Quantifying Benefits of an Improvement to the Environment: The Economics of Environment-Friendly Shrimp Farming in Mangrove Areas

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There is a way of measuring the benefits of an improvement to the environment, and comparing these with the costs of implementing such improvement is revealed from the results of this study

This study which focuses on the Experiences and Insights from the Philippines, was conducted as part of the activities of the AQD Project on the Promotion of Mangrove-Friendly Shrimp Aquaculture in Southeast Asia, which received funding from the Government of Japan through its Trust Fund Program.

Intensive shrimp farmers now employ a variety of progressive technologies and practices. Among the most notable are the reduction of stocking density, extended pond bottom preparation, crop rotation, feed quality improvement, stocking of good quality fry, use of green water and bioremediators, use of probiotics, and increased aeration. Recent practices include the screening of fry for White Spot Syndrome Virus (WSSV), the use of settling ponds and the adoption of biosecurity measures. This benefit-cost analysis study was conducted in order to measure the environment-related benefits of water quality improvements from environment-friendly shrimp farming practices.

The results of the study, which was conducted in the Philippines in 2005, indicated that the average annual investment in pollution management of the shrimp farming industry constitutes a significant portion of around 9% of the annual production costs. The opportunity cost of not utilizing this technology is estimated at PhP740,000.00/ha and PhP44,000.00 (PhP50.00 = USD 1.00), in terms of pollution damage to the fisheries and human health, respectively. Thus, environment-friendly shrimp farming practices generate net economic benefits for the Philippine economy as a whole and the society. In fact, the use of environment-friendly shrimp farming practices increases the economic value attributed to the role of mangrove habitats in supporting fisheries.

This study has shown that, in effect, shrimp pond culture has contributed to the multiple use and benefit of mangroves. The estimated net present benefits of environment-friendly shrimp farming as shown in this study could provide governments and stakeholders, including the private sector, the necessary baseline information on economic costs and benefits of appropriate technologies for non-destructive shrimp farming in mangrove areas. By providing guidelines on sustainable shrimp farming, it is expected that appropriate legislation and enforcement mechanisms could be developed to ensure responsible aquaculture, as well as the conservation and sustainable use of mangroves in Southeast Asia.

Shrimp Farming and Mangrove Conservation

Effective coastal management stresses the importance of integrating responsible shrimp farming in mangrove conservation. The task of conserving mangrove ecosystems is shared among the coastal dwellers and users, including aquaculture entrepreneurs, through responsible aquaculture practices. Responsible aquaculture encompasses the use of appropriate and efficient farming technologies and practices, which are not harmful to ecosystems and resources (SEAFDEC 2001, 2005). The Code of Practice for Sustainable Use of Mangrove Ecosystems for Aquaculture in Southeast Asia (SEAFDEC, 2005a) also provides the guidelines for responsible aquaculture in mangrove areas.

Successful technology packages developed by SEAFDEC and other ASEAN countries have focused on the management of pond effluents (Baliao and Tookwinas, 2002). However, research is still lacking on the economic assessment of these technology options and the impacts of these technologies on mangrove ecosystems. Some research projects, however, have focused on the economic

Polyculture of tilapia (in net cages) in shrimp ponds to feed on organic wastes and plankton valuation of mangroves (Barbier and Strand, 1998) or on the profitability of shrimp farming to the private sector. For example, Sathirathai (1998) presented the private sectorÊs benefits of shrimp farming in Thailand. Other studies have focused on the assessment of technology (effective microorganisms) in terms of total economic development value (Aquilar and Tabora, 2003).

In the Philippines, the farming of the black tiger shrimp (*Penaeus monodon*) as a secondary crop in milkfish pond culture is a centuries-old tradition. Large-scale monoculture of the species, however, is a fairly recent development that took off only in the 1970s. Shrimp farming has benefited greatly from advances in milkfish culture technology. As recent as the early 1980s, Philippine black tiger shrimp production was less than 2000 mt, which suggests that no greater than 6000 ha of brackishwater fishponds then was devoted to the culture of this species. The Philippines, therefore, is one of the worldÊs few shrimp farming nations which has extensively converted the mangrove resources into fishponds prior to the popularization of shrimp aquaculture.

