Factors Influencing Predation of the Waterbugs *Sphaerodema annulatum* (Fab.) and *S. rusticum* (Fab.) on the Disease Transmitting Snail *Lymnaea (Radix) luteola* (Lamarck)

JK Roy, SK Raut

Ecology and Ethology Laboratory, Department of Zoology, University of Calcutta, 35 Ballygunge Circular Road, Calcutta 700 019, India

Variations in the rate of predation of the waterbugs Sphaerodema annulatum *and* S. rusticum *on the snails* Lymnaea (Radix) luteola *have been noted in respect to the morphs of the waterbugs, size of the prey individuals, densities of prey and predators, temperature and surface area of the waterbody concerned and the seasons. Consumption rate was highest (7.2 and 2.2 individuals per day per individual of* S. annulatum *and* S. rusticum, *respectively) in prereproductive ages of the waterbugs. This was followed by a gradual decline with the increase in age of the predators. The consumption rate was gradually higher with the increase of temperature from 20 °C to 35 °C. The bugs failed to survive beyond 35 days at 35 °C. Though the bugs prey upon the snails of all sizes preference for 6.5 x 4.5 mm to 8 x 5 mm individuals by* S. annulatum *and for 5 x 3 mm to 6.5 x 4.5 mm individuals by* S. rusticum *is established. The waterbugs, irrespective of species, consumed the snail individuals belonged to 3 x 2 – 4 x 3 mm size group maximum when supplied separately. The rate of predation gradually declined with the rise of predator's density irrespective of waterbug species.*

Predation rate increased with increasing prey density. This was level off when the prey snails were 1100 and 700 in number for S. annulatum *and* S. rusticum *respectively. An adult* S. annulatum *and* S. rusticum *consumed 5.04, 3.7, 1.43 and 3.36, 2.49, 1.04 snails per day respectively in summer, monsoon and winter.*

Key words: waterbug – snail – predation – India

Considering the severity of snail-borne diseases in man and his domestic animals (Chatterjee 1952, Thomas 1973, Malek & Cheng 1974) various attempts are being made to keep the density of the snail-host population below the effective level. In such attempts, though a good number of molluscicides are giving encouraging results (Levine 1970, Chu 1978, Godan 1983, Abebe 1991) we hesitate to recommend use of the same due to evolved environmental hazards. Obviously, natural enemies, especially the predators of snail-host species are taken into account. The biological agents involved with the reduction of snail populations are leeches (Chernin et al. 1956, Wright 1968, Raut & Nandi 1985), ostracods (Lo 1967), crayfishes (Deschiens & Lamy 1955), crabs (Deschiens et al. 1955), sciomyzid flies (Berg 1953, 1964), coleopterans (Maillard 1971), waterbugs (Somasundarao 1963, Voelker 1966, 1968, Hairston et al. 1975, Raut et al. 1988, Raut & Saha 1988, 1989, Saha & Raut 1991), and snails (Chernin et al. 1956, Radke et al. 1961, Demian & Lutfy 1966, Ruiz-Tiben et al. 1969, Jobin et al. 1970). Of these, waterbugs are considered most effective agents. Based on Voelker's (1968) findings the World Health Organization recommended field trials of the waterbugs *Limnogeton fieberi* Mayr. for controlling the snails *Biomphalaria glabrata* (Say) and *Physella acuta* Draparnaud (Hairston et al. 1975).

In India, occurrence of the waterbugs *Sphaerodema annulatum* (Fab.) and *S. rusticum* (Fab.) is well established. They feed voraciously on the individuals of the medically important snail species *Lymnaea (Radix) luteola* (Lamarck). They may well be employed in controlling these snails. Since successful biological control depends on the selection of a natural enemy having high degree of host specificity or preference, a good reproductive capacity relative to the host, and good adaptation to a wide range of environmental conditions (DeBach 1974) and also on the trends of population dynamics of both the natural enemy and the pest, and on realistic quantitative assessments of the impact of the natural enemy on pest populations (Bay et al. 1976) it is essential to have data on these aspects of the concerned species before consider-

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ing the same as biological control agents. Keeping all these facts in mind and taking into consideration the results of earlier studies (Raut 1981, 1982, 1986, 1988, 1989, Raut & Ghosh 1985, Raut & Nandi 1985, Raut et al. 1988, Raut & Saha 1988, 1989, Saha & Raut 1991), an attempt was made to study the effectiveness of the waterbugs *S. annulatum* and *S. rusticum* in controlling the snails *Lymnaea (Radix) luteola* under varying ecological conditions. As in nature, the predation is continued by the morphs of two species of waterbugs simultaneously, on the prey-snails of different sizes in different seasons, at a varying surface area of the water body having different depths and temperatures the role of these parameters in influencing the predation rate could not be rulled out. And, as such, all these factors have taken into account in the present programme of experimental studies under laboratory. The results of such studies would enable us to formulate the biological control programme in a more effective way.

