How Does the Japanese Water Shrew Chimarrogale platycephalus Cross the Concrete Walls of Check Dams?

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Original paper

How does the Japanese water shrew *Chimarrogale platycephalus* cross the concrete walls of check dams?

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Abstract. The concrete walls of check dams are considered a physical barrier for aquatic and semi-aquatic animals that inhabit mountain streams. Traveling behaviors around concrete check dams by the Japanese water shrew *Chimarrogale platycephalus*, a semi-aquatic mammal, were directly observed via radio-tracking in Kamikoshi Stream in central Honshu, Japan. Traveling behaviors were mainly observed on the wet concrete walls and in the backfill sediments of check dams. *Chimarrogale platycephalus* generally crossed the wall directly, and route selection was affected by the traveling direction of *C. platycephalus* and the surface wetness of the concrete wall. Detouring behavior around the concrete walls was observed visually only once during the survey period. Using modulation of sounds on a FM receiver, the movements of *C. platycephalus* were detected in their hiding places along the stream. Some individuals frequently ceased movement within the backfill sediments. Our results suggest that existing concrete check dams do not prohibit the shrew's movements between upstream and downstream of the river and that backfill sediments may be utilized as resting places.

Key words: backfill sediment, behavior, concrete check dam, movement detection method.

The Japanese water shrew *Chimarrogale platycephalus* is endemic to Japan. It inhabits swift streams and stream banks in mountain forests and feeds on small aquatic animals such as invertebrates, fishes, and amphibians (Abe 2011). The Japanese pit viper *Gloydius blomhoffii*, the Japanese weasel *Mustela itatsi*, and the Northern goshawk *Accipiter gentilis* are known predators (Abe et al. 2015). The shrew generally travels along stream channels using a unique form of locomotion; running upstream on the bottom of swift-flowing streams and swimming downstream at the surface of the water (Imaizumi and Kitagaki 1997). This species is on the International Union for Conservation of Nature (IUCN) Red List as a species of Least Concern (Cassola et al. 2016). It has been believed to be sensitive to artificial modification of the stream environment (Abe 2003; Furuta 2004a; Ichikawa et al. 2005; Yokohata et al. 2008). Thus, it is considered a threatened or near threatened species by prefectural governments in 27 of the 41 prefectures that it inhabits; this status was determined using recent publications from each prefectural government (e.g., Nature and Environmental Conservation Division, Kyoto Prefecture Department of the Environment 2015; Environment Department, Aichi Prefectural Government 2015; effective as of May 21, 2018).

Previous trapping data suggest that the construction of check dams, commonly referred to as Sabo or Chisan dams, causes significant decline of *C. platycephalus*, but that numbers recover several years later (Abe 2003; Furuta 2004a; Ichikawa et al. 2005). Radio-tracking data suggest that *C. platycephalus* travels between upstream and downstream sites beyond a check dam (Ichiyanagi 2009), but such travel (crossing behavior) has not been confirmed. Ichiyanagi (2009) suspected that *C. platycephalus* detoured around concrete check dams because of their steep walls. If water shrews cannot climb the steep walls, check dams built with concrete river walls may block their traveling behavior (Kawamichi 1997; Ichikawa et al. 2005). In addition, *C. platycephalus* is likely to detour into the terrestrial area around the check dams unless stream banks are covered by concrete (detouring behavior), as reported in some carnivores

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*To whom correspondence should be addressed. E-mail: keiryu.fishing@gmail.com and an amphibian, such as the Japanese weasel, the Siberian weasel *Mustela sibirica*, and the Japanese giant salamander *Andrias japonicus* (Kawamichi 1997; Taguchi and Natuhara 2009). On the other hand, the detouring behavior increases the predation risk from terrestrial mammals because semi-aquatic mammals such as *C. platycephalus* often treat bodies of water as refuges from predators (Dunstone and Gorman 1998).

There have been no reports of animals passing through the backfill sediments of impermeable-type concrete dams (Ohta and Takahashi 1999). However, small birds, especially the brown dipper *Cinclus pallasii* and the American dipper *Cinclus mexicanus* often use outlets on the concrete walls as nesting sites (Hansen 1981; Kawamichi 1997). Furthermore, the Pyrenean desman *Galemys pyrenaicus*, a semi-aquatic mammal as well, uses artificial walls and small dams as resting places (Melero et al. 2012). Thus, we assume that *C. platycephalus* enters the outlets and uses them to rest.

Although many reports refer to the effects of check dams on various animals inhabiting mountain streams and their sides, including *C. platycephalus* (Ohta and Takahashi 1999; Abe 2003; Furuta 2004a), the detailed behavior of *C. platycephalus* around such dams has not been reported. To clarify the behaviors of this species around dam sites, we conducted direct observations in Kamikoshi Stream, where multiple check dams exist. Observation of numerous individuals is difficult due to the unpredictable timing of each crossing behavior; therefore, in the present study, we directly observed the crossing behavior of the Japanese water shrew at check dams using a radio-tracking technique. This study also provides behavioral information for this species and demonstrates the usefulness of a convenient movement detection technique for small mammals based on modulation of sound received via radio-tracking.

