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Distribution of Six Species of Bitterlings in a Creek in Fukuoka Prefecture, Japan

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Abstract Comparative study on the distribution of six species of bitterling in a creek in Fukuoka Prefecture was carried out. The upper part of the creek was fluvial, and the lower part stagnant. *Acheilognathus lanceolatus*, *A. tabira* subsp. (b) of Nakamura (1969), *A. rhombeus* and *Rhodeus atremius* showed wide distribution in the creek throughout their life. *A. limbatus* seemed to be a fluvial species, and *R. ocellatus smithii* a lentic species. In the spawning season, however, all the species of bitterling, excepting *R. o. smithii*, probably possess a common spawning ground in which mussels occur at a relatively high density. Adult females of *A. lanceolatus*, *A. tabira* subsp. (b) and *R. atremius* without ripe eggs aggregated in the lower, stagnant parts of the creek. Most juveniles of these species and of *A. rhombeus* seemed to grow in the lower part of the creek, and then migrate upward untill their spawning season. No species among the same phylogenetic group has the same set of the life modes (spawning season, spawning sites, aggregation of females without ripe eggs in the lower part of the creek and probability of upstream migration of 0-year-old fish toward spawning sites).

There were only a few studies on the ecology of natural populations of bitterlings (Cyprinidae). Asahina et al. (1980), Solomon et al. (1982), Asahina and Hanyu (1983) and Nagata (1985a, b, c, d) have reported on the mechanisms of population dynamics and some aspects of reproduction of the rose bitterling, *Rhodeus ocellatus*, in a river or a pond. Hirai (1964) and Kondo et al. (1984) have studied the reproductive ecology of four species bitterlings in Lake Biwa and six species in a creek in Okayama Prefecture, respectively. From these studies, avoidance of interspecific competition for host mussels among sympatric species was found on the basis of their spawning periods and preference of mussels into which they lay eggs. However, there has been no comparative study on ecological and behavioral variations with consecutive life stages of sympatric species of bitterlings.

Six species of bitterlings and seven species of mussels sympatrically inhabit the Futatsukawa Creek, a branch of the Yabe River, Fukuoka Prefecture, Japan. In this report, we describe the distribution of these bitterlings at different ages, and discuss on the mechanisms of the distribution of bitterlings in the creek.

Study sites and methods

The upper part of the Futatsukawa Creek runs through rice fields and the lower part through Yanagawa City. Total length of the creek is approximately 8 km and the width ranges from 6 to 20 m. Seven stations were set to examine the faunas of fish and mussels in the creek (Fig. 1). Topographical characteristics of the stations were as follows:

Station 1 and St. 2 are situated in the upper part of the creek. Banks of the creek were covered with reed and other weeds. The substratum consisted of grips and sandy mud, and aquatic plants (*Potamogeton malomonus* was dominant) grew from place to place. Maximum width and depth of the creek at the stations were approximately 6 to 10 m and 1.2 to 1.5 m, respectively.

Stations 3 and 4 are located in the middle part of the creek. There were houses along the creek. The bank were made from concrete. The width and depth ranged from 8 to 10 m and 0.3 to 0.8 m, respectively. The bottom was relatively flat and the substratum varied from silt to pebbles. *P. biwaensis* and other aquatic plants broadly covered the substratum.

Stations 5–7 are situated in the lower part of the creek which runs through Yanagawa City. The width was from 10 to 20 m. Maximum depths at St. 5 and St. 7 were 1.5 m and 3 m, respectively. *Hidrilla verticillata* condensely covered muddy substratum in shore parts at St. 5 and St. 6. There were no aquatic plants at St. 7. St. 5 was

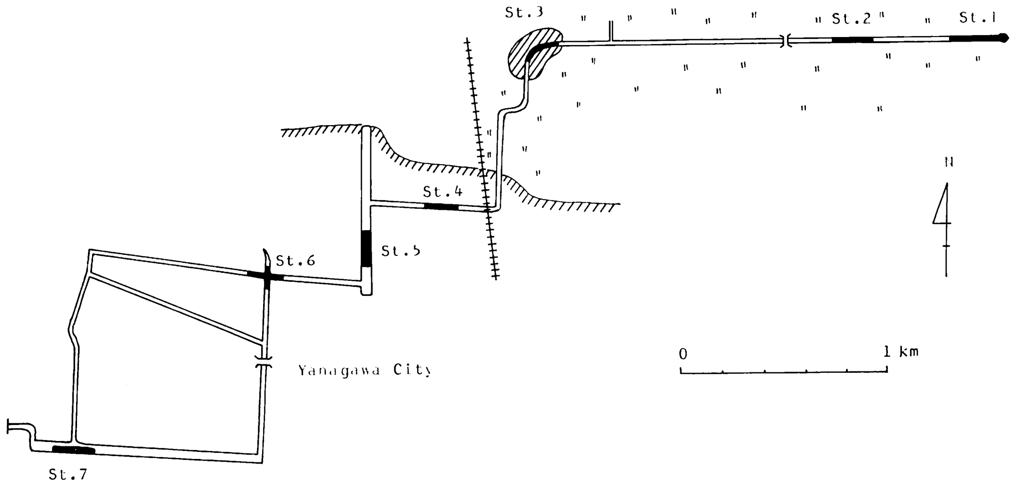


Fig. 1. Study sites in the Futatsukawa Creek, Fukuoka Prefecture. Water flows from the east. Shadow indicates human habitation. Sts. 1–4 were fluvial and Sts. 5–7 were lentic condition.

added as a station from August.

