Running header: Aural detection methods to survey pikas

Efficacy of aural detection methods for detecting Northern Pika (*Ochotona hyperborea*) occupancy in rocky and densely vegetated habitats

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Teaser text: Pikas are considered vulnerable to warming climates, but detecting their presence in rocky patches covered by dense vegetation is challenging. Here, we assessed the efficacy of aural detection methods, namely auditory observation and playback, to survey Northern Pikas in Japan.

Wildlife monitoring plays a key role in species conservation, with growing importance under the threat of climate change. The Northern Pika (*Ochotona hyperborea*) is a cold-adapted species found in Hokkaido, Japan, presumably vulnerable to such threats. However, its high elusiveness hinders detailed population surveys, and visual detection methods—often used for other pika species—are not applicable to its densely vegetated habitats. In this study, we assessed the efficacy of aural detection methods to survey the occupancy of Northern Pika through their distinct vocalizations. We conducted two types of point-count surveys—auditory observation and playback—during 2021 at 18 sites in and around Daisetsuzan National Park. We then assessed the efficacy of these methods in detecting presence and compared time until first detection of the animal. The Northern Pika was present at 11 of all surveyed sites, with a predominance at higher elevations. Our results suggest that both auditory observation and playback are effective at detecting presence, but playback is more time-efficient. We discuss the advantages and disadvantages of each method given these results. In conclusion, our results demonstrate that both survey methods are applicable for Northern Pika population surveys—even in densely vegetated habitats—representing valid and affordable survey methods that can help to improve current monitoring and conservation efforts, and will be of increasing value given potentially negative effects of climate change on persistence of the species.

Key words: aural detection, auditory observation, Northern Pika, playback, wildlife monitoring

Cumulative evidence suggests that wildlife populations are declining globally, and monitoring has been critical in detecting such changes (Collen et al. 2009; Almond et al. 2020). Understanding the drivers of these declines poses a significant challenge informing conservation policy and managing wildlife populations adaptively under global environmental changes (Yoccoz et al. 2001; Di Fonzo et al. 2016). However, some species are more elusive to detect than others (Thompson 2004), making monitoring surveys of rare and elusive species prone to inaccurate detections and hindering our ability to obtain unbiased estimates of occupancy and abundance.

Pikas are small lagomorphs found at high latitudes or altitudes in Asia and North America. Because of their adaptation to cold environments (Yang et al. 2008; Wang et al. 2020), they are considered to be vulnerable to warming climates (Beever et al. 2011; Billman et al. 2021). Therefore, efforts to monitor the status of pika populations are needed to better understand how climate change affects population distribution and abundance. However, some pika species are highly elusive given their preference to live in rocky patches (Henry and Russello 2011), and while research exists for the American Pika (*Ochotona princeps*), it is lacking for many of other rock-dwelling species. This is true for the Northern Pika (*Ochotona hyperborea*), a species found in northeastern Eurasia that has the widest distribution among all pika species (Smith et al. 2018). Although a recent study in the eastern subspecies *O. h. yesoensis* in Hokkaido, Japan suggested its vulnerability to climate change due to thermal constraints (Sakiyama et al. 2021), the effects of climate change on local populations remain largely unknown. An absence of population studies on the Northern Pika in Hokkaido is not only due to its habitat preference for rocky patches, but also to the dense vegetation that covers their rocky habitats. Moreover, most habitats are located on steep slopes, making accessibility and site navigation extremely difficult and time-consuming.

Therefore, establishing robust yet affordable methods to assess the occupancy of Northern Pikas in Hokkaido and localities with similar habitat characteristics are needed.

Previous studies have surveyed the occurrence of rock-dwelling pikas either by detecting sign of animal presence visually or aurally, or indirectly through presence of feces and haypiles (Beever et al. 2010; Erb et al. 2011; Stewart et al. 2015; Hall et al. 2016; Korolev 2017). Such multiple-evidence approaches likely aid in detecting the presence of this elusive animal, but the major assumption of the survey (although not mentioned) is that the visibility and navigability of the study sites allow for detection of these signs. This assumption, however, does not apply to the environments found in Hokkaido because of the aforementioned difficulties.

Here, we advocate instead for the use of survey methods based solely on aural detection as an affordable and reliable alternative, and test their utility in the Hokkaido locality. Northern Pikas are highly vocal, and their vocalizations are detectable from distant locations (up to 200 m; Kawamichi 1969) even when the vocalizing individual is not visible (Kawamichi 1970). Moreover, vocalizations are heard frequently during and after the reproductive season (Kawamichi 1971), permitting population surveys in the snow-free season (i.e., summer) even though their habitats—typically located in remote settings such as deep forests and alpines—are inaccessible at other times of the year. Previous efforts have been made to survey a Northern Pika population based on their vocalizations (Korolev 2017), but that survey was conducted only at sites of known presence since the study focused on abundance estimation. Occupancy surveys, in contrast, aim to establish whether the Northern Pika is present or absent at a given site.

We conducted field experiments to evaluate the efficacy of two aural detection methods—auditory observation and playback—for establishing occupancy of Northern Pikas in Hokkaido. Auditory observation refers to a passive survey that involves listening to naturally occurring vocalizations and is the most commonly used aural detection method for pikas (Billman et al. 2021). Playback uses acoustic cues to trigger vocalizations from the target animal, enabling detection of their presence. The playback method has been often used in avian studies (Conway and Gibbs 2005; Kawamura et al. 2016); however, recent studies have applied it to survey mammals including ungulates (Enari et al. 2017) and primates (Dacier et al. 2011; Gestich et al. 2017). Several studies have used playback with pikas (Somers 1973; Conner 1983, 1985a; b; Trefry and Hik 2009), but for purposes related to the communicative nature of vocalizations rather than for conducting population surveys. Studies applying the playback method to survey pika populations are scarce, with only two small-scale studies using it to assess the occupancy of the Northern Pika in Hokkaido (Ieiri and Yanagawa 2009; Sato et al. 2009), although they did not detail their description of method and efficacy, and did not objectively contrast results with the auditory observation approach.

To fill this research gap, we: (1) compare the efficacy of auditory observation and playback to survey the occupancy of the Northern Pika; and (2) further investigate how acoustic cues in playback promote species detection.

MATERIALS AND METHODS

Study area.— We conducted our study in Daisetsuzan National Park and the surrounding forests in the Tokachi region of Hokkaido, the northernmost island of Japan. We selected 18 rocky patches on talus slopes as study sites in June 2021 because rock interstices found within this landform are the primary microhabitats for Northern Pikas (Fig. 1). The study sites (elevation range 350–2200 m) were selected to cover to the greatest possible extent the known elevational distribution, ranging from 50 m (Kawabe 1990) to 2200 m (Onoyama and Miyazaki 1991). Vegetation changes across this wide elevational gradient, ranging from primarily forest vegetation at lower elevations to alpine vegetation at higher elevations. Based on differences in the structure and amount of vegetation types, we classified the study sites into higher (n = 9) and lower (n = 9) elevation sites (Fig. 1; Sakiyama et al. 2021).

All procedures in this study were conducted with the permission of the Hokkaido Regional Forest Office and Daisetsuzan National Park (Permit numbers 2106071 and 2106072) and followed the American Society of Mammalogists guidelines (Sikes et al. 2016).