Materials and methods

Study area

This study was conducted along Kamikoshi Stream, a tributary channel of the Yahagi River in Toyota City (35°07'N, 137°25'E, Fig. 1), Aichi Prefecture, central Japan. This stream has a length of 8.5 km and basin size of 45.7 km^2. The study area encompassed approximately 1.7 km along the stream [mean ± standard deviation (*SD*): stream width = 5.14 ± 1.17 m, water depth = 0.34 ± 0.25 m, number of measurement locations = 16] at elevations of 650–850 m, where logging roads run alongside the stream. The watercourse was in natural condition, and the riverbed was composed of mixed soil, rocks, and fallen leaves. The peripheral vegetation comprised plantation trees including the Japanese cedar *Cryptomeria japonica* and the Japanese cypress *Chamaecyparis obtusa*, and the riparian environment was covered by deciduous trees, shrubs, and small bamboos; such as the Japanese oak *Quercus crispula*, the winter hazel *Corylopsis gotoana*, and the northern bamboo *Sasa borealis* (Okada 2017). Known predators of *C. platycephalus*, the Japanese pit viper and the Japanese weasel, are present around the stream. In addition, the potential predators of *C. platycephalus*, including the Japanese marten *Martes melampus*, the raccoon *Procyon lotor*, the eastern buzzard *Buteo japonicus*, and the Ural owl *Strix uralensis*, are also present. During the study period, no harvesting activity or anthropogenic impacts occurred in the study area, including upstream of the survey site.

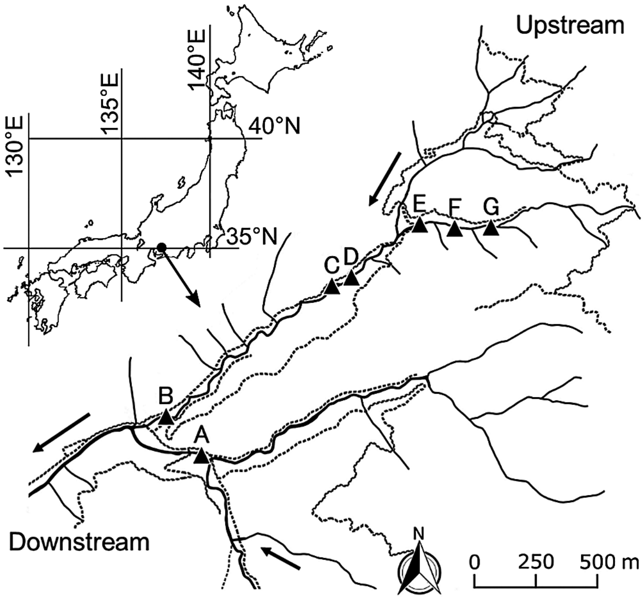

Fig. 1. Distribution of check dams in upper Kamikoshi Stream. Solid lines indicate the stream and dotted lines indicate logging roads. Capital letters, triangles, and arrows indicate each dam, along with their locations, and stream flows, respectively.

Seven check dams are located along the stream at approximately 100–850 m intervals (Fig. 1). To observe the crossing behavior of each individual shrew, fixed observation sites were built around each dam at a distance of approximately 1–3 m. All dams have an impermeable-type concrete wall (mean ± *SD* : gradient = 1 : 0.2 [78.69°] based on construction data of dams F and G; waterfall height = 3.41 ± 0.90 m, channel width of upper wall structure = 4.81 ± 2.01 m, concrete depth of upper wall

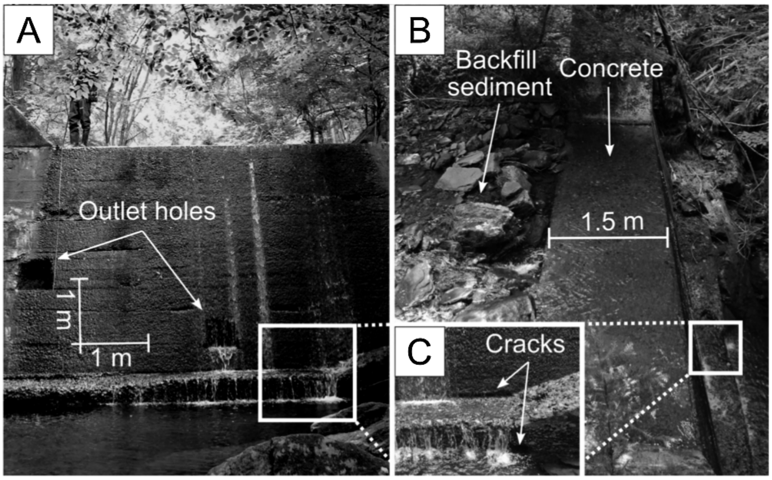

Fig. 2. Photos of an impermeable-type concrete check dam in this study area (dam D): (A) front view of the concrete wall; (B) top view of the concrete wall and backfill sediment; and (C) base of the concrete wall with cracks through which infiltrated water drained.

