The Effects of Pond Management Strategies on Nutrient Budgets: Honduras

Interim Work Plan, Global Experiment, Honduras

Bartholomew W. Green, David R. Teichert-Coddington, Claude E. Boyd
Department of Fisheries and Allied Aquacultures
Auburn University
Auburn USA

John L. Harvin, Hector Corrales, Rafael Zelaya
Grupo Granjas Marinas, SA
Choluteca, Honduras

Delia Martinez and Eneida Ramírez
Laboratorio de Calidad de Agua
La Lujosa, Choluteca, Honduras

Introduction

Semi-intensive shrimp production in Honduras is based upon use of formulated diets to supply nutrients for shrimp growth. Unconsumed feed contributes nutrients to pond water, which when discharged may deteriorate water quality in receiving waters. Estuaries are the water source and sink for shrimp farms in Honduras, and many farms have been established along individual estuaries. A key element in achieving sustainable shrimp culture in Honduras is to ensure that the carrying capacity of each estuary is not exceeded because of overdevelopment of farms or uncontrolled intensification of production practices, both of which could result in significant increases in nutrient load entering estuaries due to farm discharges. Nutrient budgets are developed to assess the fate of nutrients added to a system and to rank importance of nutrient sources and sinks. In addition, the potential pollution impact of a specific pond management system could be evaluated using nutrient budgets. The objective of this experiment was to develop budgets for nitrogen and phosphorus in semi-intensively managed shrimp ponds receiving a low or high protein feed.

Materials and Methods

Eight ponds located on a commercial shrimp farm on a riverine estuary of the Gulf of Fonseca, Honduras, were used for this dry season study. Ponds were selected at random from a group of 12 ponds. Ponds averaged 1.67 ± 0.07 ha, 0.57 ± 0.06 m, and 9431 ± 993 m^3, in area, depth and volume, respectively. Two treatments (using different feed protein content) were tested applying a completely randomized design with four replicates per treatment.

Ponds were stocked with hatchery-produced, post-larval (PL) *Penaeus vannamei* (325,000/ha) on 19 January 1996. Stocking rate of PL shrimp was based on a historical Taura Syndrome survival rate of 25%, and was selected to achieve a final stocking rate of approximately 80,000 shrimp/ha; most Taura Syndrome mortality occurs within the first month following stocking. Ponds were harvested 87 days after stocking.

Feed protein levels tested were 20% and 30% crude protein; a commercial ration manufactured locally by ALCON was used. Shrimp were offered feed six days per week beginning on 13 February 1996. Feed rate for each treatment was 50% of the theoretical feeding curve for *P. vannamei*:

$$\log_{10}Y = -0.899 - 0.561\log_{10}X$$

where,

Y = feed rate as a % of biomass; and

X = mean weight of shrimp in grams.

Daily feed rate was calculated for individual ponds, and then averaged by treatment, so all ponds within a treatment received the same quantity of feed on a daily basis. Feed was provided once daily. Weekly cast net samples of each pond's population were taken to monitor shrimp growth; feed rate was adjusted weekly based on shrimp samples. Feed conversion ratio was calculated as the weight of feed provided divided by gross whole shrimp yield.

Losses to seepage and evaporation were replaced weekly. No water was exchanged during the first three weeks of culture. Water was exchanged at 20% of the pond volume once per week beginning on week four. If early morning dissolved oxygen concentration was ≤ 2.5 mg/l, 5% of the pond volume was exchanged. In all water exchanges, pond level was lowered first and then refilled. Dates and quantities of all water additions and exchanges were recorded.

Water budgets were estimated for each pond. All ponds were equipped with staff gauges. Regulated inflow water and discharge water volumes were estimated from changes in stage. Faulty equipment prevented direct measurement of evaporation; a combined estimate of evaporation and seepage was made from changes in stage on days no water addition or exchange occurred.