In order to get further information on environmental conditions, examination of water characteristics (temperature, pH, turbidity, NH_3-N, NO_2-N, NO_3-N and PO_4-P) using HACH water analyser and the fastest velocity of water flow was carried out at all stations in June, 1976.

Collection of fishes was carried out with casting nets at all stations once a month from late January to November in 1976. The abundance of fishes was expressed by the number of fish per ten casting net operations. The casting nets were able to catch bitterlings larger than about 20 mm in body length. Young fish were caught with small-mesh hand nets from March to November in 1976.

In the laboratory, species collected were identified, and the body lengths of specimens were measured using a vernier caliper. Sex was judged by presence of ovipositor in females. The ovipositor was observed in order to identify ripe females having a long and semitransparent ovipositor (Nagata, 1985a, b). Seasonal variations of abundance of ripe females were estimated from a catch of fishes collected at the stations and other points along the course of the creek. Age was estimated from the number of annual rings on the scales.

The mussels were collected by hand using a 0.5×0.5 m^2 quardrat which was set several times in each station from April to June, 1976.

Results

1. Environment and fish and mussel faunas. Water temperature tended to be higher toward downstream in June (Fig. 2). Amount of nutrients such as PO_4-P, NO_3-N, NO_2-N, and NH_3-N seemed to be greater in lower stations. Turbidity had the same tendency. These tendencies seemed to be caused by the stagnant and polluted water condition at stations in the lower part.

Six species of bitterlings, *Acheilognathus lanceolatus*, *A. limbatus*, *A. tabira* subsp. (b) of Nakamura (1969), *A. rhombeus*, *Rhodeus ocellatus smithii* and *R. atremius*, and eighteen other species of fishes were syntopically found in July and August (Table 1). Dominant species of bitterlings in most stations were *A. limbatus* and *A. tabira* subsp. (b).

Aside from the bitterlings, *Zacco platypus* was another dominant species in all the stations except in St. 7 where *Carassius auratus langsdorfii* was dominant. The similarity of fish species composition among stations was calculated from the data shown in Table 1 using the overlapping index, $C\lambda'$ (Morishita, 1971) (Table 2). The similarity becomes higher as the value of $C\lambda'$ approaches one. The results show that species compositions at Sts. 1–4 were similar with each other. The fish fauna at St. 5 was similar to that of St. 6. Although species composition at St. 7

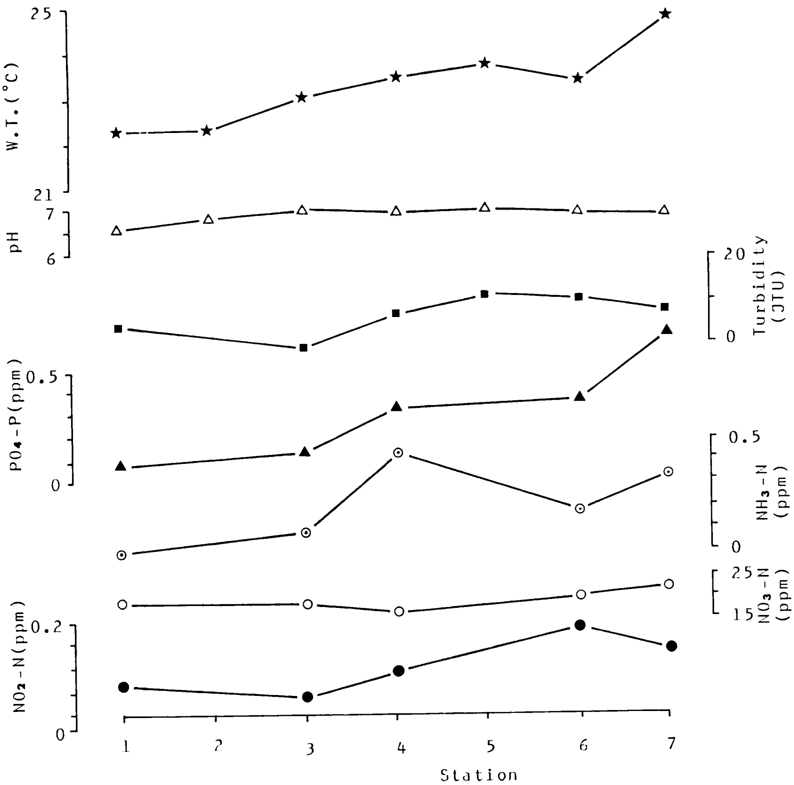


Fig. 2. Water temperature (solid star), pH (white triangle), turbidity (solid square) and amount of PO_4-P (solid triangle), NH_3-N (double circle), NO_3-N (white circle) and NO_2-N (solid circle) at seven stations of the creek in June, 1976.

Table 1. Number of fishes excepting bitterlings caught from ten casting net operations in July and August, 1976.

