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# Financial Feasibility of Green-water Shrimp Farming Associated with Mangrove Compared to Extensive Shrimp Culture in the Mahakam Delta, Indonesia

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## Abstract

This paper presents a post-hoc assessment of the introduction of intensive shrimp farming strategies, with and without green-water (GW) technology, in the Mahakam Delta where extensive systems (ES) dominate. The study also assesses the potential of integrated mangrove GW shrimp production (MGW). The method section describes the systems considered, the cost-benefit analysis applied and the assumptions for different scenarios. The data for the GW and non-GW systems were based on a survey in the Philippines. Assessing cultured shrimp yields from the total farm area showed that production from non-GW was 10% higher than from GW farms. Compared to these two systems, the MGW system produces about 20% of the total shrimp, but provides complementary livelihood options and ecosystem services. Per unit area covered, MGW system produces 20 times more shrimp than ES, while income for farmers doubles and opportunities for livelihoods enhancement associated with the mangrove area increase. Low operating costs make the ES interesting for resource poor farmers, but risks to producers and societal cost are underrated. Transferring from ES to MGW system will increase the contribution to the national economy whilst maintaining ecosystem services, that would otherwise be lost, were intensive culture systems to predominate.

## Introduction

Shrimp production and associated financial returns from semi-intensively managed culture systems in former mangrove forests were often short lived (Naylor et al. 1998). Following declines in productivity as a result of deteriorating pond bottom and water quality and outbreaks of shrimp disease such as white spot syndrome virus (WSSV), farmers operating ponds in former mangrove areas of the Mahakam Delta, East Kalimantan, Indonesia, reverted to extensive production modes (Bosma et al. 2012), while farmers elsewhere developed more intensive culture systems. In the Philippines where mangrove cutting has been prohibited since 1982 (Primavera 1993) farmers opted to pursue more intensive production strategies and developed green-water (GW) culture practices (Tendencia et al. 2005).

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In GW systems the water is conditioned either in separate ponds in which finfish are cultured before it is transferred to the shrimp pond or the finfish are stocked in an isolated net pen inside the shrimp culture pond. Tilapia is most commonly used in the Philippines, sometimes configured with an initial reservoir stocked with carnivorous seabass, *Lates calcarifer* (Bloch, 1790) that feed on potential disease agents in the system (Tendencia et al. 2006a). Tank based experiments showed that GW technology proved effective in controlling luminous bacterial disease (Tendencia et al. 2006b). The effectiveness of the GW culture system against luminous bacteria is attributed to the associated bacterial, fungal and phytoplankton microbiota resulting from consumption by and excretions of e.g. tilapia (Lio-Po et al. 2005). Harvesting of tilapia may be undertaken depending on access to market channels and production strategies adopted on individual farms.

Though GW culture practices spread rapidly throughout the Philippines and various production strategies integrating mangrove and shrimp are practised in Vietnam (Tran 2012), encouraging the introduction of such systems in e.g. Indonesia would require convincing data on financial performance. Post-hoc feasibility is invoked here to overcome this constraint and generate information for policy-makers and prospective operators.

The specific aim of this paper is to assess whether replacing the extensive systems (ES) operated in the Mahakam Delta with either shrimp farming strategies with and without GW or the GW system associated to mangrove forestry (MGW) is profitable. This paper presents the results of the assessment and the implications concerning options to move toward sustainable mangrove-shrimp agro-ecosystems management. Broader ecological, economic and social consequences of widespread adoption are discussed and research priorities proposed.

## Materials and Methods

Material and methods describes the cost-benefit analysis used for the financial assessment before giving the input data and their collection methods of the three existing systems considered. Subsequently the complementary assumptions made for assessing the financial feasibility, including the scenario for MGW, are given.