structure = 1.5 ± 0.00 m, *n* = 7, Fig. 2A and B). The upstream face of all concrete walls is filled with backfill sediment such as gravel (Fig. 2B), and water infiltrates through cracks in the sediment on the stream bottom. All dams are older than a quarter of a century: the oldest dams, A and B, were completed in 1963, and the newest dams, F and G, in 1987. All dams have two to four outlet holes on the walls (mean ± *SD*: height of wall = 1.38 ± 0.92 m, height of outlet hole = 0.52 ± 0.14 m, Fig. 2A), and cracks are present at the bases of dams A, B, and D (Fig. 2C). The lowest outlets and the cracks on the bases constantly drained infiltrated water. The Aichi Prefectural Government provided construction data for each dam, and other data were collected using tape and pole measures from June to December 2013 and during May 2017. The walls of dams A, C, F, and G were often dry during the survey period, but water had flowed into the backfill sediment and drained from outlets on the wall of each dam earlier in the year. The other dams had constant flow during the survey period. The wall surfaces of dams A–E were covered with bryophytes, and some aquatic invertebrates were present, such as the larvae of stoneflies (Perlidae) and mayflies (Heptageniidae). We obtained the permission for capturing the animals from Aichi prefectural government (25 Toyo Kan Dai 273-2).

Direct observation through radio-tracking of water shrews

Seven water shrew trapping sessions were conducted from June to December 2013. Bait traps (metal cage traps, 10.0 × 10.0 × 15.0 cm) with a dead minnow (*Rhynchocypris oxycephalus*) were set along edge of the stream from 16:00 one day to 8:00 in the next morning and monitored every two hours to avoid weakening captured individuals. We made ten captures of seven individuals (Table 1). Weight, sex (according to Ichikawa et al. 2005), and rate of wear on upper teeth (incisor–premolar) were recorded for each individual captured. Aging techniques for the water shrew using the wear rate of the upper teeth (Abe 2003; Furuta 2004b; Ichikawa et al. 2005) were difficult to apply with living animals in the field. Therefore, we observed tooth wear using skull specimens described by Abe (2003) based on the aging technique of Furuta (2004b) in August 2012. Then, we classified the rate of tooth wear into four classes according to the disappearance of particular cusps from the teeth (Fig. 3). The boundary between classes 0 and 1 (disappearance of accessory cusp in I1) occurred at approximately four months (H. Saito, unpublished data). Captured individuals were marked on the hind leg using a numbered aluminum ring (Butt-End Bands 1242-5; National Band and Tag Co., Newport, KY, USA; output power less than a milliwatt) before being released at the capture site. A very high frequency (VHF) radio transmitter (Model A2455, Advanced Telemetry Systems Inc., Isanti, MN, USA) was attached to the base of each individual's tail for later observation, excluding pregnant and injured individuals. The total weight of the attached materials per individual was 1.5–2.0 g, which represented 3–6% of their body weight (maximum = 49.2 g; minimum = 34.8 g; mean ± *SD* = 39.40 ± 4.43 g, *n* = 10).

Ten direct observation sessions supported by radio-

Table 1. Tracking and observational information of the water shrew at dam sites

Shrew ID	Body weight (g)	Sex*	Age (**)	Tracking period	Direct observations at dam sites: Total number	No of Crossings (CW, PS, and/or DW)	Dam ID
27	41.6	Female	Adult (3)	Jun. 12–14, 2013	9	3	C, D
38	38.4		Young (0)	Jan. 24–26, 2013	1	1	E
38	37.5		Young (0)	Aug. 15–18, 2013	2	2	E
41	35.4		Young (0)	Aug. 15–18, 2013	0	0	
42	49.2	Male	Adult (1)	Aug. 15–18, 2013	6	2	A, B
44	44.2	Male	Adult (1)	Sep. 22–25, 2013	4	4	E, F, G
17	37.9	Female	Adult (2)	Sep. 22–28, 2013	12	6	C, D
17	38.4	Female	Adult (2)	Oct. 27–Nov. 2, 2013	3	2	C, D
45	34.8		Young (0)	Oct. 27–Nov. 5, 2013	4	1	B
45	36.6		Young (0)	Dec. 8–12, 2013	3	2	B
X1					1	0	D
X2					1	1	B

CW, climbing the surface of the concrete wall; PS, passing through backfill sediment; DW, detouring around the concrete wall.
* Sex was identified only in adult individuals.
** Tooth wear classes.

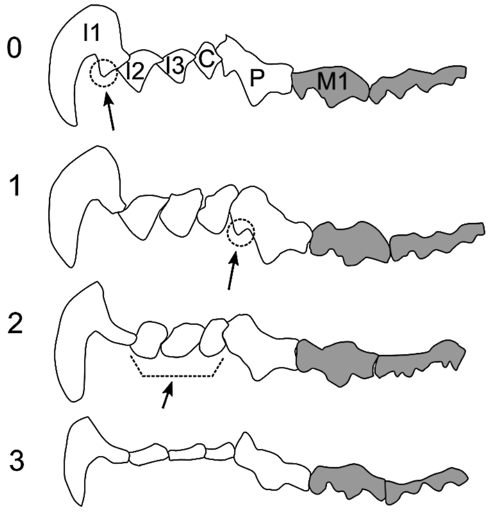

Fig. 3. Lateral view of upper teeth in each age class. White areas indicate teeth observed in living shrews in the field, and gray areas indicate teeth that could not be observed. The numbers indicate age class, which range from zero to three according to cusp disappearance, as indicated by dots with arrows.