Because of its vast developed brackishwater pond area, the Philippines rapidly became a leader in world black tiger shrimp production in the 1980s and up to the early 1990s. At a period when shrimp farming investments were fueled by quick profits rather than long-term enterprise development, the Philippines inevitably became one of the first victims of unsustainable shrimp farming practices. Within 15 years from being the worldÊs top black tiger shrimp producer, Philippine shrimp farmers found themselves in a high-risk venture threatened by serious disease and water pollution problems.

Many lessons and technologies have since been learned throughout the region from the experience of the Philippines, and the other countries that were similarly hit by shrimp diseases in the years that followed. TodayÊs shrimp farming technology centers on the concept of being environment-friendly, as evidence from the large investment that farmers now take to improve environmental conditions in the pond, as well as in the quality of inputs, such as seeds and feeds. To a large extent, the current shrimp farming industry does not deserve its image of the past, which was often depicted negatively in its economic and social contribution in relation to its use of the mangrove ecosystem.

This study looked at the economic value as a basis of determining the net benefits of the current environment-friendly shrimp farming technologies relative to past farming practices. While the data and computations presented were based on Philippine conditions, most of the environment-friendly technologies presented are also similarly employed (or can be similarly employed) in other countries. Hence, this study may provide a good basis for comparative analysis. The study also specifically reflected on the potential benefits from shrimp farming.

Economic Importance of Shrimp in Aquaculture

Shrimps, given their large demand for export, are the most valuable crop in brackishwater aquaculture. At its peak in 1991, the Philippines attained its highest export volume of 26,607 mt valued at US$269.4 million (**Fig. 1**). In the last eight years, however, the collapse of shrimp farming in the country due to unsustainable practices and diseases has effectively curtailed the growth of the aquaculture industry (**Fig. 2**). As a result, the PhilippinesÊ world ranking was brought down from the 5th place in 1991 to 11th in 2004 (by volume, all species excluding seaweeds).

On the contrary, neighboring countries such as Thailand, Indonesia, Vietnam, and Malaysia, which have managed to

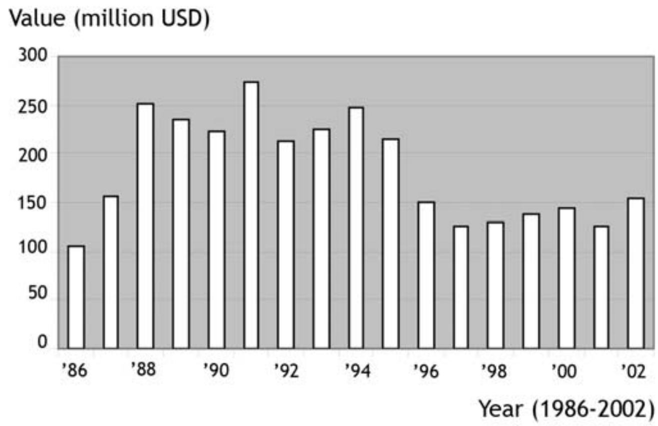


Figure 1. Philippine export of shrimps and shrimp products (Million USD) Source: FAO FishStat Plus 2006

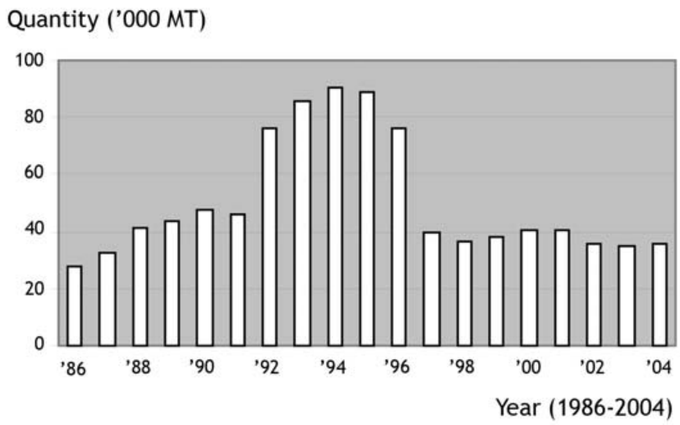


Figure 2. Philippine production of giant tiger shrimps ('000 mt) Source: FAO FishStat Plus 2006

sustain their shrimp culture industries, have either maintained or advanced their aquaculture standings. The reality is that the farming of shrimps, which demands a high level of technology and management, has become an instrument for the advancement of the aquaculture industry as a whole. It provides a catalytic role by putting valuable experience, progressive farming techniques, modern equipment, and key support industries in place for other sectors to tap. Shrimp farming in particular is credited for having rapidly advanced the technologies for intensive culture techniques, feed milling, hatchery management, and value adding. Interestingly, through shrimp farming, it is to note that many countries in Latin America, Africa, and the Middle East, which had no aquatic farming tradition in the past, have become empowered to join the league of aquaculture nations in just a span of few years.

