Asian Fisheries Science 11(1998):31-42
Asian Fisheries Society, Manila, Philippines

https://doi.org/10.33997/j.afs.1998.11.1.004

Cyprinus carpio and *Oreochromis niloticus* as Biological Control Agents of the Golden Apple Snail *Pomacea canaliculata* - Effects of Predator Size, Prey Size and Prey Density

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Abstract

The Golden Apple snail, *Pomacea canaliculata*, introduced in Asia in 1980 for farming purposes, has turned into a major pest of rice and other aquatic crops. The snail can only damage the crop when there is standing water in the field. Yet, this aquatic environment is equally suitable for raising fish - potential snail predators. To determine the impact of predation by common carp *Cyprinus carpio* and Nile tilapia *Oreochromis niloticus* on these snails, experiments were conducted under controlled laboratory conditions. In functional response experiments using juvenile snails <3-mm shell height (SH) as prey, *C. carpio* showed a distinctly stronger feeding response than *O. niloticus*. When grouped into weight classes of 5, 20 and 40 g, 40-g carp consumed significantly more snails ($P<0.05$) than 40-g tilapia at all prey densities but the lowest. Also, at this size, *C. carpio* preyed upon snails reaching up to 12-mm SH whereas, for *O. niloticus*, predation declined sharply when snail SH exceeded 4 mm. Results show that the common carp is a more effective snail biocontrol agent than Nile tilapia and could substantially contribute to snail biocontrol in rice.

Introduction

Aquatic snails are ubiquitous but rarely recorded as pests of rice or other aquatic crops (De Bont 1956; Van Dinther and Stubbs 1963; Crossland 1965; Jones 1975). This has changed recently with the introduction of the Golden Apple snail, *Pomacea canaliculata*, an aquatic snail introduced from South America to Asia in the 1980's for human consumption and its putative export

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*Present address: Food and Agriculture Organization of the United Nations, Inland Water Resources and Aquaculture Service, Viale delle Terme di Caracalla, 00100 Rome, Italy. Fax: (39)06 57053020, Email: Matthias.Halwart@fao.org potential (Saxena and De Lara 1987; FAO/DA 1989; Hirai 1989; Acosta and Pullin 1991; Mochida 1991; Litsinger and Estano 1993). A decade later, the snail has spread to Taiwan, the Philippines, Japan, P.R. China, Korea, Indonesia, Malaysia, Vietnam, Thailand, Laos and Papua New Guinea, where it poses a threat to irrigated rice and other aquatic crops such as taro, *Colocasia esculenta*, or water spinach, *Ipomoea aquatica*. The dispersal of the Golden Apple snail in Asia, its economic and ecological impact, and currently advocated integrated management practices for snail control in rice crops are reviewed in Halwart (1994c).

P. canaliculata invaded aquatic ecosystems, including rice fields, soon after its introduction. The snail lays egg masses on any hard substrates above the water surface. After hatching, neonates (2 to 3 mm) drop in the water and start feeding on algae and detrital aggregate. They start feeding on plant material when they have grown to a shell height of about 15 to 20 mm. If not controlled, the snails cause severe crop losses by feeding on newly-sown or transplanted rice seedlings. They prefer soft plant tissues, thus rice seedlings are consumed during the first 5 weeks after seeding while transplanted rice are grazed until the third week. Adult snails larger than 50 mm SH can ingest 7 to 24 seedlings per day (Oya et al. 1986; Yamanaka *et al.* 1988).

An integrated pest management (IPM) approach for the aquatic snail which involves some mechanical and cultural control measures has been developed (FAO/DA 1989). Enhancing natural enemy populations is part of this IPM concept. Specific biological control agents are lacking in the snail's exotic environment but common predators such as fish could be used for that purpose. Snails form part of the diet of fish in most aquatic environments, with different potential in mollusc feeding exhibited by various fish species (Stein *et al.* 1975; Merrick *et al.* 1992). In lakes, predation by fish has been shown to cause mortality in freshwater snails (Keller and Ribi 1993), as well as changes in their observed pattern of distribution, size, and density (Merrick *et al.* 1991, 1992).