Species	Stations						
	1	2	3	4	5	6	7
Plecoglossus altivelis	0.52						
Squalidus gracilis			0.18		3.26	4.26	
Puntungia herzi	0.26	1.05	0.89	1.93	0.47		
Sarchocheilichthys variegatus	0.78	0.53	0.89	0.55			
Abbotina rivularis			0.54	0.28	0.47		2.22
Pseudogobio esocinus	0.26						
Pseudorasbora parva	0.52				4.65	2.98	3.89
Hemigrammocypris rasborella						0.85	
Zacco temminckii	4.93	1.58	1.25		1.40		0.56
Z. platypus	9.61	13.68	7.68	7.43	6.98	5.11	5.56
Carassius auratus langsdorfii	3.12	0.53	1.25	1.38	5.12	3.41	15.56
Cobitis taenia taenia	1.04		0.54	0.55			
Parasilurus asotus	0.26						
Anguilla japonica				0.28			
Channa argus					0.47	0.43	
Coreoperca kawamebari			0.36	0.28			
Odontobutis obscurus	1.30		0.89	0.55	0.47		
Rhinogobius brunneus			0.71	0.83			
Total	22.60	17.37	15.18	14.06	23.29	17.04	27.79
Times of casting net operations	38.5	19	56	36.3	21.5	23.5	18
Number of specimens	87	33	85	51	50	40	50
Number of species	11	5	11	10	9	6	5

was different from the others, it was more similar to those of St. 5 and St. 6 than to those of Sts. 1–4. *Z. platypus*, *Puntungia herzi*, and *Sarchocheilichthys variegatus variegatus* were common and *C. a. langsdorfii* was relatively rare at Sts. 1–4. *Squalidus gracilis*, *Abbotina rivularis*, *Pseudorasbora parva* and *C. a. langsdorfii* were common in the downstream where water flowed slowly. *C. a. langsdorfii* was the most abundant at St. 7. It seems that similarity of fish composition among the stations was mainly correlated with the velocity of water flow and some factors associated with it.

Seven species of mussels were found in the creek (Fig. 3). Dominant species were *Cristaria leana* and *Inversidens japanensia*, followed by *Unio douglasiae* and *Pseudodon omeiensis* at Sts. 1–5. The density of mussels was the highest at St. 3 where *I. japanensia* was dominant. There were few mussels at Sts. 5–7 where the substratum was silt.

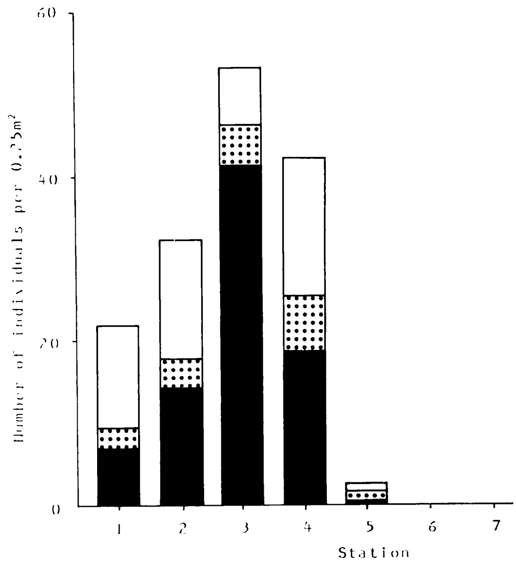


Fig. 3. Number of mussels per 0.25 m^2. Solid and white bars represent *Inversidens japanensia* and *Cristaria leana*, respectively. Bars with dots indicate other 4 species of mussels, i.e. *Unio douglasiae*, *Pseduodon omeiensis*, *I. brandti* and *Lanceolaria grayana*.

2. Ranges of body length of bitterlings at different ages. Fig. 4 shows ranges of body length of bitterlings at different ages estimated from the annual rings on the scales. 0-year-old fish (1976 year class) began to be caught from early June. From June to August or September, the bitterling populations seemed to be composed of three age-groups, except *A. rhombeus* that had only two age-groups.

The oldest fish of all species seemed to disappear from October. 0-year-old fish continued to appear in the creek from June to October, and the ranges of body length of the fish became wider gradually. On the contrary, the ranges of body length of 1-year-old fish (1975 year class) except *A. rhombeus* tended to be narrower since April.

3. Seasonal variation of the distribution of the bitterlings in the creek. Fig. 5 shows seasonal variation of the distribution of bitterlings in the creek.

Five species of the bitterling other than *A. rhombeus*, were more numerous from April to June, the most important spawning season in these five bitterlings. Most of the fish were 1-year-old in spring and early summer. 0-year-old fish that can be caught with casting nets appeared in July or August, when body length of bitterlings reached more than 20 mm.

The characteristics of distribution of the bitterlings were as follows:

Acheilognathus lanceolatus (Fig. 5a) was found at

Table 2. Degree of overlap of component species between two communities calculated from the data shown in Table 1 using Morishita's $C\lambda'$-index.

Station	1	2	3	4	5	6	7
1		0.828	0.982	0.900	0.812	0.699	0.551
2			0.923	0.925	0.610	0.578	0.353
3				1.030	0.780	0.713	0.473
4					0.748	0.697	0.482
5						1.016	0.759
6							0.674
7							