Occupancy survey.—Surveys were conducted at each site every month between July and September 2021 because Northern Pikas in Hokkaido emit vocalizations frequently during these months and the sites are not covered with snow. Surveys were conducted on both clear and cloudy days, in the morning between 05:00 and 10:30 when pika activity is reportedly highest (Kawamichi 1971).

To detect the presence of Northern Pikas, we conducted two point-count aural detection surveys using both auditory observation and playback approaches. Auditory observation consisted of listening to the natural vocalizations of the Northern Pika without intervention. By contrast, playback involved the broadcast of a prerecorded pika vocalization as a cue to elicit responding vocalizations. Upon arrival at each site, we remained silent and inactive for 10 min to reduce the possibility of human arrival stimulating pikas to vocalize. After this initial waiting period, we conducted auditory observation first, followed by playback. Nonetheless, pika vocalizations detected prior to the survey upon arrival at the site were also recorded as a baseline to assess the efficacy of auditory observation and playback. For both methods, we listened to vocalizations in a fixed facing direction (upslope or downslope) and recorded the following information for each detected vocalization activity: (i) time from start of the survey (time after the broadcast ended in the playback); (ii) vocalization type (see next section); and (iii) direction at 10-degree intervals (all surveys were conducted by T. Sakiyama). The survey timeframes were 50 min for auditory observation and 5 min for playback. Auditory observation was longer because lack of intervention could delay the first detection, whereas we expected a much quicker detection for playback. After the survey, site occupancy was marked as present if any type of Northern Pika vocalization was detected and absent if not.

For playback, we broadcast an audio file from a monophonic audio speaker (JBL CHARGE4, JBL, California, USA; frequency response 60–20,000 Hz) as a cue to provoke vocalizations from individuals. The audio file consisted of three repetitions of a Northern Pika ‘song’ (also known as ‘long call’; Kawamichi 1981), each played with the speaker facing in three directions perpendicularly (leftward, forward, and rightward relative to the facing direction) to cover the entire study site. While the vocalization type used for playback was not mentioned in previous studies (Ieiri and Yanagawa 2009; Sato et al. 2009), we used the song as a cue because we successfully heard responding vocalizations in a preliminary trial when using this type of call (T. Sakiyama, personal observation). We conducted surveys at a monthly interval to prevent pika individuals from habituating to recorded vocalizations (Trefry and Hik 2009). The song was prerecorded using a stereophonic audio recorder (Olympus LS-P4 Linear PCM Recorder) located 5 m from a Northern Pika individual. After successfully recording the song, we reduced external noise in the audio, modified the song length from six elements (as defined in Kojima et al. 2006) to ten elements to enable longer broadcast, and created an audio file comprising of three repeats of the song with an approximate total duration of 30 s long. Both modification and creation procedures were conducted using Audacity v. 3.0.0 (Audacity Team 2021). The spectrogram of a single song and the audio file of the playback are available in Supplementary Data SD1 and SD2, respectively.

In aural detection, including both auditory observation and playback, the auditory capability of a surveyor may bias the quality of occupancy detection. Therefore, each surveyor underwent preliminary training to locate pika vocalizations by ear, and we evaluated the auditory capability of the surveyor in locating the sound source (distance and direction) in a test experiment in order to confirm that a surveyor was efficient in detecting the Northern Pika vocalizations at different directions and distances (see Supplementary Data SD3). Moreover, Northern Pikas could have been more detectable from the front than from the back during the actual surveys because the surveyor faced one fixed direction in the talus patch during the surveys. To assess if such directional bias was introduced, we created histograms of the direction from which vocalization activity was detected for both auditory observation playback surveys. We counted the number of surveys that detected vocalization activities for each direction over the three sessions across sites and used it as the frequency.

Vocalization type classification.—The Northern Pika is known to emit various types of vocalizations (Kawamichi 1981; Lissovsky 2005), and therefore, we distinguished the vocalization types by ear in the surveys. However, there has been high ambiguity in the terminology of each vocalization type in previous literature. For example, Kojima et al. (2006) followed terminologies in Kawamichi (1981), but Lissovsky et al. (2021) followed a different terminological system (Lissovsky 2005; described in Russian). To minimize potential ambiguities, we consider literature descriptions of qualitative and quantitative characteristics of vocalization types as follows: the ‘long call’ described in Kawamichi (1981) matches the ‘song’ described in Lissovsky (2005); the ‘short call’ in the former matches the ‘alarm call’ in the latter; the ‘trill’ in the former equals the ‘chirring’ in the latter. Although we could not obtain detailed information on function and spectrogram for the ‘submission call’ in Kawamichi (1981) and the ‘trill’ in Lissovsky (2005), we did not detect these types in our surveys. Therefore, we only considered the three aforementioned vocalization types in our study, all being detectable by human ear (further detail in Supplementary Data SD4).

The detectable range of vocalization activities varied depending on the type of vocalization—‘long call/song’ and ‘short call/alarm call’ were detectable from a distance of

100 m, whereas 'trill/chirring' was only detectable from a distance of 25 m or closer. Our detection range is more conservative than that of Kawamichi (1969; i.e., 200 m) because those ranges probably were attained under optimal ambient noise conditions. Given that our surveys were occasionally conducted in windy conditions (≤ 6.0 m/s) and cicada singing background noise (< 60 dB), we elected to use a conservative detection range of 100 m from the site center in our surveys.

Statistical analysis.—To compare the efficacy of aural detection methods, we analyzed the accuracy of each method with respect to time spent on the survey by creating confusion matrices and computing the true positive rate and accuracy. True positive rate (also referred to as sensitivity) indicates the probability of a method detecting presence at sites that are truly occupied by the pika. Accuracy indicates the probability of a method detecting the true status of occupancy (i.e., present or absent) at each site. The true status of occupancy at a site was based on the overall combined results from all surveys over the season. Here, we assumed that our overall surveys could detect the true status of occupancy at each site and that it did not change during survey season (i.e., closed population setting). However, this assumption might not hold true because, according to one study, the Northern Pika disperses from late July through August (Kawamichi 1971), which overlaps with our survey season. Therefore, we also examined how the number of sites detected changed over time. Since the timeframe differed between auditory observation and playback (50 and 5 min, respectively), we divided each auditory observation survey record into 10 survey periods of 5 min each and computed true positive rate and accuracy of detection for each.

We compared the time until first detection between auditory observation and playback methods to understand how intervention of the playback broadcast promoted their response. We used the detection result from the first survey period for auditory observation to match the timeframe of the playback survey, and used only those cases where both methods succeeded in detecting the animal. We compared time until first detection using a generalized linear mixed model with a negative binomial distribution. We selected this distribution because our data included zero values (i.e., 0 s when detected) and because overdispersion was detected when data were first analyzed using the Poisson distribution. We fitted time of first detection as the response variable and methods (i.e., auditory observation and playback) as categorical explanatory variables. The intercept in the linear predictor was omitted from the model and site was included as a random intercept. We interpreted the difference between methods as significant if the 95% confidence interval of the prediction did not overlap.

All statistical analyses were conducted using R 4.1.2 (R Core Team 2021). Confusion matrix analysis was conducted using the *caret* package (Kuhn 2008) and mixed model analyses were conducted using the *lme4* package (Bates et al. 2015).

