

CAPACITY OF MANGROVES TO PROCESS SHRIMP POND EFFLUENTS

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Site of Activity: Barangay Bugtongbato, Ibajay, Aklan Province, central Philippines

BACKGROUND/RATIONALE

Shrimp culture has been criticized for causing mangrove loss and discharging effluents laden with chemicals, organic matter and nutrients into waterways. Hence the SEAFDEC Council mandated SEAFDEC/AQD to undertake studies that integrate aquaculture with mangroves. Thus, the Mangrove-Friendly Shrimp Culture Project follows two models: (a) the use of mangrove forests as filters to process effluents from intensive culture ponds, and (b) aquasilviculture which integrates low-density culture of crabs, etc. with mangroves. Worldwide only a few projects to date have tested mangroves as nutrient filters, hence the need to focus on this property of mangroves.

OBJECTIVES

The main objective of the study is to assess the capacity of mangrove forests to process aquaculture pond effluents, including microbial impacts. The specific objectives are to: (a) compare physico-chemical and microbial parameters as seawater from a source creek, is conditioned in a reservoir, used in a shrimp pond, then treated or filtered by a mangrove system; (b) monitor changes in levels of dissolved and particulate wastes at given intervals after draining into the mangrove system; (c) make a first order estimate of the mangrove area required to process N wastes from a given pond area; and (d) determine the effect of pond effluents on the growth and structure of natural and planted mangroves.

DESCRIPTION OF ACTIVITY

The performance of constructed mangrove wetlands (CMW) and natural, impounded mangrove wetland (IMW) in treating aquaculture wastes was evaluated. Six 265-m² CMWs were constructed at AQD's Dumangas Brackishwater Station (DBS). Seedlings of the mangroves *Avicennia marina*, *Sonneratia alba*, and *Rhizophora mucronata/R. stylosa* were planted in two CMWs each. The original intention was to pass effluents from a DBS shrimp pond through the CMWs prior to discharge to the bay, and monitor the biological, physical, chemical, and bacteriological changes, and effects on mangrove growth. However, no effluents were available for the study and therefore no results are reported.

For the IMW study, a natural mangrove forest in Bugtong Bato, Ibajay, Aklan, central Philippines was selected as experimental study site, the layout of which is shown in Figure 1: (a) Reservoir (1,480 m², estimated water area 888 m²) – a few mangrove *Avicennia officinalis/A. rumphiana* trees and *Nypa fruticans* clumps; (b) Shrimp Pond or SP (880 m²) – water circulation provided by 10 airlift pumps (38.5±0.5 Lpm each); (c) Impounded Mangrove or IM (320 m²) – temporary dikes constructed around a portion of the natural mangrove to retain water for sampling.

Following SEAFDEC/AQD's protocols the Shrimp Pond was drained, dried and fertilized with lime, chicken manure, urea and teaseed powder to grow natural food and eliminate pest species. Both Reservoir and Shrimp Pond were stocked with milkfish as "biomanipulators" following the green water technique. After one week, shrimp *Penaeus monodon* postlarvae (checked free of luminous bacteria *Vibrio* sp. and White Spot Syndrome Virus) were stocked at 25/m².

Commercial feeds (40%) were given at 8%-4% BW with six feeding trays used to monitor excess feeds. Shrimps were sampled regularly for length-weight measurements and harvested after 5 mo. Two runs were conducted – Run 1 (26 June-1 December 2001) and Run 2 (25 June-16 November 2002). Every spring tide, sea water from the Creek was allowed to flow into the Reservoir, conditioned for at least 12 h, pumped to the Shrimp Pond where it was used for 1-5 d then drained to the Impounded Mangrove and retained for at least 12 h before releasing back to the Creek (Fig. 1). Physico-chemical parameters were monitored 1-2x monthly – salinity, temperature, total suspended solids or TSS, pH, NH₃-N, NO₃-N, PO₄-P, and sulfide. For bacterial monitoring, water samples were collected from Shrimp Pond, Reservoir and Creek in three locations, while soil samples of approximately 100 g were collected from the upper 5 cm layer of the same areas. Bacteria were isolated on nutrient agar (NA), and selective media for vibrios (TCBS) and *Pseudomonas* and *Aeromonas* (GSP) following methods of Kemp *et al.* (1993). All samples were processed onsite within one h of collection and inoculated plates were incubated for 18 – 24 h at room temperature (27 - 28°C).

For Run 2, 24-h monitoring of water quality was undertaken in the 3rd and 4th mo (max. shrimp biomass and effluents). Water was drained into the Impounded Mangrove at 0800 h (day cycle) or 2000 h (night cycle). Nutrients were measured in the IM as effluents were drained from the Shrimp Pond (0 h) and at regular intervals thereafter (3, 6, 12 and 24 h). The microbiology of pond soil and water was also monitored. Samples were obtained immediately after draining, and at 6-h, 12-h and 24-h. Procedures for bacterial enumeration were as previously described using the same culture media. Plant density and basal area of the Impounded Mangrove and a Control Mangrove site (not affected by pond effluents) were determined in May 2001 (before Run 1) and in December 2001, April 2002 and November 2002. Wild seedlings of *Avicennia officinalis*, *A. rumphiana*, *Bruguiera cylindrica*, *Ceriops decandra*, *C. tagal* and *Xylocarpus granatum* were collected and planted inside the Impounded Mangrove and the Control Mangrove sites, labeled with plastic tags and measured regularly. Seedlings of *Rhizophora mucronata* were obtained from a plantation.

