



Original research article

Fisher activity patterns show potential for behavioral adaptations to human modified landscapes

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ABSTRACT

Animals alter their diel activity in response to physiological constraints and ecological conditions. Fisher (*Pekania pennanti*) activity is known to vary through the diel cycle and change in response to cold stress and generally through both the climatic and biological seasons. However, less is known whether thermoregulatory effects impact fisher activity in milder climates and in areas of high human disturbance. We focused on two distinct research objectives to understand the 1) physiological constraints, and 2) ecological components of fisher activity in a highly disturbed landscape with a relatively mild climate. We used accelerometer data from 34 individual live-captured fisher in Rhode Island, USA from 2021 to 2023. We found that fisher activity patterns were primarily driven by diel cycle with higher activity levels at night than during the day. We did not observe any physiological influence of ambient temperature on fisher activity; daily minimum temperatures did not constrain fisher activity in the colder months, nor did daily maximum temperatures in warmer months. We did find that female activity levels differed by breeding status with non-pregnant females having higher activity levels than pregnant females. Considering ecological components, we found fisher decreased activity levels in higher road density areas during warmer months that coincide with higher traffic volumes. For fisher living in areas with lower road densities, we saw higher activity in the breeding season and summer than in winter. In contrast, fisher living in areas with high road densities had lower activity in the breeding season and summer than in winter. We conclude that fisher largely do not shift their activity to mitigate thermoregulatory costs in areas where temperatures do not reach extremes for extended periods of time. However, our findings suggest that behavioral shifts in activity are impacted by human disturbance and fisher minimize activity in risky areas.

1. Introduction

Animals alter their behavior in response to spatio-temporal factors, emphasizing the importance of investigating patterns of activity and particularly how species change their diel activity (i.e., movement in a 24-hour time period) patterns (Cox et al., 2021; Fennell et al., 2023; Gallo et al., 2022; Kilfoil et al., 2023; Mayer et al., 2023; Richter et al., 2020). Animal diel activity patterns are influenced

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by many factors including photoperiod, competition, predation, and human activity (Cozzi et al., 2012; Kronfeld-Schor et al., 2017; Smith et al., 2018; van der Vinne et al., 2019). For instance, some species shift from diurnal to more nocturnal activity as daytime temperatures rise in response to seasonal changes (Alderman et al., 1989), or become less active during the day in response to increased human activity (Richter et al., 2020). These responses become more complex as predator-prey dynamics can also influence diel activity patterns as prey may shift their activity to improve survival by minimizing overlap with predators and vice-versa (van der Vinne et al., 2019).

For wide-ranging mustelids, like fisher (*Pekania pennanti*), marten (*Martes spp.*) and wolverine (*Gulo gulo*), diel activity patterns can be influenced by thermoregulation, climatic season, sex, and prey availability (Glass et al., 2021; Kilpatrick and Rego, 1999; Kupferman et al., 2021; Roy et al., 2019; Scrafford and Boyce, 2018; Thiel et al., 2019; Zalewski, 2001). Due to their body shape (i.e., high surface area to mass ratio) in addition to the extreme cold climates these species occur in, energy conservation is challenging (Brown and Lasiewski, 1972; Joyce et al., 2017). During periods of hotter temperatures, fisher utilize areas with cooler microclimates to prevent overheating (Aubry et al., 2013). Wolverine have shown a trade-off between predator avoidance and thermoregulation where they utilize surface beds instead of dens on warm days, despite exposure to predators (Glass et al., 2021). Smaller mustelids, such as marten and ermine (*Mustela erminea*), adjust their activity patterns to limit potential interactions with predators (Kupferman et al., 2021). Additionally, the activity levels of American marten (*Martes americana*) and fisher vary by season with higher activity levels in the day or during warmer temperatures, which are associated with higher prey activity levels (Kilpatrick and Rego, 1999; McCann et al., 2019; Zielinski et al., 1983). Fisher have also been observed shifting diel activity patterns in areas of more human development (Mayer et al., 2023; Poisson et al., 2023). While most investigations of mustelid activity focus on the physiological and biological (e.g., denning) needs of these species, only a few studies have examined the impacts of human disturbance and few, if any, on the impacts of high temperatures on these species' activity patterns (Kordosky et al., 2021; LaPoint et al., 2013; Scharf et al., 2016).

Little research has been conducted on the impacts of natural disturbances (e.g., fire, mass tree mortality) on mustelid diel activity patterns. Patterns of use of naturally disturbed areas, such as those post-fire, by fisher and other sympatric mesocarnivores has been shown to vary dependent on hunting strategies and structural requirements for denning/resting (Doherty et al., 2022; Kordosky et al., 2021; McNitt et al., 2020; Murray et al., 1995). Simultaneously, prey species can benefit from disturbances that can reduce their predation risk. For instance, fire events create open spaces that allows prey to detect predators more efficiently (Cherry et al., 2018). Similarly, tree mortality can create added structural components to the forest floor (e.g., downed logs, regeneration) that provides refugia for prey to hide from predators (Carey and Johnson, 1995; Doherty et al., 2015; Mitchell, 2015). Relating predator-prey dynamics (e.g., spatio-temporal partitioning) to diel activity of predator species in this context may aid in understanding the mechanisms informing shifts in diel activity patterns in naturally disturbed areas.