RESULTS

We detected Northern Pika at 11 of the 18 sites from the occupancy surveys, with eight sites corresponding to higher-elevation and three to lower-elevation sites (Fig. 1). The highest elevation among the present sites was 2220 m at Mt. Hakuun, which corresponds with previous reports (Onoyama and Miyazaki 1991). On the other hand, the lowest was 470 m along the Horoka-Piribetsu river, which to our knowledge has previously not been reported as Northern Pika habitat. The occurrence of Northern Pikas indicated a positive spatial autocorrelation pattern, where present and absent sites were found relatively close to other present and absent sites. We often detected presence upon arrival at the site in higher elevations in early summer. In contrast, such cases were uncommon at lower elevations, with lower-elevation sites necessitating the use of auditory observation or playback surveys to detect presence most of the season (Supplementary Data SD5). Among the different vocalization types, ‘long call/song’ and ‘short call/alarm call’ were more frequently heard than ‘trill/chirring’ for all months at both higher and lower elevations (Supplementary Data SD6).

Confusion matrix indices revealed that detection accuracy changed according to survey duration for the auditory observation method. When duration increased from the shortest (5 min) to the longest (50 min) setting, the true positive rate increased from 0.606 to 0.909 and accuracy increased from 0.759 to 0.944 (Fig. 2). Both indices initially changed drastically over shorter survey durations, reaching a plateau around the sixth survey period, approximately 30 min after the survey was started. For playback, which was conducted for only 5 min, the true positive rate and accuracy were 0.879 and 0.926, respectively. We found that values from playback are comparable to those of the longest duration setting of the auditory observation method (Fig. 2).

The time at first detection of Northern Pika vocalizations was statistically significantly shorter for playback than auditory observation (Table 1, Fig. 3). First vocalizations—recorded using playback—were detected 23.8 s after the audio was played on average, whereas they were detected after 127.6 s with auditory observation.

During auditory observation surveys, Northern Pika vocalizations were detected more frequently from the front side than the back side for ‘short calls/alarm calls’. However, in other cases, detections were oriented sideward (i.e., left and right sides), which differed from our initial expectations. Detection of ‘trill/chirring’ was rare during our surveys (Fig. 4, Supplementary Data SD6).

DISCUSSION

In this study, we compared the performance of two aural methods for detecting presence of the Northern Pika by listening for their vocalizations. Our results showed that both auditory observation and playback are highly and comparably effective in detecting presence. And while presence was more frequently represented at higher-elevation than lower-elevation sites

(Fig. 1), this agrees with previous reports describing their distribution in Hokkaido (Onoyama and Miyazaki 1991; Kawabe 2008), and modelled distribution of the species that reflects their adaptation to cold environments (Sakiyama et al. 2021). These results indicate that vocalization-based surveys have high potential for monitoring the Northern Pika in its natural habitat and contributing to understanding the effects of environmental change on their populations.

Occupancy survey.—The effectiveness of auditory observation increased significantly as survey duration increased. This result is intuitive because a longer duration increases the chance of recording vocalization activities. Pikas often vocalize for alarm and territorial purposes (Somers 1973; Kawamichi 1981; Lissovsky 2005; Trefry and Hik 2009), as well as for positioning and localizing other individuals (Conner 1982). Since these natural events are likely to occur randomly over time, shorter survey durations are likely to include more false-negative detections. Our initial expectation was that detection of Northern Pikas would require survey durations longer than 5 min, a timeframe used in bird surveys (Ralph et al. 1995), because of their low conspicuity. Nonetheless, our results revealed that detection efficacy reached a plateau when auditory observation was conducted for more than 30 min. This suggests that continuing the survey after 30 min does not provide significant gains in information relative to the effort invested—this saturation effect was also reported previously in a study that used a similar point-count method (Hutschenreiter et al. 2021).

Notably, the five-minute playback survey reached a similar level of efficacy as the longest auditory observation survey in detecting the presence of Northern Pikas. Moreover, the playback method detected, on average, their presence approximately four times earlier than the auditory observation method. Therefore, cues broadcast by the audio speaker are highly effective in eliciting vocal responses. Although this phenomenon has been observed and effectively used in previous studies to understand the behavioral nature of vocalization

(Somers 1973; Conner 1982; Trefry and Hik 2009), our results suggest that it can also be used as a highly effective, fast, and affordable method for surveying site occupancy in this species.

Another significant advantage of the aural detection survey was that it enabled detection of presence of Northern Pikas at lower elevations, including areas previously unreported as pika habitat (i.e., along the Horoka-Piribetsu river). These landscapes are characterized by denser vegetation structure and fewer rock interstices than higher elevations (Sakiyama et al. 2021), hampering traditional visual approaches for detection. Moreover, vocalization activities were not easily detected upon arrival at their habitats at lower elevations, in contrast to higher elevations (Supplementary Data SD5), making aural detection method the only effective approach. Lower-elevation populations inhabit marginal regions of their distribution, whereas core populations are located at higher elevations (Sakiyama et al. 2021). Therefore, aural detection provides a promising tool for efficient monitoring of Northern Pikas that might be more vulnerable to climate change and human land uses at lower elevations.

We found that the number of sites at which presences was detected increased gradually during the summer (Supplementary Data SD6), suggesting that occupancy could be detected by vocalization during and after the reproductive season, as expected from previous studies (Kawamichi 1971). This trend was more apparent at lower elevations, and it could be a result of false-negative observations, even though they did inhabit the site from early in the season. This finding emphasizes the importance of repeating the survey throughout the summer to improve chances of detecting presence. However, Northern Pikas have been reported to disperse from late July to August at lower elevations (Kawamichi 1971), whereas American Pikas disperse from mid-May to mid-August at high altitude (2000 m) habitats (Smith 1974). Therefore, the increase in number of sites at which they are present over the summer could instead be a result of dispersal events from adjacent sites. If this was the case, then the assumption of a closed population for our survey would not have been met. Although we primarily considered the timing of snowmelt to determine our survey season, a more precise definition may be needed to better accommodate the population setting in future studies. Fixing survey season prior to or after dispersal, for example, could enhance accuracy. To this end, further studies into the dispersal ecology of the Northern Pika are urgently needed.

Advantages and disadvantages of aural detection methods.—Our results suggest that both auditory observation and playback are effective in surveying the presence of the Northern Pika, but each has advantages and disadvantages.

A common advantage of using point-count aural detection is that the surveyor need not venture into densely vegetated and potentially dangerous habitats. Talus slopes consist of piles of large, loose rocks with interspersed vegetation of various types and structures including lichens, moss, herbaceous plants, shrubs, and trees (Sakiyama et al. 2021). Hence, walking steadily within the site requires care, and the simultaneous search for signs of pikas is laborious and time-consuming. Alternatively, when the surveyor does not move, vocalization is less influenced by these factors, although the observational environment (e.g., strong wind) needs to be considered in terms of its effect on auditory detection. Moreover, use of the point-count survey is advantageous because it avoids trampling on and damaging vegetation, which is the main dietary resource of Northern Pikas. Furthermore, while feces can represent incomplete signs of recent activity (Nichols 2011), vocalization-based surveys only detect active signs of occupancy.