tracking were conducted for two to seven days using seven individuals that were captured between dams B and E (Fig. 1), including two males, two females, and three individuals of unknown sex (Table 1). An observer travelling on foot used a handheld receiver (FT-817, Yaesu Musen Co. Ltd., Tokyo, Japan) with a Yagi antenna (H-4EL, Ham Center Sapporo, Sapporo, Japan) to track shrews carrying transmitters at two-hour intervals and recorded their locations for 15–30 minutes. When no obstacles blocked the observer's view of a radio-tracked shrew, the shrew's behaviors were monitored by sight from a logging road or stream bank and observation distance was ranging 1 to 20 m, respectively. Each tracking session was conducted by alternating 24 hours of tracking and six hours of rest for the observer. When an individual moved toward and/or stayed around a check dam, an observer watched from an observation site, and recorded the individual's crossing course at the dam site. When an individual was located while moving around a check dam within approximately 10 m prior to an observer's arrival, the observer did not approach the observation site to avoid disrupting the shrew's behavior. Observations of dam sites were conducted 144 times in total. Crossing courses were also recorded for unidentified individuals found around each dam site. Each tracking session continued until the shrew removed the transmitter. All observations at night were conducted using a headlamp (HW-777H, Gentos Co., Ltd., Tokyo, Japan) with rechargeable Ni-MH batteries (Eneloop, Panasonic Co., Ltd., Osaka, Japan). The headlamp's brightness was kept at the lowest setting during observation, and individuals were observed under lighted conditions as they performed each behavior, including foraging; care was taken to avoid disturbance of the water shrews. All procedures involving animals were performed in accordance with the ethical standards for animal research of Meijo University and the treatment

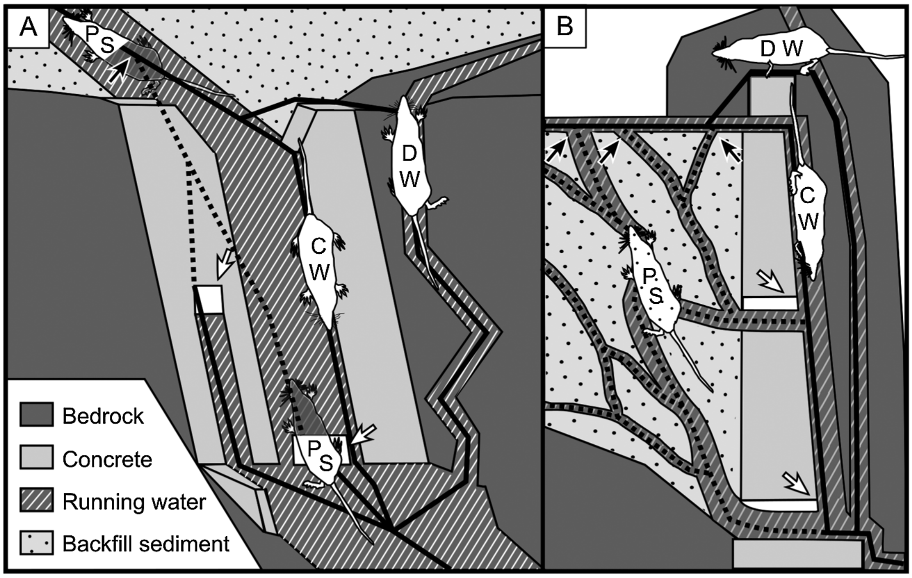

Fig. 4. Each crossing type and its course at the dam site: (A) front view of a check dam from an actual observation site; (B) general lateral view of a check dam. Black arrows indicate infiltrated water inlets, and white arrows indicate outlets. Solid lines indicate directly observed courses, and dotted lines indicate indirectly observed courses. CW: climbing the surface of the concrete wall; PS: passing through backfill sediment; DW: detouring around the concrete wall identify the crossing type indicated by each crossing course.

Table 2. Subset of the reliable models for crossing behaviors of the water shrew

Type of crossing behavior	Logistic model*	K	AIC	ΔAIC	w
Climbing the surface of the concrete wall (CW)	upstream/downstream + dry/wet + random variable	3	11.2	0.00	0.714
	upstream/downstream + dry/wet + adult/young + random variable	4	13.1	1.96	0.267
Passing through backfill sediment (PS)	upstream/downstream + random variable	2	24.5	0.00	0.498
	upstream/downstream + adult/young + random variable	3	26.1	1.66	0.217
	upstream/downstream + dry/wet + random variable	3	26.4	1.92	0.191

K, Number of model parameters; ΔAIC, differences in Akaike information criterion (AIC); w, Akaike weight.
* upstream/downstream, dry/wet, and adult/young suggest moving direction of the water shrew, condition of the concrete wall surface, and tooth wear classes (1–3 or 0), respectively.

guideline about mammal samples of the Mammal Society of Japan.

