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The Relationship between *Parafossarulus manchouricus*, the Snail Host of *Clonorchis sinensis*, and Water Qualities During the Growth Season in Okayama Prefecture, Japan

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Abstract

The relationship between the distribution, abundance, productivity, growth of *Parafossarulus manchouricus*, the snail host of *Clonorchis sinensis* and water qualities; water tempeature (WT), hydrogen ion concentration (pH), dissolved oxygen (DO), calcium (Ca) and chlorinity (Chl), were surveyed at 20 stations of 6 areas in Okayama Prefecture, Japan during the growth season from July to September in 1991. Two types of analysis were applied to the water quality parameters retroactively treated from the time of snail examination in September. One was comparative analysis of the water quality parameters at snail positive (+) and negative (–) places; Ca and Chl at snail (+) areas were significantly higher than those at (–) areas and no difference was found in WT, pH and DO, but within snail (+) areas differences of Ca and Chl between snail (+) and (–) stations were not significant. The other was correlation analysis between water quality parameters and snail parameters; abundance, productivity and growth at snail (+) stations: WT correlated with productivity (r_s=0.63–0.82) and weakly correlated with abundance and growth; pH weakly correlated with abundance, productivity and growth; DO weakly correlated with abundance and productivity; Chl correlated with abundance (r_s=0.77–1.00) and productivity (r_s=0.71–0.96). The correlations between WT, pH and DO in water samples suggest that the snail (+) stations were strongly affected by photosynthetic organisms. The effect of WT to the snail might be not only direct one but also indirect one through the richness of foods. The effect of Chl might also be indirect through the foods. The correlations between snail and pH, DO might be the reflection of the photosynthetic activity by the aquatic organisms which would supply foods for the snail. No correlation with Ca might be showed by the masking by other strongly correlated factors or by the too narrow range of Ca measurements to show the correlation.

Key words: *Parafossarulus manchouricus*, snail host, *Clonorchis sinensis*, water quality, growth season

Introduction

Parafossarulus manchouricus, the snail host of Chinese liver fluke, still widely distributes in southern Okayama in Japan (Nagahana *et al.*, 1978) and the life cycle of *Clonorchis sinensis* in Okayama completes through the reservoir hosts though the human route is very rare (Nagahana *et al.*, 1980, 1984; Hatsushika *et al.*, 1986).

On water quality at the habitat of this snail there have been many reports by Inatomi (1953), Sugihara *et al.* (1961), Sugihara (1964a, b, c), Min (1975), Soh *et al.* (1980) and Miyasaka (1983), but not have been discussed well. One possible reason for this is that there were few studies on the breeding season strongly affecting the existence of snail. Another reason may be that the most of studies were based on presence/absence study which was not necessarily to uncover the relationship between water quality and the snail as mentiond by Dussart (1979).

In the present study, the snail and the water quality were examined during the growth season which will strongly affect the population and growth of this species. To compensate a weak point of the presence/absence study, a correlation analysis between snail parameters and water quality parameters within snail (+) stations was also done.

Furthermore we adopt the analysis by the retro-

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active treatment for the data of water quality, which made the analysis of water qualities possible from the time of last snail measurement to 2 months before. We were thus able to obtain more reliable results than that from the only one series of water measurement at the snail habitats by the ordinary method used by previous workers (Sugihara, 1964a, b, c; Sugihara *et al.*, 1961; Min, 1975; Miyasaka, 1983). In addition we considered the total weight of all snails at each station, which can be regarded to the index of biomass for snail. This parameter would be a reliable and convenient to know the 'productivity' of the snail population.

We hereby revealed the relationship between *P. manchouricus* and basic water qualities; water temperature, pH, dissolved oxygen, calcium and chlorinity.

Materials and Methods

A total of 20 stations of 6 areas were selected for this study in the southern part of Okayama Prefecture, where nine series of water samplings were done from 15 July to 21 September 1991 with an exception of rainy days (Figs. 1, 2). Each series of the sampling was performed within 5 hrs around 1:00 PM to avoid diurnal fluctuation except the cases with snail collections. And in order not to be sampled at the fixed time in a day, the sampling order among 6 areas was randomized in each series as much as possible with trading-off the shortening of the total moving time among areas. All the water samples were taken at 10 cm below the water surface. When the water was not deep enough, superficial water was sampled. The temperature, dissolved oxygen and pH of water body were measured at each station with a set of portable electronic instruments (Aqua Checker U-7, HORIBA Ltd., Japan). The chlorinity was estimated by a silver nitrate method and the calcium concentration was by an EDTA method.

