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ORIGINAL PAPER

Biological control of snail hosts transmitting schistosomiasis by the water bug, *Sphaerodema urinator*

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Abstract The water bug, *Sphaerodema urinator* (Hemiptera : Belostomatidae), shares the same habitat of the freshwater snails in ponds, lakes, and streams. Studies conducted in lakes show that fish and crayfish predators play an important role in determining the abundance of freshwater snails. In contrast, shallow ponds and marches often lack fish and crayfish but have abundant insect predators. This study has been carried out to evaluate the predatory potential of *S. urinator* adult on two freshwater snails that serves as intermediate hosts of *Schistosoma*. Laboratory evaluation of predation by *S. urinator* on these intermediate hosts revealed that the adult bug could kill and consume the two intermediate hosts: *Bulinus truncatus* and *Biomphalaria alexandrina*. The number of snails consumed differed according to the snail type, size, and density. The times taken for searching and handling times were depending on the snail size, type, and vulnerability of the predator. The predation rate varied also with respect to snail type and density. Prey size is a major factor influencing predator preferences. This study indicated that the predator, *S. urinator*, may be a suitable bio-control agent in connection with *Schistosoma* intermediate hosts in the aquatic area.

Keywords Freshwater snails · Schistosomiasis · Water bug · Predator

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Introduction

Many species of freshwater snail in the family Planorbidae are intermediate hosts of *Schistosoma* species which cause schistosomiasis in Africa, Asia, and the Americas. Schistosomiasis is an endemic parasitic disease estimated to affect more than 200 million people around the world, causing high levels of morbidity and mortality in 74 countries in the tropical and subtropical areas (Rollinson et al. 2013). The freshwater gastropods are intermediate hosts of those trematodes. Snail habitats include almost all types of freshwater bodies ranging from small temporary ponds and streams to large lakes and rivers. In general, the aquatic snail hosts of *Schistosoma* occur in shallow water near the shores of lakes, ponds, marshes, streams, and irrigation channels. They live on water plants and mud that is rich in decaying organic matter (Rondelaud et al. 2011; Fu and Meyer-Rochow 2012). Schistosomiasis is one of the most widespread of all human parasitic diseases, ranking second only to malaria in terms of its socioeconomic and public health importance in tropical and subtropical areas. The trematode parasites, *Schistosoma mansoni* Sambon 1907 and *Schistosoma haematobium* Bilharz 1852, cause schistosomiasis. The intermediate hosts of these parasites are the freshwater snail, *Bulinus truncatus* Audouin 1827 and *Biomphalaria alexandrina* Ehrenberg 1831, respectively.

Snail control strategies are considered a priority for the reduction of transmission. Snails can be controlled indirectly by reducing their habitat or directly by killing them. Synthetic molluscicides (Niclosamide) have been widely used for chemical control (Jaiswal and Singh 2008), although chemical control gives only temporary reduction snail density. The biological methods, especially those involving the use of indigenous predators, were traditionally perceived as environmentally friendly and have been the foci of research and management of these pests (Suhardono et al. 2006). Predators in nature often include an array of the prey type; they often select certain prey types over others (Saha et al. 2014). Predation is a major force affecting species abundance, population dynamics, and community structure (Saha et al. 2009). The possibility of controlling freshwater snails biologically has attracted some attention in recent years (Younes et al. 2015; Younes et al. 2016). Hemiptera is a group of about 40,000 species of insects, sometimes called "True Bugs." Belostomatidae (water bugs) are particularly important and widespread generalist predators in freshwater systems which play a major role in shaping the structure and the abundance of prey species population (Leon 1998; Gilbert and Burns 1999; Hampton et al. 2000). Belostomatidae most commonly occur in the lakes, ponds, and marshes and can be found in temporary pools and ditches (Gulati 2012). In view of this, the present study aimed at evaluating the predation potential of the predatory aquatic insect *Sphaerodema urinator* Dufor 1863 (Hemiptera : Belostomatidae) on the schistosomiasis intermediate freshwater snails. The searching behavior of the predator towards the two different snail types and sizes was also measured. The results of the present study will provide a primary basis for assessment of this predator as biological resources against freshwater snails.