During the survey period, we classified the crossing behavior of each individual observed at dam sites into three types according to the crossing course (Fig. 4): climbing up or down the surface of the concrete wall (CW), passing through backfill sediment (PS), and detouring around the concrete wall (DW). Statistical analysis was conducted for each type of crossing behavior performed by identified individuals using the generalized linear mixed model (GLMM) in R ver. 3.4.2 (R Development Core Team 2017) with the lme4 package (Bates et al. 2011). We employed GLMM with a binomial error distribution, using the presence/absence of each type of crossing behavior as a dependent variable. We included the following factors as fixed variables to test our predictions: dry/wet (the condition of the concrete wall surface), adult/young (tooth wear classes: 1–3 or 0), and moving direction (upstream/downstream). We included individual identity as a random effect. Model selection was conducted with Akaike information criterion (AIC) using the R package MuMIn (Barton 2015). ΔAIC and Akaike weight were calculated to compare the relative support for each model, and we regarded the models that had < 2 ΔAIC with > 0.1 Akaike weight as reliable models (Burnham and Anderson 2002; Table 2). If a fixed variable included all reliable models for each dependent variable, we regarded that the fixed variable affects each type of crossing behavior. These statistical analyses were not conducted for one type of crossing behavior (detouring around the concrete wall; DW) because this behavior was observed only once.

Development of the novel movement detection method

During the first tracking period in June, one individual shrew (ID 27) entered and stayed for over an hour in the backfill sediment of a check dam. The entering behaviors were repeated every day during the tracking period. We assumed that the shrew utilized the backfill sediment for resting place, but there was a possibility that the shrew was just walking around the sediment. Therefore, we attempted to detect the shrew's movement in the sediment to clarify its behavior.

A direction change of the antenna used for transmission or reception causes a field intensity (FI) change in radio waves (Miwa and Kaku 1999). An actogram method with a fixed receiving antenna (Ando 1980) isolates a change in FI caused by direction change of transmitting antenna attached to animal's body, and the voltage modulation on a receiver record as the animal movement. In contrast, we required in this survey a movement detection method with receiving antenna that is not fixed. This is because we conducted the movement detection and general radio-tracking simultaneously and therefore the receiving antenna could not be fixed. In this survey, we did not use the actogram method of Ando (1980), and aimed to develop an actogram method that is not affected by movement of the receiving antennas.

The radio waves from transmitters used for radio-tracking generally have a peak with a small frequency bandwidth. Because radio waves are electromagnetic, the attenuation rate of each frequency differs when passing through a medium, according to Maxwell's equation (Huisman et al. 2003). In the VHF band, which is output by the transmitters, higher frequency radio waves attenuate more quickly than those of lower frequency when passing through a medium, especially water (Sisak and Lotimer 1998; Lanbo et al. 2008; Jiang and Georgakopoulos 2011). In the field, radio waves from transmitters carried by individuals on stream banks pass through various media due to the heterogeneous materials that make up the stream environment, including water, leaf litter, and sediments. Thus, we assumed that the peak width of a radio wave that had passed through a medium would be biased toward lower frequency than the original peak, and the peak would be modulated according to the movement of transmitter carried by individuals in the field.

A direction change of the antenna generally does not cause a peak shift of the radio-wave frequency. In this survey, we used a frequency modulation (FM) receiver for radio tracking. FM radio receivers convert the received radio-wave frequency and FI into sound frequency (SF) and sound intensity, respectively (Vance 1980; Hoeg and Lauterbach 2004). Thus, we assumed that the sounds received during radio-tracking exhibited SF modulation regardless of direction changes of the antennas, and that SF modulation could be used to detect movement of individuals with transmitters. However, we were not convinced that SF modulation occurred due to differences in the media that the radio-wave passed through. There are no previous reports of this phenomenon in radio-tracking receivers.

To test our prediction, the sounds received from radio waves that passed through each medium were recorded on June 23 and July 7 using an audio recorder (DR-05, TEAC Corporation, Tokyo, Japan) with a Yagi antenna and a receiver held by the observer. Recordings of received sounds were created using a transmitter placed in three different environments: terrestrial, 300 mm underwater, and 300 mm underground. Sounds received from the transmitters carried by each individual in captivity were also recorded indoors prior to each tracking session. Additionally, sounds received during radio-tracking from July to December were recorded for approximately five minutes after locating each individual. These recordings were conducted a total of 216 times: six recordings using three single transmitters, 11 recordings using 11 transmitters attached to captive individuals, and 199 recordings using 11 transmitters attached to released individuals. Released individuals traveled to open areas or stayed in places along the stream where sunlight did not reach (hiding places), such as behind rocks, concrete banks, and fallen trees or under leaf litter, talus deposits, and the backfill sediments of check dams. All sound data were recorded while the receiving frequency of the receiver was fixed at the original frequency of the transmitter provided by the manufacturer, and SF modulation was analyzed using sound analysis software (WavePad FFT Sound Analyzer, NCH Software, Canberra, Australia). The environment surrounding the transmitters altered the SF at the receiver. The SF peaks for the underwater and underground locations had a lower fixed frequency range than did terrestrial locations (Fig. 5A and B), and they returned to the original fixed range when the transmitter moved from underwater or underground to a terrestrial location, regardless of change in the receiving antenna direction (Fig. 5A). Transmitters attached to individuals in captivity in a room showed a fixed SF peak range regardless of shrew movement (Fig. 5C), but the peak varied with movement by these individuals in and out of aquatic or subsurface environments (Fig. 5D). This SF modulation occurred for 58 recordings, and it ceased for 119 recordings when an individual stayed in hiding places along the stream (Fig. 5E). Therefore, we concluded that SF modulation could be used to detect the movement of individuals carrying transmitters, and we analyzed 92 sounds collected at dam sites when three individuals stayed at dams A, B, and D.

