Movement patterns of adult Sakhalin taimen, *Parahucho perryi*, between stream habitats of the Bekanbeushi River system, eastern Hokkaido, Japan

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Abstract The behavior of endangered adult Sakhalin taimen *Parahucho perryi* was tracked during 2008–2010 using acoustic telemetry in the Bekanbeushi River system, which flows through eastern Hokkaido, Japan. Movement distances per unit time of tracked *P. perryi* were compared between mid- and downstream habitats. Results indicated that movement distances were significantly longer in downstream habitats during all seasons. The movement distances in each stream decreased from spring to autumn. Moreover, tracked *P. perryi* exhibited crepuscular movement patterns; however, patterns were less pronounced in downstream habitats than in up- and midstream habitats. These findings strongly suggested that adult *P. perryi* exhibit nearly distinctive movement patterns across stream habitats; thus, fish may adopt different foraging tactics in each stream habitat. Fish moved more frequently in spring, which included the post-wintering and post-spawning season, most likely to search for food and more desirable habitat for recovery.

Keywords Acoustic telemetry · Crepuscular movement · Foraging tactics · *Parahucho perryi* · Top predator

Introduction

The Maritime Province of Siberia, Sakhalin Island, the southern Kuril Islands, and Hokkaido Island encompass the primary habitat of the salmonid species, Sakhalin taimen *Parahucho perryi* (Gritsenko et al. 1974; Rand 2006), which has been classified under the International Union for the Conservation of Nature (IUCN) Red List as Critically Endangered (CR) since 2006 due to its drastic decrease over the past several decades (Rand 2006). In addition to functioning as a top predator in river ecosystems, this species can reportedly live for more than 20 years and reach at least 1.3 m in total length (Zolotukhin et al. 2000). *Parahucho perryi* is an iteroparous species (Yamashiro 1965; Kimura 1966), spawning in shallow upstream locations from March to June after snowmelt and displaying an anadromous form that is distinct from its closely related *Hucho* species (Holčík et al. 1988).

To date, numerous studies worldwide have examined the behavioral ecology of riverine fishes using telemetry methods to reveal migratory patterns and habitat uses (e.g., Gilroy et al. 2010; Hedger et al. 2010; Hahn et al. 2011). Generally, 24-h long-term tracking of fish movements is possible when using multiple stationary receivers concurrently. Furthermore, if the distances between stationary receivers are both constant and short enough to cover the migration range of the target fish, the daily or monthly movement distances of the fish can be roughly estimated without actual tracking. Moreover, recently even foraging strategies of some riverine fishes have been beginning to be revealed based on their movement patterns obtained by those telemetry methods (Hedgar et al. 2010; Schoby and Keeley 2011).

In recent years, several behavioral ecological studies have used acoustic telemetry to examine adult *P. perryi* in the Bekanbeushi River system in eastern Hokkaido (Honda et al. 2009, 2010a, 2012). Honda et al. (2010a) documented the seasonal long-term habitat use of adult *P. perryi* and classified their habitats as highly meandering and densely vegetated with riparian plants providing thick shade in the summer and autumn. Meanwhile, in a study on the seasonal stream habitats of adult *P. perryi* over 3 years, Honda et al. (2012) demonstrated that adult fish widely utilized the river system from upstream to a brackish lake that connects to the river mouth regardless of the mainstream or tributaries. These authors verified that *P. perryi* individuals significantly varied in their use of each stream habitat: some fish remained in one specific stream habitat throughout the study period from spring to autumn, whereas others seasonally migrated between upper and lower reaches. In addition, high summer water temperature in downstream habitats triggered the upward migration of this species (Honda et al. 2012). Although Honda et al. (2012) successfully documented the broad-scale use of the river system by adult *P. perryi* based on individual residence times in each stream habitat, behavioral differences among the river habitats were not examined. Furthermore, although crepuscular and nocturnal movement patterns of *P. perryi* were observed in post-spawning migrations from upstream spawning grounds, such diel movement patterns after the spawning season and seasonal differences therein were not reported.

Such behavioral ecological information would be beneficial for conserving an endangered species such as *P. perryi* as well as the environments of its various habitats. In particular, if behavioral differences exist among stream habitats, whether adult *P. perryi* remain within a habitat may vary depending on the environment of the stream habitat. Thus, studying the movement patterns of this species in each stream habitat is essential from a viewpoint of conservation ecology. Here, we examined movement distances, diel movement patterns, and seasonal differences therein in various stream habitats of adult *P. perryi* in the Bekanbeushi River system using acoustic telemetry. We then discuss the presence or absence of various foraging tactics across stream habitats.

Materials and methods

Study site. Surveys were conducted in the Bekanbeushi River system (total basin area: 738.8 km^2) situated in eastern Hokkaido, Japan, from April to November during 2008–2010 (Fig. 1). This river flows into the brackish Lake Akkeshi (circumference: 24.8 km, maximum depth: 7.0 m, salinity: 25–30 psu; Hokkaido Institute of Environmental Sciences 2005), which is connected to the Pacific Ocean by Akkeshi Bay (Fig. 1). Few artificial structures exist within this basin, and the dominant habitat in the lower reaches of the river basin is the Bekanbeushi wetlands (5,277 ha), registered under the Ramsar Convention. Much of the upstream habitat is also intact, as the presence of the Yausubetsu Japanese army training site (16,800 ha) restricts access to the area.

The study area covered the entire Bekanbeushi River system except for the Obetsu and Oboro rivers (Fig. 1), although the estuary of the latter river was initially selected as a study site in 2009 and 2010. In an effort to conserve the remaining populations of *Parahucho perryi*, the actual locations where fish were caught and released cannot be disclosed, although information on these locations is described using river domain blocks (areas). The study sites were grouped into seven areas according to channel length, junctions, and downstream tidal effects (Fig. 1). Honda et al. (2012) presents more detailed information regarding categorization of these areas.

