

First documentation of detailed behaviors of endangered adult Sakhalin taimen *Parahucho perryi* in the Bekanbeushi River system, eastern Hokkaido, Japan, using bio-logging and acoustic telemetry concurrently

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Received: 12 July 2016 / Revised: 19 December 2016 / Accepted: 20 December 2016
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Abstract Behavior of adult *Parahucho perryi* was examined using bio-logging and acoustic telemetry concurrently in the Bekanbeushi River system, eastern Hokkaido, Japan, in 2009 and 2010. Based on 46.1–87.9 h data from five *P. perryi* (69.0–80.0 cm fork length) caught from Lake Akkeshi, they used upstream ($n = 2$), midstream ($n = 3$), and downstream ($n = 4$) habitats. Large variability in diel activity and depth occupation existed in each stream habitat; however, fish in the downstream habitat tended to be more active than those in the upper habitats and mainly occupied shallower depths than mean bottom depth in this habitat.

Keywords Acoustic telemetry · Activity pattern · Bio-logging · Endangered species · *Parahucho perryi*

Introduction

The Sakhalin taimen *Parahucho perryi* has been registered as Critically Endangered on the IUCN Red List since 2006 (Rand 2006). This species reportedly lives for more than 20 years, and reaches at least 1.3 m in total length (Zolotukhin et al. 2000). *Parahucho perryi* is an iteroparous species that spawns in shallow upstream habitats from March to June after snowmelt. Unlike those closely related to the species of *Hucho*, *P. perryi* display facultative anadromy (e.g., Arai et al. 2004; Suzuki et al. 2011).

In recent years, several studies have used acoustic telemetry to examine migratory patterns and habitat use of adult *P. perryi* in the Bekanbeushi River system in eastern Hokkaido, Japan (Honda et al. 2010a, 2012, 2014). Of these, Honda et al. (2012) demonstrated that adult *P. perryi* occupied a wide range in the river system from upstream waters to brackish Lake Akkeshi that connects the river to the ocean. Honda et al. (2014) verified their crepuscular movement patterns in all three stream habitats (i.e., upstream, midstream, and downstream habitats). Honda et al. (2014) also found that adult *P. perryi* inhabiting the downstream habitat moved significantly longer distances than those in the midstream habitat from spring to autumn and suggest that the different movement patterns are caused by differences in environmental conditions between the habitats. However, because Honda et al. (2014) used passive acoustic telemetry, the movement descriptions of *P. perryi* were coarse, and the detailed behaviors of this species have not been examined.

Electronic supplementary material The online version of this article (doi:10.1007/s10228-016-0570-3) contains supplementary material, which is available to authorized users.

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Recently, there have been several important advancements in bio-logging studies on fishes (e.g., Tsuda et al. 2006; Payne et al. 2016). If bio-logging and passive acoustic telemetry are used concurrently, the resolution of behavioral data may be improved drastically; however, the number of studies integrating these two methods to study teleost fishes in coastal and inland waters remains limited (Tanoue et al. 2012).

The objective of the present study was to examine the detailed activity patterns of adult *P. perryi* in the Bekaubeushi River system using bio-logging (depth/temperature/acceleration data logger) and passive acoustic telemetry. Specifically, although the sample size of fish studied in this project was small, even qualitative descriptions of detailed behavior may provide fundamental ecological information to conserve this critically endangered species.

Materials and methods

Study site. Surveys were conducted in the Bekaubeushi River system (total basin area: 738.8 km²) located in eastern Hokkaido, Japan (Fig. 1). This river flows into brackish Lake Akkeshi, which is connected to the Pacific Ocean through Akkeshi Bay. Few artificial structures exist within this system.

Accurate locations where *Parahucho perryi* were caught and subsequently detected cannot be disclosed based on voluntary conservation regulations, so fish locations are provided using river domain blocks (areas). The study site was divided into seven areas according to channel distance, tributary confluences, and downstream tidal characteristics (Fig. 1). Honda et al. (2012) described these in detail.