Nevertheless, the use of vocalization-based methods has several disadvantages. First, it is difficult to define the area where pika vocalizations can be detected by the human ear. We conservatively assumed that the aurally-detectable range of the Northern Pika is 100 m, although complex topography could alter this range. Our results show that detection of the vocalization activities were more prevalent in frontward and sideward directions (Fig. 4), suggesting that choice of surveying point and facing direction will influence results.

Moreover, if the study area is larger than the range of detection by ear (approx. 100–200 m; Kawamichi 1969), it will be important to conduct the survey at multiple points. Second, aural detection methods require training of the surveyor to differentiate Northern Pika vocalizations from other animals. While no other small mammals cooccurring in rocky patches make vocalizations identical to the Northern Pika, the Eurasian Woodcock (*Scolopax rusticola*) makes a vocalization similar to the 'short call/alarm call' during their nocturnal flights (T. Sakiyama personal observation). Therefore, we ensured no potential confusion by planning our surveys during the morning, and likewise avoiding the active time of other animals are likely to reduce false detections. Third, although we were cautious to minimize these factors, we did not assess if and how the presence of the surveyor could affect results. For example, although we stayed silent before and during the survey, animals could still have detected our presence through olfaction. If this was the case and their vocalizing behavior was reduced as a result, our estimation of presence frequency would likely have been underestimated. Fourth, it remains unclear how behavioral differences at different life stages will affect aural detection results. For example, younger individuals might vocalize at lower volume and less frequently than older individuals, which could also lead to a reduction in detection probability.

The methodological differences between auditory observation and playback included duration of the survey (survey durations were up to 50 min for auditory observation method and 5 min for playback) and for the latter, broadcast of a prerecorded call to stimulate pika vocalizations. However, detection results between playback and auditory observation were comparable. Thus, playback has an advantage over auditory observation because it reduces survey duration and, therefore, effort and cost. Resource allocation is key in planning field surveys. With limited resources, researchers frequently face the challenging task of balancing the number of sites and survey effort within each site. A reduction in survey time enables an increase in the number of sites, which increases robustness of research results.

Playback was conducted by broadcasting prerecorded vocalizations to elicit responding calls from inhabiting individuals. The implementation of playback requires important considerations that are not required for auditory observation. First, pikas could become habituated to playback audio if it were played frequently (Trefry and Hik 2009). Habituation of target species should be avoided because it may increase false-negative observations and preclude consistent surveys. This problem can be avoided by designing surveys such that they are sufficiently spaced over time (i.e., once a month in this study)—broadcasting audios recorded from different individuals could also reduce habituation. Second, the effect of the prerecording source on response remains unclear. If the response behavior differs depending on the spatial source of the broadcast (i.e., place of prerecording), as was reported for the American Pika (Conner 1983), the efficacy of playback will likely be spatially biased. However, this effect was likely minimal in our study because only a single acoustic dialect is found in Northern Pika populations in Hokkaido (Lissovsky 2005; Lissovsky et al. 2021). Conversely, the choice of prerecording source will require in-depth consideration in situations where playback is conducted at a broader spatial extent, increasing the likelihood of including multiple dialects—in these kinds of surveys, the simplicity and passivity of auditory observation could be advantageous.

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CONFLICT OF INTEREST

The authors declare they have no conflict of interest.

AUTHOR CONTRIBUTIONS

TS contributed to conceptualization and design of methodology; TS contributed to fieldwork for data collection, data analysis, funding acquisition, and writing the original draft; TS and JGM contributed to discussion of results, writing the final manuscript and gave final approval for publication.

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author (TS) upon reasonable request.

SUPPLEMENTARY DATA

Supplementary Data SD1.— Spectrographs of the audio file used in the playback survey. The actual audio could be heard from the audio embedded in the file.

Supplementary Data SD2.— Audio file used in the playback survey.

Supplementary Data SD3.— A scatter plot showing the auditory capability of the surveyor in estimating the location of the sound source in a talus patch.

Supplementary Data SD4.— Organization process of the terminologies used for the Northern Pika vocalizations in previous literature.

Supplementary Data SD5.— Raw detection result of occupancy from the surveys.

Supplementary Data SD6.— Bar plots indicating the number of sites detected during the surveys for each method and vocalization type.

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Fig. 1.—Map of the study area in Hokkaido, Japan (top-right panel) and the study sites within to survey the occupancy of the Northern Pika (left panel), differentiated by occupancy status and elevation class (black indicates presence, white indicates absence, circle indicates higher elevations, and triangle indicates lower elevations). Aggregated sites are shown in higher resolution (mid-right panel). Regional boundary is indicated in dotted lines and the area of Daisetsuzan National Park is shown as a solid line.

Fig. 2.—Relationship between confusion matrix indices and duration of the survey to detect presence of Northern Pikas. Note that auditory observation (circle) was conducted for ten survey periods (five minutes × ten periods), whereas playback (triangle) was conducted only for one survey period (five minutes).

Fig. 3.—Difference between time of first detection of the animal using auditory observation and playback method. Error bars indicate the 95% confidence interval around the mean.

Fig. 4.—Circular histograms showing frequency of the directions from which the vocalization activities were detected, plotted separately for the survey method and detected vocalization type.

Table 1.—Parameters and performance of generalized linear mixed models to assess the difference of time until first detection of the Northern Pika between auditory observation and playback.

Parameter	*β*	SE	*z*	*P*
Auditory observation	4.849	0.267	18.142	< 0.001
Playback	3.171	0.343	9.246	< 0.001

