AQUABYTE Aquaculture Section of the Network of Tropical Aquaculture and Fisheries Professionals

EDITORIAL

What is the impact of aquaculture research? Are the research results adopted by the target beneficiaries? If not, why? What is the return from investments on research? These are some of the questions often asked by planners and donors. As one of the papers in this issue on bivalve culture has indicated, adoption of technologies/methods developed through research is dependent not only on their technical and economic viability, but also on many other aspects, such as dissemination of results, availability of inputs and finances, sociocultural factors, etc. These factors should be taken into consideration when planning research.

Integration of aquaculture with rice farming is becoming popular in some countries. The paper by Yousuf Haroon deals with the feeding ecology of two sizes of stocked species in Bangladesh and gives some useful insights for optimizing production in culture systems.

M.V. Gupta

Diet and Feeding Ecology of Two Sizes of *Barbodes gonionotus* (=*Puntius gonionotus*) and *Oreochromis* sp. in Ricefields in Bangladesh

A.K. Yousuf Haroon

Abstract

Fish culture experiments were conducted in Bangladesh to compare and evaluate the feeding pattern and strategies, daily ration, gastric evacuation rates, dietary breadth, similarity and overlap of silver barb, *Barbodes gonionotus*, and tilapia, *Oreochromis* sp. (natural hybrid of *O. mossambicus* x *O. niloticus*) in a rice-fish system. *B. gonionotus* was found to be a macrophytophagous column feeder while *Oreochromis* sp. was a detritovorous benthophagic browser. Ontogenic shifts in diet were clearly observed in *B. gonionotus* while absent in *Oreochromis* sp. For both species, daily food ration for the small fish was twice as large as that for the large fish. Mean rates of gastric evacuation were 0.18 h^{-1} for small and 0.05 h^{-1} for large *B. gonionotus* and 0.09 h^{-1} and 0.14 h^{-1} for small and large *Oreochromis* sp., respectively. In terms of intraspecific dietary width, the smaller sized individuals of both species had a wider dietary niche than the larger conspecifics. Larger fish increased their specialization and reliance on few food items with increasing size and competitive ability. When both species were reared together, *B. gonionotus* showed a wider niche width than tilapia. Wider interspecific niche width of *B. gonionotus* compared to that of tilapia and significant interspecific dietary overlap is likely to result in suppression of the growth of tilapia in mixed culture due to: i) a high degree of specialization and reliance of tilapia on food of low-nutrient value, and ii) slower gastric evacuation rates as compared to *B. gonionotus*, which would allow *B. gonionotus* to outgrow similar sized tilapia.

Introduction

The silver barb, *Barbodes gonionotus* (= *Puntius gonionotus*), and tilapia (*Oreochromis mossambicus* and *O. niloticus)* are exotic to Bangladesh and are widely cultured in ponds and rice paddies. Fish species prescribed for polyculture are generally presumed to have complementary food and feeding habits. However, under stress, they show complex feeding habits and strategies.

Silver barb are generally regarded as herbivorous (De Silva and Kortmulder 1977; Santos 1993) and tilapia as omnivorous (Dempster et al. 1993; Chapman and Fernando 1994). However, some uncertainty still remains with regard to their feeding habits. In some cases *O. mossambicus* have been observed to be detritivorous (Bowen 1981; Hofer and Newrkla 1983; Bitterlich 1985; Otto Infante 1985) while in other cases as having a preference for phytoplankton and aquatic macrophytes (Doha and Haque 1966; Premjith et al. 1987; Dempster et al. 1993). *O. niloticus* have been reported as phytophagous (Moriarty 1973; Harbott 1982; Getachew 1987; Khallaf and Alne-na-ei 1987) and detritivorous (Dewan and Saha 1979; Chapman and Fernando 1994).

The present experiment was undertaken to investigate the feeding chronology, pattern and strategies, and estimate the daily ration, gastric evacuation rates, dietary breadth, diet similarity, overlap, feeding of two sizes of *B. gonionotus* and *Oreochromis* sp. in a rice-fish culture system.

Methodology

Experiment I: Two size categories (4.5-6.9 cm and 11.5-13.6 cm total length (TL)) of *B. gonionotus*, collectively stocked at 7 fish/m², sub-surface plankton and water samples were examined every 3 hours for 48 hours (26-28 April 1994) from a ricefield (166 m²) to analyze their gut (from the esophagus to the first major bend of the small intestine) contents, abundance of forage items and the prevailing ecological condition. Ten fish of each size range were sampled every 3 hours. In total, 320 fish (160 of each size) were collected for gut analysis.