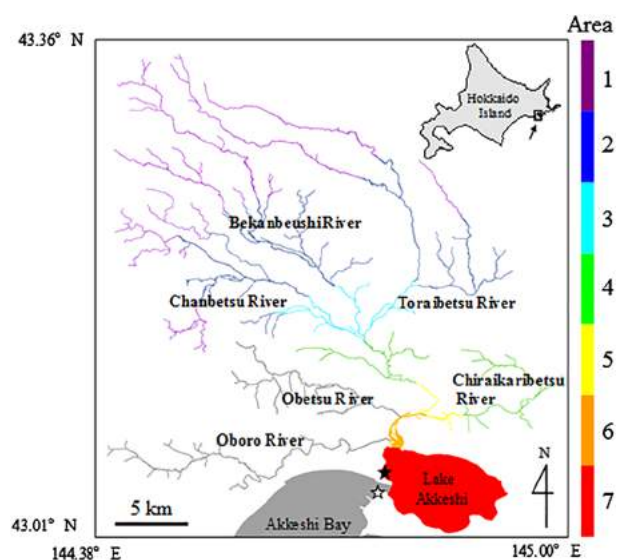


Fig. 1 Study site: the Bekaubeushi River system in eastern Hokkaido Island, Japan. Each area (1–7) is color coded. The solid and opened stars indicate the locations where *Parahucho perryi* (fish nos. 0901 and 1001–1003 and no. 1004, respectively) were released

Fish tagging and tracking. Five *P. perryi* were caught by a local set-net fishery in Lake Akkeshi on 11 May 2009 and 16 and 17 May and 22 November 2010. Fork lengths (FLs) of the tagged fish were 69.0–80.0 cm. Individual fish identities were based on the year of capture and the number of fish caught in each year (Table 1). After capture, *P. perryi* were transferred immediately to an aerated seawater tank (ca. 10 m long × 2 m wide × 1 m high) and held captive without feeding until they were tagged. The sex and maturity status of individual fish was unknown, but based on the season of capture and appearance, the fish were likely immature (Honda et al. 2010b), though it is possible that they were post-spawners. The *P. perryi* spawning season in the Bekaubeushi River system is mainly from April to early May (K. Nomoto, per. comm.).

A time-release electronic tag package covered with floating polystyrene was attached externally to the anterior portion of and ca. 2 cm away from the dorsal fin using plastic ties, after the fish was anesthetized (0.04% 2-phenoxyethanol diluted with seawater). Each electronic tag package was equipped with a Little Leonard M190-D2GT data logger (15.0 mm diameter, 53.0 mm length, 18.0 g weight; Little Leonard Co. Ltd., Tokyo, Japan), a Vemco V13-1L acoustic tag (69.0 kHz, 13.0 mm diameter, 36.0 mm length, 11.0 g weight; <http://www.vemco.com>), a Lotek Nano-Tag NTC-6-2 radio tag (0.0063 mW, 9.1 mm diameter, 30.1 mm length, 4.5 g weight; <http://www.lotek.com>), and a Little Leonard RT1 time-scheduled auto-releaser (16.0 mm diameter, 25.0 mm length, 9 g weight). The buoyancy force of the package was adjusted to <1% of fish weight in air. The Little Leonard M190-D2GT data logger has four sensors that measure biaxial acceleration (left–right and anterior–posterior directions), depth (resolution ± 5 cm), and temperature (resolution ± 0.2 °C). The accelerometer measurement range was -49.0 to 49.0 m/s² (-5 to 5 g, where $g = 9.8$ m/s²), with a resolution of 0.02 m/s². The acceleration data logger measured total acceleration consisting of both dynamic (e.g., tail beating and propulsive) and static (i.e., gravity) components. The sampling intervals for biaxial acceleration, depth, and water temperature were 0.0625 (1/16) s, 1 s, and 1 s, respectively. The acoustic tags transmitted a set of six coded pulses randomly once every 20–60 s, and the radio tag transmitted a coded pulse once every 2 s.

After confirming that the fish recovered from anesthesia for >1 h, four (nos. 0901, 1001, 1002, and 1003) and one fish (no. 1004) were released from the west coast of Lake Akkeshi and the northeastern coast of Akkeshi Bay, respectively (Fig. 1). All of the acceleration data loggers were set to start recording ca. 24 h after release.

