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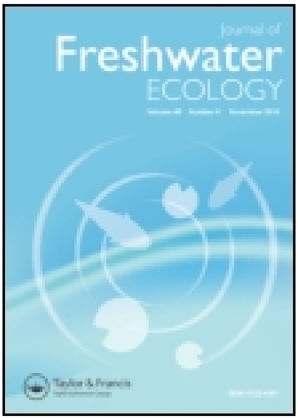

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Prey species and size choice of the molluscivorous fish, black carp (*Mylopharyngodon piceus*)

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The black carp, *Mylopharyngodon piceus*, is used for biological control of freshwater mollusks in various parts of the World. Fish-borne zoonotic trematodes (FZTs) are a public health concern in Vietnam and we suggest using black carp in nursery ponds, which are important for FZT transmission, to control snails serving as first intermediate hosts. However, the use of large juvenile (>2 kg) black carp in nursery ponds could be problematic and we decided to determine consumption rates by black carp of various sizes and their choice of different sizes of selected snail species found in aquaculture ponds in northern Vietnam. Furthermore, shell strength of common snails was assessed. Average daily consumption as percentage of fish weight ranged from 8.12% for smaller fish (100–250 g) to 4.68% in the larger fish (610–1250 g). *Bithynia fuchsiana*, the intermediate host of *Clonorchis sinensis*, and some intestinal trematodes were readily consumed by even the smallest black carp tested. The proportion of *Melanoides tuberculata*, an important host for intestinal trematodes, declined with an increase in its shell height. The same was observed for two viviparid snail species, *Angulyagra polyzonata* and *Sinotaia aeruginosa*; these species do not serve as first intermediate host for FZTs. Small black carp (100–250 g) consumed 50.4% of the second largest size class (26–30 mm) and 19% of the largest size class (>30 mm), while medium-sized black carp consumed 49.6% of the largest *M. tuberculata* and almost all snails of other size classes. Large black carp consumed 75% of the largest size class (>30 mm) of *M. tuberculata*. Crush resistance ($\log_e$-transformed) increased linearly with shell size ($\log_e$-transformed) in most species tested. Crush resistance was the lowest in *B. fuchsiana*, while there was an overlap between *M. tuberculata* and the viviparid snails. We concluded that black carp of smaller size preferentially fed on *M. tuberculata*.

Keywords: fish-borne zoonotic trematodes; biological control; intermediate host snails; crushing resistance; Red River delta

Introduction

Fish-borne zoonotic trematodes (FZT) are an important human health concern in areas where eating raw or undercooked fish is common (Rim et al. 1994; WHO 1995; Chai et al. 2005; Taylor et al. 2007). Trematodes, particularly intestinal trematodes of family Heterophyidae, but also to some extent liver trematodes (*Opisthorchis viverrini* Stiles & Hassall, 1896 and *Clonorchis sinensis* Looss, 1907) of family Opisthorchiidae, may be

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*Corresponding author: Email: hung_iebr@yahoo.com or nmhung@iebr.ac.vn found in aquaculture ponds in Vietnam (Le 2000; De 2004; Dung et al. 2007; Phan et al. 2010a) where eating raw fish is a common practice (Chi et al. 2009; Phan et al. 2011). Dung et al. (2007) found from fecal examination that 64.9% of the adult people in Nam Dinh were positive for small trematode eggs (Heterophyidae and Opisthorchiidae) and expulsion of adult trematodes from 33 people with high egg counts (>1000 eggs/g feces) showed that 51.5% were infected with *C. sinensis*.

One way to control trematode infections is to reduce intermediate host snail abundance (Madsen et al. 2011). Chemical control of these freshwater snails is not really feasible in aquaculture installations since most chemicals that are toxic to snails (molluscicides) also are toxic to fishes (Hoffman 1970; Calumpang et al. 1995). Pond management, such as regular mud removal, may reduce density of the intermediate hosts, but this may not be enough to prevent transmission (Clausen et al. 2012a). Biological control of snails, however, may be a viable option and in northern Vietnam (Red River delta) many fish farmers already use the black carp, *Mylopharyngodon piceus* (Richardson, 1846) for snail control in grow-out ponds. Generally, one-to-two specimens of black carp are released in ponds of a size of 300–400 m^2 where various other carp species are primarily cultured. The black carp feeds almost exclusively on gastropods and bivalves (Nico et al. 2005). Also, at harvesting the black carp, which is a valued species for human consumption, may be consumed or they may be transferred to other ponds. Little information, however, is available on snail species and size selection by different sizes of the black carp; fish ponds may harbor several species of snails and only some of them serve as intermediate hosts for FZTs. Controlling these snails may also benefit the production of juvenile fishes as the metacercariae of FZTs may harm fishes.