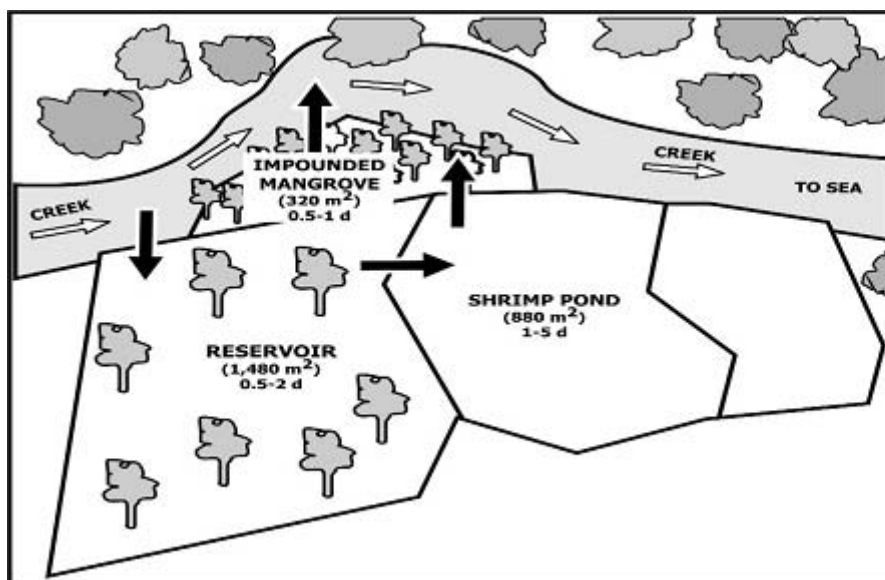


Fig. 1 Lay-out of Reservoir-Shrimp Pond-Impounded Mangrove experimental set-up including area (m²) and duration (h) of water holding in Ibajay, Aklan, Central Philippines

PROGRESS OF ACTIVITY

Total shrimp production in Run 2 (141 kg or 1.60 mt/ha) was only half that of Run 1 (253 kg or 2.87 mt/ha) because of a shorter cropping period (emergency harvest was done due to power outage) and smaller sizes (13 g vs 19 g ABW) (due to higher salinity levels and extraneous fish species).

NH₃-N levels in the Shrimp Pond and Impounded Mangrove increased only in the later months, in contrast to consistently low levels in the Creek and Reservoir. NO₃-N levels were higher in the Impounded Mangrove compared to the Shrimp Pond, Reservoir and Creek. PO₄-P showed erratic trends. Shrimp Pond DO levels remained high until the 3rd month of culture, decreasing afterwards. DO levels were similar in the Creek, Reservoir and Impounded Mangrove, but declined in the latter after August.

As effluents (from the Shrimp Pond) were passed through the Impounded Mangrove under two cycles of day and night draining (Fig. 2), levels of nutrients and suspended solids decreased. Holding or residence time of 6 h in the Impounded Mangrove removed 64.2% of TSS, 34% of sulfide, 24.8% of NH₃ and 18.7% of NO₃; after 12-24 h luminous bacterial counts increased in the sediments and decreased in the water by one order of magnitude (It is noteworthy that the duration of the flood tide when mangroves are covered with incoming seawater is 6 h, because the Philippines has semidiurnal tides – a major and minor tide daily with roughly 6 h each of flood and ebb.).