In rice-fish farming, rice crops can benefit in terms of higher nutrient availability and reduced pest incidence (Halwart 1994a). A major advantage with respect to the Golden Apple snail would be that fish are a *continuous* cause of snail mortality, keeping snail numbers low throughout crop cultivation, as opposed to a one-time control event early in the season, which only leads to a temporary reduction of the pest population.

Therefore, the objectives of this study were to determine the extent of predation of the most common and widely spread (and accepted) fish species in rice-fish farming, *C. carpio* and *O. niloticus*, on *P. canaliculata*, and the interaction effects of fish species and size with snail density and size.

Materials and Methods

General setup

The studies were conducted at the Freshwater Aquaculture Center (FAC), Central Luzon State University. A total of 30 55-l aquaria was used as experimental units in a roofed building with wire netting on the sides. Additional aquaria were placed outdoors and used for breeding snails and hatching snail egg masses. Experimental units were filled by two-thirds with tap water. Oxygen was supplied by portable NSB aerators. Electricity during power outages was provided by a backup generator.

Snails

Adult snails and egg masses (attached to plants) were collected from rice fields and irrigation canals around the FAC. For breeding purposes, adult male and female snails in varying densities were put in aquaria with rice seedlings and other aquatic vegetation as food. Egg masses on plants were placed in containers filled with mud substrate and water. Aquaria and containers were checked daily for newly hatched snails. One- to 5-day old snails were offered to the fish except in the experiment where different snail sizes were compared. Snails were introduced at 0800 - 1000 h. During the experiments, snails moving up the side walls of the experimental units were diverted back into the water with a soft brush, approximately every two hours during daytime.

Fish

C. carpio and *O. niloticus* of varying sizes from the FAC and the Bureau of Fisheries and Aquatic Resources (BFAR) were kept in holding tanks at the FAC. After determining the weight, the fish were placed individually in the experimental units and acclimatized for a minimum of one week. During this period, they were fed commercial fish feed twice a day at approximately 5% body weight. The sides of the units were covered with paper to reduce behavioral variation. Netting covered the top of the units. Fish were starved for 3 d prior to the experiments except during the functional response experiment (Experiment 1).

Sampling procedure

Unconsumed snails were counted 24 hours after introduction to the experimental units. This was done by draining approximately three quarters of the water in the experimental units with a hose through a sieve with a mesh size of 1 mm and visually checking for any remaining snails.

Experiment 1. Fish species vs. snail density

Fish of varying weight (range: 5 - 60 g fish^{-1}) were used. Snails were introduced from 0800 - 1000 h at densities of 50, 100, 200, 300, and 400 per experimental unit. The unconsumed snails were counted after 24 h and replenished to the initial snail density. Fish were usually replaced with new batches after 3 d, after which the experiments were repeated. A follow-up experiment was conducted with common carp at snail densities of 500 and 1,000 per experimental unit. The number of samples for each fish species and snail density is given in Table 1.

Table 1. Number of samples in functional response experiments using *Cyprinus carpio* and *Oreochromis niloticus* at varying snail densities.

Snail density	Number of samples	
	Common carp	Nile tilapia
50	90	75
100	36	37
200	38	37
300	37	37
400	9	9
500	8	-
1,000	3	-
Total samples	221	195

Experiment 2. Fish species vs. supplementary feeding

Twenty-four single fish were offered 50 juvenile snails each at 0800 - 1000 h for 3 consecutive days, 12 fish with supplemental feeding twice a day with commercial fish feed at approximately 5% body weight while the rest went without any supplemental feeding. Snails were replenished every 24 h.

Experiment 3. Fish species vs. fish size vs. snail density

A 2x3x5 factorial experiment was conducted using a randomized complete block design. The first factor was fish species *C. carpio* and *O. niloticus*. The second factor was individual fish weight at 5, 20, and 40 g fish^{-1}, allowing up to 10% deviation. The third factor was snail density computed as a percentage of fish weight at 1.0%, 2.5%, 5.0%, 7.5% and 10%. Treatment combinations were assigned to the 30 experimental units at random. The experiment lasted for 24 h and was repeated once after acclimatization of a second batch of fish. ANOVA was used to analyze the data while Duncan's Multiple Range Test (DMRT) was utilized for mean comparison.

