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Riverine environmental characteristics and seasonal habitat use by adult Sakhalin taimen *Hucho perryi*

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The study identified seasonal habitat use by endangered adult Sakhalin taimen *Hucho perryi* and the environmental characteristics of their habitat (water depth, amount of riparian forest and sinuosity). Fifteen adult *H. perryi* with acoustic tags were tracked by towing an acoustic receiver with a canoe in the Bekanbeushi River system in eastern Hokkaido Island, Japan, during each month from late April to late November 2008. Individuals mainly used midstream (shallower than downstream) habitats in all seasons. These locations were generally characterized by relatively dense riparian forests and high sinuosity, indicating the presence of pools. In spring, individuals used habitats with less riparian forest cover compared to mean value of the river channel. From spring to autumn, adult *H. perryi* selected limnologically complex habitats with meandering channels. From summer to autumn, individuals selected habitats with more riparian forest cover. The inverse relationship between *H. perryi* detection and riparian forest area in spring was a result of seasonal defoliation in deciduous riparian forests.

Key words: acoustic telemetry; Bekanbeushi River; endangered species; Hokkaido Island; meandering; seasonal habitat.

INTRODUCTION

Sakhalin taimen *Hucho perryi* (Brevoort) is a salmonid that inhabits the Maritime Province of Siberia, Sakhalin, southern Kuriles and Hokkaido Island (Kimura, 1966; Gritsenko *et al*., 1974). This is the only anadromous species among the five *Hucho* species and is the largest freshwater fish in Japan, reaching total lengths (L_T) >1·5 m (Gritsenko *et al*., 1974; Holcik *et al*., 1988). *Hucho perryi* is iteroparous and spawns in shallow upstream locations mainly from April to May, after snowmelt, on Hokkaido Island (Fukushima, 1994, 2001; Edo *et al*., 2000; Esteve *et al*., 2009). As it grows, *H. perryi* uses more downstream habitats, eventually reaching coastal waters (Yamashiro, 1965; Kimura, 1966; Gritsenko *et al*., 1974; Kawamula *et al*., 1983; Sagawa *et al*., 2002, 2003; Arai *et al*., 2004; Edo *et al*., 2005; Mori & Nomoto, 2005; Honda *et al*., 2009, 2010).

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Due to its population decline, this species has been registered as Critically Endangered (CR) on IUCN's red list since 2006 (IUCN, 2009). Anthropogenic factors, such as river improvement projects, have been identified as causing this decline (Fukushima *et al.*, 2008; Takami & Kawamula, 2008). The development of conservation programmes for *H. perryi* are urgently needed.

Unfortunately, ecological information regarding the life history of *H. perryi*, including seasonal habitat use and habitat requirements, remains limited. The major rivers on Hokkaido Island in which *H. perryi* reside are generally associated with peat land. It is impossible to follow fish movements by visual observation because of low visibility in murky waters, except in shallower upstream areas. Therefore, most previous studies have referred to early life history and spawning ecology (Fukushima, 1994, 2001; Mori *et al.*, 1997; Edo *et al.*, 2000; Sagawa *et al.*, 2003; Mori & Nomoto, 2005; Esteve *et al.*, 2009) using ecological information from *H. perryi*. Information except for spawning season from adult fish is limited (Kimura, 1966; Gritsenko *et al.*, 1974; Kawamula *et al.*, 1983; Sagawa *et al.*, 2002; Arai *et al.*, 2004; Edo *et al.*, 2005; Honda *et al.*, 2009, 2010). Generally, the presence of riffles and pools in rivers is important for riverine salmonids (Fausch & Northcote, 1992; Inoue & Nakano, 1994; Urabe & Nakano, 1998). Sagawa *et al.* (2002) indicated that adult *H. perryi* frequently inhabit large-scale pools in summer. Sagawa *et al.* (2002) studied the summer habitats of adult *H. perryi* in a tributary of the Teshio River in northern Hokkaido; they suggested that *H. perryi* primarily inhabit pools with large bottom areas and low flow velocities, which existed in locations with extensive riparian forest cover and highly meandering channels. Honda *et al.* (2009) tracked several adult *H. perryi* using acoustic telemetry from spring after spawning to winter and determined that adult fish migrated widely through the river system, from upstream areas to the estuary. Moreover, habitat use shifted to upper stream locations in the summer as water temperature increased. The Sagawa *et al.* (2002), study, however, was limited to the summer months, and the focus was on pool environments. In Honda *et al.* (2009), the environmental characteristics of areas that adult *H. perryi* inhabited for long periods were not clarified because of a limited sample size.