Fish tagging and tracking. Thirty-four mature *P. perryi* were captured using a seine net design (1.0 m high × 28.1 m wide, mesh size: 40 mm) at the upstream end of a tributary in which *P. perryi* spawn, located 51 km from the river mouth (area 1) from late April to early May 2008–2010 (Table 1). A fishway was placed along the riverbank with an entrance located at the upstream side of the net to target only fish moving downstream. From the middle of April to the middle of May, 11 adult *P. perryi* were additionally caught by a local set-net fishery in Lake Akkeshi over the 3 years. The sex of each fish was determined by nuptial coloration (i.e., the posterior half of bodies of males is more reddish than that of females; Esteve et al. 2009) and by pressing the abdomen to determine if unreleased gametes were present. Fork lengths (FLs) of tagged fish ranged from 46.0 to 83.9 cm, and the mean FL (± SD) was 62.7 ± 8.9 cm. The identity of each fish was described with regard to sex, FL, capture/release location, and year tagged. An acoustic tag (Vemco V13-1L; 69.0 kHz, 13.0 mm diameter, 36.0 mm length; www.vemco.com) was surgically implanted into abdominal cavity of all captured *P. perryi* using anesthesia (2-phenoxyethanol 0.04 %, diluted with river water) as in Honda et al. (2009, 2012). Battery life and pulse varied between the two types of tag used. One randomly transmitted a set of six pulses once every 20–60 s lasting 439 days, the other sent pulses every 40–90 s, with power lasting 650 days. After confirming recovery from anesthesia, the tagged fish caught upstream were released just below the net, while the tagged fish caught in Lake Akkeshi were released at the nearby lakeshore (Fig. 1). Both laboratory and field studies have noted a low probability of post-tagging mortality from stress in adult *P. perryi* (see Honda et al. 2009).

From April to November 2008–2010, 24–28 stations that harbored a VR2(W) (Vemco) acoustic receiver were arrayed from area 1 to area 7 (Table 2). Tagged *P. perryi* were tracked by these receivers during the study periods. Additional information about the receiver arrays is described elsewhere (Honda et al. 2012).

Use of detection data. Monthly data were categorized by season, in which April–June, July–September, and October–November were defined as spring, summer, and autumn, respectively (Honda et al. 2012). Detection data recorded in the second year after fish release, data regarding the “downward migration from spawning grounds,” and data recorded by a towed receiver, all of which were obtained by Honda et al. (2012), were not used for any analyses in the present study.

Movement distances in areas 4–6. Individual daily accumulated movement distances in each of areas 4–6 in the mainstream of the Bekanbeushi River system were determined based on the distances between receivers. Even movements between areas (e.g., between areas 3 and 4) were shared and counted based on the distance to the boundary. All stations used for the estimation were shown in Table 2. Data for these areas were used in this analysis because movements of all tagged fish were thoroughly monitored and the mean interval distances between stations in each area did not differ greatly over the 3 years (Table 3). Covered channel lengths in each area were 6,242, 3,888, and 3,090–3,292 m, respectively. According to Honda et al. (2012), areas 4–5 and area 6 were located mid- and downstream within the river system, respectively. Area 6 was wider and deeper than areas 4–5 because the channel of the former contained both the mainstream and the Chiraikaribetsu River (primary tributary; Fig. 1). In addition, some amount of riparian woods exists in areas 4–5, whereas forested riparian areas are rare in area 6 (Honda et al. 2010a). The sinuosity index in area 4 was more than twice higher than that in area 6 (Honda et al. 2010a). Meanwhile, due to these environmental differences, the detection ranges of receivers at stations in lower areas were assumed to be wider than those in upper areas (reviewed by Kessel et al. 2013).

The daily-converted total movement distance (DCTMD) was estimated for every individual in each month based on the "residence time" in each of areas 4–6 in the mainstream and was then compiled for seasons examined. Residence time, defined as the time during which each tagged fish remained in each area, was calculated based on its detection data (Honda et al. 2009, 2012). Time periods without detection were shared half and half between the area of detection before and the area of detection after the no detection period (Honda et al. 2009). Thus, the DCTMD represents the individual total movement distance in each area which was divided by total residence time (d) there. The differences in monthly DCTMDs among areas during the same season and among seasons in the same area were tested using nonparametric multiple comparison analysis (Steel–Dwass test) with Ky Plot 5.0 (KyensLab Inc.; www.kyenslab.com) at $\alpha = 0.05$. Here, only monthly DCTMDs, which were estimated using fish with more than 3 recorded days of residence time in each area and in each month, were used in this analysis. Because some overlapping detections were recorded between stations 23 and 25, any movement distances between station 25 and the boundary between area 5 in the Chiraikaribetsu River and area 6 (i.e., 217 m) were not included due to this uncertainty. Moreover, the lower boundary of area 6 was considered to occur at station 29 in this analysis because station 30 was absent in 2008. The time of continuous detections at station 29 was included in the residence time of area 6. Here, two or more detections within 180 s (fish equipped with a transmitter having a 20–60-s transmission interval) or 270 s (fish equipped with a transmitter having a 40–90-s transmission interval) were defined as continuous detection, as in Honda et al. (2009), based on the very unlikely possibility of three consecutive time transmissions (maximum transmission interval: 60 or 90 s) being missed from one acoustic tag.

Furthermore, in order to determine the effect of the differences of detection ranges among areas on movement distances, we assumed that the detection range of each acoustic receiver in areas 5–6 were consistently 50 m and 100 m wider, respectively than that of area 4 (liberal estimation) and that all fish movements in areas 5–6 were consisted of minimum distances within the detection range of each receiver. We then carried out same analysis described above but by shortening all movement distances by 100 m (50 m each side) in area 5 and 200 m (100 m each side) in area 6 and compared the obtained results between the two analyses.

Diel movement patterns among stream habitats. Assuming that tagged fish were moving both outside and inside of the detection range at the beginning and end of a series of multiple detections by each receiver, only the first and last detections were extracted and defined as "movement" in this analysis. Areas 1–3, 4–5, and 6–7 were defined as up-, mid-, and downstream habitats, respectively (Honda et al. 2012), while all movement data recorded by all receivers in each stream habitat were divided into day, twilight, and night. The standardized hourly rates of movement during these three time periods were also estimated. Here, the time period for twilight was considered to be 4 h (2 h each around daily sunrise and sunset), while day and night comprised the rest of the day. The timings of sunrise and sunset were determined from data recorded at the Ota weather station (43.092°N, 144.780°E) of the Japan Meteorological Agency (http://www.jma.go.jp/jma/index). Differences in movement rates for all tagged fish among time periods in each season and during all seasons combined were tested using Steel–Dwass tests ($\alpha = 0.05$). In this analysis, only fish that exhibited 10 or more movements in each season or all seasons combined were used. All overlapping detections and shuttle movements within 5 min between stations 23 and 25 were excluded from the analysis because such detections were not likely to reflect actual movements.

Results

The numbers of tagged *Parahucho perryi* detected at least once were 12, 13, and 14 in 2008, 2009, and 2010, respectively. The numbers of tagged fish tracked in mid-November or later in each year were eight, eight, and six, respectively (Table 1). More information on the basic detection results and residence time in each area is available in Honda et al. (2012).