Experiment 4. Fish species vs. fish size vs. snail size

This experiment was conducted using a split-plot design. Mainplot factors were fish species *C. carpio* and *O. niloticus* with varying weights (5, 20, and 40 g fish^{-1}) with up to 10% deviation. Subplot factor was snail size (2-<4 mm, 4-<6 mm, and 6-<8 mm SH). Snail density was constant at 45 snails per unit with 15 snails in each size group. Treatment combinations were replicated six times. In a follow-up to the above experiment, observations were continued with several 40-g carp which were kept singly in experimental units, fed with commercial fish feed, and occasionally offered snails with shell sizes between 10 - 15 mm SH.

Statistical analysis

Means and standard deviations were computed for data obtained in Experiments 1 and 2. The polynomial regression on the data of Experiment 1 was performed with MicroCal Origin 3.01 software. ANOVA and DMRT were used to analyze the data and compare treatment means of Experiments 3 and 4. Arc sine data transformation was applied, where appropriate, as suggested by Gomez and Gomez (1984).

Results

General observations

The common carp started feeding immediately after the snails were offered. After consuming one snail they appeared to be looking for new prey. The carps cracked the shells and consumed only the snail flesh then rejected the broken shells. Sometimes it was noted that a small 5-g carp took bigger (6-8 mm) snails but rejected the whole snail. This was not observed for tilapia. The tilapia seemed to remain indifferent and stayed motionless for long periods in a corner of the experimental unit.

Experiment 1. Fish species vs. snail density

The experiments showed that *C. carpio* and *O. niloticus* readily feed on *Pomacea* juveniles. While both fish species consumed approximately 25-30 juvenile snails in 24 h at the low density of 50 snails per unit, common carp consistently consumed two to three times more snails when higher snail densities were present (Fig. 1). The polynomial regression for the common carp data resulted in the function $y = 56.85334-0.30568x+0.003x^2-2.0411^{-6}x^3$, showing a sygmoid functional response (Fig. 2).

Experiment 2. Fish species vs. supplementary feeding

Without supplementary feeding, consumption of snails by carp increased from 85% on the first day of the experiment to 100% on the third day. The percent consumption increase for Nile tilapia during the same period was from 69% to 98%. When, in addition to the snails, supplementary feeding was provided, both the common carp and the Nile tilapia still consumed snails, although at a much lower rate, ranging from 39% to 57% for common carp and from 18% to 33% for Nile tilapia (Fig. 3).

Experiment 3. Fish species vs. fish size vs. snail density

A highly significant (P<0.01) interaction between fish species, fish weight and snail density was obtained when juvenile snails at varying densities were offered to different sizes of single fish. Carp clearly responded to an increase in snail density by an increase in consumption in all fish weight groups, while this was only true for 40-g tilapia. In the 20-g group, common carp consumed significantly more snails than the tilapia at the highest snail density (10% body weight), and in the 40-g group in all but the lowest snail densities (Table 2).