We were interested in understanding the physiological and ecological mechanisms behind activity patterns of fisher in a landscape of high human activity and natural disturbance as we have little understanding of fisher activity patterns in these landscapes. Population expansions in the northeastern United States have resulted in the establishment of a fisher population in Rhode Island, which is the second most densely human populated state (US Census Bureau, 2012). The landscape of Rhode Island is a matrix of forested areas crosshatched with roads and highly developed areas that experience an influx of tourism leading to higher human activity in the summer months (May – September). In the state, fisher have been documented to avoid roads and highly developed areas during the day (Ganoe, 2024). Additionally, in this area from 2015 – 2017 a wide-spread spongy moth (*Lymantria dispar dispar*) larval outbreak created a massive defoliation event that changed over 50 % of the forest (1835 km², Pasquarella et al., 2018) to an earlier successional stage (e.g., *Vaccinium* sp., *Clethra alnifolia*). Fisher have been documented to select for areas with more moth damage than those without, suggesting some benefit (e.g., prey availability) in those areas that outweighed the risk of exposure to predation and humans when no canopy was present (Ganoe, 2024). Lastly, temperatures in this region can drop below the fisher's critical temperature (i.e., temperature that incurs energy to maintain internal homeostatic regulation) of -10°C (Powell, 1979; Powell and Leonard, 1983) in the winter and in the summer temperatures can rise above 37 °C. The physiological demands associated with temperature extremes (e.g., cold or heat stress) as well as the ecological constraints imposed by a highly human modified and naturally disturbed landscape in this region provide an excellent area to study mechanisms driving behavior decisions of fisher activity.

We focused on two distinct research objectives associated with fisher activity, making inference on each separately. The first objective was to evaluate the physiological drivers of thermoregulation, sex, and reproductive status on activity and how this might change during the diel cycle. Due to their body proportions and thick fur, we hypothesized that in very cold and very hot temperatures fisher should seek thermal refugia to limit energy loss related to maintaining body temperatures (Powell, 1979); thus, we predicted that regardless of sex, fisher would have lower activity levels as temperatures reach minimum and maximum values in this region. Additionally, we hypothesized that energetic requirements for denning females would impact their ability to maximize the use of thermal refugia as they must be active more frequently at a lower activity intensity to provide food for their kits (Arthur and Krohn, 1991; Powell and Leonard, 1983); thus, we predicted that activity levels of pregnant females would be lower than non-pregnant females.

Our second objective was to evaluate how ecological factors (i.e., hunting opportunities, season, sex) interact with abiotic conditions (i.e., night brightness, road densities, diel cycle). For our inference regarding both objectives (physiological and ecological), we hold the same hypothesis related to time of day, in that fisher, being an elusive, medium-bodied carnivore, will exert more energy at night when prey species are more active. Thus, we predicted that fisher will have higher mean activity at night than in the daytime. We also hypothesized that moth damaged areas provide structural complexity that lends to prey abundance (Carey and Johnson, 1995; Kirkland, 1990; Mitchell, 2015; Muzika et al., 2004) and possibly beneficial hunting habitat for fisher (Buskirk and Powell, 1994; Naney et al., 2012; Weir and Harestad, 2003). After defoliation, the forest floor became more complex from not only dense regeneration as a result of increased light availability, but also from added coarse woody debris from the dead trees. Additionally, in these

structurally complex areas, nighttime brightness (i.e., moon light intensity and cloud cover) can enhance hunting opportunities for predators. We predicted fisher will have higher activity in moth damaged areas on nights with less brightness as this facilitates ambush hunting (Penteriani et al., 2013). Additionally, the biological seasons of fisher (i.e., dispersal, breeding, and non-breeding) coincide with shifts in human activity in this area. We hypothesized that fisher activity levels will decrease from winter (January – February) to breeding/denning (March – May), and breeding/denning into summer (June – August) in response to risk as human activity hits a peak

