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Young citizen sensors for managing large carnivores: Lessons from 40 years of monitoring a brown bear population

Hiroto Takinami[1]† | **Nobuo Ishiyama**[1] | **Hino Takafumi**[2] | **Takahiro Kubo**[3] | **Kanji Tomita**[4] | **Muku Tsujino**[5] | **Futoshi Nakamura**[1]

[1]Department of Forest Science, Graduate School of Agriculture, Hokkaido University, Sapporo, Hokkaido, Japan

[2]Tomakomai Research Station, Field Science Center for Northern Biosphere, Hokkaido University, Tomakomai, Japan

[3]Center for Environmental Biology and Ecosystem Studies, National Institute for Environmental Studies, Ibaraki, Japan

[4]Graduate School of Environmental Science, Hokkaido University, Sapporo, Hokkaido, Japan

[5]Department of Biological Sciences, School of Science, Hokkaido University, Sapporo, Hokkaido, Japan

Correspondence
Nobuo Ishiyama, Hokkaido Research Organization, Forest Research Institute, Kosyunai, Bibai, Hokkaido 079-0198, Japan.
Email: night7mare@gmail.com

Present address
Nobuo Ishiyama, Hokkaido Research Organization, Forest Research Institute, Kosyunai, Bibai, Hokkaido, Japan

Hino Takafumi, Hokkaido Research Organization, Research Institute of Energy, Environment and Geology, Sapporo, Hokkaido, Japan

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Abstract

Large carnivores encounter various threats from human activities. Population trend detection among carnivore species and implementation of management policies based on monitoring are urgently needed for human–carnivore coexistence. We demonstrate how young citizens have helped reveal long-term trends in brown bear field sign detection rates following a government policy change (i.e., abolishment of the spring cull). We used a 40-year dataset of field signs collected by volunteer college students in northern Japan and analyzed the resulting data using state-space models. The spring cull had a significant negative impact on the number of grids with field signs; the detection rate under spring cull pressure declined from 19 to 0% between 1976 and 1990. However, abolishment of the spring cull in 1990 had a significant positive effect on the number of grids with field signs; the detection rate increased from 0 to 13% between 1991 and 2015, suggesting that the government policy change strongly affected the threatened brown bear population. Structured monitoring schemes, simplicity and/or attractiveness in monitoring targets may ensure the data quality and duration of citizen-based monitoring. These findings suggest a high potential for engaging college students in developing sustainable monitoring of large carnivore populations and in supporting wildlife management.

KEYWORDS

brown bear, citizen science, large carnivores, population recovery, spring cull, *Ursus arctos yesoensis*, volunteer monitoring

† Deceased.

[Correction added on 30 July 2021, after first online publication: Third author first name and last name was swapped, updated author name is Hino Takafumi. Author name was updated in author by line, present address section, Author Contributions section and in ORCID section.]

1 | INTRODUCTION

Citizen-based monitoring is rapidly expanding and has advanced wildlife management over the last few decades. For example, long-term monitoring by citizens has detected unanticipated threats to wildlife populations. Thomas and Lenon (1999) used Britain's two breeding bird atlases, which were collected by both academic scientists and volunteers from 1968 to 1972 and from 1988 to 1991, to suggest that climate change likely caused shifts in the northern range margins of British birds. Using data from more than 20,000 nest records collected over 40 years (1952–1992), Winkler et al. (2002) found that tree swallows (*Tachycineta bicolor*) had advanced their mean date of clutch initiation by approximately 9 days over the past 30 years due to climate change. Data from citizen science surveys are also increasingly becoming a key component of invasive species management (Goldstein, Lawton, Sheehy, & Butler, 2014; Ricciardi et al., 2017). Citizen-science data can also provide an opportunity to assess a policy's effectiveness and inform future policymaking (McKinley et al., 2017). Monitoring population trends is a key component of successful wildlife management (Witmer, 2005). Citizen participation has been increasingly recognized as a powerful tool for revealing long-term population trends in wildlife (Barlow et al., 2015; Jiguet, Devictor, Julliard, & Couvet, 2012).

