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Polyculture of Nile Tilapia, *Oreochromis niloticus*, Either Confined in Cages or Unconfined in Freshwater Prawn, *Macrobrachium rosenbergii*, Ponds

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Abstract. – Polyculture of Nile tilapia, *Oreochromis niloticus*, confined in cages suspended in prawn, *Macrobrachium rosenbergii*, ponds has been shown to reduce phytoplankton densities, pH levels, and increase prawn production when compared to prawn monoculture ponds. However, as filter feeders, tilapia grazing might be more efficient if allowed free access to all portions of the water column, positively impacting both phytoplankton control and tilapia growth. This study was designed to compare the effects of confined and unconfined tilapia, in polyculture with freshwater prawns, on prawn growth, tilapia growth, algae populations, and water quality. Juvenile prawns were stocked into each of nine, 0.04 ha ponds as 60 d nursed juveniles (0.8 ± 0.3 g) at 62,000/ha. Three control ponds contained only prawns (MONO). In three other ponds, monosex (male) Nile tilapia (89.2 ± 23.6 g) were stocked unconfined into three ponds at 4400/ha (POLY-UNC). In three additional ponds, the same size and number of tilapia were stocked but confined in two, 1 m^3 cages at 100 fish/cage (POLY-CON). Prawns were fed a sinking pellet (28% protein) twice daily at a standardized rate for 114 d. Tilapia were fed a floating pellet (32% protein) twice daily to apparent satiation for 106 d. In the POLY-UNC treatment, average prawn harvest weight (26 g) and prawn production (1625 kg/ha) were significantly lower ($P < 0.05$) and prawn feed conversion ratio (3.0) was significantly higher ($P < 0.05$) than the other two treatments. However, there were no significant differences ($P > 0.05$) between the MONO and POLY-CON treatments in terms of prawn harvest weight, production and feed conversion ratio with combined averages of 38 g, 2465 kg/ha, and 1.9, respectively. Average harvest weight and production of adult tilapia were not significantly different ($P > 0.05$) in the POLY-CON and POLY-UNC treatments averaging 485 g and 2293 kg/ha, respectively. Tilapia in the POLY-CON treatment had a significantly higher ($P < 0.05$) survival rate (99.7%) and feed conversion ratio (1.5) than POLY-UNC (90.3 and 0.8, respectively). There were no consistent trends in treatment differences ($P > 0.05$) among water quality variables or phytoplankton populations. Lower prawn production in the POLY-UNC is likely due to competition for food with the large number of tilapia juveniles. Despite the use of Genetically Modified Tilapia (GMT) monosex males, several cohorts of juvenile tilapia were produced in each of the POLY-UNC ponds, resulting in over 2500 kg/ha of juveniles in the POLY-UNC treatment. No wild spawn tilapia juveniles were found in the POLY-CON ponds. In summary, confinement of tilapia in cages appears preferable when tilapia are polycultured with freshwater prawn.

In production aquaculture, direct feeding of the target species often results in eutrophication of the production waters, resulting in dense phytopankton blooms (Perschbacher 1995). This can cause problems such as wide swings in dissolved oxygen concentrations and high pH levels, which increases the toxicity of nitrogenous waste products (Boyd 1990). Also, blue-green algae often dominate these blooms and the population dynamics of these taxa are particularly unstable (Durborow and Tucker 1992). Die-offs can lead to catastrophic oxygen depletions and other water quality impacts. Despite these issues, phytoplankton populations in aquaculture production ponds remain largely unmanaged.

Current protocols to manage or reduce phytoplankton populations largely utilize regular additions of low concentrations of herbicides, such as copper sulfate (Boyd and Tucker 1998). Although these can effectively reduce phytoplankton numbers, they do nothing to eliminate or reduce the cause of their accumulation. Other methods which have been utilized include removal of excess nutrients from the water (McGee and Boyd 1983) or direct harvest of the algae by phytoplanktivorous species (Perschbacher and Lorio 1993; Turker et al. 2003).

