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Relative prawn production and benthic macroinvertebrate densities in unfed, organically fertilized, and fed pond systems

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Abstract

Relative prawn production rates in unfed, organically fertilized, and fed pond systems were evaluated. Populations of benthic macroinvertebrates that potentially serve as forage organisms in these systems were also evaluated and compared with ponds without prawns to evaluate forage preferences. Juvenile prawns ($\bar{x} = 0.36 \pm 0.02$ g) were stocked into nine 0.04 ha ponds at a density of 39 520 ha^{-1}. Prawns in three ponds were not fed, prawns in three ponds were fed a complete diet, and three ponds received organic fertilization. Three additional ponds (0.02 ha) served as controls (not stocked with prawns and received no nutrient input). Survival averaged 86%, overall, and was not significantly different among treatments. Average weights of prawns fed complete feed or raised in fertilized ponds (36 and 33 g, respectively) were not significantly different ($P > 0.05$). Prawns in unfed ponds were significantly ($P \leq 0.05$) smaller (13 g). Average prawn yields in fed, fertilized, and unfed ponds (1261, 1056, 426 kg ha^{-1}, respectively) were all significantly different ($P \leq 0.05$). In ponds receiving no nutrient input, macroinvertebrate densities were significantly higher ($P \leq 0.05$) in ponds without shrimp (controls) than in those stocked with shrimp. In ponds stocked with shrimp, macroinvertebrate densities in fed and fertilized treatments were significantly greater ($P \leq 0.05$) than in the unfed treatment, but not significantly different ($P > 0.05$) from each other. Insect taxa showed a greater negative response to prawn

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predation than non-insects. Non-insect taxa demonstrated a more positive response to fertilizer and feed than insects. Although prawn production in organically fertilized ponds was surprisingly high (> 1000 kg ha^{-1}), economic analysis demonstrated higher net returns when prawns were fed a prepared diet, principally due to the production of greater numbers of large, high value prawns.

Keywords: *Macrobrachium rosenbergii*; Diets; Unfed ponds; Organic fertilization; Benthic macroinvertebrates

1. Introduction

Feed is often the major expense in the pond production of freshwater prawns, representing as much as 40 to 60% of operating costs (D'Abramo and Sheen, 1991). However, even when prepared diets are provided, pond flora and fauna are a significant source of nutrition for prawn growth (Moore, 1986). Weidenbach (1980) demonstrated that prawns could adjust to the absence of feed pellets by increased consumption of aquatic vegetation. Tidwell et al. (1995) suggested that prawns fed diets with reduced nutritional quality in ponds could compensate by increasing predation on benthic macroinvertebrates. Although the nutritional role of natural productivity is obviously important, it remains ill defined. This lack of understanding limits the potential of developing management procedures for maximizing the availability of desirable forage organisms (Corbin et al., 1983). The present study was designed to generate information on: (1) effects of prawns on macroinvertebrate populations in ponds; (2) invertebrate taxa preferred by prawns as food; (3) level of prawn productivity supported by natural productivity; and (4) relative effects of organic fertilization and formulated diets on macroinvertebrate populations and prawn production.

2. Materials and methods

2.1. Description, preparation, and stocking of ponds

Ponds were located at the Aquaculture Research Center, Kentucky State University, Frankfort, KY. Two weeks prior to the anticipated stocking date 12 ponds were drained, allowed to dry, and raked free of accumulated organic debris (ie. algae, leaves, etc.). Less than 1 week prior to the anticipated stocking date, ponds were filled with water from a reservoir filled by runoff from the surrounding watershed. Water was filtered through a 385 μm mesh sock to prevent introduction of macroinvertebrates from the reservoir. Water surface area of experimental ponds was 0.04 or 0.02 ha and average water depth was approximately 1.3 m. A 1/2 hp vertical lift pump operated continuously in the deepest area of each pond to prevent thermal stratification and provide aeration. Within three days after filling, liquid fertilizer (10:34:0) was applied at a rate of 9.0 kg phosphorous ha^{-1} to each pond to achieve an initial algal bloom. Water for replacing evaporative losses was obtained from the reservoir.

Size-graded juvenile prawns were transported by truck from Mississippi State University on 1 June 1994. Prawns were held overnight in three 3000 l tanks containing plastic netting to provide substrate. On the stocking date (2 June 1994), a sample of 50 prawns were individually blotted free of surface water and weighed to determine a mean stocking weight ($\bar{x} \pm SD = 0.36 \pm 0.02$ g). Prawn numbers were insufficient to achieve the desired stocking density. Accordingly, additional juveniles were transported by air from a commercial hatchery (Aquaculture of Texas, Weatherford, TX). These juveniles were held overnight as previously described then stocked into ponds on 8 June 1994. The mean stocking weight of these juveniles was 0.50 g and they comprised approximately one quarter of the total stocking density. Three replicate ponds were randomly assigned to each of the four experimental treatments: control (CTL; unstocked, without feed or fertilizer), unfed (UNFD; stocked with prawns, without feed or fertilizer), fertilized (FRT: stocked with prawns, with organic fertilization of pond, but no feed), or fed (FD; stocked and fed complete feed with no fertilization). Prawns in UNFD, FRT, and FD treatments were stocked at a density of 39 250 ha^{-1} (3.9 m^{-2}).

2.2. Samples

A 3.2 mm square mesh seine was used to collect a sample of ≥ 50 prawns from each pond every 3 weeks during the growout season. Prawns composing the sample were counted, group-weighed (drained weight) to the nearest 0.1 g, and returned to the pond.

