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SHORT REPORT

Life history and migration of Sakhalin taimen, *Hucho perryi*, caught from Lake Akkeshi in eastern Hokkaido, Japan, as revealed by Sr:Ca ratios of otoliths

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Abstract Microchemical analysis of the strontium (Sr) and calcium (Ca) ratios of otoliths was conducted to determine the life history and migration of anadromous Sakhalin taimen, *Hucho perryi*. In 2008 and 2009, 10 specimens were sampled from Lake Akkeshi in eastern Hokkaido, Japan. Our results indicated that some specimens migrated to brackish waters during their early life histories. Because the Sr:Ca ratios of the specimens in this study were all less than those of specimens from Sakhalin Island during a previous study, specimens from Lake Akkeshi may have migrated to brackish water, or may have remained in the ocean for only a short period.

Keywords *Hucho perryi* · Otolith · Sr:Ca ratios · Anadromous · Brackish water

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Introduction

Populations of Sakhalin taimen, *Hucho perryi*, have decreased in recent decades; thus, this species has been registered as an IUCN endangered (CR) species since 2006 (IUCN 2009). *Hucho perryi* is the largest freshwater fish in Japan and is the only *Hucho* species with an anadromous form (Gritsenko et al. 1974; Holčík et al. 1988). In addition, this species is an iteroparous salmonid that spawns primarily from March to June in far upstream regions in Hokkaido Island (Fukushima 1994, 2001; Edo et al. 2000; Esteve et al. 2009). Not only adult *H. perryi* but also juveniles utilize a wide range of habitats, from upstream to coastal waters (Yamashiro 1965; Kimura 1966; Gritsenko et al. 1974; Kawamula et al. 1983; Sagawa et al. 2002, 2003; Edo et al. 2005; Honda et al. 2009). However, there is little information about their migration pattern, especially for anadromous *H. perryi* (Arai et al. 2004; Honda et al. 2009). In Hokkaido, only fragmented catch data from brackish water lakes or coastal areas have verified the existence of anadromous fish (Yamashiro 1965; Kawamula et al. 1983; Edo et al. 2005; Suzuki et al. 2008), and some fish migrate downstream to lower reaches or coastal waters mainly in the spring and autumn (Kawamula et al. 1983; Edo et al. 2005; Honda et al. 2009).

The microchemicals in a given habitat are incorporated for the entire lifetime of the fish in its otoliths, which control its acoustic sensing and its balance. Generally, the strontium (Sr) concentration in seawater is over 100 times greater than that in freshwater (Kennedy et al. 1997), with a few exceptions (Kraus and Secor 2004; Limburg and Siegel 2006; Elsdon et al. 2008). Thus, the migratory histories of individual specimens can be revealed by observing the Sr:Ca (calcium) ratios of otoliths (Arai 2002). Using this method, the life histories and migrations of many salmonid species have been documented (Kalish 1990; Arai and Tsukamoto 1998; Volk et al. 2000; Arai and Miyazaki 2002; Arai and Morita 2005; Brenkman et al. 2007). Arai et al. (2004) analyzed the microchemicals in otoliths of *H. perryi* in Lake Aynskoye (which is not influenced by the rising tide due to the occurrence of an intermittent river with 0 psu), Sakhalin Island, Russia, and revealed the existence of anadromous fish. The mean Sr:Ca ratio of specimens captured at Lake Aynskoye when they were assumed to inhabit saltwater (saltwater phase) was ca. 6.0×10^{-3} or more (Arai et al. 2004). This ratio was almost four times higher than that of freshwater-reared specimens [$1.58 \times 10^{-3} \pm 0.74 \times 10^{-3}$ (mean ± SD)]. Moreover, specimens that exhibited a dramatic increase in Sr:Ca ratio from the period during which they were assumed to inhabit freshwater (freshwater phase) to the saltwater phase were observed, while specimens that showed a gentle increase in Sr:Ca ratio were also confirmed (Arai et al. 2004). However, the migratory patterns of *H. perryi* populations in Hokkaido within a river system containing a large brackish lake at the river mouth have not yet been examined. Therefore, we sought to assess the life history and migration of anadromous *H. perryi* migrating between the Bekanbeushi River system and Lake Akkeshi (a brackish water lake) in eastern Hokkaido (Fig. 1) by examining otolith Sr:Ca ratios.