Benefits from Mangroves

Mangroves are highly productive ecosystems which are not only able to provide a range of valuable forest products, but also maintain estuarine water quality and play crucial roles in the life cycle of many commercially-important species of fish and shrimps. The traditional uses of the mangroves, as modified ecosystems, include firewood gathering, thatch materials (*Nypa* species) for homes and mangrove poles for lumber and construction materials, and nursery grounds for the small-scale and commercial marine fishery resources.

Thirty-five per cent of the total 18 million ha of mangrove forests are found in Southeast Asian countries of Brunei Darussalam, Cambodia, Indonesia, Malaysia, Myanmar, the Philippines, Thailand and Vietnam. Indonesia alone has 4.5 million ha of mangroves. Human activities, however, including aquaculture, have put these mangroves at risk. In the last three decades, mangrove loss has ranged from 25% in Malaysia to 50% in Thailand. In the Philippines, the mangrove cover of 418,990 ha in 1967 has been reduced to only about 100,000 ha now (Primavera, 2005). This reduction was mainly caused by charcoal and firewood utilization followed by the expansion of agricultural areas, fishponds, urban and industrial development, harbor construction, mining, and housing projects.

Mangroves also reduce coastal erosion, as they serve to dampen storm surges and to a minor extent high winds. Both events are associated with tropical and subtropical storms. The mangrove resource, where it occupies flood plains, performs a flood reduction function which may be lost if the trees are felled and the area is converted to other uses. Mangroves lining the banks of rivers also help prevent erosion of the riverbanks, which in turn helps protect adjacent property.

The mangrove area is the spawning and nursery area for many species of fish and crustaceans. The particles of vegetation (detritus) and nutrients exported out of the mangrove ecosystem from the food base of the complex marine organisms, support valuable estuarine and near-shore fisheries (finfish, shellfish and crustaceans). Those whose livelihood depends on fishing have long recognized the interconnection between mangroves and fisheries, but the values have only been slowly considered in planning processes where decisions on allocations of intertidal lands are being made.

Mangroves are not only of significance to local communities, but to the shrimp culture industry as well (Primavera, 2005). Revenues from mangrove fisheries, tourism and timber result in an annual benefit to the community of USD315.00/ha/yr (Walton, et al, 2006). This figure is likely to be considerably more if the contribution of the mangrove to the coastal catch of mangrove-associated species is included. This estimate only includes direct benefits to the community from mangroves, and not intangible benefits such as coastal protection, which paradoxically is perceived by the community as one of the most important functions. More than 90% of all fishers, regardless of where they fished, thought the mangroves provided protection from storms and typhoons and acted as a nursery site and should be protected. Annual net revenue from mangroves was estimated at USD 1000.00/ha/yr (Samonte-Tan, et al., 2007).

Mangrove resources are now under growing pressure as a result of population growth and economic development. Human activities and interventions within and near mangrove areas usually lead to the degradation of the mangroves and the coastal ecosystems as well. The demand for wood and wood products is increasing. Moreover, mangrove forests are being cleared for the construction of aquaculture ponds especially for shrimp and are likewise reclaimed for the cultivation of rice, coconuts or other agricultural crops.

But not all aquaculture requires clear-cutting of mangroves. Examples of mangrove-friendly aquaculture exist either in waterways (seaweeds; bivalves such as mussels, oysters and cockles; and cages for crab and fish) or land-based (ponds and pens for crabs, shrimps and fish). These technologies, particularly mangrove ponds and pens (also called aquasilviculture or silvofisheries) integrate the utilization of mangroves for both forestry and aquaculture production.