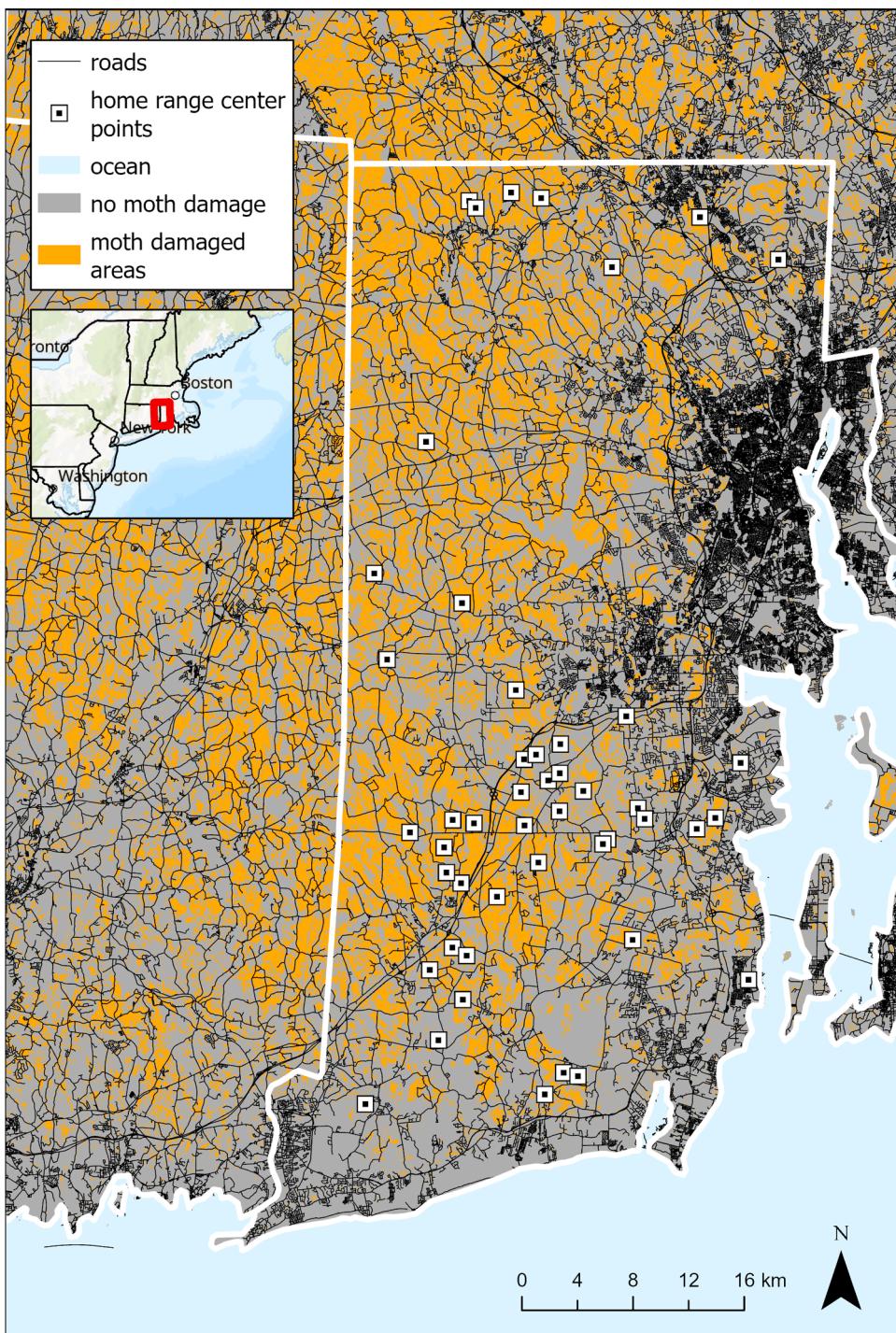


Fig. 1. Map of study area in Rhode Island, USA and surrounding states of Connecticut and Massachusetts. Home range centers represent the central point of the 95 % autocorrelated kernel density estimates for each fisher included in the study.

with abundant tourism across the study area in summer. We predicted that individuals living in areas with higher road density will be more active in winter than in summer in response to higher human activity, and will have lower activity in summer than those living in more rural areas.

2. Material and methods

2.1. Study area

Our study area was centered in Rhode Island, USA ($41^{\circ}18'N - 42^{\circ}06'N$, $71^{\circ}19'W - 71^{\circ}55'W$), and included portions of the bordering states of Connecticut and Massachusetts (Fig. 1). The landscape was composed of deciduous and coniferous forest (51 %), agricultural lands (4 %), wetlands (20 %) and developed lands (25 %). Compared to other regions of the fisher's range where temperatures in winter can be below $-30^{\circ}C$ and above $37^{\circ}C$, the climate in our study was more temperate with winter (i.e., January – March) temperatures during the study ranging from -20.7 to $22.4^{\circ}C$ and summer (i.e., June – August) temperatures ranging from 8.9 to $37.6^{\circ}C$. Rhode Island was highly populated with a human density of 409 humans/km 2 and average road density ranging from 0 to 31.1 km of total road length per km 2 (US Census Bureau, 2012). Lowest traffic volumes occurred in January and February and increase through spring reaching peak traffic volumes in June, July and August as Rhode Island is a tourist destination in the summer months (The Louis Berger Group Inc, 2017).

2.2. Capture and data collection

From January through March in the years 2021 – 2023, we captured fisher using baited live-traps (Tomahawk 608S). Captured fisher were sedated with a combination of ketamine (32 mg/kg, range: 23.55 – 41.25) and midazolam (0.20 mg/kg, range: 0.13 – 0.33) and each fisher was fitted with a store-on-board global position system (GPS) radio collar (e-obs GmbH, Grünwald, Germany). To maximize battery life and collect fine-scale GPS data, collars were programmed using an accelerometer-informed GPS feature. GPS location data were recorded in bursts of locations (fix rate of 97.3 %) every 8 minutes when above a set threshold of activity, and every 8 hours when the threshold was not reached (Brown et al., 2012). Collars were also programmed to record 12 tri-axial accelerometer readings every 2 minutes. We used UHF radio-telemetry to track each individual to within 200 m every 2 – 4 weeks for data collection using a remote download device.