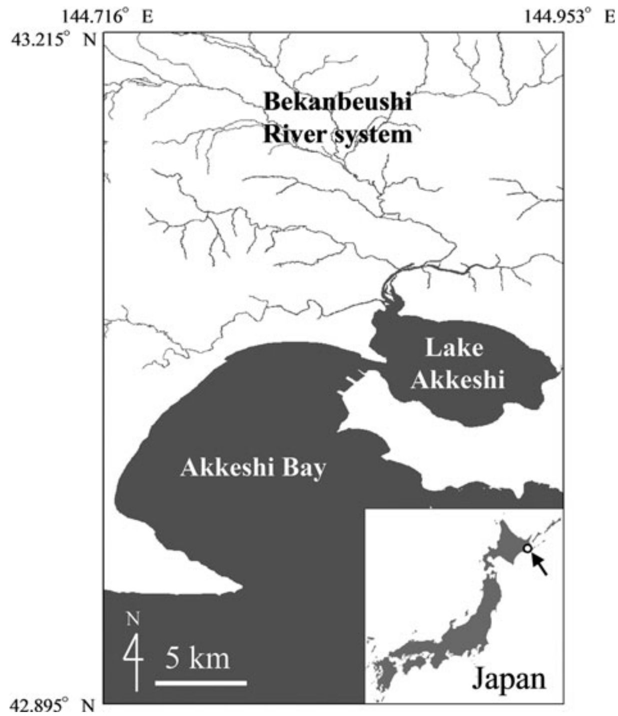

Fig. 1 Study site: the Bekanbeushi River system, Lake Akkeshi and Akkeshi Bay in eastern Hokkaido Island, Japan

Materials and methods

Sampling fish. Sampling was conducted from April 2008 to May 2009; we only sampled *Hucho perryi* caught by local set-net fisheries at Lake Akkeshi that were dead upon capture. Lake Akkeshi (circumference 24.8 km, maximum depth 7.0 m, salinity ca. 25–30 psu; Hokkaido Institute of Environmental Sciences 2005) is a brackish water lake into which the stable population of *H. perryi* within the Bekanbeushi River system migrates. The lake is connected to Akkeshi Bay (i.e., the ocean; Fig. 1). In Lake Akkeshi, set-net fisheries targeting *Osmerus mordax dentex*, *Salangichthys microdon*, *Hypomesus japonicus*, and *Eleginus gracilis* are conducted every spring (20 March–30 June) and autumn (1 October–31 December). After measurements of fork length (FL, mm) and body weight (BW, g), sex and maturity status (mature or immature) were confirmed by checking for gonads or remaining eggs or sperm. In addition, four freshwater-reared specimens (565–587 mm FL) were sampled as control fish from the Nanae Freshwater Laboratory, Hokkaido University, on 29 June 2009. We also sampled one specimen that was reared in both seawater and freshwater (827 mm FL, 5,700 g BW; the rearing duration and date of death were not recorded) from the Shibetsu Salmon Museum.

Elemental microanalysis of otoliths. Sagittal otoliths were extracted from each specimen, embedded in epoxy resin (Epofix; Struers, Copenhagen, Denmark), and mounted on glass slides. They were then ground to expose the core using a grinding machine equipped with a diamond cup wheel (Discoplan-TS; Struers). Otoliths were then polished further using an oxide polishing suspension on an automated polishing wheel (PdM-Force-20; Struers). For electron microprobe analysis, all otoliths were Pt–Pd-coated using a high-vacuum evaporator. All specimens were used for a “life history transect” analysis (transect analysis) of Sr and Ca concentrations, which were measured along the longest axis of each otolith from the core to the edge. An X-ray electron microprobe (JXA-8900R; JEOL, Tokyo, Japan) was used for the transect analysis, and wollastonite ($CaSiO_3$) and tausonite ($SrTiO_3$) were used as standard samples. The electric pressure and current values were 15 kV and 1.2×10^{-8} A, respectively, and the electron beam was focused on a point 10 μm in diameter, with measurements spaced at 10 μm intervals.

The mean (±SD) Sr:Ca ratios of the four freshwater-reared control specimens were $1.98 \times 10^{-3} \pm 0.10 \times 10^{-3}$, and transitions to the saltwater phase were not confirmed for these specimens [C1–C4 in the "Electronic supplementary material" (ESM) Fig. S1]. Therefore, a ratio of 2.0×10^{-3} was considered to roughly indicate the freshwater life stage, and this value was compared to that of each specimen caught in Lake Akkeshi following Kuroki et al. (2006).

Results

In total, 10 specimens—two in April–May 2008, one in October 2008, and seven in April–May 2009—were caught from Lake Akkeshi. Body sizes and sexes of the specimens are presented in Table 1. The mean (±SD) and range in FL were 687 ± 103 and 452–826 mm, respectively, and the mean and range in BW were 3,730 ± 1,244 and 1,120–5,690 g, respectively. All specimens were female, and only the gonads of specimen no. 0803 (caught in the autumn) were mature; those of the other specimens (caught in spring) were all immature.