2.3. Feed and fertilizer

The diet used in the FD treatment was formulated to contain 32% protein. Ingredient composition of the diet (Table 1) was similar to that of the diet utilized by D'Abramo et al. (1989) and Tidwell et al. (1993), and contained 7.5% fish meal. Dietary ingredients were processed into 5 mm sinking pellets by a commercial feed mill (Farmers Feed Mill, Lexington, KY).

One-half of the daily ration of diet was distributed over the entire surface of each pond in the FD treatment twice daily between 09.00 and 10.00 h and between 15.00 and 16.00 h. Prawns were fed a percentage of body weight based on a feeding schedule reported by Daniels and D'Abramo (1994). Feeding rates were adjusted weekly based on an assumed 2.5 feed conversion (D'Abramo et al., 1989). Every three weeks, biomass estimates from each pond were adjusted according to sample weights. Mortality was assumed to be 1% per week. In ponds receiving organic fertilization, distillers dried grains with solubles (DDGS) was added at a rate calculated to be isonitrogenous with the FD treatment (Geiger et al., 1985) and spread on the surface of the ponds according to the same schedule as the FD treatment. The DDGS used in the study was a homogeneous composite obtained from seven distilleries as provided by the Distillers Feed Research Council, Ft. Wright, KY. Composition of the DDGS is given in Table 2. The diet and organic fertilizer were analyzed for protein level using macro-Kjeldahl, dietary fat by acid hydrolysis, and moisture by drying to constant weight in a convection oven at 95°C (AOAC, 1990).

To evaluate the potential of direct consumption of fertilizer (DDGS) particles, ten prawns from each pond in all stocked treatments were captured on the same day just prior to harvest. Gut contents were flushed into a petri dish and examined under a light

Table 1
Ingredient composition (%) and proximate analysis of the diet fed to pond cultured freshwater prawns in the FD treatment

Ingredient	Percent composition
Menhaden fish meal (67% protein)	7.50
Soybean meal (44% protein)	13.75
DDGS	40.00
Wheat flour	12.50
Meat and bone meal (54% protein)	7.50
Ground corn meal	5.25
Mineral mix [a]	1.25
Vitamin mix [b]	1.25
Choline chloride	0.05
Cod liver oil	0.50
Dicalcium phosphate	0.50
Lignosulfonate binder	10.00
Analyzed composition (%) [c]	
Protein	31.9 ± 1.9
Lipid	6.5 ± 2.5
Moisture	10.1 ± 0.4

[a] Mineral mix contained: Mn, 10.0% (as $MnSO_4$); Zn, 10.0% (as $ZnSO_4$); Fe, 7.0% (as $FeSO_4$); Cu, 0.7% (as $CuSO_4$); I, 0.24% (as $CaIO_3$); Co, 0.10% (as $CoSO_4$).[b] Vitamin mix contained: thiamine (B_1), 1.01%; riboflavin (B_2), 1.32%; pyridoxine (B_6), 0.9%; nicotinic acid, 8.8%; folic acid, 0.22%, cyanocobalamine (B_{12}) 0.001%; pantothenic acid, 3.53%; menadione (K), 0.2%; ascorbic acid (c), 22.1%; retinolpalmitate (A), 4409 IU kg^{-1}; cholecalciferol (D_3), 2204600 IU kg^{-1}; α-tocopherol (E), 66.2 IU kg^{-1}; ethoxyquin, 0.66%.[3]Mean $\pm$SE based on replicate analyses. Protein and lipid are on dry weight basis.

microscope. Gut contents were compared with samples of DDGS mixed with water. Data were recorded as percentage of prawns within the pond whose gut contained DDGS.

2.4. Macroinvertebrate sampling

Individual benthic samples were taken every three weeks from the deep and shallow end of each pond using a 0.09 m^2 Ekman dredge (Lind, 1979). Samples were rinsed and

Table 2
Composition (dry weight) of distillers dried grains with solubles used in the FRT treatment

Component	% of total
Protein [a]	28.1 ± 0.14
Lipid [a]	14.45 ± 0.21
Moisture [a]	10.48 ± 0.01
Phosphorous [b]	7.05 ± 0.07
Potassium [b]	0.71
Magnesium [b]	0.44
Calcium [b]	0.15

[a] Replicate analyses. [b] NRC (1983).

sieved (No. 30 U.S. Series) according to procedures reported by Lind (1979). Macroinvertebrates in the samples were preserved in 70% ethanol until identification and enumeration.

2.5. Zooplankton sampling

Zooplankton populations were sampled weekly using a tube sampler described by Graves and Morrow (1988). Multiple sub-samples (6–8) were taken from deep and shallow areas of the pond until a total sample volume of 10 l was collected. The sample was then concentrated by filtering through a 153 μm Wisconsin-style plankton net. The concentrate was stored in 5% formalin with sucrose until analysis. Zooplankton were counted under a compound light microscope using a Sedgewick-Rafter cell and the abundance of cladocerans and copepods were calculated as number of organisms per liter.

2.6. Water quality management

Dissolved oxygen (DO) and temperature of all ponds were monitored twice daily (09.00 h and 15.30 h) using a YSI Model 57 oxygen meter (Yellow Springs Instruments, Yellow Springs, OH). Chlorophyll-*a* concentrations were determined weekly according to procedures presented by Boyd (1979). Levels of orthophosphate, total ammonia-nitrogen (TAN), nitrite-nitrogen, and nitrate-nitrogen were determined weekly according to outlined procedures for a Hach DR/2000 spectrophotometer (Hach Co., Loveland, CO) in water samples collected from each pond at approximately 13.00 h. The pH of each pond was determined daily at 13.00 h using an electronic pH meter (Hanna Instruments, Ltd., Mauritius). If afternoon pH was $\geq$ 9.5, predetermined protocol called for slow flushing of the pond overnight. However, no flushing was required.

