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The effect of the introduction of Nile tilapia (*Oreochromis niloticus*, L.) on small indigenous fish species (mola, *Amblypharyngodon mola*, Hamilton; chela, *Chela cachius*, Hamilton; punti, *Puntius sophore*, Hamilton)

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Abstract

This is the first controlled experiment to quantify the effect of introduced tilapia on indigenous species. This experiment was conducted in small earthen ponds (100 m^2) to assess the impact of mixed-sex or all-male Nile tilapia (*Oreochromis niloticus*) on small indigenous species (SIS) commonly found in south Asia, mola (*Amblypharyngodon mola*), chela (*Chela cachius*) and punti (*Puntius sophore*). Ponds were fertilized, then stocked with 0.56 fish m^{-2} of water surface area in the mixed-sex and all-male tilapia treatments and 0.42 fish m^{-2} in the treatment without tilapia. No additional nutritional inputs were applied after stocking. Treatments were: mixed-sex tilapia with SIS, mono-sex male tilapia with SIS and SIS without tilapia (control). All treatments were stocked with 14 fish per species. All species reproduced during the 21-month culture duration. The number of recruits varied by species, Tilapia reproduced in greater numbers than SIS. Tilapia numbers at harvest were the highest ($451 \pm 25/100\ m^2$) in the mixed-sex treatment compared with mola ($221 \pm 22/100\ m^2$), chela ($94 \pm 8/100\ m^2$) and punti ($100 \pm 7/100\ m^2$). The number of mola was higher ($399 \pm 33/100\ m^2$) in the all-male tilapia treatment. There was reduction in the number of mola and chela in the treatment containing mixed-sex tilapia. Gut content analysis combined with water sampling revealed that all fish species fed selectively. Significant interspecies dietary overlap was found between Nile tilapia and SIS and among SIS. Thus, there is potential for tilapia to compete with indigenous fish species when space and other resources are limiting, but a longer duration study with varying level of management is needed to determine how successfully tilapia competes with locally adapted SIS.

Keywords: tilapia (*Oreochromis niloticus*), electivity index, small indigenous species, dietary overlap, competition

Introduction

Tilapia has been a component of the ichthyo-fauna of most of Asia following its introduction into the region over five decades ago (De Silva 2005). Tilapia culture has been promoted in many parts of Asia for poor farmers as well as a fish with export potential. Despite rapid proliferation of tilapia culture worldwide, several countries continue to remain cautious because tilapia is also a prolific breeder, and the ecological impacts of introduced tilapia is not well understood. Many scientists fear that tilapia may compete with local indigenous species causing a loss of biodiversity and creating an ecological imbalance. Many of these claims are based only on anecdotal evidence from the pond experience, correlation studies and survey data (Ameen 1999; Canonico, Arthington, Mccrary & Thieme 2005). The ability of tilapia, even in the lentic environment (still water) to compete with indigenous, locally well-adapted species has not been scientifically established.

Small indigenous species (SIS) of fish are important to the rural poor in many countries of Asia as they are relatively cheap, are consumed whole and have higher nutritive value than many cultured species (Hossain 1998). Small indigenous species have several additional advantages, including self-recruitment, being fast growing, feeding at low trophic levels and having a high content of micronutrients, including calcium and vitamin A (Thilsted & Hassan 1993; Thilsted, Ross & Hassan 1997). Rural people of many South Asian countries including Bangladesh, consume 56–73 species of SIS (Minkin 1993), among which mola (*Amblypharyngodon mola*, Hamilton), chela (*Chela cachius*, Hamilton) and punti (*Puntius sophore*, Hamilton) are most commonly preferred.

Some SIS are similar to tilapia in that they also feed on natural phytoplankton and zooplankton as their primary food sources and some breed in lentic natural water (Shafi & Quddus 1982; Shrestha 1994). There is concern that introduced tilapia may compete with these SIS, causing not only loss of biodiversity but also affecting the health of the rural poor who derive year-round food and nutrition from these species. The purpose of this study was to improve our understanding of tilapia competition with SIS by determining the degree of dietary overlap and the size of the population of SIS when the Nile tilapia are introduced in a simulated natural environment. Specifically this study determined the recruitment number, fish biomass, preference level of food and dietary overlap among the species in each of the treatments. Treatments (mono sex, mixed sex and no tilapia) were selected to compare two common culture practices of Nile tilapia and what it means when stocked in a SIS environment.

