

Divergent activity patterns of male and female fishers in a human-influenced landscape

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Abstract

A species' daily and seasonal activity patterns are fundamental components of its ecological niche, shaping how it interacts with the surrounding community. Many species modify their activity patterns when near humans, with varying consequences. New technologies that identify the location of wildlife and humans, in combination with their behaviors, can offer insight into whether impacts of human–wildlife interactions are positive, negative, or neutral. We studied activity patterns of southern Sierra Nevada fishers (*Pekania pennanti* (Erxleben, 1777)) in the presence of humans in Yosemite and Sequoia & Kings Canyon National Parks and surrounding National Forests using accelerometers and a novel human mobility dataset. We found that fishers exhibit cathemeral activity patterns (i.e., not nocturnal, diurnal, or crepuscular) that changed seasonally. We found evidence that female fishers increased activity levels when in proximity to humans and we observed increased total daily activity in females that were exposed to high numbers (>75th percentile) of smartphone detections. We did not see this in males. Our analysis suggests that male and female fishers may respond differently to humans on the landscape, which is critical for management and conservation plans to consider as they evaluate what conservation actions will be most effective at increasing fisher population numbers in a landscape popular with recreationists.

Key words: fisher, activity, diel niche, seasonal, accelerometer, human mobility data

Introduction

With the expansion of the human footprint on the landscape, humans and wildlife are coming into contact more than ever before (Wittemyer et al. 2008). While some forms of human contact may be relatively benign, or even advantageous for specific species (e.g., Berger 2007), often human proximity has direct and indirect negative consequences for wildlife (e.g., Benítez-López et al. 2010; Shannon et al. 2016; Tucker et al. 2018). Understanding when species come into contact with humans, and whether that contact is beneficial, neutral, or disadvantageous for either party is a central need in natural resource management. To accomplish this goal, managers need a refined understanding of the activity patterns of both wildlife and humans.

Daily and seasonal activity patterns are important species' traits. This trait influences which members of an ecological community a species encounters, including how much they come into contact with humans. Recent papers show that species can modify activity patterns in response to human presence on the landscape (e.g., Gaynor et al. 2018; Gallo et

al. 2022; Mayer et al. 2023; Guthmann et al. 2024). For example, a global meta-analysis found that mammals increase nocturnality in areas with high human development relative to areas with low human development (Gaynor et al. 2018). This finding was consistent across continents, taxonomic groups, and trophic levels among other factors (Gaynor et al. 2018). While authors propose many potential consequences of such human-induced shifts in activity timing, work quantifying the fitness impacts of human proximity to specific populations or functional impacts to ecological communities is still limited (but see Suraci et al. 2019; Dwinell et al. 2021).

New animal borne sensors (i.e., biologgers) that collect data at fine spatiotemporal resolution are helping managers understand the potential for humans to influence wildlife movement and behavior (Williams et al. 2020). While the application of GPS tracking data for investigating wildlife responses to human infrastructure is common (e.g., Neumann et al. 2012; Merkle et al. 2013; Tucker et al. 2018), other device types can complement the insight provided by GPS. One such device is an accelerometer, which can be used to draw infer-

ences about activity patterns, energetics, and behavior (e.g., [Wilson et al. 2006](#); [Shepard et al. 2008](#)). One of the benefits of accelerometer data is that it can provide granular insight into how human proximity is affecting activities and processes that impact fitness (e.g., foraging behavior and energetic expenditure), which can improve prediction about the long-term implications of human contact for individuals and populations. However, until recently, obtaining precise measures of human presence at scales meaningful for the management of mobile species was rare and relied upon static measures of humans and human infrastructure (e.g., road classes, road size, daily visitor counts) that do not reflect fine-scale temporal variation in human use ([Abernathy et al. 2025a](#)). Discerning the difference between interactions involving wildlife and the human footprint versus direct human presence can be critical for understanding species' responses ([Suraci et al. 2021](#)). Thus, high resolution GPS and biologging datasets on wildlife become even more powerful when they can be coupled with data collected on human presence ([Corradini et al. 2021](#); [Abernathy et al. 2025a, 2025b](#)).

In this study, we combined activity data collected on free-living fishers (*Pekania pennanti* ([Erxleben, 1777](#))) ([Koepfli et al. 2008](#)) with data on human mobility to understand the potential impact of human proximity on an endangered population. The southern Sierra Nevada (SSN) distinct population segment (DPS) of fishers is small and genetically isolated from other fisher populations ([Knaus et al. 2011](#); [Tucker et al. 2012, 2017](#)). This fisher population also overlaps with popular recreation destinations, including Yosemite and Sequoia & Kings Canyon National Parks, which receive just over 4 and 1.5 million visitors annually. The population also overlaps with the Stanislaus, Sierra, and Sequoia National Forests, which serve as transportation corridors from urban centers to the parks and are heavily used recreation destinations in their own right. While a few studies in the Eastern United States have found context-dependent impacts of human infrastructure on fisher movement ([Mayer et al. 2023](#); [Ganoë et al. 2025](#)), the impact of human proximity on the SSN population is not well studied. Of particular concern is the potential for human activity to disrupt the movements, behavior, or success of denning females, which could have considerable ramifications for persistence of this already small and at-risk population. In this investigation, we studied the activity patterns of male and female fishers and the potential for interactions between fishers and humans using unique biologging and human mobility datasets collected from 2021 to 2024 in Yosemite and Sequoia & Kings Canyon National Parks and adjacent USDA Forest Service lands on the Stanislaus, Sierra, and Sequoia National Forests. Our goals included describing the diel and seasonal activity patterns of fishers, as well as exploring how those fisher activity patterns may or may not be modified when fishers come into proximity with people.

