Environmental Biology of Fishes (2005) 74: 1–7
DOI 10.1007/s10641-004-6115-z

Morphology, stomach contents and growth of the endangered salmonid, Sakhalin taimen *Hucho perryi*, captured in the Sea of Okhotsk, northern Japan: evidence of an anadromous form

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Received 8 January 2004 Accepted 18 October 2004

Key words: conservation, diadromous, linkage between rivers and sea, management, migration, rare species

Synopsis

We describe a total of 25 anadromous Sakhalin taimen *Hucho perryi* collected on the coast of Sarufutsu, northern Hokkaido, Japan in June 1997 and 1999. We examined morphology, stomach contents and growth of three anadromous taimen (one male and two females) in detail, which were preserved in good condition. The three taimen were aged and one female still had some eggs retained in her abdomen. The stomach contents of the three taimen consisted of sand lance *Ammodytes personatus* Girard and sculpin *Triglops* sp. On the basis of scale analyses, the growth rate of the three taimen was estimated by using the back-calculation method, and the highest rates were observed at young ages. Guanine pigmentation was present at the base of the caudal fin of each taimen and is considered as a potential morphological trait to differentiate anadromous from fluvial specimens. Another anadromous taimen, of which some individuals had reared for more than 3 years in seawater are also reported. For the conservation of this rare and endangered species, their migration route between rivers and sea should be protected.

Introduction

The Salmonidae consists of four genera, with the genus *Hucho* considered as rather primitive in this family (Holčik et al. 1988). This genus is composed of five species distributed on the Eurasian continent. They are iteroparous and reproductive up to about 16 years of age with a large body size occasionally reaching ca. 60 kg (Berg 1962, Gritsenko et al. 1974, Holčik et al. 1988, Edo et al. 2000). The Sakhalin taimen *Hucho perryi* (Brevoort) is characterized by the small number of lateral line scales (Kimura 1966). Its distribution is limited to the far northeast of Asia, from the Primorye region of Siberia (south of Amur River) to Sakhalin Island, southern Kurile Islands and the northernmost island of Japan, Hokkaido (Kimura 1966, Holčik et al. 1988). Unlike the other species of the genus, which are strictly resident in freshwater without migrating to the sea, only the Sakhalin taimen has been considered as an anadromous species (Gritsenko et al. 1974, Holčik et al. 1988). Actually, some Sakhalin taimen have been collected from estuarine areas (Gritsenko et al. 1974, Nakano 1992) or the brackish Lake Akkeshi (Kawamula et al. 1983). However, there is no documented information in the literature of anadromous Sakhalin taimen being collected in the sea so far, and little is known about this aspect of the life history. In Japan this species is now especially very rare and has been classed as endangered in Japanese river systems primarily because of severe habitat degradation and fragmentation including stream channelization and dam construction (Japanese Ministry for the Environment 2003).

For the adequate management and conservation action of this endangered species, it is necessary to examine its anadromous life history and consider the relationship between its habitat in the river and the sea. In this paper, we provide evidence of anadromous Sakhalin taimen collected from the Sea of Okhotsk, and describe their morphology, stomach contents and growth. Although the sample size is small, information on this species in the sea is valuable since it is difficult to obtain owing to its rarity and will contribute to the emphasis on the importance of linkage between rivers and the sea for the conservation of this rare species.

Materials and methods

In Sarufutsu village (45° N, 142° E) situated in northern Hokkaido, Sakhalin taimen inhabit four low-gradient rivers: the Sarufutsu River, Sarukotsu River, Chiraibetsu River and Onishibetsu River, which arise from low elevation mountains (<500 m) and flow into the Sea of Okhotsk (Figure 1) (Edo et al. unpublished). A relatively large population of Sakhalin taimen is sustained especially in the Sarufutsu River based on Fukushima's (2001) report of at least 309 redds of Sakhalin taimen counted in this river system. In Sarufutsu village, which faces the Sea of Okhotsk, the coastal fishery is active and many kinds of fishes such as chum salmon *Oncorhynchus keta*, masu salmon *O. masou*, pink salmon *O. gorbuscha*, flounders, family Pleuronectidae, and so on are landed all the year round. In this region, there have been some unconfirmed reports that anadromous Sakhalin taimen have previously been captured in the Sea of Okhotsk by fisherman. So we set out to collect information about anadromous Sakhalin taimen and we obtained reliable information on 25 specimens captured on the coast of Sarufutsu, from the Sarufutsu Fishery Cooperative.