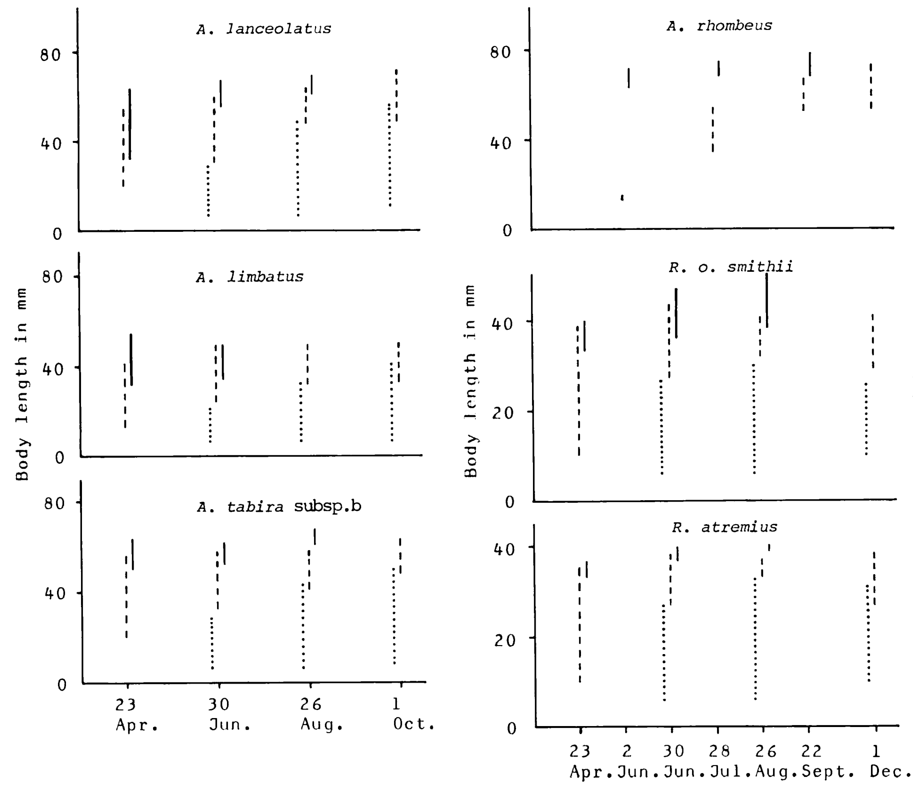


Fig. 4. Seasonal variations of ranges in body length of bitterlings at different ages. Dotted, broken and solid lines represent 0-year-old fish (1976 year class), 1-year-old fish (1975 year class) and 2-year-old fish (1974 year class), respectively.

all stations throughout the year, and the density of adult fish (1-year-old fish) was higher at St. 4 and St. 6 in April and June. There were few 2-year-old fish even in Spring. Since October, 0-year-old fish were the most abundant at St. 7 where only a few adults were found throughout the year. From these facts, it is likely that the juveniles swim out of the mussels, drift down the creek, and then swim upward as they grow.

Acheilognathus limbatus (Fig. 5b), in contrast to the pattern of occurrence of *A. lanceolatus*, was few at St. 6 and never found at St. 7 throughout the year. Thus, it seems that the larvae of this species do not perform a broad migration in the creek as in *A. lanceolatus*. *A. limbatus* of 1 and 2 years of age were markedly and equally abundant at St. 3 and St. 4 in April and June.

Acheilognathus tabira subsp. (b) (Fig. 5c) had a wide distribution in the creek with a very high level of abundance at Sts. 2–6 in April. Most of the fish in April and June were 1 year old, and few fish distribute at St. 7. While, 0-year-old fish occurred in the lower part of the creek since August. Therefore, it is suggested that the juveniles swim up to the upper part of the creek by the following spring.

Acheilognathus rhombeus (Fig. 5d) was more numerous from August to October than from March to June. Only 1-year-old fish were found in March and June, and 0-year-old fish appeared in July at St. 6 and St. 7 where adult fish were never found. It seemed that 0-year-old fish of this species move upward in the creek till September and October. In these months, *A. rhombeus* was the most abundant at St. 3.

Fish of every age of *R. o. smithii* (Fig. 5e) were distributed only in the lower part of the creek throughout the year. In April, 2-year-old fish were as many as 1-year-old fish, but the abundance of 2-year-old fish remarkedly decreases till June.

0-year-old fish were caught from August.

Rhodeus atremius (Fig. 5f) was distributed in wider range than *R. o. smithii*, but inhabited relatively lower part of the creek throughout the year. 0-year-old fish appeared in August. In April, 2-year-old fish were similar in abundance as 1-year-old fish, and then 2-year-old fish decrease in June as shown in *R. o. smithii*.

4. Seasonal fluctuations of the abundance of ripe females and spawning season. Fig. 6a shows the seasonal fluctuations of the abundance of females having ripe eggs. It is obvious that the ripe females of *A. tabira* subsp. (b) were more abundant during March and June than those of other bitterlings. Next higher abundance of ripe females was found in *A. limbatus* and *R. o. smithii* during April and August. *A. rhombeus* was abundant in both September and October. *A. lanceolatus* and *R. atremius* showed relatively low abundance of ripe females in June.

Seasonal fluctuations of the percentages of ripe females to all females caught with casting nets are shown in Fig. 6b. The values in *A. lanceolatus*, *A. tabira* subsp. (b), *R. o. smithii* and *R. atremius* were high in June. Although *A. limbatus* and *A. rhombeus* took the highest value in August and October, respectively, high values in both species appeared from April to June. The results mentioned above suggest that main spawning season of the bitterlings except *A. rhombeus* ranges from May or April to July or August. While, *A. rhombeus* spawns mainly in September and October, and additionally spawns in June when other bitterlings spawn. The results also suggest that all species of the bitterlings except *A. rhombeus* actively spawn together in May and June in the Futatsukawa creek.

5. The variations of sex ratio and abundance of the ripe females along the course of the creek. Sex ratios of both *A. lanceolatus* and *A. tabira* subsp. (b) were strikingly higher, i.e. most of fish were females, in the lower part such as St. 6 and/or St. 7 (Fig. 7a), but few females possessed ripe eggs (Fig. 7b). From these facts, it is likely that females without ripe eggs aggregated at St. 6, because these species were abundant at St. 6 in April and June (Fig. 5a, c). *A. lanceolatus* and *A. tabira* subsp. (b) had main spawning sites at St. 3 and/or St. 4, where fish were abundant and the fish having ripe eggs occupied high percentage of the females. In case of *A. limbatus*, the ripe females took the higher percentage in the upper part (Sts. 1–4) than in the lower part of the creek, and fish were abundant at Sts. 2–4. Therefore, reproduction of *A. limbatus* was mainly carried out in the area of Sts. 2–4.