Environment-Friendly Shrimp Farming Practices

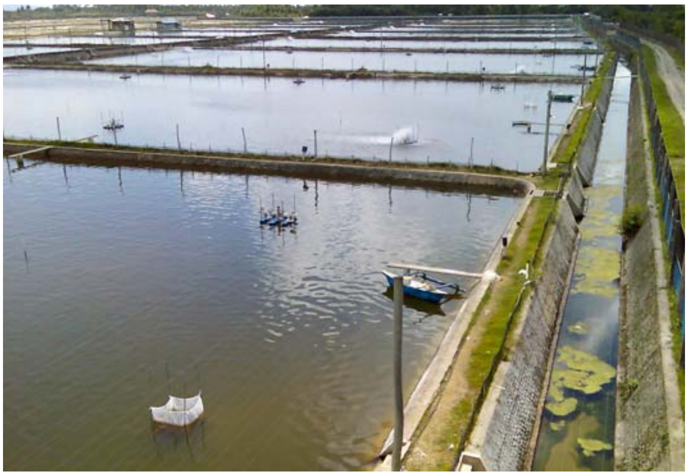
Early attempts to revive the Philippine shrimp industry in the late 1990s started with the lowering of stocking densities, as this was seen to be the major culprit behind the rampant disease problems. From the usual 25-40/m^2 stocking rate, densities were reduced to 10-15/m^2, bringing down yields from the usual 7-10 mt/ha/crop to 5-8 mt/ha/crop or a volume reduction of around 20-30%.

Farmers also improved on their pond bottom management. During pond preparation, the soil was tilled more thoroughly to enhance the oxidation process. Some farmers also adopt polyculture of tilapia in net cages along the center of the pond to feed on the sludge and unconsumed feeds as well as on suspended organic matters, bacterial floc and plankton. A net biomass gain of approximately 500 kg of fish is harvested per hectare of shrimp pond, with the fish feeding on natural food and organic wastes alone. Through these practices, waste accumulation in ponds was significantly reduced. It is interesting to note that in the 1980s, it was not uncommon for farmers to dispose of accumulated sludge along the riverbanks.

Complementing pond bottom management is the practice of crop rotation where shrimps are cultured during the summer months, while fish (usually tilapia or milkfish) are cultured during the remaining months of the year. Intercropping fish under extensive culture with no feeding has been found to reduce organic matter load in the sediment, as the accumulated wastes are allowed to be consumed in the fishÊ detrital food web or are decomposed more thoroughly. High organic matter in the soil favors the proliferation of pathogenic bacteria, particularly *Vibrio harveyii* or more commonly known as luminous bacteria.

Starting in 2003, the practice of crop rotation has become essentially mandatory as studies have indicated that WSSV disease is mostly prevalent when temperatures drop during the cool months of the year. A single summer crop per year has since led to a dramatic reduction in the occurrence of the WSSV disease in shrimps.

An important shift in the health management strategy of shrimp farmers in recent years is the attention given to proper nutrition and feed quality. In the past, price competitiveness was the major consideration in choosing a feed. Understandably, this has discouraged feed manufacturers from working with higher quality formulations as well as from investing on better processing technology that would enhance digestibility, reduce fines and improve hydrostability. In improving nutrition, farmers have also adopted on-farm supplementation with vitamins (especially vitamin C), minerals, marine lipids and immune enhancers. The obvious benefits from these practices are the improvement in feed conversion efficiency and reduction in waste, both of which have positive impacts to water quality and the environment.



Top: Aquafarm in Negros Occidental with drain water fully recirculated through tilapia ponds; Left: Pond undergoing thorough plowing using a tractor; Above: Handwash, footdip and barrier fence for biosecurity

While fry quality selection has long been adopted by progressive shrimp farmers (Cruz, 1993), the screening of the fry for possible infection by WSSV or *Vibrio harveyii* is relatively new. This practice is widely regarded to have improved markedly the survival rates. Moreover, it reduces disease outbreaks, which readily spread from pond to pond and farm to farm, and conceivably also to the surrounding environment.

Luminous bacteria was thought to be responsible for the large mortalities associated with the „30-day‰ syndrome, and „60-day‰ syndrome in 1996. The discovery by shrimp farmers from Negros Island (central Philippines) in the late 1990s of the effectiveness of green algae-rich effluent from fish farms in improving water quality, and in inhibiting luminous bacteria disease, was a breakthrough. This practice became known later as the „greenwater‰ technology. The technology as it is practiced today involves allocating 25-50% of the farm area for use as reservoir, where tilapia is raised at an ideal biomass load of 3 mt/ha. Water used for the shrimp ponds is exclusively taken from this reservoir. Results of studies by SEAFDEC/AQD indicated that tilapia promotes the bloom of green algae, particularly *Chlorella*, which has a suppressing effect on the proliferation of *Vibrio harveyii* and other pathogenic bacteria. Ammonia levels in the water were also found to be lower with the use of greenwater as a result of the algae assimilating it. Through the use of greenwater, the farmers are able to extend their first water exchange from the usual 30 days to 60-70 days, reducing the risks of water borne disease vectors and eggs of noxious fish entering the pond early during the crop.