Experiment II: The methodology used in Experiment 1 was followed with *Oreochromis* sp. as the test species. Two size categories (4.3-9.3 cm and 9.5-13.8 cm TL) were used in the experiment which was undertaken during 19-25 July 1995.

Experiment III: One size range of *B. gonionotus* (5.1-10.10 cm TL) and *Oreochromis* sp. (7.5-10.20 cm TL), stocked collectively at 7 fish/m², were studied for the same parameters as in Experiment 1, during 19-20 September 1995.

Gut analysis: Gut contents were checked for regurgitation after capture and preserved in 10% buffered formalin. Fullness of gut was assessed on a visual scale of 0 (empty) to 1.0 (full). Gut contents were weighed and expressed as $mg{\cdot}g^{-1}$ of body weight (bw) of the fish (wet weight). Percentage composition by number was used for calculating the relative abundance (%) of different food items (Bowen 1983).

Elliot and Persson's (1978) consumption model was used for food consumption estimation:

$$C_t = \frac{(S_t - S_0 e^{-kt})kt}{1 - e^{-kt}}$$

where C_t is food consumption between two sampling times in $mg{\cdot}g^{-1}$ of bw, S_0 and S_t are the amounts of food present in the gut at the beginning and at the end of a sampling interval of t hours and k is the coefficient of exponential gastric evacuation rate.

A 5th order polynominal regression line was fitted to the mean gut content data to determine the period when fish were assumed to be evacuating their gut contents. Habitat and size-wise mean k was calculated using the formula, $k = (1/t)\log_e(S_0/S_t)$ where S_0 and S_t are the maximum and minimum gut content values taken from the descending part of the polynomial best fit and t is the time interval in hours (h) between the maximum and minimum values. Only fish with food in their gut were considered in the calculation of k and daily ration. The daily ration was calculated by summing the values for C_t and expressed as $g{\cdot}kg^{-1}$ of $bw{\cdot}day^{-1}$ or % of $bw{\cdot}day^{-1}$.

Selection of available plankton by fish was calculated using Ivlev's (1961) electivity index (E). Positive values indicate selection, negative values indicate avoidance and values close to 0 indicate random ingestion.

Plankton: Plankton was sampled from three places of the paddy field every 3 hours prior to fish sampling. Relative abundance (%) and identification of each food item were done in the same way as for gut content.

Water quality: Air and water temperature, dissolved oxygen, carbon dioxide, pH, total alkalinity, total hardness and ammonia-nitrogen levels were monitored every 3 hours, prior to fish sampling.

Statistical Analyses: Water quality, plankton and gut content data for each sampling interval were averaged according to the size class. Two-way ANOVA were run (using Statistica software) on gut content values to determine feeding differences between the two size classes. Significant differences found by ANOVA were subjected to the Newman-Keuls multiple comparison test. A linear regression was run between the ln-transformed gut content data and fish size to estimate the feeding intensity (food consumption per unit bw).

Niche measurement: Diet breadth indices were calculated with Levin's modification of Simpson's diversity index B and B_n (Hurlbert 1978; Keast 1978). Diet overlap indices were calculated with Levin's α_{xy} and α_{yx} (Keast 1978; Wallace 1981) and Schoener's α (Schoener 1970).

All the indices were calculated from discrete counts and compared to evaluate appropriateness and ease of biological interpretation. Values of dietary overlap indices above the arbitrary level of 0.60 were considered as biologically significant overlap, indicative of competition (Zaret and Rand 1971; Wallace 1981; Martin 1984; Pen et al. 1993).

Feeding strategy: The Costello (1990) method as modifed by Amundsen et al. (1996) was used for graphical analysis of feeding strategy.

Results and Discussion

Feeding Pattern and Diets

B. gonionotus: The feeding activity was intense during daylight hours and lower during 2100 h through 0600 h. Small fish had a high level of feeding all through the day, with a peak at 1500 h while large fish fed at low levels with no clear peak (Fig. 1a). Mean index of gut fullness in small fish peaked up to 0.98 as compared to 0.59 for large fish. Mean gut contents reached up to 5.76 mg·g^{-1} **bw** in small fish and 4.33 mg·g^{-1} **bw** in large fish.