Materials and methods

Collection of the water bug

The water bug, *S. urinator*, adults were collected from ponds and lakes in the Giza governorate (29° 54` N, 31° 15` E). They were kept in glass aquaria (50, 30, and 20 cm in length, width, and height), respectively, fed daily to satiation on different sizes of the freshwater snails. Only the adult predators were used in the experiments. The belostomatid predators were starved for a period of 24 h before the start of the experiments.

Collection of snails

The experimental snails, *B. truncatus* and *B. alexandrina*, were collected from lakes and ponds in the Giza governorate. They were kept in a glass aquarium (50, 30 and 20 cm in length, width and height, respectively), filled with pond water up to 15 cm of height for a period of 1 week prior to the start of the experiment. The snails were provided with fresh or dried lettuce leaves as basic food. Fish food (Tetramin®) and blue green algae (*Nostoc muscorum*) were used as an additional food source for newly hatched and juvenile snails. Only laboratory-bred snails were used in experiments. Additionally, some water plants (*Ceratophyllum demersum* and *Elodea* sp.) were placed in the aquaria to simulate natural conditions. Small-, medium-, and large-sized snails measuring 2–5, 6–9, and 10–13 mm in shell height or width for *B. truncates* snail and *B. alexandrina* snail, respectively, were used in the experiments.

Experimental methods

Ten glass aquaria, each 5 L in volume, containing 3 L of pond water were used in each experiment. The experimental group was comprised of five glass aquaria, each containing a predator and experimental snails. The remaining five glass aquaria constituted the predator-free control replicates. The aquaria were covered with a nylon mosquito net to prevent possible snail escape. Snails that may leave the water and sit on the aquarium wall were not considered and deleted from the count. The snails were allowed to acclimatize for 1 h before introducing the predator. In the first experiment, only one snail species was offered to the predator. Individual predators and prey were used only once in the experiments. All experiments were carried out at constant temperature of (25 ± 2) °C and

Table 1 Searching and handling times of the predator, *S. urinator* adult, towards the freshwater snails, *B. truncatus* and *B. alexandrina*

Behavior	Adult condition	Snail types		
		B. truncatus	*B. alexandrina*	*P* value
Searching time (min)	Starved	4.8 ± 0.86 a	9.4 ± 1.1 b	0.0103
	Satiated	6 ± 0.7 a	13 ± 1.3 b	0.0015
	P value	0.312	0.0659	
Handling time (min)	Starved	24.8 ± 1.4 a	11.8 ± 1.3 b	0.0001
	Satiated	29.4 ± 1.63 a	15.8 ± 1.42 b	0.0002
	P value	0.0643	0.0706	

Means in the same row, followed by the same letter are not significantly different ($P < 0.05$)

60%–70% Relative Humidity. Fluorescent tubes (10 cm long, 32 watt) were placed 100 cm above the tanks to provide a photo period of L12: D12.

Searching and handling time

Predator and prey behaviors were quantified during a continuous 60-min period. Foraging behaviors (searching and handling prey) for both starved and satiated predators were quantified. Handling time per prey was calculated as the total time taken to manipulate a single prey item, from encounter to the end of consumption. Encounters between predators and preys, and the outcomes of the encounters, were also quantified. Encounters with prey could result in attacking, avoidance or consumption of prey. Each trial involved introducing an individual adult into the experimental glass aquaria filled with clear pond water and containing 10 live snails of one of the two different snail species. Each predator was tested only once and the large-sized snails were used in determining the searching and handling times.

Effect of prey density on the consumption and predation rate

One adult of *S. urinator* was placed in each aquarium with small-, medium- or large-sized snails of *B. truncatus* or *B. alexandrina* at densities of 5, 10, 15, 20 or 25 snails for a period of 24 h. Five replicates for each prey density / prey size / prey type were performed to determine the mean number of prey consumed / day and subsequently the predation rate.

