Japanese Journal of Ichthyology
Vol. 37, No. 2 1990

魚類学雑誌
37巻2号 1990年

Restricted Movement of the Fluvial Form of Red-Spotted Masu Salmon, *Oncorhynchus masou rhodurus*, in a Mountain Stream, Central Japan

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Abstract Movement of the fluvial form of red-spotted masu salmon (1^+ and older), *Oncorhynchus masou rhodurus*, was studied using mark-recapture methods in a Japanese mountain stream. Most (63–91%) adult salmon were recaptured in the pool in which they were marked. The rest of the salmon moved upstream or downstream <20 m during the non-breeding period. The proportion of the salmon moving increased slightly during the breeding period, but did not exceed 66%. The distance moved was also more variable during this period. The proportion of the smaller salmon which moved was larger than that of the larger fish during the non-breeding period. Conversely, during the breeding period, larger fish moved more frequently. Sedentary behaviour and local movements of adult salmon seem to be affected by their social relationships.

Restricted movement is a general aspect of the behaviour of stream fishes (Gerking, 1959). For many stream-resident salmonids it is known that, after early juvenile stages, the fish remain within a limited area of stream for long periods (Shetter, 1937; Schuck, 1945; Miller, 1957; Saunders and Gee, 1964; Burnet, 1969; Solomom and Templeton, 1976; Harcup et al., 1984). Saunders and Gee (1964) reported that Atlantic salmon parr, *Salmo salar*, were seldom observed away from the particular small areas which were designated as their homes in a small coastal New Brunswick stream. Bachman (1984) also demonstrated that the home range of most individuals of wild brown trout, *Salmo trutta*, was established in the first or second year of life and changed little thereafter in a central Pennsylvania stream by direct observation for three consecutive years.

However, little is known about the movement of masu salmon, *Oncorhynchus masou*, in streams except for studies on sea-ward migration of anadromous form, *O. masou masoua* (Ishida, 1967; Kubo, 1976). The purpose of this study was to investigate movement of adults of the fluvial form of red-spotted masu salmon, *O. masou rhodurus*, in a typical mountain stream in central Japan using mark-recapture methods.

Study site and methods

The Hirakura Stream is a headwater tributary of the Kumozu River, which discharges into Ise Bay on the east coast of Kii Peninsula in central Japan (Fig. 1). The field study was performed in the Higashimata Stream, a small tributary of the Hirakura Stream. This 1.5 km long tributary is 2–4 m wide and has an about 17% gradient (determined from map). The streambed is mainly bedrock and boulders with small areas of sand or gravel. It is a typical mountain stream with pools separated by cascades or small waterfalls of about 50–300 cm vertical drop. Most pools (126 of 144) are shorter than 10 m ($\bar{x}=6.3$, ranged 1.0–30.4 m, SD=5.1, n=144). Pools were numbered from 1 to 144 and distances between them were measured in order to record the locations where each fish was captured. The study area was described in detail by Nakano and Nagoshi (1985). The Higashimata Stream is inhabited mainly by red-spotted masu salmon, although Chinese minnow, *Phoxinus lagowski*, Japanese sculpin, *Cottus hilgendorfi*, lizard goby, *Rhinogobius flumineus*, reddish bullhead, *Linobugrus reini* and Japanese eel, *Anguilla japonica* are present.

Red-spotted masu salmon were marked and recaptured in the stream from April to November in 1986 and 1987. Salmon larger than 9.0 cm SL were