The snail examinations were done twice at the beginning of the study to get the information of the abundance of yearling snail, and at the end to get the information of the abundance, productivity and growth of newborn snails.

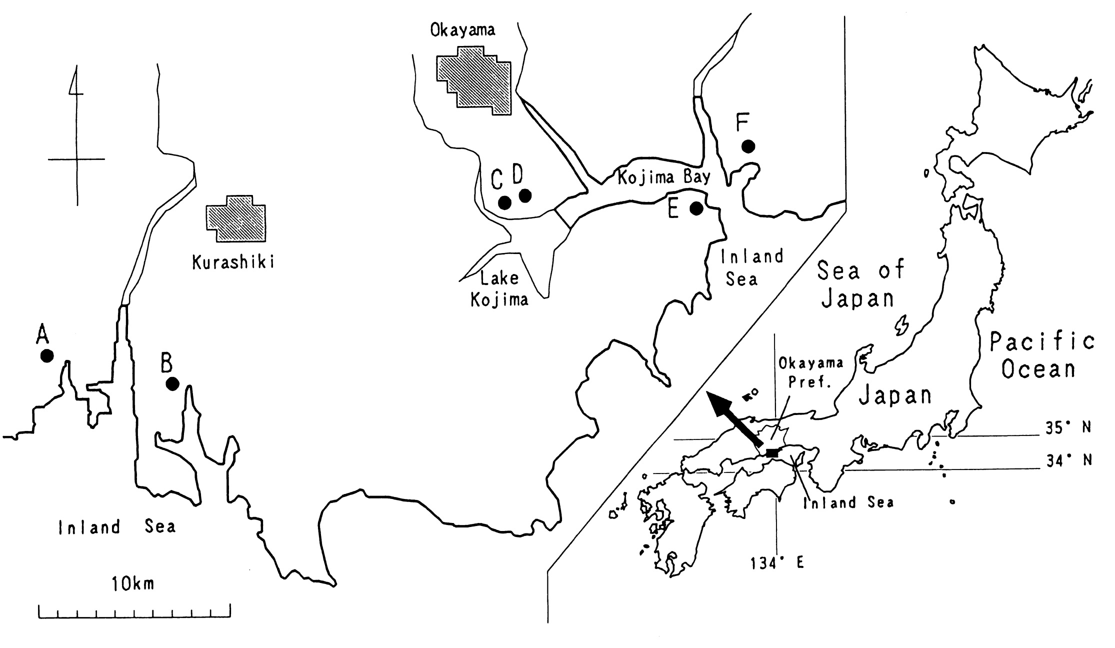

Fig. 1 Map of the study site (A–F). A: Tamashima (5), B: Mizushima (2), C: Urayasunishimachi (4), D: Urayasuhonmachi (3), E: Kogushi (1), F: Suimoncho (5). The numerals in the parenthesis indicate the numbers of examined stations.

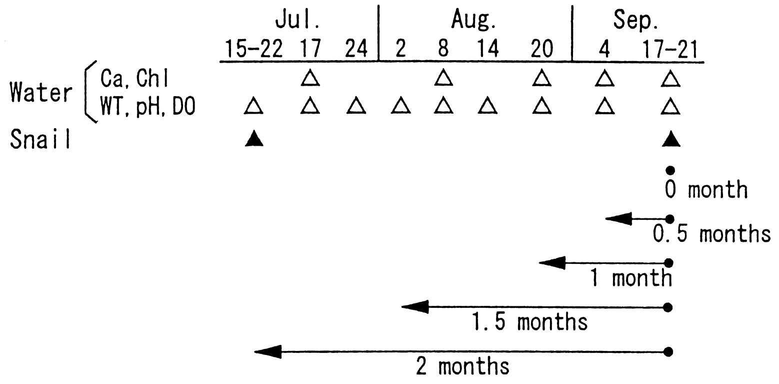

Fig. 2 Time table of water sampling and snail collection, and the retroactive periods from the last collection of the snail. Open triangle shows a series of water sampling for Ca, Chl, WT, pH and DO; Dark triangle shows a series of snail collection.