MATERIALS AND METHODS

To meet up the requirement of waterbugs (*S. annulatum* and *S. rusticum*) and snails [*Lymnaea (Radix) luteola*] for experimental studies, they were reared in aquaria (60x20x45 cm in size) under laboratory conditions following the methods described by Raut & Saha (1989). As per programme the following experiments were designed to note the effect of certain factors on the rate of predation of the waterbugs concerned.

Experiment I: age of the waterbugs – In aquaria (60x25x45 cm) five zero-day old adult morph were regularly supplied with 100 snails throughout the life span.

Experiment II: water temperature – Ten zero-day old individuals of each morph of waterbugs were constantly supplied with 200 snails at 20, 25, 30, 35 °C constant temperatures maintained in B.O.D. chambers and at room temperatures (17.5-32.5 °C) throughout the duration of morphs. Plastic containers (22 cm in diameter and 8 cm in height) containing 1.5 l water were used.

Experiment III: prey (snail) size – In plastic containers (each 22x8 cm in size containing 2 l pond water) five waterbugs of prereproductive age group were regularly supplied with 100 snails of G_1 (3x2 - 4x3 mm), G_2 (5x3 - 6.5x4.5 mm), G_3 (6.5x4.5 - 8x5 mm) and G_4 (12x7 - 14x9 mm) size groups, in equal proportion for a period of seven days.

Experiment IV: height of water column – Fifteen adult waterbugs of same age were regularly supplied with 200 snails in aquaria (58 x 28 x 32 cm) contained water up to 10, 20 and 30 cm of the height for a period of seven days.

Experiment V: predator density – Five, 10, 15 and 20 adult waterbugs of same age were supplied with 200 snails regularly for a period of seven days at room temperatures (26-28 °C) in plastic containers (23 x 12 cm), each containing 3 l water.

Experiment VI: prey density – Ten adult waterbugs were supplied with 100, 200, 300 and so on, snail individuals in aquaria (60x25x45 cm), each containing water up to 25 cm of the height, until the threshold level of predation was determined, for a period of seven days.

Experiment VII: surface area – Five adult waterbugs were supplied with 100 snails in plastic containers having 594, 1188 and 2376 cm^2 water surface area for a period of seven days at room temperatures (27-28 °C).

Experiment VIII: season – In Calcutta, India, three seasons viz. summer, monsoon and winter are well marked. Five individuals of each morph of waterbugs were supplied with 100 snails in plastic containers (22x7 cm) throughout the duration of larval morphs, and for 53, 55 and 59 days in these seasons respectively, in case of adult morph.

All the above mentioned experiments were carried out separately in respect to waterbug species. The waterbugs, in all cases were of same age and almost equally healthy. The supplied snails were of preferred size group (8x5-9x5.5 mm). A strict hygienic condition was maintained throughout by changing water of the container, by removing dead waterbug and snail individuals, if any, and also by removing the empty shells of the snails consumed by the bugs regularly.

Data collected on every 24 hr period in each experiment were analyzed and the mean was calculated. The value given after plus/minus indicates S.E. For statistical analysis, Pielou (1977) and Goon et al. (1976) were consulted.

RESULTS

The results are described in the following paragraphs as regards to experiments done.

Experiment I: the individuals belonged to *S. annulatum* and *S. rusticum* survived for 269-342 and 253-306 days, respectively. The rate of predation varied with the age of the waterbugs. On an average the five individuals belonged to *S. annulatum* and *S. rusticum* consumed 36.0 ± 2.08, 26.18 ± 0.43 and 14.42 ± 1.03, and 11.0 ± 1.18, 8.44 ± 0.20 and 7.47 ± 0.64 snail individuals per day, respectively.