As a standard practice, farmers try to maintain a plankton profile of at least 80% green algae and diatoms, with the population of non-beneficial blue-greens and dinoflagellates not exceeding 20%. Comparisons of ammonia readings and luminous bacteria population in shrimp ponds versus its water source, almost always show that water quality conditions in the culture environment are better.

The use of probiotics is a key aspect in the recent success of environment-friendly shrimp culture. Probiotics provided farmers a sound alternative to antibiotics, which were widely used in the 1980s. A stabilized mixture of naturally-occurring beneficial bacteria and enzymes, probiotics are mainly applied to: inhibit the growth of pathogenic bacteria by boosting the population of „good‰ or beneficial species; and improve the water quality by enhancing the natural decomposition process. These twin actions are now well recognized by farmers to effectively create a healthier environment. To a lesser extent, probiotics are used as on-farm feed additive to improve shrimp gut flora and improve food assimilation. The application of probiotics in the Philippines is actually not new, dating back to the late 1980s. Lack of understanding on its proper use, however, resulted to inconsistent results eventually forcing most early users to abandon it.

Complementing the use of probiotics is the increased use of aeration. This is the direct result of a higher oxygen demand from the enhanced decomposition of wastes. As a general rule, farmers today target a minimum dissolved oxygen (DO) level of 5 ppm as compared to 3-4 ppm in the past. Typically, the increased aeration requires the doubling of horsepower per hectare. It is through the combined use of probiotics and increased aeration that water use and effluent production have been dramatically reduced. In the past, water was changed 10-20% daily and this was increased to 30-40%/day during the high tide. Now, water change averages only 5-10% daily with very little water use during the first 60 days. Hence, the higher aeration cost is partly reduced by the lower pumping expense.

Experience in the past has taught farmers that organic waste coming from effluents inevitably pollutes the receiving waters. To reduce organic load of wastewater, a growing number of farmers have now adopted the use of settling ponds or settling canals. As such, a series of baffles reduce the water velocity and allow the settling of suspended wastes. The collected sludge are eventually removed and allowed to decompose aerobically on dry land. The extent of removal of suspended wastes under such facilities is yet to be studied but is believed to be significant.

The widespread occurrence of WSSV disease nowadays is the single biggest threat to shrimp farming. Even by stocking WSSV-free fry, numerous potential vectors for infection could still remain such as copepods, small shrimps, crabs, birds, feral animals, and even humans. The risk of bringing WSSV carriers is therefore naturally highest when new water is pumped in. Hence, as a biosecurity measure, farmers have capitalized on the use of probiotics in conjunction with increased aeration to cut down water exchange by at least 50%. Effluent production from the adoption of this practice has consequently been cut to at least half.

Other biosecurity measures include strict protocols on personal hygiene and movement of materials, use of bird scaring devices and crab fences, use of fine-meshed nets in screening incoming water, and sanitizing pond waters with readily degradable products such as Virkon-A™ or chlorine to rid the pond of WSSV or its potential carriers. A summary of the environmentally-friendly shrimp farming practices with information on the cost of adopting such practices to the farmer and the perceived benefits to the environment is shown in **Box 1**.

Table 1. Cost and returns analysis (PhP/ha)