Movement distances in areas 4–6. The total accumulated residence times in areas 4, 5, and 6 in the mainstream of the Bekanbeushi River system by all tracked fish in 2008–2010 were 1,611, 524, and 298 days, corresponding to total accumulated movement distances of 553, 378, and 1,417 km, respectively. The frequency of individual daily accumulated movement distances of greater than 51 m in areas 4–5 was low, whereas the frequency of movements of 0–50 m accounted for more than 70 % of all movements in these two areas (Fig. 2). In addition, over 90 % of movement distances 0–50 m were recorded in 18–24 h of daily accumulated residence time. On the other hand, movement distances of over 501 m comprised more than 50 % of all movements in area 6, and the daily accumulated residence time ranged widely from a few hours up to 24 h in this area (Fig. 2).

Mean monthly DCTMDs in each area increased toward downstream habitats regardless of season (Fig. 3a). In particular, DCTMD significantly differed between areas 4–5 and area 6 during each season ($-4.80 \leq t \leq -2.37$, $P < 0.05$); mean distances in area 6 were 4.8–39.0 times higher than in areas 4–5 (Fig. 3a). This pattern was observed in many individuals; in fact, even among individuals that were recorded in both areas 4 and/or 5 and area 6, 82 % of fish (9 of 11) exhibited values of DCTMD in area 6 that were more than twice higher than those in areas 4 and/or 5 throughout the study period.

The large variances of values of mean monthly DCTMD (Fig. 3) indicated that some individuals differed considerably in movement distances. For example, F705R09 (fish ID, see Table 1) remained in area 4 for a total of 11.6 days in the summer, but its DCTMD was 1,416 m, which was nearly five times higher than the mean value for the same season. In contrast, even though U557L09 remained in area 6 for 7.1 days in the spring, its DCTMD was only 43 m (without treatment).

In addition, the monthly DCTMDs in spring were the highest of all seasons in all areas, whereas values of DCTMD became significantly shorter from spring into autumn in areas 4 ($t = 3.93$, $P < 0.05$) and 6 ($t = 3.25$, $P < 0.05$, Fig. 3a).

The trend did not differ between the results of detection-range-considered- (Fig. 3b) and untreated analyses (Fig. 3a). Significant differences in the former were observed among same areas and seasons as the latter ($-4.74 \leq t \leq 3.93$, $P < 0.05$, Fig. 3b).

Diel movement patterns among stream habitats. The mean individual standardized hourly rates of movements during the twilight time period tended to be higher than those during the day or night (Fig. 4). With the exception of upstream habitats in autumn when only two fish were recorded, however, movements did not significantly differ between twilight and day/night in downstream habitats during the summer (t = –0.32, P = 0.95, between day and twilight; t = 0.64, P = 0.80, between night and twilight) or during all seasons combined (t = –1.65, P = 0.22, between day and twilight; t = 2.25, P = 0.06, between night and twilight; Fig. 4).

Discussion

The present study demonstrated that the movement patterns of adult *Parahucho perryi* varied among stream habitats. Most fish tracked did not move long distances in midstream habitats of the Bekanbeushi River; instead, fish in downstream habitats tended to exhibit much more movement (Fig. 3) although their short-distance movements could not be monitored using the current study design. Meanwhile, the comparison between the detection-range-considered- and untreated analyses indicated that the differences of detection ranges among areas have not affected greatly on the obtained results. Moreover, the daily accumulated residence time in area 6 was shorter than that in areas 4–5 (Fig. 2). These results indicate that fish in areas 4–5 spent most of their time in the same area, whereas fish in area 6 did not and instead included adjacent areas in their daily movement ranges. Only a limited number of studies of salmonids have reported similar differences in movement patterns among river reaches (e.g., Young 1996; Zimmer et al. 2010). Zimmer et al. (2010) used radiotelemetry to track 43 brown trout (*Salmo trutta*, 34.0–59.6 cm FL) in up- and midstream regions of the Credit River, which flows into Lake Ontario. They found that the home range and displacement (km) of individuals in upper reaches were small compared to individuals in lower reaches. These authors suggested that the difference was caused by the presence of extensive riffle areas, which deter movements, in upstream habitats, and because individuals in lower reaches sought optimal water temperatures to avoid high temperatures in the area (Zimmer et al. 2010).

In the Bekanbeushi River system, the channels in upper reaches are more meandering and are bordered by more dense riparian woods than those in the lower reaches (Honda et al. 2010a). Those channels also have few riffles even in upper reaches including area 4 because of very low difference of elevation (the elevation at headstream of the mainstream is <150 m). Such channels in the upper reaches are assumed to provide more woody debris and pools, which are likely suitable for salmonid species including adult *P. perryi* to hide from both their prey and predators such as eagles (Fausch and Northcote 1992; Sagawa et al. 2002, Nagayama et al. 2009). In addition, riverine structures such as woody debris provide refuge for prey species of *P. perryi* (Benke and Wallace 2003; Dolloff and Warren 2003). Therefore, the upper reaches offer few advantages for adult *P. perryi* in terms of wide-range searching for food; instead, ambush foraging tactics are likely to be more efficient to avoid energy costs. In fact, adult *P. perryi* remained in specific habitats in up- and midstream habitats of the Bekanbeushi River, particularly in areas with higher sinuosity and more dense riparian forests for the mid- to long term (Honda et al. 2010a). In contrast, prey fish such as *Osmerus mordax dentex*, *Hypomesus japonicas*, *Salangichthys microdon*, *Tribolodon hakonensis*, *Gasterosteus aculeatus*, *Pungitius sinensis*, and *Gymnogobius urotaenia* are assumed to inhabit, either seasonally or year-round, the downstream regions of the Bekanbeushi River (Mukai 2007; K. Honda, unpublished data). Generally, most of these prey species form schools; therefore, in these habits, cruising foraging tactics would likely be more efficient for adult *P. perryi* to encounter schools of prey fish. In addition, even though the tidal effect on fish movements was not taken into account in this study, area 6 was assumed to be more affected by tide than areas 4–5. Both *P. perryi* and its preys may have moved along with tidal changes. The effect of tide to fish movement patterns are reported in several other fish species (e.g., Childs et al. 2008; Sakabe and Lyle 2010), including some adult salmonids on their pre- and post-spawning seasons (e.g., Bendall et al. 2005; Hubley et al. 2008). Sakabe and Lyle (2010) revealed that *Acanthopagrus butcheri* in the Little Swanport Estuary in Tasmania exhibited extensive tidal movements, with small-scale upstream movements during incoming tides and downstream movements during out-going tides.

