Short Report

Evidence of downstream migration of Sakhalin taimen, *Hucho perryi*, as revealed by Sr:Ca ratios of otolith

Takaomi Arai[1]✉, Aya Kotake[2], and Kentaro Morita[3]

[1] *International Coastal Research Center, Ocean Research Institute, The University of Tokyo, 2-106-1 Akahama, Otsuchi, Iwate 028-1102, Japan (e-mail: arai@wakame.ori.u-tokyo.ac.jp)*
[2] *Ocean Research Institute, The University of Tokyo, 1-15-1 Nakano, Tokyo 164-8639, Japan (e-mail: kesshu@ori.u-tokyo.ac.jp)*
[3] *Hokkaido National Fisheries Research Institute, 116 Katsuragoi, Kushiro, Hokkaido 085-0802, Japan (e-mail: moritak@affrc.go.jp)*

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Abstract The migratory history of Sakhalin taimen, *Hucho perryi*, was examined in terms of strontium (Sr) and calcium (Ca) uptake in the otolith by using wavelength dispersive X-ray spectrometry on an electron microprobe. Otolioth Sr:Ca ratios of freshwater-reared samples remained consistently at low levels throughout the otolith. The Sr:Ca ratios of samples from Lake Aynskoye of Sakhalin Island showed a low value from the core up to a point of 700–2140 μm. Thereafter, the ratios increased sharply and remained at higher levels up to the outermost regions. The difference in Sr:Ca ratio might be the result of the presence of individuals that underwent seawater and freshwater life history phases, probably reflecting the ambient salinity or the seawater–freshwater gradient in Sr concentration. Otolith Sr:Ca ratio analysis revealed downstream migration history in *H. perryi*.

Key words *Hucho perryi* · Otolith Sr:Ca ratios · Migration · Anadromy · Life history

A salmonid, Sakhalin taimen, *Hucho perryi* Brevort, is restrictedly distributed in Hokkaido, Sakhalin, southern Kuries, and eastern Siberia (Kimura, 1966). *Hucho perryi* spawns in late June in Sakhalin (Gritsenko et al., 1974) and from mid-March to late April in eastern Hokkaido (Kimura, 1966). The species is iteroparous and is the largest salmonid in the western Pacific Ocean, attaining weights up to 25–60 kg with age up to 16 years (Berg, 1962; Khatkevich, 1973; Gritsenko et al., 1974). This species, now very rare in Japan, is seriously endangered and close to extinction because of overfishing, spawning ground loss, and water pollution.

Hucho perryi had been believed to be a strictly freshwater resident, not migrating to the sea, although Kawamura et al. (1983) reported a few individuals from brackish coastal waters, suggesting that the life history of this species is mostly freshwater resident but partly anadromous. Thus, the migratory pattern in their life cycle is variable and complicated. Information on individual migratory histories might provide a knowledge base for conservation biology as well as fish migration studies, allowing effective and sustainable management of this endangered species.

Recent studies have indicated that, based on variations in the strontium (Sr) to calcium (Ca) ratios in otoliths, the migratory history of salmonid fishes can be reconstructed (Arai et al., 2002). Strontium concentrations are one to two orders higher in seawater than in freshwater (Campana, 1999), and the Sr:Ca ratio in otoliths are positively correlated with the salinity of the ambient water (Campana, 1999; Arai, 2002). Thus, this technique might also be applied to reveal the complicated migratory pattern of *H. perryi*.

Materials and Methods

A total of eight specimens (460–720 mm fork length: FL) were collected by fishing at Lake Aynskoye, Sakhalin Island, in the Far East of the Russian Federation between 17 and 18 May 2003 (Fig. 1). This lake is not influenced by the rising tide via an intermittent river with 0 psu. For comparison of Sr:Ca ratios in the otolith, these eight plus other four freshwater-reared individuals (110–700 mm FL) were analyzed for otolith microchemistry. The latter had been reared in freshwater for 1 year (three specimens, 110–127 mm FL) or 10 years (one specimen, 700 mm FL).

Sagittae of otoliths were extracted from each fish, embedded in epoxy resin (Epofix; Struers, Copenhagen, Denmark), and mounted on glass slides. Otoliths were then ground to expose the core, using a grinding machine equipped with a diamond cup-wheel (Discoplan-TS; Struers), and polished further with 6-μm and 1-μm diamond paste on an automated polishing wheel (Planopol-V; Struers). Finally, they were cleaned in an ultrasonic bath and rinsed with deionized water before examination.