Harvest Data	Traditional practices (average of 3 ponds)	Traditional practices (average of 6 ponds)	Use of probiotics (average of 7 ponds)	Use of *Tilapia* greenwater (average of 3 ponds)	Low water discharge technique (average of 2 ponds)		Combined environment-friendly methods (average of 2 ponds)	
- Stocking density (pcs/m²)	29	33	30	19/*4*		30	13	23
- Days of culture	183	126	323		143	147	137	113
- Average body weight (g)	36.1	32	30	*33/200*	37	26	32	25
- Biomass (kg)	8057	7208	7792	4421/ *5600*	7784	5825	3883	3653
- Survival rate (%)	72.6%	70.0%	85.0%	*70.0%*	105	77.1%	94.0%	75.5%
- Feed conversion ratio	2.09	1.58	1.33	1.60/*1.50*	1.8		1.55	2.1
- Biomass (tons/ha)	8.06	7.21	7.79	4.42/*5.60*	7.8	5.82	3.88	3.7
Production Cost (PhP)								
- Pond preparation		22,083	32,250	24,999	48,565	17,341	10,000	11,264
- Fertilizer, lime			812			9,404		
- Probiotics/ biomanipulators			34,069		63,036	21,274	19,175	5,638
- Water culture					4,920			
- Fry/Fingerlings	102,083	82,084	92,717	101,099	39,975	78,999	40,899	50,459
- Feeds	677,151	606,763	423,932	537,353	603,294	416,646	297,183	350,205
- Supplementary feeds			89,381	135,930	51,913		43,513	14,167
- Conditioners, chemicals	187,399		9,679			12,890	13,497	10,167
- Sludge collectors, cages						13,357		
- Gen./Admin	80,854	208,333	76,605					
- Fuel/Oil	114,202	41,667		91,718	47,220	11,219	36,883	174,487
- Power			239,601	84,693	258,689	194,537	61,856	15,839
- Direct labor	13,851	83,333	124,812	122,585	61,909	103,256	16,665	17,074
- Lab fees	2,787		62,357	17,406	19,175	2,827	36,641	30,490
- Repairs and maintenance	16,788		2,855	10,789	10,699	68,753		14,019
- Security services			13,271		8,233	6,501		
- Other direct expenses	10,101		4,279	12,184	37,639	49,827	6,189	
Total (PhP)	1,205,216	1,044,263	1,206,620	1,138,756	1,255,267	1,006,831	582,501	693,809
- Cost to produce 1.0 kg	149.53	144.84	154.89	257.64	161.34	173.00	150.13	190.08
- Selling price	294.28	325.00	377.62	325.45/ 55.00	425.85	286.55	325.00	325.00
- Gross Sales	2,363,463	2,342,708	2,931,119	1,746,540	3,314,640	1,661,547	1,261,812	1,187,159
Net returns (PhP)	1,158,247	1,298,445	1,724,499	607,784	2,059,373	654,716	679,311	513,350

Net Benefits from Environment-Friendly Shrimp Farming

A comparison of the costs and benefits derived from using traditional shrimp farming methods, without environment-friendly practices, are presented in **Table 1**. Producer Surplus was computed for shrimp pond farming, where producer surplus is the excess of the revenue over costs received by the shrimp farmers. Gross revenue included the value of shrimp generated from shrimp farming. Total cost consisted of variable costs (materials, supplies, labor) and fixed costs (overhead, maintenance).

Since shrimp farming provides a stream of valuable services to society over time, the economic benefits derived from shrimp farming were calculated as the sum of the present value of the stream of revenues over a 15-year period (assumed lifespan of shrimp ponds). In essence, these shrimp farms generated positive private net benefits ranging from PhP607,000 to PhP2.0 million per hectare for using traditional and environment-friendly shrimp farming practices, as summarized in **Table 2**. Over a 15-year period, environment-friendly shrimp farming practices are estimated to generate net revenues of up to PhP8.5 million. This value is almost 40% more than the net present value benefits for traditional shrimp farming.

The defensive treatment expenditures of shrimp farmers provide a minimum value of the benefits of clean water. These values represent the willingness-to-pay of shrimp farmers to restore or maintain the water sources in their unpolluted state. On an incremental basis, a shrimp farmersÊ investment to the environment is PhP24.00/kg. This means that for every kg of shrimp produced, PhP24.00 is an additional investment for the environment. The average annual investment in pollution management of the shrimp farming industry constitutes a 9% of the annual production costs.

Management Implications

Surrounding waterways are the primary sources as well as recipients of pollutants and pathogens. Hence, the developments of production systems with these characteristics are the cornerstones of mangrove-friendly shrimp culture operations: (1) lower organic matter load,

Table 2. Economic benefits of environment-friendly shrimp farming

Economic Benefits	Farms employing traditional shrimp farming practices		Environment-friendly shrimp farming					
			Probiotics	Green water	Low-discharge		Use of combined Methods	
Production (mt/ha/year)	8.06	7.21	7.79	4.42	7.78	5.82	3.88	3.65
Private benefits								
- Costs per ha	1,205,216	1,044,263	1,206,620	1,138,756	1,255,267	1,006,831	582,501	693,809
- Net returns per ha	1,158,247	1,298,445	1,724,499	607,784	2,059,373	654,716	679,311	513,350
- Cost to produce 1 kg	149.53	144.84	154.89	257.64	161.34	173.00	150.13	190.08

(2) lower effluent production, and (3) lower water exchange rate. The widespread disease problems that have tremendously affected shrimp farmers in the Philippines confirmed that many aspects of intensive shrimp farming were indeed not sustainable.