2.7. Harvest

One day prior to harvest, on 26 September 1994, water depth in ponds was lowered to a level of approximately 0.9 m at the drain end. On the following day, prawns were seine-harvested from each pond using a 1.3 cm square mesh seine. After three successive seinings, ponds were drained completely. Remaining prawns were manually harvested from the pond bottom and purged in clean water. Total bulk weight and number of prawns harvested from each pond were recorded. All prawns harvested from each pond were then individually weighed and classified into either one of three female morphotypes: berried (egg carrying; BE), open (previously egg carrying; OP), and virgin (VR), or one of three male morphotypes, blue-claw (BC), orange-claw (OC), and small (< 20 g; SM) as described by Cohen et al. (1981).

2.8. Statistical analyses

Harvest data were analyzed using the SAS ANOVA procedure (Statistical Analysis Systems Institute Inc., 1988). Duncan's multiple range test was used to compare treatment means if significant differences were indicated by ANOVA. Percentage and ratio data were converted to arc sin values prior to analysis (Zar, 1984).

2.9. Economic analyses

Data from the three treatments were applied to a synthesized 4 ha prawn farm developed by Montanez et al. (1992). Input prices were based on \$254/MT for the control diet and \$138/MT for DDGS. Purchase price per juvenile prawn was \$0.07. Net returns were calculated on a range of sale prices of \$8.80–\$17.60 kg^{-1}.

3. Results

Overall mean values for water quality variables are presented in Table 3. There were no significant differences ($P > 0.05$) in overall means for morning or afternoon temperature or afternoon dissolved oxygen concentrations among treatments. Orthophosphate concentrations were significantly higher ($P \leq 0.05$) in ponds in which prawns were fed the complete diet (FD) than in the unfed (UNFD) ponds but not significantly different from the levels in fertilized (FRT) or control (CTL) ponds. Chlorophyll-*a* concentrations were significantly different among all four treatments ($P \leq 0.05$) following a relationship of FD > FRT > UNFD > CTL. Total ammonia-nitrogen concentrations were significantly different among all treatments ($P \leq 0.05$), also following a relationship of FD > FRT > UNFD > CTL. There was no significant difference ($P > 0.05$) in unionized ammonia or nitrite concentrations in FD and FRT ponds. Levels of both were significantly higher ($P \leq 0.05$) in FD and FRT than in UNFD and CTL treatments.

Table 3
Overall means (±SE) of three replicate ponds per treatment for daily morning and afternoon temperatures, dissolved oxygen, and weekly water water quality and zooplankton density determinations in unstocked ponds (CTL), stocked pond with no nutrient input (UNFD), stocked in organically fertilized ponds (FRT), or fed a complete diet (FD) [a]

Parameter	Treatment			
	CTL	UNFD	FRT	FD
AM Temp (°C)	23.62 ± 0.31 [a]	22.53 ± 3.36 [a]	22.48 ± 3.32 [a]	25.01 ± 0.12 [a]
PM Temp (°C)	25.76 ± 0.51 [a]	26.67 ± 0.11 [a]	26.69 ± 0.15 [a]	26.82 ± 0.16 [a]
PM Dissolved oxygen (mg l^{-1})	9.13 ± 0.53 [a]	11.24 ± 3.78 [a]	11.06 ± 3.91 [a]	8.48 ± 1.30 [a]
Soluble orthophosphate ($\mu g\ l^{-1}$)	7.16 ± 6.12 [ab]	4.84 ± 4.14 [b]	11.05 ± 8.04 [ab]	13.64 ± 14.38 [a]
Chlorophyll-a (mg l^{-1})	3.78 ± 2.67 [d]	5.25 ± 2.6 [c]	11.12 ± 5.6 [b]	19.82 ± 10.17 [a]
Total ammonia-nitrogen (mg l^{-1})	0.21 ± 0.12 [d]	0.31 ± 0.11 [c]	0.48 ± 0.19 [b]	0.59 ± 0.26 [a]
Unionized ammonia (mg l^{-1})	0.08 ± 0.06 [b]	0.10 ± 0.03 [b]	0.13 ± 0.09 [a]	0.19 ± 0.09 [a]
Nitrite (mg l^{-1})	0.01 ± 0.01 [c]	0.02 ± 0.01 [b]	0.03 ± 0.02 [a]	0.04 ± 0.02 [a]
Nitrate (mg l^{-1})	0.17 ± 0.21 [a]	0.15 ± 0.19 [a]	0.20 ± 0.21 [a]	0.23 ± 0.22 [a]
Cladocerans (organisms l^{-1})	2.59 ± 0.79 [b]	10.84 ± 4.05 [ab]	14.47 ± 11.37 [ab]	17.42 ± 3.95 [a]
Copepods (organisms l^{-1})	1.20 ± 0.11 [c]	1.80 ± 0.21 [c]	3.17 ± 1.16 [b]	4.61 ± 0.75 [a]

[a] Means in the same row with different superscripts are significantly different ($P \leq 0.05$).

Nitrite concentrations in UNFD ponds were significantly higher ($P \leq 0.05$) than in CTL ponds. Nitrate concentrations did not differ significantly ($P > 0.05$) among the four treatments, though the relationship of treatment means was similar to that observed for other variables.