Fish locations during the tracking periods were monitored daily using a combination of active and passive tracking. Active tracking was accomplished by towing a Vemco VR2W acoustic receiver from a canoe and using a Lotek SRX600 radio receiver and a Yagi antenna. Passive

Table 1 Fish no., size, and tag information for *Parahucho perryi* captured in Lake Akkeshi in Hokkaido, Japan

Fish no.	Fork length (cm)	Body weight (kg)	Date released	Date and time		Record duration (h)			Total no. of burst events	Recorded ambient temperature (mean, range; °C)	Area finally detected
				Recording started	Recording finished	All	Upstream*	Midstream*			
0901	80.0	4.8	16 May 2009	17 May, 11:14	19 May, 9:19	46.1	0.0	31.0	14.6	12.9, 11.7–14.3	6
1001	75.0	5.6	18 May 2010	19 May, 15:00	23 May, 6:52	87.9	22.8	45.7	8.0	10.8, 8.8–13.7	5
1002	69.0	4.6	19 May 2010	20 May, 15:00	24 May, 6:12	87.2	43.9	15.3	0.0	9.8, 8.5–11.2	3
1003	79.5	6.4	20 May 2010	21 May, 15:00	25 May, 3:51	84.9	0.0	0.0	84.9	10.2, 8.1–11.7	6
1004	72.5	3.8	23 Nov 2010	24 Nov, 15:01	27 Nov, 12:59	70.0	0.0	0.0	70.0	3.4, 1.2–6.5	6

* Recorded duration in each stream, which excluded the durations of movements among regions and of directional movements (details are described in the text)

tracking was accomplished using an acoustic receiver array that consisted of 23–26 stations in areas 1–7 [Electronic Supplementary Material (ESM) Table S1], except for the Obetsu and Oboro Rivers (Fig. 1). Additional information about the acoustic receiver array has been described previously (Honda et al. 2012).

The floating tag packages released by the auto-releaser were retrieved using both active and passive tracking. After the tag packages were released, the attachment mechanism that consisted of plastic bars with biodegradable line remained on the fish body. The effect of the attachment mechanisms on each fish was considered minimal, as preliminary laboratory and field experiments indicated a very low probability of post-external-tagging mortality in adult *P. perryi* due to stress (Honda and Yamamoto, unpublished data).

Data analysis. Data >24 h after release were analyzed for occupied depths and activity patterns to account for tagging stress. Periods of swaying (left–right) acceleration >|0.5| m/s² were defined as active swimming behavior (ESM Fig. S1), as a rearing experiment revealed that forward movements caused by caudal fin propulsion could be identified when swaying acceleration exceeded |0.5| m/s² in still water (Yamamoto, unpublished data). Additionally, periods of swaying acceleration >|3.0| m/s² were defined as burst swimming (Yamamoto, unpublished data) (ESM Fig. S1), which may indicate foraging or escaping behaviors (Tanoue et al. 2012; Makiguchi et al. 2013). If two or more bursts were observed within a 1-s interval, these multiple bursts were treated as continuous and were classified as one burst event. As a corollary, individual bursts >1 s apart were classified as multiple individual burst events. If active swimming and/or burst swimming lasted with <60 s intervals, such periods were classified as activity (active period), and the remaining periods (i.e., ≥60 s without active swimming and/or burst swimming) were classified as inactivity (inactive period). Then, we quantified active and inactive periods (min/h) and number of burst events per hour.

Behavioral patterns of individuals were described for individual fish by examining the relations between activity metrics (active, burst, and inactive) and occupied depth and/or ambient temperatures. Subsequently, the behavioral patterns were compared among time periods (day, twilight, and night) and regions. Daily twilight lasted 4 h (2 h each around sunrise and sunset), and day and night comprised the remainder of the day. Sunrise and sunset times were obtained from the Ota weather station (43.092°N, 144.780°E) of the Japan Meteorological Agency (<http://www.jma.go.jp/jma/index.html>) following Honda et al. (2014). When conducting temporal and spatial analyses, the duration of behaviors was rounded up (>30 min/h) or down (≤30 min/h) to hourly integers. Regions were defined as up- (areas 1–3), mid- (areas 4–5), and

downstream habitats (areas 6–7; Honda et al. 2012, 2014), mainly based on difference of water volume per unit channel length. Further, the upstream habitat has more meandering channels than the midstream habitat, while the downstream habitat has few riparian woods unlike the other two upper habitats (Honda et al. 2010a). Finally, individual diel depth occupations were compared with the mean bottom depths in each stream habitat reported by Honda et al. (2010a).