### *Financial calculations*

The financial indicators for each system (see below) were calculated by applying an aquaculture production model prepared for the EC funded GENESIS project (Bunting and Shpigel 2009) and for a post-hoc evaluation of introducing better management practices for shrimp production in East Kalimantan (Bunting et al. in press). Subsequently a cost benefit analyses based on discounted cash-flows permitted calculation of (1) the net present value (NPV) over 10 years at discount rates of 5%, 10%, 15% and 20%, (2) the internal rate of return (IRR) over 10 years, and (3) the estimated pay-back period. Salvage values and depreciation periods for ponds were fixed at 40%

of capital costs and 20 years, respectively, for buildings and aerators these values were 0% and 10 years, respectively.

The NPV of discounted cash-flows was calculated to assess financial returns and the IRR over 10 years employed to compare the performance of the various culture systems. Sensitivity analysis to test robustness of the results was done by assessing changes in the 10-year IRR in response to varying single input costs, management practices and commodity prices. Exchange rates for one United States Dollar (US$) of 45 Philippine Pesos and 10,000 Indonesian Rupiah were assumed to permit comparison. As shrimp is mainly produced for the world market we did not use the purchasing power parity.

***Mahakam Delta***

The main characteristics of ES systems operated in the Mahakam Delta are presented below, whilst drawing on both primary and secondary data a more detailed description of culture practices was presented in Bosma et al. (2012). Investment costs for extensive shrimp ponds and integrated shrimp-mangrove systems in the Mahakam Delta were obtained from interviews with key informants and farmers (Table 1). In the Mahakam Delta, the surface of ponds varies between 3 and 30 ha, whilst 10 ha was assumed for the baseline. Wild animals are permitted to enter during tidal exchange and constitute an important part of the harvest. Wild shrimp, average weight 25 g, are harvested every 20 days using nets in non-stocked ponds. To replicate extensive culture conditions stocking densities for post-larvae shrimp (*Penaeus monodon* Fabricius, 1798) and milkfish, *Chanos chanos* (Forsskäl, 1775) of 1 $m^{-2}$ and 0.4 $m^{-2}$ were assumed. The predicted number of days of culture for stocked shrimp and milkfish were 90 and 180 days, respectively, and no supplementary feed is provided. Survival rates of 10% and 40% were deemed appropriate for shrimp and milkfish, respectively (Table 2). The yield levels used for the 10 ha ES ponds were 490 $kg{\cdot}y^{-1}$ and 103 $kg{\cdot}y^{-1}$ of wild shrimp and crabs, and 500 $kg{\cdot}y^{-1}$ and 5,280 $kg{\cdot}y^{-1}$ of cultured shrimp and milkfish, respectively (Noryadi and Sidik, 2008; Noryadi et al. 2006).

***The green-water (GW) and non-green water shrimp farms***

Financial data on GW and non-GW systems in the Philippines were collected from eight enterprises during a survey in February 2010; these data related to 2009 when the shrimp market price was low compared to other years. The Philippines farms were purposefully selected from a large database compiled for an epidemiological study on WSSV (Tendencia et al. 2011) for having comparable intensive production characteristics. In general, intensive shrimp producers in the Philippines opted to have only one annual culture period to permit pond drying when conditions were optimal and avoid problems associated with stocking in the rainy season. Pond preparation followed a schedule of plowing, drying, harrowing, liming, draining and drying.