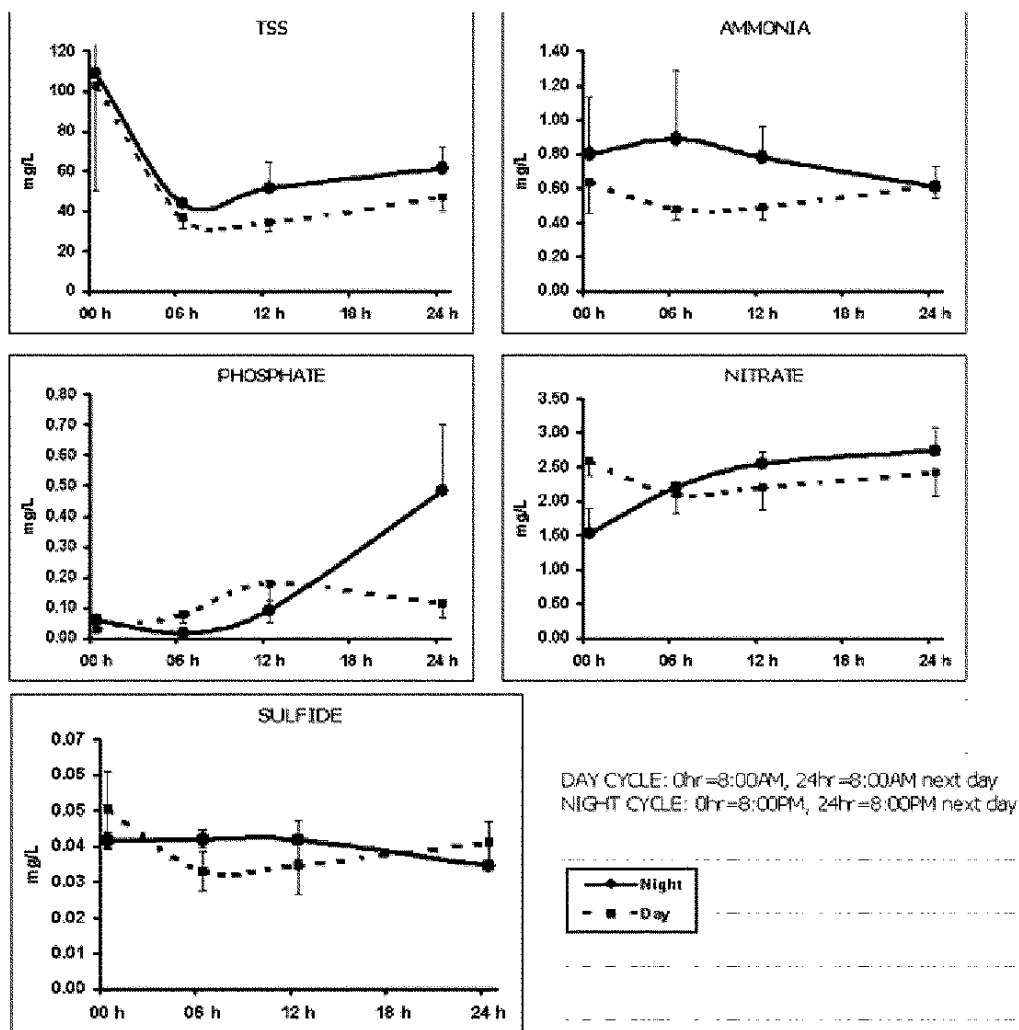


Fig. 2. Levels of nutrients, sulfide and TSS in effluents in the Impounded Mangrove (drained from the shrimp pond), start of draining was 0800h (or 8:00 a.m.) for the day cycle and 2000h (or 8:00 p.m.) for the night cycle

Fig. 2 shows that there is a net removal of NH₃-N and NO₃-N in the day (but net production at night), hence these are taken as the daily removal rate — 0.158 mg NH₃-N/L and 0.483 mg NO₃-N/L (Table 1). These N removal rates multiplied by the volume of water drained into the Impounded Mangrove give a total of 6,981.3 mg NH₃-N/d plus 29,920.3 mg NO₃-N/d (Table 2).

Table 1. Levels of solids and nutrients (mg/L) in effluents from shrimp pond at different times from draining (0800 h, day cycle) into mangrove pond

	0 hr	6 hr	12 hr	24 hr	6-h removal	12-h removal
Total suspended solids	102.833 ±52.218	36.833±5.192	34.500±4.660	47.000±6.728	66.000	68.333
Sulfide	0.050±0.011	0.033±0.006	0.035±0.008	0.041±0.006	0.017	0.015
PO ₄	0.028±0.005	0.077±0.027	0.178±0.127	0.113±0.047	net add.	net add.
NH ₃ -N	0.637±0.183	0.478±0.063	0.488±0.070	0.625±0.078	0.158	0.149
NO ₃ -N	2.583±0.206	2.100±0.286	2.200±0.335	2.417±0.347	0.483	0.383

Table 2. N removal from (shrimp pond) effluents drained into Impounded Mangrove

(1) Rate × water vol. see Table 2; 1 d = 6 h)	<u>NH₃-N: mg/L/d</u> Rep 1 0.080 × 70,400 = 5,632.000 Rep 2 <u>0.237</u> × 35,200 = <u>8,330.667</u> Mean 0.158	<u>Vol (L)</u> 6,981.333 mg NH ₃ -N/d								
	<u>NO₃-N: mg/L/d</u> Rep 1 0.733 × 70,400 = 51,626.667 Rep 2 <u>0.233</u> × 35,200 = <u>8213.333</u> Mean 0.483	<u>Vol (L)</u> 29,920.333 mg NO ₃ -N/d								
(2) Total N removal	6981.333 mg NH ₃ -N/d + 29920.000 mg NO ₃ -N/d 36901.333 mg tot. N/d 36901.333 mg tot. N/d ÷ 320 m ² Impounded Mangrove = 115.317 mg tot. N/m ² mng/d									
(3) 35%^a pond N loss via water exchange	<u>115.317 mg N/m²/d</u> = 329.48 mg (0.329 g) tot. pond N/m ² /d 0.35 N loss									
(4) 60 g (6%) N kg⁻¹ feed^b 60 g N/kg feed	<u>0.329 g tot. N/m²/d</u> = 0.0055 kg feed/d/m ² mng (55 kg feed/d/ha mng)									
(5) 4% shrimp biomass feed rate	<u>55 kg feed/d/ha mng</u> = 1,375 kg shrimp/ha mng 0.04 kg feed (kg shrimp)/d									
(6) ABW = 30 g (harvest) 20 g	1,375 kg @ 30 g = 45,833 pcs shrimp @ 20 g = 68,750 pcs									
(7) Mangrove: Pond area ratio	Semi-intensive (10 m ² , 30 g ABW) = 2.18; Intensive (20-30 m ² , 20 g ABW) = 2.91 – 4.36									
	<table border="1"> <thead> <tr> <th>S.D. (m²)</th> <th>ha mng (ha pond)</th> </tr> </thead> <tbody> <tr> <td>10</td> <td>1.45 – 2.18</td> </tr> <tr> <td>20</td> <td>2.91 – 4.36</td> </tr> <tr> <td>30</td> <td>4.36 – 6.54</td> </tr> </tbody> </table>		S.D. (m ²)	ha mng (ha pond)	10	1.45 – 2.18	20	2.91 – 4.36	30	4.36 – 6.54
S.D. (m ²)	ha mng (ha pond)									
10	1.45 – 2.18									
20	2.91 – 4.36									
30	4.36 – 6.54									

^a Briggs & Funge-Smith 1994, ^bI. Borlongan, pers. comm.

Their sum divided by 320 m² (area of the Impounded Mangrove) gives a rate of 115.3 mg tot. N removed daily by each square meter of mangrove (1.15 kg N/ha¹/d¹). The treatment rate obtained is practically similar to that estimated by Rivera-Monroy (1999) of 1.13-1.22 kg N/ha/d for riverine mangroves.

Assuming that all of the pond N lost through water exchange (35% of total) can be absorbed by the adjacent Impounded Mangrove, i.e., a rate of 115.3 mg N/m² mangrove/d, gives a total pond N budget of 329.5 mg (from 55 kg feed/d) whose excess (35%) can be assimilated or processed by one ha of mangroves. This means that towards the end of the cropping period when shrimp biomass is maximum and feeding rate is 4%, N wastes from one ha of shrimp pond will require treatment or processing by 2.18 ha of mangroves for semi-intensive culture (10 postlarvae/m², 30 g ABW) and 2.91-4.36 ha of mangroves at intensive levels (20-30 postlarvae/m², 20 g ABW) (Table 3).