Prey size preference

Two sets of experiments were conducted to determine how prey size is influenced. In the first set of experiments (dual-choice preference), each individual predator was supplied with two different prey sized snails from the same prey type, i.e. (small and medium), (small and large) and (medium and large) *B. truncatus* or *B. alexandrina* snail. Ten individuals of each size class were added to the aquarium, resulting in a total of 20 snails / predator. In the second set of experiments (three-choice preference), preference was examined when all the three snail sizes (small-, medium- and large) were offered. In this set of experiments, each predator individual was supplied with 30 preys (ten from each snail size). After 24 h, the numbers of snails consumed were recorded separately. Prey preference was subjected to the analysis of selectivity following Rehage et al. (2005); an equivalent to Manly's index.

$$S_i = W_i / \sum_{j=1}^{m} W_j$$

Where S_i = equivalent to Manly's index for prey type (i); W_i= proportion of prey (i) consumed at the end of the experiment relative to the original input. $\sum W_j$= total proportion of all prey types consumed (i = 1, 2,…m); and m = number of prey types. Manly's index can take the value between zero and one, and the values of the different prey types always sum up to one. In case of dual-choice combination, the threshold value is 0.50 while in case of three-choice combination, the threshold value is 0.33 ($S_i = {}^{1}/_{m}$). Values higher than the threshold value are indicated selectivity against it.

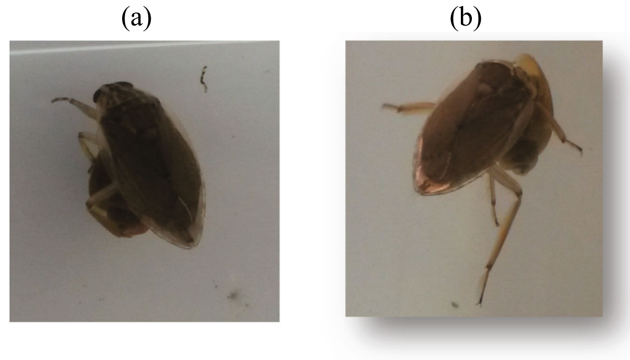

Fig. 1 Foraging behavior of the predator, *S. urinator* adult, towards the freshwater snail, *B. truncatus*. **a** Encounters **b** Devour

Table 2 Forage behavior of the predator, *S. urinator* adult towards *Schistosoma* intermediate hosts, *B. truncatus* and *B. alexandrina* snails

Behavior	Snail types		
	B. truncatus	*B. alexandrina*	*P* value
No. of encounter	70 ± 7.1 a	58 ± 4.64 a	0.1936
Encounter rate (no./min.)	1.2 ± 0.12 a	0.96 ± 0.08 a	0.1929
No. of attack/encounter	0.31 ± 0.005 a	0.29 ± 0.05 a	0.6913
No. of avoided/encounter	0.68 ± 0.01 a	0.70 ± 0.05 a	0.6831
Preying/encounter	0.02 ± 0.01	0.11 ± 0.01 a	0.536

Means in the same row followed by the same letter are not significantly different ($P < 0.05$)

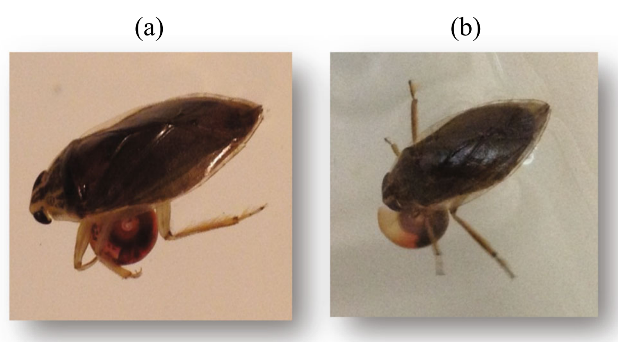

Fig. 2 Foraging behavior of the predator, *S. urinator* adult, towards the freshwater snail, *B. alexandrina*. **a** Encounters. **b** Devour

Table 3 Effect of *B. truncatus* snail density on the consumption rate of the predator, *S. urinator* adult

Prey size	Daily number of preys consumed (Mean ± SEM) at prey density				
	5	10	15	20	25
Small	3.8 ± 0.4 a	8 ± 0.31 a	12 ± 0.7 a	15.6 ± 1.03 a	17.2 ± 0.9 a
Medium	2.4 ± 0.24 b	3.6 ± 0.51 b	5.6 ± 0.51 b	8.6 ± 1.07 b	9.2 ± 1.02 b
Large	1.0 ± 0.32 c	1 ± 0.45 c	1.6 ± 0.51 c	2.2 ± 0.58 c	1.6 ± 0.4 c
P values	0.0002	<0.0001	<0.0001	<0.0001	<0.0001
F	19.6	67.07	80.94	52.64	94.1

Means followed by the same letter in the same column are not significantly different ($P < 0.05$)

Data analysis

Data considering searching, handling times, foraging behavior, prey consumption, and predation rate were expressed as mean ± SE. The comparison between three or more different groups was analyzed using one-way ANOVA. The correlation between prey density and predation rate was determined using regression analysis. Contingency table analysis (chi-square test) to compare frequency of encounter outcomes for each snail type is represented. Data were analyzed using GraphPad InStat software (2009). An alpha value of 0.05 was used to determine the significance.