For electron microprobe analyses, all otoliths were Pt-Pd coated by a high vacuum evaporator. All specimens were used for "life-history transect" analysis of Sr and Ca concentrations, which were measured along a line down the longest

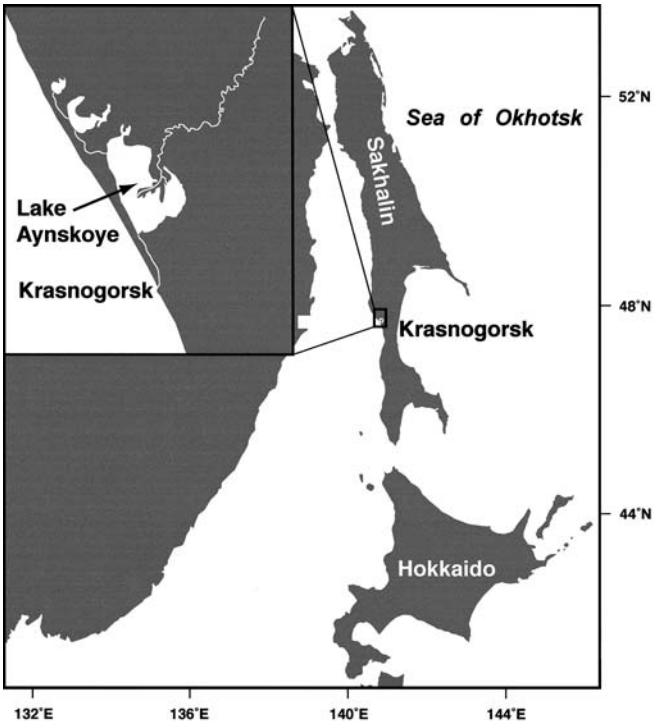

Fig. 1. Sampling sites for *Hucho perryi* collected at Lake Aynskoye, Sakhalin Island, in the Far East of the Russian Federation, between 17 and 18 May 2003

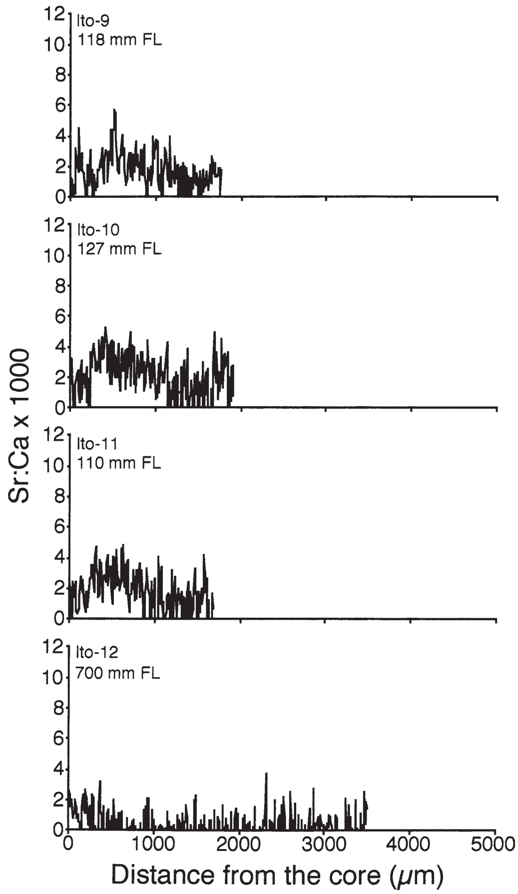

Fig. 2. Transects of otolith Sr : Ca ratios measured with a wavelength dispersive electron microprobe from the core to the edge in freshwater-reared specimens of *Hucho perryi*. Each point represents all data for the respective 10-μm intervals. *FL*, fork length

axis of each otolith from the core to the edge using a wavelength dispersive X-ray electron microprobe (JEOL JXA-8900R; Jeol, Tokyo, Japan), as described in Arai et al. (1997, 2002) and Arai and Tsukamoto (1998). Calcite ($CaCO_3$) and strontianite ($SrCO_3$) were used as standards. The accelerating voltage and beam current were 15 kV and 1.2×10^{-8} A, respectively. The electron beam was focused on a point 10 μm in diameter with measurements spaced at 10-μm intervals.