To ensure that analyses were solely focused on regional behavioral patterns, as opposed to unknown locations or transiting behavior among regions, the following data were omitted from analyses. Any data recorded when fish moved between two different regions, determined by acoustic tracking, were excluded because the exact fish location was unknown. Additionally, “directional movement” was defined as a movement across three or more areas in the same direction, and periods of directional movement were omitted because fish activity level during the period is assumed to be constantly high regardless of region. Thus, if >12 h elapsed between one receiver and the next during directional movement, the last detected location by the former receiver was regarded as completion of the directional movement. Analyses were conducted in Igor pro ver. 6.05 (WaveMetrics) and the plugin Ethographer ver. 2.0 (developed by K. Sakamoto, Hokkaido University).

Results

General results. Archived-data records ranging from 46.1 to 87.9 h (mean: 75.2 h) were obtained from tags attached to the five *Parahucho perryi* (Table 1). All fish moved into the Bekanbeushi River after release when recording by tags was started. Fish nos. 0901, 1001, and 1002 occupied multiple areas (5–6, 3–6, and 3–5, respectively), whereas nos. 1003 and 1004 occupied only area 6 (Fig. 2). Two fish (nos. 1001 and 1002) exhibited directional movement from area 3 to area 6 and from area 5 to area 3, respectively.

A total of 44–164 burst events were recorded from the five *P. perryi* (Table 1). A significant positive correlation was found between hourly active periods and numbers of burst events by each of the four fish tracked in May (Pearson’s test, $r > 0.39$, $P < 0.001$). Notably, periods of high activity and burst events that corresponded to frequent and high-amplitude vertical movements were displayed by fish nos. 1001 and 1003 mainly during the night (Fig. 2). Hourly active periods and number of burst events by nos. 1001 and 1002 drastically declined after the former moved to area 5 on 22 May and after completion of the directional movement in area 3 on 22 May by the latter (Fig. 2).

Ambient water temperatures experienced by the tracked fish in May and November ranged between 8.1 and 14.3 °C

and between 1.2 and 6.5 °C, respectively (Table 1). No remarkable relationships between temperature changes and activity patterns were observed (Fig. 2). Frequent and high-amplitude temperature changes along with occupied depth changes were observed for three fish (nos. 1001, 1003, and 1004) when they occupied area 6 (Fig. 2).

Activity patterns among stream habitats and among time periods. There was a tendency for fish in the downstream habitat to be more active (i.e., longer mean active period) than those in the up- and midstream habitats (Table 2). The trend of increased activity in downstream habitat was not corroborated by the mean hourly number of burst events (Table 2.). The mean hourly number of burst events for all individuals (except for that by no. 1001 in the downstream) were all less than 2.0 and showed high variances.

Diel activity patterns differed among individuals and no habitat-specific common characteristics were detected (Table 2). For example, fish nos. 1001 and 1002 in the upstream habitat showed nearly opposite patterns, although they were tracked in the same season.

Diel depth occupation among stream habitats. Depth occupation of individual fish differed substantially among stream habitats and the only characteristic common to all habitats was that fish rarely occupied depths near the surface (0.0–0.2 m) during the day (Fig. 3). In the meantime, the number of burst events observed by each tracked fish was insufficient to show their diel depth occupations among stream habitats.

In the downstream habitat, fish typically occupied depths (mode and median depths ranged from 0.0 to 1.0 m) above the mean bottom depth [1.79 m; see Honda et al. (2010a)] regardless of active or inactive periods (Fig. 3). In the up- and midstream habitats, depth occupation patterns differed among individuals (Fig. 3). In the upstream habitat, although no common characteristics of diel depth occupation between two fish (nos. 1001 and 1002) were observed for all periods, distinct bimodal depth occupation either above or below the mean bottom depth (0.87 m) of the stream habitat was observed during inactive periods for the two fish. In the midstream habitat, although occupied depth ranges differed among individuals, there were no large differences between depths occupied during active and inactive periods.