The present study determined the seasonal environmental characteristics of the riverine habitats, which the adult *H. perryi* occupied for a relatively long time. The seasonal habitats of adult fish in the Bekanbeushi River system, eastern Hokkaido Island, were monitored by tracking >10 fish with an acoustic receiver that was towed by a canoe. Using geographic information system (GIS) analysis, tracking data were compared with water depth, the tree density of riparian forests and river sinuosity, several factors that Sagawa *et al.* (2002) hypothesized were closely related to *H. perryi* habitat use.

MATERIALS AND METHODS

STUDY SITE

Surveys were conducted in the Bekanbeushi River system (total basin area: 738·8 km^2), which flows in Akkeshi-cho and Shibecha-cho, Hokkaido (Fig. 1). In this river system, the main stream and tributaries, except for the Oboro and Obetsu Rivers, were used as study sites. The study period spanned from the postspawning season to just before the river froze: 25 April to 28 November 2008. Survey data were categorized by season: April to June, July to September and October to November, and were defined as spring, summer and autumn,

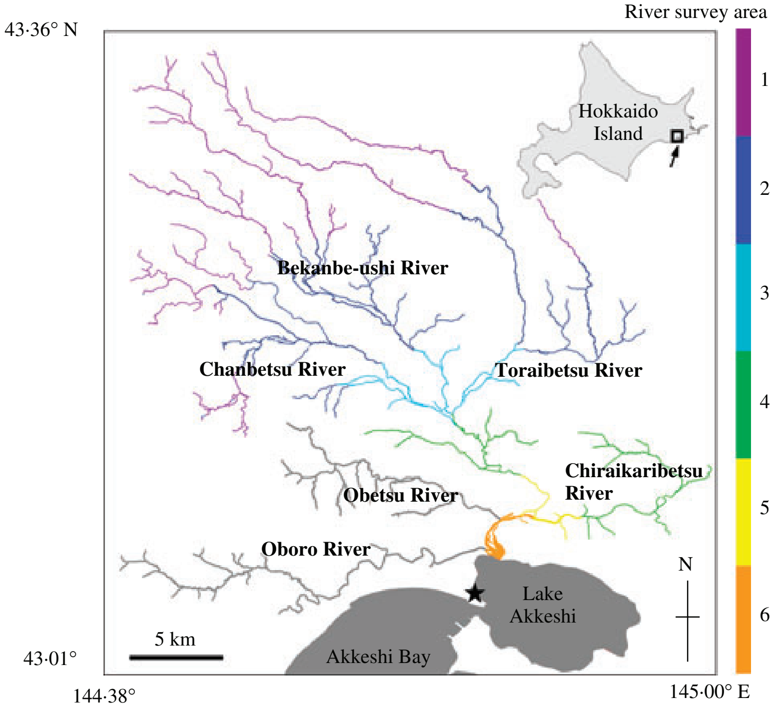

FIG. 1. Study site: the Bekanbeushi River system in eastern Hokkaido Island, Japan. The survey areas (1–6) into which the rivers are divided are indicated by colour coding. ★, the release location of three *Hucho perryi* that had been captured in Lake Akkeshi.

respectively. In this study, the sites where fish were captured and released and their detected locations are not described for reasons of conservation. Location information is described using river domain blocks (areas).

The study sites were categorized into a total of six areas by considering channel length, junctions and tidal effects at the downstream end. Area 1 (Fig. 1, purple) covered the river headwaters 30 km upstream from the river mouth, in terms of channel distance summed over the mainstream and any tributaries. The channel region from the border of area 1 to the confluence between the Bekanbeushi River, Toraibetsu and Chanbetsu Rivers was divided into upper (area 2; Fig. 1, dark blue) and lower (area 3; Fig. 1, pale Blue) areas; the lower border was 20 km from the river mouth. The downstream was divided into three areas based on changes in the flow velocity with tidal fluctuations. Area 4 (Fig. 1, green) was the region extending from the Bekanbeushi River–Toraibetsu River junction to a point 8 km from the river mouth, where flow velocity did not change with the tide. Within the tidal area, the region that extended from the border of area 4 to the Bekanbeushi River–Chiraikaribetsu River junction was area 5 (Fig. 1, yellow), and the region from the junction to the river mouth was area 6 (Fig. 1, orange). Riparian vegetation in areas 2–4 was comprised of an *Alnus–Flaxinus* association, an *Alnus* community and a *Phragmites* class; riparian vegetation in area 5 primarily comprised the *Phragmites* class. In addition, the Chiraikaribetsu River was divided into two areas (upper: area 4, lower: area 5) at a point 6·8 km from the river mouth, where the river width decreases to less than half its greatest width.