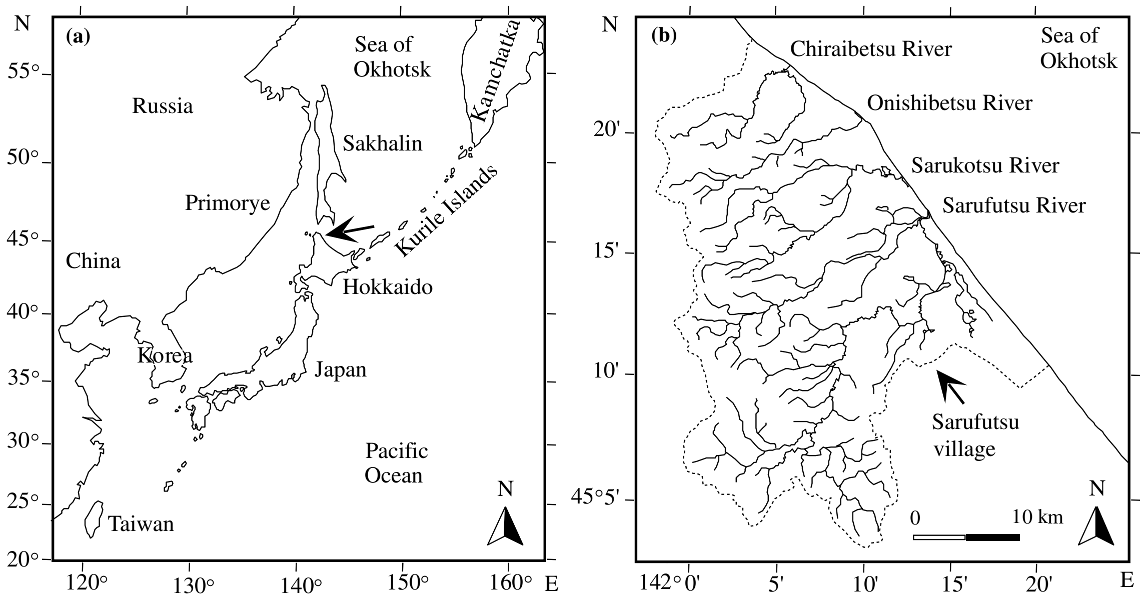

Figure 1. (a) Map of Hokkaido, northern Japan and Sarufutsu village which is marked by an arrow. (b) Map of Sarufutsu village showing the rivers where Sakhalin taimen are distributed.

Among these 25 anadromous Sakhalin taimen, 22 individuals captured on 22 June 1999, were kept alive and transported to the Wakkanai Aquarium in Wakkanai City (ca. 60 km from Sarufutsu village) by the members of Sarufutsu Fishery Cooperative. Seven of these 22 individuals have been reared for more than 3 years in seawater. The other 15 individuals perished. Although we could not obtain these 15 samples for analysis since they had already been disposed, we have data on their capture site, approximate total length and total mass when they were captured, from the aquarium records. Another three individuals that were captured on 26 June 1997 were obtained frozen and we were able to examine their morphology, stomach contents, age and growth in detail.

After sufficient thawing, the samples were weighed and measured (Table 1). We counted numbers of fin rays, lateral line scales, gill rakers, pyloric caecae and any retained eggs. We identified sex from examination of the gonads and weighed each gonad mass. We calculated the gonadosomatic index (GSI) using the formula: GSI $= M_G (M_B - M_G)^{-1} \cdot 100$, where M_G and M_B are the gonad mass (g) and the body mass (g), respectively (Table 1). We removed each stomach and weighed its contents to calculate the index of stomach fullness (ISF) using the formula: ISF $= M_C \cdot M_B^{-1} \cdot 1000$, where M_C is the stomach content mass (g) (Table 2). We identified food items from their morphology and radiographic skeleton characteristics. We weighed each food item and measured it for its maximum length to calculate the relative size of food (RSF) using the formula (Nakano 1992): RSF $= M_F \cdot L_F^{-1} \cdot 100$, where M_F and L_F are the maximum length of food item (cm) and the fork length (cm), respectively (Table 2). We removed scale samples and used them for ageing. For the estimation of fork length at age and growth, we used the back-calculation method from following formula (Campana 1990): $L_t = (S_t - S_C)(S_C - S_O)^{-1}(L_C - L_O) + L_C$, where L_t is the back-calculated fish fork length at age t, S_t is the scale length at annulus t, L_C is the fish fork length at the time of capture, S_C is the scale length at the time of capture, S_O and L_O are the observed initial scale and fish fork length. Yamashiro et al. (1975) reported that the observed initial scale and standard length of Sakhalin taimen are 0.07 and 26 mm, respectively. We used the value 0.07 mm as S_O, and transformed the standard length (L_S) 26 mm to the