Cladocerans were more abundant than copepods in all treatments and zooplankton densities among treatments largely reflected treatment relationships seen in water quality variables (Table 3). Cladoceran abundance was significantly greater ($P \leq 0.05$) in the FD treatment than in the CTL, but not significantly different ($P > 0.05$) from that in either the FRT or UNFD treatment, which were not significantly different from the CTL treatment. The abundance of copepodes again followed the relationship FD > FRT > UNFD > CTL (Table 3). Differences in mean copepod abundance among treatments were statistically significant ($P \leq 0.05$) for all treatment means except between UNFD and CTL ($P > 0.05$).

In ponds not receiving nutrient input, total macroinvertebrate densities in stocked ponds (UNFD) ponds were significantly lower ($P < 0.05$) (38%) than those in unstocked (CTL) ponds (Fig. 1). In ponds stocked with prawns, macroinvertebrate densities were significantly greater ($P \leq 0.05$) in FRT ponds (91%) and FD ponds (93%) than in UNFD ponds. Total macroinvertebrate densities among the CTL, FRT, and FD treatments were not statistically significant ($P > 0.05$).

In ponds receiving no nutrient input, insect numbers were significantly lower ($P \leq 0.05$) in stocked (UNFD) ponds (86%) than unstocked (CTL) ponds (Fig. 1). In ponds stocked with prawns, there was a significantly greater ($P \leq 0.05$) number of insects in FD ponds than in UNFD ponds but no significant difference ($P > 0.05$) between numbers of insects in FD and FERT ponds. Almost equal numbers of chironomids and trichopterans were collected from CTL ponds (Fig. 1). Both of these insect groups showed a similar response to presence of prawns with significant ($P \leq 0.05$) reductions in densities (84% and 93%, respectively). Addition of feed or fertilizer was associated with increases in numbers of trichopterans and chironomids with the magnitude of increase in chironomids being of greater magnitude. Chironomid densities in FRT and FD treatments were not statistically different ($P > 0.05$) from those in the CTL treatment.

Non-insect invertebrate populations were more dense than insects, showed less decrease in the presence of prawns, and greater positive responses to feed and fertilizer (Fig. 2). Densities of total non-insect invertebrates were significantly lower ($P \leq 0.05$) in CTL and UNFD treatment ponds than those in FRT and FD treatment ponds. There was no significant difference ($P > 0.05$) in non-insect densities between FRT and FD treatment ponds or between CTL or UNFD ponds. Oligochaetes were the most prevalent non-insect identified. In ponds not receiving nutrient input, oligochaete abundance was not significantly reduced ($P > 0.05$) by the presence of prawns (Fig. 2). In ponds stocked with prawns, oligochaete densities were 130% higher in the FD treatment and 164% higher in the FRT treatment ponds than in the UNFD ponds. These differences were statistically significant ($P \leq 0.05$) while the difference in the FRT and FD treatments were not ($P > 0.05$). Within the non-insect grouping there were no significant differences ($P > 0.05$) in abundance of gastropods, pelecypods, and nematodes among the four treatments (Fig. 2).

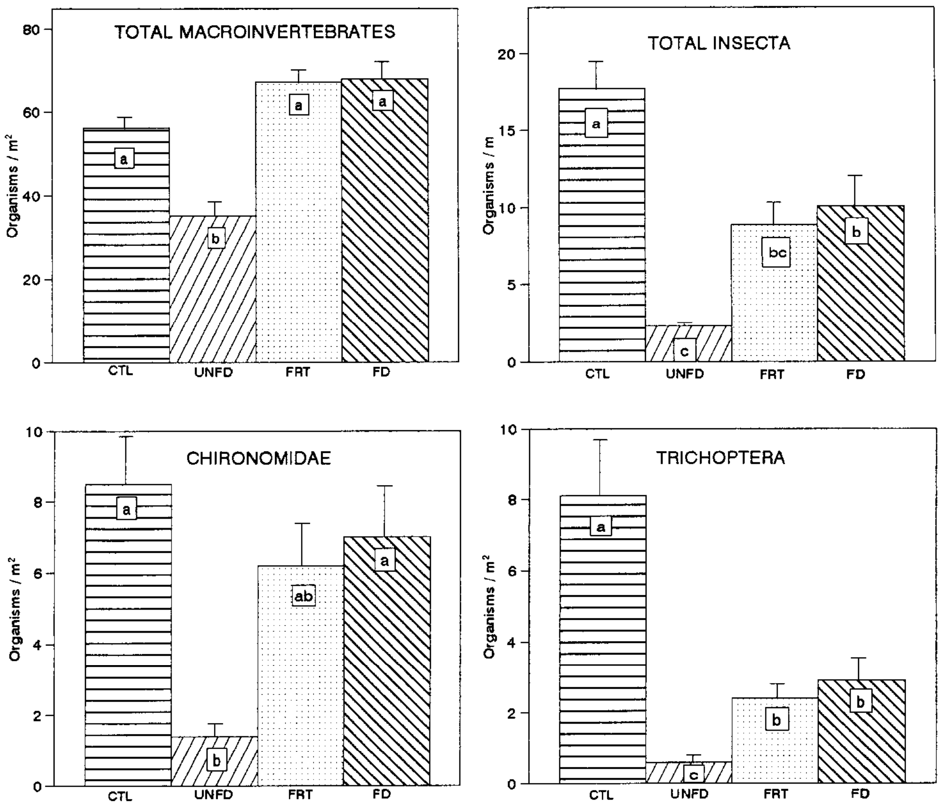

Fig. 1. Overall mean (±SE) number of (a) total macroinvertebrates; (b) total insecta; (c) chironomids; and (d) trichopterans per m^2 in ponds without prawns (CTL) or in which prawns were either unfed (UNFD), raised in organically fertilized ponds (without feeding) (FRT), or fed a complete diet (FD). Each bar represents 18 samples (three replicate ponds and six sampling dates) over a 117 day period. Bars with different letters were significantly different ($P \leq 0.05$).