Fish of both sizes consumed relatively large amounts of macrophytes (39.2% of total gut contents in small fish and 15.7% in large fish) and showed clear evidence of nibbling on the rice grains. The small fish had a greater preference and electivity (Ivlev's index) for aquatic macrophytes (+1.0), *Spirogyra* sp. (+0.93), *Oedogonium* sp. (+0.97) and *Cyclops* sp. (+0.27) but not the tiny molluscs. This presumably reflects the size limit imposed on prey size by the relatively underdeveloped pharyngeal teeth of the predators. The large fish had a greater preference and electivity for aquatic macrophytes (+1.0) and tiny molluscs (+1.0). Zooplankton were more important to small (0.07) than to large fish (-0.90), as were insects (+1.0), while crustacean nauplii were not consumed by either size (from -0.9 to -1.0). Absence of intraspecific overlap in peak feeding time and intraspecific differences in resource utilization indicate that *B. gonionotus* are able to partition and share their resources temporally and spatially and escape intraspecific competition in a rice-fish system.

On the basis of the food items found in their guts, *B. gonionotus* can be regarded as macrophytophagous column feeders, with benthic foraging on tiny molluscs as the fish grow larger.

Oreochromis sp.: In both size groups, feeding activity was intense during sunlight hours and lower during the night. Mean index of stomach fullness ranged between 0.33 and 0.91 for the small as compared to 0.01 to 0.97 for the large fish. Mean gut content varied from 9.76 to 26.72 mg·g^{-1} **bw** for the small as compared with 2.27 to 13.68 mg·g^{-1} **bw** for the large size class. Fish of both sizes were observed feeding through midday into the afternoon (Fig. 1b). Tilapia were earlier reported as frequent feeders as they have small, rudimentary, thin-walled acidic stomachs and benefit from several feedings per day (Lobel 1981; Lovell 1995).

Stomach contents did not differ qualitatively with size. Fish of both sizes fed mainly on the periphytic detrital aggregate (PDA) (83.37% of total gut content in small and 99.17% in large fish) and had overall strong negative selection for zooplankton (-0.94 in small and -0.98 in large). Phytoplankton was negatively selected by fish of both sizes (small fish -0.41, large fish -0.98). Crustacean eggs were often selected by the small size fish (+1.0) while nauplii were avoided by fish of both sizes (from -0.92 to -0.96). There was no evidence of tilapia nibbling on the rice panicles. The overlap in intraspecific peak feeding time and preference for the same food resource (PDA), irrespective of size, indicate that tilapia can-