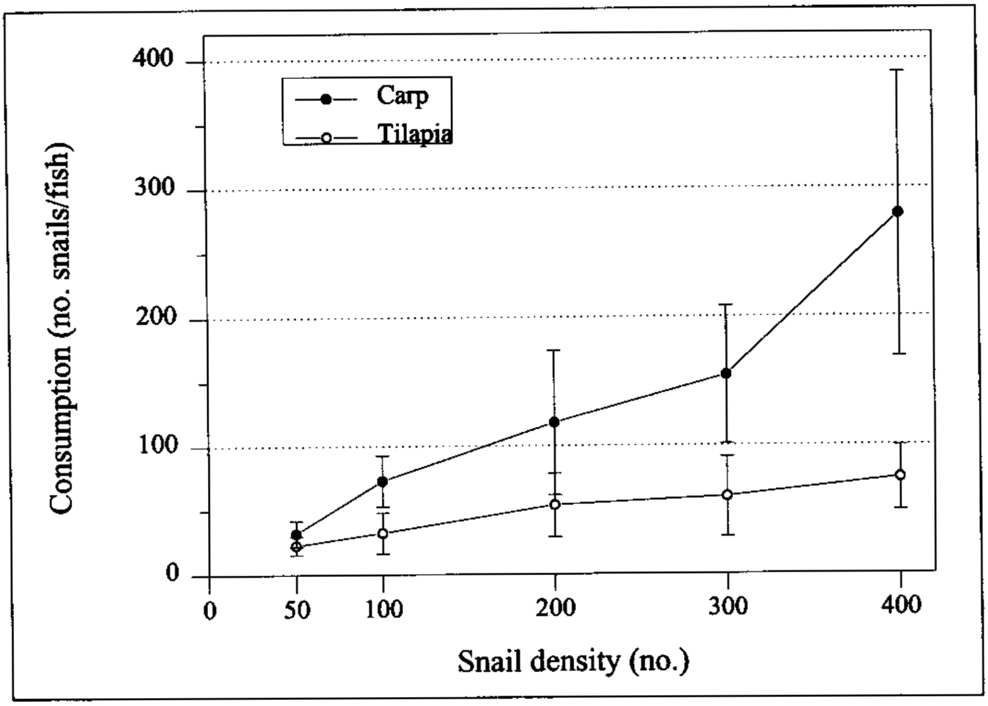

Fig. 1. Number of juvenile *Pomacea canaliculata* consumed per 24 hours at different initial snail densities by single *Cyprinus carpio* and *Oreochromis niloticus* (see Table 1 for number of samples).

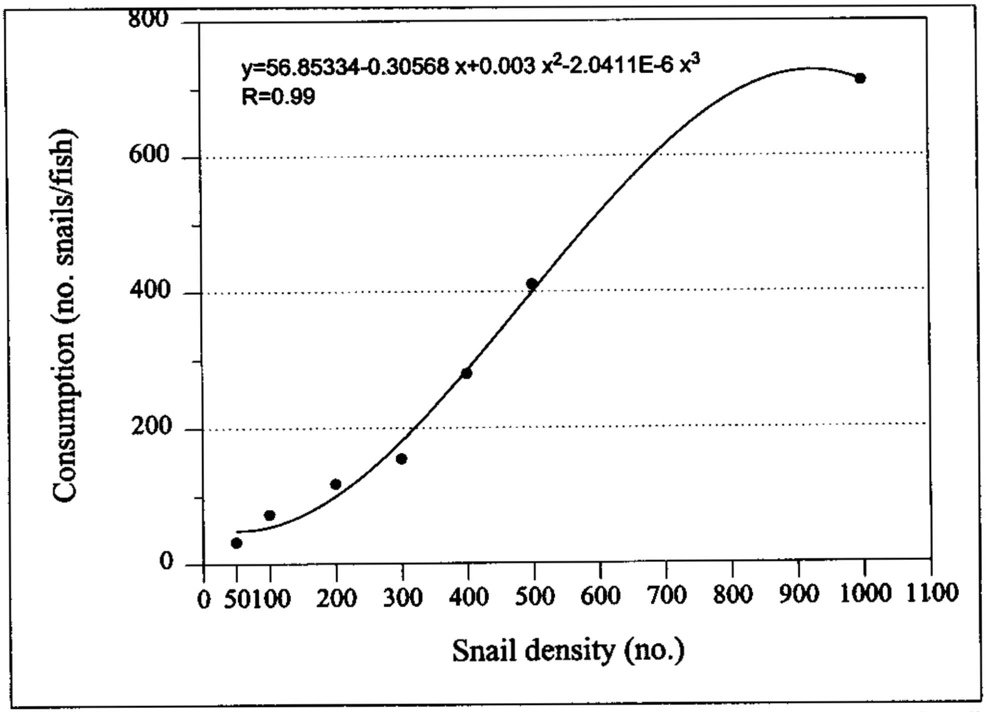

Fig. 2. Number of juvenile *Pomacea canaliculata* consumed per 24 hours at different initial snail densities by single *Cyprinus carpio* (see Table 1 for number of samples).