Materials and methods

Experimental site and animals

The experiment was conducted at the Bangladesh Agricultural University (BAU) in Mymensingh, Bangladesh. Nine earthen ponds, 100 m^2 and 1.0 m deep, were used. Experimental ponds were drained, dried and limed with agricultural grade $CaCO_3$ at 250 kg ha^{-1}. Cow dung was applied at 1000 kg ha^{-1} and the ponds were filled with ground water. A week before stocking, ponds were fertilized with urea at 100 kg ha^{-1} and triple super phosphate at 50 kg ha^{-1}. No additional nutrient input was added to the ponds after stocking.

Adult SIS (mola, chela and punti) were collected from local perennial ponds and held 1 day in hapas before stocking in the experimental ponds. Juvenile Nile tilapia, *Oreochromis niloticus* Chitralada strain, were acquired from the Bangladesh Fisheries Research Institute and stocked 74 days after the SIS were stocked. Male and female fish were identified manually. Before stocking, the abdominal area of randomly selected fingerlings was swiped with cotton soaked in methylene blue staining solution to improve the visibility of uro-genital pore (BFRI 1990; Popma & Masser 1999). Only fish with a clearly visible single abdominal vent (uro-genital pore) was considered male and stocked under respective treatment and in respective ponds.

Experimental design and treatments

This experiment used a completely randomized design with three treatments and three replications per treatment. The treatments were: mixed-sex tilapia with the three indigenous fish species (T_1), mono-sex male tilapia with SIS (T_2) and SIS without tilapia (control; T_3). In each pond, 14 individuals of each species were stocked reaching a total stocking density of 0.56 fish m^{-2} for the two tilapia treatments (T_1 and T_2) and of 0.42 fish m^{-2} for the control (T_3). The male to female ratio of SIS was 1:1. Individual fish weights were determined during stocking. The initial mean weights at stocking of mola, chela, punti and tilapia were 0.68 ± 0.03, 0.73 ± 0.40, 4.54 ± 0.35 and 5.12 ± 0.34 g respectively. The experiment continued for 21 months (December 2004–September 2006), after which the ponds were drained and harvested.

The first fish sampling was done after 2 months of SIS stocking. The subsequent samplings were performed monthly measuring both batch and individual weights. Sampling of fish was performed with a fine meshed (2.0 mm) net. At harvest, all ponds were seined and drained. Fish from each pond were separated by species, counted and batch weighed.

Dissolved oxygen, water temperature, pH and Secchi disc visibility were measured weekly. Total alkalinity, nitrate-nitrogen, nitrite-nitrogen, total ammonia-nitrogen, phosphate-phosphorous and chlorophyll *a* concentrations of pond water were analysed monthly. Standard procedures and methods followed APHA, AWWA and WEF (1999). Plankton samples were collected at monthly intervals and identified to genus level.

Zooplankton and phytoplankton enumeration

Water samples were randomly collected monthly from three different places in each pond, combined and decanted into a 2 L labelled plastic bottle. Lugol's iodine (1:1000) was added to the samples and left for 72 h. Approximately 1.9 L of supernatant was carefully siphoned off. The remaining 100 mL was left for another 24 h for sedimentation. Then 80 mL of supernatant was carefully siphoned off and the plankton content of the 2 L sample was concentrated in 20 mL. Plankton numbers of preserved samples were estimated using a Sedgewick-Rafter counting cell (S-R cell) under a binocular microscope. A 1.0 mL sub-sample of each stored sample was transferred to the S-R cell and left a few minutes to allow plankton to settle. All plankton found in 10 randomly selected fields of the S-R cell were identified to genus level. Plankton was identified using the standard keys of Needham and Needham (1962) and Bellinger (1992). The identified organisms were grouped in major taxonomic classes. For each pond sample, the mean number of plankters of three sub-samples was recorded. Plankton density was estimated following Stirling (1985) and Azim, Wahab, Van Dam, Beveridge and Verdegem (2001)

$$N = (P \times C \times 100)/L$$

where N is the number of plankton cell or units per liter of original water, P the number of plankton counted in 10 fields of S-R cells, C the volume of the final concentrate of the sample (mL), L the volume (L) of the pond water sample.