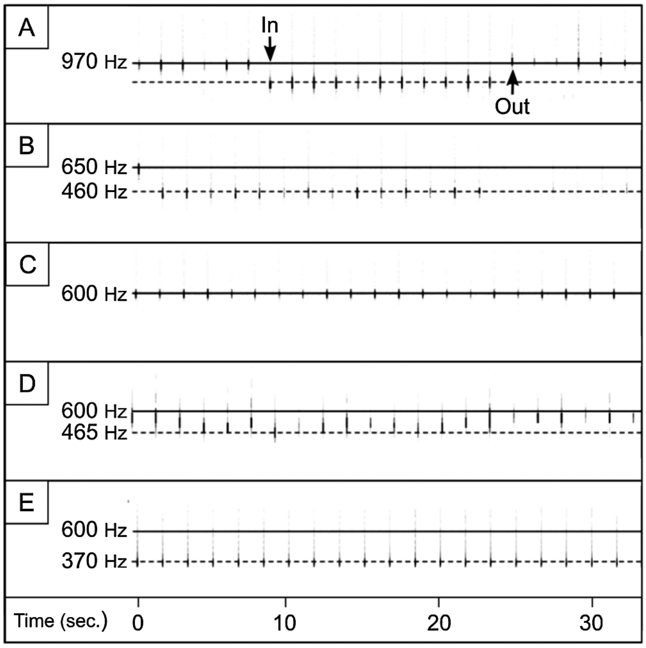

Fig. 5. Frequency modulation of received signals in each situation. Black vertical bars indicate these time lines. Y-axis indicates sound frequency (higher: higher frequency), and X-axis indicates recording time (right side: later). Solid lines indicate a frequency transmitter in a terrestrial location, and dotted lines indicate the amplitude of the frequency modulated by changes in the location of the transmitter. A: frequency modulation by location change (in-out water); B: underground; C: attached to *Chimarrogale platycephalus* standing in a room; D: attached to *C. platycephalus* moving along a stream; and E: attached to *C. platycephalus* remaining in a stream bank hiding place.

Results

Crossing behavior at dam sites was observed 24 times, and was performed by six tracked individuals and one unidentified individual (ID-X2; Table 1). One individual (ID-41) did not come within 100 m of the check dams. These behaviors included three types of crossing courses and one mixed type (Figs. 4 and 6). The CW and PS behaviors were performed by most individuals, regardless of whether they were adults or young. The mixed behavior type indicates that both common behaviors were observed at a dam site.

CW behavior was performed by five identified individuals and ID-X2 on the concrete walls of dams B–E. Based on the model selection, all reliable models for CW behavior included two variables: direction of movement and condition of concrete wall surface (Table 2). This

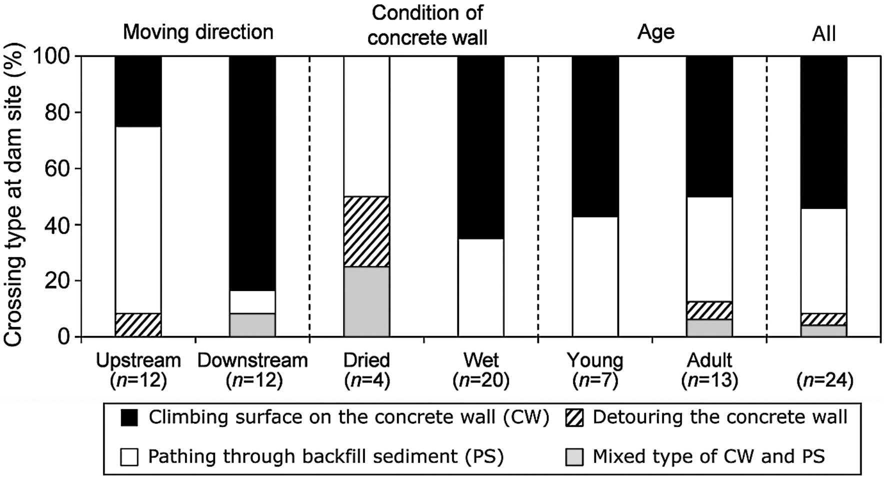

Fig. 6. Percentages of each crossing behavior at dam sites. Numbers in parentheses indicate the sums of observed crossing behaviors for each independent variable performed by identified individuals.