FISH CAPTURE AND ACOUSTIC TAG ATTACHMENT

From 25 April to 3 May 2008, a net was set at the upstream end of a tributary in which *H. perryi* spawn, located *c*. 51 km from the river mouth by channel length (area 1); 12 adults

TABLE I. Fish identification (ID), measurements and tagging information for tagged adult *Hucho perry* captured from a tributary of the Bekanbeushi River and Lake Akkeshi *c*. 51 km upstream from the river mouth

Fish ID	Acoustic tag number	Sex	L_F (cm)	M_T (kg)	Captured and released place	Released date
M699R	4726	Male	69·9	3·5	Tributary upstream	26 April
M520R	4652	Male	52·0	2·0	Tributary upstream	26 April
M566R	4722	Male	56·6	2·1	Tributary upstream	26 April
M839R	11 753	Male	83·9	6·0	Tributary upstream	26 April
F815R	11 756	Female	81·5	6·0	Tributary upstream	26 April
M595R	4723	Male	59·5	2·3	Tributary upstream	26 April
F560R	11 754	Female	56·0	1·8	Tributary upstream	26 April
M605R	4725	Male	60·5	2·5	Tributary upstream	26 April
M476R	11 757	Male	47·6	1·4	Tributary upstream	26 April
M563R	11 755	Male	56·3	2·0	Tributary upstream	27 April
F661R	4724	Female	66·1	2·6	Tributary upstream	29 April
M529R	95	Male	52·9	1·7	Tributary upstream	3 May
U705L	96	Unknown	70·5	4·5	Lake Akkeshi	7 May
U741L	94	Unknown	74·1	5·0	Lake Akkeshi	9 May
U800L	98	Unknown	80·0	6·3	Lake Akkeshi	9 May

M, F, U, R and L in fish ID show male, female, unknown, river and lake, respectively. Numbers in fish ID show fork length L_F (mm) of each tagged fish. M_T, body mass.

were captured (nine males and three females; Table I). The identity of each fish was described with regard to sex, fork length (L_F) and capture and release location. Fish were captured using a set net design with a seine (1·0 m high × 28·1 m wide, mesh-size: 40 mm). A fishway was placed along the riverbank. The entrance was located at the upstream side of the net to target *H. perryi* moving downstream. The sex of each fish was determined using physical characteristics and by pressing the abdomen to determine if unreleased gametes were present (Kawamula *et al*., 1996).

After anaesthetizing (2-phenoxyethanol 0·04%, diluted with river water) the 12 captured fish, a small incision (*c*. 1 cm) was made to the abdomen with a scalpel, and an acoustic tag (Vemco V13-1L; www.vemco.com) covered with latex was inserted into the abdominal cavity. The acoustic tags randomly transmitted a set of six pulses (69 kHz) once every 20–60 s for almost a year. A biodegradable line was used for suturing. After tagging, L_F, total length (L_T), and body mass (M_T) of each individual were measured. Measured individuals were immediately moved into a holding tank (60 cm long × 60 cm wide × 100 cm high) and held for >30 min. Individual fish were released immediately downstream of the net after they had recovered from the anaesthetic.

Acoustic tags were also implanted in three additional adult *H. perryi* that had been caught by a set-net fishery in Lake Akkeshi and had been held in a large fish tank in the market of the fisheries co-operative association of Akkeshi for several hours. These three fish were released at the nearby lakeshore after their recovery (Table I and Fig. 1).

It has been found that there is a low probability of post-tagging mortality of adult *H. perryi* from tagging stress in either laboratory or field studies (Honda *et al*. 2009).

TRACKING TAGGED FISH

Tagged fish were tracked using an acoustic receiver (Vemco VR2) that was towed behind a canoe in the river system. During the survey, the acoustic receiver's location was continuously recorded by a GPS receiver (Garmin eTrex Legend; www.garmin.com). Because individual fish were continuously detected at ranges of 10–300 m in the channel, the centre of the detection range was defined as a fish's position, with the stipulation that the location be within the channel. The acoustic receiver was towed in the river system from area 2 to area 6 at least once per month from late April to late November (see Appendix).