In freshwater prawn, *Macrobrachium rosenbergii*, production ponds, prawn mortality has

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at times been directly attributed to high pH levels (Osunde et al. 2003). While many finfish species will tolerate pH levels >10, prawns are stressed at 9.5 and complete mortality can result at a pH of 10 (Straus et al. 1991). The monoculture of a benthic animal, such as prawns, provides no grazing or stabilizing effect on the phytoplankton populations, potentially contributing to heavy blooms and elevated pH levels (Cohen et al. 1983; Hepher et al. 1989). Danaher et al. (2007) demonstrated that Nile tilapia, *Oreochromis niloticus*, confined in cages suspended within prawn ponds could reduce pH levels. In that study, prawns polycultured with tilapia in cages also demonstrated increased growth, possibly due to improved water quality and an additional food source in the form of tilapia feces. While this system proved effective, the full efficacy and efficiency of the filter-feeding tilapia could have been compromised by their confinement in cages. Tilapia allowed unconfined access to all parts of the water column might prove to be more effective in grazing and controlling phytoplankton populations. Conversely, they might also be more directly competitive with the prawns.

Polyculture of freshwater prawn and tilapia was first suggested by Ling (1969) and now is a relatively common practice (Zimmermann and New 2000). Several papers have been published on different aspects of prawn/tilapia polyculture. Studies where the tilapia were unconfined included Cohen and Ra'anan (1983) who examined the effects of different densities of unconfined tilapia. McGinty and Alston (1987) evaluated prawn/tilapia polyculture systems with prawns at low densities, whereas Mires (1987) evaluated a polyculture system with prawns at higher densities. Siddiqui et al. (1996) evaluated prawns with both unconfined tilapia and unconfined carp and found that prawns were negatively impacted. Garcia-Perez et al. (2000) evaluated the prawns with unconfined tilapia and also found that prawns were negatively impacted. Later studies evaluated polyculture systems with the tilapia confined in cages to reduce competition for feed. Tidwell et al. (2000a) reported that prawn/tilapia polyculture increased total pond productivity 81% without impacting prawn production, compared to previous years. Danaher et al. (2007) reported that when tilapia were confined in cages, prawns in polyculture actually had higher total production, higher average weight, and more efficient feed conversion than prawns raised in monoculture.

A review of these studies demonstrates that there are conflicting data and that the interaction between the two species remains ill defined. The objective of this study was to examine and directly compare, under standardized conditions, the effects of confined and unconfined tilapia on water quality, prawn growth and survival, and tilapia growth when polycultured in ponds.

Materials and Methods

The experiment was carried out in nine, 0.04 ha earthen ponds (1.5 m depth) located at the Aquaculture Research Center, Kentucky State University (KSU), Frankfort, Kentucky, USA. Ponds were drained and allowed to dry 4 wk before stocking. Vertically oriented polyethylene "construction/safety fence" panels measuring 120 cm wide with a mesh size of 7.0 × 3.5 cm were suspended from metal fence posts to increase available surface area by 50% (Tidwell et al. 2000b). A total of 20 panels were used in each pond and included twelve, 26.0 m panels and eight, 17.8 m panels to allow room for cages. Water from a reservoir was passed through a 1 mm mesh filter sock to fill each pond to an initial depth of 0.5 m. All ponds were treated with 22.4 kg/ha copper sulfate ($CuSO_4$) to kill filamentous algae and 1 wk later 7.5 L/ha of liquid fertilizer (NPK, 0:45:0) was added with 45.0 kg/ha of dried distiller's grains (DDGS) to initiate a phytoplankton bloom. Water was slowly added to bring the ponds to 1.5 m depth and subsequently to replace evaporation and seepage for the duration of the experiment. The experiment consisted of three treatments with three replicate ponds per treatment. Treatments were prawn monoculture (MONO), polyculture with caged tilapia (POLY-CON), and polyculture with unconfined tilapia (POLY-UNC).