Table 3. Growth in mangrove plant numbers (stems/ha) and biomass (stand basal area in m²/ha) of mangrove with (impounded) shrimp pond effluents and controls in Ibaday, Aklan, central Philippines

	Impounded Mangroves			Control Mangroves		
	Apr. 2002	Nov. 2002	% change	Apr. 2002	Nov. 2002	% change
A. Stems/ha						
Seed.	516,667	787,500	52.42	45,600	74,933	64.33
Sap.	12,400	19,933	60.75	10,533	9,067	13.92
Tree	469	656	39.87	900	967	7.44
Total	529,536	808,089	52.60	57,033	84,967	48.98
B. Standby						
Seed.	10.14	15.46	52.46	0.90	1.47	63.33
Sap.	3.64	6.16	69.23	3.31	2.85	13.90
Tree	13.58	26.74	96.91	17.50	23.77	35.83
Total	27.36	48.36	76.75	21.71	28.09	29.39

Figure 3 shows the bacterial profile of water in the Shrimp Pond from the day juvenile milkfish were stocked until shrimp were harvested 27 weeks after. Note the emergence of LBC on week 9, four weeks after stocking of shrimp post larvae, and its consistent isolation thereafter. An increasing pattern of PVC population was also observed (Fig. 3). Luminous bacteria are not the dominant bacterial population in the Shrimp Pond water even after more than one month of stocking. Probably, the presence of fish within the pond helped in maintaining microbial diversity. The bacterial profile of seawater obtained from the Creek is shown in Fig. 4, while the bacterial profile of the same water after conditioning in the Reservoir is shown in Fig. 5. Data extracted from Figs. 3, 4 and 5 show the comparison of LBC populations obtained in the same sampling period in water from the Shrimp Pond, Creek and Reservoir (Fig. 6). High LBC population in the Creek disappears or becomes undetectable in the Reservoir especially in the first 6 weeks. Luminous bacteria were consistently isolated from the Creek, but seldom from the Reservoir. The presence of fish as well as mechanical treatment of the water in the Reservoir (settling) improves its microbial quality (based on the absence of luminous bacteria). Based on our observations on luminous vibriosis in shrimp grow-out culture, shrimp mortality was always preceded by the dominance of luminous bacteria in the water (Lavilla-Pitogo *et al.* 1998), thus bacterial diversity of the shrimp pond needs regular monitoring to recognize early signs of *Vibrio* dominance (based on plate count results). Effective water change using water that has been conditioned in a reservoir, and which contains comparatively low LBC, should be done.

Figure 7 shows the bacterial profile of soil from the shrimp pond starting in the 9th week after stocking of milkfish and 4 weeks after stocking of shrimp postlarvae. Comparison of the LBC profile of this sample with that of the water (Fig. 3) shows no correlation. Very minor LBC populations were recovered in the soil from the Creek (Fig. 8) and the Reservoir (Fig. 9); these numbers hardly correlated with the LBC of water samples from the same environment (Figs. 4 and 5).

Bacterial population in the IM (Fig. 10) also shows minimal LBC population. Bacterial population of effluent from Shrimp Pond that passed through the IM for 24 h is shown in Fig. 11. A one-log reduction of LBC occurred after 12 h. In contrast, bacterial population of soil bacteria shows a one-log increase in LBC in sediments after 24 h. Such bacterial reduction in the water and increase in soil signifies retention of LBC in the IM during the holding period. The IM in this integrated system was meant to treat Shrimp Pond effluents. While the study of Teichert-Coddington *et al.* (1999) recommends holding of harvest effluents in settling ponds for no more than 6 h residence to mitigate the release of nutrients, results from this study show that reduction in LBC population by one-log occurs only after 12 h, although a generally safe level of 10^2 cfu/ml was attained in 6 h.

The experimental Impounded Mangrove is a predominantly *Avicennia* community. Although the 7-mo (April-Nov. 2002) increase in total plant numbers was similar in the Control Mangrove (49.0%) and experimental Impounded Mangrove (52.6%), growth in biomass in the latter was more than 2.5 times that of the former (76.8% vs 29.4%). Increases in seedling densities and biomass were similar in the Impounded and Control Mangroves but those for saplings and trees were much higher in the former (Table 3). Growth rates in terms of increase in plant height of planted mangrove seedlings in Run 1 were higher in the experimental Impounded Mangrove (0.45 to 24.2%) vs Control Mangrove (-9.5% to 6.8%) (Table 4). For Run 2, 6 out of 7 mangrove species had similar or higher growth rates in the Impounded Mangrove compared to the Control Mangrove.

Table 4. Growth of mangrove seedlings in the Impounded Mangrove (with shrimp pond effluents) and Control Mangrove

	Impounded Mangrove			Control (Open) Mangrove		
	Init. ht (cm)	Final ht (cm)	% change change	Init. ht (cm)	Final ht (cm)	% change
Run 1 (Jul.-Nov. 2001)						
<i>Avicennia rumphiana</i>	69.33	84.00	21.15	67.50	70.17	3.95
<i>Ceriops decandra</i>	31.00	38.50	24.19	19.33	17.50	-9.48
<i>Rhizophora mucronata</i>	69.67	70.00	0.48	61.00	60.33	-1.09
<i>Xylocarpus</i> spp.	100.50	114.00	13.43	83.33	89.00	6.80
Run 2 (Jul.-Nov. 2002)						
<i>Avicennia officinalis</i>	30.20	39.20	29.80	36.13	48.40	33.96
<i>Avicennia rumphiana</i>	89.38	93.17	4.24	64.10	54.25	-15.37
<i>Bruguiera cylindrica</i>	40.75	41.83	2.66	27.50	24.70	-10.18
<i>Ceriops decandra</i>	58.30	66.80	14.58	17.67	20.60	16.58
<i>Ceriops tagal</i>	24.50	25.25	3.06	28.67	29.00	1.15
<i>Rhizophora mucronata</i>	69.00	67.60	-2.03	67.13	71.00	5.76
<i>Xylocarpus granatum</i>	109.38	121.13	10.74	91.67	81.00	-11.64