Ambush and cruising foraging tactics generally exhibit a trade-off relationship (O'Brien et al. 1990). Furthermore, differences between the two tactics are closely related to different alternative life history types of freshwater resident and seaward migrant salmonids (Elliott 1994; Yamamoto et al. 1999). The migratory ranges of *P. perryi* are generally limited up to the connected coastal zone (Arai et al. 2004; Edo et al. 2005; Suzuki et al. 2011; Zimmerman et al. 2011). Among individuals of *P. perryi* from the Bekanbeushi River system, few fish are thought to migrate into Akkeshi Bay (i.e., the ocean) from the brackish Lake Akkeshi (Kawamula et al. 1983; Honda et al. 2010b, 2012). Because of their limited migratory ranges, *P. perryi* may not face the rigid alternative choice between seaward migratory or freshwater resident life histories. In fact, *P. perryi* in the study system exhibited large individual variability in their use of seasonal stream habitats, and this variability did not appear to exhibit remarkable seasonality or size- and/or sex-dependent patterns (Honda et al. 2012). Therefore, it is not surprising that this species might adopt different movement patterns in each stream habitat depending on individual requirements. With regard to the observed individual differences in movement distances, we suspect that some fish may have tracked prey fish even in area 4 and that large woody debris that provided suitable hiding places may have existed even in area 6.

Movement distances of *P. perryi* significantly differed among seasons in each area, and the tracked fish moved the farthest distances in spring (Fig. 3). Honda et al. (2012) reported that the number of individuals that used multiple stream habitats was higher in the spring. Similar increases in fish activity in the post-wintering/spawning season have also been reported for other salmonid species (Meka et al. 2003; Gilroy et al. 2010). Overwintering and spawning utilize body strength and exhaust reserves; therefore, to recover in the spring, *P. perryi* may search for food and more desirable habitat, resulting in variable movement within the river system.

In the present study, adult *P. perryi* exhibited crepuscular movement patterns (Fig. 4). Endogenous circadian rhythms of salmonids fluctuate depending on differences in species, growth stages, and external factors such as photoperiod or water temperature (e.g., Fraser et al. 1993; Alanärä and Brännäs 1997; Metcalfe et al. 1999; Baldwin et al. 2002; Bendall et al. 2005). Similar crepuscular movement patterns have been reported in other salmonid species (e.g., Douglas 1982; Ovidio et al. 2002); the purpose of active movements during twilight is likely foraging (Boujard and Leatherland 1992). This particular time period may offer an efficient foraging opportunity for adult *P. perryi* not only because prey may be less likely to notice sudden attacks, but also because they can target both nocturnal and diurnal prey species (Hobson 1972). Meanwhile, whether the high summer water temperatures in downstream habitats (Honda et al. 2012) caused the lack of crepuscular movement patterns in fish in these areas remains unclear. In the future, the actual swimming information which can be obtained by such as acceleration data logger (see Tsuda et al. 2006) and electromyogram transmitter (see Makiguchi et al. 2007) can be used to more clearly verify the differences of movement patterns of *P. perryi* among different time periods and also among different stream habitats.

In Hokkaido, a main habitat of *P. perryi*, the loss of riverine heterogeneity due to river developments such as channelization has resulted in marked uniformity of river channels over the past several decades (Fukushima et al. 2005). For aquatic species such as *P. perryi* that widely utilize the river system and exhibit nearly distinctive movement patterns across stream habitats, reduced riverine heterogeneity would probably compromise their options for foraging tactics. Thus, when conserving and restoring the habitats of *P. perryi*, barrier-free physical connectivity among their habitats must be considered (Honda et al. 2012). Moreover, conservation and restoration based on the original environmental characteristics of each stream habitat should be a requirement.

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References

Alanärä A, Brännäs E (1997) Diurnal and nocturnal feeding activity in Arctic char (*Salvelinus alpinus*) and rainbow trout (*Oncorhynchus mykiss*). Can J Fish Aquat Sci 54:2894–2900

Arai T, Kotake A, Morita K (2004) Evidence of downstream migration of Sakhalin taimen, *Hucho perryi*, as revealed by Sr:Ca ratios of otoliths. Ichthyol Res 51:377–380

Baldwin CM, Beauchamp DA, Gubala CP (2002) Seasonal and diel distribution and movement of cutthroat trout from ultrasonic telemetry. Trans Am Fish Soc 131:143–158

Bendall B, Moore A, Quale V (2005) The post-spawning movements of migratory brown trout *Salmo trutta* L. J Fish Biol 67:809–822

Benke AC, Wallace JB (2003) Influence of wood on invertebrate communities in streams and rivers. In: Gregory S, Boyer KL, Gurnell AM (eds) The ecology and management of wood in world rivers. American Fisheries Society, Symposium 37, Bethesda, Maryland, pp 149–177

Boujard T, Leatherland JF (1992) Demand feeding behaviour and diel pattern of feeding activity in *Oncorhynchus mykiss* held under different photoperiod regimes. J Fish Biol 40:535–544

Childs A-R, Cowley PD, Næsje TF, Booth AJ, Potts WM, Thorstad EB, Økland F (2008) Do environmental factors influence the movement of estuarine fish? A case study using acoustic telemetry. Est Coast Shelf Sci 78:227–236

Dolloff CA, Warren ML (2003) Fish relationship with large wood in small streams. In: Gregory S, Boyer KL, Gurnell AM (eds) The ecology and management of wood in world rivers. American Fisheries Society, Symposium 37, Bethesda, Maryland, pp 179–193

Douglas RH (1982) An endogenous crepuscular rhythm of rainbow trout (*Salmo gairdneri*) photomechanical movements. J Exp Biol 96:377–388

Edo K, Kawaguchi Y, Nunokawa M, Kawamula H, Higashi S (2005) 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. Environ Biol Fish 74:1–7

Elliott JM (1994) Quantitative ecology and the brown trout. Oxford University Press, Oxford

Esteve M, McLennan DA, Kawahara M (2009) Spawning behaviour of Sakhalin taimen, *Parahucho perryi*, from northern Hokkaido, Japan. Environ Biol Fish 85:265–273

Fausch KD, Northcote TG (1992) Large woody debris and salmonid habitat in a small coastal British Columbia stream. Can J Fish Aquat Sci 49:682–693

Fraser NH, Metcalfe NB, Thorpe JE (1993) Temperature dependent switch between diurnal and nocturnal foraging in salmon. Proc R Soc Lond B Biol Sci 252:135–139

Fukushima M, Iwadate T, Kaneko M, Yabuki T, Kameyama S (2005) Changes in the fluvial morphology of Hokkaido rivers—Loss of geodiversity due to channelization—. Chikyukankyo 10:135–144

Gilroy DJ, Jensen OP, Allen BC, Chandra S, Ganzorig B, Hogan Z, Maxted JT, Vander Zanden MJ (2010) Home range and seasonal movement of taimen, *Hucho taimen*, in Mongolia. Ecol Freshw Fish 19:545–554