Results

Searching and handling times

The predator, *S. urinator* adult, shows clear differences in searching and handling times towards the two snail types (Table 1). The results show that searching times significantly differed in both starved and satiated predator individuals comparing the search time of the predator towards the two snail types. The obtained data shows that the predator required more time in searching for the *B. alexandrina* snail and less time in searching for the snail, *B. truncatus*. The maximum searching time (13 ± 1.3 min) was obtained by the predator towards *B. alexandrina* when the predators were satiated while the minimum searching time (4.8 ± 0.86 min) was obtained with the snail *B. truncatus* when the predators were starved. For, the handling time, statistically, significant differences ($P < 0.05$) were obtained in the handling time of the predator towards the two snail types. Handling time of the starved predators towards the snails was (24.8 ± 1.4) and (11.8 ± 1.3) min, concerning *B. truncatus* and *B. alexandrina* snails, respectively. A similar relationship was also obtained with the handling time of the satiated predator, obtained handling times were (29.4 ± 1.63) and (15.8 ± 1.42) min, considering *B. truncatus* and *B. alexandrina* snails, respectively. Comparing searching time or handling time of starved and satiated predator, no significant differences ($P < 0.05$) were obtained in both searching and handling times of the predators towards the two different snails. These results indicate that starved and satiated predators have the same behavior towards the snails (Table 1).

Encounter between the predator, *S. urinator* adult, and the preys, *B. truncatus* and *B. alexandrina* snails

Data in (Table 2) and (Figs. 1 and 2) show the encounter behavior of the predator, *S. urinator* adult, towards the *Schistosoma* intermediate hosts. Most observed encounters with snails ended in avoiding the preys before preying or attacking it. The maximum number of encounters was obtained with *B. truncatus* snail while the encounter number recorded with the *B. alexandrina* snail was the lowest. Statistically, no significant differences ($P > 0.05$) were obtained considering the encounter, the encounter rate (no./min), attack/encounter, avoided/encounter also predation rate/encounter. The obtained attacking rates (no. of attack/encounter) were

Table 4 Effect of *B. alexandrina* snail density on the consumption rate of the predator, *S. urinator* adult

Prey size	Daily number of preys consumed (Mean ± SEM) at prey density				
	5	10	15	20	25
Small	2.4 ± 0.24 a	6 ± 0.32 a	9.6 ± 0.51 a	12.6 ± 0.66 a	12.6 ± 1.07 a
Medium	1.2 ± 0.32 b	1.4 ± 0.24 b	2.8 ± 0.37 b	5.8 ± 0.86 b	5.2 ± 0.58 b
Large	0.4 ± 0.24 c	0.4 ± 0.24 c	0.6 ± 0.4 c	0.6 ± 0.4 c	0.4 ± 0.24c
P values	0.0007	<0.0001	<0.0001	<0.0001	<0.0001
F	14.36	121.63	117.93	75.58	72.64

Means followed by the same letter in the same column are not significantly different ($P < 0.05$)

Table 5 Regression analysis of the effect of *B. truncatus* snail density on the predation rate of the predator, *S. urinator* adult

Snail size	Slope	(*r*)	*P* value
Small	−0.328	−0.558	0.328
Medium	−0.368	−0.612	0.273
Large	−0.51	−0.803	0.102

Regression analysis based on the men predation rate (n = 5 sets/prey density)

(0.31 ± 0.005) and (0.29 ± 0.05) considering *B. truncatus* and *B. alexandrina* snails, respectively. In case of the avoiding, the rate of (0.68 ± 0.01) *B. truncatus* snail was avoided while the rate of (0.70 ± 0.05) *B. alexandrina* snail was avoided. The preying rates (preying/encounter) were (0.02 ± 0.01) and (0.11 ± 0.01) considering *B. truncatus* and *B. alexandrina* snails, respectively.

