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Effect of rainfall on nocturnal activity of the Japanese dormouse

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ABSTRACT: The response of small rodents to rainfall is largely species-specific. There is a need to widely survey the effects of rainfall among varied rodent species, particularly arboreal rodents to accurately understand their response to rainfall. Therefore, in this study, we examined changes in the activity patterns of Japanese dormice *Glirulus japonicus* in relation to rainfall. We undertook extensive camera trapping for 2 yr to collect data on dormouse activity. During all 63 camera-trap detections (i.e. 24 on rainy nights and 39 on nights without rain) using cameras set at 214 sites, dormice demonstrated perfect nocturnality. Dormice were active throughout the nights when there was no rain; however, on rainy nights, their activity tended to be limited to close to sunset. Our results provide important evidence that rainfall limits the activity of Japanese dormice. In Japan, precipitation has increased with recent climate change; thus an increase in precipitation in the future could increasingly limit the periods of activity of the Japanese dormouse.

KEY WORDS: Activity pattern · Precipitation · Climate change · Mammal · Camera trapping

1. INTRODUCTION

Precipitation has increased recently due to climate change (Trenberth 2011), and has affected the ecosystems and ecology of various organisms (O'Connor et al. 2001, Walther et al. 2002). For example, the population dynamics of rodents correlates with the degree of plant cover, which is directly influenced by precipitation (Ernest et al. 2000). In addition, climate change also affects animals on a smaller scale, at the individual level. Several terrestrial rodents are known to increase their activities on rainy days (Vickery & Bider 1981, Maestri & Marinho 2014) while other rodent species show decreased activity in the rain (Wróbel & Bogdziewicz 2015), suggesting that response to rainfall is largely species-specific. Thus, the effect of rain on rodent activities should be surveyed in a wider range of rodent species.

The effects of weather on the activity patterns of arboreal rodents remains largely unknown. Bright et al. (1996) monitored hazel dormouse *Muscardinus avellanarius* nests and showed that rainfall was negatively correlated with the initiation and duration of dormouse activities, but the effect of rain on other dormouse species has not been determined. Moreover, climatic factors affecting activity patterns are not limited to rainfall. For example, the duration of activity in other dormouse species has been observed to change with changing air temperatures (Bright et al. 1996). Thus, to more accurately clarify the effect of rain on activity patterns in dormice, air temperatures should be evaluated simultaneously.

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In addition, it may be necessary to survey not only the initiation and completion time points of activities within nests, but also the activities that occur outside the nest, because determining the time point of completion of an activity in other species is difficult. For example, Japanese dormice *Glirulus japonicus* have no specific nest aside from the breeding site, and roam extensively within their home-range (Shibata 2008). Thus, in this species it is necessary to observe roaming activity within the woodland.

The recent development of camera trapping has facilitated surveillance of wildlife activity patterns throughout the night (Rowcliffe et al. 2014). In addition, automated camera trapping can circumvent the effects of rainfall that can otherwise hamper field observations. Initially, large- and medium-sized animals were the primary targets of camera trapping. However in recent years, arboreal camera trapping has improved the detection of small mammals (Suzuki & Ando 2017, 2019), and it has the potential to become an important tool for clarifying the effects of climate change on activity patterns in Japanese dormice.

Distributed throughout the mountainous regions of 3 of the 4 main islands of Japan, the endemic arboreal Japanese dormouse primarily moves within areas where it can nest in tree cavities (Shibata et al. 2004). Because dormice are active at night, hibernate during the winter, and have a small body size (10–20 g in summer or after hibernation, and 34–40 g before hibernation; Iwasa 2009), direct observation of the species is difficult. However, using camera trapping, researchers have recently been able to determine the initiation of dormice hibernation in relation to air temperature (Yasuda & Matsuo 2015). Encouraged by such research, in this study we used camera trapping to evaluate how climatic features such as rainfall and air temperature affect the nocturnal roaming activities of Japanese dormice during their active season.

2. MATERIALS AND METHODS

We performed camera trapping in 2 areas: on Daibosatsu Mountain (35° 40′–43° N, 138° 49′–51° E; altitude: 1350–1600 m a.s.l.) and in the Tanzawa Mountains (35° 26′–27° N, 139° 11′–13° E; 560–850 m a.s.l.), both located on Honshu Island, Japan. Trapping was conducted from 2 June to 20 November 2007 and from 11 April to 14 November 2008, as these periods covered the active season of Japanese dormice (Iwasa 2009). Vegetation at these sites has been described by Suzuki & Ando (2019). We chose 214 camera sites (100 on Daibosatsu Mountain and 114 sites in the Tanzawa Mountains), each separated from its neighbour by a distance of >50 m. We performed camera trapping from 8–60 nights, for a total of 7317 camera nights (mean ± SD: 34.2 ± 11.1 nights). The cameras (FieldNote IIa; Marif) were equipped with an infra-red motion sensor and a visible spectrum flash. Cameras were placed on a tree trunk approximately 2–3 m above the ground, pointing toward the tree trunks. While the minimal interval between shutters was set at 2 min, we considered detection separated by more than 30 min to be independent captures (Kelly & Holub 2008). The date and time were automatically recorded on each picture. The camera trapping method used and the performance of the cameras has been detailed in other articles (Suzuki & Ando 2017, 2019).