The mean (±SD) Sr:Ca ratio of all 10 specimens from Lake Akkeshi was $2.02 \times 10^{-3} \pm 0.46 \times 10^{-3}$ (range 1.48×10^{-3} to 2.97×10^{-3}; we will omit the "$\times 10^{-3}$" when mentioning ratios from hereon). This value was close to the mean value of the freshwater-reared control specimens. The transition points between freshwater and saltwater (including brackish water for specimens caught from Lake Akkeshi) phases for some specimens such as nos. 0802 and 0905 were clear, while those for some specimens, such as no. 0801 and 0903 were unclear (Fig. 2). Moreover, the ratios of nos. 0902 and 0904 fluctuated at higher levels (around 2.0–4.0) from their early life stages (<1,000 μm) than those of other specimens (Fig. 2). The mean (±SD) Sr:Ca ratio of no. 0902 (2.97 ± 0.86) was the highest of all the specimens. The ratio of no. 0904 transitioned to the saltwater phase during its early life stage; its ratio remained high thereafter (2.64 ± 0.84, from 530 μm to the edge).

Discussion

It is known that females of iteroparous salmonids generally tend to migrate to the sea more than males (Maekawa 1987; Yamamoto et al. 1999). From past studies of anadromous *Hucho perryi*, females were observed to migrate more than males (Kawamula et al. 1983; Komiyama 2003; Arai et al. 2004; Edo et al. 2005), and all of the females sampled from Lake Akkeshi in spring had immature gonads (Kawamula et al. 1983). In this study, the 10 *H. perryi* caught from Lake Akkeshi were all female. All of the specimens except no. 0901 were mature in size but had immature gonads. These findings indicate the existence of anadromous females that do not spawn every year and instead migrate downstream during the spawning season, and they also indicate that females occur more often than males.

Our results demonstrated that the first sea-run timing of *H. perryi* at our study site was probably not constant; we observed specimens (nos. 0902 and 0904) that migrated to brackish water as juveniles as well as those that migrated after maturing. Therefore, individuals of *H. perryi* at our study site varied in the timing of their first sea run; the determining factor for this was neither a certain age nor a certain body size but other internal or external factors. As reported for many salmonid species, the age at first smolt is likely determined by the growth rate during the early life stage (reviewed by Jonsson and Jonsson 1993; Tamate and Yamamoto 2004). Titus and Mosegaard (1992) studied brown trout inhabiting in a small river in Sweden and

Table 1 Fish number, date captured, body size, sex and maturational status of *Hucho perryi* caught from Lake Akkeshi, Hokkaido, Japan

Fish no.	Date captured	Fork length (mm)	Body weight (g)	Sex	Maturational status
0801	30 April 2008	815	5,690	Female	Immature
0802	10 May 2008	681	3,770	Female	Immature
0803	28 October 2008	691	3,670	Female	Mature
0901	26 April 2009	452	1,120	Female	Immature
0902	18–22 May 2009	773	4,570	Female	Immature
0903	18–22 May 2009	657	3,640	Female	Immature
0904	18–22 May 2009	677	3,610	Female	Immature
0905	15–31 May 2009	826	5,150	Female	Immature
0906	18–22 May 2009	690	3,790	Female	Immature
0907	15–31 May 2009	603	2,290	Female	Immature

Accurate capture dates for 0902–0907 were not recorded; these specimens were landed on one of the days within the range indicated