All ponds were equipped with a 0.5-horsepower aerator (Airolator, Kansas City, MO, USA) equipped with a "deep draw" tube. Aerators were operated every night (1600–0800 h) to aerate and prevent stratification (Tidwell et al. 2002). Oxygen concentrations in all ponds were monitored twice daily (0800 and 1600 h) using an YSI Model 85 meter (Yellow Springs Instruments, Yellow Springs, OH, USA). Surface and bottom pH and temperature for all ponds were monitored twice daily (0800 and 1600 h) using YSI Model 60 meter (Yellow Springs Instruments, Yellow Springs, OH, USA). Total ammonia-nitrogen (TAN) and nitrite-nitrogen were monitored twice weekly according to procedures for a HACH DR/2500 spectrophotometer (HACH Company, Loveland, CO, USA). Un-ionized ammonia-nitrogen was calculated from TAN and corresponding water temperature and pH values at the time of monitoring (Boyd 1990). Alkalinity, total hardness, and calcium hardness were monitored once weekly according to procedures for a HACH FF2A test kit (HACH Company, Loveland, CO, USA). Water quality measurements were compared based on weekly means, monthly means, and overall means for differences between treatments.

Total chlorophyll and spectral algae classes green algae, blue-green algae, brown algae (diatoms and dinoflagellates), and cryptophyceae, determined weekly for each pond using a bbe Algae Laboratory Analyser (bbe Moldaenke, Kiel-Kronshagen, Germany).

Monosex (genetically modified tilapia [GMT]) male Nile tilapia were shipped by truck from a commercial hatchery (Southern Farm Tilapia, Louisburg, NC, USA). They were maintained in four 2450-L raceways for 1 wk before pond stocking. Adequate water flow and aeration were provided. Tilapia were not fed during the holding period. Before stocking, tilapia were graded using #62 and #74 grader-bars (24.6 and 29.4 mm, respectively) to remove the largest and smallest of the population. A subsample of 300 individuals were anesthetized with 25 mg/L clove oil and individually weighed (89.2 ± 23.6 g) using an electronic scale and measured for total length (16.8 ± 1.3 cm). For stocking the confined treatment (POLY-CON), tilapia were weighed in groups of 25 fish on an electronic scale and stocked in a rotation until each cage achieved a density of 100 fish per cage. Cages were 1-m^3 round cages constructed of 1.75-mm plastic mesh. For the unconfined treatment (POLY-UNC), the same procedures were followed but the fish were released into the open pond.

The culture period for tilapia was 106 d. Despite the use of "monosex" male tilapia, several cohorts of juvenile tilapia were produced in each of the POLY-UNC ponds. No wild spawn tilapia juveniles were found in the POLY-CON ponds. Tilapia cages were harvested one at a time and the fish were transported from the pond to the hatchery using a 970-L transport container supplied with pure oxygen. When harvesting the POLY-UNC ponds, a sorting table was used to manually separate young of the year (YOY) tilapia from adults, whereby each fish was visually determined to be either adult or YOY. A total count of adult and YOY fish was conducted and bulk weight was recorded for each group from each pond to determine average weight and production for each group and survival for stocked (adult) tilapia. A random sample of three adult tilapia from each replicate pond was manually processed to determine dress-out percentages.

Post-larval (PL) prawns were shipped by air from a commercial hatchery (Aquaculture of Texas, Weatherford, TX, USA) and nursed in a greenhouse at KSU for 60 d. PLs were stocked into 3680-L tanks with horizontal substrate, fed a 40% protein sinking salmonid diet (Rangen Inc., Buhl, ID, USA) based on percent body weight each day and water quality was monitored. Before stocking the nursed juvenile prawn (PL-60) were size graded using a #14 grader-bar (5.6 mm spacing) and retained individuals (0.93 ± 0.58 g) (top-grade) were used for stocking purposes. A subsample of 400 prawns was individually weighed to determine the initial stocking weight using an electronic balance (Ohaus Corporation, Pine Brook, NJ). Juveniles were hand counted into groups of 100 and stocked in rotation between the 9 ponds until the desired stocking density of 69160/ha were achieved in each pond.

