人工湖建設によるイワナの生活史の変化

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Change of the Life Cycle of Japanese Charr Following Artificial Lake Construction by Damming

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We describe several reproductive characteristics of two types of Japanese charr *Salvelinus leucomaenis* found in Arimine Lake, an artificial lake-inlet stream system in Toyama, Japan. Larger-sized individuals, which migrate downstream to the lake and grow to maturity there, later migrate up several inlet streams to spawn. Smaller-sized individuals, however, are resident in streams and spawn there. These types are respectively similar to sea-run or lake-run and stream resident types of other salmonid fish. During the 26 years following lake construction by damming, the migratory life cycle of part of the population of this charr appears to have changed from the fluvial form. During spawning activity, mature females and males presumably form pairs of each type, with the pair formation assortatively depending upon their body size.

As with other anadromous charrs in the northern part of their distribution, Japanese charr (white spotted charr) *Salvelinus leucomaenis* includes both the sea run types, most of which are female and some of which are male, and the stream resident type males within a population.[1-3] In the southern part of the distribution range, however, all populations of *S. leucomaenis* have been land-locked in mountain streams and have adapted to a dwarf form and fluvial life cycle.

Although some fragmentary reports have appeared on the ecology and morphology of land-locked stream populations of this charr,[4-7] little is known of its life cycle in the lake-inlet stream systems at the southern part of the distribution, nor of the influence of artificial lake construction upon the life cycle.[8]

Following the construction of Arimine Lake for hydroelectric use by damming in 1962,*4 lacustrine or migratory Japanese charr, which had originally been of the fluvial type dwelling in the head waters of the Joganji River, Toyama Prefecture, Japan, have appeared in the artificial lake and its inlet streams.

In this paper we described several reproductive characteristics of this charr, with special reference to the change of life cycle from the fluvial to the migratory type.

Study area and Methods

Arimine Lake is situated in a mountainous area at an elevation of about 1088 m above sea level and nearly 36°N 137° in central Honshu (Fig. 1). The lake, 5.1 km^2 surface area and 120 m maximum depth, was artificially constructed in 1962 by damming the upper reach of the Joganji River for hydroelectric power. The limnological characteristics of the lake have been reported by Hori *et al.**5 Prior to this, the entire population of *S. leucomaenis* were typically fluvial and dwarf (non-anadromous). According to Yamamoto (unpublished), from late August this charr appears to migrate up to several inlet streams of the lake to spawn there during mid October to early November.

From 7th September to 12th October, 1988, fish specimens were collected from Nishidani Stream, 2–5 m width, and from the stream mouth by gill, cast and hand nets. During the entire

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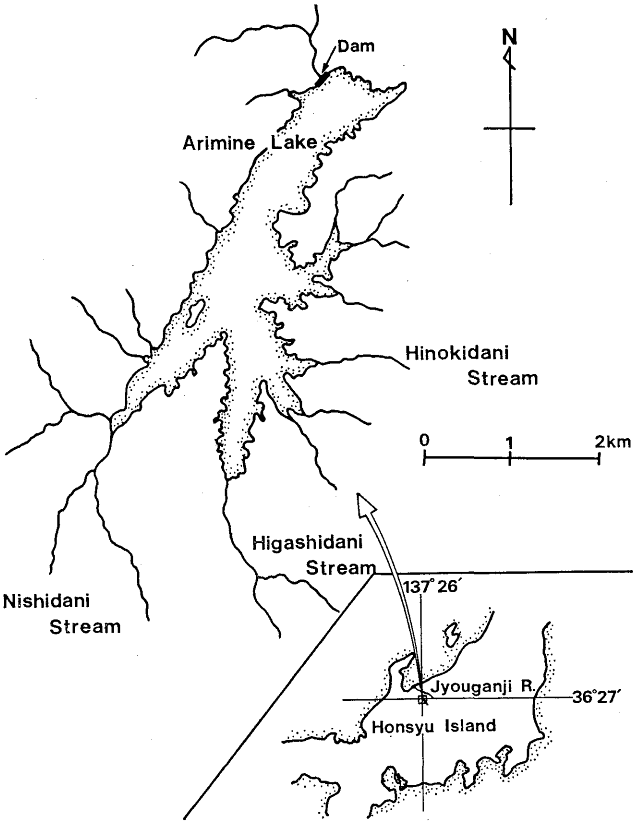