Prey consumption and predation rate

(Tables 3 and 4) show the effect of prey densities on the number of preys consumed for snail species, *B. truncatus* and *B. alexandrina*. Obtained data shows that the predator could consume a mean of (17.2 ± 0.9), (9.2 ± 1.02), and (1.6 ± 0.4) individuals of *B. truncatus* snails/day with the snail density of 25 individuals conceding the small-, medium- and large-sized snails, respectively. Subsequently, *S. urinator* adult consumed a mean of (12.6 ± 1.07), (5.2 ± 0.58) and (0.40 ± 0.24) individuals of *B. alexandrina* snails/day at the same density considering small-, medium-, and large-sized snails, respectively. Statistically, significant differences were obtained ($P < 0.05$) in comparison the prey consumed of small-, medium-, and large-sized *B. truncatus* snail at the same density. The predator could consume (3.8 ± 0.4), (2.4 ± 0.24), and (1.0 ± 0.32) preys of small-, medium-, and large-sized *B. truncatus* snail at density of five preys, respectively. On the other hand, the predator could consume (2.4 ± 0.24), (1.2 ± 0.32), and (0.4 ± 0.24) individuals of small-, medium-, and large-sized *B. alexandrina* snail per day at the same density, respectively. Comparing the preys consumed at density 5, 10, 15, 20, and 25 individuals/day, significant differences ($P < 0.05$) were obtained between

Table 6 Regression analysis of the effect of *B. alexandrina* snail density on the predation rate of the predator, *S. urinator* adult

Snail size	Slope	(*r*)	*P* value
Small	0.116	0.130	0.835
Medium	0.332	0.483	0.411
Large	−0.276	−0.916	0.029

Regression analysis based on the men predation rate (n = 5 sets/prey density)

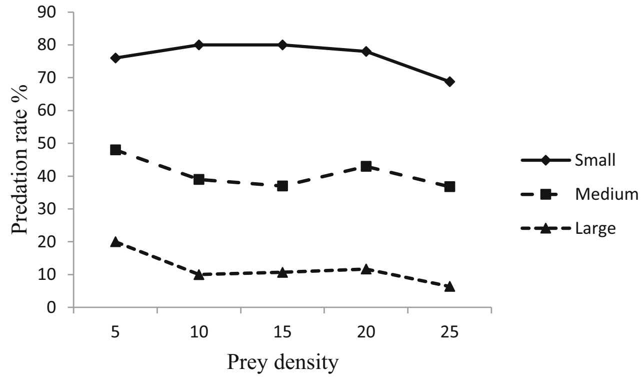

Fig. 3 Predation rate of *S. urinator* adult on the freshwater snail, *B. truncatus*

small-, medium-, and large- sized snails considering *B. truncatus* snail and *B. alexandrina* snail. The predation rate of *S. urinator* adult towards *B. truncatus* and *B. alexandrina* snail species at the different densities are shown in (Figs. 3 and 4) and (Tables 5 and 6). The regression analysis showed that no significant differences ($P > 0.05$) in the predation rate of *S. urinator* towards *B. truncatus* (r = −0.558, −0.612, and −0.803 with P values = 0.328, 0.273, and 0.102) considering small-, medium-, and large-sized *B. truncatus* snail, respectively. Linear regression analysis also showed that by increasing the density of *B. alexandrina* snail from 5 to 25 individuals, no significant differences in the predation rate could be obtained (r = 0.130, 0.483 and −0.916 with P values = 0.835, 0.411, and 0.029 considering small-, medium-, and large-sized *B. alexandrina*, respectively, as shown in (Tables 5 and 6).