behavior did not occur on dry concrete walls (Fig. 6). CW was performed 13 times (54% of total observed crossings), mainly while moving downstream (Fig. 6). All individuals moved to edge of the stream before arriving at the concrete wall, and climbed head first down the concrete wall more slowly than the water flow. The climbing courses were straight and vertical, and no individuals exhibited backward movement. While moving upstream, two individuals (ID-42 and ID-X2) performed repeated vertical climbs up and down dam B, and entered various outlets in the middle of the concrete wall. Then, these individuals left toward the same location from which they entered. These individuals repeated this behavior, reaching the top of the concrete wall, for approximately five minutes before traveling upstream again from the top of the concrete wall. The climbing courses up other dam walls were in a vertical straight track. We could not observe the details of the climbing limb posture due to light reflected by water spray on the concrete walls.

PS behavior was performed nine times (38% of total observed crossings) by four individuals at dams B–F, regardless of water flow on the concrete wall. All individuals entered and left the backfill sediment from the water flow outlets on each concrete wall and/or cracks on the stream bottom upstream of the concrete wall (infiltrated water inlets, Fig. 4B). Based on the model selection, all reliable models for PS behavior included one variable, direction of movement (Table 2). PS was mainly performed while moving upstream (Fig. 6), with the shrew entering at the lowest water-flowing outlets on the concrete walls and exiting from infiltrated water inlets on the upstream side of concrete walls; one occurrence of this took behavior more than one hour. PS behavior while moving downstream was performed once by individual ID-44, which entered from an infiltrated water inlet of dam F and exited from a downstream outlet of water flow.

DW behavior was performed once by individual ID-27 while moving upstream through running rainwater on a rock bank connected to dam C in June.

The mixed type, including CW and PS behaviors, was performed once by individual ID-44 when moving downstream at dam G, which did not have any overflowing water and drained water from an outlet in the middle of the concrete wall. This individual entered an infiltrated water inlet upstream of the wall and climbed down the wall after leaving through an outlet with water flow in the middle of the wall.

Four identified and one unidentified individual (ID-X1) were observed 22 times entering and/or leaving check dams from alternative entrances (infiltrated stream inlets or outlets at dam sites) at dams A, B, and D (Table 1). These behaviors were observed at infiltrated water inlets on the upstream bottoms or the lowest outlets on each concrete wall. Among these occurrences, three individuals entered and left check dams from the same location, and stayed in the backfill sediment for over an hour, with a maximum period of 11 hours for individual ID-42. This behavior was performed five times in total at dams A, B, and D. Sound recordings showed 37 single peaks and 55 varied peaks from three individuals that stayed at dams A, B, and D.

Discussion

Crossing behaviors at dam sites

Ichiyanagi (2009) suspected that *C. platycephalus* detoured around check dams because of the steepness of the concrete walls. In the present study, however, *C. platycephalus* climbed and passed through the concrete walls (Table 1). These behaviors are useful for reducing predation risk, as mammalian predators of *C. platycephalus* detour around the concrete walls of check dams (Kawamichi 1997). Detouring behavior was observed only once in June, when an individual climbed the rock bank connected to the concrete wall along a rainwater flow. Ichiyanagi (2009) reported that dead young individuals were sometimes found on the ground far from streams in July, which is the rainy season in Japan and the dispersal season for *C. platycephalus* (Koyasu 1998; Abe et al. 2015). Therefore we speculate that *C. platycephalus* may use temporary water flow caused by rain as well as stream flow as travel routes for dispersal.

In the present study, *C. platycephalus* generally moved downstream in the surface stream to the concrete wall. Imaizumi and Kitagaki (1997) reported that *C. platycephalus* often moved downstream floating in the stream, and were carried down steps with running water. In the present study, however, they moved to edge of the stream before arriving at a concrete wall, likely to avoid falling directly from the top of the concrete wall with the running water. Furthermore, *C. platycephalus* climbed down the concrete wall more slowly than the water flow did. The difference in crossing behavior on steps and concrete walls suggests that *C. platycephalus* can recognize the elevation of each physical structure in streams and the risk level of falling from each structure.

Chimarrogale platycephalus descended the vertical concrete walls headfirst. Similar descent postures are known in arboreal mammals that can rotate their feet 180°, such as tree squirrels and tree shrews (Jenkins and McClearn 1984). This behavior is considered useful for awareness of their surroundings, i.e., to avoid predators, find a mate, or search for food (Steele and Koprowski 2001). In soricids, however, no species has been reported to rotate its feet 180° (Reed 1951). Trowbridge's shrew (*Sorex trowbridgii*) backed down a vertical screen, and never turned completely head downward when descending (Reed 1951). On the other hand, the desert shrew *Notiosorex crawfordi* descended rocks headfirst using the claws of its hind feet, which were extended at right angles (Dixon 1924). Similar descent behavior has also been observed in the Eurasian water shrew *Neomys fodiens* (Carter and Churchfield 2006). Therefore we speculate that the posture of the hind feet and claws may allow safe descent of a vertical surface, and that *C. platycephalus* may exhibit descent behavior similar to that reported by Dixon (1924) on concrete walls.