**Table 1**. Supplementary data on the extensive system practised in the Mahakam Delta, East Kalimantan.

| Method used | Operating procedures and inputs assessed | Practices employed and costs incurred |
|---|---|---|
| Focus group discussion | Harvest period and weight for wild shrimp entering traditional and extensive ponds. | Caught every 20 days with nets with market size shrimp (20 g) being retained. |
| | Pond pre-treatment and disinfection prior to stocking extensive ponds. | Saponin, a naturally occurring plant extract, is applied at a rate of 100 $kg{\cdot}ha^{-1}y^{-1}$ and costs Rupiah 5,000 per kg (US$0.57 $kg^{-1}$). |
| | Culture periods for extensive production. | Culture typically 2-3 crops per year, May to July, September to November and Jan to March; highly dependent on weather with stocking starting in dry season to avoid rainy season. |
| Key informant interview | Cost of production enhancing inputs for culture systems. | Rupiah 500 (US$0.06) per kg for lime; Rupiah 25,000 (US$2.85), 6,000 (US$0.68) and 5,000 (US$0.57) per kg for urea, superphosphate and NPK, respectively. |
| | Value of aquaculture production. | Crab and milkfish both valued at Rupiah 15,000 $kg^{-1}$ (US$1.71 $kg^{-1}$); wild and cultured (30 pieces per kg) shrimp valued at Rupiah 40,000 (US$4.56) and 120,000 (US$13.68 $kg^{-1}$, resp.. |
| | Cost for land and access rights. | Producers estimated land cost at Rupiah 5 million per ha (US$570 $ha^{-1}$), but in reality it is not possible to purchase land, only acquire *de facto* rights under which cultivation is permitted. |
| | Costs of establishing and maintaining an integrated mangrove-shrimp systems, | Rupiah 2,000 (US$0.23) per tree for sapling, planting labour and maintenance; planting density at 25,000 trees per ha. |
| | Value of mangrove wood in local markets. | Biomass derived from thinning and pruning and destined for charcoal estimated at Rupiah 1,500 per kg (US$0.17 $kg^{-1}$) from year 5; timber extraction may be expected from year 15 according to Department of Forestry. |

Source: Bunting et al. in press

Estimated mortality on GW farms was lower than on non-GW farms at 11% and 29%, respectively (Table 3). Though a degree of caution is required owing to differences in the calculation methods and small sample, these higher survival rates as well as the higher final weight related to a better growth rate in the GW compared to the non-GW (Tendencia et al. 2011 and Tendencia et al. in press, respectively) and were confirmed in others years. Average harvested biomass for GW and non-GW from stocked pond areas was close to 6,500 and 6,065 $kg{\cdot}ha^{-1}$, and average shrimp weights at harvest were 32 and 28 g, respectively, while the length of the culture periods was about equal (Table 2).

**Table 2**. Operating parameters for culture systems specified.

| Operating parameter[1] | Extensive [2] | MGW | Intensive | |
|---|---|---|---|---|
| | | | Non GW | GW |
| Net pond area (ha) | 10 | 2 | 9.2 | 8 |
| Total farm area (ha) | 11 | 11 | 11 | 11 |
| Pond depth (m) | 0.6 | 1.25 | 1.25 | 1.25 |
| Shrimp stocking density (PL15-20 $m^{-2}$) | 1 | 22 | 31 | 22 |
| Shrimp survival [3] (%) | 10 | 90 | 71 | 89 |
| Mean shrimp harvest weight (g) | 25 | 25 | 28 | 32 |
| Days of culture | 90 | 120 | 152 | 148 |
| Milk fish stocking density (no. $m^{-2}$) | 0.4 | | | |
| Milkfish survival (%) | 40 | | | |
| Mean milkfish harvest weight (g) | 330 | | | |
| Lime (kg $ha^{-1}$ $cycle^{-1}$) | 0 | 1,000 | 1,160 | 1,040 |
| NP fertiliser (kg $ha^{-1\cdot}$ $cycle^{-1}$) | 50 | 0 | 0 | 0 |
| Urea (kg $ha^{-1}$ $cycle^{-1}$) | | 30 | | |
| Super-phosphate (kg $ha^{-1}$ $cycle^{-1}$) | | 75 | | |
| Saponin (kg $ha^{-1}$ $cycle^{-1}$) | 100 | 100 | | |
| Feed input (kg $ha^{-1}$ $cycle^{-1}$) | 0 | 9,050 | 9,640 | 11,900 |

PL - Post-larvae; GW - Green-Water
[1] supplementary inputs are mentioned in Table 1 or in text;
[2] data from Bunting et al. in press;
[3] Survival rate either given by the farm that recounted the PLs or recalculated based on stocking density and given individual and total harvest weight.

Ponds on most farms had been constructed by former owners and costs of US$ 16,000 $ha^{-1}$ were associated with rehabilitating these ponds; an investment cost of US$ 20,000 $ha^{-1}$ was estimated and applied in the model (Table 3). Production ponds on shrimp farms occupied on average close to 60% of the total farm area, whilst GW reservoirs occupied an area equivalent to 15% of the pond surface area.