Prey preference

Dual-choice preference

When given the choice, the water bug, *S. urinator* adult, consumed more individuals of small- sized than medium- or large-sized *B. truncatus*. Preference indexes obtained were

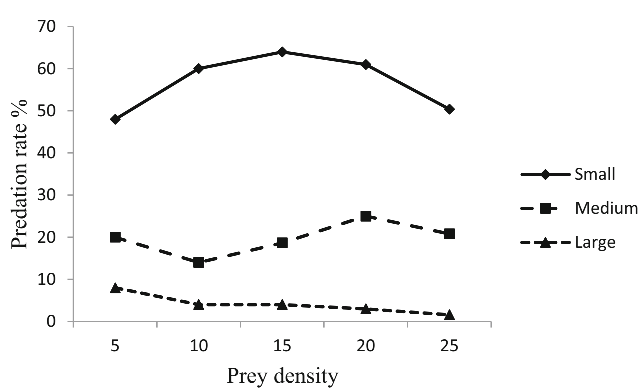

Fig. 4 Predation rate of the *S. urinator* adult on the freshwater snail, *B. alexandrina*

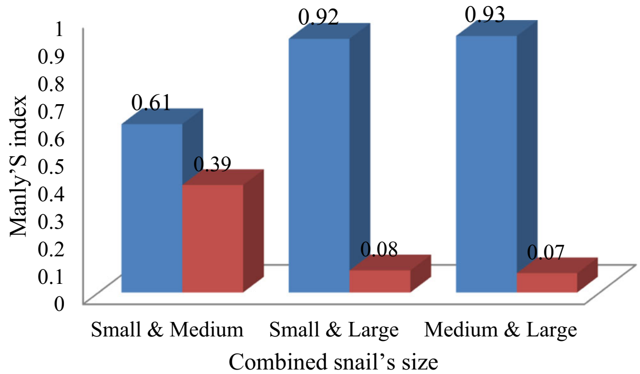

Fig. 5 Mean value of Manly's preference index for *S. urinator* adult towards the freshwater snail, *B. truncatus* (dual-choice preference)

(0.61 and 0.39), (0.92 and 0.08), and (0.93 and 0.07) considering the dual choice of (small and medium), (small and large), and (medium and large), respectively. The same result was obtained with *B. alexandrina* snail. The obtained preference indexes were (0.88 and 0.12), (1.0 and 0.0), and (1.0 and 0.0) considering the dual choice of (small and medium), (small and large), and (medium and large) *B. alexandrina* snail, respectively. Obtained preference index showed that *S. urinator* adult preferred consumption of one prey from the two exposed as are shown in (Figs. 5 and 6).

Three-choice preference

Figures 7 and 8 show preference tests with starved water bug, *S. urinator* adult, when the three-prey snail sizes were offered in combinations. The predator adult preferred small-sized *B. truncatus* snail than the two other sizes. The obtained Manly's preference indexes were (0.75, 0.25, and 0.0), considering small-, medium-, and large-sized *B. truncatus* snail, respectively. The same results were obtained with *B. alexandrina* where the Manly's preference indexes obtained were (0.66, 0.34, and 0.0) considering small-, medium-, and large-sized snail, respectively.

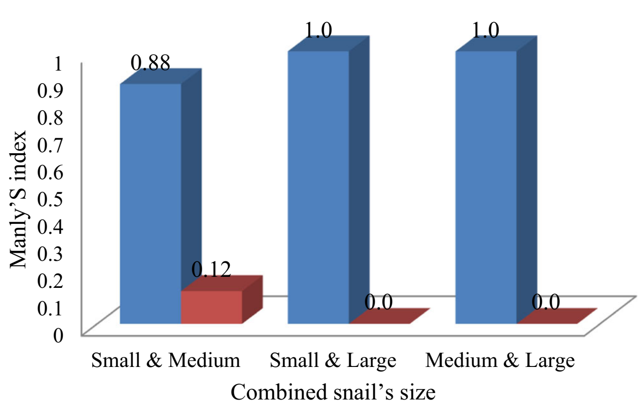

Fig. 6 Mean value of Manly's preference index for *S. urinator* adult towards the freshwater snail, *B. alexandrina* snail (dual-choice preference)

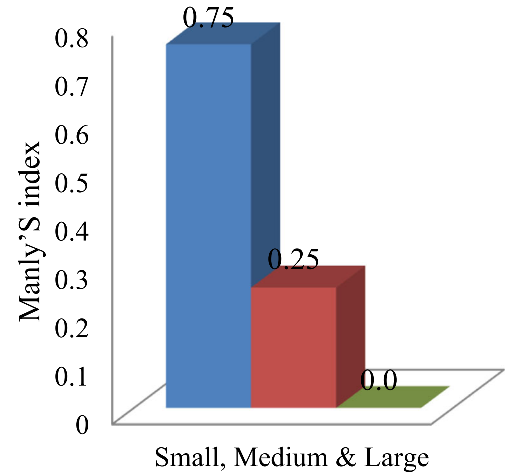

Fig. 7 Mean value of Manly's preference index for *S. urinator* adult towards the freshwater snail, *B. truncatus* (three-choice preference)