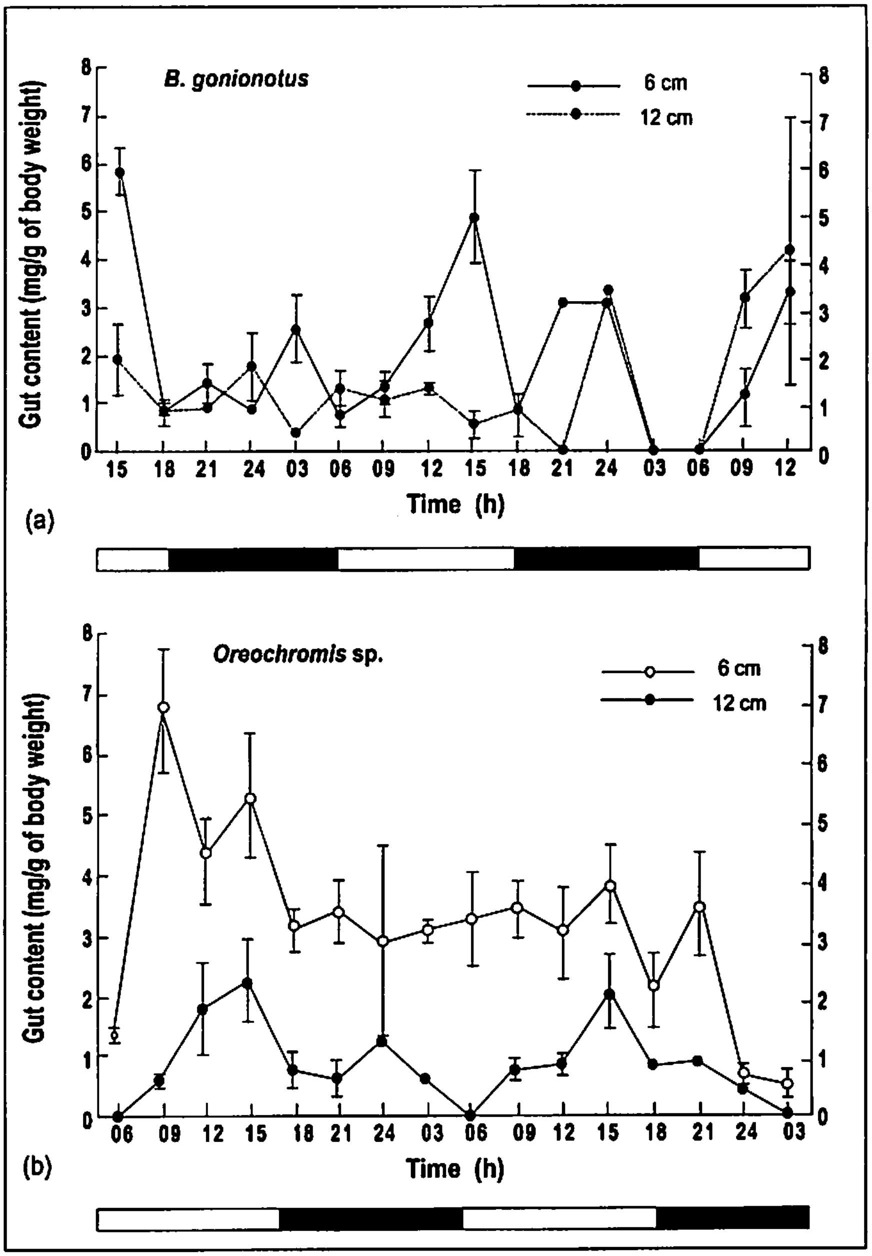

Fig. 1. Diel patterns of gut content (mean ± SEM) of two sizes of (a) B. gonionotus (= Puntius gonionotus) *and (b)* Oreochromis *sp. in a ricefield in Bangladesh. The shaded portions of the time bar indicate night.*

not partition and share their resources temporally and spatially. Hence, they are not able to escape intraspecific competition in a rice-fish systems.

On the basis of the type of food items found in their stomach, tilapias can be regarded as detritivorous benthophagic browsers, as has also been reported by Chapman and Fernando (1994).

Ontogenic Shifts in Diet

B. gonionotus: Feeding electivity of the size range studied indicates pronounced ontogenetic shifts in diet. Small fish select zooplankton and become more reliant on aquatic macrophytes (including the attached molluscs) with increase in size and development of pharyngeal mill. Ukkataweat (1979) described *B. gonionotus* as plankton feeders at a length of <7.5 cm, omnivorous between 7.5 and 12.5 cm and macrophyte feeders at >12.5 cm.

Oreochromis sp.: In contrast to ontogenic dietary shifts observed by Northcott and Beveridge (1988), Tudorancea et al. (1988) and Yowell and Vinyard (1993) in tilapia in different habitats and wider size groups, the present study did not indicate any ontogenetic diet shift in the size groups observed. The small contribution of zooplankton may reflect tilapia's opportunistic and relatively unimportant filter feeding mechanism in contrast to their benthophagic browsing.

Daily Ration and Gastric Evacuation

B. gonionotus: Food consumption for small fish ranged from 0.07 to 4.36 $mg \cdot g^{-1}$ bw in 3 hours (mean 2.25), while it was 0.26 to 3.81 $mg \cdot g^{-1}$ bw in 3 hours (mean 1.54) in large fish. The daily ration of small fish was 1.12% of bw, about twice that of large fish at 0.61% of bw. Mean rates of gastric evacuation were 0.18 h^{-1} for small fish and 0.05 h^{-1} for large fish. For both sizes, the gut contents were computed to be completely evacuated in about 1-5 hours at water temperature of 27.5-34.0°C.