Prawns were fed one-half the daily ration twice daily (0900 and 1400 h) using a 28% protein sinking prawn diet (Farmer's Feed, Lexington, KY, USA) distributed evenly across the pond surface. Prawn feeding was based on a schedule from Coyle et al. (2003). Prawns were sampled every 3 wk to determine average weights. Each pond was seined for prawns ($n \geq 30$) in areas where substrate could be avoided. The sample was drained free of water and group weighed and counted to obtain the average weight. On the last two pond sample dates (August 5 and 23) sampled prawns were each classified into one of six sexual morphotypes – male: blue claw (BC), orange claw (OC), or small male (SM); female: open female (OF), berried female (BF), or virgin female (VF) and each was individually weighed. Data on open and BFs were later pooled into a combined group called reproductive females (RF) (Tidwell et al. 1999).

The culture period for prawn was 114 d. On the day of harvest, water levels in each pond were lowered to 0.5 m. Initially, substrates were removed and each pond was seined at least three times, then the residual water was drained and remaining prawns were picked by hand to ensure all prawns were harvested. Prawns were transported from the pond to the hatchery in a 970-L transport container equipped with pure oxygen. A bulk weight and total count was recorded to determine final production, average weight and survival by pond. Random samples of ≥300 prawns from each pond were categorized into their respective sexual morphotypes and individual weights were recorded.

A one-way ANOVA analysis was used to compare spectral algae, water quality, and prawn harvest data between treatments. If ANOVA indicated significant differences among treatments ($P \leq 0.05$), means were separated using the least significant difference (LSD) test (Zar 1984). A two-sample t test was used to compare tilapia harvest data between polyculture treatments. Feed conversion ratio (FCR) was calculated as FCR = weight of diet fed (kg)/live weight gain (kg). Specific growth rate (SGR) was calculated as: SGR (g/d) = ([average harvest weight − average stock weight]/T), where T is the total days of the study. Production/size index (PSI) was calculated on prawns as: production (kg/ha) × average weight (g) ÷ 1000 (Tidwell et al. 2000b). All percentage and ratio data were transformed to arcsin values before analysis (Zar 1984). Data are presented in the untransformed form to facilitate interpretation.

Results and Discussion

Average (±SE) pond pH for the month of August was significantly higher ($P < 0.05$) in the prawn monoculture treatment (MONO; 9.3 ± 0.2) compared to polyculture treatments; which were not significantly different ($P >$ 0.05) from each other and averaged 9.0 ± 0.2, overall. In a previous experiment comparing stocking densities of caged tilapia polycultured with freshwater prawns, Danaher et al. (2007) also reported that tilapia polyculture resulted in lower afternoon pH readings compared to prawn monoculture ponds and suggested that phytoplankton grazing by the tilapia may have been the mechanism for this occurrence based on reduced phytoplankton cell size in polyculture treatments. There were no other significant differences ($P > 0.05$) in measured water quality variables based on weekly, monthly, or overall mean. Overall means (±SE) for TAN (mg/L), un-ionized ammonia-nitrogen (mg/L), nitrite-nitrogen (mg/L), pH, total alkalinity (mg/L), total hardness (mg/L), and calcium hardness (mg/L) were: 0.93 ± 1.78, 0.20 ± 0.13, 0.04 ± 0.06, 8.4 ± 2.2, 71.9 ± 33.7, 131.0 ± 11.1, and 103.6 ± 10.0, respectively. All water quality measurements were considered suitable for good growth and survival of both prawn and tilapia (Straus et al. 1991).