A constructed N budget for a mid-intertidal mangrove (similar to the present study site) in Phuket, Thailand shows a total of influx of 47.5 mg N/m²/d from litterfall, microalgae and N-fixation (Kristensen *et al.*, 1995). Our calculated 115.3 mg N/m²/d from shrimp pond effluents is 2.4 times this total budget and represents a significant anthropogenic N source which could be categorized under “import”. In terms of N sinks, plant uptake both by the microflora (planktonic and benthic algae) and macroflora (mangroves) accounts for more than 90% of the mineralized N in the Phuket mangroves with only 7% going to burial (sediment immobilization, bacterial processing) and nitrification/denitrification (Kristensen *et al.*, 1995). These rates probably apply to the Ibajay forest as well — evidence of nutrient assimilation from pond effluents by the mangrove flora can be seen in the increased mangrove biomass from April to November 2002 which was 2.5 times greater in the Impounded Mangrove over the Control Mangrove.

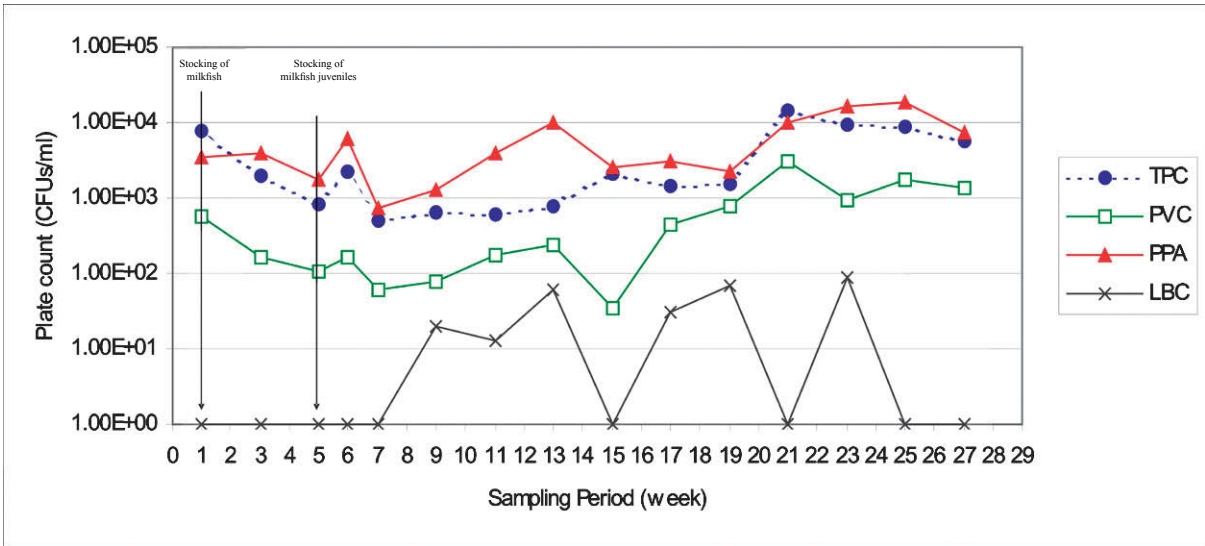


Fig. 3. Bacterial profile of the Shrimp Pond water (TPC = total plate count; PVC = Presumptive Vibrio count; PPA = bacterial count on *Pseudomonas-Aeromonas* agar; LBC = luminous bacterial count)

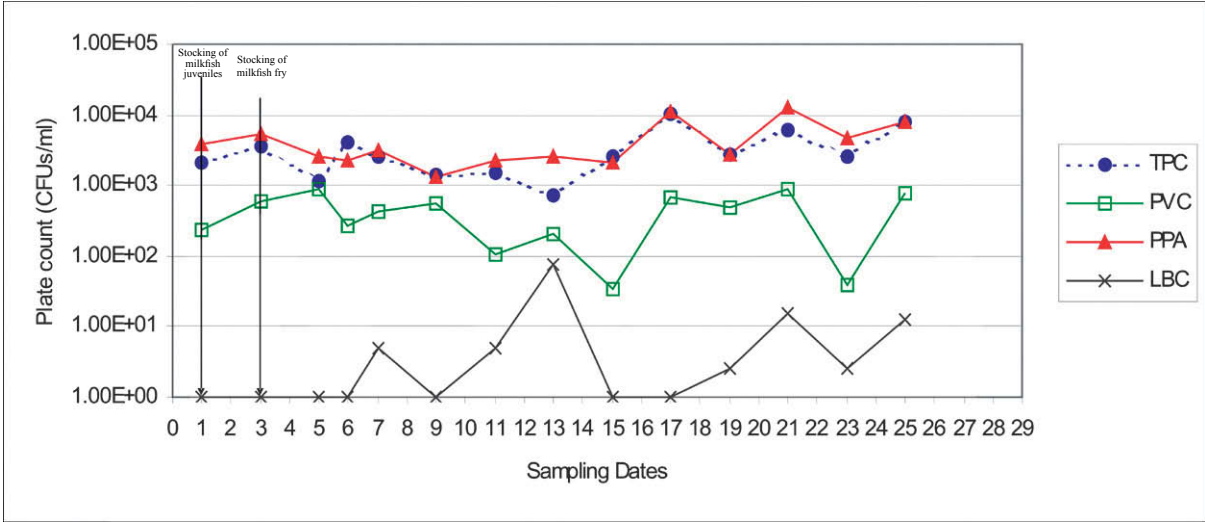


Fig. 4. Bacterial profile of seawater from the Creek (TPC = total plate count; PVC = Presumptive Vibrio count; PPA = bacterial count on *Pseudomonas-Aeromonas* agar; LBC = luminous bacterial count)