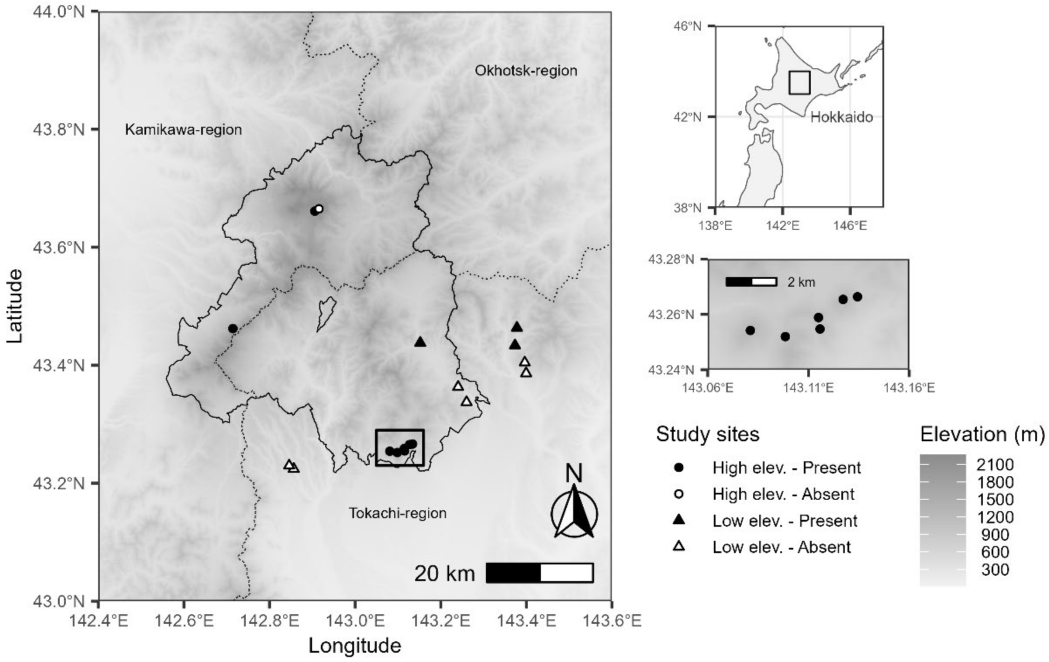

Okhotsk-region
Kamikawa-region
Tokachi-region
Latitude
Longitude
44.0°N
43.8°N
43.6°N
43.4°N
43.2°N
43.0°N
142.4°E
142.6°E
142.8°E
143.0°E
143.2°E
143.4°E
143.6°E
N
20 km
46°N
42°N
38°N
138°E
142°E
146°E
Hokkaido
43.28°N
43.26°N
43.24°N
143.06°E
143.11°E
143.16°E
2 km
Study sites
High elev. - Present
High elev. - Absent
Low elev. - Present
Low elev. - Absent
Elevation (m)
2100
1800
1500
1200
900
600
300

Fig. 1

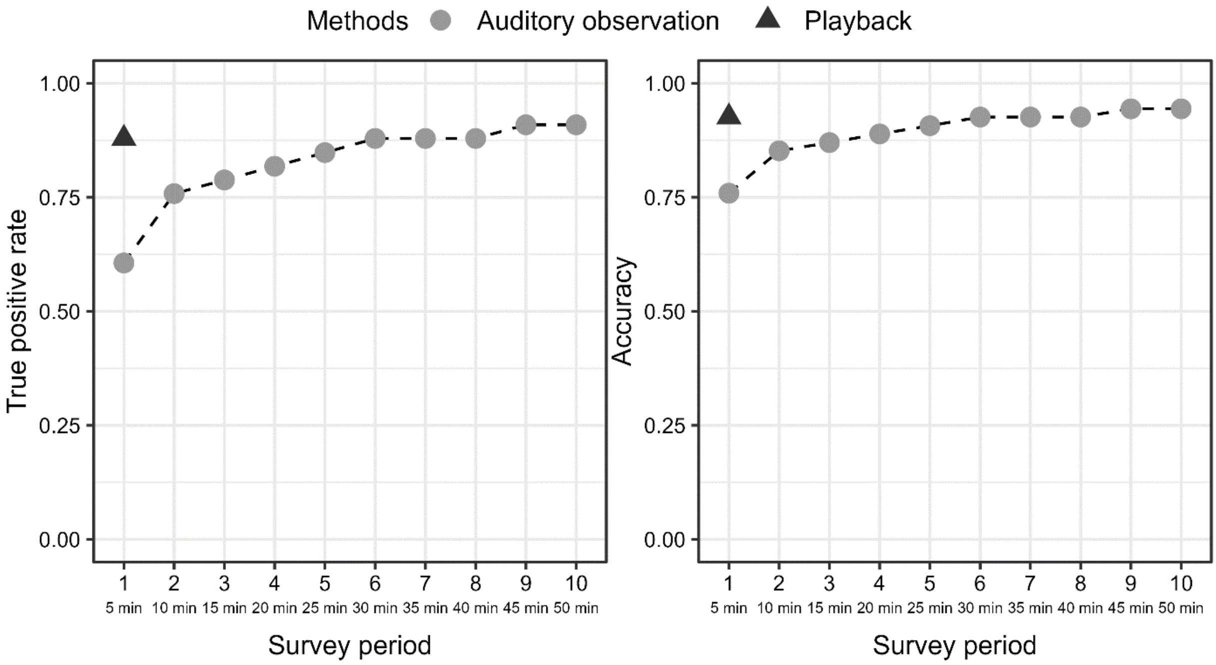
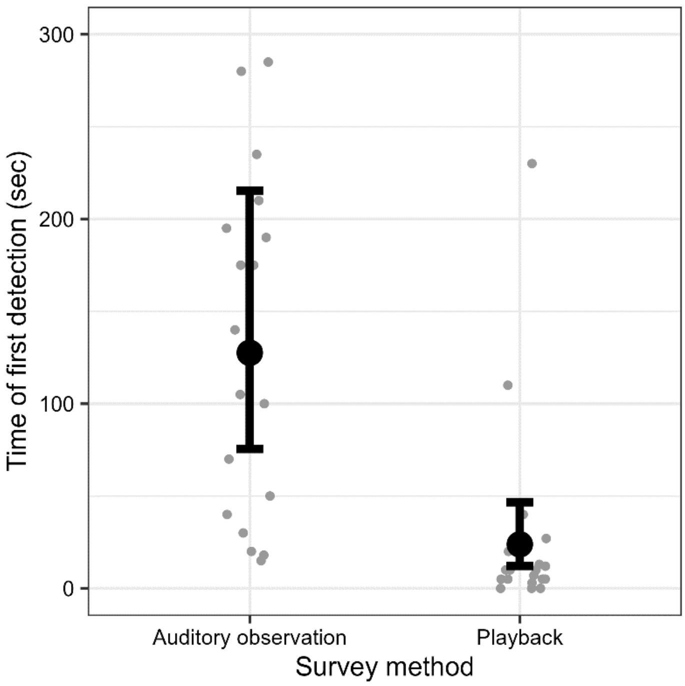
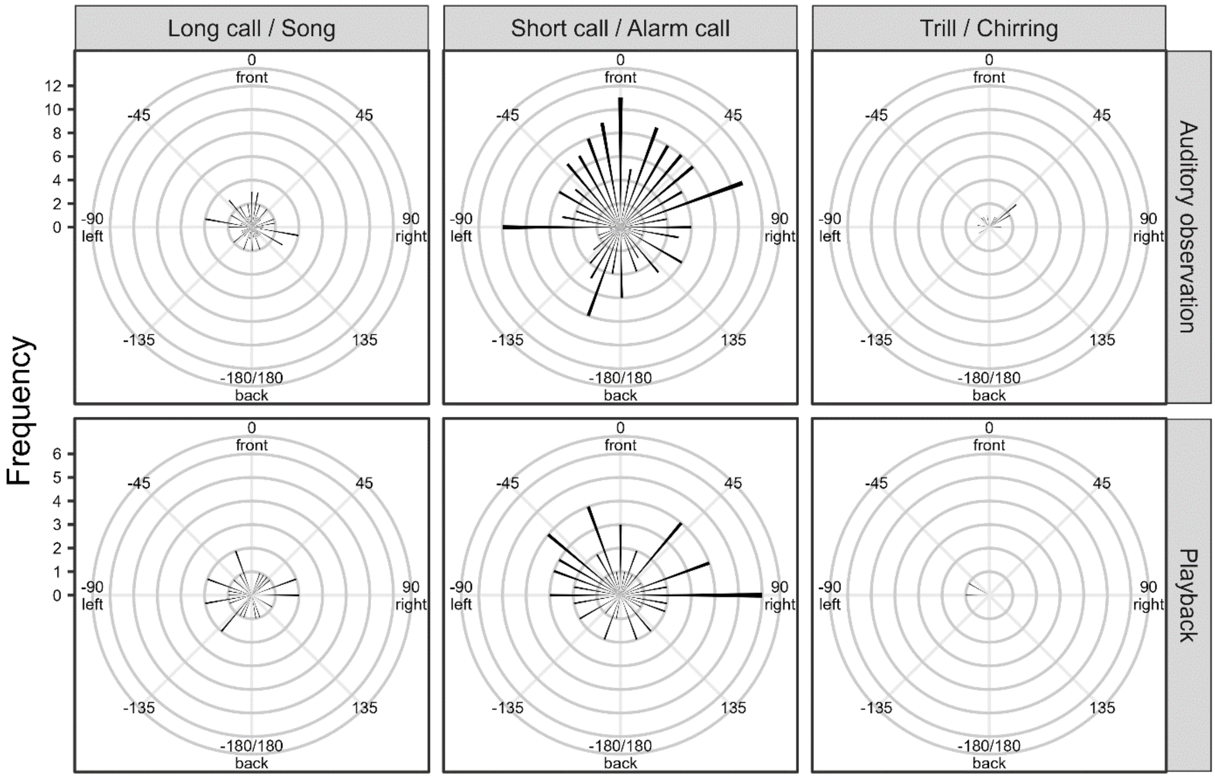