2.3. Accelerometer data

Using the tri-axial accelerometer readings, we calculated overall dynamic body acceleration (ODBA) for each collared fisher at each 2-minute interval for each individual as

$$ODBA_j = \frac{\sum_{i=1}^n (|x_{j,i} - \bar{x}_j| + |y_{j,i} - \bar{y}_j| + |z_{j,i} - \bar{z}_j|)}{n_j},$$

where the ODBA is defined for each burst j with $i = 1$ to n samples (in our case 12) of three-dimensional accelerometer readings (x, y, z) (Scharf et al., 2016; Wilson et al., 2006). Higher ODBA values indicate high movement, such as trotting or running, while lowest ODBA values correspond with resting (Rast et al., 2020). Sun altitude was calculated for each burst using the 'suncalc' package in R (Thieurmel and Elmarhraoui, 2022), and each ODBA burst was categorized by time of day (TOD) as either night (sun position below the horizon) or day (sun position above the horizon). Since night periods overlap in calendar days, TOD entries were further categorized by study day where nighttime values for each date consisted of the post-sunset values of that night and the pre-dawn hours of the following morning (i.e., day 1 = daytime values of 01/14/21, night 1 = post-sunset values of 01/14/21 and pre-dawn hours of 01/15/21). Additionally, since each ODBA burst was not associated with a GPS location and we were interested in generalized fisher activity patterns, ODBA readings were averaged for each individual within each study day and night.

2.4. Spatial and temporal covariates

To account for the amount of human disturbance in the form of roads within each fisher's home range, we calculated the average road density (km/km 2) within each fisher's home range using road line layers provided by state GIS databases (CTDEPGIS, 2021; MassGIS, 2022; RIGIS, 2016). We estimated individual fisher home ranges as the 95% autocorrelated kernel density estimate (AKDE) using the package 'ctmm' in R (Calabrese et al., 2016). We also used the central point of each individual home range, calculated using the 'Feature to Point' tool in ArcGIS Pro (Version 3.0.3; ESRI, 2022), to extract hourly cloud cover and temperature data pertinent to each individual fisher. We obtained the multidimensional raster datasets for hourly cloud cover and temperatures for the region from the Copernicus Climate Change Service Climate Data Store (Hersbach et al., 2023). Additionally, we also calculated moonlight intensity at the central points for each hour of all study days using the 'moonlit' package in R (Śmielak, 2023). We then calculated night brightness from this as described by Brivio et al., (2024),

$n.\text{brightness} = \text{moon intensity} - (\text{cloud cover} \times \text{moon intensity})$ where night brightness ($n.\text{brightness}$) values closer to 0 represent darker nights. Night brightness values were normalized to values between 0 and 1.

We averaged hourly cloud cover and night brightness in the same manner as described above for ODBA for each study day and night, however, location data associated with each day and night was calculated as the centroid of all GPS locations for each respective night and day. We also identified the minimum and maximum temperatures for each day and night. To assess the general amount of time an individual fisher spent each day and night in moth damaged areas, we calculated the percentage of GPS points within any moth damaged areas for each night and day using ArcGIS Pro and a 2017 Landsat dataset depicting severity of moth damage (Pasquarella et al., 2018). Lastly, we considered temporal and demographic variables. These included season (i.e., winter (January – February), breeding/denning (March – May), and summer (June – August)), month, sex, and breeding status (i.e., pregnant female, non-pregnant female, male). Females were identified as either pregnant or not pregnant at the time of capture.

2.5. Activity modeling

We used separate generalized linear mixed models to evaluate our two research questions and test predictions. We modeled the mean ODBA for each fisher by fitting models in the R programming language version 4.0.1 (R Core Team, 2023) using the ‘glmmTMB’ R package (Magnusson et al., 2019) with individual random intercepts and gamma distribution with a log link. We estimated confidence intervals of coefficients and fitted values using a parametric bootstrap ($N = 100$ bootstraps) using the ‘bootMer’ function in the package ‘lme4’. We considered a physiological model of fisher activity by including variables of TOD, breeding status, minimum and maximum temperatures, and month as fixed effects. To account for potential confounding of temperature and seasonal change, both minimum and maximum temperatures were normalized (centered and scaled) separately within each month where a minimum temperature of 0 represents the mean minimum temperature for each particular month. We chose for minimum temperature to only interact with colder months (January – March) to assess how cold temperature affects activity levels during those months. Similarly, we chose for maximum temperature to only interact with warmer months (May – August). Reference levels for the physiological model were for pregnant females in the daytime in April, so all coefficients report differences from these reference levels (i.e., the intercept). We determined statistically clear differences based on a Type I error rate of $\alpha = 0.05$.

We considered an ecological model by considering TOD, sex, average moth damage, night brightness, biological season (winter, breeding/denning, summer) and road density within a fisher’s home range. Since we were interested in assessing how changes in nighttime brightness may provide hunting opportunities in moth damaged areas, these two terms were included in a three-way interaction with night only. To assess if shifts in human activity by season impact fisher activity levels, we included an interaction of season and road density within a fisher’s home range; traffic volumes increase across seasons through the year and fisher with higher road densities in their home range will experience larger traffic volumes than those with less roads. Lastly, we expected activity levels to vary by season and differently for each sex, so we included a pair-wise interaction of season and sex. Coefficients for the ecological model are interpreted as the change in activity from the reference levels of females in winter during the daytime (i.e., the intercept).