Fig. 1. Location and map of the Arimine Lake system showing Nishidani Stream used in this investigation.

study period the following fish species were collected and/or observed; *Oncorhynchus mykiss*, *Hypomesus transpacificus*, *Cyprinus carpio*, *Carrasius cuvieri*, *Pungitius pungitius*, *Phoxinus lagowski*, *Cottus polux* and *S. leucomaenis* (see also[8]). The latter 3 species are native fish to this system. One hundred and eightly seven specimens of *S. leucomaenis* were collected, including 80 immature fish. Fork length, body weight and gonad weight of each specimen was measured, and their sex and degree of ripeness was examined. For most specimens, otoliths were removed and preserved in 70% alcohol immediately following collection. These were later used to determine the age and the individual growth rate by examining the distance between each winter zone of the otolith. We also recorded the body size (total length) of *S. leucomaenis* pairs estimated from comparison with marked fish or stone size in stream bed, which was measured, by direct visual observation during spawning on 18th and 19th October, 1988 and 12th and 27th October, 1989. The exact error of total length observed was not examined, however.

Results and Discussion

Samples of *S. leucomaenis* collected during the study period included both the mature male and female of two types. Smaller sized individuals (termed S-type) at the mature stage were easily distinguishable from larger sized individuals (termed L-type) not only by body size, as mentioned below, but also by body colur and sexual dimorphism (Fig. 2). Male and female S-type individuals exhibited a light yellow abdomen and dark-brown body colour with some typical parr marks, showing precocious characteristics, whereas L-type individuals, particularly females, exhibited a light-silver body colour without clear parr marks, and the males develop a pronounced kype.

The S-type individuals were usually smaller in body size (female $\bar{x}=156.7$ mm± 17.6 sd, N=3, male $\bar{x}=162.1\pm 21.6$, N=19) than the L-type (female $\bar{x}=332.0\pm 46.1$, N=42, male $\bar{x}=325.3\pm 41.3$, N=43) (Fig. 3). Mature adults of these two types showed a discrete size distributions.