Experiment II: the morphs of *S. annulatum* and *S. rusticum* consumed a varying number of

TABLE I

Daily rate of predation (in number) by ten individuals of different morphs of *Sphaerodema annulatum* (A) and *S. rusticum* (B) on a constant supply of the snails *Lymnaea (Radix) luteola* under different temperatures, separately

Temperature		1st instar		2nd instar		3rd instar		4th instar		5th instar		Adult	
(ºC)		A	B	A	B	A	B	A	B	A	B	A	B
20	Range	10-24	7-18	14-27	9-20	18-33	9-26	19-36	12-22	21-40	18-26	20-39	18-24
	Mean ± SE	18.11 ± 1.74	12.00 ± 1.21	20.85 ± 1.92	14.37 ± 1.34	24.57 ± 2.21	15.57 ± 2.46	26.85 ± 2.27	16.00 ± 1.29	30.28 ± 2.67	21.42 ± 1.13	29.42 ± 2.58	20.57 ± 0.92
25	Range	14-27	9-21	16-30	11-23	19-39	13-23	20-39	16-25	24-42	18-28	23-40	18-27
	Mean ± SE	20.57 ± 1.83	14.20 ± 1.98	23.57 ± 1.73	17.14 ± 1.73	20.57 ± 3.16	17.57 ± 1.65	27.42 ± 2.55	20.85 ± 1.43	33.14 ± 2.29	23.00 ± 1.41	31.57 ± 2.32	22.14 ± 1.40
30	Range	16-30	12-21	19-35	15-23	22-38	14-26	20-45	15-33	23-51	17-36	24-52	17-35
	Mean ± SE	22.42 ± 1.99	16.57 ± 1.08	26.14 ± 2.18	19.42 ± 0.99	30.00 ± 2.35	20.42 ± 2.02	32.71 ± 3.55	22.28 ± 2.46	37.28 ± 3.60	26.75 ± 4.06	37.00 ± 3.51	25.28 ± 2.33
35	Range	17-25	12-36	18-36	18-28	17-35	24-33	19-41	–	30-44	–	29-43	–
	Mean ± SE	23.75 ± 2.92	19.50 ± 5.60	27.00 ± 3.87	22.33 ± 2.96	27.66 ± 2.67	30.00 ± 3.00	31.71 ± 3.25	–	38.28 ± 1.75	–	36.71 ± 1.88	–
Room	Range	17-31	10-22	19-33	12-23	20-35	10-30	22-38	10-35	28-46	12-42	27-44	13-41
(22.5-26.5)[a]	Mean ± SE	22.71 ± 2.11	15.85 ± 1.79	25.14 ± 2.00	17.14 ± 1.60	27.00 ± 2.08	19.28 ± 2.89	29.71 ± 2.16	20.57 ± 3.17	35.00 ± 2.92	23.85 ± 3.58	33.28 ± 2.87	23.42 ± 3.49

a: average of the data collected on minimum and maximum temperatures during summer and winter

L. (R.) luteola in respect to temperature (Table I). The consumption rate was gradually higher from first instar larva to fifth instar larva irrespective of temperature grades.

Experiment III: the waterbugs consumed the snails of all the four size groups but the rate of consumption varied with the size of the snails supplied. Irrespective of waterbug species, the snail individuals belonged to G_1 size group were most preferred while individuals belonged to G_2, G_3 and G_4 size groups were next in order of consumption rate (Table II) when supplied separately. Considering the rates of predation by *S. annulatum* (A) and *S. rusticum* (R) the order of preference could be arranged in the following way:
$G_2R - G_1R - G_3A - G_3R - G_4R - G_4A - G_2A - G_1A - G_4R$.