Sample weights for prawns in the UNFD, FRT, and FD treatments are presented in Fig. 3. Differences in average individual weights among the three stocked treatments were not statistically significant ($P > 0.05$) until the sample taken nine weeks post-stocking, when prawns in the UNFD treatment were significantly smaller ($P \leq 0.05$) than prawns in the FRT or FD treatments. There was no significant difference ($P > 0.05$) in the mean individual wet weight of prawns in the FRT or FD treatments at any sampling date or at final harvest.

Total yield of prawns was significantly greater ($P \leq 0.05$) from FD ponds (1261 kg ha^{-1}) than from FRT ponds (1056 kg ha^{-1}) or UNFD ponds (426 kg ha^{-1}) (Table 4). The yield of prawns from FRT ponds was significantly ($P \leq 0.05$) greater (148%) than that of UNFD ponds while prawn yield in FD ponds was (196%) greater than UNFD ponds. There was no significant difference ($P > 0.05$) in survival among the three treatments, which averaged 86%, overall.

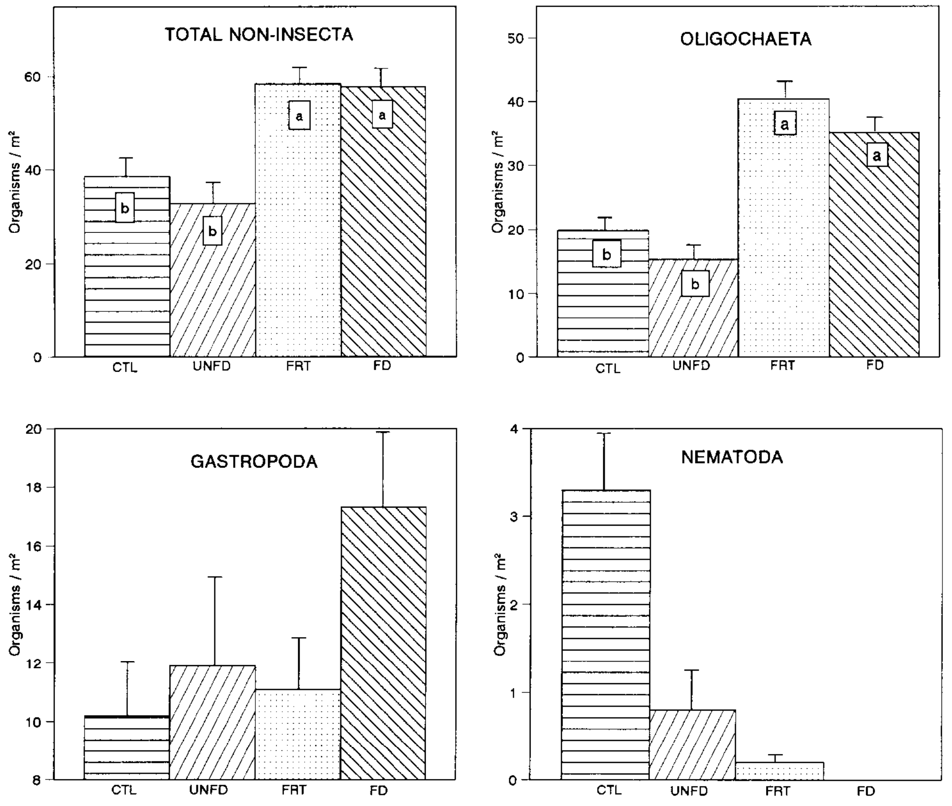

Fig. 2. Overall mean (±SE) number of (a) total non-insects; (b) oligochaetes; (c) gastropods; and (d) nematodes per m^2 in ponds without prawns (CTL) or in which prawns were either unfed (UNFD), raised in organically fertilized ponds (without feeding) (FRT), or fed a complete diet (FD). Each bar represents 18 samples (three replicate ponds and six sampling dates) over a 117 day period. Bars with different letters were significantly different ($P \leq 0.05$).

The percentage of prawns that attain marketable sizes is an important factor in profitability. Assuming a marketable size of ≥ 20 g (MacLean et al., 1989), then significantly more ($P \leq 0.05$) prawns achieved marketable size in the FD treatment (90%) than in the FRT (81%) or UNFD (27%) treatments (Fig. 4). The difference between FRT and UNFD was also statistically significant ($P \leq 0.05$). If marketable size is defined as ≥ 30 g (D'Abramo et al., 1989), then there was no significant difference ($P > 0.05$) between percentages in the FD and FRT treatments (58 and 44%, respectively). The lack of a significant difference between the FD and FRT treatments is at least partially due to the high within treatment variation that characterized the FRT treatment (Fig. 4). The percentage of prawns weighing ≥ 30 g in the UNFD treatment ($< 1\%$) was significantly less ($P \leq 0.05$) than that of other treatments.