Stomach content analysis (SCA)

At the end of the experiment, SCA was performed according to Dewan, Wahab, Beveridge, Rahman and Sarkar (1991) to determine the electivity index (EI; Ivlev 1961) and dietary overlap index (DOI; Schoener 1970) of each species. Twenty fish from each species were collected randomly by partial seining of each pond 1 day before harvest. The entire alimentary canal was removed, blotted with dry tissue paper and dissected longitudinally. All the gut content was transferred into a Petri dish and diluted with distilled water to reach 5.0 mL. A 1.0 mL sub-sample was transferred to a S-R cell where zooplankton and phytoplankton were identified following the procedures described by Dewan and Saha (1979). All the organisms were identified to genus level and grouped under major taxonomic classes. Three sub-samples were enumerated per fish, and the mean numbers of food items in the three sub-samples were recorded. Food items were identified in the same way as plankton. The identified plankters in the gut were calculated numerically per gut using the following equation:

$$N = P \times C \times 100$$

where N is the number of a specific food items in the gut; P the total number of the specific item observed in 10 fields of S-R cells; C the volume (mL) of sample in the Petri dish.

The Ivlev (1961) index was determined using the following equation:

$$E = \frac{P_g - P_w}{P_g + P_w}$$

where E is the electivity index; P_g the per cent of each food component in the gut of fish; P_w the per cent of the same food organisms in the pond environment. Electivity index values range from +1.0 for a very high degree of selection to −1.0 for complete avoidance. A value of zero indicates that the food organism is present in the diet in the same proportion as it is found in the pond environment.

Dietary overlap among mola, punti, chela and tilapia was measured using Schoener's index (Schoener 1970) and determined by applying the following equation:

$$\alpha = 1 - 0.5\left(\sum_{i=1}^{n} [P_{xi} - P_{yi}]\right)$$

where α is the overlap index, P_{xi} the proportion of food category i in the diet of species x, while P_{yi} the proportion of food category i in the diet of species y and n the number of categories.

Data analysis

The mean values from the three treatments were analysed with a one-way analysis of variance (Ott

1993) to compare differences in the number of fish and biomass at harvest and the plankton population. A Tukey's honesty test was used to rank means (SPSS version 11.5, Chicago, IL, USA). Differences among treatment means were considered significant at $\alpha = 0.05$. Means were given with $\pm$ SE. The analysis of DOI set at an arbitrary level of > 0.60 to represent a biologically significant level of overlap (Martin 1984; Pen, Potter & Calver 1993).

Results

Fish number and weight at harvest

Harvested fish appeared healthy and without any sign of external infections. In each treatment all the species stocked were recovered. Table 1 presents the stocking and harvesting data in each treatment. Harvested total biomass varied among the three treatments. The SIS numbers harvested were similar in the mono-sex tilapia and without tilapia treatments. In all treatments, all the species stocked were recovered. During the culture period, SIS increased 21-fold by number and up to 26-fold by weight in the presence of mono-sex tilapia; similarly as in the control treatment without tilapia. This increase was less dramatic in the mixed-sex tilapia treatment, where the increase was 10-fold by number and 17-fold by weight. The number of mola increased 29-fold in the mono-sex male and without tilapia treatments and 16-fold in the mixed-sex tilapia treatment. In the mixed-sex tilapia treatment, the increase in the number of tilapia (451 at harvest) was higher than the number of three SIS species together. At harvest, tilapia biomass in this treatment was higher (7.2 kg) than all three SIS (1.41 kg) species combined.