To evaluate the effects of rainfall on the activity patterns of Japanese dormice, we compared dormouse activity with nightly rainfall (NRF). We defined ‘time from sunset’ as the difference between the time recorded on each picture of an active dormouse and the time of sunset. Such values can be used to evaluate changes in the activity patterns of nocturnal mammals (Suzuki & Ando 2017). We also obtained nightly precipitation data from weather stations near the study areas (Japan Meteorological Agency 2018). In addition, we checked the pictures taken during nights when NRF occurred and dormice were detected to establish if wet trees or water droplets appeared on the pictures. To simultaneously evaluate the effect of air temperature on dormouse activity patterns, we calculated mean nightly temperature (MNT), basing this on hourly temperature data from the weather stations, with an altitudinal compensation of 0.6°C per 100 m of elevation (Japan Meteorological Agency 2018).

We evaluated the presence or absence of dormice on rainy and non-rainy nights by a chi-squared test. For this analysis, we defined a non-rainy night as when precipitation during the night was 0 mm; even a little precipitation was defined as a rainy night.

Next, we evaluated the effects of NRF and MNT on dormouse activity using a general linear mixed model (GLMM). We used the time of activity from sunset (normal distribution; Kolmogorov-Smirnov test, $D = 0.127$, $p = 0.261$) as a dependent variable. Presence or absence of NRF as well as MNT were used as independent variables. However, since the activity period of dormice may increase as the nights become longer, we also evaluated the effect of the duration of night (henceforth, night length [NL]), which we defined as the difference between the times of sunset and sunrise the following day. Since Bright et al. (1996) reported that the effects of rainfall on hazel dormice activities were limited in spring, we also used the interaction between NRF and NL as an independent variable to evaluate the seasonal effects of precipitation on Japanese dormice activity. To avoid pseudo-replication and the unclear effects of camera sites, we added camera site ID to the model as a random effect (Bolker et al. 2009). The GLMM was formulated as:

$$y = a + \mathrm{NRF} + \mathrm{MNT} + \mathrm{NL} + \mathrm{ir}(\mathrm{NRF}, \mathrm{NL}) + \mathrm{re}(\mathrm{site})$$

where y is the time from sunset, a is the intercept, ir() is interaction, re() is random effect function, site is the camera site ID, and other terms are as defined above. The model with the smallest Akaike's information criterion (AIC) value was determined to be the best model. We ran the GLMM using the 'lmer' function of the 'lme4' package and evaluated the effects of the independent variables with a chi-squared test performed in R version 3.2.4 (R Core Team 2016).

3. RESULTS

During the study period, we detected Japanese dormice 63 times (0.86 times per 100 camera trap nights) at 28 sites (1–3 times site^{-1}). Because no detection occurred within 30 min of the last detection at the same site, we treated all detections as independent detection events. Throughout the study period (total 780 nights; 390 nights in each study area), 198 were rainy nights according to precipitation levels recorded from local weather stations (>0.0 mm mean nightly precipitation); the remaining 582 were non-rainy nights. A total of 24 (16 nights) of the 63 detections occurred on rainy nights; the remaining 39 detections (31 nights) occurred on nights without rain. On rainy nights with dormice detections, wet trees or water droplets appeared in the pictures, confirming precipitation suggested by the local weather stations. The frequency (16/198) of rainy nights was similar to that of non-rainy nights (31/582) (χ^2 = 1.523, df = 1, p = 0.217).

We only detected dormice between sunset and sunrise (Fig. 1). Their patterns of activity revealed a unimodal peak 4–6 h following sunset (Fig. 2). The difference of photographed times from sunset on rainy and non-rainy nights were 4.4 and 6.5 h, respectively. AICs values of the GLMM are shown in Table 1. The best model (r^2 = 0.391, df = 5) with minimum AIC included 2 independent variables: NRF and NL. The chi-square test indicated a significant effect of NRF (estimate = −0.078, χ^2 = 9.03, p = 0.003) and NL (estimate = 0.792, χ^2 = 6.69, p = 0.010). Dormice tended to be active during the relatively early periods following sunset on rainy nights