Black carp is one of the large Chinese carps and has been introduced and used for the control of freshwater snails in different parts of the World (Venable et al. 2000; Ben-Ami and Heller 2001; Ledford and Kelly 2006). Black carp were used to control *Pomacea canaliculata* (Lamarck, 1819), which damages rice plants in Taiwan (Mochida 1991). In the United States, the trematodes, *Bolbophorus confusus* Dubois, 1935 and *Centrocestus formosanus* Nishigori, 1924 cause serious losses in catfish culture, and black carp is used successfully to control the first intermediate host snails of these trematode species, for example, *Planorbella trivolvis* (Say, 1817) (Venable et al. 2000; Ledford and Kelly 2006). Black carp may feed on commercial catfish feed and this may reduce its consumption of snails but its effectiveness as a biological control of ramshorn snails was not affected (Ledford and Kelly 2006).

Using black carp for snail control was the most cost-effective strategy in hybrid striped bass farms compared to no snail control, chemical control with hydrated lime or copper sulfate, and biological control with redear sunfish, *Lepomis microlophus* (Günther, 1859) (Wui and Engle 2007). In Israel, black carp has been used in reservoirs and canals to control *Melanoides tuberculata* (Müller, 1774) and *Physella acuta* (Draparnaud, 1805), which can block filters and pipes and thus reducing water flow (Shelton et al. 1995; Ben-Ami and Heller 2001). The major concern about using black carp outside its natural distribution is its potential spread to large rivers, where it may establish populations with potential severe effect on native mollusk populations (Nico et al. 2005; Wui and Engle 2007).

Its natural distribution is the largest rivers in Eastern China and Russia. The Red River in Vietnam marks its southern distribution, although its presence may be the result of an early introduction (Nico et al. 2005). These fish are capable of feeding on mollusks from an early developmental stage. Larva and juvenile fish consume a variety of soft food items, but as soon as pharyngeal teeth are formed they start to feed on hard food such as small snails and bivalves; moreover, mature individuals (from about 6 kg) feed exclusively on mollusks (Nico et al. 2005).

The intermediate hosts of the FZT include species of Thiaridae, Bithyniidae, and Stenothyridae (Dung et al. 2010). The species of Thiaridae (intermediate hosts of intestinal trematodes), including *M. tuberculata*, *Thiara scabra* (Müller, 1774), *Tarebia granifera* (Lamarck, 1822), and *Sermyla riquetti* (Grateloup, 1840) are commonly found in aquaculture ponds. The species of Bithyniidae are the main hosts for the liver trematode, *C. sinensis* in this area but are not commonly found in aquaculture ponds (Dung et al. 2010). Other snail species commonly found in aquaculture ponds include species of Viviparidae, primarily *Angulyagra polyzonata* (Frauenfeld, 1862) and sometimes *Sinotaia aeruginosa* (Reeve, 1863), but these seem to play no role in transmission of FZT (Dung et al. 2010). Since the black carp is also a valued species for human consumption, farmers who use black carp may also provide snails collected from outside the pond as feed for the black carp; thus black carp maintenance could potentially also become a risk factor for FZT transmission if the snails collected as feed for black carp from outside the ponds would include intermediate host snails. Infection levels with FZT in intermediate hosts collected from small canals and rice fields were high, that is, 15.4% and 6.2%, respectively, for thiarid snails (Dung et al. 2010).

The transmission of FZT to fish is intense in nursery ponds (Thien et al. 2009; Phan et al. 2010b), and this seems to be partly linked to favorable conditions for snails in these ponds (Dung et al. 2010). Nursery ponds are stocked with fry (mainly carp species) from commercial hatcheries about 1 week after hatching and they will be kept in the pond for about 9 weeks (the normal duration of a nursing cycle) when the juvenile fish will be sold to for growth in a potentially large upland. During this period, the prevalence of infection with FZT may reach more than 80% (Clausen et al. 2012a).

Using black carp in these ponds could be problematic because the fry that it should protect from infection are of very small size (15–20 mm when stocked); large juvenile specimens (>2 kg) might affect pond conditions, for example, by suspension of bottom sediment as a result of its feeding; furthermore, small-sized black carp (<250 g) might not be able to feed on the intermediate host snails but would focus on juvenile specimens of the Viviparidae which have relatively fragile shells. Hung (2013) showed that black carp are not likely to feed on fry raised in nursery ponds, but the question is whether small black carp can control populations of the FZT intermediate hosts. Some farmers actually produce *A. polyzonata* in their ponds; large specimens can be collected and sold for human food when ponds are emptied before introducing a new fish stock.

The purpose of this study was to assess species and size preferences among the snail species commonly found in aquaculture ponds in northern Vietnam by black carp of various sizes. These findings are then viewed in relation to the crush resistance of the snails.