When traveling upstream in the present survey, *C. platycephalus* repeatedly climbed up and down, entering some outlets in the concrete wall that were also observed to be used by invertebrates. These results suggest that *C. platycephalus* can safely access prey by climbing concrete walls that have flowing water.

There have been no reports of animals passing through the backfill sediments of impermeable-type concrete dams (Ohta and Takahashi 1999). In the present study, *C. platycephalus* frequently entered the backfill sediments from water outlets on the concrete walls or infiltrated water inlets on the upstream side of concrete walls and left from similar inlets or outlets. This observation suggested that the infiltrated water created sufficiently large routes through the backfill sediments, which contained sufficient air for *C. platycephalus* to breathe.

Imaizumi and Kitagaki (1997) reported that *C. platycephalus* chose points with strong water pressure for climbing up steep places in surface streams to reduce predation risk and that *C. platycephalus* entered stream sediments through gaps in the bottom to hunt aquatic animals including invertebrates and fishes. Impermeable-type check dams are generally designed so that infiltrated water can flow within the backfill sediments (Chanson 2004; Huang et al. 2007; Okada 2014). In addition, the lowest outlet on each concrete wall constantly drained a large amount of water during this study. Thus, we concluded that passing through backfill sediments would be followed by traveling or hunting, as reported by Imaizumi and Kitagaki (1997).

Utilization of backfill sediments at check dams as resting places

Some small bird species, especially the brown dipper and the American dipper, regularly use the outlets on the concrete walls of artificial dams for nesting (Hansen 1981; Kawamichi 1997). Furthermore, the Pyrenean desman uses artificial walls and small dams as resting places (Melero et al. 2012). Thus, we assumed that *C. platycephalus* entered and used the outlets to rest, as long as there was sufficient space. In the present study, *C. platycephalus* frequently entered hiding places around the stream: behind rocks, concrete banks, and fallen trees; additionally, they were observed in other hiding places such as under leaf litter, talus deposits, and the backfill sediments of the check dams. Some individuals remained in hiding for extended periods of time, during which recorded sounds showed fixed frequency peaks. These results suggest that *C. platycephalus* used these hiding places, including backfill sediments, as resting places. Yukawa (1968) observed a parenting nest of *C. platycephalus*, which was an ellipsoidal dry nest located about 1 m above the water surface, with a course connecting it to a subterranean stream channel. In the present study, infiltrated water had flowed into the backfill sediment, probably leading to a similar arrangement, with nests built above the water line. Small birds use waterfalls and rock walls for nesting places in natural environments (Hansen 1981; Kawamichi 1997), though the details of nesting may differ between *C. platycephalus* and birds in terms of how each species recognizes a check dam structure. Similar nesting behavior is also observed in some amphibians, such as the Tago frog *Rana tagoi* and the Hida salamander *Hynobius kimurae*, which enter infiltrated streams to hide their offspring during the breeding season (Matsui et al. 2004; Eto et al. 2012). Thus, we concluded that *C. platycephalus* recognized the backfill sediments at check dams as infiltrated streams, as do amphibians, and thus chose them for resting places.

Chimarrogale platycephalus used infiltrated streams for resting places. Most behaviors observed in the present study have not been reported in other mammals. Churchfield (1990) reported that the genera *Chimarrogale* and *Nectogale* live only alongside mountain streams in Asia and are best adapted to a semi-aquatic lifestyle. These suggestions support the peculiarity of the observed behaviors and the possibility of observing such behavior in other semi-aquatic mammals that are found in mountain streams.

Conservation of animals around concrete check dams

Concrete check dams were thought to be a physical barrier to travel along the stream by this species because of their steep walls (Kawamichi 1997; Ichiyanagi 2009). However, in the present study, *C. platycephalus* frequently crossed check dams (Table 1). *Chimarrogale platycephalus* generally traveled along the stream channel at each dam site including infiltrated streams within the backfill sediment, and climbed concrete walls with flowing water (Fig. 6). This tendency was observed in both adult and young individuals. These results suggest a low impact in terms of barrier effects for *C. platycephalus* from the existing concrete walls of check dams due to *C. platycephalus*' strong traveling capabilities. However, this study does not clarify the other effects of check dams on *C. platycephalus*, such as spacing pattern of each shrew individual, so further research is needed.

In Japan, many concrete check dams are present to control the flow speed and sediment discharge of mountain streams and to stabilize the foot of mountain slopes (Chanson 2004; Katano et al. 2006; Huang et al. 2007; Okada 2014). Removal or improvement of existing check dams is occasionally recommended (Ohta and Takahashi 1999; Oohama and Tuboi 2009) because of barrier effects on aquatic fauna (Kawamichi 1997). In the present study, check dams had water flowing in spaces within the backfill sediments, and these spaces were utilized as traveling routes and resting places by *C. platycephalus*. Our results suggest that these spaces may be utilized by many animals that inhabit mountain streams and stream bank environments, such as aquatic insects, fishes, and amphibians. Therefore, further studies around check dams, including behavioral and ecological analyses, are necessary for understanding the effects of the check dams on the stream fauna.

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