Citizen science programs are often characterized by surveillance monitoring (Dickinson, Zuckerberg, & Bonter, 2010). Surveillance monitoring is generally conducted without a priori hypotheses, with the idea that the collected data will ultimately be useful for answering a broad array of research questions. In contrast to targeted monitoring with clear scientific hypotheses, long-term surveillance monitoring is often avoided by academic researchers because this ad hoc research does not provide immediate results and is not cost-effective. “Surveillance” is thus one of the key practical advantages of citizen-based monitoring, and this approach has accumulated crucial data for academic researchers to analyze.

Large carnivore abundance and distribution have historically decreased worldwide, despite the diverse ecological functions of these animals (Ripple et al., 2014). However, applying citizen science to the long-term monitoring of large carnivores is still a work in progress, although studies that use citizen science to manage large carnivores are gradually increasing (e.g., Cretois, Linnell, Grainger, Nilsen, & Rød, 2020; Petracca et al., 2018). The brown bear (*Ursus arctos*), which is one of the largest apex predators in terrestrial ecosystems, has been widely conserved as an umbrella species (e.g., Carroll, Noss, & Paquet, 2001; Noss, Quigley, Hornocker, Merrill, & Paquet, 1996). Recent studies suggest that hunters can be reliable citizen sensors for brown bear monitoring. For example, Kindberg et al. (2011) reported that field signs collected primarily by moose hunters, such as scat and observation records, helped detect population trends of the Swedish brown bear over a 10-year period. Bones collected by Japanese hunters have contributed to the detection of a historical shift in the brown bear diet caused by human activities (Matsubayashi et al., 2015). However, in many countries, hunters are decreasing in number and/or aging (Enck, Decker, & Brown, 2000; Riley et al., 2003; Ueda, Kanzaki, & Koganezawa, 2010). For example, the Japanese Ministry of the Environment reports that the number of Japanese hunters has declined by 65% over the past four decades, and approximately 65% of hunters are over age 60. These recent hunting trends indicate that citizen-based monitoring that depends excessively on hunters is unsustainable. For sustainable population monitoring of large carnivores, including brown bears, additional citizen sensor options should be further explored.

There is growing interest in engaging young people in citizen science because of the associated potential to broaden environmental education outcomes and contribute to ecosystem management (Ballard, Dixon, & Harris, 2017; Zoellick, Nelson, & Schauffler, 2012). Recent studies have demonstrated the importance of data collected by students for conservation and ecological research on large carnivores (e.g., Schuttler et al., 2019; Scott et al., 2018) but have so far been limited to snapshot surveys. Here, we analyzed long-term data on field signs collected on a local population of the Ezo brown bear (*Ursus arctos yesoensis*) and showed how surveillance monitoring by volunteer college students contributed to revealing nearly a half-century of population trends corresponding to a historical policy change. We focused on the spring cull, which was a hunting measure used to remove bears that could be a nuisance in the future. The spring cull targeted bears in hibernation or those recently emerging from hibernation. More females and cubs tended to be killed during the spring cull than during other hunting seasons (Brown Bear Research Group of Hokkaido University [BRGH], 1982; Mano, 1995). The numerical impact of the spring cull was also extensive. Aoi (1990) reported that individuals killed during the spring cull accounted for more than 80% of bears controlled from 1983 to 1986 in northern Hokkaido (150 of 184 individuals). The spring cull was legally abolished in 1990 to reduce its negative impact on brown bear populations, although the autumn sport-hunting season continued. We expected that long-term monitoring by college students would detect (a) a negative impact from past hunting (i.e., a decrease in the detection rate of field signs) and (b) the efficacy of the change in the wildlife management policy (i.e., an increase in detection rates of field signs).