### *The integrated mangrove green-water scenario*

The ratio of surface areas in the integrated mangrove green-water (MGW) system was set at 1:0.15:3.6 for culture ponds, reservoirs and mangrove, respectively. Cost and production assumptions for MGW culture were the same as those for the GW system when it came to pond operation and for the ES when it came to anticipated wild catches. Income from wild species harvested from ponds and aquaculture products was estimated based on local market prices in 2009. Additional labour costs of US$ 100 $ha^{-1\cdot}y^{-1}$ were anticipated for the mangrove stand. The value of mangrove wood from thinning and pruning estimated at US$ 0.18 $kg^{-1}$ was based on the prevailing market price in 2009 for wood to make charcoal in Balikpapan. Potential income generation from mangroves that might be realised through capitalising on broader ecosystem services, namely provisioning (other than thinning), supporting, regulating and cultural services was not included in this financial assessment (see Discussion).

**Table 3**. Average capital and operating costs of the extensive system in East Kalimantan (Bunting et al. in press) and of the two intensive shrimp culture systems in the Philippines, the last including financial results for 2009.

| **Capital costs** (US$ ha$^{-1}$) | | | **Fixed and variable operating costs** (US$ yr$^{-1}$·ha$^{-1}$) | | | |
|---|---|---|---|---|---|---|
| Description | GW & non-GW | ES | Description | Non-GW | GW | ES |
| Value of land | 2,500 | 555 | Pond bottom preparation * | 1,390 | 580 | 0 |
| Farm construction | 20,000 | 3,500 | Maintenance * | 870 | 400 | 0 |
| Aerators | 2,050 | | Pesticides & T-seed | 500 | 300 | 111 |
| Other equipment | 330 | 444 | Chlorine * | 170 | 700 | 0 |
| | | | Lime | 460 | 485 | 11 |
| | | | Fry | 2,250 | 1,580 | 78 |
| | | | Feed | 15,085 | 15,450 | 56 |
| | | | Probiotics & molasses | 1,690 | 950 | 0 |
| | | | Electricity, fuel & freight * | 5,440 | 7,580 | 53 |
| | | | Permit & Taxes | 850 | 1,920 | 0 |
| | | | Labour* | 5,250 | 4,220 | 67 |
| | | | Incentives and operation* | 990 | 1,160 | 0 |
| Totals | | | | 34,945 | 35,325 | 376 |
| Value of shrimp harvest (including fish, collected shrimp and crab for ES) | | | | 40,750 | 42,240 | 1,217 |
| Gross income | | | | 5,805 | 6,885 | 841 |

* Cost factors included by GW and non-GW farmers in these categories varied and thus they are not directly comparable.

***Complementary assumptions***

Relative to pond area, an additional land area was included for access and infrastructure; this was set at 10% for the extensive system and at 25% for the others, giving a total area of 11 ha for all systems. Costs for a guardhouse and storage facilities and laboratory equipment to monitor water quality were assumed at US$ 444 ha$^{-1}$ and US$ 330 ha$^{-1}$, respectively (Table 3). We assumed that the value of land in the Mahakam Delta would increase five-fold to US$ 2,500 ha$^{-1}$ following investment in ponds for system intensification. The required GW reservoir area was included in calculating the cost of land and construction; we considered the construction cost to be identical to the ponds which might be an overestimation for farms with concrete lined shrimp ponds.

# Results

Capital cost per ha were about 50% higher for the MGW system than for the ES but about one-quarter of those for the intensive systems (Table 4). Operating costs per ha for the MGW system were over fifteen-fold that of the ES and net profit five-fold; operating cost for the intensive systems are five-fold those for MGW culture. Consequently returns on operating cost were highest for the ES. Average annual profits including depreciation were highest for the GW system (approaching US$ 4,800 ha$^{-1}$ for the 2009 price level) and about six-fold the profits from non-GW culture. Profits including depreciation of the ES were about equal that from non-GW culture, whilst profits for MGW were 50% higher, and GW six-fold ES and non-GW. Returns on capital and operating cost were lowest for non-GW, thus resulting in the longest pay-back period. At the 2009 farm-gate price for shrimp the 10-year NPV of MGW, GW and non-GW was negative for a 10% discount rate; ES became slightly negative at a 15% rate. The 10-year IRR was highest for ES (14%), intermediate for the GW (4.3%), minimal for the MGW (2.8%) and negative for non-GW systems.