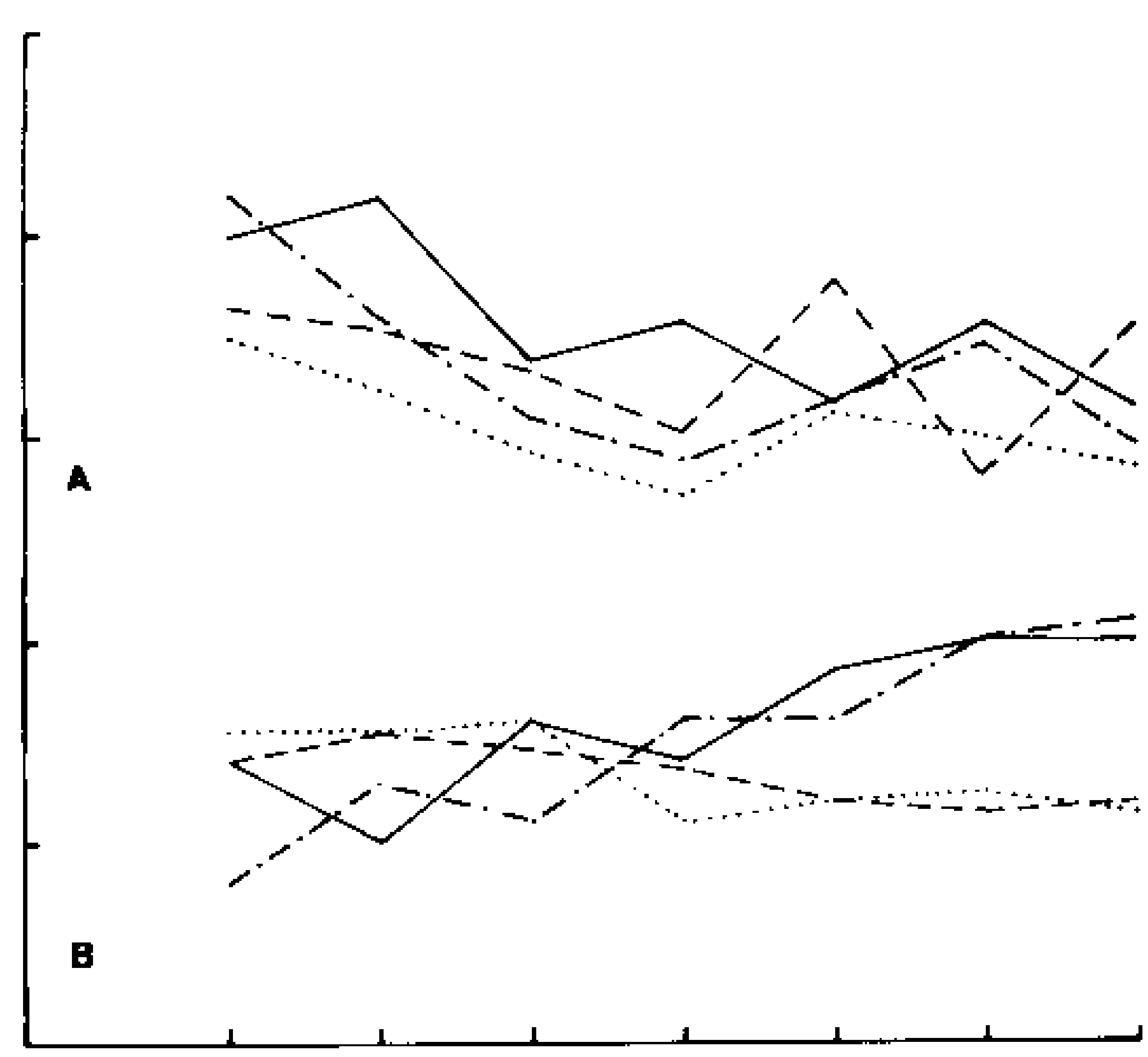
Experiment IV: the selected 15 adult *S. annulatum* and *S. rusticum* consumed more or less same number of snail individuals in respect to the height of the water column. On an average 41.71 ± 3.68, 40.57 ± 3.51 and 39.28 ± 3.57 and 32.28 ± 2.94, 31.28 ± 2.28 and 30.28 ± 2.9 snails were consumed per day at 10, 20, and 30 cm height of the water column by the 15 individuals of *S. annulatum* and *S. rusticum* respectively.

TABLE II

Daily rate of predation (range and mean ± S.E. in number) by five (adult) *Sphaerodema annulatum* and *S. rusticum* on a constant supply of the snails *Lymnaea (Radix) luteola* of different sizes, separately

	Snail size	Rate of predation (in number) per day	
		S. annulatum	*S. rusticum*
Supplied separately	G_1	25-44 (31.00 ± 2.28)	15-27 (24.71 ± 1.84)
	G_2	7-16 (13.71 ± 1.22)	1-7 (4.57 ± 0.71)
	G_3	10-14 (12.28 ± 0.52)	2-7 (3.28 ± 0.68)
	G_4	3-11 (7.28 ± 1.04)	0-1 (0.42 ± 0.20)
Supplied together	G_1	0-6 (2.19 ± 0.62)	0-10 (4.61 ± 0.49)
	G_2	0-8 (3.14 ± 0.45)	2-11 (5.90 ± 0.62)
	G_3	1-9 (4.57 ± 0.48)	0-10 (3.95 ± 0.50)
	G_4	1-7 (3.19 ± 0.35)	0-2 (0.57 ± 0.14)