A hand-collection method for 30 person-minutes was applied at each station. In the rice fields, the snails were searched on the mud surface and algae around stems of rice plants and weeds. In the canals, they were searched on the mud surface at the bottom, at canal walls and on scooped algae or plants. The collected snails were classified to two groups of yearling and newborn, and counted separately. Then at the second series of snail examination the shell length was measured, and the total weight was weighed together with all individuals collected from each station after cleaning off the mud and small organisms from the shell surfaces. The snails captured at the first series of collections in July were released back into the same stations within a day not to disturb the natural population.

Besides collections of *P.manchouricus* not only other snails but also vegetations were visually observed and took photos every time of water sampling.

The representative values of water quality parameters were taken by retroactive averaging from the time of the second series of snail collection to the time to be treated (Fig. 2). The snail parameters of abundance, growth, and productivity were indexed by the values of the number, mean length, and total weight of the snails at each snail (+) station in the second series of snail collection in September.

Results and Analyses

The obtained results of water temperature, pH, dissolved oxygen, calcium, chlorinity are summarized in Table 1. There were 7 snail (+) stations and 13 (–) ones. The measurements of water qualities were showed in Fig. 1. At snail (+) 7 stations the range of water temperature was 23.4–39.3°C, pH was 6.9–9.2 and dissolved oxygen was 3.1–17.5mg/l. Calcium concentrations were gathered in a narrow range of middle class of the hardness (14.1–47.3mg/l). The range of chlorinity was wide (11.3–306.9 mg/l).

The relationship within water quality parameters themselves was analyzed by Pearson's correlation coefficient for all water samples from snail (+) stations (Table 2). Water temperature, pH and dissolved oxygen showed definite positive correlation each other ($P<0.002$).

A comparative analysis of the water quality parameters at snail (+) and (–) areas, and snail (+) and (–) stations within snail (+) areas were presented in Table 3. There were no significant differences in water temperature, pH and dissolved oxygen in the two combinations. The calcium levels and chlorinity at 14 stations of snail (+) areas were significantly higher than those at 6 stations of the snail (–) areas ($p<0.01$), but these differences were not significant in the combination 2 between the snail (+) and (–) stations within the snail (+) areas.

Table 1 Measurements of water qualities at 20 stations of *P. mancouricus* habitats from July to September 1991 in Okayama Prefecture