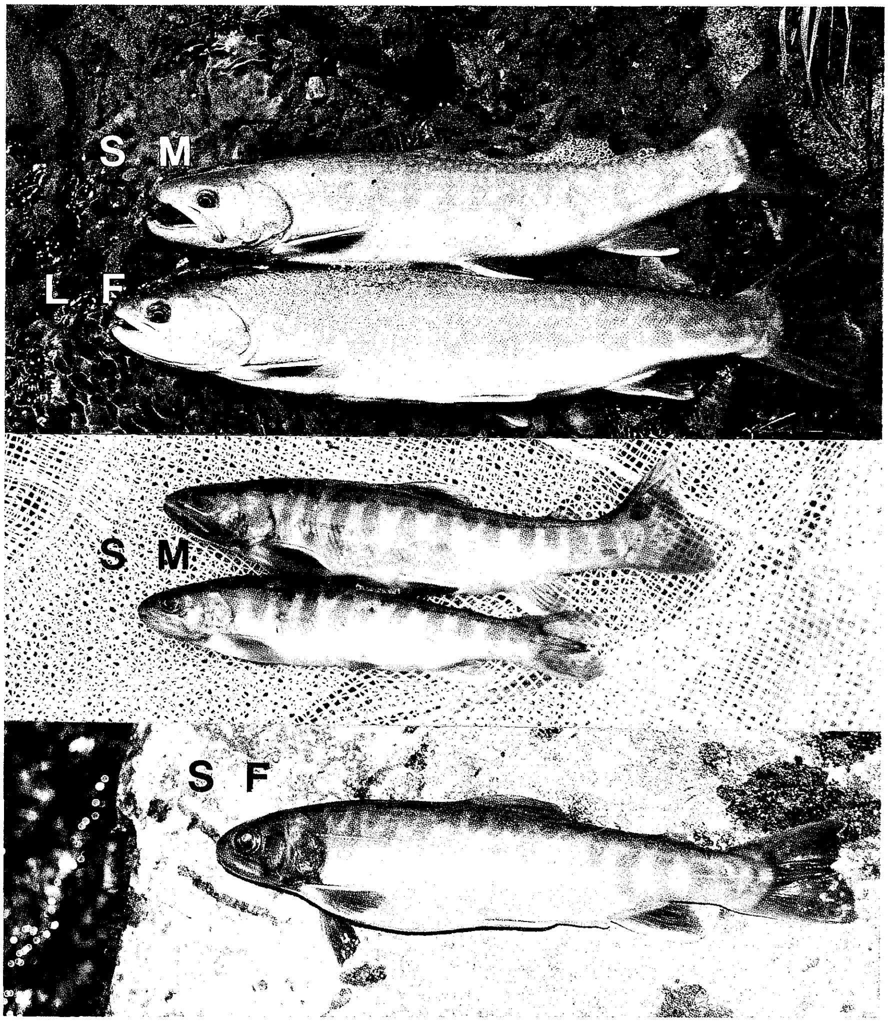

Fig. 2. Photographs of L-type male (LM-33.5 cm F.L.) and female (LF-38.3 cm) and S-type males (SM-15.3 cm and 13.4 cm) and female (SF-17.3 cm) of *S. leucomaenis* collected in the Nishidani stream in late September, 1988.

S-type males were more precocious (from 1^+ of age) than were L-type males (2^+ of age), but this trend were not evident between females (2^+ of age in both S- and L-type). The sex ratios of individuals collected showed strong male bias in the S-type (4: 1), but an even 1: 1 ratio in the L-type. S-type females appeared to be much less abundant. No significant difference was evident between the two types in the gonad-somatic index (GSI) of both sexes (S-type: female, $\bar{x}=13.51\pm3.92$ sd, $N=3$; male $\bar{x}=0.90\pm0.39$, $N=6$ and L-type: female, $\bar{x}=11.00\pm2.41$, $N=18$; male, $\bar{x}=0.94\pm0.29$, $N=27$, t-test, $P>0.1$ for female, $P>0.5$ for male).

Interestingly, the body size of the silvery fish appeared to be the largest of all individuals in the same age cohort (1+ of age) and larger than that of the S-type (both the female and male) at the first maturation of age (Fig. 3). This suggests that smoltification of this charr occurs through the same mechanism as with other migratory salmonid fish[9-11] and fluvial type of charr.[12] A significant relationship was recognized between fork and otolith length ($y=0.94+0.11\chi$, $N=158$, $r=0.97$, $p<0.01$), but no significant difference was evident in otolith radius length from the focus to the first winter zone between either sex of both the S- and L-types, excluding the S-type female (Table 1). Examination of the otolith radius length from the first to second winter zone revealed an incipient wider growth-zone, distinct from the growth-zone of the central part of the

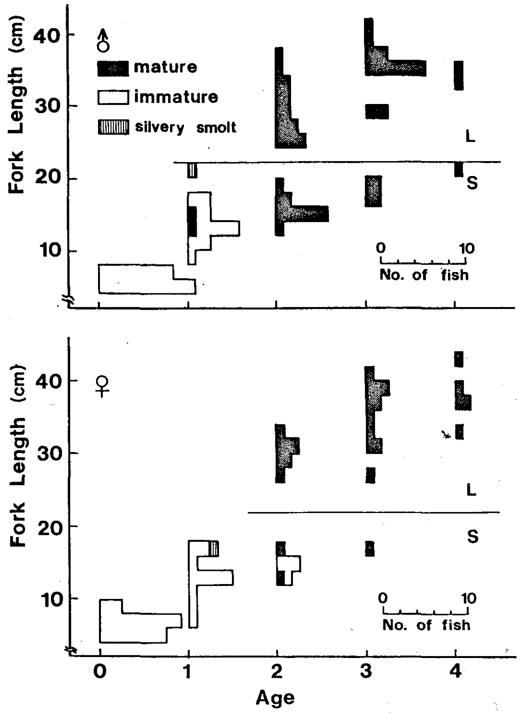

Fig. 3. Frequency distribution of fork length of each age cohort. S and L show S- and L-type, respectively.