Methods

The specimens of black carp were purchased from farmers in Tu Son town. The fish were grouped into three size classes based on their weight and fork length: large (610–1250 g; 320–455 mm), medium (260–600 g; 210–370 mm), and small (100–250 g; 155–220 mm). Prior to the trials, 40 individuals of each size class were maintained separately in enclosures (3 × 3 × 1.4 m). The enclosures were made of nylon net with a mesh size of 1 × 1 mm at the bottom and of 2 × 2 mm around the sides to permit water circulation. They were fixed in the pond bottom to ensure that the enclosures would always be extended. Water level was maintained at 0.8 m inside the enclosure. Snails of different species and sizes collected nearby were supplied as food for the black carp at a rate of 10% of their body weight per day; this amount is close to satiation level (Nico et al. 2005).

Tank experiment

Three cement tanks (1.2 × 3 × 1.4 m, W × L × H) were used for this experiment. Water level in the tanks was kept at 1.2 m, and water was constantly aerated and recirculated through a filter system at a rate of 0.5 m^3/hour. The filter contained a net (mesh size 0.5 × 0.5 mm), and water filtered through foam rubber and sand before returning to the tank. One specimen (either large, medium, or small) of black carp was released in each tank 24 hours before the trial started. After this period, 50 specimens of thiarid snails (mainly *M. tuberculata* and a few *T. scabra*) and 30 specimens of viviparid snails (mainly *A. polyzonata* and a few *S. aeruginosa*) of various sizes were introduced every second day for 2 weeks. The trial was repeated three times. The total weight of snails introduced in each tank and the total weight of live snails at termination of experiment were recorded.

Prey size selection experiment

Eight glass tanks (0.6 × 0.4 × 0.45 m) were prepared for experiments with well water to a level of 0.4 m and constant aeration. Twenty-four hours before snails were introduced, black carp of different sizes were introduced to the aquaria, one specimen in each aquarium, and each size class of black carp was represented by two to three aquaria. A black carp specimen was used in only one trial. Snails were collected the same day as used in the experiment from canals in the neighborhood and included *Bithynia fuchsiana* (Moellendorff, 1888), *M. tuberculata*, *S. aeruginosa*, and *A. polyzonata*.

Snails were grouped into six size classes (<10 mm, 10–15 mm, 16–20 mm, 21–25 mm, 26–30 mm, and >30 mm) on the basis of shell height. For *B. fuchsiana* and *M. tuberculata*, 50 specimens representing as much of the size variation as possible were introduced in each aquarium. Due to the availability, all size classes could not be equally represented in each repeat trial. For *A. polyzonata* and *S. aeruginosa*, only 30 specimens were used per aquarium. For *M. tuberculata*, the trial was repeated eight times, for *A. polyzonata* five times, while for *B. fuchsiana* and *S. aeruginosa* it was done only once (i.e., eight aquaria). After 24 hours, the number of live snails of each class was counted. In a separate but otherwise similar trial, the two viviparid snail species were tested together in the same aquaria. This experiment was repeated five times.

Crushing study

Crush resistance was measured as described by Brodersen et al. (2003) by placing snails with the aperture facing down on a glass plate underneath a plexiglass cylinder closed at the bottom with a glass plate. This procedure ensured that force was applied to snails against their minimal dimension (Evers et al. 2011). For crushing, we used two cylinders of different sizes; one for small or fragile snails (diameter 42 mm, height 500 mm, weight 427 g) and one for large and strong shells (diameter 85 mm, height 1200 mm, weight 2723 g). Before the actual experiment started, we estimated the approximate crush resistance of larger shells because the tube for larger shells had to be preloaded with extra weight to create the necessary crush weight. Sand was slowly poured into the tube until

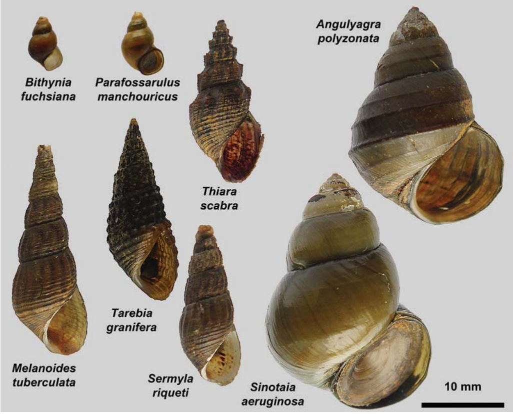

Figure 1. The snail species mentioned in this study. *Bithynia fuchsiana* and *Parafossarulus manchouricus* are important hosts for *Clonorchis sinensis. Melanoides tuberculata*, *Sermyla riquetti*, *Thiara scabra*, and *Tarebia granifera* are hosts for some intestinal trematode species. *Angulyagra polyzonata* and *Sinotaia aeruginosa* are not hosts of these trematodes but are common in aquaculture ponds.

the snail shell crushed. The weight of the tube, additional weights, and sand were determined to the nearest 2 g using an electrical balance. The snails selected represented as much of the size variation as possible for each species.