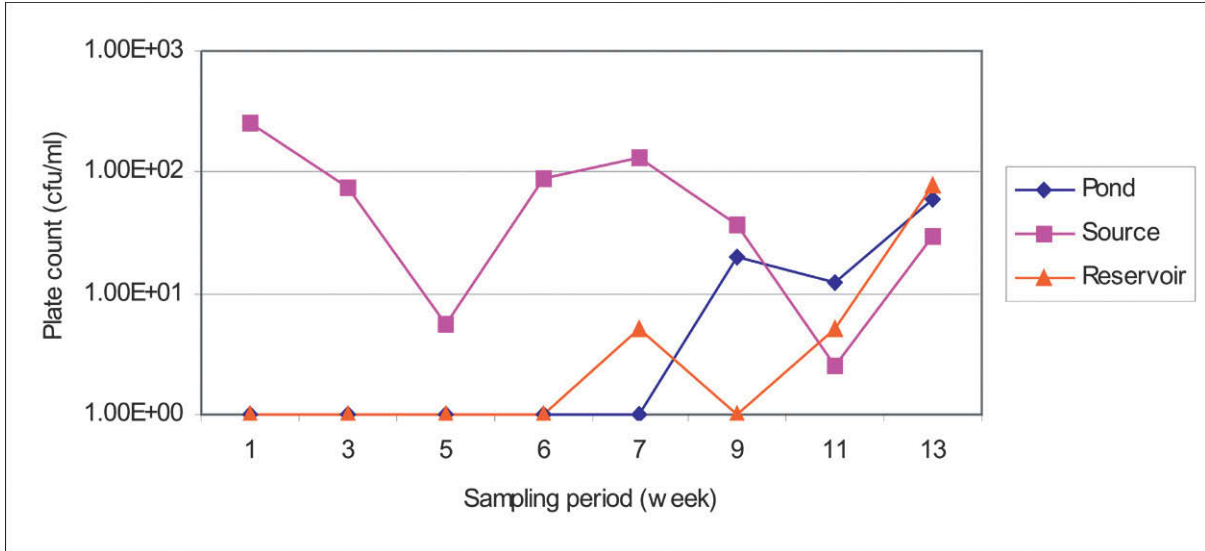


Fig. 5. Bacterial profile of water in the Reservoir (TPC = total plate count; PVC = Presumptive Vibrio count; PPA = bacterial count on *Pseudomonas-Aeromonas* agar; LBC = luminous bacterial count)

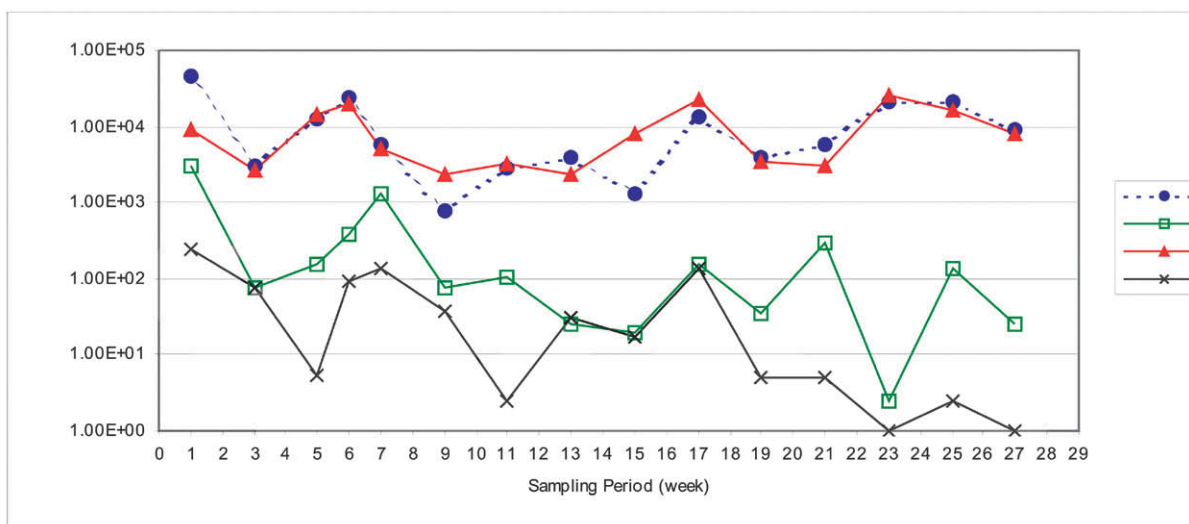


Fig. 6. Comparison of luminous bacterial count (LBC) in water from Shrimp Pond, Reservoir and Creek