Station 6 was the only station where many specimens of *R. o. smithii* were caught in April and June. At this station, sex ratio was approximately 1, and the percentage of the ripe females took high value. It seemed that most part of the population of *R. o. smithii* reproduced at St. 6 and its vicinity, where there were few mussels.

Although *R. atremius* was abundant at St. 4 and/or St. 6 in April and June (Fig. 5f) and sex ratio was high at St. 6, none of the ripe female was found at all stations. Therefore, main sites for reproduction of *R. atremius* were unknown.

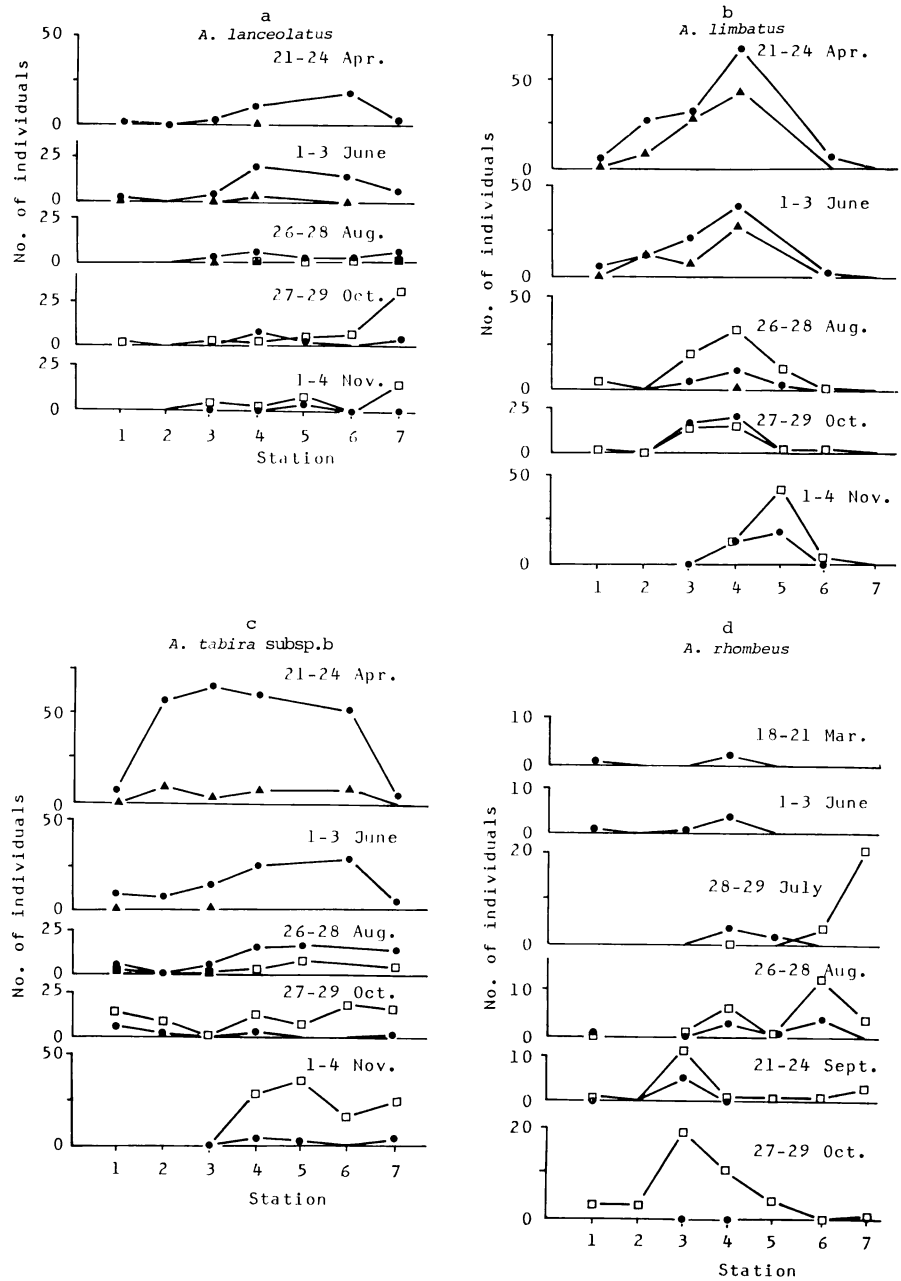
Regarding *A. rhombeus* in the spawning season (27–29 October), abundance of the fish (Fig. 5d) and the percentage of the ripe females were higher at St. 3 and St. 4 than at other stations. The sex ratio was approximately 1 or 2. It is assumed that most of *A. rhombeus* reproduced at St. 3 and St. 4.

Discussion

The results of the present study suggest that three factors affect the distribution of bitterlings in the Futatsukawa Creek.

1. Topographical factors. The inorganic environmental factors affecting the distribution of bitterlings were caused by topographic characteristics of the creek. Nakamura (1969) reported that fluvial fish species of creeks tended to be found in the area of running water as Sts. 1–4 in this study. Both the fluvial and lentic species of bitterlings observed in the present study almost agree with those of Nakamura (1969) who stated that *A. lanceolatus*, *A. limbatus*, *A. tabira* subsp. (b), *A. rhombeus*, and *R. atremius* are fluvial species, and that *R. o. smithii* is lentic species in the creek. However, our study showed that even a fluvial species of bitterlings could live in the lower and the lentic part of the creek, in both reproductive season and term of the young.