The snail species used in the crushing resistance study were the most common species in fish ponds and rice fields (Figure 1) and included *M. tuberculata*, *T. scabra*, *T. granifera*, *S. riquetti*, *A. polyzonata*, *S. aeruginosa*, and *B. fuchsiana*. Snails were collected from different rice fields, small canals, or ponds in Nam Dinh, Hanoi, and Bac Ninh provinces and were preserved in 70% ethanol. Shell height and shell diameter were measured for each shell to the nearest 0.01 mm using an electronic caliper.

Statistical analysis

Survival of snails was compared between treatments using logistic regression with data arranged in binomial form using a generalized linear model with a logit link function. All standard errors were adjusted for clustering within an aquarium. Consumption of snails in the tank experiment was related to fish size using linear regression, and similarly, crush resistance ($\log_e$-transformed) was related to either shell height or shell diameter (both $\log_e$-transformed) using linear regression. Comparisons of regression lines among species or families were done using analysis of covariance. All analyses were done in STATA 12 and the differences with probability values below 0.05 were considered significant.

Results

Tank experiment

The proportion of snails consumed by black carp was positively related to fish size (Figure 2a). Small black carp consumed more than 50% of the snails released, while large black carp consumed almost 100%. The average daily consumption as percentage of initial fish weight throughout the experiment ranged from 8.12% for smaller fish to 4.68% in the larger fish. Consumption decreased as fish size increased but this trend was not significant.