Results

Otolith Sr : Ca ratios measured along a transect from the core to the edge of four freshwater-reared individuals showed consistently low Sr : Ca values [$1.58 \times 10^{-3} \pm 0.74 \times 10^{-3}$ (mean ± SD) (range: 0.50×10^{-3} to 2.17×10^{-3}) with no transition point (TP) from the low (phase L) to the high (phase-H) Sr : Ca ratios phase (Fig. 2)], suggesting continuous residence in a freshwater environment after hatching. All samples from Lake Aynskoye showed phase L from the core up to a point of 700–2140 μm, averaging $2.96 \times 10^{-3} \pm 0.61 \times 10^{-3}$ (mean ± SD) (range: 2.11×10^{-3} to 3.62×10^{-3}) (Fig. 3). Thereafter, the ratios increased sharply, averaging $6.36 \times 10^{-3} \pm 0.90 \times 10^{-3}$ (mean ± SD) (range: 5.50×10^{-3} to 7.79×10^{-3}) (Fig. 3), and were maintained at higher levels up to the outermost regions (phase H, Fig. 3). Significant differences were observed between the Sr : Ca ratios in the former phase L from the core up to a point of 700–2140 μm and the ratios in the latter phase H from the point to the edge in each fish (Mann–Whitney *U* test, $P < 0.0001$).

Discussion

Fluctuation patterns of Sr : Ca ratios in otoliths were significantly different between freshwater-reared and field samples from Lake Aynskoye. All samples collected from the lake had a TP (transition point) from phase L (low Sr : Ca ratio) to phase H (high Sr : Ca ratio) and thereafter maintained constantly high Sr : Ca ratios up to the edge. In contrast, freshwater-reared specimens did not show a TP, and maintained consistently low Sr : Ca ratios from the core to the edge. The freshwater reared samples appeared to be a standard freshwater resident type of the species. Therefore, the difference in Sr : Ca ratio might be the result of the presence of individuals that underwent seawater or freshwater life history phases. Salinity was quite different between coastal seawater and inland freshwater. The difference in otolith Sr content of *Hucho perryi* specimens between seawater and freshwater environments was probably