Table 1. Characters of individual anadromous Sakhalin taimen captured on the coast of Sarufutsu on 26 June 1997.

Individual no.	1	2	3
Sex	Male	Female	Female
Age (years)	13	9	8
Total length (cm)	77.1	78.4	73.3
Fork length (cm)	75.2	74.4	69.4
Scaled body length (cm)	70.7	70.2	65.5
Standard length (cm)	69.3	68.1	64.0
Body mass (g)	6180	5500	4600
Condition factor[a]	14.5	13.4	13.8
Body height (cm)	16.5	15.1	14.4
Caudal peduncle height (cm)	5.9	5.8	5.5
Head length (cm)	18.6	16.4	15.8
Snout length (cm)	5.2	4.4	4.3
Upper jaw length (cm)	9.5	7.7	7.3
Number of dorsal fin rays	14	14	15
Number of anal fin rays	13	13	12
Number of lateral line scales	117	118	118
Number of gill rakers	5 + 6	5 + 9	5 + 7
Number of pyloric caeca	221	212	216
Gonad mass (g)	12.6	27.2	25.4
GSI (%)[b]	0.20	0.49	0.55
Number of retained eggs	–	2	0

[a] Condition factor: Body mass (g) × Fork length (cm)$^{-3}$ × 1000
[b] GSI: Gonad mass (g) × (Body, mass (g) − Gonad mass (g))$^{-1}$ × 100

Table 2. Stomach contents of the anadromous Sakhalin taimen captured on the coast of Sarufutsu in 1997.

Individual fish	1	2	3
Stomach content mass (g)	97.7	20.0	15.3
Index of stomach fullness[a]	15.8	3.6	3.3
Relative size of food[b]	15.2–32.2	28.2	20.7
Food items			
Ammodytes personatus Girard			
N	2 (66.7%)	1 (100%)	1 (100%)
Mass (g)	4.3 (4.4%), 12.7 (13.0%)	15.8 (79.0%)	8.6 (56.2%)
Size (cm)	11.4, 19.1	21.0	14.4
Triglops sp.			
N	1 (33.3%)	–	–
Mass (g)	60.9 (62.3%)	–	–
Size (cm)	24.2	–	–
Unidentified			
mass (g)	19.8 (20.3%)	4.2 (21.0%)	6.7 (43.8%)

[a]Index of stomach fullness: Stomach content mass $(g)^{-3} \times$ Body mass $(g)^{-1} \times 1000$
[b]Relative size of food: Food size (cm) $\times$ Fork length $(cm)^{-1} \times 100$
N = sample size.

fork length (L_F) 29.84 mm in order to use as L_O, by the following regression line: $L_F = 1.057 L_S + 0.236$ ($r = 0.99$, n = 53, $p < 0.001$) (Edo et al. unpublished).

Results

The 25 anadromous Sakhalin taimen were all captured by a fixed net set in the Sea of Okhotsk, at a point ca. 2 km northwest and ca. 0.5 km offshore from the mouth of the Sarufutsu River, by the members of the Sarufutsu Fishery Cooperative. The 22 individuals captured on 22 June 1999 were 83 kg in total body mass (mean: 3800 g) and were ca. 40–70 cm in total length. Body measurements of seven of the 22 individuals reared in seawater until recently were not made due to long term chronic effects to the shape of their heads or fins by abrasion with the tank surfaces.

The other three individuals captured on 26 June 1997 were comparatively large; the fork lengths and body masses were 75.2 cm and 6180 g for individual No. 1, 74.4 cm and 5500 g for No. 2, 65.5 cm and 4600 g for No. 3, respectively (Table 1). Individual No. 1 was male and the others were females. The GSI values of the females (0.49, 0.55) were more than twice greater than that of the male (0.20). One female (No. 2) had two eggs retained in her abdomen. The results of the other morphological counts (numbers of fin rays, lateral line scales, gill rakers and pyloric caecae) are also shown in Table 1. The other distinctive morphological characteristic of these three individuals was guanine pigmentation present at the base of the caudal fin of each fish (Figure 2).