**Table. 4**. Financial indicators for developing an 11 ha shrimp farm under different management regimes with a farm gate shrimp price of US$ 6.4 $kg^{-1}$.

| Characteristic | | Unit | Extensive | MGW | Intensive | |
|---|---|---|---|---|---|---|
| | | | | | non-GW | GW |
| Capital costs | | US$ $ha^{-1}$ | 4,100 | 6,600 | 35,500 | 35,500 |
| Operating costs | | US$ $ha^{-1}$ | 380 | 5,800 | 26,400 | 23,100 |
| Gross Income | | US$ $ha^{-1}$ | 1,120 | 6,100 | 28,100 | 28,000 |
| Profit excluding depreciation | | US$ $ha^{-1}$ | 830 | 1,110 | 1,700 | 4,800 |
| Profit including depreciation | | US$ $ha^{-1}$ | 680 | 940 | 610 | 3,760 |
| Return on capital costs | | % | 20% | 17% | 5% | 14% |
| Return on operating costs | | % | 218% | 21% | 6% | 21% |
| Pay-back period | | year | 5 | 6 | 21 | 7 |
| Ten year NPV at: | 10% | US$ $ha^{-1}$ | 650 | -1,800 | -23,400 | -6,900 |
| | 15% | US$ $ha^{-1}$ | -90 | -2,500 | -23,800 | -10,800 |
| | 20% | US$ $ha^{-1}$ | -600 | -3,000 | -23,900 | -13,300 |
| IRR (%) over: | 10 y | % | 14,3% | 2.8% | < 0% | 4,3% |

## *Sensitivity analysis*

Sensitivity analysis showed that a 10% increase of the farm-gate price of shrimp resulted in a promising 10-year IRR for all systems (4.5 to 16.5%), though apparent benefits for the ES remained limited (Table 5). The effect of a 10% decrease of the price for feed was about equal to a 5% increase in shrimp market price; a 10% increase of the feed cost gave a negative IRRs for all intensive systems. The effect of increasing fuel prices was less dramatic but a 10% increase brought a negative IRR for the non-GW. The change in market prices of the collected shrimp and crab has less dramatic effects for the two systems, ES and MGW, producing these.

**Table. 5**. Sensitivity of 10-year IRR (%) to changing costs and commodity prices, for the four shrimp farming systems.

| Parameter | Extensive | MGW | Intensive | |
|---|---|---|---|---|
| | | | Non-GW | GW |
| Baseline | 10.1 | 1.7 | < 0 | 4.3 |
| Cultured shrimp farm-gate price increased, +10% | 15.3 | 16.5 | 4.5 | 16.4 |
| Cultured shrimp farm-gate price increased, +20% | 16.5 | 30.1 | 19.0 | 28.1 |
| Site development cost, +10% | 8.2 | 0.7 | < 0 | 2.8 |
| Feed cost decrease, -10% | 10.1 | 7.9 | < 0 | 8.7 |
| Feed cost increase, +10% | 10.1 | < 0 | < 0 | < 0 |
| Fuel cost increase, +10% | 14.1 | 0.1 | < 0 | 2.0 |
| Value of wild shrimp and crab decreased, -50% | 7.9 | 1.0 | < 0 | 4.3 |
| Value of wild shrimp and crab increased, +50% | 20.1 | 4.4 | < 0 | 4.3 |

Assuming the farm-gate price of shrimp increased to US\$ 7 $kg^{-1}$, 9% higher than in 2009, all systems continue to give reasonable returns even with a 20% increase in feed, fuel and labour costs (Table 6). While the 10-year IRR of the ES is hardly effected, the non-GW system is most vulnerable while the GW performance is most robust continuing to give good returns even with 50% cost increase for labour and feed. Making a similar assumption on land cost to that for intensive GW and non-GW, i.e. the value of land converted to ponds in the MGW system would increase five-fold whilst the value of land under mangrove would remain constant, resulted in a 10-year IRR of 6.4%, i.e. four-fold the MGW baseline (Table 5).