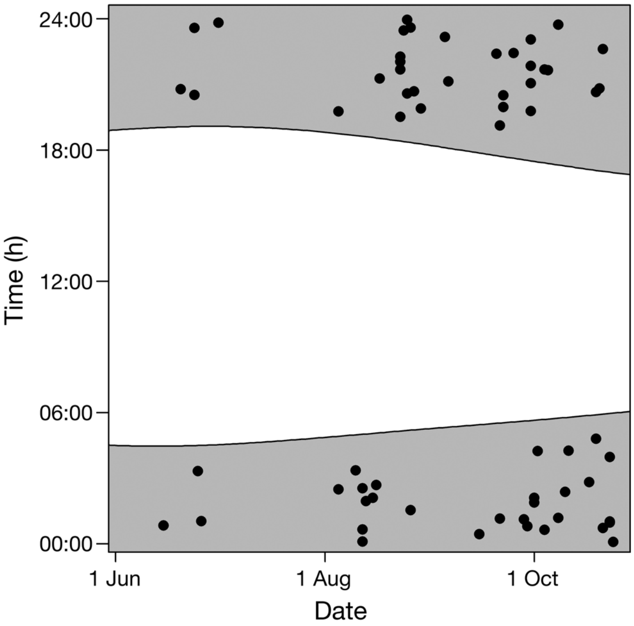

Fig. 1. Activity patterns of Japanese dormice *Glirulus japonicus* determined through camera-trap detections. Grey shading: night

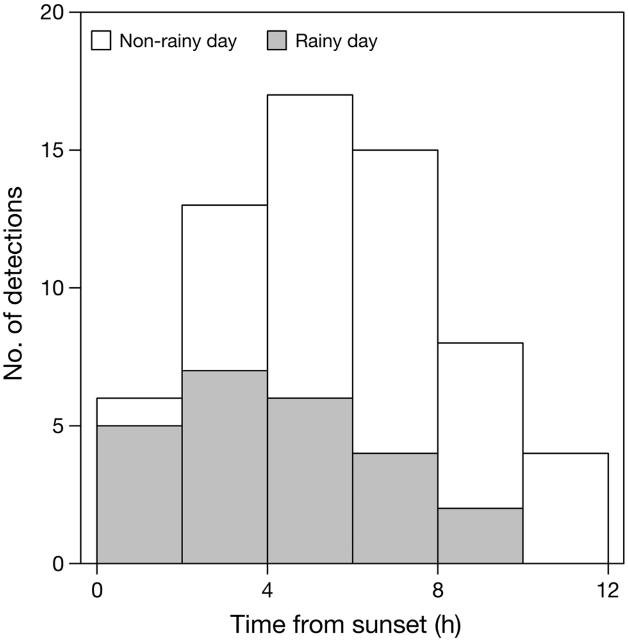

Fig. 2. Number of camera-trap detections of Japanese dormouse with increasing hours after sunset on rainy and non-rainy days

Table 1. Model selection based on Akaike's information criterion (AIC) values in a generalized linear mixed models. NRF: presence or absence of rainfall; NL: night length; MNT: mean nightly temperature. Site: camera site ID; ir() is interaction, and re() is random effect function

Variables	AIC	ΔAIC
NRF + NL + re(Site)	−94.4	0
NRF + NL + ir(NRF, NL) + re(Site)	−93.9	0.5
NL + re(Site)	−93.5	0.9
NRF + re(Site)	−90.7	3.7
NULL	−88.9	5.5

(Fig. 2). Even though dormice were active later with increasing NL, the interaction between rain fall and NL was not included in best model. Therefore, no difference of the effect of the NRF on dormice activity was shown among seasons.

4. DISCUSSION

Japanese dormice demonstrated only nocturnal behaviours throughout the study period (Fig. 1). However, on rainy nights, they were active only during the earlier part of the night (Fig. 2). Similar to other dormouse species, whose activity decreases on rainy nights (Bright et al. 1996), Japanese dormice appear to reduce their activity on rainy nights.

In mammals, prolonged exposure to rain decreases body temperature. Because decreasing body temperature beyond a certain point can cause death, mammals adopt strategies to avoid lowering their body temperature, viz. consumption of more energy (Fedyk 1971, Stapp et al. 1991). Accordingly, to avoid decreases in body temperature caused by getting wet, dormice might limit their activity on rainy nights. Although our findings only indicate changes in Japanese dormouse activity patterns due to NRF, other dormice also exhibit similar changes in activity patterns to avoid getting wet and risking reduction in body temperatures (Bright & Morris 1996).

Wildlife activity patterns can easily change due to changes in ambient conditions (Eppley et al. 2015). Our results provide important evidence that rainfall limits the activity of the Japanese dormouse. Climate change represents one of the most serious global environmental problems (Thomas et al. 2004), with yearly precipitation in wet regions increasing with recent climate change (Wentz et al. 2007). Because precipitation also increases with increases in air/sea-surface temperature in Japan (Fujibe 2015), heightened precipitation could increasingly limit the activity of the Japanese dormouse in the near future. Climate-caused changes to individual activity patterns could affect foraging and mating opportunities and this could have population-level implications.

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