Discussion

Our results demonstrate that adult *Parahucho perryi* in the Bekanbeushi River system showed individual variability in their diel activity and corresponding depth occupation patterns. Moreover, frequent depth changes corresponding to their activity levels were observed for some fish, but not others. Nonetheless, adult *P. perryi* in the downstream

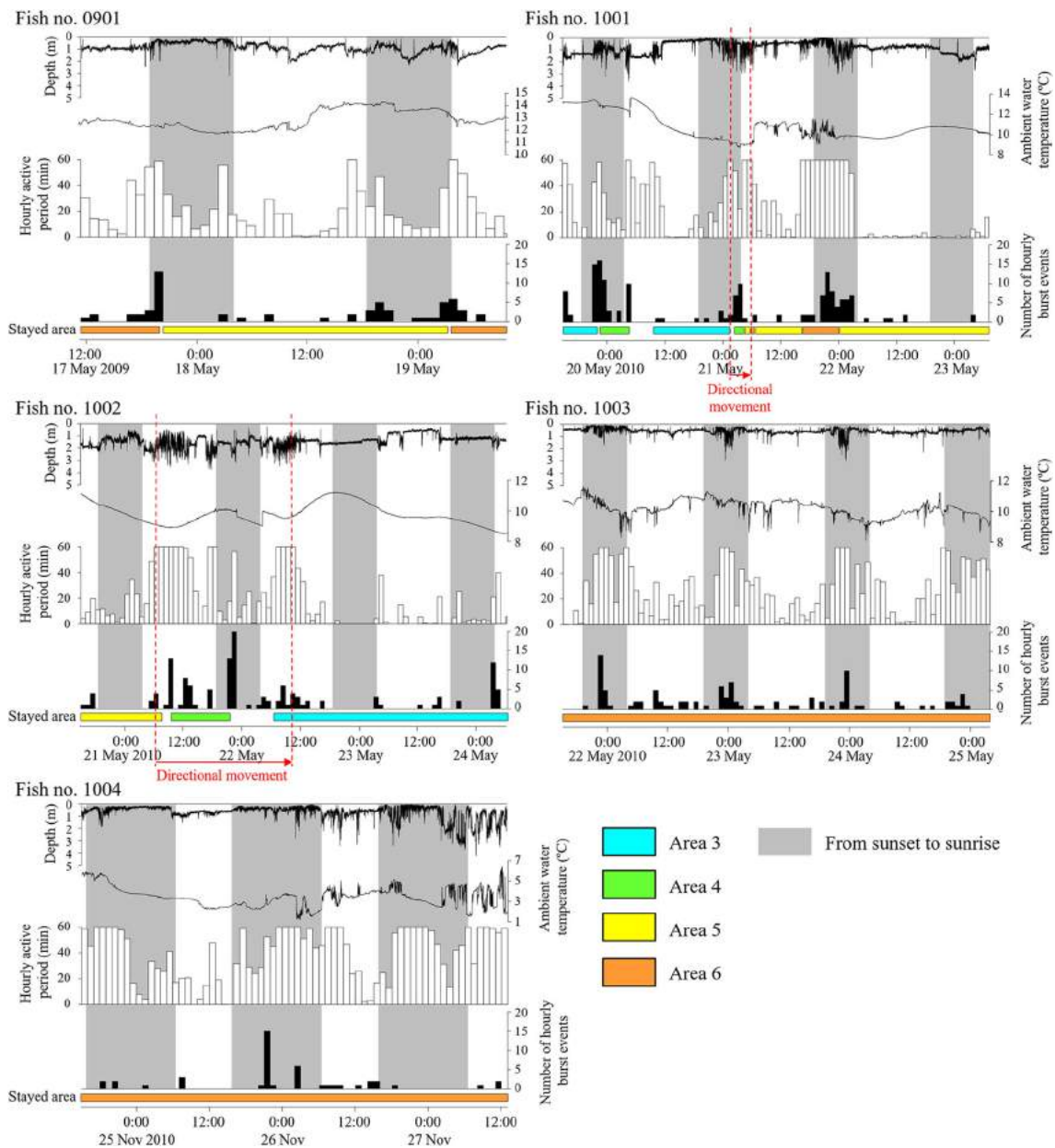


Fig. 2 Depth, activity, and temperature data, as well as occupied area, for five *Parahucho perryi*

habitat tended to swim more actively than those in the up- and midstream habitats.