otolith, around the edge in the L-type, whereas in the S-type, no such growth-zone was observed. The former coincides with the lake-growth zone and the latter with the river-growth zone, as also seen in anadromous and stream resident individuals of other salmonid fish (e.g.[13,14]). Therefore, the difference of body size between the S- and L-type is due to the difference of growth rate after 1^+ of age, when the L-type individuals are expected to migrate down to the lake. Most of the characteristics of the L- and S-types are respectively very similar to those of sea or lake run types, and stream resident types of other charrs (e.g.[15-17]). Therefore, as with the lacustrine charr (e.g. Miyabe charr of Dolly varden, *S. malma*), the life cycle of lake run and stream resident types of this charr in Arimine Lake-inlet stream system, appears to have changed from the fluvial life cycle during the 26 years following dam construction. However, one important difference is that a few stream resident females occur in the charr of the Arimine Lake-inlet stream system, which is rather rare in other anadromous form of charr.

From records of the body size of 12 pairs observed during spawning activity (Table 2), two tendencies were evident: (1) females and males

Table 1. Otolith radius length between the focus and each winter zone in S- and L-types

Type	Sex	Otolith radius length (mm)			
		1st	2nd	3rd	4th
L-type	Male	0.56±0.09 (28)*	1.14±0.13 (32)	1.55±0.14 (20)	1.91±0.10 (18)
	Female	0.55±0.09 (19)	1.07±0.13 (21)	1.50±0.13 (22)	1.84±0.17 (14)
S-type	Male	0.55±0.11 (18)	0.95±0.09 (18)	1.24±0.08 (15)	1.44±0.06 (5)
	Female	0.63±0.02 (3)	0.96±0.01 (3)	1.12±0.04 (3)	1.38 (1)

* Mean±SD (Number of specimen).

Table 2. Total length (TL: cm) of paired fish and satellite males at each spawning site

Date	TL of pairs		TL of satellite male		Bheavioural stage of female
	Male	Female	S-1	S-2	
Oct. 18th '88	L 33	L 38	L 26	S 16	Digging
	S 16	S 18	—	—	Digging, Crouching
	L 40	L 37	—	—	Digging
Oct. 19th '88	L 38	L 40	—	—	Digging
	L 30	L 32	S 14	—	Digging
	L 38	L 36	—	—	Digging, Crouching
	L 38	L 38	S 18	—	Digging
	S 18	S 17	—	—	Digging
Oct. 12th '89	L 40	L 30	—	—	Digging
	L 25	L 30	—	—	Digging
	L 35	L 30	L 28	S 13	Digging
Oct. 27th '89	L 30	L 25	—	—	Digging

L, L-type; S, S-type; S-1, satellite male No. 1; S-2, satellite male No. 2.

presumably form pairs of each type, and (2) males of the S-type and subordinates of the L-type attend to spawn as satellites or sneakers as seen in other salmonid fish with stream resident types.[16-18] Since their body size was usually smaller than that of the paired males, evolutionary theory suggests them as requiring this alternative mating strategy. The significant correlation of body size recognized between females and males of each pair ($y=8.19+0.79x$, $N=12$, $r=0.74$, $p<0.05$), suggests mating to be assortative by body size at pair formation, as reported in other salmonid.[19,20] L-type males were also observed to attack and drive S-type females away. Miyabe charr, *S. malma* which has a life cycle similar to that of *S. leucomaenus* of the Arimine Lake-inlet stream system, also form pairs by type (Maekawa, unpublished). Detailed investigations are needed on the life cycle and mating systems of migratory charr, and should contribute greatly towards understanding the evolution and speciation of salmonid fish.

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