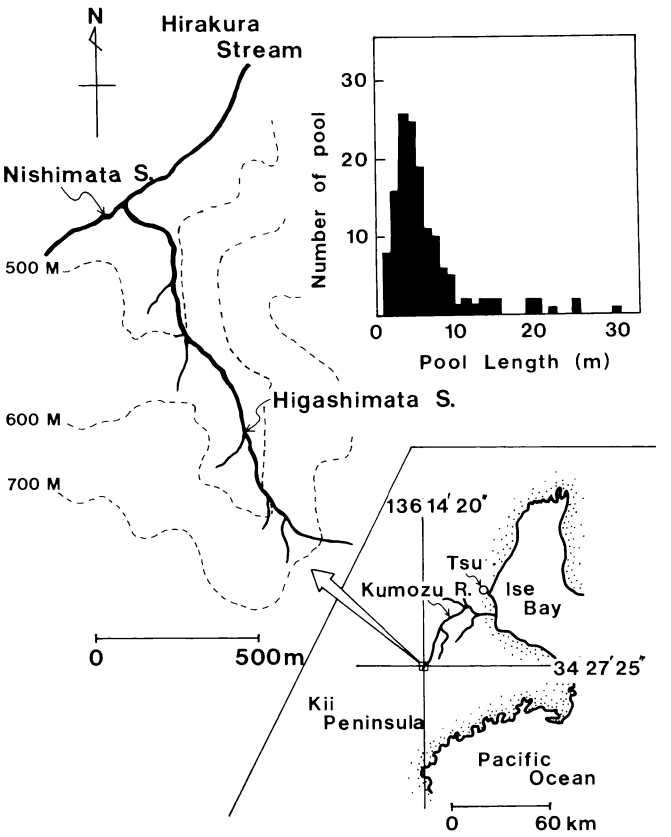

Fig. 1. Map of the Hirakura Stream showing contours of 100 m elevation, and frequency distribution of the pool length in the Higashimata Stream.

caught by angling or additionally a casting net, and measured to the nearest 1.0 mm. Fish were individually marked and their scales were collected for age determination at first capture and then released in the pool in which they were captured. Numbered plastic anchor and ribbon tags were used to mark fish in 1986 and 1987, respectively. Fish were captured and marks applied or recorded every two or three days during the study periods. Movement of recaptured salmon was estimated from the distance between the pools where the fish was marked and recaptured.

Results

A total of 1,165 individnals of red-spotted masu salmon, ranging 9.0–22.7 cm SL (1+ and older), were marked and released. However, 10–20% of them showed evidence of tag loss when recaptured. Of the marked salmon, 519 (44.5%) were recaptured from 1 to 7 times.

More than 60% of the salmon were recaptured in the same pools in which they were originally marked except October and November 1986, April, October and November 1987. Further, in 8 of the 11 remaining months, over 80% of the salmon were recaptured in the same pools where they were previously marked (Table 1).

The proportion of salmon that moved (41.7–66.7 %) during the breeding period (October and November) was significantly larger than that (9.1–47.2 %) of the non-breeding period (April–September); (Mann-Whitney U-test, $p<0.01$). The time when the marked fish moved could not be accurately determined, especially when the period between captures was relative long. However, nearly half of the salmon recaptured during the breeding period (6 of 12 (50.0%) in October, 8 of 15 (53.3%) in No-

vember 1986, 4 of 8 (50.0%) in October and 3 of 8 (37.5%) in November 1987) had been previously captured within one month.

In April 1987, 17 of 36 (47.2%) recaptured salmon were captured in pools other than those where they were marked. It was likely that some of the salmon moved during the 1986 breeding period since 12 of 17 (70.6%) were marked before October 1986.

The proportion of the small (<16 cm) salmon that moved during the non-breeding period was significantly larger than that of large (≧16 cm) salmon ($X^2=4.63$, $p<0.05$). Conversely, during the breeding period, the proportion of large salmon moved was cosiderably larger than that of small salmon ($X^2=9.37$, $p<0.01$) (Table 2).

Of 151 salmon that had moved, 102 (67.5%) were recaptured in downstream pools and 49 (32.5%) in upstream pools (Table 3). Incidence of downstream movement was significantly greater than upstream movement in both 1986 ($X^2=6.80$, $p<0.01$) and 1987 ($X^2=13.76$, $p<0.001$). More than twice the number of salmon moved downstream as moved upstream in both years.

Most of movements were shorter than 20 m from the original capture location (74 of 98 in 1986, 28 of 53 in 1987), which correspond to about 2–3 pools in the Higashimata Stream. Maximum distance of downstream movement was 360 m, recorded for the fish which was 13.7 cm SL from October 1986 to April 1987, and 35 m upstream for 14.2 cm SL fish from September to October 1986. Mean distance of downstream movement ($\bar{x}=23.6$ m, SD=37.2, n=62 in 1986, $\bar{x}=65.8$ m, SD=84.9, n=41 in 1987) was significantly larger than upstream movement ($\bar{x}=9.1$ m, SD=6.5, n=36 in 1986, $\bar{x}=15.9$ m, SD=8.8, n=12 in 1987) in both 1986 (t-test, $p<0.05$) and 1987 ($p<0.025$). The mean distance of movement during the breeding period ($\bar{x}=31.6$ m, SD=49.8, n=27 in 1986, $\bar{x}=58.0$ m, SD=90.1, n=16 in 1987) was significantly larger than during the non-breeding ($\bar{x}=14.6$ m, SD=17.5, n=71 in 1986, $\bar{x}=39.3$ m, SD=46.0, n=37 in 1987) in 1986 (t-test, $p<0.005$) but not in 1987 ($p>0.1$).