It was possible that all five fish released into Lake Akkeshi or Akkeshi Bay entered the river just after release and the movements of two towards area 3 during the tracking periods were caused by tagging stress. However, a number of adult *P. perryi* used in Honda et al. (2012) also exhibited frequent cross-stream habitat movements within a few days and this trend was more significant for fish in the downstream habitat including Lake Akkeshi (Honda et al. 2014; Honda, unpublished data). Therefore, an alternative explanation for the observations that all fish entered the river after release and that some fish moved to

upper reaches was probably due to their high plasticity in habitat selection (Honda et al. 2012).

In addition to the observed different trend of activity patterns among stream habitats, fish in the downstream habitat occupied mostly shallower depths than the mean bottom depth in this habitat unlike in the up- and mid-stream habitats. Considering also that hourly active periods of fish nos. 1001 and 1002 drastically declined after completion of movements toward areas 5 and 3, respectively, our results might support the hypothesis of Honda et al. (2014) that the adult *P. perryi* in the Bekanbeushi River system adopt different lifestyles depending on the stream habitats occupied.

Table 2 Mean \pm standard deviation of hourly active periods and hourly number of burst events among stream habitats [i.e., up- (area 3), mid- (areas 4–5), and downstream (area 6) habitats] (upper) and among time periods in each stream habitat (lower) for five adult *Parahucho perryi*

		0901			1001			1002			1003			1004		
		Up	Mid	Down	Up	Mid	Down	Up	Mid	Down	Up	Mid	Down	Up	Mid	Down
<i>Among stream habitats</i>																
Fish no.		0901			1001			1002			1003			1004		
Stream habitat		Up	Mid	Down	Up	Mid	Down	Up	Mid	Down	Up	Mid	Down	Up	Mid	Down
<i>N</i> (h)		0	31	15	23	46	8	44	15	0	0	0	85	0	0	70
Hourly active period (min)		-	18.4 \pm 15.8	28.9 \pm 20.2	18.8 \pm 21.0	10.1 \pm 16.9	60.0	8.2 \pm 13.4	15.0 \pm 13.0	-	-	-	27.1 \pm 20.0	-	-	54.6 \pm 10.2
Hourly number of burst events		-	0.9 \pm 1.4	1.9 \pm 3.0	1.4 \pm 3.4	1.3 \pm 2.9	4.9 \pm 4.0	0.9 \pm 2.4	0.5 \pm 1.1	-	-	-	1.2 \pm 2.2	-	-	0.6 \pm 2.1
<i>Among time periods in each stream habitat</i>																
Fish no.		0901			1001			1002			1003			1004		
Time period		Day	Twilight	Night	Day	Twilight	Night	Day	Twilight	Night	Day	Twilight	Night	Day	Twilight	Night
<i>N</i> (h)		Up	0	0	11	4	9	21	8	14	0	0	0	0	0	0
		Mid	4	13	24	8	13	4	4	7	0	0	0	0	0	0
		Down	3	0	2	2	4	0	0	0	42	15	28	20	12	39
Hourly active period (min)		Up	-	-	19.2 \pm 23.8	8.9 \pm 8.6	26.1 \pm 22.7	9.7 \pm 15.9	13.2 \pm 19.5	3.2 \pm 7.8	-	-	-	-	-	-
		Mid	15.7 \pm 18.1	27.8 \pm 12.1	15.8 \pm 10.9	9.3 \pm 19.0	15.8 \pm 22.4	20.1 \pm 16.5	11.3 \pm 5.7	13.0 \pm 9.1	-	-	-	-	-	-
		Down	19.0 \pm 14.4	50.7 \pm 11.5	-	60.0	60.0	-	-	-	14.6 \pm 11.7	34.1 \pm 21.3	41.6 \pm 17.4	50.7 \pm 14.1	53.2 \pm 11.8	57.3 \pm 7.1
Hourly number of burst events		Up	-	-	1.1 \pm 2.4	0.3 \pm 0.5	4.4 \pm 7.7	0.8 \pm 1.3	2.6 \pm 4.3	0.1 \pm 0.5	-	-	-	-	-	-
		Mid	0.5 \pm 0.8	1.5 \pm 1.9	0.3 \pm 0.6	1.7 \pm 3.9	2.3 \pm 3.4	2.4 \pm 2.2	0.0	0.0	-	-	-	-	-	-
		Down	0.7 \pm 1.0	4.3 \pm 2.5	3.0 \pm 0.4	1.0 \pm 1.4	7.8 \pm 5.5	-	-	-	0.8 \pm 1.0	0.5 \pm 0.7	2.1 \pm 3.0	0.5 \pm 0.8	0.3 \pm 0.7	0.7 \pm 2.7