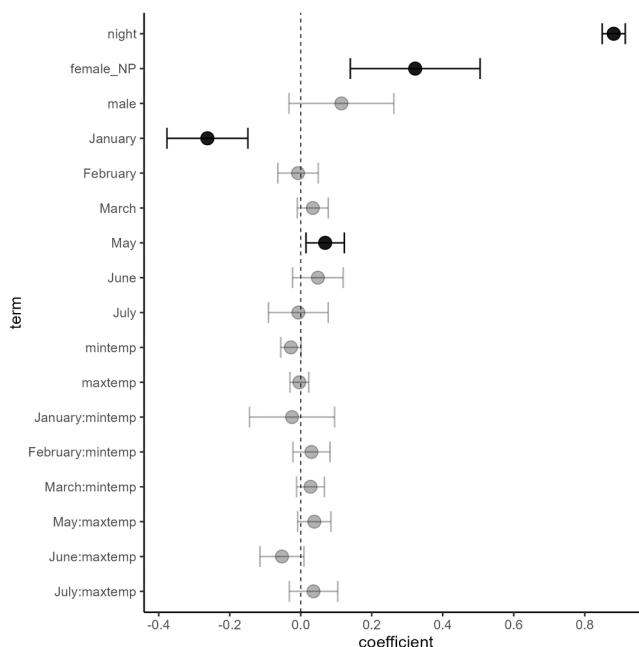


Fig. 2. Coefficient estimates of the physiological model with 95% bootstrapped ($n = 100$) confidence intervals indicated by error bar. Statistically clear terms with associated p-values (Table S1) less than the type I error rate of 0.05 and confidence intervals not overlapping zero (dashed line) represented by solid black dots and error bars. Variables of interest include months, breeding status (female_NP [non-pregnant female], male), and minimum and maximum temperature (mintemp, maxtemp). For graphical reasons, the intercept ($\beta_0 = 4.21$, 95% CI = (4.08, 4.34)) is not included in the figure.

2.6. Ethical note

Animals were ethically capture and handling followed the institutional care and use standards approved by the University of Rhode Island Institutional Animal Care and Use Committee (#1676641–3).

3. Results

We captured and GPS collared 56 individual fisher across the state of Rhode Island from 2021 to 2023, of which we recovered data on 48. We included data on 34 individuals (i.e., 13 females [5 non-pregnant and 8 pregnant females], 21 males) in our analyses, of which each had more than 20 nights and 20 days of data collected with an average of 171 sampling days (range: 27–219; Appendix 1, Figure S2). Only two individuals, both males, retained collars through August, so we removed any data associated with August from the physiological model. We found the range in observed ODBA bursts varied from 0.15 (i.e., representative of resting/sleeping) to 3409 (i.e., representative of sprinting), while average day and night ODBA ranged from 3–516, and 10–557, respectively.

From the physiological model we found there to be differences in activity levels by night and day, by breeding status, and by month (Fig. 2; Appendix Table S1). Fisher had higher activity during the night ($\beta_{\text{night}} = 0.88$, $P < 0.001$) and non-pregnant females had higher activity ($\beta_{\text{female-NP}} = 0.32$, $P < 0.001$) than pregnant females while males did not ($\beta_{\text{males}} = 0.11$, $P = 0.13$; Fig. 3). Minimum and maximum temperature ranges during the study were equivalent to ranges observed over the last 20 years in the region, indicating that the temperatures during the study were representative of longer-term variation for this region (Appendix Figure S1). January and May were the only months where activity levels were different than in the reference month of April (Fig. 3, Appendix Table S1). The lowest mean day and night activity levels occurred in January ($\beta_{\text{January}} = -0.26$, $P < 0.001$), while the highest activity levels occurred in May ($\beta_{\text{May}} = 0.07$, $P < 0.013$). No relationship was supported between either minimum nor maximum temperature and activity (Figs. 2 and 4; Appendix Table S1).

We found differences in fisher activity levels from the ecological model by night, as well as by season and with increasing road density in a home range. Our model indicated support for the influence of the conditional effect of season, and the pairwise effect of season and road density on activity levels (Fig. 5; Appendix T2). There was no difference in activity between the sexes or in the 3-way interaction of moth, night brightness and night (Fig. 5, Appendix Table S2). In winter, activity levels were the same regardless of road density for both sexes (Fig. 6). As seasons transition from winter into breeding/denning season and as traffic volumes and potential resources increase, fisher living in areas with lower road densities have higher activity than in winter, while those individuals with higher road densities in their home range had lower activity than in winter ($\beta_{\text{breed-den}} = 0.36$, $\beta_{\text{breed-den.roads}} = -0.16$, $P < 0.001$; Fig. 6). In summer, when traffic volumes are highest, the relationship between season and road density shifts to lower activity than both winter and breeding season, particularly at night and for males, in home ranges with road densities greater than 2 km/km² ($\beta_{\text{summer}} = 0.45$, $\beta_{\text{summer.roads}} = -0.19$, $P < 0.001$; Fig. 6).