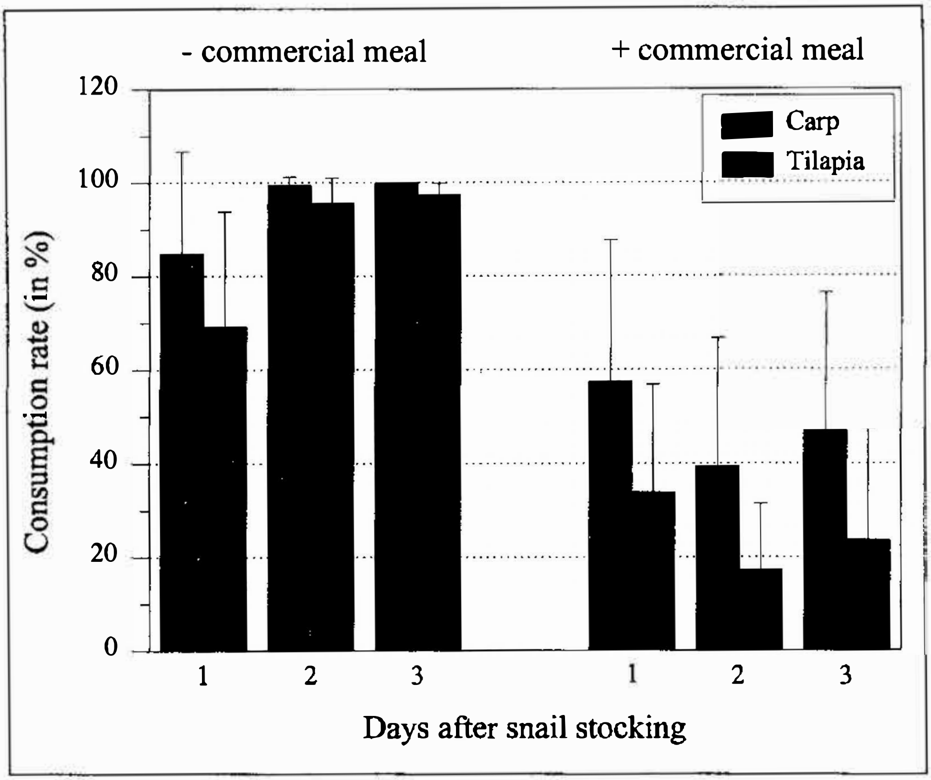

Fig. 3. Daily percent consumption of juvenile *Pomacea canaliculata*, offered at a density of 50 snails per experimental unit and replenished every 24 hours, by *Cyprinus carpio* and *Oreochromis niloticus* with and without supplementary feeding, N=12.

Table 2. Number of juvenile *Pomacea canaliculata* (less than 5 days old) consumed within 24 h by *Cyprinus carpio* and *Oreochromis niloticus* at varying snail densities and fish weight groups.

Fish weight (g)	Snail density[1] (in % of fish weight)	Consumed snails (no.)		
		Common carp	Nile tilapia	Difference
5	1.0 (3)	2.5 b	1.7 a	0.8 ns
	2.5 (7)	5.8 ab	3.5 a	2.3 ns
	5.0 (13)	10.8 ab	7.5 a	3.3 ns
	7.5 (19)	19.0 ab	10.8 a	8.2 ns
	10.0 (25)	23.8 a	15.7 a	8.2 ns
20	1.0 (10)	10.0 d	8.0 c	2.0 ns
	2.5 (25)	23.7 cd	22.8 bc	0.8 ns
	5.0 (50)	41.2 c	37.8 ab	3.3 ns
	7.5 (75)	67.2 b	55.0 a	12.2 ns
	10.0 (100)	92.0 a	19.5 bc	72.5 **
40	1.0 (20)	18.8 e	14.2 c	4.7 ns
	2.5 (50)	43.8 d	25.0 c	18.8 *
	5.0 (100)	95.8 c	22.2 c	73.7 **
	7.5 (150)	142.3 b	48.7 b	93.7 **
	10.0 (200)	173.3 a	152.5 a	20.8 *

[1]Values in brackets indicate no. of snails offered.
** = significant at 1 % level, * = significant at 5 % level, ns = not significant.
In a column under each fish weight group, means followed by a common letter are not significantly different at the 5% level by DMRT.

Experiment 4. Fish species vs. fish size vs. snail size

The interaction of fish species, fish weight and snail size was highly significant (P<0.01). A large proportion (86-99%) of the small snails (2-<4 mm SH) was consumed by the different sized common carp. Percent consumption did not exceed 12% for all size groups of tilapia and snails except for 20-g and 40-g tilapia feeding on the small (2-<4 mm SH) snails. The importance of carp size became evident at snail's size classes of 4-<6 mm and 6-<8 mm SH when percent consumption increased with fish weight from 24% to 99% and 20% to 100%, respectively (Table 3). Highly significant differences (P<0.01) between fish species were obtained for small fish and small snails (5 g vs. <4 mm), medium fish and medium to big snails (20 g vs. 4-<8 mm), and big fish and all snail size groups (40 g vs. 2-<8 mm). The follow-up observations revealed that the 40-g carp will consume snails up to 12 mm shell height whereas larger snails were generally rejected.