USE OF DETECTION DATA

A total of 25 stationary acoustic receivers were also deployed in the river system during the study (K. Honda, K. Miyashita, H. Kagiwada & N. Takahashi, unpubl. data; mean $\pm$ S.D. distance between receivers: 1363 ± 998 m). When a fish was detected by a deployed receiver within 3 h before or after the same fish was detected by the towed receiver, it was assumed the fish was actively migrating and the detection was excluded from the analyses.

Fish positions were plotted monthly on a map (ESRI ArcGIS ver. 9.2; www.esri.com), and an area spanning 400 m of channel length, centred on the fish's position, was defined as the occupied habitat, based on the maximum detection range of the receiver. If two or more tagged *H. perryi* were present in the same 400 m channel segment, the 400 m segment centred on the multiple fish positions was defined as the occupied habitat. If a tagged individual was found several times in the same habitat segment within a single month, the individual was regarded as having stayed in that habitat, and the multiple detections were counted as a single occurrence.

ENVIRONMENTAL FACTORS AND METHODS FOR ANALYSIS

The environmental characteristics of *H. perryi* habitats were measured and recorded during the survey. Selected variables were river depth, tree cover of riparian forests and sinuosity as environmental characteristics; these factors are thought to be highly correlated with habitat use by adult *H. perryi* (Sagawa *et al*., 2002). These environmental characteristics were compared between occupied habitats and all 400 m channel segments in each river area or in all river areas.

On 15–19 June, 16–17 July and 18 and 20 August 2008, water depth was measured using a compact fishfinder (Honda Electronics HE-51C 4.3; www.honda-el.co.jp) attached to the canoe while traversing the river system from area 2 to area 6. Zigzag transects were designed with multiple parallel lines within each subarea. Time was recorded from a radio-controlled clock that was captured by a digital video camera while waypoints were recorded on the GPS unit at *c*. 7 m intervals. The mean depths of occupied habitats and all 400 m channel segments in each river area or in all river areas were calculated by interpolating depth through GIS analysis (normal kriging). The ratio of maximum to mean depth was also calculated as an index of pool existence at the habitat scale. This ratio was used for comparisons between occupied habitats and all segments in each river area or in all river areas, as were mean depth and maximum depth.

On 13 and 15 July 2008, the number of trees in riparian forests was counted along the river system from area 2 to area 6. Trees in riparian forests within 1 m of the river edge (on both sides of the river) were counted by visual observation along 40 m channel segments (20 m upstream and 20 m downstream) that were centred at points spaced at 100 m intervals along the channel length. Trees were classified into six groups based on diameter at breast height (D_{BH}: 5, 10, 20, 30, 40 and 50+ cm), and the number of trees in each class was counted at each station. To minimize bias, measurements were taken by one person. The breast-height area of trees, calculated from D_{BH}, was regarded as proportional to the projected area of tree cover for the river (Waring *et al*., 1982). As a riparian forest index (I_{RF}), the number of trees in a riparian forest was used as an index of forest cover by:

$I_{RF} = 0{\cdot}05^2a + 0{\cdot}1^2b + 0{\cdot}2^2c + 0{\cdot}3^2d + 0{\cdot}4^2e + 0{\cdot}5^2f$, where a to f represent the number of trees in each class. Mean values of I_{RF} for each 400 m channel segment were calculated and used to compare occupied habitats with all 400 m channel segments in each river area or in all river areas.

Channel central points were connected by the longest straight line, and the number of lines was defined as the sinuosity index of a 400 m stretch (Sagawa *et al*., 2002). The 1:25 000 map issued by the Geographical Survey Institute (Japan) was used for GIS analyses.

All environmental indices were compared among habitats and all 400 m channel segments in each river area or in all river areas; significance was tested at $\alpha = 0{\cdot}05$ level by Mann–Whitney *U*-tests to compare the difference between mean ranks for the variables.

RESULTS

RIVER ENVIRONMENTAL CHARACTERISTICS

The water depth and the sinuosity index was not different among areas 2 and 3, but mean I_{RF} was smaller in area 3 (Table II). At the point where the Bekanbeushi, Toraibetsu and Chanbetsu Rivers diverge in area 4, the environment was characterized as being deeper, with a larger I_{RF} and a smaller sinuosity index compared to area 3. The environment in area 5 was deeper, had a smaller I_{RF} value and a smaller sinuosity index compared to area 4. Area 6, which consisted of the Bekanbeushi and Chiraikaribetsu Rivers, was deeper and had a smaller sinuosity index than area 5. Trees were rarely found on the riverbank in area 6.