Oreochromis sp.: Food consumption for small and large fish ranged from 0.06 to 6.47 $mg \cdot g^{-1}$ bw in 3 hours (mean 1.15) and 0.14 to 1.91 $mg \cdot g^{-1}$ bw in 3 hours (mean 0.99), respectively. Small fish fed significantly more per unit bw than the large ($p<0.001$). Linear regression analysis indicated a significant decrease ($p<0.0001$) in feeding with increase in size. This observation is in contrast to that of Dewan and Saha (1979) and Saha and Dewan (1979). Similar decrease in feeding with increase in size was reported for *O. aureus* by Salvadores and Guzman (1983). The daily ration of small fish (0.91% of bw) was about twice that of large fishes (0.45% of bw). Mean rate of gastric evacuation was 0.09 h^{-1} for small fish and 0.14 h^{-1} for large fish. Small fish showed three possible evacuation peaks (at noon, sunset and midnight through early morning), while the large fish showed a single evacuation peak at sunset. In both sizes the gut contents were computed to be completely evacuated in about 1-4 hours at water temperature of 29.0-33.3°C.

Niche Measurement

INTRASPECIFIC DIETARY WIDTH

The smaller sized individuals of both species had a wider dietary niche than the larger conspecifics. Larger fish increased their specialization and reliance on few food items, with increasing size and competitive ability.

B. gonionotus: Levin's dietary breadth was a little wider for small fish ($B=4.0$, $B_n=0.12$) as compared to large fish ($B=3.4$, $B_n=0.07$). Czekanowski's Proportional Similarity (PS) Index (Feinsinger et al. 1981) reflected that fish of both sizes are using some resource items exclusively, though small fish have a 5 times broader niche width ($PS=0.15$) or power of selection of prey than the large ($PS=0.03$).

Oreochromis sp.: Liven's dietary width was marginally broader in small ($B=1.432$, $B_n=0.05$) than large fish ($B=1.02$, $B_n=0.04$). PS index also confirmed this trend of reliance of large and small fish on a single or a few selected food items ($PS=0.02$ in small and 0.015 in large fish).

INTRASPECIFIC DIETARY OVERLAP

B. gonionotus: Levin's dietary overlap of large (y) on small fish (x) was much greater ($a_{yx}= 0.41$) than the reverse ($a_{xy}= 0.24$), but biologically insignificant both ways. Schoener's (1970) index ($a= 0.33$) also supported this trend of biologically insignificant intraspecific dietary overlap.

Oreochromis sp.: Levin's dietary overlap of large (y) on small fish (x) was much greater ($a_{yx}= 1.2$) than the reverse ($a_{xy}= 0.84$) and was biologically significant both ways. Schoener's index ($a= 0.85$) also confirmed this biologically significant intraspecific dietary overlap in tilapia.

INTERSPECIFIC DIETARY WIDTH

The interspecific dietary niche was wider for *B. gonionotus* (y) than that for tilapia (x) indicating greater specialization by the latter. Both Levin's and Czekanowski's indices were a little higher for *B. gonionotus* ($B=4.35$, $B_n=0.21$ and $PS=0.21$) than for *Oreochromis* sp. ($B=1.05$, $B_n=0.05$ and $PS=0.02$), indicating a broader niche width for the former than the latter. *Oreochromis* sp. had exclusive specialization for PDA, while *B. gonionotus* had many alternative preferences in addition to PDA.

INTERSPECIFIC DIETARY OVERLAP

Levin's dietary overlap of *B. gonionotus* (y) on *Oreochromis* sp. (x) was more than 4 times greater and biologically significant (a_{yx}= 1.46) than the reverse (a_{xy}= 0.35). This indicates the competitiveness of *B. gonionotus* over *Oreochromis* sp. Schoener's index (a= 0.36) revealed biologically insignificant interspecific dietary overlap. This indicates the importance of using Levin's model, which is more robust over Schoener's.

In analyzing dietary width, Czekanowski's PS index was found to be more robust than Levin's **B** and B_a indices as it simultaneously included resource availability (prey) and their use by the predator. Similarly, in analyzing dietary overlap, Levin's a_{xy} and a_{yx} indices were found to be more robust than Schoener's a index as they not only indicated the direction but also the strength of the overlap.