Stations	Snail	WT-°C Range (Mean)	pH Range (Mean)	DO-mg/l Range (Mean)	Ca-ppm Range (Mean)	Chl-mg/l Range (Mean)	Remarks
A-1	–	24.3–35.3 (30.2)	7.1–8.1 (7.7)	5.9–12.7 (10.0)	22.6–48.7 (34.3)	12.9–71.7 (52.3)	RF
A-2	+	25.2–36.5 (31.9)	7.1–9.2 (8.3)	5.7–17.4 (11.3)	24.7–36.3 (29.9)	12.5–187.3 (83.4)	RF
A-3	+	25.5–33.7 (30.4)	7.4–9.2 (8.2)	9.7–17.5 (12.0)	26.1–32.1 (30.0)	11.3–61.4 (38.9)	RF
A-4	–	26.7–36.9 (32.4)	7.7–9.3 (8.5)	11.1–16.8 (14.2)	22.3–52.5 (35.5)	30.4–108.6 (67.5)	RF
A-5	+	24.7–34.3 (29.4)	6.9–7.8 (7.3)	3.1–11.4 (6.7)	27.9–34.7 (31.5)	24.1–68.9 (49.3)	C
B-1	–	25.3–35.1 (30.7)	7.3–8.8 (8.2)	6.0–17.4 (11.9)	15.6–23.0 (19.7)	17.3–22.7 (19.1)	RF
B-2	–	25.2–33.0 (28.7)	7.0–8.0 (7.6)	4.1–6.7 (5.6)	20.0–26.9 (22.3)	16.0–37.2 (22.2)	C
C-1	+	29.1–39.3 (35.0)	7.1–9.2 (8.3)	6.3–13.2 (9.9)	23.2–31.3 (26.8)	90.8–124.0 (105.6)	RRF
C-2	–	27.0–37.2 (31.7)	7.1–8.3 (7.7)	6.1–14.0 (11.1)	31.4–39.7 (34.5)	31.9–112.7 (67.1)	RF
C-3	+	29.6–38.1 (34.7)	8.0–9.1 (8.4)	7.9–13.2 (10.8)	21.3–47.3 (37.1)	56.5–210.5 (125.8)	RRF
C-4	–	25.8–37.0 (31.6)	6.5–8.9 (7.8)	6.3–15.9 (11.5)	20.0–29.9 (23.8)	71.4–96.6 (85.2)	C
D-1	–	30.1–37.3 (33.2)	7.1–8.7 (8.0)	8.3–11.2 (9.8)	8.7–11.2 (9.9)	12.0–40.5 (23.3)	RF
D-2	–	28.5–35.8 (32.6)	7.2–9.5 (8.3)	7.9–15.7 (12.4)	7.2–18.3 (12.0)	14.2–39.8 (25.3)	RF
D-3	–	26.2–37.6 (30.6)	7.1–9.2 (8.4)	4.7–16.9 (12.2)	11.5–18.6 (15.0)	19.0–62.7 (42.5)	C
E-1	–	26.5–33.6 (30.4)	7.1–8.9 (7.9)	5.7–19.1 (10.8)	17.9–24.8 (20.5)	12.2–30.5 (22.9)	C
F-1	–	27.2–36.6 (31.5)	7.3–9.7 (8.6)	6.3–18.7 (12.8)	9.0–24.8 (18.4)	9.1–239.1 (78.6)	RF
F-2	–	27.7–33.5 (30.2)	7.3–9.3 (8.1)	9.0–15.5 (10.7)	15.3–21.8 (18.9)	18.7–228.6 (76.7)	C
F-3	+	27.6–36.9 (32.5)	7.3–8.7 (7.8)	7.2–15.8 (12.0)	14.2–32.5 (24.2)	20.5–306.9 (186.9)	RRF
F-4	+	23.4–35.5 (31.1)	7.1–9.0 (7.9)	7.7–16.6 (12.0)	14.1–35.8 (25.9)	19.4–293.4 (195.8)	RF
F-5	–	25.9–33.5 (30.6)	7.2–8.5 (8.0)	8.5–20.2 (12.1)	17.8–33.5 (25.7)	24.3–255.2 (130.8)	C
Total snail (+) stations		23.4–39.3 (32.1)	6.9–9.2 (8.0)	3.1–17.5 (10.7)	14.1–47.3 (29.3)	11.3–306.9 (112.2)	
Total snail (–) stations		24.3–37.6 (31.1)	6.5–9.7 (8.1)	4.1–20.2 (11.1)	7.2–52.5 (22.4)	9.1–255.2 (54.9)	

RF: Rice field, RRF: Water reserved resting rice field, C: Irrigation canal.

Table 2 Correlation within water quality parameters at *P. manchouricus* positive stations

	Pearson's correlation coefficient (Rp)			
	Ca	Log-Chl†	WT	pH
Log-Chl†	0.283			
WT	–0.264	–0.128		
pH	0.037	–0.089	0.534*	
DO	–0.255	0.033	0.412*	0.677*

*: $p<0.002$.
†: Chlorinity was log transformed because of better fitting to normal distribution.

The results of the snail examined are summarized in Table 4. At the start of the examination the number of collected snails was 0 to 10, and the generation type was newborn in all cases except A-5 and F-3. At the end of the examination, all snails collected were newborn type. The numbers of snails collected were remarkably different among the stations. At stations C-3 and F-3 there were 86 and 268 snails respectively, however, at stations A-2, 3 and 5, the numbers of the snails ranged from 1 to 6.