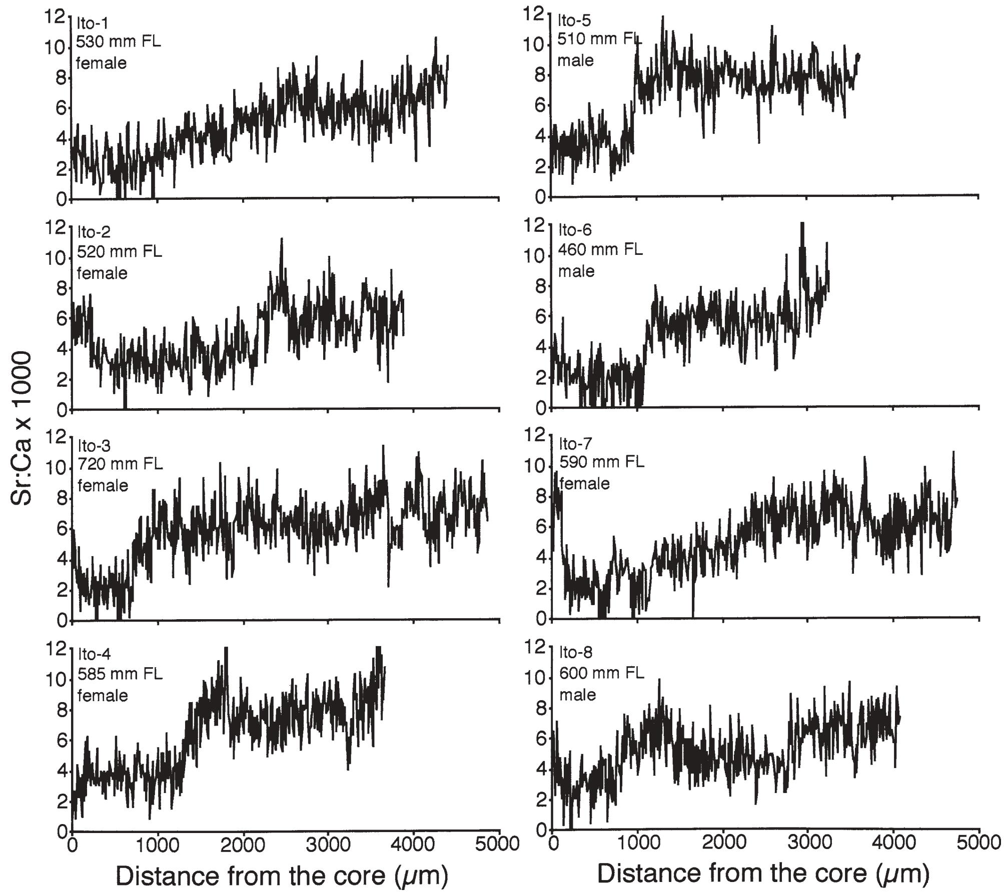

Fig. 3. Transects of otolith Sr:Ca ratios measured with a wavelength dispersive electron microprobe from the core to the edge in specimens of *Hucho perryi* collected at Lake Aynskoye, Sakhalin Island, in the Far East of the Russian Federation. Each point represents all data for the respective 10-μm intervals. *FL*, fork length

caused by the effects of ambient salinity. Therefore, those field specimens had experienced the marine environment following downstream migration. Overall, Sr:Ca ratio patterns observed in otoliths of *H. perryi* were consistent with those seen in other salmonids, e.g., *Salmo trutta* and *Oncorhynchus mykiss* (see Kalish, 1990), *O. nerka* (see Rieman et al., 1994), *O. masou* (see Arai and Tsukamoto, 1998), *Oncorhynchus keta* (see Arai and Miyazaki, 2002), and *S. trutta* (see Arai et al., 2002). These considerations strongly suggested that otolith Sr:Ca ratio analysis was useful for the estimation of individual migratory history in *H. perryi*.

Most individuals of *H. perryi* collected in Lake Aynskoye did not show a clear phase L. This might be due to timing; such individuals may have recently immigrated into the lake to breed. Accordingly, low freshwater Sr:Ca ratios would not be incorporated into the edge of otolith. Furthermore, *H. perryi* is iteroparous and, thus, some individuals might migrate between coastal seawater and inland freshwater a few times. However, a clear phase L was not observed in the life history transects of Sr:Ca ratios. Booke (1964) and Elliot et al. (1979) suggested that during the period leading up to spawning, salmonids were characterized by a gradual increase in levels of both plasma Ca and plasma protein, both being involved in the synthesis of gonadal tissue. Kalish (1989) suggested that seasonal variations in Sr:Ca ratios in otolith of blue grenadier, *Macruronus novaezelandiae*, could have resulted from high plasma protein levels during gonad maturation and spawning. Increases in Ca-binding plasma protein due to a decrease in free Ca could result in an increase in the Sr:Ca ratios in the endolymph and, accordingly, a corresponding increase in the otolith Sr:Ca ratios during the period.

This study is the first description of the occurrence of sea-run (anadromous) specimens of *H. perryi*, based on otolith microchemical analysis. Although genus *Hucho* is composed of five species, *H. perryi* is different from the other species by living mainly in freshwater and rarely in coastal brackish water. Our results suggested that the majority of individuals in Sakhalin migrated to the sea for growth, while few individuals in Hokkaido migrated narrowly to coastal brackish waters (Kawamura, 2002). All specimens collected from Sakhalin showed a typical anadromous form. Therefore, the migration pattern of this species might be different according to latitude. Fish migration is generally explained by a difference in food abundance between marine and freshwater habitats (Gross, 1987). In salmonids, juveniles of anadromous fishes utilize freshwater habitats at high latitudes with low productivity, and migrate to higher productivity habitats in the ocean for growth before returning to freshwater for breeding. A latitudinal cline in which marine-dependent *H. perryi* would occur more frequently at higher latitudes, and where the productivity of the freshwater habitat is lower than that of the ocean, might be predicted. Analysis of the otolith Sr : Ca ratio on various latitudinal distributions needs to be made, and mean otolith Sr : Ca ratios as an index of the environmental life history should be compared among habitats.

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