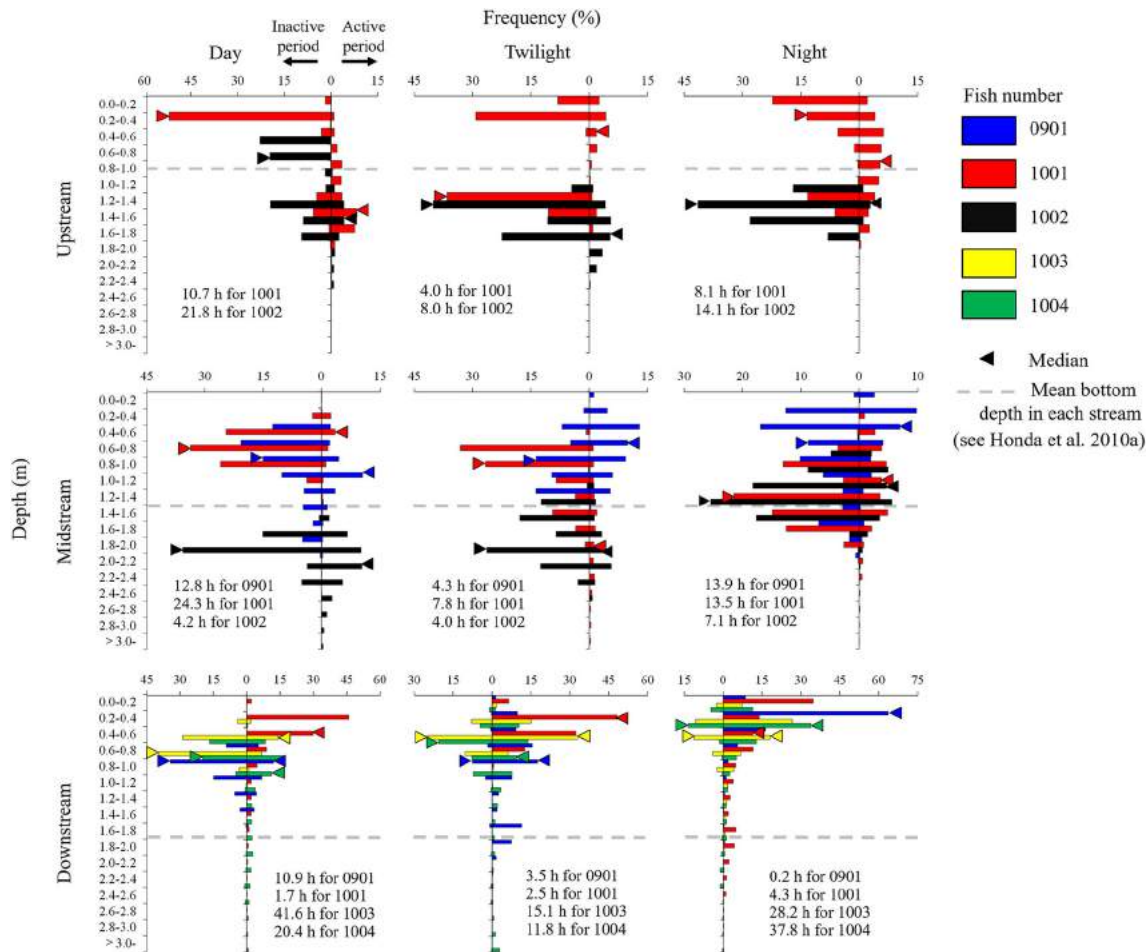


Fig. 3 Depth occupation histograms for active and inactive periods in the up- (area 3, upper), mid- (areas 4–5, middle), and downstream (area 6, lower) habitats during the day (left), twilight (middle), and the night (right) for each tracked *Parahucho perryi*