Correlation analyses of 5 water quality parameters and 3 snail parameters are shown in Table 5. On

Table 3 Comparison of water quality parameters; Combination 1: all stations of snail (+) areas and those of snail (–) areas, Combination 2: snail (+) and (–) stations within the snail (+) areas

	Retroactive period from last snail collection (months)	Mean of representative values			
		Combination 1		Combination 2	
		Snail (+) areas (n=14)	Snail (–) areas (n=6)	Snail (+) stations (n=7)	Snail (–) stations (n=7)
	0	26.4	27.0	26.5	26.4
	0.5	28.9	29.1	29.3	28.5
WT	1.0	28.9	29.1	29.1	28.7
(°C)	1.5	29.9	30.0	30.4	29.3
	2.0	31.7	31.0	32.1	31.2
	0	7.7	7.7	7.4	8.0
	0.5	7.6	7.7	7.5	7.7
pH	1.0†	–	–	–	–
	1.5	7.8	8.0	7.8	7.8
	2.0	8.0	8.1	8.0	8.0
	0	9.3	7.7	8.1	10.4
	0.5	9.7	8.3	8.7	10.7
DO	1.0	10.0	9.0	9.2	10.8
(mg/l)	1.5	10.6	10.1	10.3	10.9
	2.0	11.2	10.4	10.7	11.8
	0	28.3	14.4*	31.0	25.6
	0.5	28.8	15.6*	31.2	26.4
Ca	1.0	30.0	15.7*	31.1	28.9
(mg/l)	1.5	30.2	16.1*	31.2	29.3
	2.0	28.4	16.6*	29.8	27.3
	0	109.8	18.2*	133.6	86.0
	0.5	105.8	22.2*	136.5	75.1
Chl	1.0	121.2	21.9*	141.5	100.8
(mg/l)	1.5	112.4	25.4*	132.3	92.4
	2.0	95.2‡	25.9*	113.3§	79.7

*: Two groups were different at $p<0.01$ by Wilcoxon's two-sided tests.
†: pH was not measured in August 20.
‡,§: The treated numbers were 13 and 6 respectively.

Table 4 Results of snail examination at 7 stations positive for *P. manchouricus*

Stations	Start of the examination (July)		End of the examination (September)			
	No. of snail		No. of snail		Mean length (mm)	Total* weight (g)
	Yearling	Newborn	Yearling	Newborn		
A-2	0	7	0	6	7.4	0.423
A-3	0	7	0	4	8.5	0.315
A-5	0	0	0	1	6.2	0.082
C-1	0	8	0	18	10.1	2.789
C-3	0	1	0	86	9.1	9.890
F-3	9	0	0	268	7.8	18.943
F-4	0	10	0	23	8.0	2.107

*: Mixed weight of soft tissue and shell.

the water temperature there was clear correlation with total weight of the snails (r_s>0.79 in 4 of the 5 cases), but there were weak correlations with number and mean length. Weak correlations on pH with number, total weight and mean length were found, and also on dissolved oxygen with number and total weight but not clear with mean length. On calcium, there was no correlation with number, total weight and mean length. Clear correlations of chlorinity with number and total weight were showed (r_s>0.71, 4 cases were $0.05<p<0.072$), but not with mean length of the snails. The similar results of correlation analyses were got by the treatment among 6 snail (+) stations without F-3 station where the yearling snails were collected at the beginning of the survey.

The snails and dominant vegetations observed during surveyed period were listed in Table 6. The distribution of the pond snails seemed same as *P. manchouricus*, and Pulmonata snails were general in rice fields. Apple shell was newly immigrating species into area C. For vegetation rice plant was dominant in rice fields and gramineous weeds were noted in 3 water reserved resting rice fields where *P.manchouricus* was occurrent. At stations C-1 and F-3 other vascular plants were noted, in particularly at F-3 *Monochoria vaginalis* thickly grew in September and almost of *P. manchouricus* was observed on this plant at last collection day. In addition Zygnemataceae planktons were observed commonly in all rice fields and resting rice fields. No aquatic plant was observed at D-3 because of rearing ducks in the canal and also at F-2, -5 because of concrete placed walls and bottoms of canals.