Experiment V: an increased rate of predation has been noted in respect to increased predator density from 5 to 20. The selected 5, 10, 15, and 20 individuals belonged to *S. annulatum* consumed on an average, 13.00 ± 0.72, 23.57 ± 1.7, 36.14 ± 1.92, and 42.71 ± 2.83 snail individuals per day. Under similar situations same number of *S. rusticum* consumed 8.00 ± 0.60, 15.00 ± 1.77, 19.55 ± 0.55 and 26.85 ± 1.62 snail individuals daily. Figs 1a and b represent the rate of prey consumption per predator individual per day for a period of one week, separately, specieswise. It is clear that the rate of predation decreased when predator densities were 5 to 10 respectively but at such densities the predation rate became stable by the week end. At predator densities 15 and 20 respectively the rate of predation remained more or less stable throughout the week in case of *S. annulatum* (Fig. 1a). But, in case of *S. rusticum* (Fig. 1b) the pattern of prey consumption per predator increased to some extent over the stable rate by the end of the week when the predator-densities were 5 and 10 respectively. Whereas, when predator densities were 15 and 20 the rate of predation remained stable or parallel to the day axis throughout the week.



Impact of predator density (—— 5, --.--. 10, ------ 15, ... 20) on the rate of predation. The number of prey snails was kept constant (200) in all experiments. Predators: A - *Sphaerodema annulatum* B - *Sphaerodema rusticum*.

Experiment VI: the predation rate in waterbugs varied with the densities of prey-snail individuals (Table III). A gradual increase in the rate of predation with the increase in density of the prey-snail has been noted up to a certain level of snail density. The rate of predation was highest at 1100 snail density level in *S. annulatum* and at 700 snail density level in *S. rusticum* (Table III).

TABLE III

Daily rate of predation (range and mean ± S.E. in number) by ten adult *Sphaerodema annulatum* and *S. rusticum* on a constant supply of *Lymnaea (Radix) luteola* in different numbers for a period of seven days, separately in respect to waterbug species

Snail (in number)	Rate of predation (in number) per day	
	S. annulatum	*S. rusticum*
100	22-59 (39.00 ± 5.50)	8-17 (11.85 ± 1.33)
200	26-69 (46.42 ± 5.80)	12-18 (15.28 ± 1.01)
300	27-71 (50.71 ± 6.24)	15-24 (18.71 ± 1.26)
400	34-94 (58.14 ± 7.06)	19-29 (23.28 ± 1.76)
500	30-85 (65.71 ± 7.20)	28-36 (34.42 ± 1.28)
600	46-97 (71.28 ± 8.06)	32-44 (38.00 ± 1.38)
700	50-100 (78.42 ± 6.37)	26-55 (38.57 ± 3.35)
800	49-102 (81.42 ± 6.80)	32-48[a] (38.14 ± 2.26)
900	53-104 (84.57 ± 6.52)	–
1000	60-112 (89.71 ± 6.96)	–
1100	62-110 (90.14 ± 6.42)	–
1200	61-108 (89.14 ± 6.43)	–

a: experiment discontinued afterwards

TABLE IV

Daily rate of predation (range and mean ± S.E. in number) by five individuals of different morphs of *Sphaerodema annulatum* and *S. rusticum* on a constant supply of the snails *Lymnaea (Radix) luteola* in different seasons

Season	Morph	Rate of predation (in number) per day	
		S. annulatum	*S. rusticum*
Summer	Instar I	6-41 (16.10 ± 1.05)	5-15 (9.92 ± 0.41)
	II	8-45 (19.28 ± 1.22)	6-19 (11.74 ± 0.46)
	III	8-50 (20.83 ± 1.34)	7-32 (13.55 ± 0.79)
	IV	10-57 (23.01 ± 1.43)	7-33 (14.49 ± 0.88)
	V	13-62 (25.69 ± 1.55)	8-37 (17.24 ± 0.97)
	Adult	11-61 (25.22 ± 1.65)	8-35 (16.84 ± 0.91)
Monsoon	Instar I	4-14 (8.65 ± 0.36)	3-15 (8.32 ± 0.37)
	II	5-34 (11.74 ± 0.86)	5-15 (9.66 ± 0.39)
	III	5-42 (14.46 ± 1.15)	5-17 (9.98 ± 0.41)
	IV	5-49 (16.70 ± 1.40)	7-19 (11.00 ± 0.44)
	V	6-51 (19.10 ± 1.45)	7-29 (13.07 ± 0.72)
	Adult	3-50 (18.54 ± 1.73)	7-23 (12.45 ± 0.58)
Winter	Instar I	1-7 (3.69 ± 0.20)	1-6 (3.33 ± 0.17)
	II	2-11 (4.92 ± 0.28)	1-7 (3.67 ± 0.22)
	III	2-12 (6.13 ± 0.33)	1-9 (3.96 ± 0.26)
	IV	2-13 (6.79 ± 0.36)	2-10 (5.18 ± 0.26)
	V	3-14 (8.64 ± 0.39)	2-12 (6.83 ± 0.39)
	Adult	1-21 (7.18 ± 0.57)	1-11 (5.20 ± 0.38)

Experiment VII: the five adult *S. annulatum* and *S. rusticum* consumed, on an average 42.85 ± 4.83, 35.42 ± 3.62 and 27.57 ± 3.16 and 27.00 ± 2.08, 18.71 ± 1.82 and 13.85 ± 1.12 individuals of *L. (R.) luteola* per day at 594, 1188 and 2376 cm^2 surface area of water respectively.