The return on operational cost of the ES remained highest under the various scenarios tested in the sensitivity analysis. However, the MGW aquaculture system can more than double farmer's income, without accounting for the livelihood contributions from collecting in close to 8 ha mangrove (Table 6).

**Table 6.** Sensitivity of the 10-year IRR (%) to changing costs with a 9% higher farm-gate price (US\$ 7 $kg^{-1}$) for shrimp, and productivity of the three scenarios for a shrimp farm-gate price of US\$ 7 $kg^{-1}$ and an 11 ha area.

| Parameter | Unit | Extensive | Intensive | | |
|---|---|---|---|---|---|
| | | | MGW | non-GW | GW |
| 10 yr NPV for shrimp price +9% | US\$ $kg^{-1}$ | 1,760 | 11,670 | -100,100 | 70,170 |
| 10 yr IRR for shrimp price +9% | % | 11.1 | 13.9 | 2,4 | 14.8 |
| Labour cost increase, + 20% | % | 10.6 | 11.4 | < 0 | 12.7 |
| Labour cost increase. + 50% | % | 10.0 | 7.4 | < 0 | 9.4 |
| Feed cost increase. + 20% | % | 11.1 | 4.2 | < 0 | 6.7 |
| Fuel cost increase, + 20% | % | 10.7 | 9.3 | < 0 | 10.9 |
| Fuel cost increase. + 50% | % | 10.2 | 1.7 | < 0 | 4.7 |
| Pond area | ha | 10 | 2.2 | 8.3 | 7.2 |
| Total cultured shrimp | kg | 500 | 10,900 | 50,000 | 46,500 |
| Return on operating costs | % | 194 | 31 | 17 | 32 |

### *Macro-economic implications*

The total shrimp production from the non-GW farm was about 5 tonnes·$yr^{-1}$ higher than the GW, due to the larger pond area of the first. The quantity of shrimp produced in the MGW was about one–fifth of the two intensive systems having larger pond areas. However, compared to ES, MGW can deliver 20 times more shrimp per farm area. The capital needs of a transfer to MGW system would be less than investing in one of the two intensive systems, while maintaining mangrove ecosystems services and livelihood contributions.

## Discussion

The farm-gate price of shrimp fluctuates widely and differs between countries due to input price levels, market access and regulations. For example, while the farm-gate shrimp price in Vietnam had been US$ 10.5 $kg^{-1}$ in 2000, it decreased to 6 in 2004 and further to 4.5 in 2005-2006, recovering to US$ 5.7 $kg^{-1}$ only in 2009 (Vu et al. 2011). Then the shrimp price was US$ 6.4 $kg^{-1}$ in the Indonesia and the Philippines, where it decreased to US$ 6.2 $kg^{-1}$ in 2012. Thus comparisons between countries and years should be viewed with caution.

Financial returns from ES are modest but associated operating costs are considerably lower as compared to the other systems, explaining the attractiveness of the system to poor migrants (Bosma et al. 2012). In 2004-2005, comparable extensive systems in India yielded 337 $kg{\cdot}ha^{-1}$ and earned US$ 1,085 $ha^{-1}$, while the most intensive system studied yielded 12-fold: 4,927 $kg{\cdot}ha^{-1}$ and earned US$ 12,643 $ha^{-1}$ (Bhattacharya and Ninan 2011). In Vietnam, using data from 2008-2009, Tran et al (in press) confirmed this gap in gross income between extensive and semi-intensive systems: 352 compared to 5,941 US$ $ha^{-1}$, respectively. The more than five-fold difference in our model, i.e 1,120 and 6,100 US$ $ha^{-1}$, respectively, is modest compared to the differences reported in India and Vietnam; this better performance of the ES might be due to integrating milkfish and accounting for wild crab and shrimp collected. Though ES are generally perceived as low risk owing to reduced stocking densities, absence of feed inputs and minimal operating costs, all hazards are not expressed in these figures because the large pond area requires long protective dikes increasing the risk of abrasion and demanding high maintenance cost while capital availability is low. Damage occurring in consecutive years of low benefits resulted in abandonment of farms which were either returned to nature or were taken-over by neighbours (Bosma et al. 2012).