Gritsenko OF, Malkin EM, Churikov AA (1974) Sakhalinskii taimen’ *Hucho perryi* (Brevoort) reki Bogatoi (vostochnoe poberezh’e Sakhalina). Izv Tikhookean Nauchno-Issled Inst Rybn Khoz Okeanogr 93:91–100

Hahn L, Agostinho AA, English KK, Carosfeld J, da Câmara LF, Cooke SJ (2011) Use of radiotelemetry to track threatened dorados *Salminus brasiliensis* in the upper Uruguay River, Brazil. Endang Species Res 15:103−114

Hedger RD, Dodson JJ, Hatin D, Caron, Fournier D (2010) River and estuary movements of yellow-stage American eels *Anguilla rostrata*, using a hydrophone array. J Fish Biol 76:1294–1311

Hobson ES (1972) Activity of Hawaiian reef fishes during the evening and morning transitions between daylight and darkness. Fish Bull 70:715–740

Hokkaido Institute of Environmental Sciences (2005) Lakes and marshes in Hokkaido (revised edition). Hokkaido Institute of Environmental Sciences, Sapporo

Holčík J, Hensel K, Nieslanik J, Skácel L (1988) The Eurasian huchen, *Hucho hucho*. Largest salmon of the world. Dr W Junk, Dordrecht, The Netherlands, pp 2–12

Honda K, Noda Y, Tsuda Y, Yasuma H, Miyashita K (2009) Tracing seasonal migration of adult Sakhalin taimen, *Hucho perryi*, using acoustic telemetry. Jpn J Ecol 59:239–247

Honda K, Kagiwada H, Tojo N, Miyashita K (2010a) Riverine environmental characteristics and seasonal habitat use by adult Sakhalin taimen, *Hucho perryi*, in the Bekanbeushi River system, Japan. J Fish Biol 77:1526–1541

Honda K, Arai T, Takahashi N, Miyashita K (2010b) 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. Ichthyol Res 57:416–421

Honda K, Kagiwada H, Takahashi N, Miyashita K (2012) Seasonal stream habitat of adult Sakhalin taimen, *Parahucho perryi*, in the Bekanbeushi River system, eastern Hokkaido, Japan. Ecol Freshw Fish 21:640–657

Hubley PB, Amiro PG, Gibson AJF, Lacroix GL, Redden AM (2008) Survival and behaviour of migrating Atlantic salmon (*Salmo salar* L.) kelts in river, estuarine, and coastal habitat. ICES Mar Sci 65:1–9

Kawamula H, Mabuchi M, Yonekawa T (1983) The Japanese huchen, *Hucho perryi* (BREVOORT), collected in brackish water Lake Akkeshi, eastern Hokkaido, Japan. Sci Rep Hokkaido Fish Hatch 38:47–55

Kessel ST, Cooke SJ, Heupel MR, Hussey NE, Simpfendorfer CA, Vagle S, Fisk AT (2013) A review of detection range testing in aquatic passive acoustic telemetry studies. Rev Fish Biol Fisheries DOI 10.1007/s11160-013-9328-4

Kimura S (1966) On the life history of the salmonid fish, *Hucho perryi* (BREVOORT), found in Nemuro, Hokkaido. Jpn J Ichthyol 14:17–25

Makiguchi Y, Nii H, Nakao K, Ueda H (2007) Upstream migration of adult chum and pink salmon in the Shibetsu River. Hydrobiologia 582:43–54

Meka JM, Knudsen EE, Douglas DC, Benter RB (2003) Variable migratory patterns of different adult rainbow trout life history types in southwest Alaska watershed. Trans Am Fish Soc 132:717–732

Metcalfe NB, Fraser NHC, Burns MD (1999) Food availability and the nocturnal vs diurnal foraging trade-off in juvenile salmon. J Anim Ecol 68:371–381

Mukai H (2007) Fish. In: Akkeshi history editorial committee (ed) New Akkeshi history, Akkeshi-cho, Hokkaido, pp 80–84

Nagayama S, Kawaguchi Y, Nakano D, Nakamura F (2009) Summer microhabitat partitioning by different size classes of masu salmon (*Oncorhynchus masou*) in habitats formed by installed large wood in a large lowland river. Can J Fish Aquat Sci 66:42–51

O’Brien WJ, Browman HI, Evans BI (1990) Search strategies of foraging animals. Am Sci 78:152–160

Ovidio M, Baras E, Goffaux D, Giroux F, Philipart JG (2002) Seasonal variation of activity pattern of brown trout (*Salmo trutta*) in a small stream as determined by radio-telemetry. Hydrobiologia 470:195–202

Rand PS (2006). *Hucho perryi*. In: IUCN 2012. IUCN Red List of Threatened Species. Version 2012.2. www.iucnredlist.org. Accessed 18 Apr 2013

Sagawa S, Yamashita S, Nakamura F (2002) Summer habitat use of adult Sakhalin taimen in a tributary of the Teshio River, Hokkaido, Japan: management implications for habitat conservation. Jpn J Ecol 52:167–176

Sakabe R, Lyle JM (2010) The influence of tidal cycles and freshwater inflow on the distribution and movement of an estuarine resident fish *Acanthopagrus butcheri*. J Fish Biol 77:643–660

Schoby PS, Kline ER (2011) Home range size and foraging ecology of bull trout and westslope cutthroat trout in the upper Salmon River Basin, Idaho. Trans Am Fish Soc

140:636–645

Suzuki K, Yoshitomi T, Kawaguchi Y, Ichimura M, Edo K, Otake T (2011) Migration history of Sakhalin taimen *Hucho perryi* captured in the sea of Okhotsk, northern Japan, using otolith Sr:Ca ratios. Fisher Sci 77:313–320

Tsuda Y, Kawabe R, Tanaka H, Mitsunaga Y, Hiraishi T, Yamamoto K, Nashimoto K (2006) Monitoring the spawning behavior of chum salmon with an acceleration data logger. Ecol Freshw Fish 15:264–274

Yamamoto S, Morita K, Goto A (1999) Geographic variations in life-history characteristics of white-spotted charr (*Salvelinus leucomaenis*). Can J Zool 77:871–878

Yamashiro S (1965) Age and growth of the ITO (*Hucho perryi*) in northeastern Hokkaido. Bull Jpn Soc Sci Fish 31:1–75

Young MK (1996) Summer movements and habitat use by Colorado River cutthroat trout (*Oncorhynchus clarki pleuriticus*) in small, montane streams. Can J Fish Aquat Sci 53:1403–1408

Zimmer M, Schreer JF, Power M (2010) Seasonal movement patterns of Credit River brown trout (*Salmo trutta*). Ecol Freshw Fish 19:290–299

Zimmerman CE, Rand PS, Fukushima M, Zolotukhin SF (2011) Migration of Sakhalin taimen (*Parahucho perryi*): evidence of freshwater resident life history types. Environ Biol Fish 93:223–232

