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Using Biologging Devices to Characterize How Temperature Affects the Activity of Yellow-bellied Marmots

Kira Ewell, Camille Testard, Emily Renkey, Daniel T. Blumstein

Abstract

Animal populations facing new environmental pressures can respond by moving to a new area, being able to plastically respond to the newly changed environment, or by having sufficient genetic variation to evolve a new response. A commonly used strategy is behavioral flexibility, such as seen when animals change their activity patterns in response to changes in temperature. Yellow-bellied marmots (*Marmota flaviventer*) are a particularly good system for studying these behavioral responses to temperature because they are easily heat-stressed. Previous studies of the response to temperature have been based on direct observations, but with the development of biologgers, we can follow marmots' movements throughout the whole day using a ccelerometers. This offers insight into the activity patterns of the marmots, even when we are unable to observe them. I hypothesize that with an increase in temperature during the afternoon, marmots will be less active. Instead, they will be more active during the cooler hours of the day, such as in the mornings and evenings.

Introduction

Animals may change their behavior in response to temperature, since there are certain temperatures they can not physically live in, and therefore must exhibit behavioral flexibility to maintain homeostasis (Terrien et al., 2011). For instance, the thermoneutral zone is the range of temperatures within which an organism does not need to expend extra energy to maintain its body temperature (Sanz, 2018). Outside of the thermoneutral zone, there are critical temperature maximums and minimums outside of which they can no longer function normally (Lutterschmidt & Hutchison, 1997). When air temperature approaches the maximum critical temperature, organisms exhibit physiological and behavioral changes to regulate their body temperature and avoid heat stress (Mota-Rojas et al., 2021). Behavioral changes to maintain homeostasis include shifting habitat ranges, adjusting foraging or other activity patterns, and utilizing microhabitats such as shady areas and burrows (Aublet et al., 2009; Terrien et al., 2011; van Beest et al., 2012).

Increasing temperature variation due to climate change is reshaping ecosystems globally (Malhi et al., 2020; Oldfather et al., 2025), leading to more frequent severe storms, habitat loss, changes in plant growing seasons, and shifting geographical ranges (Weiskopf et al., 2020). To survive these changes, animals must either evolve adaptations, migrate to a new suitable habitat, or change their behavior (Buchholz et al., 2019; Terrien et al., 2011; Weiskopf et al., 2020).

Previous research shows that heat may affect cognition, aggression, and foraging efficiency. Using experimentally provoked heat waves, researchers found that zebra finches (*Taeniopygia guttata castanotis*) exhibit reduced cognitive performance when it is too hot. The finches had to sacrifice certain tasks to engage in heat-dissipation behaviors and were therefore less efficient at foraging (Danner et al., 2020). During another experiment testing extreme temperatures, goats (*Capra aegagrus hircus*) spent significantly less time eating and being aggressive (Appleman & Delouche, 1958). These findings demonstrate numerous behavioral responses to heat.

As the climate changes, alpine environments are warming significantly faster than low-elevation areas (Pepin et al., 2025). The animals in these ecosystems may be more sensitive to warming because suitable habitat is limited as they move higher up the mountain (Elsen & Tingley, 2015). Yellow-bellied marmots (*Marmota flaviventer*) studied in and around the Rocky Mountain Biological Laboratory (RMBL) are a useful system for examining the behavioral effects of heat because they inhabit alpine and subalpine environments, making them more vulnerable to dramatic temperature shifts (Cordes et al., 2020). Marmots specifically are also susceptible to heat stress since they are highly adapted to lower temperatures. For instance, they must gain weight during their active season to survive hibernation (Cordes et al., 2020; Kilgore & Armitage, 1978; Lenihan & Vuren, 1996), but greater weight gain makes them more vulnerable to heat stress (Armitage, 2013). The marmots at the Rocky Mountain Biological Laboratory have extensive background information on behavior and their response to climate change, which makes them appropriate for further mechanistic study. Prior work has shown that marmots are less active during the hottest time of day, as they are not seen above ground when temperatures exceed 26.4 °C (Kilgore & Armitage, 1978; Melcher et al., 1990; Travis & Armitage, 1972). Other studies focused on how temperature and other weather conditions influence the foraging behavior of yellow-bellied marmots. For example, Melcher et al. (1990) discovered that marmots will reduce foraging at high temperatures. Additionally, increased rainfall is associated with increased antipredator vigilance (Bobb et al., 2025). This study also tried to focus on temperature, but they were unable to quantify marmot behaviors when it was too hot outside because the marmots were not visible (Bobb et al., 2025).

Overall, previous studies found that changes in activity patterns may help marmots avoid heat stress. For instance, they may exhibit strategies such as being more active during the cooler parts of the day to prevent overheating. However, these studies focused only on directly observable activities. Less is known about marmot activity when we are unable to observe them, such as when they are in their burrows or at night. Specifically, we do not have abundant information on their daily sleeping or resting patterns. The main gap in research comes from being unable to observe marmots at all times.