HABITAT OF ADULT *HUCHO PERRYI*

Tagged fish were detected 468 times. Eleven tagged fish were detected across all areas, from areas 2 to 6. After excluding detections during migration, 66 habitat locations were found from areas 2 to 4 (see Appendix). All the detections in area 2 involved the same fish (U741L), and they were all located *c*. 50–100 m upstream from the border of area 3. Therefore, these detections were pooled with the area 3 data. Two tagged individuals (F560R and F661R) remained in one location; they were found 20 times from July to November at a location in area 4. A large tree (D_{BH} *c*. 60 cm) had fallen at right angles to the flow in this non-meandering area; considering the hydrographic disturbance to the habitat from the fallen tree, these data were excluded from the analysis. As a result, 24 habitat locations were found in area 3, and 22 locations were identified in area 4 (Table III).

SEASONAL CHANGES IN ENVIRONMENTAL CHARACTERISTICS

For each factor, total values were compared between occupied habitats and all 400 m channel segments in all river areas, and these are shown in Fig. 2. Mean depth of occupied habitats ranging from 0·5 to 1·5 m was significantly shallower than that of all segments in all river areas [Fig. 2(a)], while there was no significant difference in maximum depth between occupied habitats and all segments [Fig. 2(b)]. For maximum depth mean depth^{-1}, mean I_{RF} and sinuosity index, the values of occupied habitats were all significantly higher than those of all segments in all river areas ($P < 0{\cdot}001$), no occupied habitat occurred in the river segments for which the maximum depth mean depth^{-1}, mean I_{RF} and sinuosity index ranged between 1·0–1·1, 0 and 1–2, respectively [Fig. 2(c)–(e)].

Each environmental factor was also compared between occupied habitats and all 400 m channel segments (Table IV). Data pooled over all areas was compared to areas 3 and 4 where habitats occurred. Each combination of season and area as well as seasonal differences was analysed (Table IV). To test for differences between

TABLE II. Number (*N*) of 400 m channel segments, channel distance and mean ± S.D. of five environmental factors in each river area of the Bekanbeushi River system

	Area 2	Area 3	Area 4	Area 5	Area 6	All
N of 400 m channel segments	5	30	21	16	8	80
Channel distance (m)	2124	11 665	8230	6049	3114	27 009
Mean depth (m)	0·87 ± 0·10	0·87 ± 0·15	1·20 ± 0·26	1·67 ± 0·31	1·79 ± 0·46	1·21 ± 0·44
Mean maximum depth (m)	0·96 ± 0·06	1·09 ± 0·18	1·62 ± 0·46	1·92 ± 0·35	2·19 ± 0·44	1·50 ± 0·52
Mean of maximum depth mean depth^{-1}	1·12 ± 0·12	1·25 ± 0·12	1·33 ± 0·15	1·16 ± 0·10	1·24 ± 0·12	1·25 ± 0·14
Mean riparian forest index	0·45 ± 0·16	0·21 ± 0·15	0·42 ± 0·29	0·13 ± 0·17	0·00	0·24 ± 0·24
Mean sinuosity index	6·40 ± 0·89	6·80 ± 1·73	3·43 ± 1·36	1·94 ± 0·57	1·38 ± 0·52	4·38 ± 2·56

TABLE III. Number (N) of detected *Hucho perryi* and occupied habitats by season and river area of the Bekanbeushi River system

		Area 3	Area 4
Spring	N of detected fish	6	6
	N of habitat	7	7
Summer	N of detected fish	4	5
	N of habitat	12	10
Autumn	N of detected fish	3	3
	N of habitat	5	5
All	N of detected fish	7	9
	N of habitat	24	22

occupied habitats and the all segments in river areas 3 and 4, the factor values for each area were standardized by dividing by the area's mean value, because mean values of each factor in each area were not uniform (Table II); standardized values were used in statistical tests. Generally, there was no difference between occupied habitats and the all segments in river areas 3 and 4 in mean or maximum depth (Table IV). There were no significant differences between the maximum depth: mean depth ratio for occupied habitats and all segments in areas 3 and 4 (Table IV). Except for spring in area 3, there was a significant difference between the frequency distributions of I_{RF} in occupied habitats and all river segments in areas 3 and 4 (Table IV). For the sinuosity index, the values were significantly higher in occupied habitats than in all segments of areas 3 and 4, except in autumn (Table IV).

