salinity (2). An extended nursery period, however, will result in slightly higher cost for transport, as juveniles will be heavier, and perhaps with increased risk (8).

In Vietnam, Pangasius farms have started experimenting with recirculating aquaculture system (RAS) during the nursery and grow-out phases. This can also be regarded as an autonomous adaptation. Results seem promising but the full cost and benefit is not known yet (31, 32, 33). The water intake for RAS system is very restricted, except for the last weeks of the grow-out period. The RAS system would simultaneously reduce water pollution, a mitigation benefit in favour of reducing the pollutants coming from Pangasius sector (4). This system may also contribute to the mitigation of climate change impact; a bone of contention of many environmental lobby groups (9).

Shifting to other species

To deal with saltwater intrusion, Pangasius farmers in the coastal provinces of the Mekong Delta might also choose to grow other species. Anh *et al.* (1) reviewed several experimental studies on the salinity tolerance of several freshwater fish species, including Pangasius in the Mekong Delta.

Table 1

The generic cost (USD) of a fish breeding program in Vietnam, respecting the principles of an effective population size as established by Ponzoni *et al.* (35).

	Year 1	Year 2	Year 3	Year 4
Fixed cost of infrastructure for renting 1.5 ha with 1.1 ha of ponds*	7.200	7.200	7.200	7.200
Salary cost	4.700	6.400	6.000	4.250
Materials: broodstock and feed	4.000	6.800	16.100	16.000
Accessories, disposable tools	480	2.850	950	950
Electricity, gasoline, diesel	320	1.700	320	320
Equipment	1.400	200	12.700	0
Maintenance cost	700	2.100	1.600	1.400
Total	18.800	27.300	44.770	30.120

Cost of land USD 30,000 and of infrastructure USD 23,0000; accounted for an interest rate of 8% and a depreciation of infrastructures over 20 years; exchange rate 21000 VND for 1 USD (Source of primary data: Dr. Trinh Quoc Trong, Director of National Breeding Centre for Southern Freshwater Aquaculture, Vietnam, personal communication).

The embryos of striped catfish can develop and hatch in brackish water at 11% (11); 25g individuals can grow in salinity of up to 9 % (30). Choosing to grow other species, farmers need to develop new adaptive capacity, like changing infrastructure, in particular that of ponds.

A pond with water depth of 3 to 4 m is preferred for Pangasius grow-out, but such deep ponds are unsuitable for most other commonly farmed salinity-tolerant species, like the Asian seabass or shrimp. Pond restructuring is required especially for those located on the river banks or main canals, and is likely to be very costly as lowering the water level in these deep ponds will increase; for example, the pressure on the dykes by the river water at high tides. For other ponds, lowering pond depth may be realised by just using a lower water level. Both technical and economic aspects on the feasibility of shifting to another species need further study.

Breeding salinity-tolerant Pangasius

Many farmers, who face the risk of salinity intrusion, prefer to continue producing Pangasius rather than shifting to other species. They believe that with Pangasius, they can maintain their revenues at a sufficiently high level and recover their investments (2).

Along this line, researchers suggest that breeding of a salinity-tolerant strain of Pangasius would be a good option as well.

A tolerant strain would require only a minimal change to farming practices and the related infrastructure, and also would avoid the need to develop new market chains (8, 9).

Though there is a potential for developing a salinity-resistant strain of Pangasius, one should consider that Pangasius matures for more than 3 years (40) which implies a longer generation interval, thus slowing the progress of a breeding program. The use of modern molecular genetic techniques in selective breeding can reduce the time period required to develop a strain with a desired trait, for example, in the case of tolerance to salinity, breeding time can be shortened significantly, unlike that of the traditional selective breeding programs used in the past. However, this would be a costly option.

According to Trong (personal communication), the generic cost of a Pangasius breeding program is about USD 120,000 (Table 1). Due to the long generation interval, the actual cost will be fourfold (USD 484,000) for a program starting from 150 individuals of wild broodstock of various origins in the Mekong river. This program will serve only the farmers in the coastal provinces who produce about 10% of the 1.2 million tonnes produced annually by Vietnam, i.e. 120 million kg. The cost per kg of Pangasius produced in the coastal provinces would be USD 0.004 kg^{-1}.

This is slightly less than 0.4% of the present production cost (USD 1.1 kg^{-1}) and seems a feasible investment. Whether or not such a program can successfully breed a salinity-tolerant Pangasius, however, remains to be seen.

The relatively long time frame and large costs of such a program require the continuous and persistent involvement of public agencies or a private company.

Reinforcing the pond dykes

The dykes of Pangasius farms and ponds have been threatened by flooding due to the increased water levels in the rainy season. This risk will worsen in the context of sea level rise caused by climate change (1). To deal with flooding, Pangasius farmers need to increase the height of their dykes. This would increase investment and operation costs for both dyke and water exchange. According to Sinh (37), the cost for dyke maintenance of Pangasius farms in up- and mid-stream regions accounted for 0.23% of the total variable costs (per ha and per crop), while in the downstream region cost was 0.12% depending on flooding intensity and farm location.

While investigating autonomous adaptation measures of Pangasius farmers, Kam *et al.* (20) estimated the costs for individual dyke upgrading in the period of 2010-2020 to be about USD 14.6 million in the up- and mid-stream regions and USD 3.0 million in the downstream region.