4. Discussion

We separately investigated the physiological and ecological factors driving fisher diel activity and found mixed support for our hypotheses. Fisher activity in both models was primarily driven by time of day with higher activity at night, supporting our hypothesis that fisher spend more time active at night, possibly related to prey activity (Carey and Johnson, 1995; Kirkland, 1990; Mitchell, 2015;

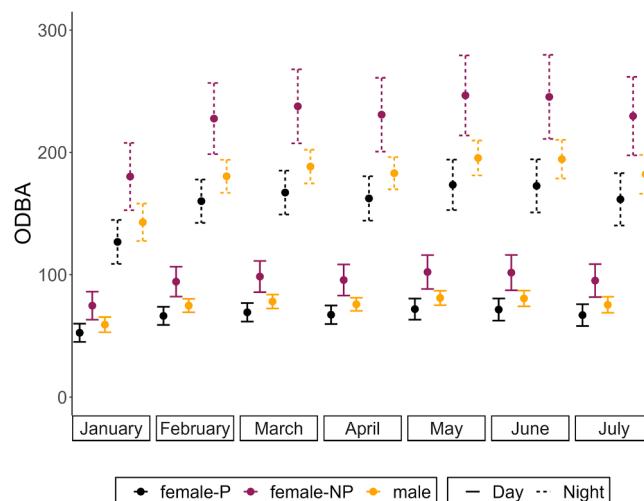


Fig. 3. Predicted mean fisher overall dynamic body acceleration (ODBA) and 95 % bootstrapped ($n = 100$) confidence intervals at the mean temperature for each month from the physiological model by month (x-axis), breeding status (color; P = pregnant, NP = non-pregnant), and time of day (line type).

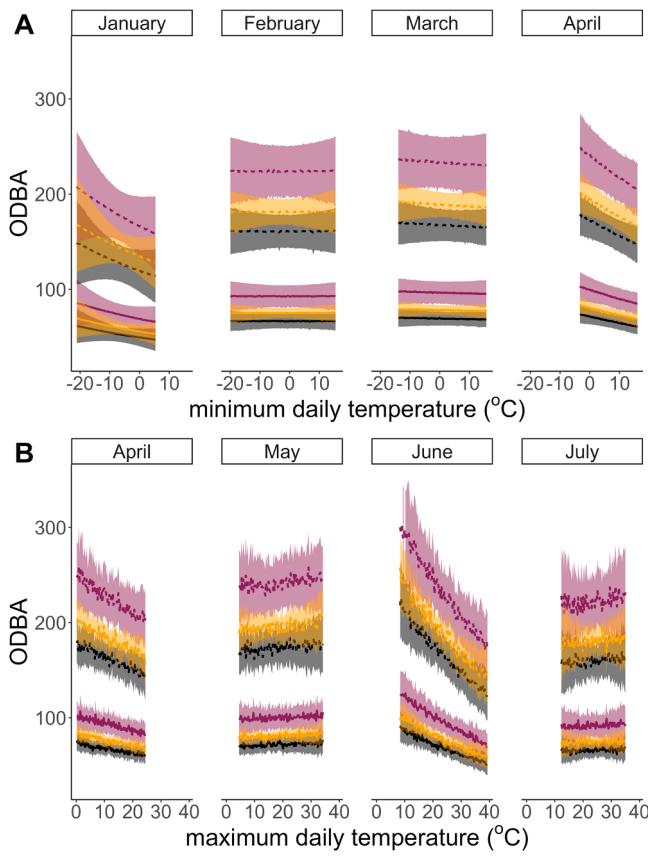


Fig. 4. Predicted mean dynamic body acceleration (ODBA) and 95 % bootstrapped ($n = 100$) confidence intervals (shaded areas) for the physiological model with respect to changes in monthly interactions of minimum daily temperature (A) and maximum daily temperature (B) for different times of day and breeding status (color; P = pregnant, NP = non-pregnant). For plots in panel A, minimum temperature increased linearly, while maximum temperature was allowed to vary by adding a random number drawn from a normal distribution with a mean and standard deviation equal to the mean and standard deviation of the difference between maximum and minimum temperatures for each time of day and particular month. For plots in panel B the inverse was true where maximum temperature increased linearly while minimum temperatures varied in the same manner as described for panel A maximum temperatures.

(Muzika et al., 2004). In some instances, nighttime activity was over twice as high as daytime activity. Our findings support the existing literature on fisher diel activity peaks occurring during the night (Arthur and Krohn, 1991; Kelly, 1978; Powell, 1993). While fisher were primarily active at night, they also displayed activity in the day, as seen in other studies (Arthur and Krohn, 1991; Mayer et al., 2023; Powell, 1993; Weir and Corbould, 2007).

The physiological model indicated that fisher activity levels regardless of sex were highest in May. This finding supports previous literature documenting higher fisher activity in the summer than winter (Arthur and Krohn, 1991; Leonard, 1980; Weir and Corbould, 2007), however activity levels began decreasing after May. Considering confounding factors related to our month variable (e.g., human activity patterns, climatic variables), this may be evidence of a mechanism shifting fisher activity that may be unique to this region but we failed to capture directly in our physiological model.