Discussion

Laboratory experiments have been frequently used to test predator-prey relationships and develop models of interaction (Hassell 1976). They are useful in determining the relative importance of different life stages or sizes of predators and prey (Khadka and Rao 1986; Roberts and Kuris 1990), and help in testing hypotheses on the importance of habitat complexity and prey activity (Folsom and Collins 1984). Parameters such as encounter rate, attack probability and capture success, which are useful in predicting predator-prey relationships, can be measured (Osenberg and Mittelbach 1989; Chiotha *et al.* 1991). Findings may serve as a basis for predicting potential biocontrol under field conditions.

In this study, a simple controlled environment without refuge was provided to increase the encounter rate between predator and prey. It was first established that both the common carp, a bottom feeder, and Nile tilapia, a column feeder, consume juvenile *Pomacea* snails. Their feeding behavior, as observed in these experiments, strongly suggested that common carp is more adapted to feeding on snails. By crushing and ejecting the broken shells, carps

Table 3. Percent consumption of *Pomacea canaliculata* with different shell size by different size groups of *Cyprinus carpio* and *Oreochromis niloticus*.

Fish species	Fish weight (g)	Consumed snails (%)		
		small*	medium	large
Common carp	5	86.7 a	24.4 b	20.0 c
	20	85.9 a	83.2 a	65.6 b
	40	98.9 a	98.9 a	100.0 a
Nile tilapia	5	12.2 b	5.6 a	2.2 a
	20	80.8 a	7.8 a	10.1 a
	40	64.4 a	7.8 a	4.4 a

*small = 2-<4 mm, medium = 4-<6 mm, large = 6-<8 mm shell height.
In a column under each fish species, means followed by a common letter are not significantly different at the 5 % level by DMRT.
Note: 15 snails of each size group were offered to single fish in the experimental unit for 24 hours.

facilitate digestion and do not fill their digestive tract with food of no nutritional value. Furthermore, they reduce the energy costs of carrying around indigestible shell material which would also require extra swim bladder volume for vertical migration (Hoogerhoud 1987). Cichlids that have specialized on molluscs in their diet do eject snail shells (Hoogerhoud 1987; Chiotha *et al.* 1991).

The functional response experiments provide information on the rate of snail consumption. Regardless of snail density, tilapia did not consume more than 100 snails in 24 h, while common carp still depleted snails at densities of 400 snails per unit. The data curve for tilapia (Fig. 1) suggests a Holling 'type II' response (characterized by a negatively accelerating rise to an upper plateau). The curve for common carp (Fig. 2) resembles the Holling 'type III' functional response. The sygmoid shape is conventionally thought to result from learning in vertebrate predators (Hassell 1976).

Knowing the activity pattern and the snail-feeding potential of the two fish species is important for assessing their impact in the field. In rice-fish farming, the majority of the stocked fish are grazing throughout the day in the entire rice field (Halwart et al. 1994, 1996), where high snail densities may occur when egg masses containing up to 500 snails hatch (Halwart 1994b). While common carp could readily devour this number of hatchlings, this would take tilapia 3 to 5 days, enough time for the snails to disperse and seek shelter among the vegetation to avoid predation. Group effects have not been considered in these studies. Juvenile snails could be depleted if several fish attack at a time. Specialized molluscivorous tilapias in Africa, for example, forage in groups, a mechanism which may help them in finding unevenly distributed snail populations in natural habitats (Chiotha *et al.* 1991).

Experimental conditions were further standardized to determine the importance of fish size in relation to snail density. As rice fields are frequently stocked with small fish, defined sizes of 5, 20 and 40 g were used in the wetlab trials. The starving of the fish prior to the start of a feeding trial increases the probability that encountered prey would be attacked (Osenberg and Mittelbach 1989). Fish were kept single because keeping more than one individual of *O. niloticus* in one tank frequently resulted in fish attacking each other and injuring themselves (pers. observation). Territoriality and early sexual maturity in tilapias add to the complexity of individual differences in their feeding behavior. Covering the sides of the experimental units was considered useful in minimizing disturbance and behavioral variation, although it has been shown that feeding of singly-kept snail-eating cichlids increased when fish see each other (Hoogerhoud 1987).