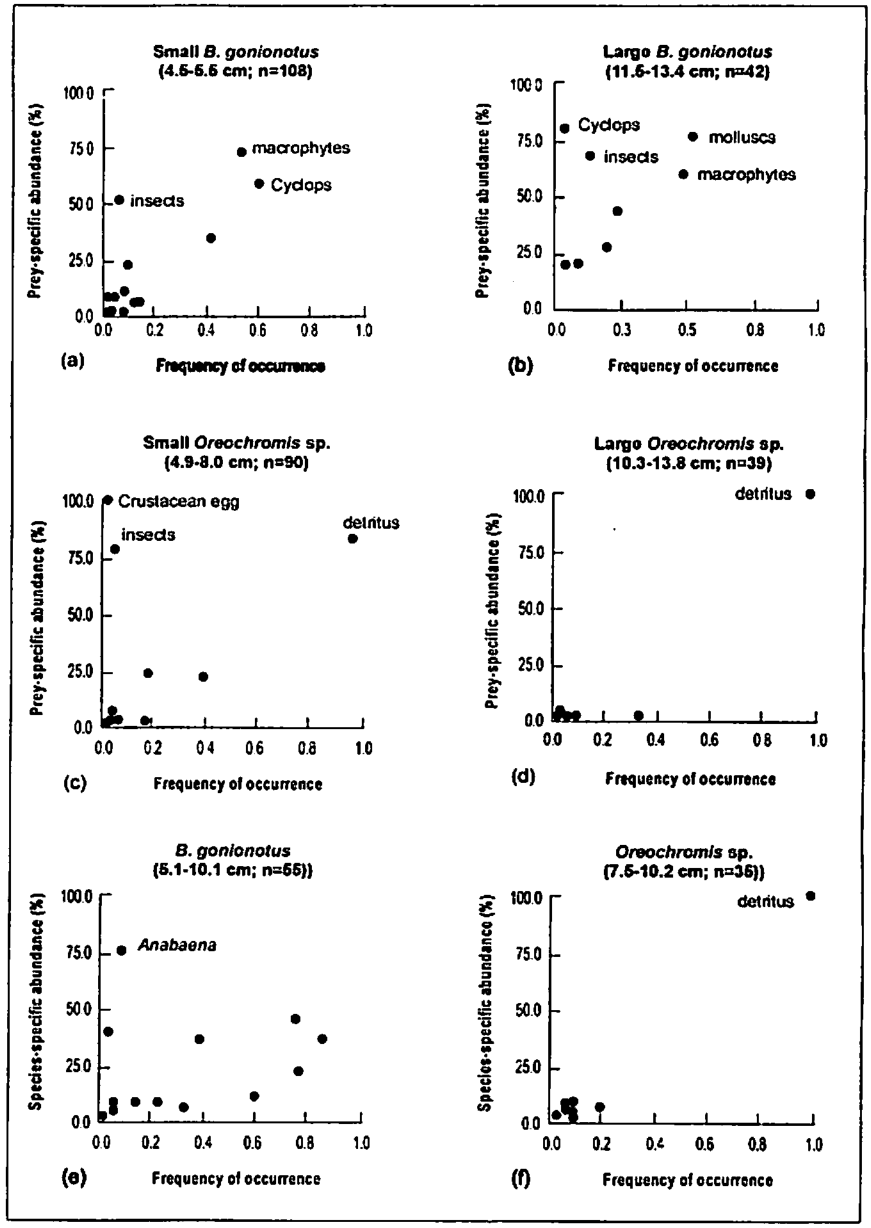

Fig. 2. The feeding strategy diagram: Amundsen et al.'s (1996) modified approach to Costello's (1990) method: prey-specific abundance plotted against frequency of occurrence of different food items in the diet of two sizes of B. gonionotus *and* Oreochromis *sp. and a single size of* B. gonionotus *and* Oreochromis *sp. from a ricefield, Bangladesh. (a) small* B. gonionotus *(4.5-5.5 cm; n=108), (b) large* B. gonionotus *(11.5-13.4 cm; n=42), (c) small* Oreochromis *sp. (4.9-8.0 cm; n=90), (d) large* Oreochromis *sp. (10-3-13.8 cm; n=39), (e)* B. gonionotus *(5.1-10.1 cm; n=55) and (f)* Oreochromis *sp. (7.5-10.2 cm; n=35). Only fishes with food in their gut were considered in the analysis. The black dots represent different food items (only important ones are labeled).*

Feeding Strategy

INTRASPECIFIC

B. gonionotus: The small-sized group showed a mixed feeding strategy, with varying degrees of specialization and generalization for different food items and a rather narrow dietary width. Most of the small fish consumed moderately dominant food items, occasionally including items with low specific abundance and low occurrence, reflecting a mixed feeding strategy. Nonetheless, some individuals showed moderate specialization (at the individual level) for aquatic insects while others showed moderate population level specialization for aquatic macrophytes and the microcrustacean, *Cyclops* sp. There was neither a high within-phenotype (generalization) nor high between-phenotype (specialization) contribution to the niche width, showing a mixed feeding strategy for different food items (Figs. 2a and 2b).