Small size aquatic crustaceans were observed in rice fields with no relation to the occurrence of *P. manchouricus* such as Anostraca, Notostraca, Conchostraca and Cladocera spp., and other animals such as tadpoles, fogs and Cyprinodont fishes were also noted but rare. Aquatic insects noted rarely and not commonly, for example whirligig beetles and water beetles were only at A-2, -4, C-1, -3 and F-4 and mosquito larvae were at F-1.

Discussion

In present study the 13 stations were rice fields where all organisms would be affected more or less by human farm workings such as water management and application of agricultural chemicals. For water management water samplings were not affected in most cases except at August 2 when the water level of the canals were very low in every area by the midsummer drainage of rice field, and water samplings were not performed at 8 stations. And the possibility of moving of the snails by the water pumping-up from the canals into rice fields would be also negligible, because almost of canals were snail negative or in very low density. For application of pesticide direct effect to *P. manchouricus* would be thought not to be strong. Because not only other species of snail but also some aquatic crustaceans, amphibians and fishes were observed common with

Table 5 Correlation analysis between snail parameters and water quality parameters at *P. manchouricus* (+) stations

	Retroactive period from last snail collection (months)	Rank correlation coefficient		
		Number	Total weight	Mean length
WT	0	0.43	0.63†	0.70†
	1.5	0.64†	0.79*	0.54†
	1.0	0.71†	0.82*	0.50
	1.5	0.64†	0.79*	0.54†
	2.0	0.68†	0.82*	0.68†
pH	0	0.77*	0.65†	0.45
	0.5	0.76*	0.81*	0.68†
	1.0‡	–	–	–
	1.5	0.75†	0.79*	0.75†
	2.0	0.25	0.36	0.75†
DO	0	0.56†	0.50†	0.52
	0.5	0.79*	0.75†	0.43
	1.0	0.64†	0.61†	0.39
	1.5	0.82*	0.68†	0.14
	2.0	0.46	0.36	0.00
Ca	0	–0.18	–0.25	–0.14
	0.5	–0.18	–0.25	–0.14
	1.0	–0.32	–0.36	–0.14
	1.5	–0.43	–0.46	–0.07
	2.0§	–0.43	–0.43	0.26
Chl	0	1.00*	0.96*	0.36
	0.5	0.96*	0.89*	0.29
	1.0	0.86*	0.71†	0.14
	1.5	0.86*	0.75†	0.18
	2.0§	0.77†	0.77†	0.14

*: $p<0.05$, †: $p<0.25$.
‡: pH was not measured in August 20.
§: The number of treated pairs is 6.

no relation to the occurrence of *P. manchouricus*, though the insects were not. This reason might be the recent promoting usage of low toxic agricultural chemicals for the animals and/or specific ones for the pest insects. The effect of weedicide could not denied in the rice fields, but might be limited in the short time in July. In fact gramineous weeds start to grow more or less at the edge of cultivated rice fields in August. The effect of fertilizer might be indirect through the vegetations, and for Ca the direct application of Ca related fertilizer to rice fields usually performed at once early in the cultivation period and not during surveyed period.

There has been no report on the interspecific competition between *P. manchouricus* and other snails. In C-area, the biotopes of this snail and apple shell were overlapped partially in the leaves and stems of young aquatic plants. But competition between them would not so affective because the density of apple shell was very low and main biotope of the *P. manchouricus* were surfaces of mud and thickly grown Zygnemataceae planktons and the emerged leaves of grown up gramineous plants.

Nagano (1928) reported the cyprinid fishes were predator of newly hatched *P. manchouricus*, but their predation pressures were not complete and the snail among the stems of plants could survive. In present study the cyprinid fishes were common and rare in snail (+) stations. Therefore if the predation pressure would be exist, it would be no problem to treat the snail data as ranking parameters in correlation analyses.

Water temperature

In this study there was no difference in water temperature between snail (+) and (–) places, which has been agreed by previous workers (Sugihara *et al.*, 1961; Sugihara, 1964c; Min, 1975; Soh *et al.*, 1980). There has been no available evidence on the correlations between water temperature and abundance, productivity and growth of *P. manchouricus*.