Contrary to our expectation that adult *P. perryi* show crepuscular activity patterns as reported by Honda et al. (2014), common diel activity patterns were not observed in any of the stream habitats in the present study. This may have been caused by our small sample size and short tracking periods.

One of the major reasons of the observed individual differences in diel depth occupation in each stream habitat was probably because physical microhabitat characteristics were different, particularly in the upper reaches. The upper reaches of the river system have more complex physical structures than the lower reaches (Honda et al. 2010a). This possibly led to a highly variable depth occupation in the upper reaches. The occupied depths for two fish in the upstream habitat were bimodally distributed either shallower or deeper than the mean bottom depth of the stream habitat during inactive periods, depending on time period. Considering that channels having deep pools and cover are preferably used by adult *P. perryi* (Sagawa et al. 2002; Honda et al. 2010a), it is speculated that the two fish occupied such microhabitats. The fact that few fish stayed

near the surface (0.0–0.2 m) during the day in any of the stream habitats may be related to terrestrial predator avoidance or to possible preference of low light intensity as observed by rainbow trout, *Oncorhynchus mykiss* (see Kwain and MacCrimmon 1969).

Adult *P. perryi* shows a preference for cooler water only in summer (Honda et al. 2012). In this study, there was generally no obvious correlation between water temperature and fish activity patterns. Even though fish no. 1004 experienced much colder water than fish tracked in May, no remarkable differences were detected. These suggest that their behaviors did not differ much under certain low temperature conditions. Changes in ambient temperature corresponding to depth changes that occurred downstream in area 6 were most probably caused by the thermocline formation resulting from an influx of warmer saline water under colder freshwater.

No common characteristics were found among individual burst swimming frequency and the corresponding variances were large, implying these behaviors occurred regardless of the stream habitats. Nonetheless, high

positive correlation between hourly activity periods and numbers of burst events was found in four individuals (except for no. 1004), indicating that these fish displayed bursts when actively swimming. However, we were not able to evaluate what specific activity was actually observed during bursts, because we did not obtain ground-truth accelerometer data with similar experiments conducted in captivity. Further study is needed that uses longer duration data loggers and captive experiments as in Tanoue et al. (2012) and Tsuda et al. (2006), so that actual behaviors, such as foraging or escaping, can be identified.

The present study provides the first documentation of detailed behaviors of adult *P. perryi* and verified the effectiveness of concurrent bio-logging and telemetry for behavioral monitoring. Our results demonstrate that fish activity and depth occupation patterns among individuals differed considerably, even in the same stream habitat, implying adult *P. perryi* can use various types of micro-habitat. Thus, further study is needed to identify their detailed microhabitat use and activity and depth occupation patterns there. Finally, as suggested by the results of the current study and those of Honda et al. (2014), that adult *P. perryi* in the Bekanbeushi River system change their behaviors depending on the difference in river basins, indicating the importance of conserving the original channel conditions.

Acknowledgements We thank T. Sato, M. Kuribayashi, K. Nakano, and the other staff members of the Fisheries Cooperative Association of Akkeshi; S. Takeyama of the Akkeshi-cho Oyster Seedlings Center; T. Shibuya and the other staff members of the Akkeshi Waterfowl Observation Center; M. Nakaoka and the other staff of the Akkeshi Marine Station, Hokkaido University; and many graduate and undergraduate students of Hokkaido University for their cooperation and assistance during the field study. We would also like to thank A.C. Seitz of the University of Alaska Fairbanks for his helpful suggestions and English proofreading. This study was supported by a grant-in-aid from the Foundation of River & Watershed Environment Management, Japan (No. 20-1215-1), and a grant-in-aid for Scientific Research of Lake Akkeshi and Bekanbeushi Wetland (No. 23). We declare that our experiments complied with the current Japanese laws.

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