DISCUSSION

In this study, persistence of adult *H. perryi* was only found in midstream (shallower than downstream) habitats, which are assumed to be seasonal territories. These habitats were characterized by a relatively large ratio of maximum depth against mean depth, highly meandering channels and high riparian forest cover. Also, compared to the whole channel in each river area, these habitats were characterized by highly meandering channels and high levels of cover from the riparian forest in summer and autumn. These findings correspond to previous results, emphasizing the importance of river meandering and the existence of riparian forests for adult *H. perryi* (Sagawa *et al*., 2002). Furthermore, this study evaluated seasonal changes in the environmental characteristics of their habitats.

Hucho perryi used habitats with sinuous channels and larger ratio of maximum depth against mean depth which indicates the existence of pool. These environmental conditions are probably correlated in natural settings; meandering rivers create a variety of horizontal flow velocities and provide vertical complexity in the channel (Morisawa, 1985; Harris *et al*., 1995; Smith, 1998; Huggett, 2003). The importance of pools in river habitats has been suggested for several species of adult salmonids (Sagawa *et al*., 2002; Baigún, 2003; Edo & Suzuki, 2003). Deeper pools help individuals hide from natural predators, such as eagles or bears (Power, 1987; Schlosser, 1987, 1988; Harvey & Stewart, 1991; Edo & Suzuki, 2003). In addition, the energy

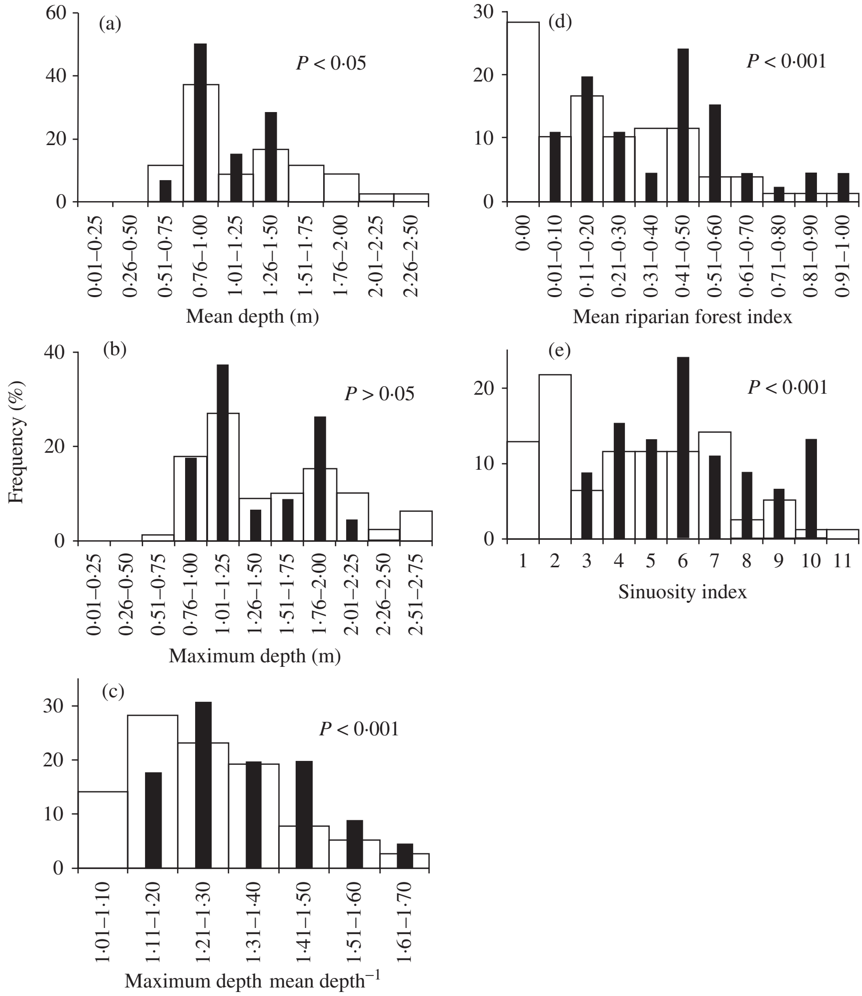

FIG. 2. Overlaid histograms of five environmental factors: (a) mean depth, (b) maximum depth, (c) maximum depth mean depth^{-1}, (d) mean riparian forest index and (e) sinuosity index among all 400 m channel segments in all survey areas (areas 2–6) of the study site (□, $n = 78$) and occupied habitats of adult *Hucho perryi* (■, $n = 46$). P-values of the Mann–Whitney U-test between survey areas and occupied habitats are shown.