2 | MATERIALS AND METHODS

2.1 | Study area

In the present study, we used data on the field signs of the Ezo brown bear, namely scat and tracks, which were collected by the BRGH from the Teshio Experimental Forest (TEF). The TEF, which has an area of 220 km^2, is located in northernmost Hokkaido. Conifer-broadleaf mixed forest covers the TEF, and there has not been any extensive logging since the 1980s (Hokkaido University, 1985, 2017). The south-eastern TEF is connected to the largest preserve in Japan, Daisetsuzan National Park, through mountain forests (Figure 1). On Hokkaido Island, there are two large mammals, the Ezo brown bear and sika deer. Two local brown bear populations (Figure 1), the Teshio-Mashike and Shakotan-Eniwa populations, are listed as endangered local populations by Japan's Ministry of the Environment. The TEF is located on the northern fringe of the population range of the endangered Teshio-Mashike population (Tsubota & Yamazaki, 2011).

2.2 | BRGH monitoring

The BRGH was established in 1970 by students at Hokkaido University to survey the Ezo brown bear. Initially, the students' motivation for establishing the BRGH was to observe wild bears; however, the program subsequently expanded to include ecological research, such as foraging ecology and population density estimations (BRGH, 1982). Members of BRGH are recruited from among freshman students of Hokkaido University via advertisements at the beginning of the semester. BRGH conducts field sign surveys of brown bears in some regions of Hokkaido from spring to autumn every year (Figure 2). In the TEF, field sign monitoring runs annually from late July to late August. An average of 38 parties (91 individuals) participated in the annual census. Fixed survey routes along forest roads and streams have been instituted to cover the entire TEF, although the routes are not completely consistent year-to-year due to the condition of the access roads and stream water levels. Each party walked the census route in the daytime and recorded the type of each field sign (scat or tracks) on the survey routes and its spatial position on a 1:25,000 scale map. These methods for surveying field signs were selected by the students based on expert opinions and previous studies (e.g., Klein, 1959).

During the summer monitoring, a leader who has sufficient census skills, such as identification and fieldwork, is included in each party to maintain the data accuracy, and each route is monitored once. Well-trained students are certified as leaders if they pass an examination evaluating their census skills, which are judged by students who have conducted the survey for more than 2 years. Several times per year, most of the BRGH members attend lectures given by brown bear researchers to improve their census skills and knowledge. This monitoring system has been maintained since the establishment of the BRGH. Monitoring was not conducted from 1987 to 1989 because students could not sustain their motivation to continue the monitoring due to very few field

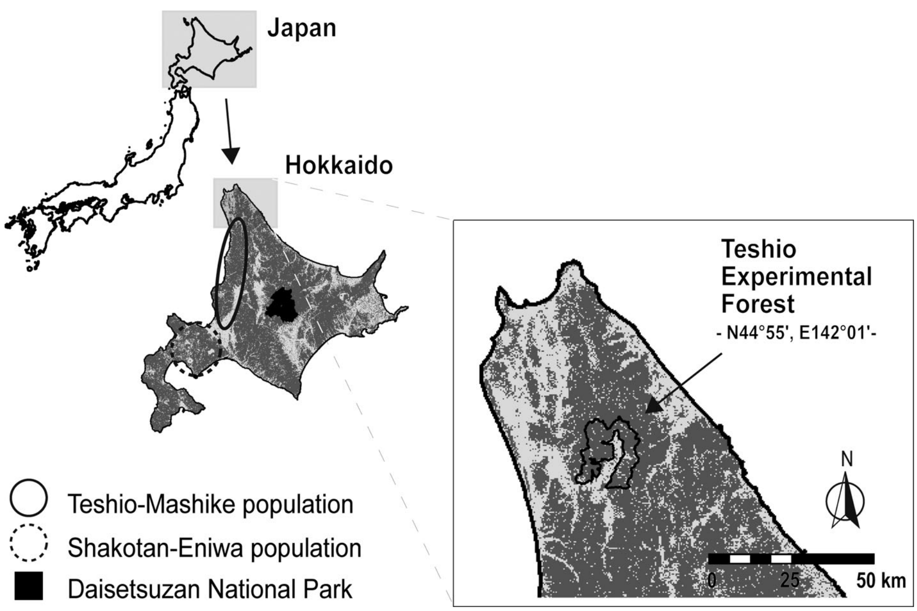

FIGURE 1 Location of BRGH monitoring. In the map, dark grey represents forest areas. The Teshio-Mashike and Shakotan-Eniwa populations are listed as endangered local populations by Japan's Ministry of the Environment. BRGH, Brown Bear Research Group of Hokkaido University