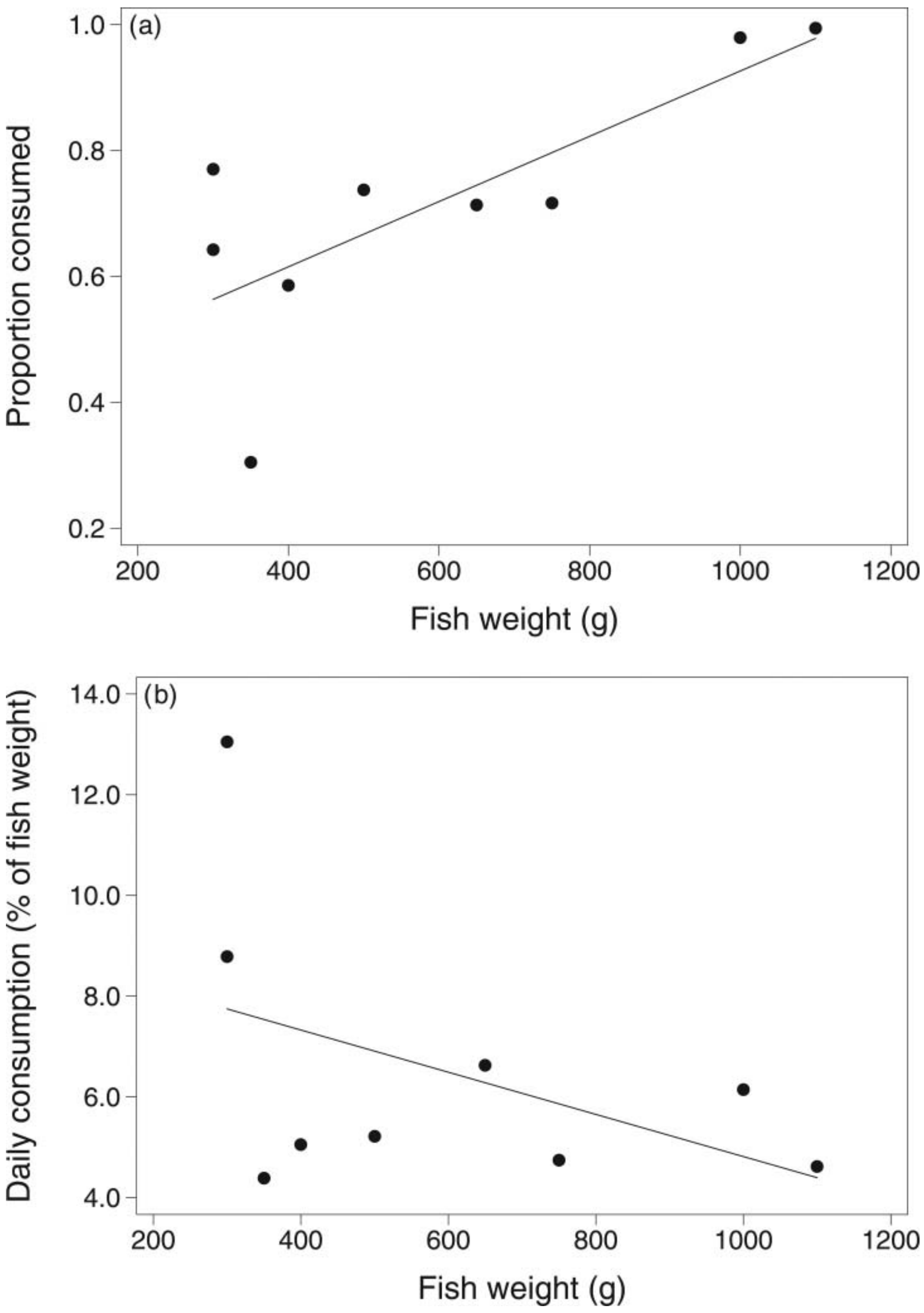

Figure 2. (a) Consumption as proportion of weight of snails added ($y = 0.00052 \times \text{weight} + 0.4080$; $r^2 = 0.572$; $p < 0.05$); and (b) daily consumption as percent of fish weight ($y = 0.00419 \times \text{weight} + 9.0022$; $r^2 = 0.2247$; p not significant) by individual black carp ($n = 9$) in cement tanks over 14 days.

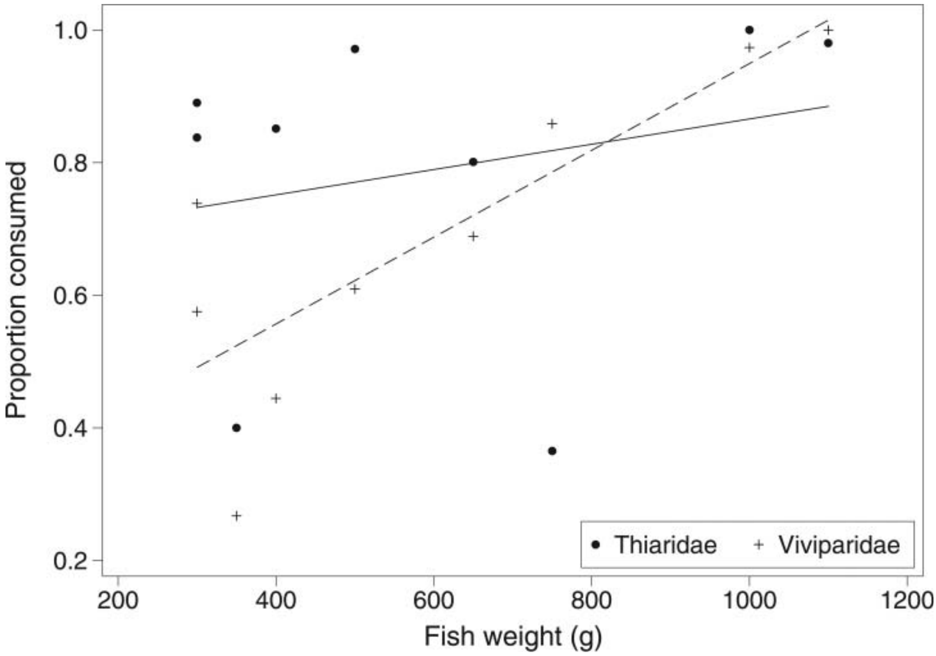

Figure 3. Consumption as proportion of weight of thiarid ($y = 0.00019 \times \text{weight} + 0.6751$; $r^2 = 0.0572$; p not significant) and viviparid ($y = 0.00065 \times \text{weight} + 0.29486$; $r^2 = 0.6694$; $p < 0.01$) snails added by individual black carp ($n = 9$) in cement tanks over 14 days.

This is probably because larger fish were food limited in these trials (Figure 2b). The proportion of viviparid snails consumed was linearly related to fish weight (Figure 3), while this was not the case for thiarid snails; thus the smaller fish fed relatively more on thiarid snails than did the larger fish.

Prey selection

The characteristics of the black carp used in this trial are summarized in Table 1 and the overall consumption of snails of the various species and size classes is summarized in Table 2. All *B. fuchsiana* specimens were consumed while the proportion consumed of the other three species, *M. tuberculata*, *A. polyzonata*, and *S. aeruginosa* declined with increase in size (Table 2). Some of the size classes for these three snail species were poorly represented, and therefore, were pooled with the adjoining size class for the subsequent analysis. The snail consumption by the three sizes of black carp is shown by snail size class in Figure 4.

Small black carp consumed 91.6% of the smallest *M. tuberculata* specimens (11–15 mm); they consumed 50.4% of *M. tuberculata* in the second largest size class (26–30 mm) and 19% of the largest size class. For medium-sized black carp, 49.6% of the largest *M. tuberculata* size class was consumed, while most of the snails in the other size classes were consumed. The ‘large’ black carp used with *M. tuberculata* were smaller than those used for viviparid snails, yet they consumed 75% of the largest size class (>30 mm). Logistic regression showed that the odds of *M. tuberculata* being consumed compared to this group declined with an increase in snail class ($p < 0.001$), while

Table 1. Characteristics of the black carp specimens used in the four-prey selection trials.