To solve this problem, we used biologging devices to collect activity data from tri-axial accelerometers attached to collars placed on yellow-bellied marmots. The accelerometers were used to understand the marmots' general activity patterns. This gave us insight into when they are active and at what temperature. By having biologgers, we address a limitation of prior marmot work that was based entirely on observations. With just observational data, we are limited in how much information we can gather based on what we can see, which is sometimes a challenge given the rapidly growing subalpine wildflowers. With biologgers, we gathered information throughout the day without having to rely on direct observations. Therefore, we are better able to document activity and behavioral changes as a function of ambient temperature.

Previous work in our system found that yellow-bellied marmots forage more on cloudy days (Travis & Armitage, 1972). Those results led us to hypothesize that marmots will decrease general activity during the hottest hours of the day to help maintain homeostasis. For instance,

they may be more active during the mornings and evenings when it is cooler compared to the hotter afternoons.

Overall, the accelerometer and temperature data collected by the biologgers provided insight into the role of temperature in time-activity budgets in marmots and, therefore, into marmot activity based on temperature. This new technology offers a glimpse into the world of a marmot, allowing us to understand its behaviors and activities at all times. It unlocks a whole new dataset that has not been seen over the many decades of the marmot project at RMBL.

Methods

Study System and Collar Deployment

Between late May and July 2026, we deployed collars on marmots in and around the Rocky Mountain Biological Laboratory (RMBL) in Gothic, Colorado (38.9592° N, 106.9897° W). The colony sites used for this study included Picnic, Boulder, and Bench, which are located near Gothic Mountain. They consist of steep talus, with some vegetated areas and limited shade. At these locations, the marmots were live-trapped and individually marked with ear tags for permanent identification. Only known individuals who were seen often and easy to recapture were collared for this study. When deploying the collars, two fingers had to fit under the collar so there was room for the marmot to grow comfortably. At three different colonies, we deployed a total of twenty collars between 27 May and 21 July, on 15 individuals, and recovered the collars from thirteen individuals.

Validation

To validate the collar data, we deployed two collars on yearlings at another colony, Bench, and recorded video footage of the individuals. We developed Python algorithms to line up the accelerometer data with the videos. Next, we validated the data and identified thresholds of when the marmots were at rest, active, and high activity. Additionally, videos of collared animals were recorded and matched with thresholds to continuously validate the thresholds and accelerometer data.

Accelerometer

The collars, manufactured by Technosmart, are equipped with two main data loggers: Axy-5 and Gipsy6. We primarily used the Axy-5 logger, which contains a 3-axis accelerometer to measure the acceleration, and therefore activity, of the marmot. The accelerometer records data 25 times per second and records acceleration up to 2 g at 8 bits.

Ambient Temperature

Lastly, to accurately record air temperature, we deployed two HOBO temperature loggers within the colony, one shielded and one exposed, which recorded temperature at

1-minute intervals. For the two individuals at Bench, we used temperature data recorded every fifteen minutes at a private weather station approximately 350 m from the Bench colony.

Ethics

During the pilot period at Bench, we continuously monitored collared individuals to ensure the collars did not disrupt their typical movement and behavior. We inspected all marmots for irritation or damage to the skin that the collar might have caused and found no abrasions and only minor hair loss at the collar site.

Statistical Analysis

To visualize the results, we used Python to plot HOBO temperature data alongside overall dynamic body acceleration (ODBA). ODBA was calculated using the raw 25 Hz accelerometer data and subtracting static acceleration. Static acceleration is the gravitational force component measured by the accelerometer, representing the animal's posture. By subtracting the static acceleration, we obtained the overall acceleration of the marmot. We categorized rest and activity based on certain thresholds of the mean ODBA determined through video analysis. For instance, we identified rest as short bouts of inactivity and prolonged rest as bouts lasting over twenty minutes. Active behaviors were labeled as either “active” or “high activity” based on the magnitude of the mean ODBA. Lastly, proportion active was calculated using the rest threshold and looking at fifteen-minute periods to determine the percent time the marmots were active during this period. For our analyses, we created a dataset with the ODBA, proportion active, and ambient temperature data. Additionally, we included individual marmots' information, such as unique identification, age class, and sex.

We tested the proportion of time marmots were active in relation to ambient temperature. To do so, we used general additive mixed models (GAMM) with the response variable being the beta-distributed proportion active. Fixed effects included age classes, season periods, and sex, while random effects accounted for each individual and repeated observations from the same individual. To account for the nonlinear daily activity rhythm, we used a cyclic cubic spline to understand the relationship. Additionally, for the nonlinear temperature and activity relationship, we used a thin plate regression spline. We calculated two GAMMs to understand how each demographic group exhibits nonlinear daily activity rhythms and temperature responses and the differences between groups. Lastly, we looked at the differences in these relationships between early season, before 15 June, and late season, after the 15th.