On the other species the recruitment rate, r_m or abundance correlated with water temperature in *B. globosus* (Shiff, 1964a; Woolhouse and Chandiwana, 1989, 1990), in *Gyraulus albus* (Dussart, 1979) and in *Biomphalaria pfeifferi* (Woolhouse and Chandiwana, 1989), and the growth rate also correlated with it in *B. globosus* (Shiff, 1964b; Woolhouse and Chandiwana, 1990). These reports agree with present study though the abundance cannot be directly compared with recruitment rate or r_m.

But these relations on recruitment rate or r_m turn to negative over 20.6°C (Woolhouse and Chandiwana, 1990), 28.5°C (O'Keeffe, 1985a) and 25°C (Shiff, 1964a) in *B. globosus*, and on growth rate also turn over 25°C in *B. globosus* (Shiff, 1964b). These temperature-dependent depression under high temperature was not recognized in the

Table 6 List of snails and dominant vegetations observed during surveyed period

Stations	Field type	Snails: *P. manchouricus*	Snails: Pond* snail	Snails: Pulmonata† spp.	Snails: Apple‡ shell	Vegetations: Rice plant	Vegetations: Gramineous weeds	Vegetations: Zygnemataceae spp.	Remarks
A-1	RF			+		+		+	
A-2	RF	+	+	+		+		+	
A-3	RF	+	+	+		+		+	
A-4	RF			+		+		+	
A-5	C	+	+				+		§
B-1	RF		+	+		+		+	
B-2	C						+		
C-1	RRF	+		+	+		+	+	‖
C-2	RF			+		+		+	
C-3	RRF	+	+	+	+		+	+	
C-4	C				+		+		
D-1	RF			+		+		+	
D-2	RF			+		+		+	
D-3	C								
E-1	C			+				+	¶
F-1	RF			+		+		+	
F-2	C								
F-3	RRF	+					+	+	**
F-4	RF	+	+	+		+		+	
F-5	C								

RF: Rice field, RRF: Water reserved resting rice field, C: Irrigation canal.
*: *Cipangopaludina chinensis malleata.*
†: *Physa acuta*, Limnaeidae spp. and/or Planorbidae spp.
‡: *Ampullarius* sp.
§: *Elodea* sp. was noted from August.
‖: *Dopatrium junceum* was noted from the middle of August.
¶: *Trapa bispinosa* observed growing from the beginning of August.
**: *Monochoria vaginalis* observed thickly growing in September.

present study. Such difference may be due to the difference of tolerance to high temperature between *P. manchouricus* and pulmonata, even if the effect that the levels of water temperature in our study was generally high because of the sampling was done in the time of diurnal maximum temperature or near, is subtracted. This supports the field observation that *Physa acuta*, one of the pulmonata, significantly distributes in the area of lower temperature at the sunny rice field in summer though the *P. manchouricus* does not show such distribution (Ohyama unpublished).

In the present study we should also concern the indirect effect of temperature through the food environment of photosynthetic organisms. Because positive correlations between water temperature, pH and dissolved oxygen at snail occurrent stations suggest that these places were strongly affected by photosynthesis i.e. the strong summer sunlight rose water temperature and coincide with active photosynthesis which cause an increase of dissolved oxygen and a decrease of carbon dioxide in the water, and the latter brought high pH as mentioned by Boycott (1936).

pH

There was no difference in the pH between snail (+) and (–) places. This finding agrees with the reports of Inatomi (1953) and Sugihara (1964a). The correlation analysis showed that pH weakly correlated with abundance, productivity and growth.

On *Planorbis planorbis* Dussart (1979) reported positive relations between snail abundance and pH, but not discussed. The only laboratory study reports direct effect on the development and hatching of *Oncomelania* eggs that no clear damage was observed within the range of pH 6.6 to 8.8 (Nojima and Katamine, 1976). Therefore it might be difficult to explain the positive relation with pH by the direct effect of pH. As mentioned above we should better to understand that high pH reflected the active photosynthesis by the aquatic plants or phytoplankton which may supply the abundant foods for the snail.