Experiment VIII: a marked variation in the rate of predation in respect to seasons have been noted in all experiments conducted with different morphs of *S. annulatum* and *S. rusticum* (Table IV).

Statistical analysis of the data clearly revealed that the age of the water-bugs has a significant effect on predation. It is also evident that the age and species of waterbug interact to have a significant effect on predation (Table V). The variations noted in the rates of predation by these waterbugs in respect to temperatures are not statistically significant. The size of prey individuals has biggest effect so far rate of predation of *S. annulatum* is concerned (Table VI). But such an effect in *S. rusticum* is insignificant

TABLE V

Analysis of variance (ANOVA) showing the effect of the age of the waterbugs *Sphaerodema annulatum* and *S. rusticum* on the rate of predation on the snails *Lymnaea (Radix) luteola*

Source of variation	df	SS	MS	F
Species	1	38109.34	38109.34	1467.02[a]
Age	2	2336.75	1168.37	44.98[a]
Species X Age	2	926.24	463.12	17.83[a]
Error	511	13274.40	25.98	
Total	516	54646.73		

a: significant at 5% level

TABLE VI

Analysis of variance showing the impact of preysize on the rate of predation of the waterbugs *Sphaerodema annulatum*

Source of variation	df	SS	MS	F
Species	1	787.5	787.5	66.886[a]
Size	3	4963.857	1654.6191	139.827[a]
Species X Size	3	35.5	11.833	1.005[b]
Error	48	565.143	11.774	–
Total	55	6352.0	–	–

a: significant at 5% level; *b*: insignificant

(Table VII). Though both the waterbug species consumed *L. (R.) luteola* of different size groups *S. annulatum* has a significant effect on predation rate. Interestingly, the species *S. rusticum* and the size of *L. (R.) luteola* interact to have a significant effect. On a fixed density of prey individuals each waterbug species has a significant effect on the rate of predation. The increased predator density from 5 to 20, as well as the interaction of the predator species and the predator density have no effect on predation rate. To justify the validity of the recorded threshold density level of the prey-snails χ^2 test was applied. Such a phenomenon is justified from the difference noted in χ^2 calculated = 1141.12 and χ^2 observed = 18.48 values. Moreover, it is evident that the time (days) period has a significant effect on the rate of predation in *S. annulatum* while the prey density level has a significant effect on the rate of predation in both the waterbug species. Though the height of water column has no role in regulating the predation rate the surface area of the waterbody has a significant effect on the same (Table VIII).

Considering surface area as x and predation rate as y an exponential model was fitted with the observed data to determine the desired accuracy. The linear and the first degree exponential models for both the species were:

Linear: $y = 46.725619 - 0.0082972x$

Exponential: $y = 48.5414\ (0.9997577)x$

while the second degree exponential model for

S. annulatum

$y = 25.38769\ x \exp\ [0.000000061x\ (x - 3523.41)^2]$

S. rusticum

$y = 13.3245x \exp\ [0.00000013x\ (-2924.49)^2]$.

TABLE VII

Analysis of variance showing the impact of preysize on the rate of predation of the waterbugs *Sphaerodema rusticum*

Source of variation	df	SS	MS	F
Species	1	10.006	10.006	2.364[b]
Size	3	178.827	59.609	0.859[b]
Species X Size	3	208.065	69.355	16.39[a]
Error	160	667.0476	4.2315	–
Total	167	1073.946		

a: significant at 5% level; *b*: insignificant

TABLE VIII

Analysis of variance (ANOVA) showing the effect of the surface area on the rate of predation of the waterbugs *Sphaerodema annulatum* and *S. rusticum*