It would seem likely that the lower pH measurements in the polyculture treatments in August could be attributed to the grazing activity of the tilapia; although this was not supported by algae data. There were no significant differences ($P > 0.05$) between treatments in concentration of total chlorophyll or the four spectral algae groups measured either weekly, monthly, or overall. Overall means (±SE) for total chlorophyll (μg/L), green algae (μg/L), blue-green algae (μg/L), brown algae (μg/L), and cryptophyceae (μg/L) were: 65.2 ± 8.7, 27.4 ± 4.6, 27.1 ± 6.8, 4.1 ± 0.8, and 6.5 ± 0.9 μg/L, respectively. Average blue-green algae and total chlorophyll concentrations increased from an average of 6.6 and 45.2 μg/L, respectively, in July to an average of 30.0 and 81.0 μg/L, respectively, in August. However, there were no significant differences ($P > 0.05$) between the control group and polyculture treatments, overall. Danaher et al. (2007) reported that tilapia did not produce a long-term shift in the percent contribution of algal groups; which is in agreement with the results of this study.

The tilapia stockers were purchased as sex reversed monosex "all-male" tilapia; however, at harvest, of the 120 fish processed for dress-out measurements, it was verified that they were actually 4.2 ± 1.3% female. The presence of female tilapia resulted in the recruitment of an average (± SD) of 3893 ± 2151 offspring per pond (85,763 fish/ha) in ponds where the tilapia were unconfined compared to no recruitment in ponds where the tilapia were confined in cages (Table 1). The average weight of tilapia progeny was 21.7 ± 3.0 g and total production weight of progeny was 2539 ± 591 kg/ha in POLY-UNC ponds. This uncontrolled reproduction resulted in a higher combined biomass (prawn + tilapia) in the POLY-UNC treatment (6411 kg/ha) compared to either the POLY-CON (4776 kg/ha) or the MONO treatment (2497 kg/ha) with no increase in feed allocation. Although total pond production was higher in the POLY-UNC group, approximately 40% of the production was from unintended reproduction and unmarketable due to small size. There may be some benefit to tilapia reproduction in tropical environments with year-round production where these progeny could be used for restocking purposes; however, in the current temperate production cycle they are of little to no value to the producer unless they can be moved into heated indoor tanks and cultured to market size.

TABLE 1. *Mean harvest weight, production, survival, feed conversion ratio (FCR), specific growth rate (SGR), and percent dress-out of stocked Nile tilapia grown either in cages (POLY-CON) or unconfined in ponds (POLY-UNC) also containing freshwater prawns.*

	Treatment	
Variable	POLY-CON	POLY-UNC
Harvest weight (g)	470.1 ± 24.2[a]	498.8 ± 26.0[a]
Production (kg/ha)	2339 ± 87.4[a]	2247 ± 25.7[a]
Survival (%)	99.7 ± 1.4[a]	90.3 ± 3.8[b]
FCR	1.45 ± 0.09[a]	0.78 ± 0.01[b]
SGR (g/d)	3.46 ± 0.22[a]	3.72 ± 0.24[a]
Whole dressed (%)	65.2 ± 2.1[a]	62.2 ± 2.2[a]
Fillet (%)	36.7 ± 1.7[a]	33.5 ± 0.9[a]
Unintended reproduction		
Average weight (g)	—	21.7 ± 3.0
Production (kg/ha)	—	2539.2 ± 591.2
Density (#/ha)	—	3892.7 ± 2150.8

Treatment means within a row followed by a different superscript letter are significantly different ($P \leq 0.05$) using a two-sample t test.