Discussion

These observations suggested that most red-spotted masu salmon remained in particular pools, and of those that do move, most moved short distances upstream or downstream. Also, movements increased slightly during the breeding period.

A number of freshwater fishes, including some salmonids, which spend their entire lives in streams also make extensive spawning migrations within the streams (Northcote, 1978). Solomon and Templeton (1976) demonstrated that brown trout migrated upstream during spawning to winterbournes area in a spring-fed English chalk stream. By contrast, in the Hirakura Stream representing Japanese mountain streams, about 50% of the red-spotted masu salmon remained in their home pools during the breeding season and both down- and upstream movement was generally restricted to a short distance. Northcote (1978) noted that spatial separation between rich feeding habitats and suitable

Table 1. Number (%) of the captured red-spotted masu salmon that moved or were resident in the same pool in each month of 1986 and 1987.

	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Total
					1986				
Moved	7	4	18	30	5	7	12	15	98
(%)	(28.0)	(12.9)	(27.3)	(37.6)	(17.9)	(11.3)	(50.0)	(41.7)	(27.7)
Resident	18	27	48	52	23	55	12	21	256
(%)	(72.0)	(87.1)	(72.7)	(63.4)	(82.1)	(88.7)	(50.0)	(58.3)	(72.3)
					1987				
Moved	17	8	6	2	1	3	8	8	53
(%)	(47.2)	(19.5)	(18.2)	(12.5)	(9.1)	(17.8)	(44.4)	(66.7)	(28.8)
Resident	19	33	27	14	10	14	10	4	131
(%)	(52.8)	(80.5)	(81.8)	(87.5)	(89.9)	(82.4)	(55.6)	(33.3)	(71.2)

Table 2. Number (%) of the red-spotted masu salmon of two size classes that moved or remained resident during the non-breeding (April–September) and breeding (October–November) periods.

	Standard length	Moved (%)	Resident (%)	Total
Non-breeding period	< 16 cm	89 (26.6)	245 (73.4)	334
	≧ 16 cm	19 (16.7)	95 (83.3)	114
	Total	108 (24.1)	340 (75.9)	448
Breeding period	< 16 cm	24 (37.5)	40 (62.5)	64
	≧ 16 cm	19 (73.1)	7 (26.9)	26
	Total	43 (47.8)	47 (52.2)	90

Table 3. Directions and distances that red-spotted masu salmon moved in 1986 and 1987. D, downstream movement; U, upstream movement.

1986

Distance (m)	Apr.		May		Jun.		Jul.		Aug.		Sep.		Oct.		Nov.		Total		
	D	U	D	U	D	U	D	U	D	U	D	U	D	U	D	U	D	U	(%)
–10	1		3		4	6	8	8	2	2	2	1		2	2	2	22	21	(43.9)
10–20	4				1	3	8	3			3		2	1	4	2	22	9	(31.6)
20–30	1		1		1	1		1					2	2	2		7	4	(11.2)
30–40					1		1		1					2			3	2	(5.1)
40–50																	0	0	(0.0)
50–60	1				1										1		3	0	(3.1)
60–70															1		1	0	(1.0)
70–80																	0	0	(0.0)
80–90											1						1	0	(1.0)
90–100															1		1	0	(1.0)
100–											1		1				2	0	(2.0)
Total	7	0	4	0	8	10	17	12	3	2	7	1	5	7	11	4	62	36	(100.0)

1987

Distance (m)	Apr.		May		Jun.		Jul.		Aug.		Sep.		Oct.		Nov.		Total		
	D	U	D	U	D	U	D	U	D	U	D	U	D	U	D	U	D	U	(%)
–10	3	1	1			1	1	1			3		3	1	1	1	12	4	(30.2)
10–20	4	1		3	1										3	2	8	6	(26.4)
20–30		2													1		1	2	(5.7)
30–40			1												1		2	0	(3.8)
40–50					2								1				3	0	(5.7)
50–60	2																2	0	(3.8)
60–70																	0	0	(0.0)
70–80																	0	0	(0.0)
80–90																	0	0	(0.0)
90–100													1				1	0	(1.9)
100–	4		2		2				1				2		1		12	0	(22.6)
Total	13	4	5	3	5	1	1	1	1	0	3	0	7	1	5	3	41	12	(100.0)