Source of variation	df	SS	MS	F
Due to species	1	2392.5952	2392.5952	36.894[a]
Due to surface area	2	1414.9047	707.452	140.818[a]
Species X Surface area	2	10.0477	5.0238	< 1[b]
Error	36	2334.5714	64.8492	–
Total	41	6152.1190	–	–

a: significant at 5% level; *b*: insignificant

From the above fittings it is clear that in *S. annulatum* the mean minimum consumption rate (five individuals together) would be 25.38 in a surface area 3523 cm^2 while in *S. rusticum* the minimum average predation rate would be 13.32 in the surface area 2924.49 cm^2. In all probabilities there exists a significant effect of the season on the rate of predation of *S. annulatum* and *S. rusticum*. The results of ANOVA (Table

IX) studies clearly indicate that the season has the biggest effect while predator species, instar stages of the predator species, the interaction of predator species and the season, the predator species and its instar stages, the season, the instar stages and the predator species, and the instar stages and season have significant effect on the rate of predation of *S. annulatum* and *S. rusticum*.

TABLE IX

Analysis of variance (ANOVA) showing the impact of seasons on the rate of predation of the waterbugs *Sphaerodema annulatum* and *S. rusticum*

Source of variation	df	SS	MS	F
Species (A)	1	475.549	475.549	185.417[a]
Season (B)	2	5061.598	2530.799	986.762[a]
Instar (C)	4	945.354	236.388	92.148[a]
AB	2	594.995	297.497	115.994[a]
AC	4	209.208	52.302	20.392[a]
BC	8	142.179	17.772	6.929[a]
ABC	8	1778.106	222.263	86.661[a]
Error	180	461.655	2.5647	–
Total	209	9668.645	–	–

a: significant at 5% level

DISCUSSION

From the results it is evident that the rate of predation in *S. annulatum* and *S. rusticum* is greatly influenced by the age and/or size and density of predators and prey animals; by the temperature and surface area of water-body, and by the seasons of the year. It appears that an individual *S. annulatum* and *S. rusticum* consumed, on an average 7.2, 5.2 and 2.9, and 2.2, 1.7 and 1.5 *L. (R.) luteola* per day respectively at pre-reproductive, reproductive and post-reproductive ages. The estimated average total number of consumption is going to be 1601.18 and 488.24 during the period of 303.2 and 284 days of average total life span of *S. annulatum* and *S. rusticum* respectively. It seems that the rate of predation is age dependent, perhaps in respect to nutritional requirement of the waterbug species concerned. This can also be explained from the fact of gradually higher rate of consumption by the larvae as they moved from first to fifth instar stages.

The increased consumption rate by the larvae of same stage and age with the rise of temperature from 20 °C to 30 °C, at an interval of 5 °C may be accounted from the fact of higher rate of digestion as has been discussed by Schmidt-Nielsen (1973). Since, at higher temperatures, more energy is needed to maintain respiration as per physiological stage of the individuals concerned, additional snail consumption is a must at each higher temperature grade. The impact of temperature on consumption rate is well evident from the fact of consumption rates noted at 25 °C and 30 °C constant temperatures, and room temperatures (mean minimum 22.5 °C and mean maximum 26.5 °C). This indicates that temperature determines the rate of consumption in animals. This could further be substantiated from the fact of highest and lowest consumption rates noted during summer (27-32.5 °C) and winter (17.5-20.5 °C) respectively in these waterbugs.

Prey size has an impact on the predator's performance. Predators prefer certain sizes of the prey and are known to consume them in a higher proportion as they are relatively abundant in nature (Peckarsky 1982). *Lethocerus americanus* is reported to capture prey as large as the lethocerine itself (Nieser 1975). In the aquatic hemipterans prey size selection is governed by the hit distance and strike efficiency (Cloarec 1980), time spent to capture the prey (Thompson 1978, Evans 1982) and the potency of the bug in turn depend on its foreleg movements (Cloarec 1983). Predation rate has been reported to decrease with the increasing prey size (Venkatesan & Cloarec 1988). The same phenomenon has also been noted in *S. annulatum* and *S. rusticum* in the present studies. The consumption of higher number of prey individuals of lower size group not only related with the fact of easy over-powering of the prey individual but also to fulfil the need of required food. Since small prey snail individuals contain less amount of food a waterbug had to consume the snails as many as six individuals of smallest size group per day contrast to an average consumption rate of 1.5 individuals belonged to largest size group. As the waterbugs consumed higher number of snail individuals belonged to larger size groups while prey snails of all the sizes were supplied together, it is most likely that the bugs prefer to attack the prey individuals of maximum size to be captured by them. This sort of prey selection enables the predator to have the require amount food by capturing less number of larger prey individuals. A similar phenomenon has also been noted in *Ilyocoris cimicoides* by Venkatesan and Cloarec (1988). This suggests that the waterbugs are also conscious to avoid unnecessary troubles in capturing large number of prey individuals. The present findings support the idea of Glasser (1978) that the predators utilise the resource selectively when prey species are abundant in nature.