required to maintain position is expected to be lower in slow-flowing pools compared to riffles. Thus, the presence of pools associated with channel complexity is a key environmental characteristic of adult *H. perryi* territories. In spring, mean I_{RF} values were smaller in occupied habitats than in the entire channel in each area. Because the study area is located in the subarctic zone, deciduous leaves, which shade the surface of the river, are absent in spring. The presence or absence of foliage influences the amount of cover a river has from sunlight. Water temperature can fluctuate widely because of differences in cover between the summer (July to September), when leaves are profuse, and winter to spring (November to May), when leaves are absent (Nakamura & Dokai, 1989). Studies have shown that riparian forests help

TABLE IV. Average standardized values (values of habitats and mean values in each river area of the Bekanbeushi River system) and *P*-values of the Mann–Whitney *U*-test between habitats of *Hucho perryi* and all 400 m channel segments in each river area, for five environmental factors in each season, each river area and pooled over all river areas

	Areas 3 and 4						All season					
	Spring (n = 14)		Summer (n = 22)		Autumn (n = 10)		Area 3 (n = 24)		Area 4 (n = 22)		Area 3 and 4 (n = 46)	
	Mean ± S.D.	P	Mean ± S.D.	P	Mean ± S.D.	P	Mean ± S.D.	P	Mean ± S.D.	P	Mean ± S.D.	P
Mean depth (m)	1·03 ± 0·19	>0·05	0·95 ± 0·16	NS	1·03 ± 0·09	>0·05	1·00 ± 0·16	>0·05	0·99 ± 0·16	>0·05	0·99 ± 0·16	>0·05
Maximum depth (m)	1·09 ± 0·24	>0·05	0·96 ± 0·19	NS	1·06 ± 0·08	>0·05	1·02 ± 0·17	>0·05	1·03 ± 0·22	>0·05	1·02 ± 0·19	>0·05
Maximum depth mean depth^{-1}	1·05 ± 0·10	>0·05	1·02 ± 0·10	NS	1·04 ± 0·05	>0·05	1·02 ± 0·09	>0·05	1·04 ± 0·10	>0·05	1·03 ± 0·09	>0·05
Mean riparian forest index	0·96 ± 0·51	>0·05	1·40 ± 0·70	<0·05	1·45 ± 0·51	<0·05	1·07 ± 0·71	>0·05	1·50 ± 0·71	<0·05	1·28 ± 0·63	<0·05
Sinuosity index	1·38 ± 0·33	<0·001	1·18 ± 0·26	<0·05	1·18 ± 0·33	>0·05	1·15 ± 0·24	<0·05	1·33 ± 0·34	<0·05	1·24 ± 0·30	<0·001

Each number in parenthesis shows number of occupied habitats.

supply terrestrial invertebrates as prey for salmonids (Hunt, 1975; Cada *et al*., 1987; Nielsen, 1992; Wipfli, 1997; Nakano *et al*., 1999). The quantity of terrestrial invertebrates that fall into a river is relatively small in spring (March to May), but can become large in summer (June to August; Kawaguchi & Nakano, 2001). Kawaguchi & Nakano (2001) found that the proportion of foraging on terrestrial invertebrates by rainbow trout *Oncorhynchus mykiss* (Walbaum) that occurred in June to August was larger than in any other month. Growth of prey and the presence of foliage in forests may seasonally alter the importance of riparian forests for *H. perryi*. Cover from riparian foliage helps individuals hide from terrestrial predators, as do pools (Shirvell, 1990; Edo & Suzuki, 2003). Furthermore, Honda *et al*. (2009) suggested that adult *H. perryi* avoid open areas with high temperatures in downstream regions in summer. Adult *H. perryi* probably select habitats with high levels of riparian forest cover, which promise cooler environments with higher prey availability, from summer to autumn. In addition, fallen trees and drifting trees, which originate from riparian forests, provide pools and hiding places for salmonids (Urabe & Nakano, 1998; Nagayama *et al*., 2009). Although the data were excluded from the statistical analyses, two tagged fish remained near a large fallen tree for several months, suggesting that habitats can be created by occasional hydrographic events. Quantification of fallen trees and underwater habitat complexity should be addressed in future habitat assessments for *H. perryi*.