Zolotukhin SF, Semenchenko AY, Belyaev VA (2000) Taimen and Lenok of the Russian Far East. TINRO Center, Khabarovsk

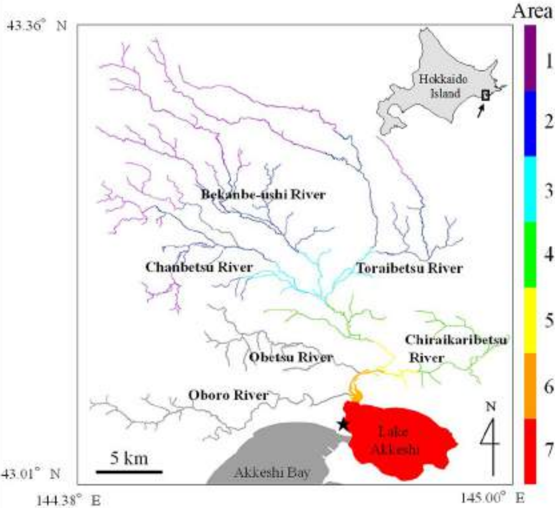
Figure legends

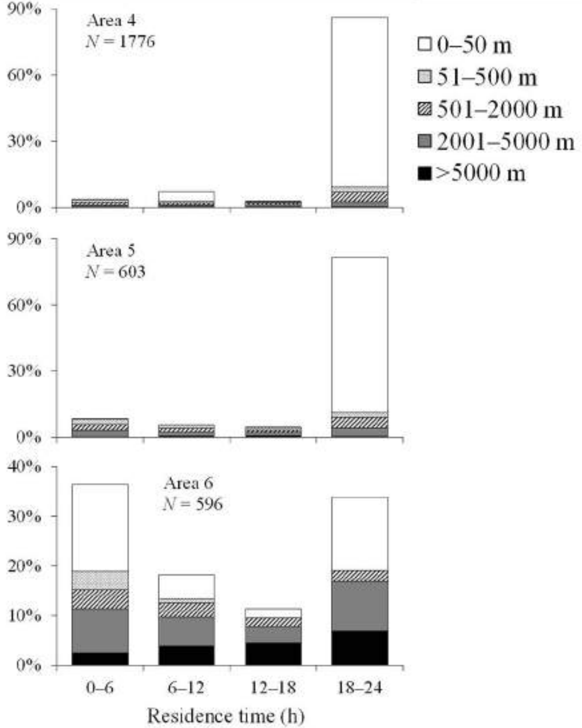
Fig. 1 Study site: the Bekanbeushi River system in eastern Hokkaido Island, Japan. Each area is color-coded. The *star* indicates the location where *Parahucho perryi* captured in Lake Akkeshi were released. Figure reproduced from Honda et al. (2012), with permission from John Wiley & Sons

Fig. 2 Frequency of daily accumulated movement distances by each tagged *Parahucho perryi* for each classified daily accumulated residence time in areas 4–6 in the mainstream of the Bekanbeushi River system

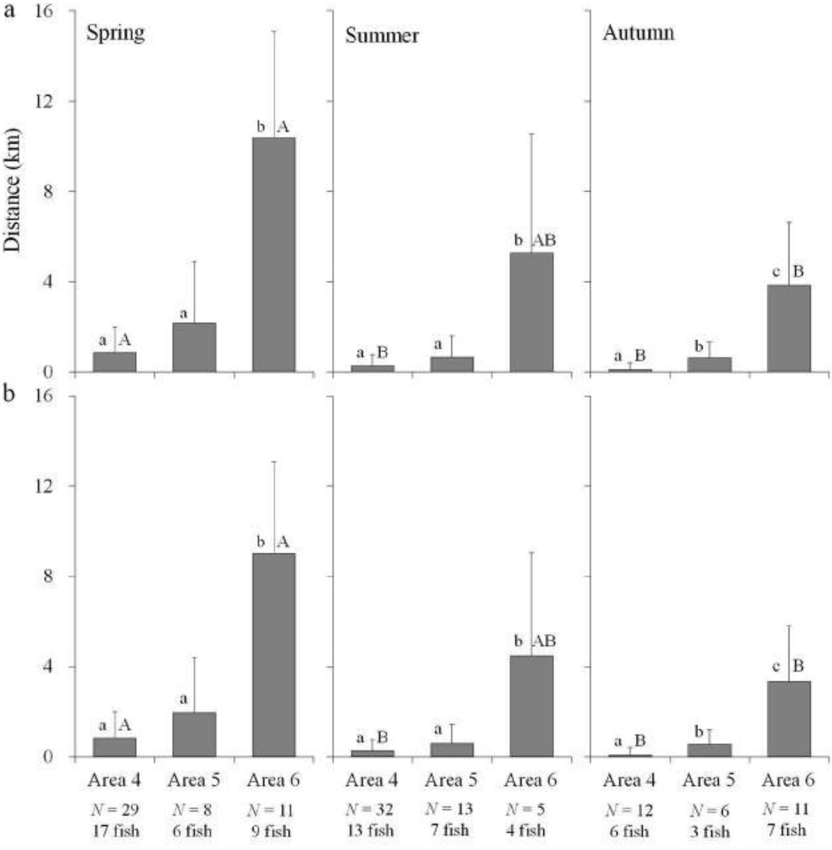
Fig. 3 Mean monthly daily-converted total movement distance (DCTMD) by each tagged *Parahucho perryi* in areas 4–6 in the mainstream of the Bekanbeushi River system in each season. **a** Untreated, **b** detection-range-considered by shortening all movement distances by 100 m (50 m each side) in area 5 and 200 m (100 m each side) in area 6. *Error bars* represent standard deviations. Significantly different data are coded by *a*, *b*, or *c* among areas, and by *A* and *B* among seasons ($P < 0.05$)