Efficiency of predation is mostly density dependent (Odum 1971). It is also well evident from the fact of gradually higher rate of predation by the ten waterbugs with the gradual increase of prey density from 100 to 1100 for *S. annulatum* and from 100 to 700 for *S. rusticum*. After this, prey density had no role on the rate of predation of waterbugs. This means that prey density above the threshold density level never invites competition among the predators for prey catching. A similar phenomenon has also been noted by Sjostrom (1983) in *Dinocras cephalotes* and by Cloarec (1983).

Both the waterbugs and snails are surface dwellers. The water surface not only provides accommodation for these animals but also determines the rate of predation. This is well evident from the fact of increased predation rate in *S. annulatum* and *S. rusticum* under increased surface area. On the contrary, no change in predation rate, in waterbodies having different depths is expected, and justified from the results obtained.

Predators may respond to an increase of prey 'functionally', by an increase in number of prey consumed per individual predator 'numerically', by an increase in number of predators, or by a combination of the two (Solomon 1949, Holling 1959). This has already been observed in the present study on *S. annulatum* and *S. rusticum*. Though in nature, the predators have the chance to accept different kinds of prey individuals, the waterbugs mostly prefer the snails *L. (R.) luteola* over other (Raut & Saha 1989). It is evident that an adult *S. annulatum* in its average life span of 303 days (from the date of attainment of adult stage i.e., zero-day old, to the date of death) consumed an average total of 1601 *Lymnaea (Radix) luteola*. An individual of *S. rusticum* in its average life span of 284 days (from zero-day old adult stage to the date of death) consumed on the average 488 *Lymnaea (Radix) luteola*. However, the total kill of *Lymnaea (Radix) luteola* by an individual of waterbug of any species would be higher. Because, the bugs had to overcome the five larval stages to be metamorphosed into the adult stage. Since a larva belongs to first, second, third, fourth and fifth instar nymphs of *S. annulatum* consumed, on the average 2.3, 2.5, 2.7, 3.0 and 3.5 *Lymnaea (Radix) luteola* daily and the duration of first, second, third, fourth and fifth instar stages were 6.2, 5.3, 8.0, 10.1 and 13.6 days respectively at room temperatures (22.5-26.5 °C), it is estimated that a total of 127 *Lymnaea (Radix) luteola* are consumed by a larva prior to attainment of adult stage. Now, it is clear that, an individual *S. annulatum* consumed a total of 1728 *Lymnaea (Radix) luteola* in its entire life span i.e., from the date of hatching to the date of death. Under similar conditions a larva belongs to *S. rusticum* consumed 1.6, 1.7, 1.9, 2.0 and 2.4 *Lymnaea (Radix) luteola* per day at first, second, third, fourth and fifth instar stages respectively. Since the duration of instar stages was 8.9, 6.9, 7.04, 7.93 and 17.16 days respectively, an individual belongs to *S. rusticum* consumed an average total of 585 *Lymnaea (Radix) luteola* during its entire life span i.e. from the date of hatching to death.

It is observed that the larvae of *Limnogeton fieberi* consumed 126 individuals of *Biomphalaria glabrata* (Say) and *Physella acuta*. Taking total consumption of both the larvae and adults Voelker (1966, 1968) estimated that in the life span of a female and male, *L. fieberi* can destroy as many as 1800 and 670 snail individuals respectively. Raut and Saha (1989) reported that one generation of *S. annulatum* can consume three generations of *Lymnaea (Radix) luteola, Lymnaea (Radix) acuminata* and *Gyraulus convexiuxculus*. In the present study an individual belongs to *S. annulatum* consumed a total of 1728 *Lymnaea (Radix) luteola* and an individual belongs to *S. rusticum* consumed a total of 585 *Lymnaea (Radix) luteola*. These findings confering the potentiality of waterbugs in reducing the host snail population of the locality concerned. Since the waterbugs, *S. annulatum* and *S. rusticum* have shown wide range of variations in consumption rate of the snails *Lymnaea (Radix) luteola* in respect to seasons, studies on the rates of recruitment of *Lymnaea (Radix) luteola* and the waterbugs *S. annulatum* and *S. rusticum* are to be conducted with great care with a view to determine the most effective predator-prey ratio. It is sure that the vector snail population could drastically be reduced if the predaceous waterbugs are employed in that effective ratio after determining the same following experimental studies.

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