Comparisons of tilapia include only POLY-CON and POLY-UNC treatments (Table 1). Confinement of tilapia in cages had no significant impact ($P > 0.05$) on average harvest weight of tilapia, SGR, or total production of adult tilapia; which overall averaged 484.5 g, 3.6 g/d, and 2293 kg/ha of pond, respectively (Table 1). However, confinement did have a significant positive impact ($P \leq 0.05$) on stocked tilapia survival which was reduced from 99.7% in the POLY-CON treatment to 90.3% in POLY-UNC. Lower survival rates of stocked tilapia in the POLY-UNC treatment were likely attributed to bird predation, which was visually observed during the rearing period. Tilapia confined in cages with lids were actually protected from bird predation. FCRs for stocked tilapia were significantly lower ($P \leq 0.05$) in POLY-UNC ponds (0.78) than in POLY-CON ponds (1.45) (Table 1). Tilapia in both treatments were fed floating feed to apparent satiation. Possible explanations for poorer feed efficiency in unconfined tilapia include reduced feeding activity in the POLY-UNC tilapia. Compared to fish in the POLY-CON treatment, unconfined fish only consumed about one-half as much feed (56.4 ± 0.4 kg and 110.0 ± 5.3 kg, respectively). Another option is the tilapia preferentially consumed the sinking prawn feed in the POLY-UNC treatment. This is supported by a significant increase ($P \leq 0.05$) in FCR in prawns in the POLY-CON versus the POLY-UNC treatment. A third possibility is a greater utilization of natural food by tilapia in the POLY-UNC treatment.

Comparisons of prawn production included prawns in monoculture (MONO), polyculture with tilapia confined in cages (POLY-CON), and polyculture with tilapia unconfined (POLY-UNC) (Table 2). POLY-UNC produced was significantly lower ($P \leq 0.05$) in terms of average prawn weight (27 g), SGR (0.24), production (1625 kg/ha), and PSI (43) compared to MONO and POLY-CON. POLY-CON had average weights (38 g), SGR (0.34), production (2437 kg/ha), and PSI (93) that were not significantly different ($P > 0.05$) from MONO, which had average weights of 37 g, SGR of 0.33, production of 2497 kg/ha and PSI of 93. Survival of prawns in POLY-UNC (88%) was significantly lower ($P \leq 0.05$) than survival of prawns in the MONO treatment (96%) but not significantly different ($P > 0.05$) than POLY-CON prawns (91%). The FCR of prawn in the POLY-UNC treatment (3.0) was significantly greater ($P \leq 0.05$) than the FCR of MONO prawns (1.9) and prawns in the POLY-CON treatment (1.9), which were not significantly different ($P > 0.05$). Production of marketable (>20 g) and premium (>30 g) size prawns was also reduced ($P < 0.05$) in the POLY-UNC treatment (70 and 22%, respectively) compared to the POLY-CON and MONO treatments; which were not significantly different ($P > 0.05$) from each other with an overall average of 94 and 74% for marketable and premium prawns.

The prawn production results in the POLY-UNC treatment are similar to those reported by Garcia-Perez et al. (2000) who reported that 78% of the prawns reached a size >20 g and 25% of the population was >30 g in a polyculture treatment with free-roaming tilapia stocked at similar stocking densities. In the current experiment, prawn production was not affected by the presence of tilapia when confined in cages. Danaher et al. (2007) reported that compared to prawns in monoculture, prawn average weight, production and marketable percentages increased in polyculture treatments using caged tilapia stocked at similar densities. One notable difference between the current experiment and that of Danaher et al. (2007) is that tilapia average harvest weight and biomass densities were much higher in the previous experiment (854 g and 4010 kg/ha, respectively) compared to caged tilapia in this trial (470 g and 2339 kg/ha, respectively) when stocked at the same density (4400 fish/ha of pond). These production differences are partially due to a larger size of tilapia at stocking in the Danaher et al. (2007) trial (116 g) compared to those used in this experiment (89 g), and the corresponding increase in tilapia feed applied. Wang et al. (1998) reported an increase in prawn production as tilapia densities increased