FIGURE 2 Pictures of BRGH monitoring. (a) & (b) Students at work performing the monitoring, (c) bear tracks, and (d) monitoring route along streams. BRGH, Brown Bear Research Group of Hokkaido University

signs. Therefore, we used data from 1976 to 1986 and from 1990 to 2015 in the present study.

2.3 | Data sources

We summarized the annual presence/absence of field signs in the 1 km × 1 km square grid known as the standard regional grid of Japan (JIS X 0410). The standard regional grid was established by the Japanese government for use in various spatial databases (e.g., demography and land use). The grid divides the area of Japan into approximately equally sized grid units based on latitude and longitude. Streambanks are a major summer feeding habitat for brown bears in the study region, because the giant butterbur (*Petasites japonicus*), which is a major food resource for brown bears in summer, often occurs on the streamside (Ohdachi & Aoi, 1987). Additionally, the spatial distribution and length of forest roads changed during the monitoring period. The coverage of forest roads in the TEF rapidly increased in total length from 1983 to 2000 by ca. 140 km, representing an increase from 0.83 to 1.44 km/km^2 (Hokkaido University, 1985, 2017). Thus, only field signs in streamside sections were used in the analysis. The vegetation density at a site can influence the detectability of the survey target (Guillera-Arroita, 2017). It is intuitively evident that there is a big difference in the vegetation density between the two types of census routes, suggesting that this data treatment would also help to reduce spatial variations in detectability. During the monitoring, browsing signs were recorded as well as scat and tracks. However, we did not include a browsing sign in the following analyses to mitigate observation errors because the browsing sign of the brown bear can sometimes be confused with those of sika deer.

2.4 | Statistical analyses

The occupancy models are an ideal statistical tool to address imperfect detection in species distribution modeling (e.g., MacKenzie, 2005). If researchers are interested in how the level of occupancy changes over time in the study region, each study site generally should be surveyed for multiple years with repeated surveys each study season (MacKenzie, 2005). However, we cannot apply the modeling to our data because the long-term monitoring has been conducted once a year at each study grid. Instead, as we explained above, we tried to minimize the influence of imperfect detection with various procedures, such as improving surveyor skills, standardizing the monitoring scheme, and careful data treatments.

After taking measures for detectability, to test our hypothesis regarding the usefulness of young citizen sensors, we analyzed the temporal trends in the number of grids with field signs using the state-space model. In this model, we estimated the impact of culling and the abolishment of culling on the temporal trends in the number of grids with field signs using the following set of equations:

$$\mathrm{F}_{\mathrm{obs}\,t,i} \sim \text{Negative Binomial}\left(p_{t,i}, r_i\right)$$

$$p_{t,i} = \frac{r_i}{r_i + \mu_{t,i}}$$

$$\ln\left(\mu_{t,i}\right) = \ln\left(F_{exp\,t-1,i}\right) + \beta_{\mathrm{cull}}\mathrm{C}_t + \beta_{\mathrm{abo}}\mathrm{A}_t + \ln\left(\frac{\mathrm{S}_t}{\mathrm{S}_{t-1}}\right) + Y_{t,i}$$