Pond water quality variables were measured upon initiation of the experiment, and beginning with the initiation of scheduled water exchange on week four, discharge and replacement water quality was monitored weekly. Weekly discharge water samples were collected from each pond's outfall during water exchange. Because all ponds were supplied from a common water supply canal, water samples for replacement water analysis were collected at each of the extremes and the middle segment of the canal supplying the ponds. At harvest, water samples were collected at 100%, 10%, and 0% of pond volume for analysis. Initial pond water and replacement water samples were obtained with a column sampler. Water samples were analyzed for nitrate-nitrogen by cadmium reduction (Parsons et al., 1992), total ammonia-nitrogen (Parsons et al., 1992), filterable reactive phosphate (Grasshoff et al., 1983), chlorophyll-*a* (Parsons et al., 1992), total alkalinity by titration to pH 4.5 endpoint, salinity, and BOD_2 at ambient temperature. Total nitrogen and total phosphorus were determined by nitrate and phosphate analysis, respectively, after simultaneous persulfate oxidation (Grasshoff et al., 1983).

Pond sediment samples were collected using a core sampler (4.2-cm ID) following pond inundation and prior to pond draining. Five to six core samples were collected along a transect across the width of the pond. Samples were collected along three transects per pond: near the inlet, the center, and the outlet. The top 2.5 cm of each soil core was collected according to methodology described by Munsiri et al. (1995); all core samples along a transect were pooled for analysis. Soils were analyzed for total phosphorus (perchloric acid digestion; Olsen and Sommers, 1982) and total nitrogen using a Leco Carbon-Hydrogen-Nitrogen Analyzer.

Nutrient budgets were estimated for total nitrogen and total phosphorus. Nutrient content in pond discharge was calculated from weekly water quality analysis data and the volume of water discharged. It was impossible to collect samples of discharge water during unscheduled water exchanges; therefore, water quality analysis data from the date closest to the exchange was used to estimate quantities of nutrients discharged. Samples of feed were collected monthly for nutrient analysis according to methodology described by Jackson (1958). Nitrogen and phosphorus concentrations of shrimp were taken (Boyd and Teichert-Coddington, 1995).

Table 1. Production data (mean ± SD) from 1.67-ha semi-intensively managed earthen shrimp ponds where a 20% or 30% protein feed was tested. Post-larval shrimp were stocked to achieve a final stocking rate of approximately 80,000 shrimp/ha. Four replicate ponds were used per treatment.

Variable	Treatments	
	20% Protein Feed	*30% Protein Feed*
Gross Yield Whole Shrimp (kg/ha per 87 d)	412 ± 50	490 ± 99 NS
Average Final Weight (g/shrimp)	6.1 ± 0.3	5.7 ± 0.4 NS
Survival (%)	21.1 ± 0.0	31.0 ± 1.4 NS
Feed Conversion Ratio	1.0 ± 0.1	0.9 ± 0.1 NS

NS: Variable means did not differ significantly (P > 0.05) between treatments.

Table 2. Mean water budget for 1.67-ha earthen shrimp production ponds used to test a 20% or 30% protein feed.

Variable	Treatments	
	20% Protein Feed	*30% Protein Feed*
Initial Fill (m^3)	10020	8842
Water Exchanged (m^3)	32314	30972
Replacement Water (m^3)	38296	35804
Drain Volume (m^3)	9657	8669
Seepage and Evaporation (m^3)	6784	6521
Difference (added - discharged) (m^3)	-439	-1516
Mean Seepage and Evaporation (cm/d)	0.48	0.45

Data were analyzed by ANOVA (Haycock et al., 1992). Percent data were arcsine transformed prior to analysis. Differences were declared significant at alpha level 0.05.

Results

Gross shrimp yields and mean final weights did not differ significantly between treatments (Table 1). Taura Syndrome continued to affect shrimp survivals, with mean survivals of 21% and 31% observed in the 20% protein and 30% protein feed treatments, respectively. Feed conversion ratios (FCR) were close to one and did not differ significantly (Table 1). Feed application was suspended during a 4- to 6-day episode of chronic low dissolved oxygen that occurred in ponds during week nine. Mean daily feeding rate did not differ between treatments and averaged 8.2 and 8.1 kg/ha per day in the 20% and 30% protein feed treatments, respectively.