In recent years, declines in the habitats and species diversity of freshwater fishes have been noted. River channelization, flood control and water utilization, the loss of continuous structure consisting of shallows and pools, and floodplain area changes from river linearization have been regarded as the main reasons for these ecological patterns in fishes (Golden & Twilley, 1976; Swales, 1982; Takahashi & Higashi, 1984; Brooker, 1985; Brookes, 1985, 1988; Shimatani *et al*., 1994). Reductions in the complexity of riverine environments affect fish habitat availability and the socio-ecological costs required for the future sustainability of river basins. The present findings show that ecological complexity is essential in *H. perryi* habitats. Therefore, there is a need to maintain and recover natural channel environments, complete with horizontal and vertical complexity, for future conservation of the species. Vegetation in riparian zones should be considered with respect to seasonal movements and habitat selection by *H. perryi*. The conservation of riparian forests is important for the protection of seasonal habitats of *H. perryi* in the Bekkanbeushi River.

The methods used in this study were successful for examining the movements and the environmental characteristics of selected habitats of adult *H. perryi*. Methodological improvements, however, are expected for future management. The accumulation of time-series data and additional surveys on biological aspects such as sex, age and body size will provide additional information and generate a detailed understanding of *H. perryi* ecology in the future. Moreover, to measure ecological characteristics in detail, new environmental factors, such as the effects of fallen trees or flow velocity, need to be considered. At the same time, the seasonal habitat use of *H. perryi* should be compared with prey distributions. Underwater objects, such as drifting trees and prey availability, should be included in future ecological surveys and habitat assessments. Finally, the management of endangered species requires spatial information without abundant *in situ* information. The integration of accumulated ecological information using GIS, as was done in this study, shall prove valuable for the conservation of suitable habitats for endangered freshwater fishes.

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APPENDIX. Date (in 2008), area and channel distance over which a receiver was towed by a canoe to detect tagged *Hucho perryi* in each river area of the Bekanbeushi River system. Migrating fish are underlined

Date	Areas	Distance a receiver towed (m)	Detected fish identification (see Table I)				
			Area 2	Area 3	Area 4	Area 5	Area 6
28 April	3–4	5812			M605R		
30 April	4–6	8783					
1 May	4–5	5556			M563R, F815R	M839R	
2 May	4–6	5743					
4 May	3–4	11 368					
5 May	3–6	14 444			M563R, F815R	M839R	
6 May	4–6	8632					
7 May	3–4	5812			M605R		
9 May	4–6	7263					M563R, U705L
10 May	3–4	5812			M476R		
12 May	6	1520					U800L
13 May	4–6	8632			F815R	M839R	
14 May	3–6	14 444		M476R	F815R, M563R	M839R	
15 May	2–4	11 050					
19 May	2–4	13 324		M605R, M699R, F560R, F661R			
14 June	4–6	7263					
15 June	2–5	16 606		M699R, U705L	M605R, M839R, F815R		
18 June	4–6	8632			M563R, F815R		
19 June	2–4	11 050		U705L			
20 June	3–4	6957			F560R, F661R, M839R, M563R		
14 July	3–5	5556			M563R, F815R		
15 July	2–4	11 050	U741L	U705L	U800L, M839R, F661R		
16 July	3–4	5812		M605R	M839R, F661R		

APPENDIX. Continued

Date	Areas	Distance a receiver towed (m)	Detected fish identification (see Table I)				
			Area 2	Area 3	Area 4	Area 5	Area 6
17 July	4–6	5743					
16 August	4–6	7263					
17 August	3–5	14 019			M839R, U800L, F560R, F661R, F815R		
18 August	4–5	7062			F815R		
19 August	2–5	16 606	U741L	M699R, U705L	U800L, F560R, M839R, F661R, F815R		
20 August	2–4	13 386	U741L	M699R, U705L, M605R	M839R, F560R, F661R		
16 September	4–6	7263					
17 September	2–4	11 050	U741L	M699R, U705L	U800L, F815R, F560R		
19 September	3–4	6312		M605R	F815R, F661R, F560R, M563R		
16 October	3–6	14 444			F815R, F661R, F560R	M563R	
17 October	4–6	7263					
18 October	2–4	11 050			F815R, F661R, F560R		
19 October	2–4	9753		M699R, M605R			
18 November	4–6	5743					
19 November	3–5	12 874		M605R	F661R, F560R, F815R	M563R	
20 November	2–4	11 050	U741L	M699R	F661R, F560R		
21 November	3–5	11 368		M605R	F661R, F560R, F815R		
22 November	3–5	11 368		M605R	U705L, F661R, F560R, F815R		
24 November	4–5	5556			F815R, U705L		
26 November	3–4	6612		M605R	F661R		
28 November	3–4	6612			F560R, F661R		