$F_{\mathrm{obs}\,t,i}$ is the number of grids with field signs i (scat or tracks) in year t, and the assumed negative binomial distribution is due to the overdispersion of the count data. $p_{t,i}$ and r_i are the probability parameter and size parameter of a negative binomial distribution, respectively. $F_{exp\ t-1,i}$ is the expected value of the number of grids with field signs i in year $t-1$ from the model and can be calculated from r_i and $p_{t-1,i}$ as $r_i \times (1 - p_{t-1,i})/p_{t-1,i}$. β_{cull} and β_{abo} are the impacts of the spring cull and the abolishment of the spring cull on the number of grids with field signs, respectively; C_t indicates whether the spring cull is conducted in year t ($C_t = 1$ if t is from 1976 to 1990 and 0 otherwise); and A_t indicates whether the spring cull is abolished in year t ($A_t = 1$ if t is from 1991 to 2015 and 0 otherwise). S_t is the number of grids surveyed in year t. We also included random effects to control for year-specific observation errors for specific field signs i (e.g., sign-specific detectability influenced by weather conditions) as $Y_{t,i}$. We introduced NA into $F_{\mathrm{obs}\ 1987-1989,i}$ and the average number of grids with surveys into $S_{1987-1989}$ for estimation convenience. We applied vague prior distributions to all the estimated parameters in the model (Supporting Information S1).

We estimated all the parameters using Markov chain Monte Carlo (MCMC) simulations with JAGS 4.2.0 and the rjags and R2WinBUGS packages in R 3.4.2 (R Development Core Team, 2017). The convergence of the MCMC (50,000 iterations after an initial burn-in of 100,000) was evaluated using the criterion that $\hat{\mathrm{R}}$ should be less than 1.1 and by checking the MCMC trace plots. The $\hat{\mathrm{R}}$ values of all the estimated parameters were ≤1.1 (Gelman et al., 2013), and their trace plots indicated convergence. To conduct posterior predictive checks, we estimated Bayesian *p*-values for each field sign with χ^2 statistics (Gelman et al., 2013). Bayesian *p*-values quantify the discrepancies between observed data and the posterior predictive distribution, which ranges from zero to one. A *p*-value near zero or one indicates that the model lacks fitness, while a value near .5 indicates that the model fits the data (Gelman et al., 2013).

3 | RESULTS

The number of route grids was 140 ± 32 (mean ± *SD*), and the number of grids with field signs was 14 ± 11 (mean ± *SD*; Supporting Information S2). Annual search events encompassed 255 km on average. The detection rate of field signs (the number of grids with field signs/number of surveyed grids) gradually decreased during the 1970s and 1980s and remained at a low level until the early 1990s. The percentage declined from 19 to 0% between 1976 and 1990 (scat: 3–0%; tracks: 18–0%; Figure 3, Supporting Information S2). The percentage gradually recovered beginning in the 1990s and reached the same level as that in the late 1970s; the percentage increased from 0 to 13% between 1991 and 2015 (scat: 0–4%; tracks: 0–12%). The Bayesian *P*-values (scat; 0.46 and tracks; 0.56) of our state-space model suggest that our model adequately fit the data. The estimated β_{cull} was −0.15 (−0.27 to 0.06; 95% credible interval [CI]). The 95% CI did not include zero, indicating that the spring cull had significant negative effects on the number of grids with field signs. The estimated β_{abo} was 0.07 (0.01–0.17; 95% CI), which indicates that the abolishment of the spring cull had significant positive effects on the detection rate of field signs. The spatial distribution pattern of the field signs also tended to change temporally during monitoring (Supporting Information S3).