spawning sites might bring about extensive migrations in some freshwater fishes. However, spawning of fluvial form of masu salmon occurs near the downstream end of each pool and fish did not congregate into any particular spawning ground (Maruyama, 1981; Nakano, pers. observ.). Therefore, spawning sites of adult masu salmon are assumed to be close to feeding sites within short reaches of the stream, possibly within one pool. We suspect that the relatively limited movement of masu salmon even in the breeding period reflects the juxtaposition of areas suitable for feeding and spawning. Miller (1957) reported similar findings for stream-resident cutthroat trout, *Oncorhynchus clarki*, in a small Alberta mountain stream. He concluded that the whole life of the trout, including spawning, was spent within their home pools.

In the Hirakura Stream, 60–80% of masu salmon adults were generally recaptured in the pools, where they were marked during the non-breeding period, which is consistent with observations on many stream-resident salmonids (Miller, 1957; Burnet, 1969; Solomon and Templeton, 1976; Harcup et al., 1984). Why do most of the adult masu salmon exhibit such sedentary behaviour? Many authors report that stream resident salmonids form dominance hierarchies or territories (Newman, 1956; Kalleberg, 1958; Chapman, 1962). The social relationship is possibly organized among inhabitants of small strech of the stream such as one local pool. Individual recognition, which was referred to for some fishes (e.g., Gorlick, 1976; Katano, 1985), is expected to develop more intensively among fish that remain within a restricted area for a fairly long time. Individual recognition is usually advantageous for each individual in a social group because stable dominance-subordinate relationships prevent individuals from wasting energy and risking injury by excessive aggressive behaviour. Furthermore, the fish remaining in a restricted area appear to learn characteristics of their local physical environment which allows them to use efficiently foraging and refuge sites in their home ranges. For example, Bachman (1984) reported that wild brown trout learned their home range thoroughly and used several precise foraging and refuge positions with little lost time or energy. He proposed that this behaviour enabled the fish to grow faster and to avoid predation.

On the other hand, another important observation in this study is that 10–30% of masu salmon did in fact move short distances, usually within 20 m from their home pool during the non-breeding period. Chapman (1962) demonstrated that aggressive behaviour of dominant coho salmon fry, *Oncorhynchus kisutch*, caused movement of smaller subordinates from a specific pool. In the Hirakura Stream, smaller salmon (9–16 cm), which were expected to be subordinate in local social groups, tended to move more than larger fish. Therefore, we suggest that the local movement of adult masu salmon during the non-breeding period is affected by social relationships among fish inhabiting the same pool. Detailed investigations are needed on the relationship between movement and the social structure among fish in individual stream pools.

Aknowledgments

We are sincerely grateful to Dr. K. D. Fausch, Colorado State University, Dr. T. Tanaka, Kyoto University, Prof. K. Ishigaki and Mr. T. Hino, Hokkaido University, for invaluable advice during the study and critical reading of an early manuscript. We are also grateful to Dr. I. Shimaji and other staff of Mie University Experimental Forest and Mr. T. Sakamoto of Kawakami Fish Culture Farm for their kindness during our work. We also thank Mr. and Mrs. Koido, who provided us a pleasant room during our field study.

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(Received October 25, 1989; accepted April 14, 1990)

山地渓流におけるアマゴの河川内移動

中野　繁・可知　隆・名越　誠

本州中央部の典型的な山地渓流において，陸封型アマゴ (*Oncorhynchus masou rhodurus*) の河川内移動を個体識別タッグを用いた標識再捕法によって調査した．非繁殖期には，60–80% のアマゴがある特定の淵に定住していた．残り 20–40% のアマゴには，上下流両方向への移動がみられたが，その距離は 20 m 以下の小規模なものが多かった．繁殖期には，移動する個体の割合が増加し 40–60% となり，移動距離もわずかに増加した．非繁殖期には，小型個体に移動が多くみられたが，繁殖期にはむしろ大型の個体がよく移動した．アマゴにみられる高い定住性は，社会関係の中での他個体の認知や摂餌場所及び隠れ家の効率的な利用に役立つと考えられた．また，非繁殖期における小規模な移動には，個体間の社会関係が関与すると考えられた．

(中野：098–25 北海道中川郡音威子府村　北海道大学農学部中川地方演習林；可知：514 津市江戸橋　三重大学水産学部；名越：630 奈良市北魚屋西町　奈良女子大理学部)