TABLE 2. *Mean harvest weight, production, survival, feed conversion ratio (FCR), standard growth rate (SGR), production/size index (PSI), percent of marketable prawn, and percent of premium prawn cultured either in ponds without tilapia (MONO), with tilapia confined in cages (POLY-CON) or with tilapia unconfined (POLY-UNC).*

	Treatment		
Variable	MONO	POLY-CON	POLY-UNC
Harvest weight (g)	37.1 ± 1.3^a	38.3 ± 2.3^a	26.6 ± 4.5^b
Production (kg/ha)	2497 ± 35^a	2437 ± 109^a	1625 ± 211^b
Survival (%)	96.3 ± 3.4^a	90.8 ± 2.3^{ab}	87.5 ± 3.2^b
FCR	1.89 ± 0.03^b	1.94 ± 0.09^b	2.98 ± 0.38^a
SGR (g/d)	0.33 ± 0.01^a	0.34 ± 0.02^a	0.24 ± 0.04^b
PSI	92.7 ± 3.8^a	93.4 ± 9.6^a	43.4 ± 13.3^b
%Marketable (>20 g)	93.6 ± 3.4^a	93.6 ± 3.2^a	70.0 ± 14.9^b
%Premium (>30 g)	73.0 ± 7.1^a	75.7 ± 6.3^a	22.0 ± 15.1^b

Treatment means within a row followed by a different superscript letter are significantly different ($P \leq 0.05$) by ANOVA.

in net pen enclosures within prawn ponds; the authors concluded that biomass densities of >400 kg/ha of tilapia positively affect prawn yield. However, in the current experiment, caged tilapia polycultured at biomass densities >2000 kg/ha did not result in increased prawn yield and the presence of free-swimming tilapia decreased prawn yield by 65% compared to prawn monoculture.

The POLY-UNC treatment resulted in a shift in the population structure of male morphotypes (Table 3). Prawns in the POLY-UNC treatment resulted in a higher percentage ($P < 0.05$) of SM morphotypes (32%) and a lower percentage ($P < 0.05$) of OC males (65%) compared to the other treatments, which were not different from each other and averaged 9 and 84%, respectively. Garcia-Perez and Alston (2000) also reported a higher frequency of SMs in polyculture ponds using free-swimming tilapia (22%) compared with prawn monoculture ponds (5%), and suggested this was likely a result of competition for food. Conversely, Cohen and Ra'anan (1983) reported that prawn population structure was not affected by free-swimming tilapia. Danaher et al. (2007) reported that prawn population structure was not affected by tilapia when confined in cages.

Based on prawn growth and feed conversion data it appears that the tilapia may have consumed a major portion of the prawn diet in POLY-UNC treatment. Similarly, Siddiqui et al. (1996) reported that when prawn were polycultured with unconfined Nile tilapia and common carp, *Cyprinus carpio*, prawn production was reduced from 1152 kg/ha in monoculture ponds to an average of only 711 kg/ha in polyculture ponds. This is in agreement with Garcia-Perez et al. (2000) who reported prawn growth was significantly reduced by the presence of tilapia in a polyculture experiment in which the tilapia were stocked unconfined with the prawn. The authors concluded that higher feed rates and greater feed distribution over the ponds surface may be warranted. Rouse and Stickney (1982) reported competition for food between the two species, suggesting that the tilapia out-compete prawn for prepared diets by aggressively feeding near the surface. Previous polyculture experiments with finfish and prawns have indicated that prawns do not effectively compete for floating feed (Behrends et al. 1985) and suggested that the use of a combination of floating and sinking feed would reduce interspecific competition among co-stocked pelagic and benthic organisms (Miltner et al. 1983). In this study, tilapia feed inputs were managed independently of the prawn ration by offering tilapia a floating feed twice daily to satiation, but tilapia did not feed actively on the water surface, whereby limiting feed inputs due to poor feed response. Unconfined tilapia may have preferred the sinking ration due to bright sunlight on the waters surface at feeding times or by avoidance of bird predation. It may be best to increase the allotment of the sinking ration when prawns are polycultured with free-ranged tilapia to ensure that prawn receive adequate nutrition.