While Philippine shrimp production continues to be threatened by luminescent *Vibrio* and WSSV disease, the recent developments have been encouraging in that many shrimp farmers have already adopted major changes in their culture technologies consistent with Âbest management practicesÊ for mangrove-friendly shrimp farming. As described by Baliao and Tookwinas (2002), these include: (1) lowering of stocking density; (2) improvement of pond bottom management; (3) crop rotation; (4) improvement in feed quality; (5) stocking of laboratory-screened fry; (6) use of „greenwater‰ technology; (7) use of probiotics; (8) increase in aeration; (9) use of settling ponds; and (10) employment of biosecurity measures. Compared to intensive shrimp farms in the past, most existing shrimp ponds in the Philippines today are able to maintain the necessary water quality standards or requirements for producing healthy shrimps up to harvest.

The quality of water in the mangroves is essential to sustain ecological or life-support benefits for associated species for coastal and fisheries livelihood activities. In general, no cost is attributed to discharges from shrimp ponds because, with the environment-friendly production techniques, effluents are not expected to result in significant negative impacts on water quality.

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Box 1: Summary of costs-benefits of environment-friendly shrimp culture practices

Feature/Description	Cost to Farmer	Benefits to Farmer	Benefits to Environment
Lowering of stocking density			
• Decrease in stocking density from 25-40/m^2 to 15-30/m^2 resulting to drop in harvest biomass from 7-10 mt/ha/crop to 5-8 mt/ha/crop	• Decrease in harvest volume by around 20-30%	• Increased harvest value by 8-10% due to bigger and better quality shrimps • Improved feed conversion • Reduced opportunistic diseases	• Reduced feed use (hence nutrient load) by at least 20%
Improvement of pond bottom management			
• Increased frequency and depth of tilling to allow better soil oxidation during drying period • Concentration of sludge along pond center where caged fish feed on waste	• Increase plowing/tilling cost by ₱5000.00-7000.00/ha/yr • Additional ₱12,000/ha for net cages (to be depreciated in 2 years) and ₱5000/ha/yr for tilapia fingerlings (note: cost is recovered from sale of fish)	• Improved bacterial profile of sediment and reduced count of pathogenic *Vibrio*, resulting to healthier shrimps and reduced risk of opportunistic diseases	• Improved effluent quality, with lower levels of nutrients (*i.e.* N and P) and suspended solids
Crop rotation			
• Culture of tilapia or milkfish at low density for 2-4 months, alternate with shrimp crop, to fallow pond bottom and reduce OM load	• Cost of ₱25,000-35,000/ha/yr for fish culture inputs (e.g. fry, feeds, etc.) and labor (note: cost is recovered from sale of fish) • Loss of 1 shrimp crop per year	• Improved bacterial profile and reduced pathogenic *Vibrio* in sediment (healthier shrimp) • Significantly reduced risk of WSSV disease as virus is active only during cold months	• Reduced organic load in receiving waters during fish culture period enhancing breakdown of accumulated waste
Improvement in feed quality			
• Improved formulation with higher micronutrients and use of immune enhancers • Reduced fines and increase hydrostability • Enhanced nutrition through on-farm supplementation of Vitamin C, immune enhancers, and other nutrients	• Increase in commercial feed cost by ₱3-4/kg and additional cost of around ₱2/kg feed for farm level nutritional supplements; equivalent to a ₱30,000-60,000/ha/crop increase in feed cost	• Better growth, health, and appearance of shrimps • Reduced feed use by 10-15% based on improved FCR; partly due also to enhanced natural food productivity (*i.e.* from heterotrophic food web) resulting from use of probiotics and the increased aeration	• Improved effluent quality, with lower levels of nutrients (*i.e.* N and P) and suspended solids
Stocking of laboratory-screened fry			
• Screening of fry for infection of WSSV (through PCR) and *Vibrio harveyii*; in addition to standard tests for physical health, and infection from MBV and other opportunistic bacteria and fungi	• Higher fry cost, from ₱0.12-0.16/pc to ₱0.25-0.30/pc, increasing seed expense by around ₱40,000/ha/crop • Additional fry screening expenses of ₱2,000/ha/crop • 3-4 weeks delay in stocking	• Reduced risk of WSSV disease and pathogenic *Vibrio* infection • Improved growth performance and survival of stocks	• Minimized risk of spreading diseases to receiving waters
Use of "greenwater" technology			
• Culture of milkfish or tilapia in reservoir, and in net cages inside shrimp grow-out pond to stabilize plankton bloom and to discourage growth of pathogenic bacteria	• Reduced grow-out area by 25-50% due to bigger reservoir • Fish culture inputs of ₱25,000-35,000/ha/yr in reservoir (*e.g.* fry, feeds, labor, etc.) but may be recovered from fish sale • Modification of water supply channel and acquisition of transfer pump at ₱5,000-10,000/ha (depreciation in 3 years)	• More stable water quality which reduces stress to cultured animals • Suppressed growth of pathogenic bacteria, particularly *Vibrio harveyii*, minimizing risk of disease and premature harvest	• Reduced water use and effluent volume • Reduced load of pathogenic *Vibrio* in effluent water
Use of probiotics in water and feed			
• Suppressed growth of pathogenic bacteria through domination of beneficial bacteria • Hastened degradation of organic waste and oxidation of noxious gases (*e.g.* ammonia and hydrogen sulfide) • Improved gut flora and hence lower disease incidence and increased food assimilation	• Total cost of ₱20,000-40,000/ha/crop, depending on type of probiotics and dosage	• Production of antibiotic-free shrimp • Control of pathogenic *Vibrio*, minimizing risk of disease and premature harvest • Improved water quality and lower sludge accumulation, reducing stress and opportunistic diseases • Reduced water exchange (*i.e.* lower pumping cost)	• Reduced risk of more virulent antibiotic-resistant strains of bacteria • Lower nutrients (*i.e.* N and P) and suspended solids in effluents • Reduced load of pathogenic *Vibrio* in effluent water