Methods
Auditory observation
Playback
True positive rate
Accuracy
1.00
0.75
0.50
0.25
0.00
1 2 3 4 5 6 7 8 9 10
5 min 10 min 15 min 20 min 25 min 30 min 35 min 40 min 45 min 50 min
Survey period

Fig. 2



300
200
100
0
Time of first detection (sec)
Auditory observation
Playback
Survey method

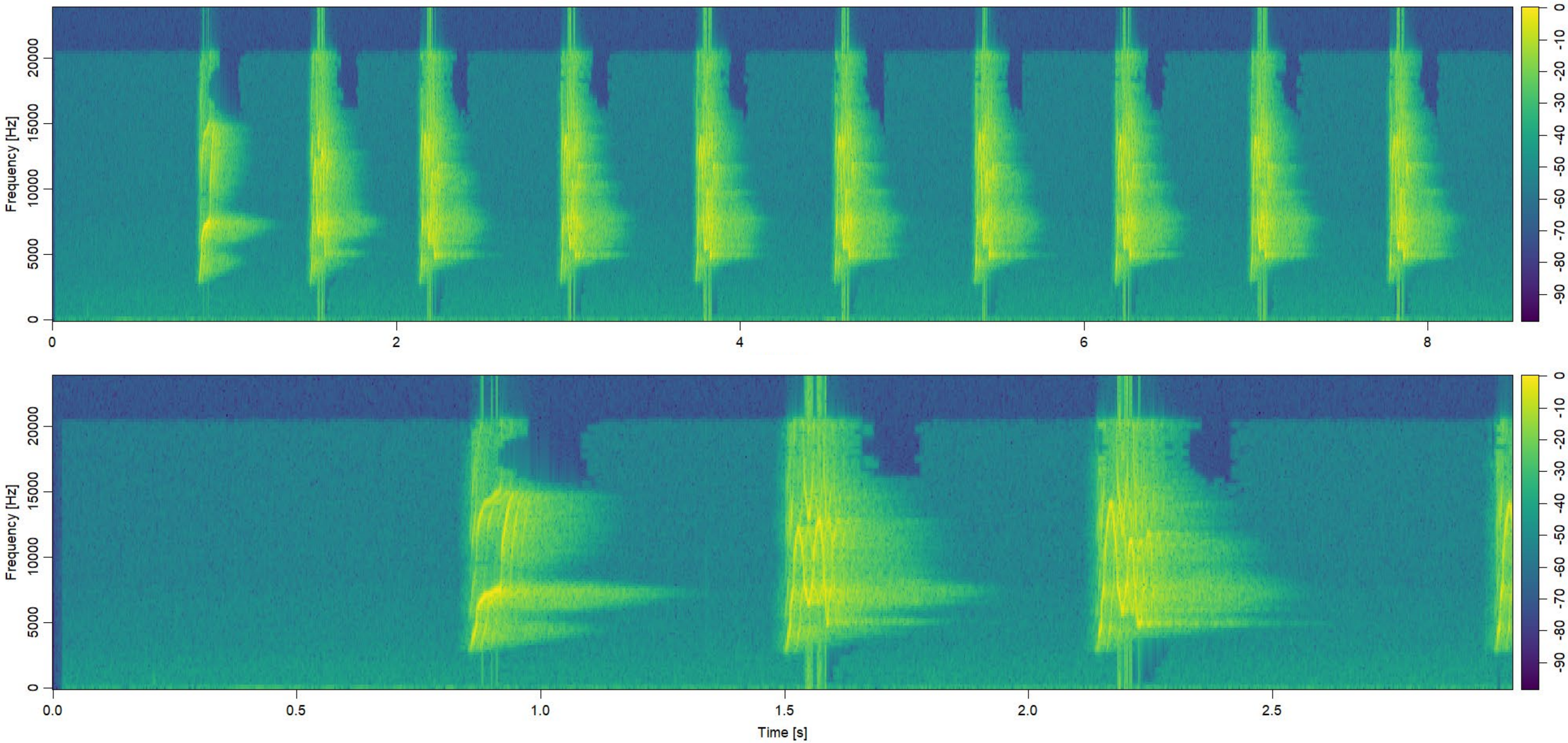
Fig. 3


Long call / Song
Short call / Alarm call
Trill / Chirring
Auditory observation
Playback
Frequency
0
front
-45
45
-90
left
90
right
-135
135
-180/180
back
12
10
8
6
4
2
0
6
5
4
3
2
1
0

583
584 **Fig. 4**

Aural detection methods enable detection of northern pika occupancy in densely vegetated habitats

Supplementary Data SD1



Spectrographs of the audio file used in the playback survey, showing the whole length (top) and the first three seconds in zoom (bottom) of one “long call” or the “song” of the northern pika. Three repeats of this long call was broadcasted from an audio speaker in the actual survey. Audio could be heard from the input audio on the right. Actual audio file used for the playback is archived in Supplementary Data SD2.