The presence of tilapia offspring in the POLY-UNC treatment made harvest much more difficult, and competition with the tilapia progeny almost certainly contributed to treatment differences in prawn production. Rouse

TABLE 3. *Population structure (% of sex) of freshwater prawns cultured in ponds either without tilapia (MONO), with tilapia confined within cages (POLY-CON) or with tilapia unconfined (POLY-UNC).*

	Treatment		
Variable	MONO	POLY-CON	POLY-UNC
Blue claw male	7.2 ± 1.1^{a}	6.4 ± 2.3^{a}	2.9 ± 2.0^{a}
Orange claw male	84.1 ± 1.5^{a}	84.6 ± 5.4^{a}	64.7 ± 6.2^{b}
Small male	8.7 ± 1.6^{b}	9.0 ± 3.5^{b}	32.4 ± 7.9^{a}
Reproductive female	34.4 ± 7.3^{a}	26.4 ± 10.1^{a}	28.0 ± 10.5^{a}
Virgin female	65.6 ± 7.3^{a}	73.6 ± 10.1^{a}	68.5 ± 13.9^{a}

Treatment means within a row followed by a different superscript letter are significantly different ($P \leq 0.05$) by ANOVA.

et al. (1987) polycultured prawn and unconfined tilapia which were hand sorted to obtain an "all-male" population. They also reported tilapia reproduction which had a negative impact on prawn production, whereby prawn growth decreased as the amount of tilapia reproduction increased. The tendency of tilapia females to reach sexual maturity at small sizes and the resulting inhibition of growth remains one of the major constraints to tilapia farming (Turner and Robinson 2000; Phelps 2006; Rad et al. 2006). Phelps (2006) reported that "mono-sex" male tilapia fingerlings can be obtained by four methods: hybridization, sex-reversal, genetic manipulation, and manual sexing, and that none of these methods are 100% effective. The authors suggested that females should comprise 4% or less of the population, which is similar to the number of females reported in this study. Lovshin et al. (1990) reported that a tilapia population made up of only 2.5% females resulted in 58% of the harvest weight coming from reproduction after 9 mo. Pompa and Lovshin (1996) suggested that reproduction can be prevented in mixed-sex tilapia by growing them in cages, stating that, as mouth brooders, the eggs will fall through the bottom of the cage before the female can recover them for incubation. The results of this study and that of Danaher et al. (2007) support that statement because no reproduction was observed when tilapia were confined to cages. As unconfined tilapia produced no production advantage for either the tilapia or prawn, no apparent water quality advantage, and greatly increased complexity of harvest due to the required sorting, there appears to be no advantage, and significant disadvantages, to unconfined culture of tilapia in prawn ponds.

Based on these data, it appears that free-ranged tilapia may actually decrease prawn production and survival and possibly compete with prawn for food. This decrease in production and survival is most likely due to the reproduction that occurred in the ponds where the tilapia were unconfined. Furthermore, the tilapia did not perform as well (reduced survival) in the unconfined treatment as they did in cages. Results for unconfined tilapia could be different if unintended reproduction could be prevented or offspring numbers controlled. In this study, the polyculture treatment using caged tilapia increased total pond production by 191% without affecting prawn production when compared to monoculture prawns. Danaher et al. (2007), in a previous study under similar conditions, reported that polyculture of tilapia confined in cages in prawn ponds could increase profit 239% (from $ 3930/ha to $ 13,330/ha) using similar densities of prawns and confined tilapia. Polyculture treatments resulted in a decrease in pond pH during the month of August compared to prawn monoculture. Tilapia polyculture in prawn ponds should be considered beneficial for increasing pond production efficiencies and lowering pond pH, but only when the tilapia are confined in cages.

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