Water budgets were developed for ponds (Table 2). No significant differences between treatments were observed for any component of the water budget. More than three pond volumes of water were exchanged as part of the routine and emergency water exchange protocols. Mean estimated evaporation and seepage was 0.47 cm/d. No rainfall occurred during this study, which took place entirely during the dry season. Water outflow exceeded inflow.

Concentrations of water quality variables increased throughout the culture period (Figure 1). Total nitrogen and phosphorus, chlorophyll-*a*, and BOD_2 concentrations in inlet water were significantly lower than in pond water (Table 3). Nitrate was not detected in either the inlet water

Table 3. Mean concentrations (± SD) of water quality variables in 1.67-ha shrimp production ponds and in water supply canal. Shrimp in four replicate ponds each were offered a 20% or 30% protein feed.

Variable	Treatments		Water Supply Canal
	20% Protein Feed	*30% Protein Feed*	
Total Ammonia Nitrogen (mg/l)	0.022 ± 0.005 a	0.020 ± 0.008 a	0.017 ± 0.006 a
Total Nitrogen (mg/l)	1.77 ± 0.09 b	1.78 ± 0.13 b	0.69 ± 0.05 a
Soluble Reactive Phosphorus (mg/l)	0.10 ± 0.11 a	0.11 ± 0.05 a	0.05 ± 0.01 a
Total Phosphorus (mg/l)	0.25 ± 0.10 ab	0.32 ± 0.08 b	0.12 ± 0.01 a
Total Alkalinity (mg/l as $CaCO_3$)	154.6 ± 19.9 a	147.7 ± 5.2 a	-
Chlorophyll-*a* (mg/m^3)	54.96 ± 8.08 b	53.19 ± 13.41 b	24.21 ± 7.63 a
BOD_2 (mg/l)	9.84 ± 1.21 b	9.69 ± 1.32 b	5.52 ± 0.44 a

ab: Variable means followed by the same letter are not significantly different ($P < 0.05$).