There were lower numbers of SIS in the mixed-sex tilapia treatment than in the mono-sex treatment and control. In the mono-sex tilapia treatment, SIS numbers and harvest biomass were similar to the control. Compared with the control (without tilapia), mixed-sex or mono-sex stocking reduced the harvest and biomass of chela, while mola (number and biomass) and punti (biomass) were negatively affected in mixed-sex treatment. In the aggregate, there was reduction in SIS (number and biomass) in mixed-sex tilapia treatment.

Among SIS, the number of mola at harvest was the highest of all species in all treatments although mean individual weights at harvest were the lowest (Table 1). The number and total weight (biomass) of chela were the lowest of the three species in all treatments. The number of punti harvested was highly variable among replications, which lead to no significant differences among treatments. The biomass at harvest of punti was not only greater than other SIS but also the mean individual weight was larger in the mixed-sex tilapia treatment.

Table 1 Mean ($\pm$ SE) number (fish 100 m^{-2}), biomass (g 100 m^{-2}) and mean individual weight (g fish^{-1}) of mola (*Amblypharyngodon mola*), chela (*Chela cachius*), punti (*Puntius sophore*) and Nile tilapia (*Oreochromis niloticus*) in mixed sex, mono sex and without tilapia treatments at stocking and harvest

		Treatments (at harvest)		
Parameters	**At stocking**	**Mixed-sex tilapia (T_1)**	**Mono-sex tilapia (T_2)**	**Without tilapia (T_3)**
Number of mola	14	221 ± 22^b	399 ± 33^a	358 ± 46^a
Biomass of mola	9.62	238.33 ± 24.34^b	496.33 ± 57.44^a	424.63 ± 62.61^a
Mean individual weight of mola	0.69	1.08 ± 0.05	1.24 ± 0.05	1.18 ± 0.03
Number of chela	14	94 ± 8^c	157 ± 6^b	238 ± 7^a
Biomass of chela	10.22	162.50 ± 8.85^b	234.57 ± 19.17^b	421 ± 38.62^a
Mean individual weight of chela	0.73	1.73 ± 0.07	1.49 ± 0.07	1.75 ± 0.41
Number of punti	14	100 ± 7	304 ± 116	308 ± 43
Biomass of punti	63.56	1010 ± 153^b	1400 ± 247^{ab}	2053 ± 157^a
Mean individual weight of punti	4.54	10.22 ± 1.76^b	5.73 ± 1.5^a	6.8 ± 1.19^a
Number of tilapia	14	451 ± 25^a	14 ± 0.0^b	–
Biomass of originally stocked tilapia	71.68	3390 ± 330	6387 ± 438	–
Mean individual weight of originally stocked tilapia	5.12	242.1 ± 17.4^b	456.2 ± 31.3^a	–
Biomass of newly recruited tilapia	–	3811 ± 374	–	–
Mean individual weight of newly recruited tilapia	–	8.71 ± 1.18	–	–
Total number of SIS-only	42	415 ± 25^b	861 ± 110^a	905 ± 85^a
Total biomass of SIS-only	83.3	1.41 ± 0.12^b	2.13 ± 0.29^{ab}	2.84 ± 0.14^a

Mean values with different superscript in the same row were significantly different ($P < 0.05$).

Recruitment

The SIS were stocked in the first week of December, and the first sampling was carried out in February when no new recruits were found (Table 2). Of the three SIS species, the first recruits were observed from punti in all treatments in April. The first chela recruits were observed in June and those of mola in the May sampling. After October, no new recruits were found until the next April sampling. Tilapia on the other hand, started to spawn in May, within 3 months after stocking, and new recruits were found every month until the November sampling. No tilapia recruits were observed during December, January and February samplings, after which new tilapia recruits were again found every month.

The total number of tilapia recruits (harvested–stocked) assessed at harvest (437) was similar only to that of mola in mono-sex tilapia treatment (385) and the without tilapia treatment (344). The total number of punti recruits at harvest were 86, 290 and 294 while chela recruits were, 80, 143 and 224 in mixed-sex, mono-sex and without tilapia treatment respectively.