2. Factors caused by reproductive acts. The spawning seasons of bitterlings in the Futatsukawa Creek almost agreed with the results of Hirai (1964), Nakamura (1969), Kondo et al. (1984) and Nagata (1985a). However, the term of


a
A. lanceolatus
21-24 Apr.
1-3 June
26-28 Aug.
27-29 Oct.
1-4 Nov.
No. of individuals
Station
b
A. limbatus
21-24 Apr.
1-3 June
26-28 Aug.
27-29 Oct.
1-4 Nov.
No. of individuals
c
A. tabira subsp.b
21-24 Apr.
1-3 June
26-28 Aug.
27-29 Oct.
1-4 Nov.
No. of individuals
Station
d
A. rhombeus
18-21 Mar.
1-3 June
28-29 July
26-28 Aug.
21-24 Sept.
27-29 Oct.
No. of individuals
Station

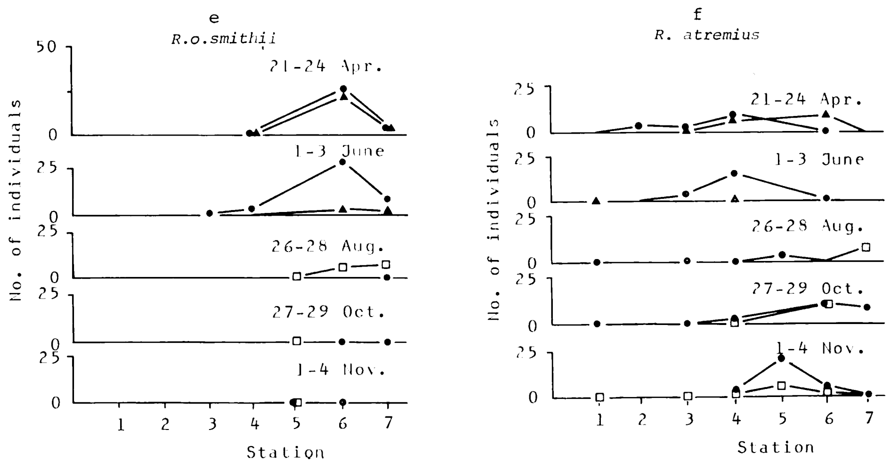


Fig. 5. Seasonal variations of the distribution of bitterlings in the Futatsukawa Creek. Number of fish is from ten casting net operations. Triangles, squares and dots represent 2, 1 and 0-year-old fish, respectively.

spawning season of *A. rhombeus* in Lake Biwa was limited during September and October, and was shorter than that in the creeks of Fukuoka and one in Okayama Prefecture (Kondo et al., 1984).

There were few studies on the distribution of bitterlings during the spawning season. The males and the ripe females of rose bitterling, *R. o. ocellatus* which approaches and lays eggs into the mussels, inhabited shallower part where the density of mussels was relatively high (Nagata, 1985a). Hirai (1964) has reported that high densities of *A. lanceolatus*, *A. tabira tabira* and *A. rhombeus* during their spawning season in Lake Biwa were found in the shore where mussels inhabited. In Futatsukawa Creek, main spawning sites of bitterlings except *R. o. smithii* appear to be commonly located at St. 3 and/or St. 4 where high density of mussels was found. It is, however, necessary to study how to closely correlate the density of spawning fish with the density of mussels in spawning sites.

Nagata (1985a) compared the sex ratio of rose bitterling in spawning season with that in non-spawning season. He found that the proportion of both females and females having ripe eggs was remarkedly higher in the central area than in inshore area of the pond. The results suggested that the ripe females came to spawning sites of inshore in which mussels were perished, and then came back to central area after spawning.

In Futatsukawa Creek, the females without ripe eggs of both *A. lanceolatus* and *A. tabira* subsp. (b) aggregated, and so sex ratios were high in the lower and the stagnant part in which mussels were poor. This phenomenon shows that the effect of reproductive acts on the distribution of bitterlings. It is, however, not clear whether the females of these species migrated between the running part and the stagnant part before and after spawning.

3. Factors due to growth of fish. It is well known that many species of fish, besides the so-called migrating ones, transfer habitats as they grow. Most of the Japanese cyprinid fishes live in the surface layer of stagnant waters in their larval stages, and then move to deeper or running part of river with growth (Nakamura, 1969).

Nagata and Kato (1986) reported that juveniles of *R. o. ocellatus*, *P. parva* and *R. brunneus* gradually transfer their habitats to deeper layer of a pond as they grow. The juveniles of many species of fishes in Lake Biwa live in aquatic plant zone and adjacent area (Maki, 1964; Hirai, 1970). The larvae of *A. lanceolatus*, *A. tabira tabira*, *A. cyanostigma* and *R. o. smithii* began to appear in the surface layer of aquatic plant zone in early May, and they left the place upon reaching approximately 15 mm of body length, with the exception of *R. o. smithii*. The appearance of juvenile bitterlings lasted until mid August. The juveniles of *A. rhombeus* appeared from early May and disappeared in late June (Hirai, 1970).