Additionally, we found that non-pregnant females were more active than pregnant females and males, supporting our hypothesis that the activity of pregnant females is lower than that of non-pregnant females (Fig. 3). Considering the difference in energetic needs of females with kits and females without kits, we suggest that while kit-rearing females need to collect more resources and prey, they are typically older (ages > 1) with more hunting experience than younger lone females (ages 0–1), allowing them to limit over-exertion to balance their energetic needs (Arthur and Krohn, 1991; Powell, 1979; Powell and Leonard, 1983). To another point, kit-rearing females may also select den sites in locations with abundant prey that allows lower levels of activity while collecting resources for their kits. This may explain why kit-rearing females had lower activity overall, suggesting activity may be more stable through the day in a location with abundant prey. Non-kit-rearing females, which may also be considered juveniles, do not have the additional cost of raising kits but are at the point in their life history where they are beginning to establish territories. Thus, they may have more infrequent bouts of high activity (dispersal events, avoiding competition) than adult females and males that have already established their territories (Leonard, 1980; Weir and Corbould, 2007). Since activity levels in our model were based on the mean overall dynamic body acceleration measurements for each night and day, we are unable to identify if pregnant females actually had more frequent bouts of activity at lower levels. Thus, low mean activity levels of pregnant females could represent little to no activity

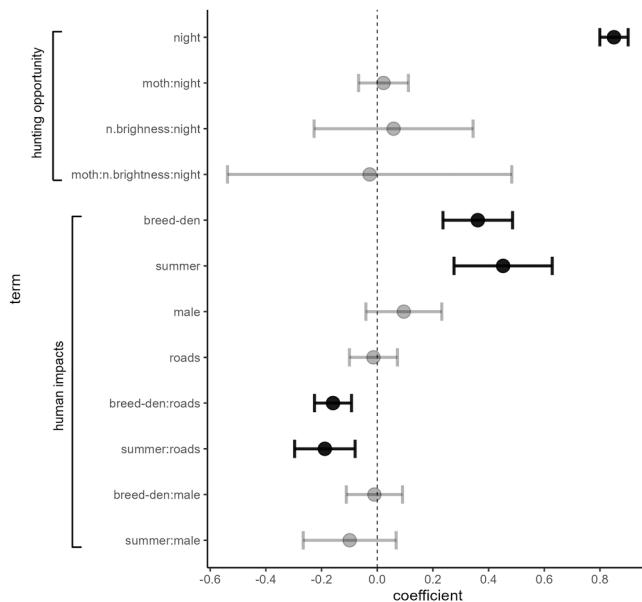


Fig. 5. Coefficient estimates of the ecological model with 95 % confidence intervals indicated by error bars. Statistically clear terms with associated p-values (Table S2) less than the type I error rate of 0.05 and confidence intervals not overlapping zero (dashed line) represented by solid black dots and error bars. For graphical reasons, the intercept ($\beta_0 = 4.27$, 95% CI = (4.10, 4.44)) is not included in the figure.

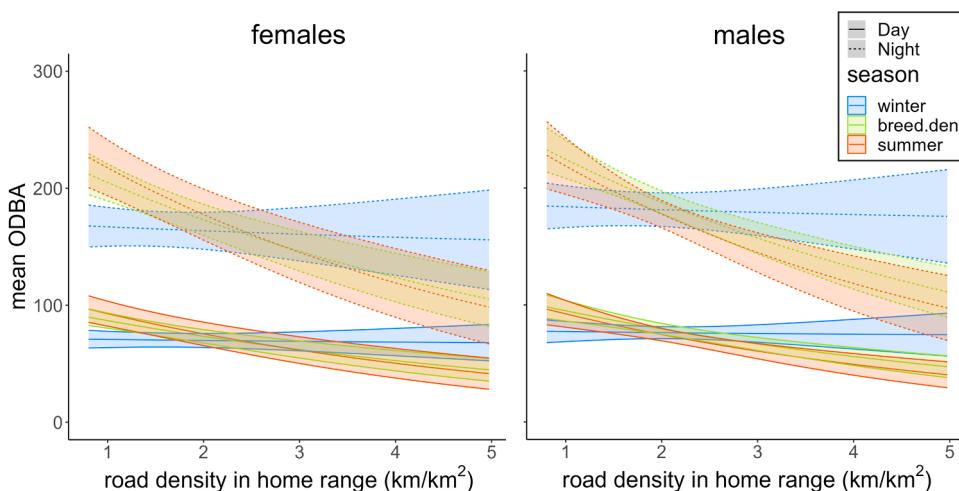


Fig. 6. Predicted mean dynamic body acceleration (ODBA) and 95 % bootstrapped ($n = 100$) confidence intervals (shaded areas) from the ecological model for fisher as a function of time of day, season, and road density within a home range.

with a few moderate peaks through the night/day, or it may represent a consistent level of low activity.