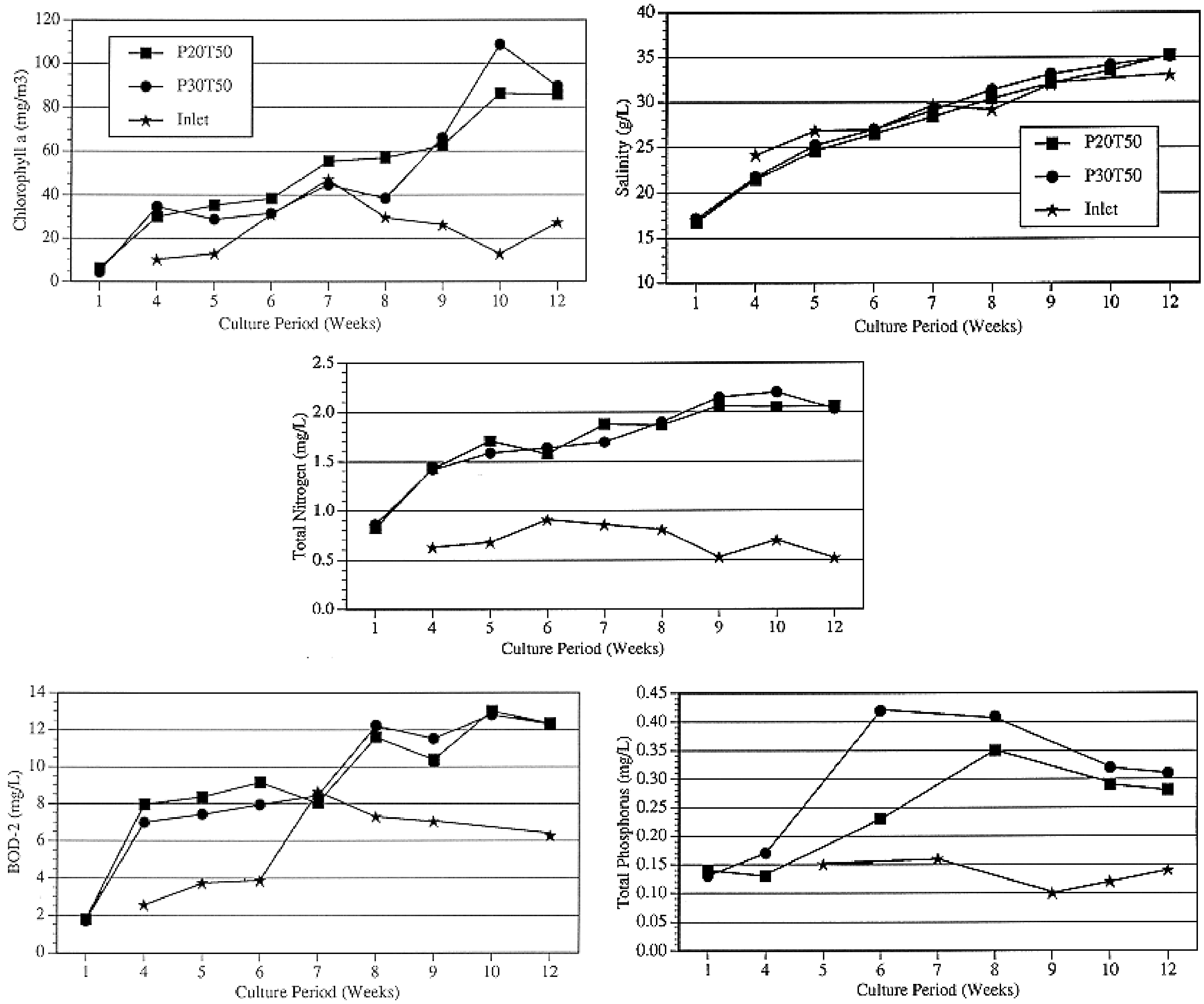

Figure 1. Mean weekly concentrations of 5 variables in ponds receiving a 20% protein (P20T50) or a 30% protein (P30T50) feed, and in inlet water.

or in pond water. No significant differences were detected between treatment water quality means (Table 3). However, inorganic nitrogen and phosphorus introduced to ponds in inlet water were converted to organic forms. Salinity in pond water and inlet water increased similarly during the experiment (Figure 1).

The shrimp biomass stocked into ponds was less than 0.5 kg and did not contribute any nitrogen or phosphorus to the pond, although at harvest a mean of 22.3 kg nitrogen and 2.4 kg phosphorus were removed as adult shrimp (Table 4). Significantly greater quantities of nitrogen and phosphorus were added to ponds as feed in the 30% protein feed treatment. The concentration of nitrogen in pond sediments increased significantly during the 87-day culture period, but sediment phosphorus concentrations were unchanged (Table 5). Nutrient budgets showed that a total of 57 to 66 kg nitrogen and 11 to 12 kg phosphorus were added to ponds and 101 kg nitrogen and 12 to 13 kg phosphorus were exported from ponds; export of nitrogen exceeded import of nitrogen by 35 to 44 kg, while export of phosphorus exceeded import of phosphorus by 0.26-0.46 kg (Table 6). Feed accounted for 41 and 52% of added nitrogen and 47 and 55% of added phosphorus in the 20% protein and 30% protein feed treatments, respectively. Inlet water, either from

Table 4. Mean (± SD) quantities per pond of shrimp stocked and harvested, and feed applied, and mean nutrient composition of feed and shrimp. Each treatment was replicated in four 1.67-ha earthen ponds.