The costs for dyke upgrading of the entire Pangasius farming sector will be approximately 1% of the total annual Pangasius export value in 2013 (41). Sinh (2008) projected that for this decade, the operation cost for dyke upgrading (per ha) of the Pangasius farms in up- and mid-stream is expected to increase by six times and those located downstream, by fifteen times. The extra cost of autonomous adaptation for dyke upgrading per ha and per crop would be USD 222 in the up- and mid-stream region, and USD 223 in the downstream region. These figures were obtained by dividing USD 14.6 million and USD 3.0 million by the number of ha (4380 and 896 respectively) and by the number of crops over ten years (15 for both regions). This would imply an increase of the cost for dykes to about 0.34% and 0.25% of the total variable costs (per ha and per crop) in the up- and mid-stream regions and in the downstream region, respectively.

Improving public flood protection dykes

The action plan of MARD (26) foresees improvements of the government dyke system as an appropriate adaptation measure to protect agricultural activities against flooding. The Pangasius farms located within these dykes, therefore, will have lower autonomous adaptation cost for dyke upgrading at farm level.

The cost of this adaptation measure will be higher because of its large coverage area. However, the benefits accruing to the entire economy goes beyond the protected area covering the Pangasius farming sector. Since these adaptations take time, sea level rise may impact the Pangasius producers before these dykes are finalised.

Discussion

According to Kabari and Nwachukwu (19), decision trees are specifically used in decision analysis to support identification of strategies.

This study analysed the plausible adaptive measures of both autonomous and planned adaptation to deal with impacts of climate change by using a decision tree framework. Decision support tools are often built through modelling (15, 19, 27). Modelling is appropriate to support decision makers choosing suitable adaptation option when referring to data from statistics or from observational studies such as household surveys. However, without time series of sea level rise impacts and adaptation processes, the statistical uncertainty of modelling is high. We chose for a rule-based decision support tree, also because the preliminary analysis summarized above (1, 2) showed that in most cases the problems are well circumscribed, and consequently the number of choices is limited.

This study used results from Kam *et al.* (20) for the analysis of the autonomous adaptation.

Just like all economic studies on climate change adaptations, their study was subjected to uncertainty surrounding the impacts of climate change projection, as well as to changes in input and output of commodity prices, in production technologies among others (20).

The future changes, both in the market and in international trade policies may affect the Pangasius sector without linear adjustment of the farm gate prices. Thus predictions on the financial capacity of farmers to adapt may not be valid. At present, the profit margins of Pangasius farming are lower than in the past (22, 8). The estimated increase of cost due to the climate change adaptations will further reduce profits. Thus if the margins do not improve, the risk of not recovering investments is high. If a farmer decides not to adapt to the impacts of climate change, the investment cost will be less than the cost for the farmers who adapt, but the former will face the risks induced by sea level rise. Some farmers may terminate farming operation either because they do not want to compromise the benefits they have accumulated already from Pangasius culture, or because they think that they will not be able to recover investment costs. The economic efficiency of farmers' autonomous adaptations by replacing species or changing aquaculture practice needs to be considered.

The preparation of these measures needs long-term (public) investments, first for the studies and later for support to the transfer of technology. The autonomous adaptation thus becomes planned adaptation involving more, such as institutes and local government (38).

Both options, reinforcing a pond dyke and improving the public dyke system, are appropriate measures to protect Pangasius farming against increased flooding risks. Increasing public dyke heights will not only benefit Pangasius farmers, but also most other agricultural activities, as well as rural and urban infrastructures. Hence this option is attractive to the government in general, though trade-offs on bio-diversity and on deposition of fertile sediments in e.g, rice-fields need to be considered (23, 25).

In the downstream region, the breeding of a salinity-tolerant strain of Pangasius might be the most efficient option for about 10% of the sector to adapt to the salinity intrusion due to the least disruption to livelihoods, the minimal change requirement in infrastructure and the maintenance of existing and reputedly highly established market channels. The use of modern molecular genetic techniques has shortened the time period required to develop strains with specific traits significantly (18). Perhaps Pangasius offers a good opportunity to develop a selected trait of salinity-tolerant strain relatively fast. On the other hand, breeding and selection need to be a continuous process otherwise the acquired characteristics will be diluted and might be lost (39, 35). The case of tilapia shows very well what happens if selection is not continuous (12), and special breeding programs have been designed to maintain stock quality when institutional capacity is low (13).

Conclusion

The options for Pangasius to respond to climate change depend on their location. The farms located in the coastal provinces affected by salinity intrusion in the dry season may either modify their Pangasius farming practice, or stock other species or stock saline-tolerant Pangasius. The modification would imply further prolonged nursery in fresh water basins or in water recirculation systems. A breeding program for saline-tolerant striped catfish will cost 0.4 % of the present production costs for the coastal provinces, and can be cost–efficient.

The Pangasius farms, which are not located within upgraded government dyke-protected areas, will be affected by flooding at the end of each rainy season. This would imply an increase of the cost for dykes to about 0.34% and 0.25% of the total variable cost for one harvest per ha in the up- and mid-stream regions, and in the downstream region, respectively.

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