Electivity and dietary overlap assessment

Gut content analysis from fish collected 24 h before harvest from all treatments had both phytoplankton and zooplankton, and these comprised 100% of the stomach contents. By number, phytoplankton was the most abundant (> 95%) of the two (Table 3). Five major groups of phytoplankton and three of zooplankton were identified consisting of 58 and 14 genera respectively. Two phytoplankton groups, Bacillariophyta and Chlorophyta, comprised over 80% of the phytoplankton in the gut of all species. Copepoda and Rotifera were the primary groups of zooplankton in fish guts.

All four species were selective for specific phytoplankton and zooplankton major groups (Table 4).

Table 2 Recruits of mola, chela, punti and tilapia observed during monthly sampling over the 21-month study period across all treatments

	Months																				
Fish	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A
Mola						√	√		√	√							√	√	√		
Chela							√		√		√						√	√		√	
Punti					√		√				√							√	√		
Tilapia						√	√	√	√	√	√	√				√	√	√	√	√	√

Reproduction ceased during the winter months (Dec–Feb for tilapia and Nov–March for SIS). Tick marks indicate the observed month of recruitments.

Table 3 Relative mean proportion (%) of plankton group/family in the gut of mola (*Amblypharyngodon mola*), chela (*Chela cachius*), punti (*Puntius sophore*) and Nile tilapia (*Oreochromis niloticus*) in mixed-sex, mono-sex and without tilapia treatments

	Treatments										
	Mixed-sex tilapia (T_1)				Mono-sex tilapia (T_2)				Without tilapia (T_3)		
Plankton major group	Punti	Chela	Mola	Tilapia	Punti	Chela	Mola	Tilapia	Punti	Chela	Mola
Bacillariophyta	27.1	29.4	29.7	31.3	35.7	36.2	36.1	41.6	31.1	25.3	26.1
Chlorophyta	58.6	55.4	54.5	51.8	53.3	48.3	48.1	40.4	52.8	54.7	60.3
Rhodophyta	0.2	2.6	4.9	2.2	1.5	1.0	3.2	0.3	1.4	1.6	2.9
Cyanophyta	8.4	8.3	6.5	11.5	6.6	8.8	9.9	15.1	9.8	11.5	6.0
Euglenophyta	3.6	2.5	2.2	1.8	1.9	2.3	2.0	2.1	2.3	2.3	1.2
Phytoplankton	97.9	98.2	97.8	98.6	99.0	96.6	99.3	99.5	97.4	95.4	96.5
Rotifera	0.7	1.4	1.6	1.3	0.4	0.8	0.6	0.4	1.4	2.8	2.1
Cladocera	0.2	0.1	0.2	0.1	0.2	1.3	0.0	0.0	0.1	0.7	0.3
Copepoda	1.2	0.3	0.4	0.0	0.4	1.3	0.1	0.1	1.1	1.1	1.1
Zooplankton	2.1	1.8	2.2	1.4	1.0	3.4	0.7	0.5	2.6	4.6	3.5
Total plankton	100	100	100	100	100	100	100	100	100	100	100

Table 4 Plankton group/family wise electivity index of mola (*Amblypharyngodon mola*), chela (*Chela cachius*), punti (*Puntius sophore*) and Nile tilapia (*Oreochromis niloticus*) for five phytoplankton and three zooplankton groups in mixed-sex, mono-sex and without tilapia treatments