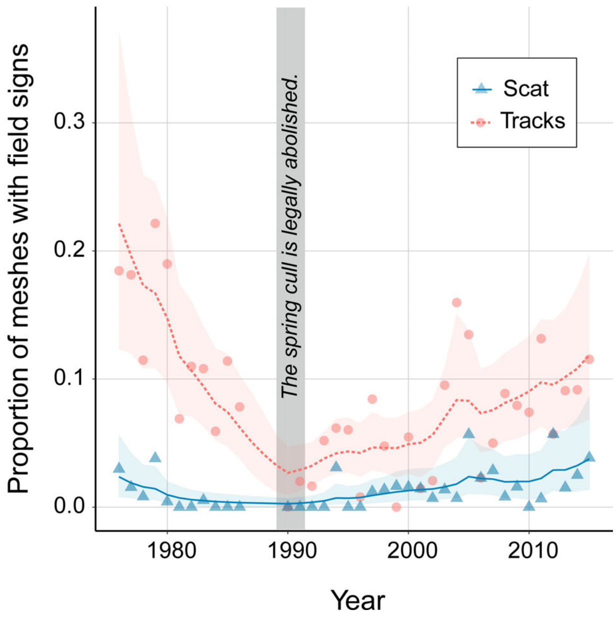

FIGURE 3 Observed and estimated trends in the proportion of grids with field signs of brown bears from 1976 to 2015 in the TEF. The spring cull was legally abolished in 1990, and monitoring was not conducted from 1987 to 1989. For the observed data, tracks and scat observations are shown as circles and triangles, respectively. The estimated values based on state-space models are shown as a dashed line for tracks and a solid line for scat. The red and blue shaded areas indicate the 95% credible interval of the estimated tracks and scat, respectively

4 | DISCUSSION

We demonstrated how young citizens have helped to reveal a long-term trend in the detection rate of brown bear field signs following a change in government policy (i.e., the abolishment of the spring cull) by integrating citizen-collected data and state-space modeling. This study demonstrates the potential for engaging college students in developing sustainable population monitoring of large carnivores, including that of our target species. The duration of the structured monitoring by college students (>40 years) is also remarkable. Most management agencies have not focused on young citizen sensors in large carnivore management, although long-term and structured population monitoring has been considered a key aspect of sustainable population management. BRGH monitoring emphasizes that young citizen sensors complement existing citizen sensors and shed light on long-term population monitoring by citizens.

4.1 | Temporal trends in observed field signs in the TEF

We found that the estimated β_{cull} and β_{abo} before and after the abolishment of the spring cull were −0.15 and 0.07, respectively. The significant decrease and increase in the detection rates of field signs are consistent with our expectation. The spring cull was a preventive measure that targeted bears in hibernation or recently emerging from hibernation, and such culls have also been considered cost-effective management tools for bears in North America (Hristienko, Pastuck, Rebizant, Knudsen, & Connor, 2004). The spring cull was likely to kill more individuals than hunting during other seasons and was further biased toward females and cubs (Mano, 1995), partly because females with cubs were easily identified by their tracks in the snow. The selective hunting pressures on females and cubs might have seriously affected the reproductive output of brown bear populations, as suggested by the decline in field signs detected by BRGH monitoring. This trend was consistent with the temporal change in the number of culled bears in this region. The reported number was 0.66 individuals/100 km^2 at the beginning of the spring cull from 1967 to 1971, after which it was dramatically reduced to 0.07/100 km^2 over the next 15 years, although the hunting effort was not greatly changed during this period (Aoi, 1990). Subsequently, an analysis of the BRGH monitoring data revealed a gradual increase in field signs beginning in 1991. Population recoveries for brown bears have been reported in European countries, and legal protection is a key reason for these recoveries (Chapron et al., 2014). BRGH monitoring likely detected the positive influence of elimination of the spring cull in 1990 on the local population.

However, we should also keep in mind that the relative abundance of observed field signs does not completely reflect the population size of target species (e.g., Sollmann, Mohamed, Samejima, & Wilting, 2013). For example, the number of grids with field signs can also indicate the activity of individuals. In addition, the decreasing and increasing tendency is more obvious in tracks than in scat (Figure 3). We speculate that the difference occurred because one individual can leave more track signs than scat signs. More information on the relationship between numbers of each field sign and individual density is needed if managers want to understand the detailed changes in the population size of a target species (Iijima, Nagaike, & Honda, 2013).