Size class	*M. tuberculata*	*B. fuchsiana*	*A. polyzonata**	*S. aeruginosa**
Number of black carp used				
Small	23	2	25	9
Medium	33	6	22	10
Large	8		23	19
Weight range (g)				
Small	100–250	120	100–250	100–250
Medium	260–590	260–600	270–600	260–600
Large	610–620		610–1250	610–1250
Length range (mm)				
Small	155–210	165–170	150–220	150–220
Medium	210–350	210–360	210–370	215–355
Large	360–365		320–455	320–455
Gape width (mm); estimated				
Small	12–16	13–13	12–17	12–17
Medium	16–26	16–26	16–27	16–26
Large	26–27		24–33	24–33

*Includes trials where the two viviparid species were tested together in the same aquarium.

consumption of small snails by the two larger fish size classes did differ significantly (Table 3). There was, however, a significant interaction ($p < 0.001$) between fish size class and snail size class. Thus, the larger fish (just over 600 g, see Table 1) consumed more of the larger size classes (i.e., in the range of 21–30 mm), while smaller and the largest size classes appeared to be less consumed (Figure 4). Gape size of medium and large fish used in the trial with *M. tuberculata* was substantially greater than the largest shell diameter of *M. tuberculata* (about 11 mm), while the smaller black carp had estimated gape widths of 12–16 mm. Thus, the largest *M. tuberculata* could be too large for small black carp to manipulate and also they might be too hard to crush.

Small black carp consumed 84.5% of the small (<16 mm) *A. polyzonata* and the odds of this snail species being consumed relative to the smallest size category declined significantly ($p < 0.001$) with snail size and increased ($p < 0.001$) with the size of the black carp. The interaction between size class of *A. polyzonata* and black carp size was not

Table 2. Number of snails of various species and sizes used in experiments and the overall proportion consumed by black carp.

	M. tuberculata		*B. fuchsiana*		*A. polyzonata*		*S. aeruginosa*	
Size class (mm)	No. tested	Proportion consumed	No. tested	Proportion consumed	No. tested	Proportion consumed	No. tested	Proportion consumed
<10			400	1.00	12	0.75	6	0.67
10–15	773	0.93			417	0.92	202	0.72
16–20	918	0.84			480	0.81	437	0.55
21–25	700	0.85			496	0.65	136	0.29
26–30	327	0.77			281	0.49	57	0.14
>30	482	0.42			114	0.18	2	0.50

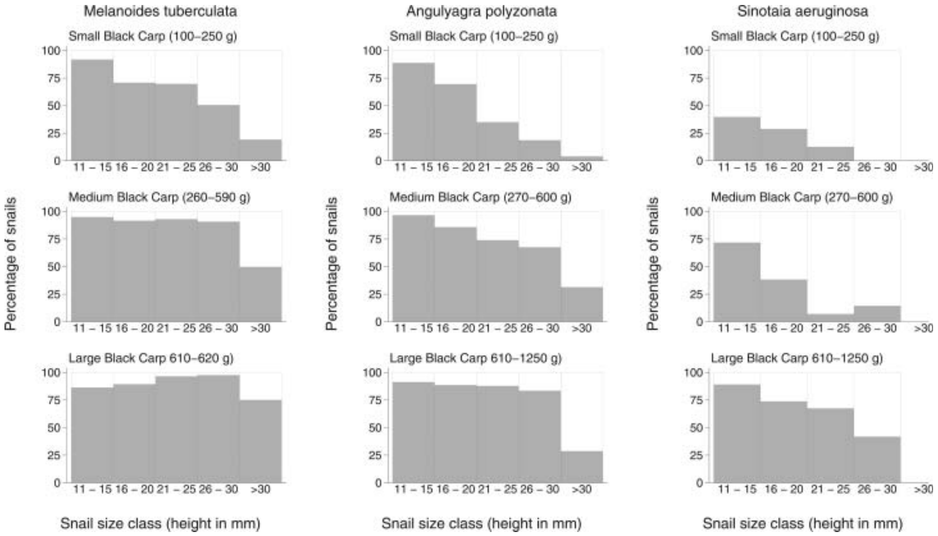

Figure 4. Percentage of snails of various species and size classes consumed (gray columns) by different size classes of the black carp. The size class <11 mm is excluded as this class could not be tested for all species (not available).

significant. The estimated gape width of small black carp (12–17 mm) showed that large-sized *A. polyzonata* (up to about 21 mm in diameter) would be too large for this size class of black carp to handle. The largest three size classes from shell diameter 15–21 mm could be problematic, although the fishes managed to consume some of them.

Small black carp consumed 39.6% of the smallest size class of *S. aeruginosa* and the odds of a snail being consumed declined with increasing size class ($p < 0.001$) and

Table 3. Odds of snails of different species and sizes being consumed by black carp of different sizes; the reference group is small black carp feeding on small sized snails.