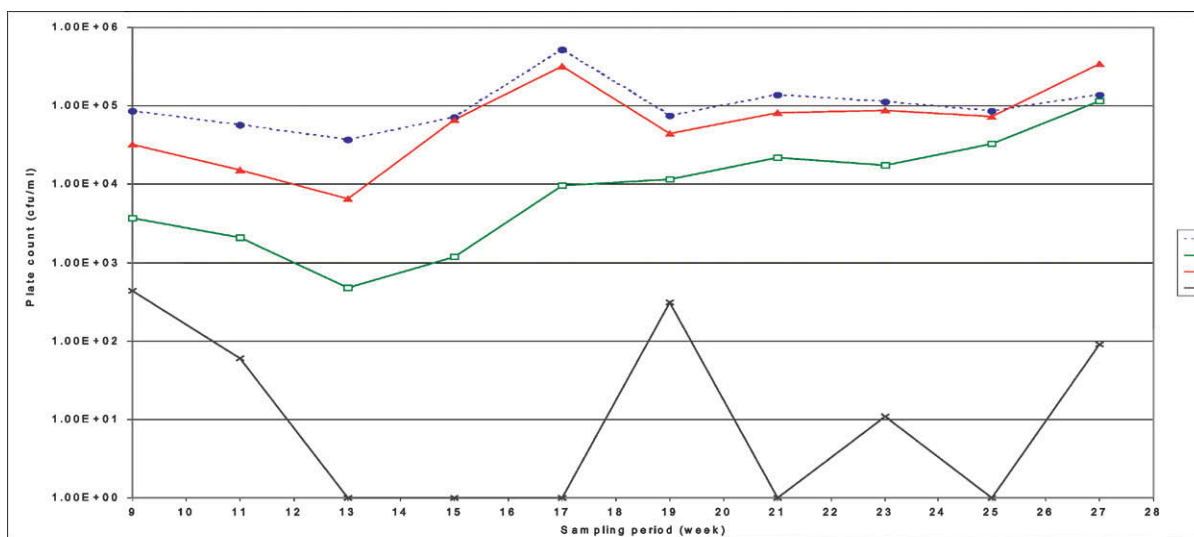


Fig. 7. Bacterial profile of sediments from Shrimp Pond (TPC = total plate count; PVC = Presumptive Vibrio count; PPA = bacterial count on *Pseudomonas-Aeromonas* agar; LBC = luminous bacterial count)

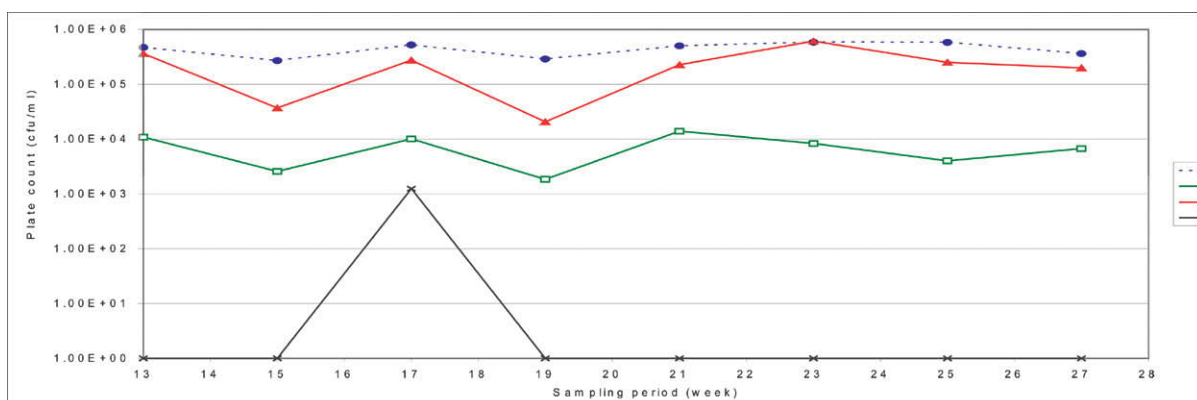


Fig. 8. Bacterial profile of sediments from the Creek (TPC = total plate count; PVC = Presumptive Vibrio count; PPA = bacterial count on *Pseudomonas-Aeromonas* agar; LBC = luminous bacterial count)

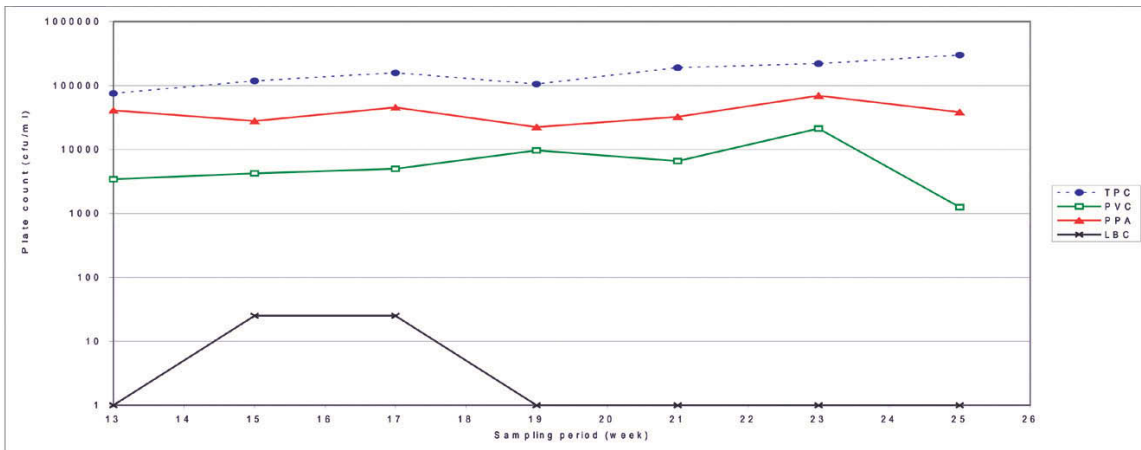


Fig. 9. Bacterial profile of sediments from the Reservoir (TPC = total plate count; PVC = Presumptive Vibrio count; PPA = bacterial count on *Pseudomonas-Aeromonas* agar; LBC = luminous bacterial count)