	Treatments										
	Mixed-sex tilapia (T_1)				Mono-sex tilapia (T_2)				Without tilapia (T_3)		
Plankton major group	Punti	Chela	Mola	Tilapia	Punti	Chela	Mola	Tilapia	Punti	Chela	Mola
Bacillariophyta	0.27	0.31	0.31	0.34	0.26	0.26	0.26	0.33	0.22	0.12	0.14
Chlorophyta	0.09	0.06	0.05	0.02	0.09	0.04	0.04	0.05	0.07	0.09	0.14
Rhodophyta	– 0.18	– 0.13	– 0.23	– 0.05	– 0.17	– 0.38	– 0.20	– 0.29	– 0.27	– 0.32	– 0.16
Cyanophyta	– 0.30	– 0.30	– 0.42	0.15	– 0.37	– 0.24	– 0.18	0.09	– 0.10	– 0.02	– 0.33
Euglenophyta	0.09	– 0.09	– 0.14	– 0.23	0.11	– 0.13	– 0.21	– 0.17	0.06	– 0.11	– 0.32
Phytoplankton	0.07	0.07	0.07	0.07	0.08	0.06	0.08	0.08	0.07	0.06	0.07
Rotifera	– 0.82	– 0.67	– 0.64	– 0.69	– 0.92	– 0.86	– 0.89	– 0.93	– 0.76	– 0.58	– 0.67
Cladocera	– 0.87	– 0.91	– 0.89	– 0.93	– 0.66	0.31	– 1.00	– 1.00	– 0.83	– 0.13	– 0.48
Copepoda	– 0.60	– 0.88	– 0.84	– 1.00	– 0.79	– 0.46	– 0.93	– 0.95	– 0.57	– 0.57	– 0.57
Zooplankton	– 0.75	– 0.77	– 0.74	– 0.82	– 0.88	– 0.63	– 0.91	– 0.94	– 0.71	– 0.54	– 0.63

For example, while Bacillariophyta were selected by all four species with relatively higher EI ranging from +0.12 to +0.34 than Chlorophyta (+0.02 to +0.14), only punti selected Euglenophyta although at a low level of preference (+0.06 to +0.11). Only tilapia preferred Cyanophyta while all the other species tended to strongly avoid them. The Rhodophyta (one of the five most abundant phytoplankton groups in the ponds) was avoided by all four species. The EI placed all zooplankton in the negative selection category. Only chela seemed to select for Cladocera in the mono-sex treatment. No fish species completely avoided (– 1.0) any of the major groups of phytoplankton in the pond while only tilapia avoided Copepoda in mixed-sex tilapia treatment. Mola and tilapia also completely avoided Cladocera in the mono-sex group. No clear trends were apparent among the three treatments, except in the control where all species seemed to score lower in the selectivity of Bacillariophyta.

Dietary overlap between species was apparent when relative gut composition and electivity assessment were conducted (Table 5). Schoener's index also indicated that the dietary overlap was significant (i.e. > 0.60) among all four species only in the mixed-sex treatment. In the presence of tilapia in both treatments, there was tilapia–SIS dietary overlap. Although not biologically significant, the dietary overlap was higher in mixed sex than in mono sex and control. In mono-sex tilapia treatment, significant dietary overlap was found between tilapia and SIS, but not among SIS. No overlap among SIS was observed in the treatment without tilapia.

Table 5 Overall dietary overlap (Schoener's index) between punti–mola, punti–chela, mola–chela, punti–tilapia, mola–tilapia, chela–tilapia in mixed-sex, mono-sex and without tilapia treatments

	Treatments							
	Mixed-sex tilapia (T_1)			Mono-sex tilapia (T_2)			Without tilapia (T_3)	
Fish species	Punti	Mola	Chela	Punti	Mola	Chela	Punti	Mola
Mola	0.69	–	–	0.58	–	–	0.52	–
Chela	0.70	0.65	–	0.57	0.55	–	0.54	0.51
Tilapia	0.79	0.75	0.70	0.64	0.65	0.66	–	–

Dietary overlap values > 0.60 are considered to be biologically significant (Zaret & Rand 1971; Wallace Jr 1981; Martin 1984; Pen *et al.* 1993).

Water quality profile

Measured values of water quality parameters in mixed sex, mono sex and control were within the acceptable range for aquaculture. Measured water quality parameters were not different among the treatments, except for Secchi disc visibility. Secchi disc visibility was higher in without tilapia (control) treatment.

Discussion

This is the first experimental study to report the effect of Nile tilapia on indigenous species. This study clearly showed that none of the indigenous species were lost from the treatment pond after the introduction of tilapia. Moreover, SIS reproduced in the experimental ponds. Healthy stocks of SIS and tilapia at harvest also indicated that food was not limiting in this semi-natural system suggesting that there was low competition with tilapia or at least competition not strong enough to eradicate any species.