Size class (shell height in mm)	Shell diameter (mm)	Small fish	Medium fish	Large fish
Melanoides tuberculata				
10–15	3.8–5.5	1.00	1.67	0.58
16–20	5.5–7.1	0.22	1.01	0.76
21–25	7.1–8.8	0.21	1.20	2.47
26–30	8.8–10.5	0.09	0.89	3.57
>30	>10.5	0.02	0.09	0.27
Angulyagra polyzonata				
10–15	9.7–12.4	1.00	4.88	7.40
16–20	12.4–15.1	0.31	1.50	2.28
21–25	15.1–17.9	0.12	0.57	0.86
26–30	17.9–20.6	0.07	0.32	0.48
>30	>20.6	0.01	0.06	0.10
Sinotaia aeruginosa				
10–15	8.7–12.0	1.00	3.86	12.35
16–20	12.0–15.3	0.61	0.94	4.28
21–25	15.3–18.6	0.22	0.11	3.15
>26	18.6–21.9	<0.01	0.25	1.09

increasing fish size ($p < 0.05$). There was, however, a significant interaction between snail size class and fish size class ($p < 0.001$). The trial with the two viviparid species tested together showed that the odds of *S. aeruginosa* being consumed was 0.63 of that of *A. polyzonata* ($p < 0.05$) when adjusting for snail size class, fish size class, and the interaction between these two factors ($p < 0.001$).

Crushing resistance

The characteristics of snails used in this experiment and linear regression between crush resistance and either shell height or shell diameter are summarized in Table 4. Except in *S. riquetti* and *A. polyzonata*, crush resistance ($\log_e$-transformed) was linearly related to shell size ($\log_e$-transformed). Crush resistance was very variable for most species probably because more populations were represented in each sample. For the thiarid snails, slopes of the regression lines did not differ significantly, but *T. granifera* had higher crush weight than *M. tuberculata* ($p < 0.001$), *S. riquetti* ($p < 0.001$), and *T. scabra* ($p < 0.01$). *M. tuberculata* and *S. riquetti* did not differ in crush resistance and *T. scabra* had lower crush resistance than both *M. tuberculata* ($p < 0.001$) and *S. riquetti* ($p < 0.01$). The crush resistance of *S. aeruginosa* increased with size while this was not observed for *A. polyzonata* but within the size range covered by both species, differences were not pronounced.

The relationship between crush resistance and shell size of the species used in the prey selection trial showed that *B. fuchsiana* had the lowest crush weight, while there was considerable overlap between *M. tuberculata* and the viviparid snails when using shell height as measure for size. Using shell diameter the size range covered by both groups was small and *M. tuberculata* was smaller than the viviparid snails, but crush resistance in *M. tuberculata* overlapping the viviparid was similar to that of the viviparid (Figure 5).

Table 4. Shell size range (height or diameter), crush weight range and slope, and intercept from linear regression analysis on $\log_e$(crush weight) and $\log_e$(shell size).

	No.	Shell size (mm)	Crush weight (kg)	Slope	Intercept	R^2	p values
Shell height							
Bithynia fuchsiana	61	6.2–10.6	0.8–6.7	2.57	2.19	0.47	<0.001
Tarebia granifera	11	14.3–41.1	14.2–59.0	0.93	7.18	0.63	<0.01
Sermyla riquetti	15	11.9–23.7	4.5–17.4	1.06	6.04	0.23	n.s.
Thiara scabra	65	9.0–24.3	4.8–22.0	0.66	7.44	0.29	<0.001
Melanoides tuberculata	152	6.5–39.6	2.3–31.6	1.10	5.97	0.48	<0.001
Angulyagra polyzonata	121	13.8–32.5	6.5–60.5	−0.18	10.32	0.00	n.s.
Sinotaia aeruginosa	63	10.1–32.1	12.3–68.3	0.64	8.36	0.18	<0.001
Shell diameter							
B. fuchsiana	61	4.9–6.2	0.8–6.7	5.85	−2.35	0.47	<0.001
T. granifera	11	5.3–15.7	14.2–59.0	0.91	8.11	0.63	<0.01
S. riquetti	15	5.1–8.1	4.5–17.4	1.57	6.12	0.23	n.s.
T. scabra	65	4.5–10.8	4.8–22.0	0.74	7.78	0.29	<0.001
M. tuberculata	152	2.3–13.4	2.3–31.6	1.13	7.09	0.48	<0.001
A. polyzonata	121	11.2–21.4	6.5–60.5	−0.24	10.44	0.00	n.s.
S. aeruginosa	63	8.1–22.6	12.3–68.3	0.71	8.36	0.18	<0.001

Note: n.s.- not significant.