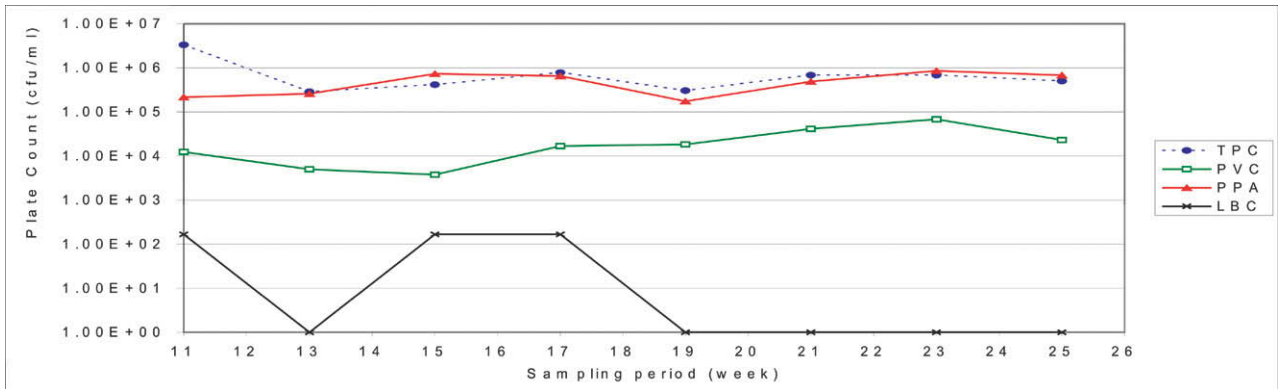


Fig. 10. Bacterial profile of sediments from the Impounded Mangrove (TPC = total plate count; PVC = Presumptive Vibrio count; PPA = bacterial count on *Pseudomonas-Aeromonas* agar; LBC = luminous bacterial count)

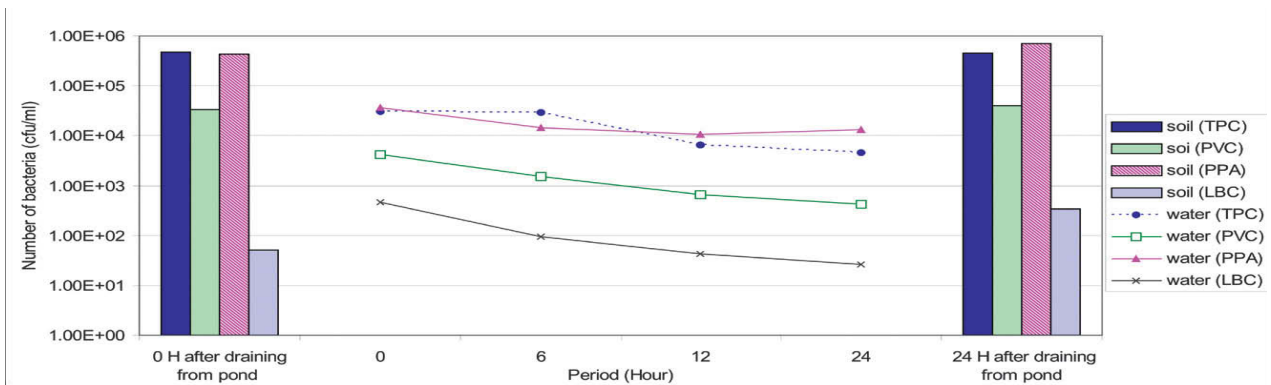


Fig. 11. Bacterial population of soil and water in the impounded mangrove area during a 24-h holding period before finally draining Shrimp Pond effluents into the Creek (TPC = total plate count; PVC = Presumptive Vibrio count; PPA = bacterial count on *Pseudomonas-Aeromonas* agar; LBC = luminous bacterial count)



Seaward view of CMW compartment (left) and landward view (right)

The growth rate of planted seedlings was also generally higher in the Impounded Mangrove compared to the Control Mangrove. Regular harvest of mangrove flora, or nipa leaflets in this study, is necessary to maximize the efficiency of plant uptake and the role of mangrove ecosystems as a N sink. The role of phytoplankton and bacteria in stripping nutrients from shrimp farm effluents is suggested by the similar (low) rates of primary and bacterial production in the lower reaches of mangrove creeks receiving pond discharges compared with non-discharge areas (MacKinnon et al., 2002).

RECOMMENDATIONS

- 1) The present study provides evidence that mangroves can remove significant levels of nitrogen and solid wastes from shrimp pond effluents and gives a first-order estimate of 2.2-4.4 ha of mangrove area required to process wastes from one ha of semi-intensive or intensive shrimp pond. These estimates cover only the waste assimilation function and are therefore minimum levels. Moreover, aquaculture operations should not use antibiotics and other chemical or biological inputs that may be harmful to the mangrove organisms.
- 2) Mangrove trees may be harvested partially (as branches of *Avicennia*, *Sonneratia* and other non-Rhizophoraceae) or as the whole tree (for *Rhizophora*, *Ceriops* and other Rhizophoraceae) with replanting of the latter. For ponds that border a waterway (creek, river or shore), the mangrove treatment area can also serve as the 20-m to 50-m greenbelt required by Philippine law.
- 3) Further studies are needed a) to refine estimates of waste treatment area for different types of mangroves (in terms of tidal elevation/flushing, mangrove species composition, biomass and other aspects of community structure), b) to partition the contribution of different sinks (mangrove flora, phytoplankton, denitrification, etc.) to the removal of N and other wastes, and c) to evaluate the impact of effluents, particularly sediments, on mangrove organisms such as benthic fauna.
- 4) The present results also confirm the efficacy of fish as biomanipulators in a green water system to control potentially pathogenic luminous bacteria in shrimp culture.
- 5) Holding of Shrimp Pond effluents for 6 h or more in Impounded Mangrove reduced the level of LB before discharge into the Creek.

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