Variable	Treatments		
	20% Protein Feed	30% Protein Feed	
POST-LARVAL SHRIMP			
Quantity Added (kg)	0.3	0.3	NS
Dry Matter (%)[1]	25.5	25.5	na
Nitrogen (% of dry weight)[1]	10.6	10.6	na
Phosphorus (% of dry weight)[1]	1.3	1.3	na
Nitrogen Added as Shrimp (kg)	0	0	NS
Phosphorus Added as Shrimp (kg)	0	0	NS
ADULT SHRIMP			
Quantity Harvested (kg)	699	788	NS
Dry Matter (%)[1]	26.5	26.5	na
Nitrogen (% of dry weight)[1]	11.3	11.3	na
Phosphorus (% of dry weight)[1]	1.2	1.2	na
Nitrogen Removed as Shrimp (kg)	20.9	23.6	NS
Phosphorus Removed as Shrimp (kg)	2.2	2.5	NS
FEED			
Quantity Added (kg)	674	672	NS
Dry Matter (%)	91.2	91.6	NS
Nitrogen (% of dry weight)	3.744	5.544	*
Phosphorus (% of dry weight)	0.908	1.107	*
Nitrogen Added as Feed (kg)	23.0	34.1	*
Phosphorus Added as Feed (kg)	5.6	6.6	*

[1] Source: Boyd and Teichert-Coddington (1995).
NS: Variable means did not differ significantly ($P > 0.05$) between treatments.
* Variable means differed significantly ($P < 0.05$) between treatments.
na: Comparison not appropriate.

the initial fill or from water exchanges and replacement, was the source of all other nitrogen and phosphorus added to ponds. Harvest of shrimp accounted for 36 to 37% of applied nitrogen and 19 to 20% of applied phosphorus.

Discussion

Shrimp yields and final weight were not affected by dietary quality, and were similar to reported dry-season shrimp yields and final weights in Honduras (Teichert-Coddington and Rodriguez, 1995a and 1995b; Teichert-Coddington et al., 1996b). Taura Syndrome is endemic in southern Honduras and observed shrimp survivals in this experiment were typical for animals exposed to Taura Syndrome (Lightner and Redman, 1994; Brock et al., 1995).

Water quality variables were not affected significantly by feed protein content, although nearly 50% more nitrogen was added to ponds in the 30% protein feed treatment. Observed concentrations of water quality variables were consistent with data reported from previous shrimp production trials in Honduras (Teichert-Coddington and Rodriguez, 1995a). Additions of feed nitrogen represented 41 to 52% of total nitrogen additions to ponds. Total feed added to

Table 5. Mean (± SD) total nitrogen and total phosphorus concentrations in initial and final soil samples from experimental ponds. Treatments using 20% and 30% protein feed were tested. The top 2.5 cm of pond sediment from core samples were taken for analysis. Samples were collected after pond flooding and prior to pond draining.

Variable	Treatments	
	20% Protein Feed	*30% Protein Feed*
TOTAL NITROGEN		
Initial Sample (%)	0.11 ± 0.001	0.13 ± 0.000
Final Sample (%)	0.21 ± 0.000 *	0.19 ± 0.000 *
TOTAL PHOSPHORUS		
Initial Sample (mg/kg)	1214.1 ± 111.6	1266.4 ± 62.6
Final Sample (mg/kg)	1204.4 ± 145.7	1254.2 ± 124.8

* Initial and final variable means within treatment were significantly different ($P < 0.05$).

Table 6. Mean gains, losses and unrecovered quantities (in kilograms) of nitrogen and phosphorus in 1.67-ha earthen shrimp production ponds where shrimp were offered a 20 or 30% protein formulated ration. Four replicate ponds were used for each treatment.

Variable	Treatments			
	20% Protein Feed		*30% Protein Feed*	
	Nitrogen	Phosphorus	Nitrogen	Phosphorus
GAINS				
Shrimp Stock	0	0	0	0
Canal Water				
Initial Flooding	8.12	1.45	7.60	1.14
Replacement Water	25.36	4.59	23.99	4.41
Feed	23.43	5.38	34.30	6.87
LOSSES				
Shrimp Harvest	20.90	2.20	23.60	2.50
Pond Water				
Exchange Discharge	62.21	9.17	59.87	10.09
Draining	18.16	0.31	17.45	0.29
UNRECOVERED	-44.36	-0.26	-35.03	-0.46

ponds did not differ between treatments because there was no response in shrimp growth to improved diet quality. Also, the total quantity of feed added to ponds was low, equivalent to 8.2 kg/ ha per day, a quantity well below the 40 to 50 kg/ha per day, which results in low dissolved oxygen and deteriorated water quality (Boyd, 1989; 1990).