The percentages of prawns in each treatment classified into the different sexual morphotypes are presented in Table 5. Significantly greater ($P \leq 0.05$) percentages of

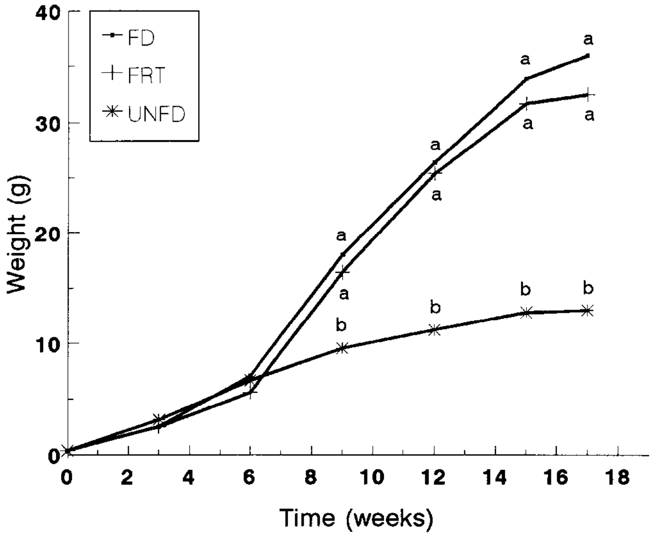

Fig. 3. Mean sample weights of prawns sampled triweekly from earthen ponds in which prawns were either unfed (UNFD), raised in organically fertilized ponds (without feeding) (FRT), or fed a complete diet (FD). Each data point represents a mean of three replicate ponds per treatment. Sample points with different letters were significantly different ($P \leq 0.05$).

stunted (SM) males and virgin females were present in the UNFD treatment than in either the FRT or FD treatments. The average individual weight of all morphotypes, except SM males, was significantly lower ($P \leq 0.05$) in the UNFD treatment than in other treatments (Table 6). There was no significant difference ($P > 0.05$) in average weight of the six morphotypes between FRT and FD except for the BC morphotypes, which was significantly greater ($P \leq 0.05$) in FD ponds (61.8 g) than in FERT ponds (47.4 g).

Net returns were negative for unfed prawns and positive for FD and FRT treatments at all analyzed selling prices. Based on the farm model, net return on 4 ha was $16 127

Table 4
Individual weight, survival, yield, and feed conversion ratio (FCR) for prawns raised in ponds with no nutrient input (UNFD), in organically fertilized ponds, (FRT) or fed a complete diet (FD) for 117 days. Values are means ± SE of three replications *

Parameter	Treatment		
	UNFD	FRT	FD
Individual wet weight (g)	13.01 ± 1.8 [b]	32.5 ± 3.9 [a]	36.1 ± 0.7 [a]
Survival (%)	85.8 ± 5.8 [a]	84.9 ± 7.3 [a]	88.4 ± 2.2 [a]
Yield (kg ha^{-1})	425.6 ± 44.1 [c]	1055.9 ± 196.2 [b]	1261.0 ± 119.3 [a]
FCR †	-	3.11 ± 10.19 [a]	2.31 ± 10.04 [b]

* Means within a row with different superscripts are significantly different ($P \leq 0.05$).† FCR: Total dry weight of nutrient input/total wet weight gain.

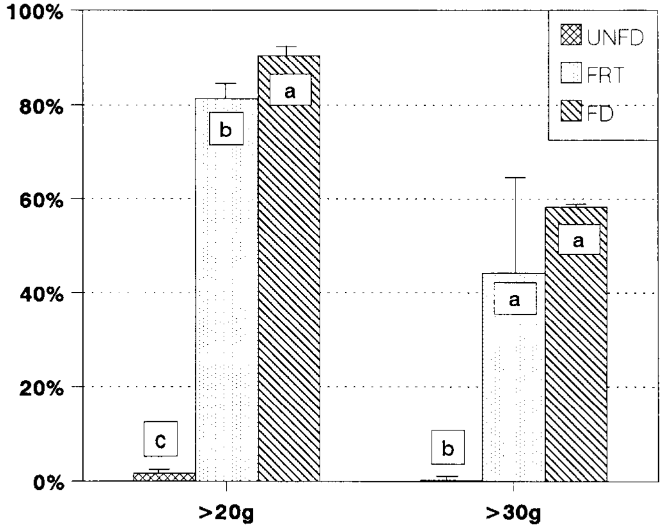

Fig. 4. The percentage mean (±SD) of prawns reaching minimum marketable size of 20 g or 30 g at harvest from ponds in which prawns were either unfed (UNFD), raised in organically fertilized ponds (without feeding) (FRT), or fed a complete diet (FD). Each bar represents a mean of three replicate ponds per treatment. Bars with different letters were significantly different ($P \leq 0.05$).

Table 5
Percent distribution according to number of each male and female morphotype for prawns raised in ponds with no nutrient input (UNFD), in organically fertilized ponds (FRT), or fed a complete diet (FD) for 117 days. Values are means ± SE of three replications *

Treatment	Male			Female		
	Blue Claw	Orange Claw	Small	Berried	Open	Virgin
FD	4.8 ± 2.34^{ab}	43.8 ± 4.3^{a}	5.4 ± 1.1^{b}	12.5 ± 4.5^{a}	9.43 ± 1.7^{a}	24.2 ± 4.0^{b}
FRT	5.8 ± 2.1^{a}	44.7 ± 3.7^{a}	9.3 ± 1.7^{b}	10.6 ± 3.1^{ab}	6.96 ± 4.5^{ab}	22.7 ± 3.6^{b}
UNFD	1.2 ± 0.9^{b}	1.2 ± 1.2^{b}	44.2 ± 3.7^{a}	4.2 ± 3.3^{b}	2.28 ± 2.0^{b}	45.9 ± 10.0^{a}

* Means within a column with different superscripts are significantly different ($P \leq 0.05$).