Oreochromis sp.: All small individuals were feeding on PDA, with a small proportion of other food types included occasionally. Small tilapia demonstrated individual specialization for crustacean eggs and aquatic insects in addition to population specialization for PDA. Similarly, all large individuals were feeding on PDA, with a small proportion of other food items being consumed occasionally by some individuals. Large tilapia specialized exclusively on PDA at the population levels (Fig. 2c and 2d).

INTERSPECIFIC

The most important food items were consumed by more than half of the *B. gonionotus* studied, but their average contribution to the gut content was low. Some individuals showed specialization for *Anabaena* sp. When reared with tilapia in the ricefield, *B. gonionotus* showed a wider niche width ($B=4.35$, $B_a=0.21$ and $PS=0.21$) than the *Oreochromis* sp. ($B=1.05$, $B_a=0.05$ and $PS=0.02$) and a relatively high within-phenotype contribution to the niche width, indicating a more generalized feeding strategy (Fig. 2e).

In contrast, *Oreochromis* sp. was found feeding almost exclusively on the PDA, with a few individuals consuming other food items in small proportions. When reared in association with *B. gonionotus*, it showed a narrower niche width ($B=1.05$, $B_a=0.05$ and $PS=0.02$) than the *B. gonionotus* and displayed a similar feeding strategy as when reared alone (Fig. 2f).

Ecological Conditions

There were no striking differences in water quality characteristics and qualitative and quantitative composition of plankton in the rice-fish and rice-alone situations. A buffering effect of fish on increasing water pH, particularly during noon through afternoon hours, was observed. This minimizes nitrogen losses from the rice-fish ecosystem due to grazing of fish on the photosynthetic aquatic biomass (PAB).

High water pH (>8.5) is generally conducive to N_2 loss through NH_4 volatilization and is primarily controlled by PAB. Fish in search of food turns over the soil-water interface, contributes to high turbidity, thereby limiting light availability and thus controls the growth and proliferation of the PAB. Nitrogen transfer efficiencies analyzed by ECOPATH II model (Lightfoot et al. 1993) were higher at all trophic levels in rice-fish systems than in rice-alone systems, suggesting that fish play a prominent role in ameliorating nitrogen utilization within such ecosystems (Dela Cruz 1994).

Practical Applications

Broader interspecific niche width of the *B. gonionotus* and broader intraspecific niche width of the smaller fish than the large ones is indicative of the species capability to use more of the available resources than the *Oreochromis* sp. Hence, *B. gonionotus* are more suitable for culture in ricefields.

This study indicated that larger individuals of both species were already narrowing down their food selectivity. This needs to be taken into account when considering stocking strategies and managing natural biotopes in such shallow water.

Insignificant intraspecific dietary overlap in *B. gonionotus* supports and reflects pronounced ontogenic diet shifts, partitioning of resources according to size and avoiding intraspecific feeding competition. Resource partitioning was also occurring temporally, since small fish were feeding most actively around midday while large ones are more active around dusk and after dawn. Hence, mixed-size stocking of *B. gonionotus* would be better. By contrast, in addition to the significant intraspecific dietary overlap (less pronounced or no ontogenic shifts in diet), both sizes of *Oreochromis* sp. displayed peak feeding activity in the afternoon.

There seem to be few opportunities for habitat segregation in the mixed culture of *B. gonionotus* and *Oreochromis* sp. in rice-fish systems. Wider interspecific niche width of *B. gonionotus* compared to that of *Oreochromis* sp. and significant interspecific dietary overlap is likely to result in a suppression of the growth of tilapia in mixed culture due to: i) a high degree of specialization and reliance of *Oreochromis* sp. on food of low-nutrient value, and ii) their slower gastric evacuation rates as compared to *B. gonionotus*. The latter factor would allow *B. gonionotus* to outgrow similar sized tilapia.

Management of ricefield biotope and enhancement of the forage bases are important criteria in small-scale aquaculture without supplemental feeding. An understanding of the ontogenic diet shifts, for example, would allow the farmers to utilize even natural weed growth or other ecosystem dynamics to enhance fish production by stocking suitable species of appropriate size in rain-fed or irrigated ricefields.

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