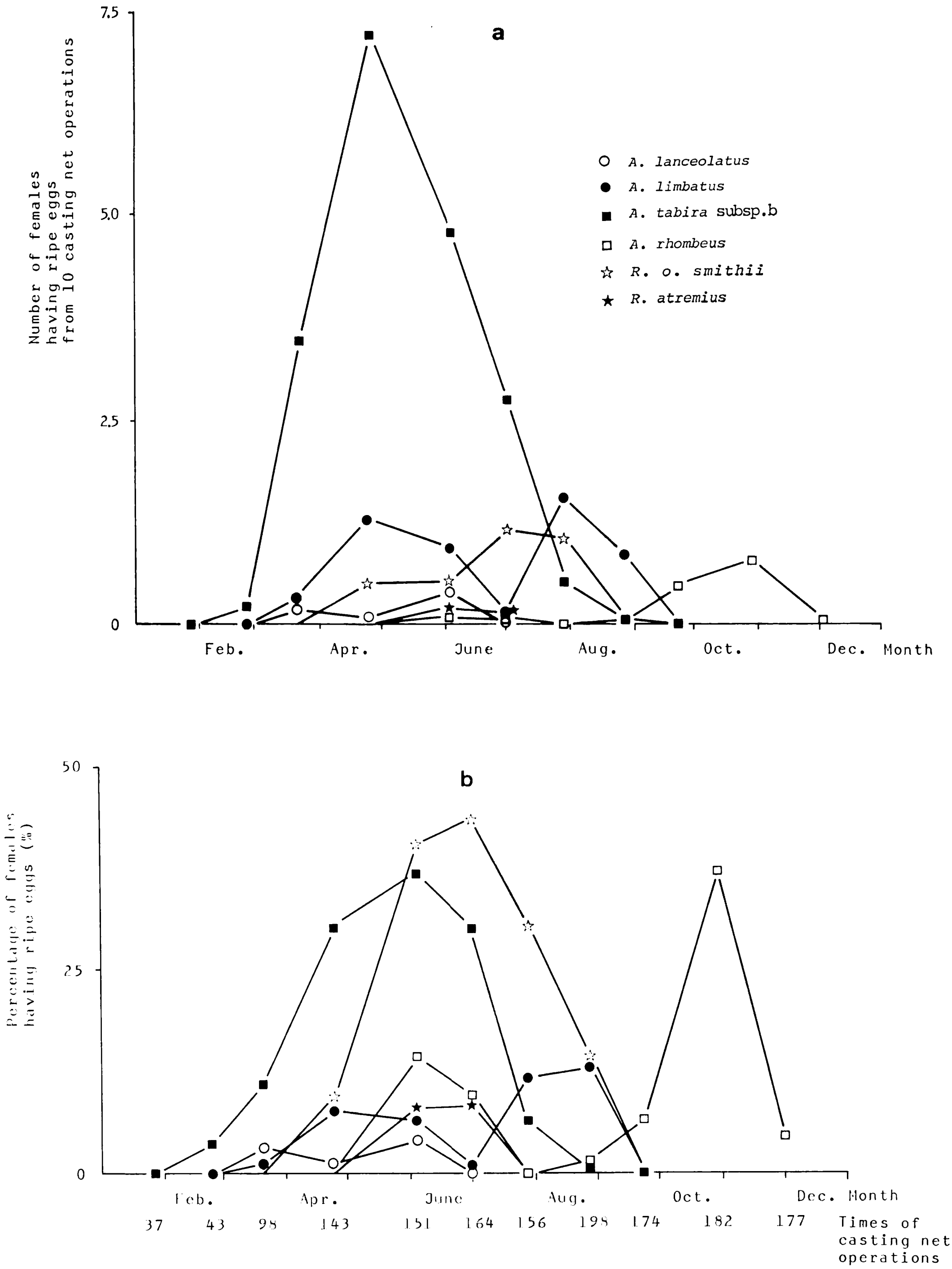


Fig. 6. Seasonal fluctuations of the number from ten casting net operations (a) and of the percentage (b) of ripe females.