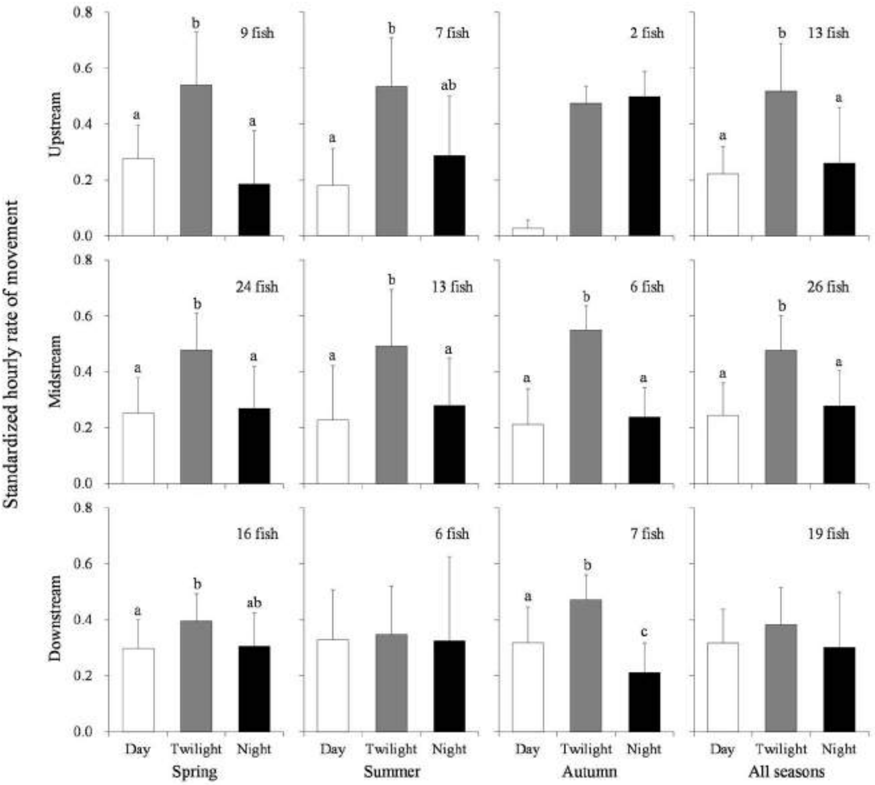
Fig. 4 Standardized hourly rate of movements among three time periods by each tagged *Parahucho perryi* among up- (areas 1–3), mid- (areas 4–5), and downstream (areas 6–7) habitats in each season and in all seasons combined. Error bars represent standard deviations. *White*, *gray*, and *black bars* indicate daytime, twilight, and nighttime periods, respectively. Significantly different data are coded by *a*, *b*, or *c* ($P < 0.05$)


Area
1
2
3
4
5
6
7
43.36° N
43.01° N
144.38° E
145.00° E
Hokkaido Island
Bekanbe-ushi River
Chanbetsu River
Toraibetsu River
Chiraikaribetsu River
Obetsu River
Oboro River
Lake Akkeshi
Akkeshi Bay
5 km
N



Area 4
N = 1776
Area 5
N = 603
Area 6
N = 596
0–50 m
51–500 m
501–2000 m
2001–5000 m
>5000 m
90%
60%
30%
0%
40%
20%
10%
0–6
6–12
12–18
18–24
Residence time (h)


a
b
Spring
Summer
Autumn
Distance (km)
16
12
8
4
0
a A
a
b A
a B
a
b AB
a B
b
c B
Area 4
Area 5
Area 6
N = 29
17 fish
N = 8
6 fish
N = 11
9 fish
N = 32
13 fish
N = 13
7 fish
N = 5
4 fish
N = 12
6 fish
N = 6
3 fish
N = 11
7 fish



Standardized hourly rate of movement
Upstream
Midstream
Downstream
0.0
0.2
0.4
0.6
0.8
9 fish
7 fish
2 fish
13 fish
24 fish
13 fish
6 fish
26 fish
16 fish
6 fish
7 fish
19 fish
a
b
ab
c
Day
Twilight
Night
Spring
Summer
Autumn
All seasons

Table 1 Fish ID, measurements, and tagging information for tagged adult *Parahucho perryi* captured in an upstream tributary (51 km upstream from the river mouth) of the Bekanbeushi River and in Lake Akkeshi in Hokkaido, Japan. Table reproduced from Honda et al. (2012), with permission from John Wiley & Sons

Fish ID	Sex	Fork length (cm)	Body weight (kg)	Transmission interval (once in: s)	Capture and release location	Release date	Date of final detection
M699R08	Male	69.9	3.5	20–60	Tributary upstream	26 Apr 2008	20 Nov 2008
M520R08	Male	52.0	2.0	20–60	Tributary upstream	26 Apr 2008	Non
M566R08	Male	56.6	2.1	20–60	Tributary upstream	26 Apr 2008	6 Jun 2008
M839R08	Male	83.9	6.0	20–60	Tributary upstream	26 Apr 2008	4 Sep 2008
F815R08	Female	81.5	6.0	20–60	Tributary upstream	26 Apr 2008	24 Nov 2008
M595R08	Male	59.5	2.3	20–60	Tributary upstream	26 Apr 2008	Non
F560R08	Female	56.0	1.8	20–60	Tributary upstream	26 Apr 2008	28 Nov 2008
M605R08	Male	60.5	2.5	20–60	Tributary upstream	26 Apr 2008	26 Nov 2008
M476R08	Male	47.6	1.4	20–60	Tributary upstream	26 Apr 2008	19 May 2008

M563R08	Male	56.3	2.0	20–60	Tributary upstream	27 Apr 2008	23 Nov 2008	
F661R08	Female	66.1	2.6	20–60	Tributary upstream	29 Apr 2008	28 Nov 2008	*
M529R08	Male	52.9	1.7	20–60	Tributary upstream	3 May 2008	Non	
U705L08	Unknown	70.5	4.5	20–60	Lake Akkeshi	7 May 2008	24 Nov 2008	*
U741L08	Unknown	74.1	5.0	20–60	Lake Akkeshi	9 May 2008	20 Nov 2008	*
U800L08	Unknown	80.0	6.3	20–60	Lake Akkeshi	9 May 2008	17 Sep 2008	
U593L09	Unknown	59.3	2.1	20–60	Lake Akkeshi	13 Apr 2009	24 Nov 2009	
U627L09	Unknown	62.7	2.7	20–60	Lake Akkeshi	13 Apr 2009	29 Nov 2009	*
U650L09	Unknown	65.0	3.0	40–90	Lake Akkeshi	20 Apr 2009	7 May 2009	
U557L09	Unknown	55.7	1.8	20–60	Lake Akkeshi	24 Apr 2009	28 Nov 2009	*
M663R09	Male	66.3	2.7	20–60	Tributary upstream	26 Apr 2009	27 Nov 2009	*
F685R09	Female	68.5	2.8	20–60	Tributary upstream	26 Apr 2009	29 Nov 2009	*
M606R09	Male	60.6	2.2	20–60	Tributary upstream	26 Apr 2009	27 Nov 2009	*
M584R09	Male	58.4	1.9	40–90	Tributary upstream	26 Apr 2009	Non	
F585R09	Female	58.5	1.9	20–60	Tributary upstream	26 Apr 2009	27 Nov 2009	*
F691R09	Female	69.1	2.9	40–90	Tributary upstream	29 Apr 2009	26 Aug 2009	