Results

Visualization

In total, we retrieved data from four female yearlings, four male yearlings, three adult females, and one adult male throughout our study period, as shown in Figure 1. Based on the thresholds determined through video analysis, we categorized prolonged rest, rest, active, and

high activity for each animal over the study period. Figure 2 shows a portion of these individuals separated by age class. Lastly, in Figure 3, we graphed the proportion of activity over the time of day for all individuals separated by adults and yearlings. This was also broken down into early and late seasons to help visualize our statistical analysis.

Statistical Analysis

The first analysis used a GAMM including age class, season, sex, nonlinear effects of hour of day and ambient temperature, and individual identity as a random effect (adjusted $R^2=0.436$, deviance explained 53.2%, n=8,977). Hour of day significantly predicted activity in early-season adults ($F=26.07$, edf = 10.66, $P<0.001$), late-season adults ($F=26.63$, edf = 11.43, $P<0.001$), and early-season yearlings ($F=24.73$, edf = 11.04, $P<0.001$). Yearlings exhibited higher overall activity levels than adults (estimate = 0.398 ± 0.105 SE, $t=3.79$, $P<0.001$), whereas season and sex did not significantly affect mean activity after accounting for nonlinear temporal effects.

The second analysis looked at the difference between age-season groups. This model uses early-season adults as a reference group and estimated difference smooths for early-season yearlings and late-season adults. The relationship between activity and temperature differed among age-season groups. Early-season adults showed a significant nonlinear response to temperature (edf = 2.65, $F=5.78$, $P<0.001$), whereas temperature effects were not statistically significant in late-season adults (edf = 3.48, $F=1.40$, $P=0.225$) or early-season yearlings (edf = 3.16, $F=1.91$, $P=0.106$). Individual identity explained a significant proportion of the remaining variation in activity ($P<0.001$).

Discussion

Overall, our results showed a differing relationship between activity and temperature among age-season groups. Early-season adults showed a significant nonlinear response to temperature, unlike late-season adults where temperature had a statistically insignificant effect on activity. This was also true for early-season yearlings, where temperature was not statistically significant in affecting their proportion active. Interestingly, the temperature constraint seems to lessen as the season continues. The adults no longer have a dip in proportion active, and seem to be active throughout the daytime with a spike during dusk.

We propose three possible hypotheses to explain the lack of temperature constraints during the late season in adults. Firstly, as the active season progresses, they are getting closer to the time for hibernation. To survive hibernation, they must gain as much weight as possible to survive (Frase & Hoffmann, 1980). This could explain why they are more active later in the season, as they must forage more to gain weight and survive.

Secondly, this smoothing trend of activity could be the result of acclimatization, where the animal adapts to the temperature as the season progresses (Collier et al., 2019). There is a lack of research specifically on marmots and acclimatization.

Lastly, during the late season, the pups started to emerge, which could possibly alter the results as this changes the dynamics of the colony as well. In 2026, the pups emerged on 18 June. All three of the adults that we collared were reproductive females with litters. Therefore, our last proposed hypothesis is that the adults became more active throughout the day because they have to stay vigilant to protect their pups. Other studies have shown that adult females with pups alarm more often (Blumstein et al., 1997) or are more active in general (Travis & Armitage, 1972). However, we do have data on one male individual that also follows the same smoothing pattern during the late season. This could be explained by the pup as well, but males generally have less parental care compared to females, since males are more territorial (Johns & Armitage, 1979).

These analyses were done based on the pilot data of 13 individuals, so we hope to continue collaring marmots at RMBL to gain more information. This pilot study revealed significant effects of temperature on activity of marmots. By continuing to collar, we will be able to test out the proposed hypotheses and understand why we are seeing this pattern.