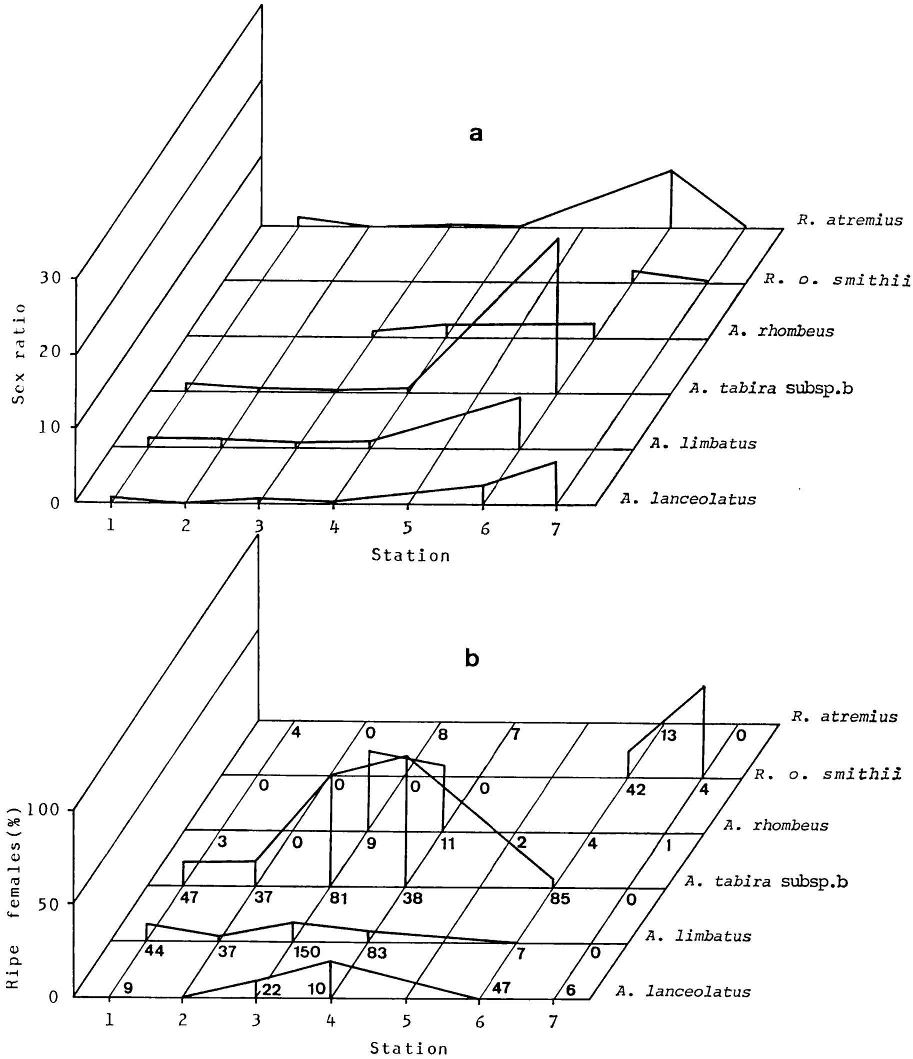


Fig. 7. Sex ratio (a) and the proportion of ripe females (b) in six species of bitterlings. Figures indicate the sample size of specimens collected from 21 to 24 April and from 1 to 3 June, and from 27 to 29 October in case of *A. rhombeus*.

Table 3. Comparison of life modes in consideration of phylogenetic relationship of bitterlings.
* Adult females without ripe eggs.

Phylogenetic group	Species	Spawning season (Month)	Spawning sites	Aggregation of non-ripe females*	Upstream migration of juveniles
I	*Acheilognathus lanceolatus*	Mar.–Jun.	Sts. 3–4	clear	probable
	A. limbatus	Mar.–Aug.	Sts. 2–4	not clear	improbable
II	*A. tabira* subsp. (b)	Feb.–Aug.	Sts. 3–4	clear	probable
	A. rhombeus	Jun. –Nov.	Sts. 3–4	not clear	probable
III	*Rhodeus ocellatus smithii*	Apr.–Aug.	St. 6	not clear	improbable
	R. atremius	Jun.	St. 4	unknown	probable

The time and place of appearance of *A. lanceolatus*, *A. tabira*, *A. rhombeus* and *R. o. smithii* juveniles in the Futatsukawa Creek agreed with the results in Lake Biwa.

The fact that there were many 0-year-old bitterlings except *A. rhombeus* in the lower and stagnant parts of the creek in November suggests that 0-year-old fish tend to move toward the lower part from their spawning sites in upper and running part. *R. o. smithii* lives continuously in the stagnant part through larval and adult stages. 0-year-old *A. rhombeus* may move upward from the stagnant parts to the spawning sites in the running part. The larvae of other bitterlings besides *R. o. smithii* also seem to migrate upward toward spawning season as they grow.

4. Phyletic aspects of the life modes of bitterlings. Ojima et al. (1973) and Arai (1978) reviewed the phyletic relation among the bitterlings. They suggested that the related species were classified into three groups: first group—*A. lanceolatus* and *A. limbatus*; second group—*A. tabira* subsp. (b) and *A. rhombeus*; and third group—*R. o. smithii* and *R. atremius*.

Table 3 shows the life modes: spawning season, spawning sites, aggregation of females whithout ripe eggs in the lower part of the creek and probability of upstream migration of 0-year-old fish toward spawning sites with their growth. Two species in the first group had similar spawning season and spawning sites, but the other two life modes were different with each other. Two species in the second group were different regarding the spawning season and aggregation of non-ripe females, but were same for the other life modes. The third group spawn together in spring and early summer, but other life modes were different between the two species that favored the contrary habitats, i.e. the stagnant condition in *R. o. smithii* and the fluvial condition in *R. atremius*. Nakamura (1969) stated the habitat segregation between both species in the creek of Yanagawa City.

Our results show that no species has all the same sets of the life modes in a same phyletic group.

A coincidence of not only spawning season but also spawning sites among bitterlings may bring about interspecific competition for mussels into which fishes lay eggs. Kondo et al. (1984) and Fukuhara et al. (1984) reported that some species of bitterlings undoubtedly had a preference of species of mussels for spawning. We will describe mussels preference for spawning of bitterlings in the Futatsukawa Creek in another report.

The aggregation of juveniles and females without ripe eggs in the lower and stagnant part may bring good situations for their survivorship and growth, because the lower part is highly eutrophic. While, migration toward spawning sites from the lower part may be disadvantageous for the survival of juveniles and females.

The studies on ecological significance of other life modes are necessary to know the mechanisms of coexistence of the bitterlings in a creek.

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福岡県の水路に生息する6種のタナゴ類の分布の比較

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柳川市を流れる矢部川水系二ツ川に生息する6種のタナゴ類の分布を 1976 年に調査した．本水路の上流部は流水域であり，下流部は静水域である．ヤリタナゴ，セボシタビラ，カネヒラそしてカゼトゲタナゴは水路の流域を広く使用していた．アブラボテはより好流水性であり，ニッポンバラタナゴは主に静水域に生涯生息する．繁殖期には，ニッポンバラタナゴを除くすべての種類が二枚貝類の多い中流域で主に産卵するものと推定された．完熟卵を保有しないヤリタナゴ，セボシタビラそしてカゼトゲタナゴの成雌は下流の静水域に集合していた．これらの種とカネヒラの幼魚は下流域で成長し，そして繁殖期までに産卵場に遡上するものと推察された．6種のタナゴ類の生活様式を系統的類縁関係をもとに比較したところ，同一の類縁群内の種間では異なる生活様式の組合わせを持つことが分った．

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