We found no evidence that temperature extremes constrained day or night fisher activity. Our hypothesis that ambient temperature extremes would decrease fisher activity to limit loss of energy was not supported. There was no influence of minimum temperatures in colder months, and there was no influence of maximum temperatures in warm months. Cold temperatures have been previously shown to influence fisher energetics (Powell, 1977; Weir et al., 2005) in areas where temperatures drop below -10°C for extended periods of time. At temperatures below the female fisher lower critical temperature of -10°C , an individual's metabolic rate rises and energy is expended to maintain thermoregulation (Powell, 1979; Powell and Leonard, 1983). During our study we only observed minimum temperatures below -10°C for a maximum of five consecutive days, suggesting that fisher in southeastern New England do not have long-term exposure to extreme minimum temperatures that would require behavioral shifts to mitigate energy deficits. It is also possible that this lack of response to cold temperatures could be due to anthropogenic drivers, as related species like stone marten, *Martes foina*, are also known to not alter their activity in cold temperatures while living in anthropogenic areas in response to avoiding humans and supplemental food supplies (Wereszczuk and Zalewski, 2023). Similarly, maximum temperatures only exceeded 32°C one

summer for a total of 6 days (maximum of 3 consecutive days), suggesting our study region did not experience prolonged exposure to extreme temperatures that would require fisher to alter their activity levels. While extreme high temperatures can cause heat stress and dehydration, there are few studies on the impact of heat stress on fisher activity (Aubry et al., 2013). Our study provides one of the first investigations in a region with a mild climate. To confirm the impacts, or lack thereof, of extreme temperatures on fisher activity, more studies across various climatic regions are warranted.

In considering the ecological components driving fisher activity, our prediction that activity levels would be higher within moth damaged areas was not supported. There was also no support for the impact of night brightness on nighttime activity in or out of moth damaged areas. These findings combined with previous research done in this study area (Ganoe, 2024) suggest that there is either an alternative mechanism driving fisher use and activity in moth areas unrelated to hunting or canopy cover, or that we are unable to use activity levels as a signal for hunting behavior. Habitat-specific variables, such as downed woody debris could be guiding fisher activity, however, we did not have fine-scale location data associated with each accelerometer reading which limited our activity analysis to focus on examining day and night fisher activity in these areas (Aubry et al., 2013; Scharf et al., 2016). Further investigations of fisher behavior in moth damaged areas that connect behaviors with ODBA readings would be beneficial in understanding the patterns of use and the importance of those areas as fisher habitat.

We found clear support for our hypothesis that fisher activity levels shift in response to changes in human activity. We found support for the relationship between fisher activity levels, season, and road density within their home ranges. These findings supported our predictions that fisher living in areas with higher road densities had lower activity in summer than winter and their summer activity levels were lower than those of fisher living in rural areas. Previous investigations in this study area have shown that fisher avoid roads and heavily urbanized areas (Ganoe, 2024). Our findings provide additional support for temporal variation in fisher road avoidance. Fisher decreased activity levels in higher road density areas during warmer months that coincide with higher traffic volumes. We saw higher activity in the winter months regardless of road density, suggesting that in winter months fisher maintain a certain level of activity to find food and resources to survive. For fisher living in an area with lower road densities, we saw higher activity in the breeding season and summer than in winter, which supports previous literature that fisher are more active in the summer (Arthur and Krohn, 1991). These relationships were less pronounced for females than for males, possibly due to the fact that data for females is pooled across breeding status and there are higher energy requirements of the pregnant females while raising kits in the summer months.

In contrast, fisher living in areas with high road densities had lower activity in breeding season and summer than in winter. Curiously, nighttime summer activity for fisher in high road density areas was similar to daytime activity levels. Lower activity in high road density areas may also be related to behavioral shifts in physical movements as fisher slow down with less-energetic bouts of activity to navigate risky areas near roads as compared to high-energetic bouts of activity when bounding through open forest. There may also be a resource-related driver in changes in activity as urban fishers may have more access to scavenging opportunities that require less energy to obtain than traditional hunt-and-chase methods of acquiring food (Powell, 1979). Fisher are known to readily scavenge carcasses (Kilpatrick and Rego, 1999; Powell and Zielinski, 2003), particularly during the daytime (Allen et al., 2021), however, little is known about fisher diet and scavenging activity in urban areas. To confirm our speculations, further investigations of predator-prey and diet composition between urban and rural locations is warranted. Our research provides implications for other cryptic carnivores, beyond fisher, living in highly human-modified landscapes as the potential for predator activity pattern shifts in response to human activity may lead to changes in predator-prey dynamics, interspecies competition and niche overlap, and ecosystem function. Future investigations on activity patterns of the predator guild and their prey would aid in further understanding the impacts that human activity has on wildlife communities.

Ethics

Animals were ethically capture and handling followed the institutional care and use standards approved by the University of Rhode Island Institutional Animal Care and Use Committee (#1676641–3).

Data Availability

Dataset and code for analyses available at <https://doi.org/10.5281/zenodo.11211137>.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Dataset and code for analyses available at <https://doi.org/10.5281/zenodo.11211137>.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:[10.1016/j.gecco.2024.e03225](https://doi.org/10.1016/j.gecco.2024.e03225).

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