Discussion

Predation is a major force affecting species abundance, population dynamics and community structure (Sih 1987; Lima and Dill 1990). Also, predation influences the evolution of prey characteristics such as morphology, physiology, chemistry, life history or behavior (Alexander and Covich 1991; Chivers and Smith 1998). The nature of interactions between predators and their prey are important because they determine: which prey is sought by predators, how prey are captured and processed by the predator, and ultimately, the effect of predation on prey abundance and population dynamics (Taylor 1984). Predator searching efficiency is another important determinant of the predation rate, and it should decline with increasing use of refuges by prey; otherwise, density-dependent predation at low prey density may not

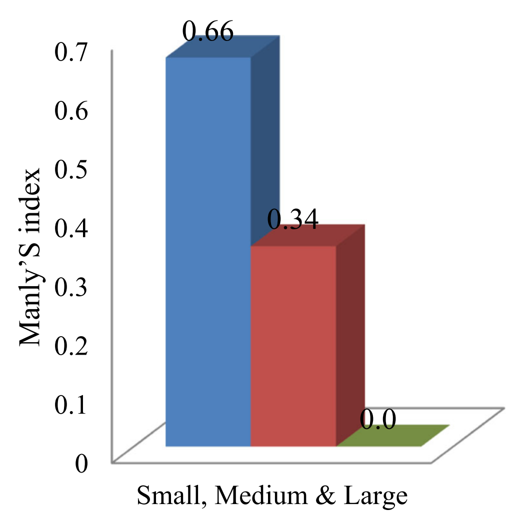

Fig. 8 Mean value of Manly's preference index for *S. urinator* adult towards the freshwater snail, *B. alexandrina* (three-choice preference)

occur (Hassell 1978). The starved predators require shorter time in attacking (searching) and handling time towards the preys in comparison with the satiated predators. Searching and handling times are major factors in the determination of the functional response of the predator to its prey and should predict how the predators behave when different prey species are presented (Turner 2008). Fincke et al. (1997) and Yanoviak (2001) indicated that successful biological control depends on the use of native predators that share the same habitat and are a part of the natural food web. Water bugs mainly feed on juice of insects, snails, small fishes, and tadpoles (Saha and Raut 1992). It has a predacious nature and the ability to feed on a large number of snails which formed the intermediate hosts of parasitic helminthes. Because the water bug, *S. urinator*, is an active swimmer, it could assess prey density on the basis of encounter rate with prey as has been suggested for Dytiscidae (Younes 2008). The predator may distinguish between preys of differing profitability and select the more profitable prey. Prey-predator attributes that affect selection involve the encounter rate with a particular prey type, probability of attack given in an encounter, probability of capture given an attack, and probability of ingestion in a capture (Sih 1982). The present study reveals that the adult water bug *S. urinator* can consume a good number of *B. truncatus* and *B. alexandrina* snails and thus can significantly reduce the population of snails. Though the number of small- or medium-sized snails consumed per day was quite higher than the large-sized one, it remains a question, still about the situation when all prey types will be equally available. Since, from the *S. urinator* viewpoint, capturing a small snail is an easier job involving less energy to carry from the water bottom to the water surface where the predator begins to feed. For aquatic predatory insects, ponds and temporary pools are habitats with ample heterogeneity with regard to spatial structures and abundance of prey species (Bambaradeniya et al. 2004). When ample prey species are available, structural complexity is more important in determining predator success. Furthermore, alternative prey may buffer the vulnerability of a preferred prey type. This will have an important consequence when freshwater snails and their natural predators are considered. Existing control methods are aimed principally at the management of snail populations that inhibit endemic areas. Alternative methods of snail control have been developed using different biological control agents. Our laboratory study on the adult water bug, *S. urinator* adult, showed that this predator has the ability to search, encounter, attack, and devour the examined snails. Determination of the daily prey consumed and the predation rate confirm the predatory efficiency of this predator against *B. truncatus* and *B. alexandrina* snails. Further field studies are required to determine the ability of these predators with the other control types in reducing the snail population.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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