Total ammonia-nitrogen and soluble reactive phosphorus concentrations in ponds were low and did not differ significantly from concentrations in inlet water. However, total nitrogen and total phosphorus concentrations in ponds were significantly greater than in inlet water, although a significant difference between treatments was not observed. Greater than 98% of total nitrogen and 30 to 40% of total phosphorus were in the organic form, which was composed of plankton, bacteria, and particulate organic matter, as evidence by greater chlorophyll-*a* and BOD_2 concentrations observed in pond water. The impact of shrimp pond effluents on receiving waters would result from elevated organic nitrogen and phosphorus loads, and BOD.

Feed applied to ponds contributed 41 to 52% of total nitrogen and 47 to 55% of total phosphorus added to ponds. Significantly more nitrogen and phosphorus were added to ponds that received the 30% protein feed. Exchange water accounted for the remaining nitrogen and phosphorus added to ponds. In an earlier trial, Teichert-Coddington et al. (1996a) reported that addition of feed to shrimp ponds represents 40 and 54% of total nitrogen and phosphorus additions, respectively. In contrast, feed accounted for 88.3 to 92.3% and 74.5 to 95.9% of measured nitrogen and phosphorus input, respectively, in ponds with no water exchange (Boyd, 1985; Daniels and Boyd, 1989).

Harvest of shrimp accounted for 36 to 37% of added nitrogen and 19 to 20% of added phosphorus in this experiment, which was higher than the 16% of added nitrogen and 10% of added phosphorus reported by Teichert-Coddington et al. (1996a). This difference in nutrient removal due to shrimp harvest likely resulted from a total feed usage per hectare. Teichert-Coddington et al. (1996a) reported values of total feed usage per hectare which were approximately three times greater than in the present study. Harvest of fish from fed ponds accounted for 19.7 to 24.7% of nitrogen and 29.7 to 41.8% of phosphorus (Boyd, 1985; Daniels and Boyd, 1989). When data from this study were pooled with data from these other studies by Boyd (1985), Daniels and Boyd (1989), Teichert-Coddington et al. (1996a) and nitrogen or phosphorus removed in animals at harvest was regressed against FCR, a significant relationship was observed for nitrogen ($R_2 = 0.772$; $p < 0.05$), but not for phosphorus. Thus, careful management of feed application could result in less feed nitrogen ending up in the environment.

Pond water discharged during water exchange and draining contained 77.3 to 80.4 kg nitrogen and 9.5 to 10.4 kg phosphorus. Considerably more nitrogen was exported from ponds than was added, while import and export of phosphorus was closely balanced, showing a net export of 0.3 to 0.5 kg phosphorus. There are several possible explanations for the discrepancy between nitrogen and phosphorus imports and exports during unscheduled water exchanges: inlet and outlet water were not analyzed for nutrient content, rather the data from the most recent weekly water quality analysis were used. Use of weekly data could have resulted in an overestimation of nutrients discharged. Also, the water exchange protocol (drain first, then refill) may not have been adhered to during unscheduled exchanges to rectify acute low dissolved oxygen, which would result in an overestimation of nutrient discharge because the pond inlet is opposite from the pond outlet. Finally, it is possible that nitrogen fixation occurred in ponds, which would have resulted in nitrogen input being underestimated.

Anticipated Benefits

Results of this study improve our understanding of nutrient budgets in fed brackish water ponds. At low feed rates during the dry season, feed protein level did not affect shrimp yields but did result in significantly greater feed nitrogen input with the high protein feed. Careful management of feed application could reduce nitrogen discharge from ponds.

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