As demonstrated in Bangladesh (Hossain et al. 2004) and Vietnam (Joffre and Schmitt 2010), low-skilled and lowly-educated farmers, as is the case for most farmers in the Mahakam Delta, generally have only one alternative: abandon farming at the present site and open new mangrove stands for shrimp culture or forest areas for other activities elsewhere. Thus, diversification of livelihood activities based on the mangrove ecosystem can contribute to increased sustainability and sedentarisation of their farming system. The positive impact mangrove may have on income from aquaculture farms was confirmed by findings from Tran et al (in press) where improved extensive shrimp farms with mangrove made US$ 824 $ha^{-1}$, while those without mangrove made less than half (US$ 352 $ha^{-1}$).

Observing various shrimp production systems in South Vietnam, Tran (2012) concluded that integrating mangrove stands in ponds was more beneficial and robust than the associated system we modeled. The integrated mangrove-shrimp system yielded US$ 1,110 $ha^{-1}$ while the gross income of the associated mangrove-shrimp system was US$ 512 $ha^{-1}$. Such a system might be easier to implement in the Mahakam Delta as farmers can increase gradually the number of ditches for shrimp and of bunds with mangrove trees.

Neither Tran (2012) nor the anticipated income generation in the MGW scenario did include mangrove's potential revenues from collection other than timber, nor its societal services. Next to timber, crustaceans, fish and shellfish, thatch, charcoal, honey, tannins, medicines and raw materials for handicrafts can be marketed from mangrove stands (Ruitenbeek 1994). Moreover, mangroves generate supporting services e.g. soil formation and nutrient cycling, regulating services e.g. water purification, erosion regulation and storm protection, and cultural services e.g. aesthetic, educational and spiritual and inspirational benefits (de Groot et al. 2002). In Thailand, the total economic value (TAV) of intact mangrove forest ecosystems was up to 70% higher than the economic value when converted to a shrimp farm (Sathirathai 1998 cited by Balmford et al. 2002). The need for biodiversity conservation and $CO_2$ sequestration are further arguments to strive for conversion of extensive culture areas to mangrove-GW shrimp production systems. Economic returns could be enhanced by capitalising on the ecosystem services through carbon credits and through organic certification giving a price premium for the products. DebRoy (2012) estimated the TAV of the Pichavaram mangroves at about US$ 57,000 $ha^{-1}$, which includes valuation estimates of the indirect services such as bio-fencing and carbon sequestration. This is double the gross income from the two intensive systems modelled here and suggests that the TAV of the MGW system might be higher than these intensive systems. Capitalisation of ecosystem services may enhance the sustainable management of mangroves if contracted out to farmers, as done in Vietnam (Tran et al. 2012).

Regarding the GW technology, tilapia are exotic species in the Mahakam Delta and milkfish does not reduce luminous bacteria (Tendencia et al. 2006a). Considering biodiversity conservation it is recommended to identify indigenous species that efficiently can replace tilapia in the GW system. The integration of seabass will increase the system's resilience if there is market demand for this fish. Though capital investments for conversion are high, a well-managed GW system improves financial robustness and thus attractiveness for investors.

## Conclusion

Though the total cultured shrimp production from intensive non-GW farms was 10% higher than from GW farms, the latter are more resilient and generate higher profits. An integrated mangrove GW shrimp farm would yield only about 20% of the amount of shrimp produced by similarly sized non-GW and GW farms, but the integrated MGW farms would sustain additional ecosystems services, such as fish breeding and nursing grounds and coastal protection. Transition from prevailing extensive farms to the integrated mangrove green-water shrimp production system will increase the contribution of the sector to the national economy twenty-fold, whilst simultaneously doubling the income of farmers and enhancing even more the economic value of the coastal ecosystem services.

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