Table 6
Average weight of each morphotype of prawns raised in ponds with no nutrient input (UNFD), in organically fertilized ponds (FRT), or fed a complete diet (FD) for 117 days. Values are means ± SE of three replications *

Diet	Male			Female		
	Blue Claw	Orange Claw	Small	Berried	Open	Virgin
FD	61.8 ± 4.3^{a}	43.0 ± 1.2^{a}	10.9 ± 2.12^{a}	36.0 ± 1.2^{a}	32.5 ± 1.2^{a}	27.2 ± 0.7^{a}
FRT	47.4 ± 8.4^{b}	37.1 ± 5.6^{a}	10.6 ± 1.3^{a}	32.5 ± 4.3^{a}	31.0 ± 5.5^{a}	24.9 ± 1.9^{a}
UNFD	21.8 ± 5.2^{c}	24.5 ± 2.6^{b}	11.2 ± 0.65^{a}	14.2 ± 0.9^{b}	13.8 ± 8.0^{b}	11.5 ± 1.1^{b}

* Means within a column with different superscripts are significantly different ($P \leq 0.05$).

in the FRT at a selling price of \$12.10 kg^{-1}. Net return was increased 54% in FD ponds to \$24 752. At a selling price of \$17.60 kg^{-1}, which is less than the average of \$22.00–\$22.50 kg^{-1} reported for sale of live prawns in the United States (New, 1995), the synthetic 4 ha farm generated a net return of \$39 701 in the FRT treatment and \$52 909 in the FD treatment (a 33% difference). Although input prices in the FRT treatment were lower, and production was only slightly reduced, the lower percentage of marketable size prawns, and prawns of premium size, negatively impacted net returns.

4. Discussion

There was a very consistent relationship among treatment means for the water quality variables chlorophyll-*a*, total ammonia-nitrogen, unionized ammonia, nitrite-nitrogen, nitrate-nitrogen, and densities of zooplanktors (cladocerans and copepods) with FD > FRT > UNFD > CTL. The difference in the CTL and UNFD treatments is most problematic in that there was no nutrient input in either treatment. However, presence of prawns would likely increase levels of nitrogenous compounds due to direct metabolic production and release of ammonia. These could increase chlorophyll-*a* as ammonia-nitrogen, and especially its bacterial derivative nitrate, can be assimilated by plants (Boyd, 1979). Also, prawns in UNFD ponds appeared to be actively disturbing the mud in searching for food. Some nitrogen is normally deposited in mud as a component of the organic matter (Boyd, 1979). Bioturbation of the mud by prawns would likely increase exchange rates and solubility of naturally occurring nutrients (White, 1986) increasing their levels in UNFD ponds relative to CTL ponds. Conversely however, phosphorous levels showed a 32% decline between CTL and UNFD ponds. Boyd (1979) stated that some phosphorous loss in ponds may be due to uptake by plants and bacteria. Grazing of algae and bacterial periphyton by prawns would potentially remove these from the system, thereby lowering measured levels of phosphorous.

In ponds not receiving nutrient input, presence of prawns was associated with 38% decrease in total benthic macroinvertebrate populations. In ponds stocked with prawns, feed and fertilizer were associated with similar increases in densities of all macroinvertebrate taxa except gastropods, which showed a greater increase with feed, and pelecypods, which showed a greater increase with fertilizer.

Decreased benthic macroinvertebrate densities were also observed by Tidwell et al. (1995) in ponds in which prawns were fed supplemental diets (without fish meal or vitamin and mineral supplements) rather than complete diets. This reduction was possibly due to increased predation by prawns on benthic fauna in response to decreased nutritional quality of the diet. However, a lack of unstocked or unfed ponds in that study made it difficult to discern whether differences in macroinvertebrate numbers were due to negative effects of prawn predation or positive effects of added micronutrients in the complete diet. Based on these current data it appears that both factors may be involved. Differences in macroinvertebrate population densities in UNFD and CTL ponds indicate substantial predatory pressure by prawns. If feeding or fertilization only reduced the intensity of prawn predation, then macroinvertebrate densities in the FD and FRT treatments would be expected to only return to levels in the CTL treatment. However, total invertebrate numbers (Fig. 1) in both FD and FRT treatments were greater than that of the CTL treatment, indicating direct positive effects of both feed and fertilizer, even in the presence of prawns. This increase was primarily due to increases in non-insect taxa, especially oligochaetes. As mud-dwelling detritivores (Klots, 1966) oligochaetes could be well suited to deriving direct benefit from uneaten feed and decomposing fertilizer particles.

Insect populations appear to be most negatively impacted by the presence of prawns and showed less positive response to feed and fertilizer than non-insects. Within the insects, chironomids and trichopterans showed similar decreases in the presence of prawns. However, chironomids showed greater positive responses than trichopterans to feed and fertilizer. Chironomids are more detritiverous, and may react more similar to oligochaetes. In contrast, trichopterans are more omnivorous and carnivorous (Klots, 1966) and less likely to receive direct benefit from decomposing feed and fertilizer.

By comparing densities of different taxa in CTL ponds with UNFD ponds we have some measure of prawn grazing effects on macroinvertebrate populations and prawn food preferences. Of the benthic macroinvertebrates that showed decreases, 73% of the decrease were insects and 27% were in non-insect taxa. Trichopterans accounted for 35% of the total decrease, chironomids 33%, oligochaetes 21%, and nematodes 11%. Gastropods and pelecypods did not show negative responses to the presence of prawns. Previous work by Tidwell et al. (1995) demonstrated greater decreases in oligochaetes and gastropods.