In the TEF, few field signs were observed around 1985, which was during the later stage of the spring cull (Figure 3, Supporting Information S1). Shortly after the abolition of the cull, however, field signs gradually increased in the southeast region, which is contiguous to a large forested area. Subsequently, field signs eventually recovered throughout the entire TEF. Habitat connectivity generally supports recolonization from source populations to shrinking populations (Taylor, Fahrig, Henein, & Merriam, 1993). We speculated that the detected spatial trends suggested that the forested mountains connecting to the largest nature reserve in Japan, Daisetsuzan National Park, played a role as source habitats. Spatiotemporal analyses of data that are more directly indicative of population variability, such as the population size and the number of bears killed during the spring cull, are needed to evaluate this speculation in future studies.

4.2 | Key features of BRGH monitoring

Why did this student-based monitoring detect reasonable observation trends? One possible reason is the structured monitoring scheme of BRGH. Data collected without following a structured observation protocol may include shortcomings such as variations in observer skill. For instance, Kamp, Oppel, Heldbjerg, Nyegaard, and Donald (2016) showed that unstructured citizen science data were less sensitive to population changes in Danish birds and missed population declines in comparison to structured data. In BRGH monitoring, most summer monitoring was conducted on standardized routes across the study region. Additionally, the participants receive a preliminary education from senior students to develop their skills in identification and fieldwork (see Section 2 for details). Another likely reason for the success of this project is the high detectability of bear signs. Citizen-driven data sometimes exhibit a high misidentification rate, thus decreasing the quality of the monitoring results. The identification difficulty of a monitoring target generally affects the rates of misidentification (Crall et al., 2011). However, field signs of brown bears, such as tracks and scat, are very large and distinctive; thus, they can be easily detected after appropriate training. The structured monitoring scheme and simplicity of monitoring targets will enhance the quality of future bear monitoring by young citizens.

Sustainability is a key issue in citizen science programs. Theobald et al. (2015) summarized 388 citizen science projects and reported that the mean project lifetime is 10.9 years. By contrast, BRGH monitoring has continued for more than 40 years. One of the key reasons for this longevity is the charisma of the target species. Although large carnivores, including brown bears, sometimes invoke obvious risks regarding human-wildlife conflict, citizens are often attracted to this large, symbolic mammal (Kubo & Shoji, 2014). The highly popular brown bear fascinates young citizens, contributing greatly to maintaining the viability of monitoring. The student-specific annual schedule may also be closely related to the monitoring sustainability. Japanese college students are generally given a long vacation every summer. Considering this semester system, the BRGH monitoring period was scheduled during the summer vacation to secure a sufficient number of participants. Moreover, continuous supplies and technical support from TEF staff and local residents, such as the provision of low-cost accommodations and ongoing maintenance of the forest roads, are essential for continued student-based monitoring. The popularity of brown bears and the available time that college life provides are common worldwide. Therefore, college students have strong potential to contribute successfully to the long-term monitoring of brown bear populations in other regions, and consistent support from older adults will expand the capabilities of the young sensors.

Citizen science is closely related to a variety of educational outcomes. Chase and Levine (2018) recently demonstrated that citizen science programs strengthen the pro-environmental attitudes and behavior of participants, and younger participants are more likely to exhibit changes. Surprisingly, more than 50 people who graduated from BRGH are engaging in environmental management as researchers, government officers, and environmental NGO staff, some of whom have been researching and/or managing bears in Japan. In addition, direct contact with nature and/or associated wildlife encourages positive emotions and behavior regarding the environment (Soga et al., 2016). Thus, experience with wildlife monitoring in nature may provide a good opportunity for young participants to contemplate natural environments and their career directions. We believe that the integration of young people into citizen science will lead to mutual benefits for citizens and managers, thereby supporting future sustainable wildlife management.