When examining the interaction of fish species, fish size and snail density, significant differences between fish species were obtained for bigger fish at high snail densities. Contrary to the earlier functional response experiments, 40-g tilapia consumed more than 100 snails at the highest snail density (Table 2), which is probably due to the previous starving of the fish. The nutritional status of the predator is certainly of importance. The results from trials with supplemental feeding show that the fish fed on the juvenile snails in the presence of other feed (Fig. 3). This suggests that *Pomacea* snails, in addition to other prey, will also form part of the diet of both fish species in the ricefield environment. It is a well established fact that molluscs constitute part of the diet of common carp in pond culture (Schäperclaus 1967) but whether this contributes to biological control in a sufficient manner remains to be investigated. Increasing the stocking density of fish in rice fields is one management option which may force the fish to rely on the abundantly available but less preferred snails as a result of limited natural food supply.

As a next step, the importance of snail size was determined. Only small snails below 4 mm SH were consumed in considerable numbers by tilapia, whereas larger snails were neglected. Bigger carp (20-40 g) fed intensely on larger snails up to 8 mm SH, and follow-up observations confirmed that 40-g carp will accept *Pomacea* snails up to about 12 mm SH. This implies that snails in the rice field are vulnerable to predation by carp for a longer period. Encounter rates usually increase with snail size but at the same time the capture probability decreases, leading to a hump shaped attack probability (Osenberg and Mittelbach 1989). Crushing resistance increases with snail size which may lead to a preference in the consumption of small snails (Stein *et al.* 1975; Chiotha *et al.* 1991). Shell shape and thickness may be of importance in the prey selection process in rice fields where several benthic mollusc species are available. Freshwater prawns have been shown to consume all sizes of *Biomphalaria glabrata*, and, for smaller prawns, a size-specific upper limit of snail consumption was determined, below which little selectivity for prey size was demonstrated (Roberts and Kuris 1990). In the present study, 40-g carp easily consumed all snail sizes that were offered, but smaller carp could not. This means that bigger fish in rice fields can control a larger number of snails at a time and is therefore likely to be more promising for biocontrol of snails than small fish.

The results suggest that common carp are more efficient snail predators than Nile tilapia in a controlled environment and may therefore also successfully be utilized for the biological control of *Pomacea* snails in rice fields. This is due to the carp's voracious feeding on snails, their ability to consume larger sized snails and their density-dependent feeding response. Computer simulations of snail population dynamics can help in determining the efficacy of fish farming alone or in combination with other control measures, and research in this direction has been initiated (Halwart 1994b; Heidenreich *et al.* 1997; Heidenreich and Halwart 1997). However, behavioral aspects of fish and snails, the role of a complex vegetation as refuge for snails, preferences of fish predators in a multiple prey environment, and effects (other than predation) of fish on snails have not been considered. Snails may avoid predation due to faster growth and earlier maturation (Crowl and Covich 1990). Apple snails can grow quickly to a large size of about 50 mm SH and predation can certainly be limited by fish's mouth gape and the shell's crushing resistance. The composition of the snail community is also of importance as carp prefer snails that are easy to crush (Stein *et al.* 1975). Also, oxygen supply and other hydrological conditions differ between wetlab and field. While the laboratory experiments have provided valuable insight on the importance of predator size, prey size and prey density, further studies now need to confirm the impact of fish on noxious snail communities under field conditions.

Acknowledgments

The authors thank the Freshwater Aquaculture Center (FAC) of the Central Luzon State University (CLSU) for providing wetlab space and institutional support and the International Rice Research Institute (IRRI) for hosting the senior author. Dr. J.A. Litsinger gave valuable suggestions during the planning and implementation of the experiments, and Dr. V.A. Samaranayake and Ms. J. Mojica of IRRI Biometrics provided advice on the statistical design and analysis of Experiments 3 and 4. This study was part of the FAC/CLSU-IRRI-University of Stuttgart Collaborative Research Project on 'The Potential of Fish as Biocontrol Agents in Rice', funded by the Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ).

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Manuscript received 19 March 1996; Accepted 23 February 1998.