M535R09	Male	53.5	1.6	20–60	Tributary upstream	29 Apr 2009	19 May 2009	
F705R09	Female	70.5	3.1	40–90	Tributary upstream	1 May 2009	5 Aug 2009	
M605R09	Male	60.5	1.9	20–60	Tributary upstream	1 May 2009	10 Oct 2009	*
M585R09	Male	58.5	2.0	40–90	Tributary upstream	2 May 2009	Non	
U645L09	Unknown	64.5	2.9	40–90	Lake Akkeshi	7 May 2009	27 Nov 2009	*
F618R10	Female	61.8	2.6	40–90	Tributary upstream	27 Apr 2010	17 Jun 2010	
M705R10	Male	70.5	4.2	40–90	Tributary upstream	27 Apr 2010	12 May 2010	
M514R10	Male	51.4	1.9	40–90	Tributary upstream	27 Apr 2010	24 Nov 2010	
M510R10	Male	51.0	1.8	40–90	Tributary upstream	29 Apr 2010	20 May 2010	
M460R10	Male	46.0	1.5	40–90	Tributary upstream	29 Apr 2010	Non	
M625R10	Male	62.5	2.8	40–90	Tributary upstream	1 May 2010	26 Oct 2010	*
M462R10	Male	46.2	1.6	40–90	Tributary upstream	1 May 2010	26 May 2010	*
M570R10	Male	57.0	2.3	40–90	Tributary upstream	2 May 2010	15 Jul 2010	
M733R10	Male	73.3	4.5	40–90	Tributary upstream	3 May 2010	2 Dec 2010	*
F638R10	Female	63.8	3.1	40–90	Tributary upstream	3 May 2010	24 Nov 2010	
F708R10	Female	70.8	3.6	40–90	Tributary upstream	3 May 2010	5 Jun 2010	

F632R10	Female	63.2	2.9	40–90	Tributary upstream	3 May 2010	14 May 2010	
U725L10	Unknown	72.5	4.5	40–90	Lake Akkeshi	17 May 2010	2 Dec 2010	*
U650L10	Unknown	65.0	3.8	40–90	Lake Akkeshi	19 May 2010	1 Dec 2010	*
U668L10	Unknown	66.8	3.3	40–90	Lake Akkeshi	19 May 2010	2 Dec 2010	*

M, *F*, *U*, *R*, and *L* in fish ID indicate male, female, unknown, river, and lake, respectively. *Numbers* in the fish ID column show the fork length (mm) of each tagged fish and the year caught and released

* Fish detected the following year

Table 2 Station details and dates of deployed and recovered acoustic receivers during 2008–2010. Table modified and reproduced from Honda et al. (2012), with permission from John Wiley & Sons

Station number	Channel length from the river mouth (m)	Area	Mainstream (M) or tributary (T)	2008		2009		2010	
				Date deployed	Date recovered	Date deployed	Date recovered	Date deployed	Date recovered
1	30,607	1	T	21 Apr	27 Nov	14 Apr	26 Nov	25 Apr	28 Nov
2	22,264	2	T	21 Apr	27 Nov	14 Apr	26 Nov	25 Apr	28 Nov
3	22,224	2	M	21 Apr	27 Nov	10 Apr	27 Nov	24 Apr	1 Jun
4	18,364	3	T	20 Apr	27 Nov	11 Apr	26 Nov	17 Apr	1 Jun
5	17,871	3	M	15 May	20 Nov	10 Apr	27 Nov	24 Apr	1 Dec
6	16,208	3	T			11 Apr	27 Nov	24 Apr	1 Dec
7*	14,729	3	T	20 Apr	26 Nov	11 Apr	27 Nov	19 Apr	29 Nov
8*	14,441–14,483	3	M	20 Apr	26 Nov	11 Apr	27 Nov	19 Apr	1 Dec
9*	13,901	4	M	20 Apr	26 Nov	10 Apr	27 Nov	19 Apr	29 Nov
10*	13,604	3	T	20 Apr	26 Nov	11 Apr	27 Nov	19 Apr	1 Dec

11*	12,958	4	M	20 Apr	26 Nov	10 Apr	27 Nov	19 Apr	29 Nov
12*	11,865	4	M			10 Apr	27 Nov	19 Apr	29 Nov
13	11,444	4	M			19 May	27 Nov		
14*	11,235	4	M	18 Apr	24 Nov				
15*	10,654	4	M			8 Apr	27 Nov	16 Apr	29 Nov
16	9,795	4	M			19 May	27 Nov		
17*	9,128	4	M	18 Apr	24 Nov	8 Apr	27 Nov	16 Apr	29 Nov
18	8,285	4	T	19 Apr	23 Nov	9 Apr	29 Nov	17 Apr	31 May
19*	7,553	5	M	18 Apr	24 Nov	8 Apr	27 Nov	16 Apr	29 Nov
20	6,744	5	T	19 Apr	23 Nov	9 Apr	29 Nov	08 Apr	2 Dec
21*	6,484	5	M	18 Apr	24 Nov				
22*	5,618–5,883	5	M	18 Apr	24 Nov	8 Apr	27 Nov	16 Apr	29 Nov
23*	4,494–4,672	5	T	18 Apr	24 Nov	9 Apr	29 Nov	12 Apr	2 Dec
24*	4,590	5	M	19 Apr	23 Nov	8 Apr	29 Nov	16 Apr	28 Nov
25*	3,807–3,895	6	M	19 Apr	23 Nov	8 Apr	29 Nov	12 Apr	2 Dec
26*	2,542	6	M	19 Apr	23 Nov	8 Apr	29 Nov	12 Apr	2 Dec

28	1,156	6	T			14 Apr	29 Nov	12 Apr	2 Dec
29*	870–1,022	6	M	19 Apr	23 Nov	9 Apr	29 Nov	12 Apr	2 Dec
30*	0	7				13 Apr	29 Nov	23 Apr	1 Dec
31	–2,754	7		23 Apr	25 Nov				
32	–3471	7		21 Apr	25 Nov	13 Apr	30 Nov	23 Apr	1 Dec

* Stations that were used to estimate movement distances of each tagged fish in areas 4–6 in the mainstream of the Bekanbeushi River system

Table 3 Channel distances (per station) and mean distances between stations among areas 4–6 in the mainstream of the Bekanbeushi River system during 2008–2010

	Area	2008	2009 and 2010
Covered channel distance (m)	4	6,242	6,242
	5	3,888	3,888
	6	3,090	3,242
Channel distance per station (m)	4	1,561	1,248
	5	972	1,296
	6	1,030	1,081
Mean (± SD) distance between stations (m)	4	1,591 ± 593	1,193 ± 247
	5	988 ± 107	1,482 ± 267
	6	1,437 ± 118	1,469 ± 288