Box 1: Summary of costs-benefits of environment-friendly shrimp culture practices (Cont'd)

Feature/Description	Cost to Farmer	Benefits to Farmer	Benefits to Environment
Increase in aeration			
• 1 HP/400-500 kg biomass (from 1 HP/800 kg) raising minimum DO levels from 4 ppm to 5 ppm • Addition of long-arm paddle-wheels or diffuser-type aerators for water circulation and development of bacterial floc • Enhances probiotic efficacy	• Additional fixed cost for aerators and electrical distribution/generation system amounting to ₱150,000-200,000/ha (to be depreciated in 3 years) • Increase in power consumption by 50-60%	• Faster growth, improved feed conversion, better physical quality, and reduced risk of opportunistic diseases • Reduced water exchange (*i.e.* lower pumping cost) • More stable plankton (*i.e.* less plankton crash) and hence lesser water exchange	• Increased DO level in effluent (from 4 ppm to 5 ppm) and reduced level of noxious metabolites, especially ammonia and hydrogen sulfide • Lower water exchange and effluent volume
Use of settling pond			
• Modification of canal system for dual use as drainage and effluent settling pond to reduce suspended solids	• Cost of ₱2500-5000/ha/yr for construction and maintenance of baffles and bamboo support, and removal of settled waste	• Improved water quality in receiving waters	• Reduced suspended solids in effluent and sediment build-up in receiving waters
Employment of biosecurity measures			
• Application of chlorine (15-20 ppm) or Vikron-A™ to sanitize the pond of WSSV or its potential carriers • Setting up of crab fence and bird scaring devices • Filtering new water thru 150-300μ net to screen out potential virus carriers • Proper sanitation of workers, visitors, equipment, facilities • Reduced water use to 5-10%/day (from 10-20%), with zero exchange during 1st 60 days	• Additional cost of ₱15,000-20,000/ha/yr for pond sanitation, carrier exclusion devices, filters, and worker hygiene	• Significantly reduced risk of introducing viral diseases, particularly WSSV	• Reduced water usage and effluent volume by 60-70% • Minimized risk of spreading diseases in receiving waters

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