By the analysis of stomach contents, two kinds of the marine fishes, sand lance *Ammodytes personatus* Girard and sculpin *Triglops* sp., were confirmed from the stomachs of these three individuals (Table 2). Mean food size and RSF value were 18.0 cm ± 5.1 (SD) (range: 11.4–24.2 cm) and 24.3% ± 6.6 (15.2–32.2%), respectively. The stomach contents of the individual No. 1 consisted of two specimens of sand lance and one sculpin and ISF value was 15.8; the stomach contents of the other two individuals were one sand lance each and their ISF values were comparatively low (3.6 and 3.3, Table 2).

From scale analyses, all individuals were aged and their ages (years) were 13 for individual No.1, 9 for No. 2 and 8 for No. 3, respectively (Table 1). Based on scale analyses, growth of the three individuals were estimated by using the back-calculation method. The highest growth rates were observed at ages of 2–4 (Figure 3). Though the growth rates of individual No. 1 and No. 3 were reduced after the age of 5 and the curves showed loose S-shapes as a whole, the growth curve of No. 2 was nearly linear (Figure 3).

Figure 2. Caudal fin of an anadromous Sakhalin taimen captured on the coast of Sarufutsu in 1997. Guanine pigmentation is present at the base of the fin (in the ellipses).

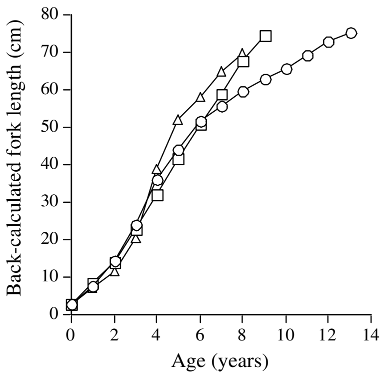

Figure 3. Relationships between age and back-calculated fork length of the anadromous Sakhalin taimen captured on the coast of Sarufutsu in 1997. Open circles, individual No. 1; open squares, No. 2; open triangles, No. 3.

Discussion

In the present study, we demonstrated for the first time that some specimens of Sakhalin taimen migrate not only to brackish water or estuaries but also into the sea. In addition, since some marine prey fishes were confirmed from their stomachs, it is evident that Sakhalin taimen can feed in the sea, suggesting that this species has the ability to live in the sea. In the Wakkanai Aquarium and the Shibetsu Salmon Museum (in Shibetsu Town, eastern Hokkaido), some specimens of Sakhalin taimen captured in a freshwater river have been reared in 100% seawater, with two specimens being reared for more than 10 and 8 years, respectively (A. Horiuchi, E. Komiyama, personal communication). These facts indicate that they have a strong tolerance of seawater. According to the Sarufutsu Fishery Cooperative, more than 50 anadromous Sakhalin taimen have been captured every year by fixed nets set at various places within the range of ca. 20 km along the coastline of the Sarufutsu village. However, in these fixed nets, although there are three bag nets (main nets) in which the fish are actually captured are set from the shore towards the offshore (0.2–2 km offshore), most taimen are captured in the net set at the point nearest to the shore (< ca.1 km from the shore). This suggests that the sea area which the Sakhalin taimen occur in this region is limited to the coast.

Of the two females captured in the sea on 26 June 1997, one female had two eggs retained in her abdomen. This indicates that this female migrated from the upstream spawning grounds of their home river to the sea within 2 months in 1997, since Sakhalin taimen in this region spawns from late April to early May in the upstream tributaries (Fukushima 1994, 2001). According to the Sarufutsu Fishery Cooperative, although the fixed nets are established in the sea from early May to December, most Sakhalin taimen are captured by the net only in May to June and September. Thus, it is likely that the Sakhalin taimen in this region migrate into the sea at least after they have finished spawning in late spring. For the iteroparous Sakhalin taimen, especially in the high latitude populations, it seems advantageous to migrate into the sea to forage in order to recover from the energy loss of breeding activities and increase reproductive success for subsequent years, since the aquatic productivity in the sea usually exceeds that in freshwater in temperate and polar latitudes (Gross et al. 1988).