Dissolved oxygen

Min (1975) reported that the dissolved oxygen levels in May at Korea in *P. manchouricus* (+) stations were higher than those at (–) stations, but it lacked discussion on the summer measurements. Other workers have observed that snails could not survive under extreme low oxygen condition; e.g., 0.08–3.6 ppm for *O. hupensis quadrasi* (Garcia, 1972), and 0 ppm with organic pollution for *B. globosus* and *B. pfeifferi* (Smith, 1982). In this study there was no station with extremely low oxygen level, accordingly no difference of dissolved oxygen level between snail (+) and (–) places would be found.

On the dissolved oxygen in the present study, there were weak correlations with abundance, and productivity. We would better to understand that such correlations is through the food environment as mentioned above, though the possibility of direct effect of dissolved oxygen remains.

Calcium

In our field study, there was a significant difference in the calcium levels between snail (+) and (–) areas, but not between snail (+) and (–) stations within snail (+) areas. Some reasons of the difference in Ca level among areas could be considered, for example the difference of the water system or of the volumes of applied fertilizer related to Ca, but not clear. Whatever the reason of difference in Ca is, Ca level might be related to the snail distribution, which supports the observation by McKillop (1985) on *Aplexa hypnorum, Helisoma campanulatum campanulatum* and *Valvata tricarinata.*

Sugihara (1964c) indicated that the presence or absence of *P. manchouricus* could not be explained only by Ca level. This reason may be that his study was performed in the narrow area just same as present case in which the Ca level was not different within snail (+) areas.

No correlation was found between the calcium concentration and the snail parameters. There has been no previous report on this species in this regard. On other species various relations with the snail abundance are known: positive, negative, bell shape and no relations from field studies (Williams, 1970; Dussart, 1979; McKillop, 1985; Rumi and Hamann, 1990). On the other hand little importance of water calcium for the several species of the snail under the adequate food condition was reported by Young (1975). In the present study even if calcium concentration dependent relation exists, this effect might be masked by other strongly influential factors or the distribution range of calcium concentration might be too narrow to show the correlation.

Chlorinity

It is clear that moderate high chlorinity is favorable to *P. manchouricus.* The direct effect of moderate chlorinity below 350mg/l has not been reported, but an indirect effect has been reported by Inatomi (1953). He observed that *P. manchouricus* grew better in the water moderately affected with sea water than in fresh water, and the consumption of $KMnO_4$ was higher in the former. Therefore he suggested the moderately high chlorinity led to richness of organic matter, which might relate to the nutrition for the snail. Dussart (1979) found the similar finding in *Lymnaea peregra* and Watson (1958) in *B. truncatus.*

The stations surveyed in our study were situated in reclaimed saline land (Yoneda, 1964). Accordingly, some stations showed high chlorinity should be affected by high level of underground saline water, although the possibility of organic pollution cannot be excluded. Therefore whichever the cause of high chlorinity was, the clear relationships between chlorinity and abundance and productivity would indicate indirect effect of chlorinity to the snail through food environment. Inatomi (1953) reported the existing of the relationship between the growth and chlorinity, but there was no correlation in the present study. This reason is not clear, but it might be due to the difference of survey stations: the former were canals or rivers and the latter were mainly rice fields where the water temperature was constantly higher than in canals. Such complex relations should be clarified by the further detailed study adding the fecundity and/or mortality.

In this study, vegetative factor related to the *P. manchouricus* population was suggested especially in relation to food environment as mentioned by O'Keeffe (1985b) and Woolhouse and Chandiwana (1989). The dominant vegetations in snail (+) stations were vascular plants and zygnemataceous planktons, and latter planktons have not been noted in previous canal studies (Min; 1975, Miyasaka; 1983, Nagano; 1928). But we usually observed zygnemataceous planktons more or less on the leaves or stems of aquatic plants in the irrigation canals. Therefore these planktons should be paid attention in the field study of this snail in growth season.

We have sometimes encountered the very high density places of this snail but not have observed the environment prior to it. In the case of F-3 station only a few snail visually observed till 2 weeks prior to the last collection, and relatively grown snails increased very quickly with the thickly growth of vascular plants, *M. vaginalis*. This might suggest that the thickly growing vascular plants with zygnemataceous planktons may give the biotopes not only to release the intensive egglaying behavior for this snail but also to maintain the high survival rate under high density population.

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