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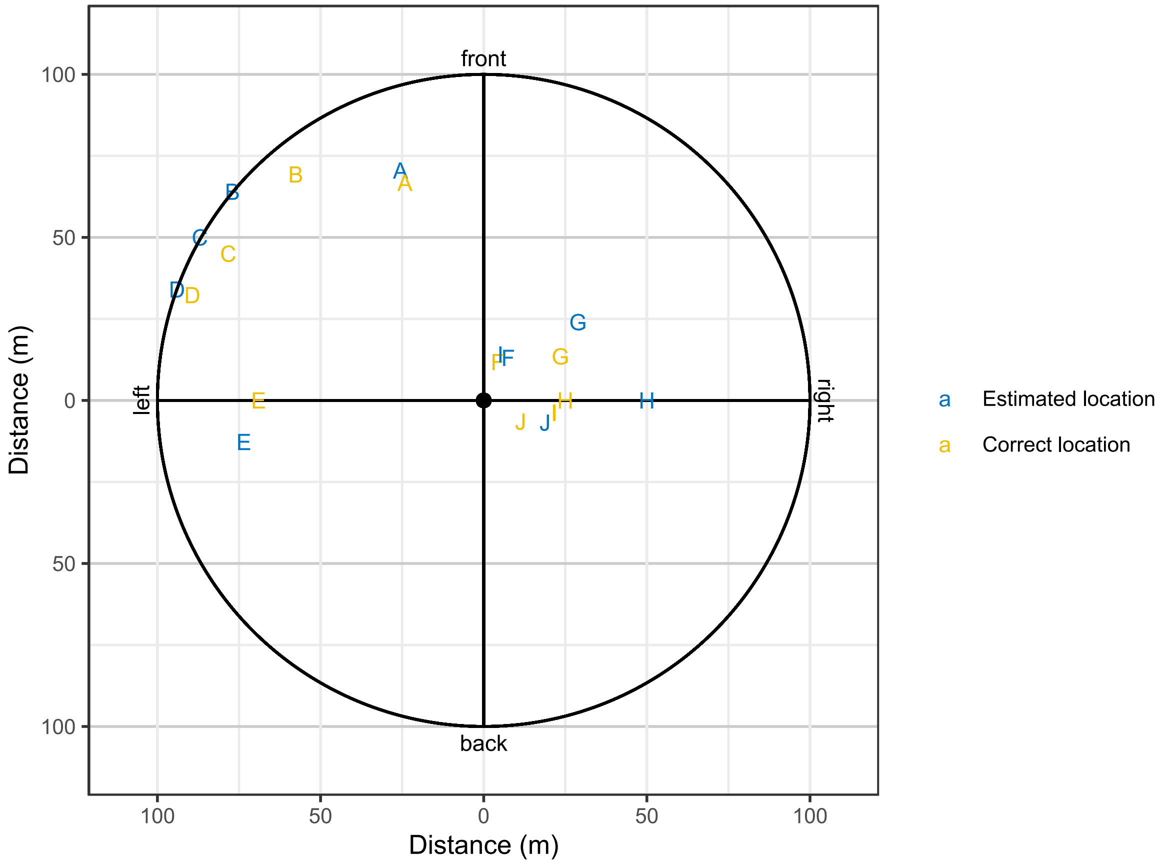
Supplementary Data SD3



We evaluated the auditory capability of the surveyor to detect the presence of the northern pika. Given that controlling the location of the animal vocalization is impossible, a survey assistant instead broadcasted the northern pika vocalization from an audio speaker hidden at a random location in the talus patch and the surveyor estimated the distance and direction to the sound source from the site center. These records were then compared with the correct location of the sound source. The plot shows the estimated and correct location of the sound source, indicating that the surveyor was efficient in detecting the northern pika vocalization heard from various directions and distances.

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Supplementary Data SD4

Various types of vocalizations are known to be used for specific functions in northern pikas, as described in detail in Kawamichi (1981) and Lissovsky (2005) (described in Russian). However, different terminologies were used between these literatures to describe the vocalization system of northern pikas. Moreover, since such terminological ambiguity remained untouched for unification, successive literature often refer to either terminological system for citation, which hamper comparison between studies. For example, Kojima et al. (2006) followed terminologies in Kawamichi (1981), whereas Lissovsky et al. (2021) followed Lissovsky (2005).

To reach a unified understanding of the vocalization system of the northern pika between Kawamichi (1981) and Lissovsky (2005), we referred to the characteristics and functions of each vocalization type and situations in which they are used for qualitative comparison. We also considered the spectrographs (= sonograms) of the vocalizations to enable quantitative comparison. Since large geographical variation are known to exist even within a same vocalization type in northern pikas (Lissovsky 2005; Lissovsky et al. 2021), we referred to geographically close population pairs between the literature for spectrograph comparison (i.e., Hokkaido, Japan in Kawamichi (1981) and Sakhalin and Sikhote-Alin, Russia in Lissovsky (2005)).

Various terms such as *long call*, *short call*, *trill*, and s*ubmission call* have been used in Kawamichi (1981) with reference to American pika literature. And *alarm call* (Предупреждающий об опасности сигнал), *song* (Песня), and *chirring* (Стрекотание) have been used in Russian terms in Lissovsky (2005), and *song* of the northern pika consist of vocalization elements such as the *trill* (Трель) and *modulated call* (модулированный сигнал) (Note that these Russian-English translations follow the English abstract of Lissovsky 2005). As we compared the qualitative and quantitative characteristics between the literature, we organized the vocalization terminology as follows (Fig. SD4-1, SD4-2): *long call* in Kawamichi (1981) matched with the *song* in Lissovsky (2005) because elements of the *long call* showed similar spectrographic shape of modulation with the *modulation call* of a *song* (W-shaped waves) and both are explained as being made by males only and for territorial demonstration; *short call* in the former matched with *alarm call* in the latter because both showed similar spectrographic shape (upward stroke) and are described as being emitted in single or multiple vocalizations with irregular intervals in response to an approaching danger or without any reason; *trill* in the former matched with *chirring* in the latter because both showed similar spectrographic shape (diminishing upward strokes) and are explained as being heard when the animal escapes into the rock under fright conditions. We could not obtain detailed information of function and spectrogram for *submission call* in Kawamichi (1981) and *trill* in Lissovsky (2005). The term *trill* was used differently between the literature, but we classified them as different vocalization types since the spectrographic shape and situation of their use were not resembling, suggesting that their use requires care (Lissovsky 2005).

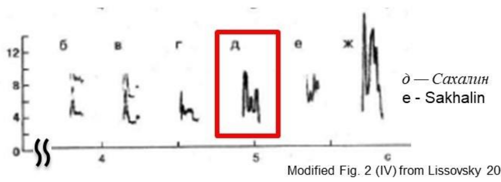
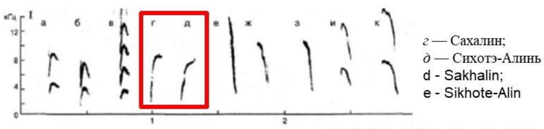
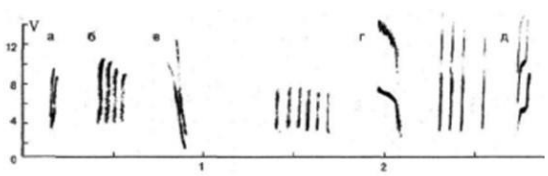
Kawamichi 1981 Study region: Hokkaido, Japan	Lissovsky 2005 Study region: Russia
Long call Explanation: Emitted in series, consisting of 4 -16 cries. Given only by males in both reproductive and non - reproductive season. May function as territorial advertisement.	**Песня** English translation: song Explanation: Emitted in series, consisting of 1-23 modulated calls (модулированный сигнал). Used only by males for roll -calls and territory demonstrations.
Shown as A-D in Fig.1 in Kawamichi 1981	 Modified Fig. 2 (IV) from Lissovsky 2005
Short call Explanation: Emitted singly or in series at irregular intervals. Produced by all individuals, irrespective of sex and age. Increase in the non -reproductive season and may be related with food storage.	**Предупреждающий об опасности сигнал** English translation: Alarm call Explanation: Emitted in series at irregular intervals, consisting of 1-20 cries. Produced both in response to an approaching danger: a person, a bird, or a rock fallen from a rock, and without any visible reason.
Shown as E-J in Fig.1 in Kawamichi 1981	 Modified Fig. 1 (I) from Lissovsky 2005
Trill Explanation: Produced by all individuals, irrespective of sex and age. Emitted singly when pikas quickly enter rock crevices.	**Стрекотание** English translation: Chirring, chirping Explanation: Consist of short chirp or a series of squeaks. Produced during a strong fright, when the animal unexpectedly collides with a human and rushes under rocks.
Shown as M and N in Fig.1 in Kawamichi 1981	 Modified Fig. 1 (V) from Lissovsky 2005

Fig. SD4-1 Matching vocalization types between Kawamichi (1981) and Lissovsky (2005). Spectrograms with a red box in Lissovsky (2005) are from northern pikas in Sakhalin or Sikhote-Alin, which are the geographically closest populations from that in Kawamichi (1981).