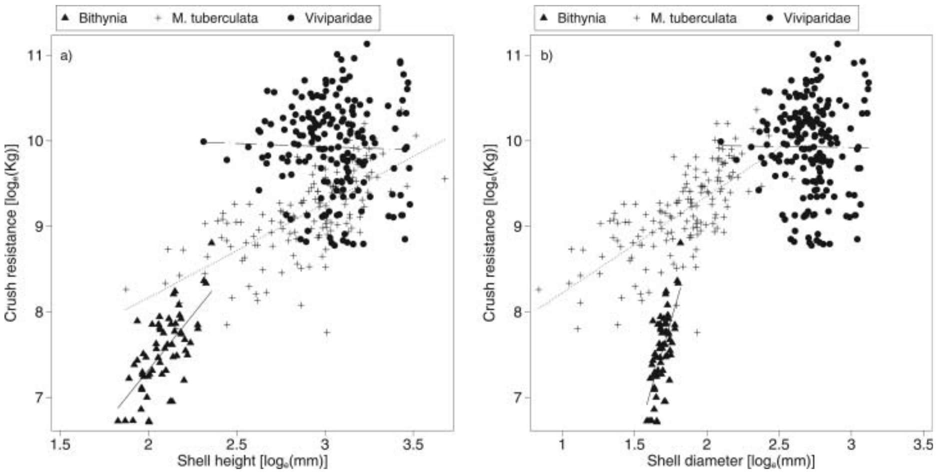

Figure 5. Crush resistance of *Bithynia fuchsiana*, *Melanoides tuberculata*, and the pooled data for *Angulyagra polyzonata* and *Sinotaia aeruginosa* in relation to shell height (a) and shell diameter (b).

Discussion

Small black carp mostly fed on *M. tuberculata*, with even small (100–250 g) fish consuming fairly large specimens (>30 mm). *M. tuberculata* is the primary host for intestinal trematodes in aquaculture ponds i.e., mainly *Haplorchis* spp., *Stellantchasmus falcatus*, and *C. formosanus* (Phan et al. 2010a). The black carp is primarily molluscivorous and most fish ponds have a dense population of viviparid snails, in particular, *A. polyzonata*. Since this species is also consumed by black carp, it could switch to feeding on these snail species if *M. tuberculata* becomes scarce. The intermediate hosts of *C. sinensis, B. fuchsiana*, and *Parafossarulus manchouricus* are readily consumed by even the smallest (about 120 g) black carp. The bithynid snails are not commonly found in the majority of fish ponds, but occasionally occur at relatively high density.

The tall and slender shell shape of *M. tuberculata* makes it more vulnerable to predation by black carp, which has a comparatively small mouth opening (gape width) while the larger specimens of *A. polyzonata* have refuge from predation. When the black carp reach a size where they can manipulate them in their buccal cavity, however, they can also exert sufficient pressure to crush the shell. Occasionally, we found shells where the black carp had only been able to cause partial damage.

Small black carp fed primarily on thiarid snails, whereas larger ones tended to consume more viviparid snails. This could be partly related to the shell strength relative to the energy gain. Thus, Brodersen et al. (2003) showed that *Sargochromis codringtoni* consumed *Bellamya capillata* specimens with relatively low energetic cost/benefit (C/B) ratio. Also for the redear sunfish, *L. microlophus*, low energetic C/B ratio was found to be the best determinant for snail selectivity (Stein et al. 1984). Other experiments have indicated that handling time is also important for snail size selectivity by fish (Slootweg 1987). Relative abundance of the different snail species would be another determinant of food selection (Evers et al. 2006).

The thiarid species, which all seem to serve as intermediate hosts for intestinal trematodes differ in their shell strength. *T. granifera* has the strongest shell and this probably is due to its thicker shell. A shell's strength is typically correlated with its size (Miller and

LaBarbera 1995; Cote et al. 2001), but the correlation with its thickness is stronger (Zuschin and Stanton 2001).

Shell shapes also profoundly affect strength and resistance against lethal breakage. This factor is not well understood because comparing shells of distinctly different shapes is very difficult (Currey 1988). In gastropods, globular compact shapes are more resistant against crushing than loosely coiled ones (Vermeij 1983; Palmer 1990a, 1990b; Savazi 1991). The presence of an umbilicus decreases the strength of shell (Palmer 1983).

The implication of our findings is that black carp of relatively small size (100–200 g) should be used for the control of the intermediate host snails of FZT because this size class would feed primarily on snails with small shell diameter. This size class of black carp can handle most of the size ranges available in *M. tuberculata* populations. Although it may be possible to control snails in aquaculture ponds by pond management, this may not be sufficient for controlling infections in fishes because ponds may interact with the surrounding habitats such as small canals and rice fields (Clausen et al. 2012b). Thus, we also recommend that the possibility of stocking surrounding habitats, especially small canals, with black carp should be further explored. This, however, would require very strong community collaboration as the small canals are commonly targeted for fishing. The chances of success would be increased if this could be seen as part of the production system as the black carp is a valued fish for human consumption.

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