Yamashiro (1965) has reported that the smolting of Sakhalin taimen might occur at the age of 2–3 since the highest growth rates of 28 Sakhalin taimen captured in a freshwater river in eastern Hokkaido were observed at these ages. Komiyama (1981) has described two juvenile Sakhalin taimen (1^+ and 2^+) captured in a river of the Shiretoko peninsular in eastern Hokkaido, where no population of Sakhalin taimen is sustained, and suggested that these fish invaded the river by way of the sea. In the present study, the highest growth rates of the three anadromous Sakhalin taimen were observed at ages of 2–4. However, it does not necessarily follow that the smolting of Sakhalin taimen occurs at these ages just because the highest growth rates were observed, since they become piscivorous at the age of 2–4 with the size of ca. 15–30 cm (Kimura 1966, Gritsenko et al. 1974, Kawamula et al. 1983). Thus, further research on ages and/or sizes of smolting of Sakhalin taimen needs to be conducted.

From the stomach content analysis, four specimens of sand lance and one sculpin were confirmed from the stomachs of the three taimen. Although the sample size is small and it is necessary to consider the possibility that they fed on these prey fish in the fixed net, this result is similar to that of Gritsenko et al. (1974). Gritsenko et al. (1974) reported that adult Sakhalin taimen (>50 cm) in the Bogataya River of Sakhalin most frequently fed on sand lance. The mean prey size of the three anadromous Sakhalin taimen was 18.0 cm (range: 11.4–24.2 cm) and were larger than in the Bogataya River taimen since 90% of the prey fish of adult Sakhalin taimen (>50 cm) in this river ranged from 7 to 13 cm (Gritsenko et al. 1974). This difference in the diet of Sakhalin taimen might depend on the abundance and availability of prey in each of the environments (Holčik et al. 1988).

As a distinctive morphological characteristic of the three anadromous Sakhalin taimen, guanine pigmentation was present at the base of the caudal fin of each fish. Although this guanine pigmentation has not been confirmed in land-locked taimen, it has been confirmed in those captured in the estuary in brackish water and those reared artificially in seawater (E. Komiyama, personal communication). Thus, this guanine pigmentation might be utilized to differentiate anadromous and fluvial Sakhalin taimen, but further research on guanine pigmentation of Sakhalin taimen needs to be conducted quantitatively.

In the present study, we confirmed that some Sakhalin taimen in the Sarufutsu district do migrate into the sea and feed on marine fishes. In addition, Sakhalin taimen captured in the Sarufutsu River feed on anadromous and brackish water species such as juvenile chum salmon, three spine stickleback *Gasterosteus aculeatus*, dace *Leuciscus* sp., Mysida and so on (Nakano 1992). This suggests that the populations of Sakhalin taimen in this region are sustained by prey species that originate and/or feed in the sea and thus the populations are directly and indirectly dependent on the sea. Therefore, a better understanding into the relationship between rivers and the sea is considered to be essential and the preservation of migration routes between rivers and the sea by diadromous aquatic organisms including Sakhalin taimen will contribute to the conservation and restoration strategy of this endangered species. Especially in Japanese river systems, there are many artificial obstacles such as dams, which are dividing migration routes between rivers and the sea. The effects of migration disturbance by them on Sakhalin taimen populations should be investigated adequately, and if the negative effects of them are detected, it is necessary to install efficient fish ladders or remove them immediately for the preservation of migration routes of diadromous aquatic organisms including Sakhalin taimen.

Acknowledgements

We thank K. Fujimoto, T. Fujimoto, M. Kimura, F. Fujii and S. Motozawa of the Sarufutsu Fishery Corporative for collecting information about the anadromous Sakhalin taimen on the coast of Sarufutsu; E. Komiyama of Wild Salmon Research Center and A. Horiuchi of Wakkanai Aquarium for providing information about the Sakhalin taimen reared in seawater; K. Maeda of Muroran Branch, Hokkaido Hakodate Fisheries Experimental Station for his help in identifying prey items; T. Kuwahara of Kon-Photography & Research for his help in photographing and measuring the samples. The samples of the three anadromous Sakhalin taimen were provided by K. Suzuki of the Hokkaido Fish Hatchery, Mashike Research Branch. Unfortunately, K. Suzuki died during a climbing accident in July 2001. We extend our deepest sympathies in this time of bereavement.

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