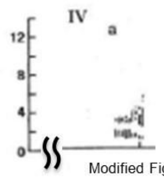
Kawamichi 1981 **Study region: Hokkaido, Japan**	**Lissovsky 2005** **Study region: Russia**
No matching vocalization type.	**Трель** English translation: Trill Explanation: Produced both independently and in combination with other vocalization types. Used for territorial and mating demonstrations. Given only by males.
	 Modified Fig. 2 (IV) from Lissovsky 2005
Submission call Explanation: Whining sound. Repeated several times. Used when an individual was approached or chased by another.	No matching vocalization type.
No spectrogram provided.	

Fig. SD4-2 Unmatching vocalization types between Kawamichi (1981) and Lissovsky (2005).

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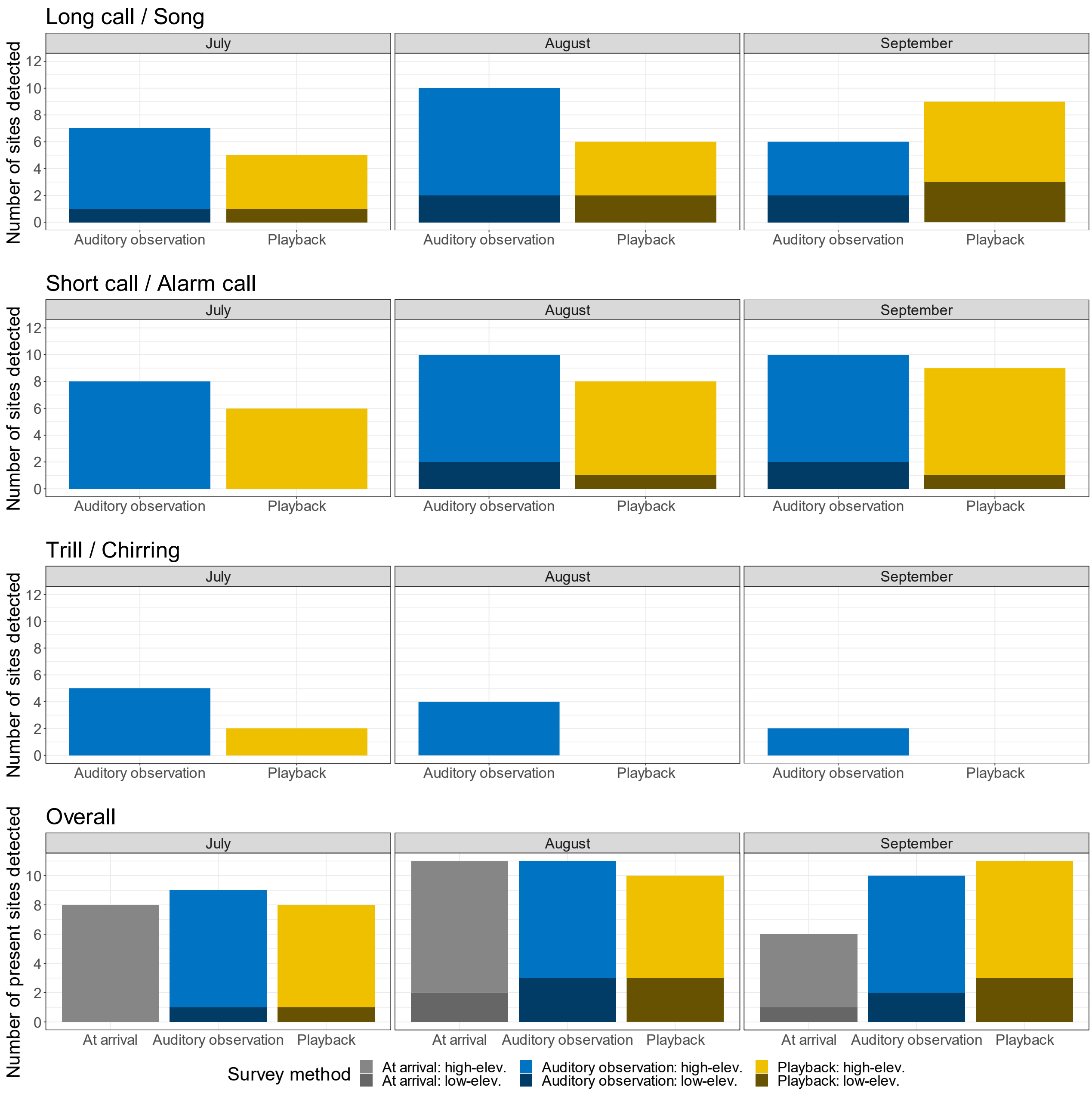
Supplementary Data SD5

Detection result of occupancy upon arrival at the site, after auditory observation, and after playback. “0” and “1” indicate absence and presence, respectively.

Site	Elevation (m)	Class	Upon arrival			Auditory observation			Playback			True occupancy
			Jul	Aug	Sep	Jul	Aug	Sep	Jul	Aug	Sep	
1	350	lower	0	0	0	0	0	0	0	0	0	0
2	350	lower	0	0	0	0	0	0	0	0	0	0
3	450	lower	0	0	0	0	0	0	0	0	0	0
4	450	lower	0	0	0	0	0	0	0	0	0	0
5	470	lower	0	0	0	0	1	0	0	1	1	1
6	510	lower	0	0	0	0	0	0	0	0	0	0
7	560	lower	0	1	0	1	1	1	1	1	1	1
8	590	lower	0	1	1	0	1	1	0	1	1	1
9	650	lower	0	0	0	0	0	0	0	0	0	0
10	900	higher	1	1	0	1	1	1	1	1	1	1
11	1010	higher	1	1	1	1	1	1	1	1	1	1
12	1010	higher	1	1	0	1	1	1	1	1	1	1
13	1150	higher	0	1	1	1	1	1	1	1	1	1
14	1160	higher	1	1	1	1	1	1	1	1	1	1
15	1190	higher	1	1	0	1	1	1	1	0	1	1
16	1420	higher	1	1	0	1	1	1	1	1	1	1
17	2100	higher	0	0	0	0	0	0	0	0	0	0
18	2220	higher	1	1	1	1	1	1	0	1	1	1

Aural detection methods enable detection of northern pika occupancy in densely vegetated habitats

Supplementary Data SD6



Bar plots indicating the number of sites where each vocalization type was heard by using auditory observation (blue) and playback (yellow) methods. Overall result shows the number of present sites including detection at arrival (gray). Darker and lighter colors indicate lower- and higher-elevation sites, respectively.