These data indicate that preferred prey items (by number) for prawns in the UNFD treatment were trichoptera > chironomids > oligochaetes > nematodes. The most reliable method of determining food preferences is using a combination of food item availability and stomach sampling. However, in crustaceans, such as prawns, food habits studies are difficult, and their results suspect, due to incidental ingestion of nutritionally unimportant items, small stomach size, small prey size, and mastication of food items at consumption and in the stomach (Brown et al., 1992). Comparisons of ponds receiving no nutrient inputs, with and without prawns should give reliable data on prey preferences under production conditions.

Prey items vary not only in the number of individuals consumed, but also in what each individual represents in terms of nutritional quantity and quality. Natural forage organisms usually contain a high proportion of protein, with most averaging 50–60% protein on a dry matter basis (Hepher, 1989). Published values indicate that chironomids contain 59.0% protein (Hepher, 1989), oligochaetes 49.3% (Hepher, 1989), nematodes 40.0% (Ivleva, 1969), and trichopterans 34.7% (Hepher, 1989). The biological value of the proteins in those natural food items is also high as amino acid profiles closely resemble requirements of the consuming species (Hepher, 1989). Prey sizes may also vary several orders of magnitude greater than nutritional quality (Bowen, 1983) (i.e. the weight of one oligochaete may be 100 times that of a nematode).

Although these data do not indicate reduced densities of gastropods or zooplankton (cladocerans and copepods) in the presence of prawns, recent controlled studies in tanks indicate that gastropods may be important food items and that zooplankton may be utilized by prawns even at large sizes (Coyle et al., 1996). Studies on crawfish also indicate that snails are an important food (Huner and Naqvi, 1984) and that zooplankton may play an important nutritional role (Brown et al., 1992), with even large individuals able to filter feed on zooplankton (Huner and Naqvi, 1984).

Ultimately the value of a feed or fertilizer, whether it represents an indirect or direct source of nutrients, will be based upon the magnitude of the prawn standing crop it supports and its effect upon the biology of the pond. Natural productivity alone, without nutrient input, was able to support a standing crop of 426 kg ha^{-1} of prawns. This represents 34% of the standing crop in ponds in which prawns were fed a complete diet. This value likely represents the maximum proportion of the prawns nutrition (34%) that could be derived from natural productivity in a fed pond. With feed available, the formulated diet would likely contribute a large portion of the prawns nutrition and natural productivity a correspondingly smaller portion. McClain et al. (1992), working with crayfish in static water microcosms found that prepared feed furnished 72% of the nutrition whereas 10% was contributed by soil substrate and soil benthos. In the current study, natural productivity (UNFD) supported approximately 40% of the standing crop supported by the fertilized systems (FRT). This agrees closely with McClain et al. (1992) who reported 38% of crawfish nutrition was derived from soil substrate and benthics in a system based on detrital rice.

Yield data for ponds receiving only fertilizer (FRT) are similar to data obtained in previous studies at this facility using pelleted prepared diets (990–1268 kg ha^{-1}) under similar culture conditions and stocking rates (Tidwell et al., 1993; Tidwell et al., 1995). Moore (1986) stated that the carrying capacity of a fertilized pond for prawns is about 600 kg ha^{-1}, far lower than the 1056 kg ha^{-1} attained here. The material intended as an organic fertilizer here may actually play a dual role, fertilizing the system but also being consumed directly by the prawns to some extent. The material used (distillers dried grains with solubles; DDGS) is a readily available by-product of beverage and fuel ethanol production and contains 27–28% crude protein. This protein content of DDGS agrees well with the 25–30% dietary protein content recommended for prawns raised in mud bottom ponds (Moore, 1986). Of the 90 prawns examined, 47% of those in the FRT treatment were found to contain DDGS particles in the gut. No material identified as DDGS was found in the gut of prawns in other treatments. Direct consumption of unpelleted DDGS particles indicates a dual role is likely for DDGS as both feed and fertilizer.

Even with these considerations, production in the FRT treatment remains surprisingly high, being similar to studies using pelleted feeds. These results contrast with those of Fair and Fortner (1981) who found that growth using pelleted feeds was twice that achieved using the same feed in pulverized form, but agree with those of Stanley and Moore (1983) who reported no difference in growth of prawns fed bound or unbound forms of a given diet. The later authors (Stanley and Moore, 1983) also reported that a feed containing 27% protein with low water stability produced better growth than more water stable diets containing 28, 41, and 44% protein. In this study, use of a complete formulation in pelleted form resulted in only a 19% increase in production from 1056 to 1261 kg ha^{-1} over ponds fertilized with unpelleted DDGS.

Not only is total production important but the proportion of a crop which attains harvestable weights has a strong affect on commercial viability (Smith et al., 1978). If 20 g is used as the minimum harvestable weight (MacLean et al., 1989) the FD ponds had 11% more harvestable prawns than the FRT treatment, while if 30 g is used (more likely for markets in this area) the FD treatment produced 32% more marketable prawns. The larger proportion of prawns ≥ 30 g in the FD treatment may indicate that concentrated sources of nutrition (i.e. feed pellets) are more important to large animals (> 30 g). The significantly larger size of the largest morphotype (BC) in the FD treatment (62 g) compared with that of BC males in the FRT treatment (47 g) may reflect a change in food habits as body sizes increases. This is of added importance as it was the greater number of large, high value prawns that positively influenced profitability in the FD treatment compared with the FRT ponds.

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