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Tables and Figures

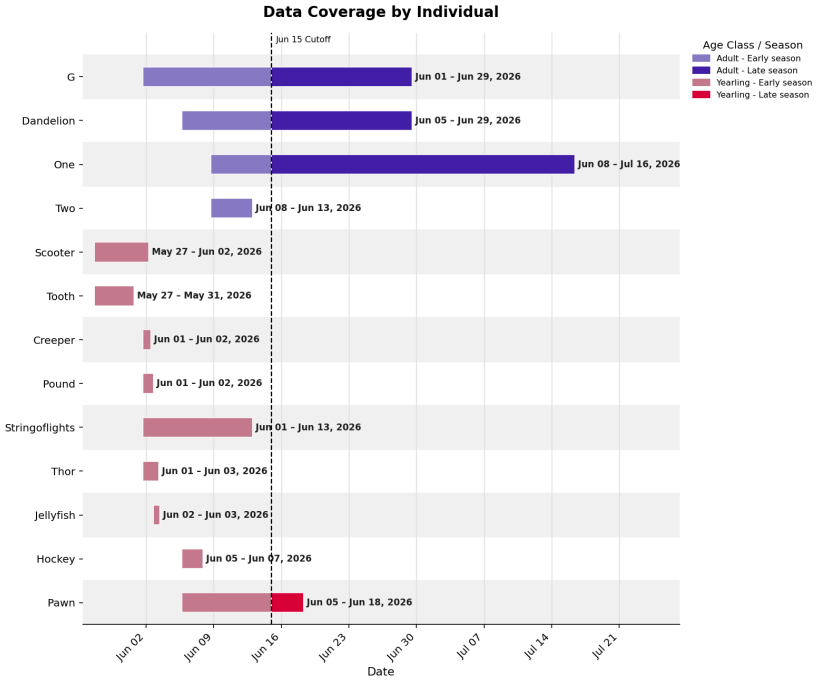

Figure 1. Data coverage by individual over the study period

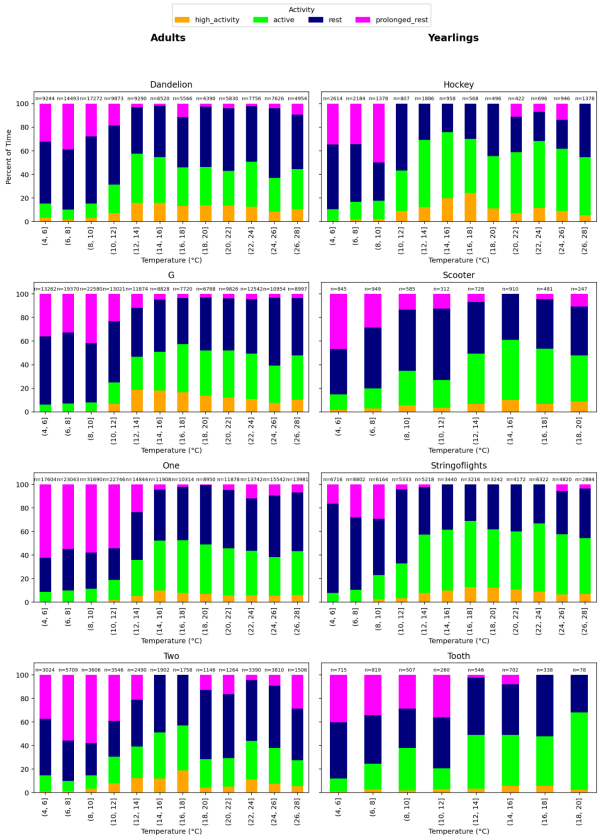

Figure 2. Percent of activity categories based on temperature bins for individuals

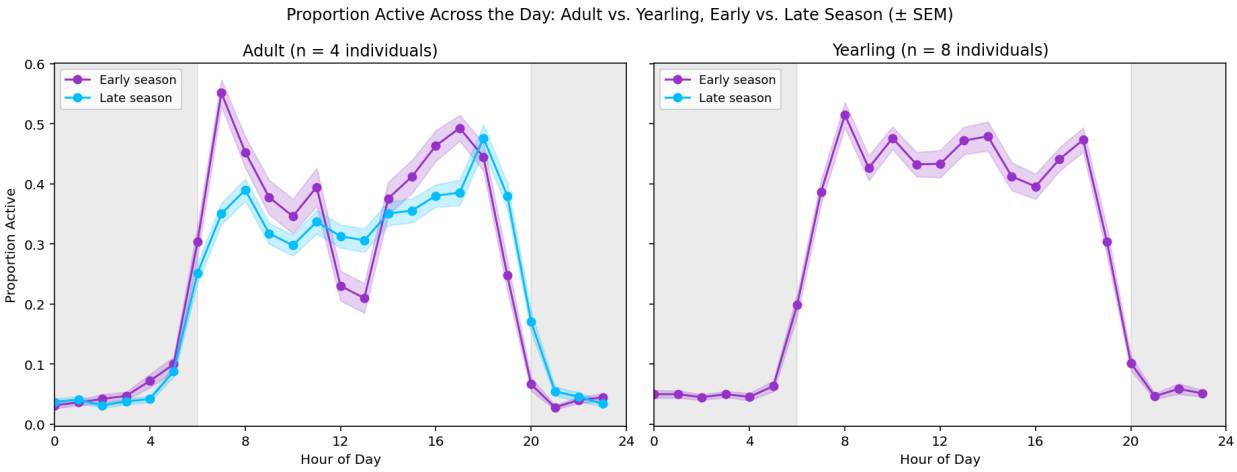

Figure 3. Proportion active of all individuals during the day separated by age class and season