4.3 | Managing imperfect detection

Although our results clearly showed a decrease and increase of the detection rate of brown bears field signs in association with the government policy change, field sign surveys are always associated with varying degrees imperfect detection. In the present study, we aimed to minimize the influence of detectability through various procedures, such as improving the surveyors' skills, standardizing the monitoring scheme, careful data treatments, and statistical approaches (see Section 2 for details). These measures could help reduce observation errors by reducing the problem of imperfect detection. However, researchers cannot completely remove false absence records from data sets regardless of the amount of effort expended to implement measures to reduce imperfect detection. Disregarding false absences can lead to biased inference about occurrence (e.g., Kéry, Gardner, & Monnerat, 2010). Another key solution for considering imperfect detection is a hierarchical model, which is an ideal statistical tool to address imperfect detection in species distribution modeling (e.g., Hines et al., 2010; MacKenzie, 2005). In hierarchical models, the effects of factors affecting detection and occupancy can be separately assessed (Guillera-Arroita, 2017). Future studies using models that account for imperfect detection and information on the relationship between numbers of each field sign and individual density can allow for estimation of temporal changes in bear abundance in the TEF and increase understanding of the negative impact of the spring cull.

4.4 | Management implications

Given the increasing calls for citizen science to contribute to wildlife management, it is essential to establish an enduring and accurate monitoring system. In BRGH monitoring, the traditional track survey has been used historically. However, the suitable monitoring technique depends on the target species or population status (Gompper et al., 2006; Long, Donovan, Mackay, Zielinski, & Buzas, 2007). For example, our approach may yield low detectability of temporal population trends when field signs saturate the study area. This inherent problem may be more apparent when the population density or mobility of the target species is very high. Over recent decades, many population-monitoring methods have been advanced in academia, such as camera traps and environmental DNA (Charbonnel et al., 2014; Franklin et al., 2019). In addition, the modeling of temporal changes in occupancy has been developed to account for imperfect detection, as mentioned above (Royle & Kéry, 2007). Support from professionals such as researchers and government agencies may be helpful for future monitoring by young citizens because their knowledge of monitoring, statistics, and target species can aid the construction of well-designed monitoring systems (e.g., Schuttler et al., 2019; Scott et al., 2018). We also demonstrate the potential use of intensive local monitoring by young citizens as a sentinel of local populations. Young citizens and other types of citizens in the monitoring network can provide complementary data. For example, hunters dispersed across many regions can cover a wide range of monitoring sites, but the specific monitoring locations cannot be easily assigned to hunters because their volunteer monitoring is a by-product of hunting. Therefore, hunters are likely more suitable for large-scale, low-intensity monitoring, which can reveal the general population trends of target species. This type of monitoring can inform managers of high-priority regions that need wildlife conservation or management. By contrast, young citizens, such as college students, can participate in fine-scale intensive monitoring, such as that conducted by BRGH, to provide detailed assessments of high-priority regions revealed by hunters' monitoring data. Recent studies have also demonstrated the potential use of other citizen sensors, such as hikers, in brown bear monitoring, although the associated monitoring duration is limited (Sawaya, Stetz, Clevenger, Gibeau, & Kalinowski, 2012). Wildlife managers and/or researchers should further understand the effectiveness of each citizen sensor and create a monitoring network using the complementary relationships among citizens.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Hiroto Takinami conceived the ideas. Nobuo Ishiyama, Hino Takafumi, Takahiro Kubo, Kanji Tomita, Muku Tsujino, and Futoshi Nakamura designed the methodology. Hino Takafumi analyzed the data; and Nobuo Ishiyama led the writing of the article. All authors contributed critically to the drafts and gave their final approval for publication.

DATA AVAILABILITY STATEMENT

Analyzed data are provided in Supporting Information.

ORCID

Nobuo Ishiyama https://orcid.org/0000-0001-9912-0237
Hino Takafumi https://orcid.org/0000-0002-0192-645X
Takahiro Kubo https://orcid.org/0000-0002-4832-5539
Kanji Tomita https://orcid.org/0000-0001-9044-5318
Futoshi Nakamura https://orcid.org/0000-0003-4351-2578

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

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