Although there are no similar controlled studies for comparison, a number of studies in the natural environment have shown strong competition between native fish and tilapia (Canonico *et al.* 2005; Zengeya & Marshall 2007). The reason we observed weak competition could be because of differential growth rates and subsequent early large size of tilapia compared with SIS. Although, all species were stocked at approximately the same size, tilapia quickly turned larger than the SIS. Larger tilapia then could utilize different food. However, in the mixed-sex treatment the same may apply for the first 4 months of the experiment. Afterwards there would be more small tilapia to compete.

Another reason for not observing stronger competition may be due to the omnivorous nature of the studied species. Gozlan (2008) showed that cichlids (including tilapias) had a relatively small likelihood of an effect (the ratio of documented negative effects to the number of introductions was $< 10\%$ for cichlids) compared with many groups of introduced species. Moreover, the experimental set-up of our study was such that it might have minimized competition. For example, stocking density was low and water level and quality was optimum for primary production. Natural predators (i.e. snakehead fish) that would be normally present in a natural environment were not introduced in the culture system.

Usually competition is apparent when a species utilizes more of the limited resources (i.e. exploitative competition) or exhibit behaviours that interfere with other species' ability to utilize resources (i.e. interference competition; Weber & Fausch 2003). To have a negative effect on members of another species, the inter-specific competition needs to occur under, (a) limited resources, (b) a high degree of overlap in resource requirements and, (c) competing species for co-occurring conditions. The very first condition, 'limited resources' may not have been met in this study.

If the experimental period had been longer, we may have observed greater reproductive competition. Although the study was carried out over a 21-month period, tilapia was stocked for only 18 months. Additionally, stocked fish did not reproduce 7 months out of 21 months because of under maturation and cooler water temperature.

Although this experiment was not designed to study production optimization of tilapia with SIS, the production of fish (total harvested biomass) was clearly higher in the treatment with tilapia (about 8.5 kg) compared with the tilapia-free treatment (2.84 kg; Table 1). When tilapia biomass was excluded in our analysis, SIS biomass was similar in the mono-sex treatment and the control. This suggests the potential for stocking tilapia with the SIS in polyculture and the benefit from larger size tilapia for the market and SIS for household consumption.

Clearly, mixed-sex treatment had higher total biomass with a large number of small size tilapia in the mix. If small size tilapia is preferred for household consumption and mid size tilapia can be sold in the market this could be advantageous to a poor farmer, although this would be at the cost of SIS number. The culture of SIS with mono-sex tilapia did not seem to affect SIS population recruitment, except in the case of chela where recruitment was highly variable. Recruitment rates of mola and punti were similar to the control, suggesting a potential for farming of SIS with mono-sex tilapia. The current practice of tilapia culture is moving towards all-male populations. Thus, stocking all-male tilapia with SIS in polyculture could contribute towards household consumption while at the same time allowing them to generate income by selling larger size tilapia in the market. The culture of male tilapia with SIS in this study represented nearly threefold increase in fish biomass (8.5 kg) compared with without tilapia (2.8 kg). Based on this study, the culture of mono-sex tilapia together with SIS would not negatively impact indigenous species or compromise the nutrition and health of a rural population which depends on SIS in their diet.

Conclusion

This study suggests a low negative effect of Nile tilapia on indigenous species because no indigenous species was lost from treatment ponds, and a healthy population of SIS was found to reproduce in the experimental ponds. However, lower recruitment of SIS in the mixed-sex treatment, the selective nature of tilapia and SIS food habits combined with significant inter-specific dietary overlap suggests the potential for competition. The study also suggests that the competitive advantage of tilapia over SIS could have been better tested in a resource-limiting environment. Further, longer-term studies in larger water bodies with varying levels of input are needed to better understand the ability of tilapia to compete with locally well-adapted SIS. Total fish production in an unfertilized and unfed system was higher in the presence of mixed-sex tilapia. Moreover, SIS with monosex tilapia is one possible option for the rural fish farmers because this combination retains a large population of SIS while also provides larger size tilapia for sale or consumption. Therefore, the people who are in need of protein and higher income are better off with tilapia in the mix.

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