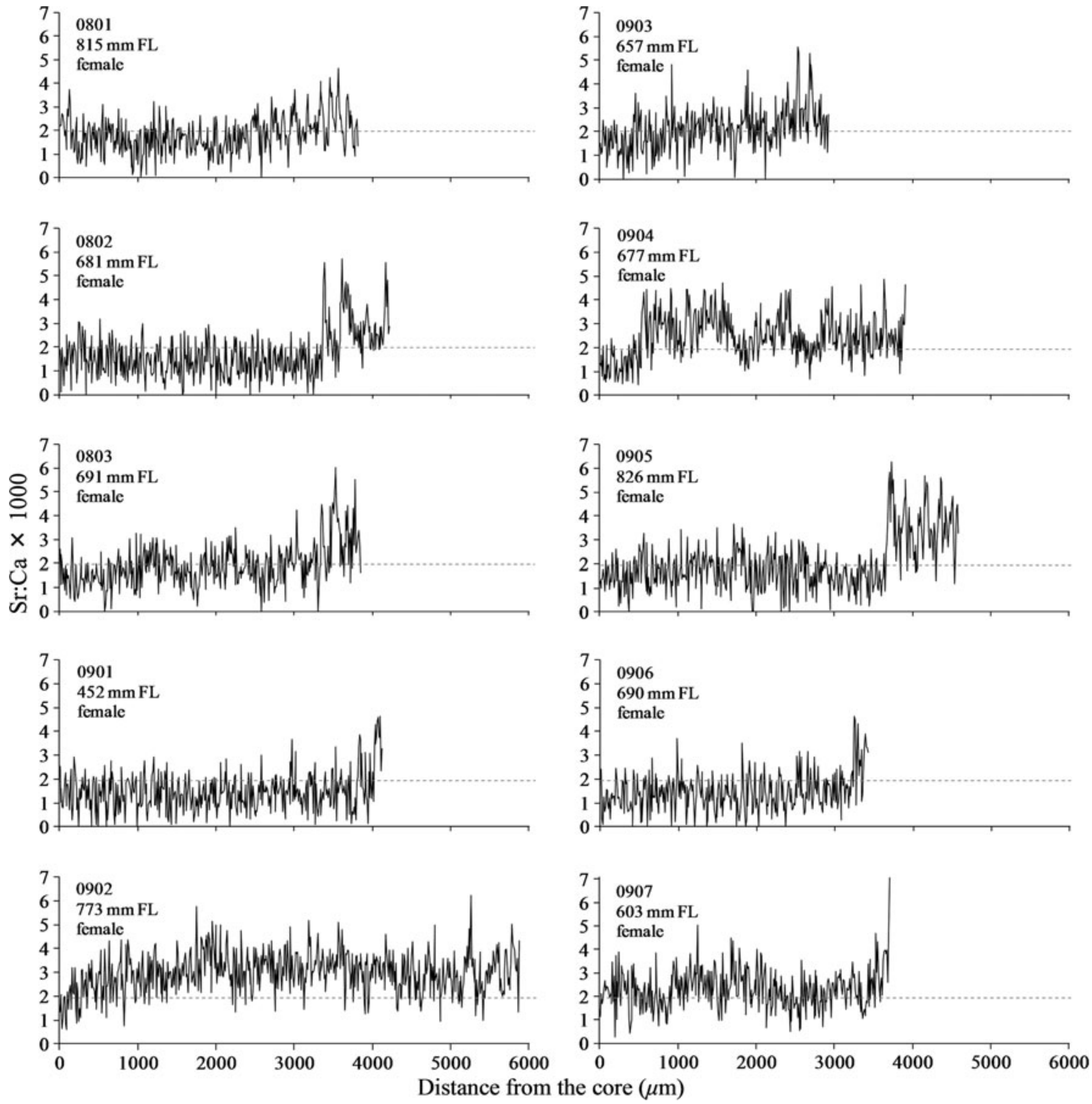

Fig. 2 Transects of otolith Sr:Ca ratios measured with a wavelength-dispersive electron microprobe from the core to the edge in specimens of *Hucho perryi* collected at Lake Akkeshi, Hokkaido Island, Japan. *Each point* represents all data for the respective 10 μm intervals. *Dotted lines* show the mean Sr:Ca ratios of four freshwater-reared control specimens. The *four-digit number on the left* indicates the fish number. *FL* fork length

reported that habitat density potentially affected the age at first smolt.

The Sr:Ca ratio at the saltwater phase of specimens caught from Lake Akkeshi rarely exceeded 6.0, which was much less than that observed for anadromous specimens in Lake Aynskoye, Sakhalin Island (see Arai et al. 2004). Moreover, the mean Sr:Ca ratio at the saltwater phase of the seawater- and freshwater-reared specimens (ESM Fig. S1, C5) was also much higher than that of specimens caught from Lake Akkeshi. Furthermore, Arai (2010) studied the change in Sr:Ca ratio in otoliths of *H. perryi* which experienced changes in salinity during its lifetime, and revealed the relationship between its Sr:Ca ratio and the salinity of its environment. The Sr:Ca ratios of specimens in the study were ca. 5.0, 3.8 and 3.1 as the amount of seawater experienced during the lifetime of the fish compared to the amount of freshwater it experienced increased from 0 to 1/3 to 2/3, respectively. Thus, specimens from Lake Akkeshi were very unlikely to have migrated to the ocean, or if they did, they did not stay there for a long time. If the pattern of these ten specimens caught from Lake Akkeshi represents the population in the Bekanbeushi River system, it may relate to the existence of the large brackish lake at the mouth of the Bekanbeushi River. Regarding this hypothesis, Honda et al. (unpublished) used an acoustic receiver at the border between Lake Akkeshi and Akkeshi Bay to trace 15 acoustically tagged adult *H. perryi* from spring to autumn 2008; although some tagged fish that had migrated to Lake Akkeshi were observed, no fish remained in Akkeshi Bay for more than one day. Furthermore, *H. perryi* has rarely been caught by set-net fisheries in Akkeshi Bay (T. Sato, personal communication).

Considering the pattern of *H. perryi* migration extrapolated from our findings, the brackish Lake Akkeshi appears to play an important role in the life history of the population within the Bekanbeushi River system as one of their habitats. In the future, deducing detailed migration patterns for these fishes, including the lake and estuary, will help to reveal the as-yet unknown part of its life history and provide useful information for understanding and protecting the other populations.

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