Materials and methods

Study system

Fishers in the SSN typically inhabit dense forests comprised of mixed-conifers, ponderosa pine, and mixed hardwood-conifer forest types that support large diameter trees and

dense canopies ([Spencer et al. 2015](#)). These habitat types typically occur in moderate climates and at intermediate elevations, although the exact elevation of fisher habitat may vary latitudinally. In recent years, fisher habitat in the SSN has declined rapidly due to drought, wildfire, and ongoing tree mortality from pest outbreaks ([Fettig et al. 2019](#); [Thompson et al. 2021](#); [Steel et al. 2023](#); [Hart et al. 2025](#)). Fishers also face direct threats from toxicants from illegal marijuana grow operations ([Thompson et al. 2013](#); [Sweitzer et al. 2016a](#)). This suite of concerns led the US Fish and Wildlife Service to list the SSN population segment as endangered ([United States Federal Register 2020](#)). The most recent population size estimate found that the DPS likely numbers fewer than 300 adults ([Spencer et al. 2011](#)). While the current population size is unknown, it has been estimated that female fisher habitat has declined by nearly half (48%) between 2012 and 2022 due to a combination of drought, tree mortality, and wildfire ([Hart et al. 2025](#)).

Fishers are sexually dimorphic with females differing from males in smaller body mass and size ([Powell 1993](#)), smaller home range size ([Spencer et al. 2015](#)), habitat preferences ([Green et al. 2019](#)), mortality risks ([Wengert et al. 2014](#); [Sweitzer et al. 2016b](#)), and more limited dispersal abilities ([Tucker et al. 2017](#)). Females are considered the most important demographic class for conserving the population as they occupy a narrower range of elevations and habitat conditions in the SSN, and habitat that supports reproduction is the focus of conservation efforts for the population ([Spencer et al. 2016](#); [Thompson et al. 2020](#)). Seasonally, females are considered especially sensitive during the denning period, which runs from early spring through early summer; during this time, reproductive females have high energetic costs as they give birth, mate, and then care for young independently.

Field data collection

Between Fall 2021 and Spring 2024, fishers at Yosemite and Sequoia & Kings Canyon National Parks were live-trapped and collared according to capturing and handling protocols published in [Green et al. \(2017\)](#). Briefly, fishers were captured in Tomahawk Live Traps (model 108, Hazelhurst, WI) baited with chicken legs and scent lure, and sedated using a combination of ketamine (20 mg/kg) and midazolam (0.2 mg/kg). While under sedation, individual fishers were fitted with either Lotek LT40 (females and younger/smaller males) or Lotek LT60 (males > 3.5 kg) collars, which contained hand-made breakaway devices to reduce the risk of injury. Males of intermediate size (~3.5 kg) were given either LT40 or LT60 collars, depending on what fit the best during handling. These devices collected both GPS information as well as overall dynamic body acceleration (ODBA), a quantity derived from tri-axial acceleration measures. ODBA correlates strongly with energetic expenditure ([Gleiss et al. 2011](#); [Halsey et al. 2011a](#)). While there are some interpretive caveats with its use and calibration ([Halsey et al. 2011b](#); [Halsey and Bryce 2021](#)), it can be a very useful tool for studying activity and energetics in free-living species, especially in situations when energy expenditure due to movement is of primary interest ([Wilson et al. 2020](#)). Low ODBA values represent low activity and low energy expenditure, while high ODBA

values indicate higher activity and higher energy expenditure (Halsey and Bryce 2021). Importantly, ODBA does not capture energy expenditure from non-movement processes (e.g., non-shivering thermoregulation or lactation). Both GPS and ODBA data were retrieved from collars via remote download, when fishers were re-captured, or when collars were dropped and recovered. All animal protocols were conducted in accordance with US Fish and Wildlife Service recovery permits (ESPER0010754, ESPER2381586), research permits from National Park Service units (YOSE-2021-SCI-0098, YOSE-2022-SCI-0040, YOSE-2023-SCI-0002, YOSE-2024-SCI-0010, SEKI-2021-SCI-033, SEKI-2023-SCI-001), USDA Research and Development IACUC (2021-008, 2021-009, 2023-02, 2023-03), and NPS IACUC permits (CA_SEKI.YOSE_Green_Fishers_2021.A3, CA_YOSE_Smith_Fisher_2022.A3, CA_YOSE_Stock_Fisher_2023.A3, CA, CA_SEKI_Green_Fisher_2023.A3) as well as a California Department of Fish and Wildlife Special Use Permit (S-192680003-20097-001).

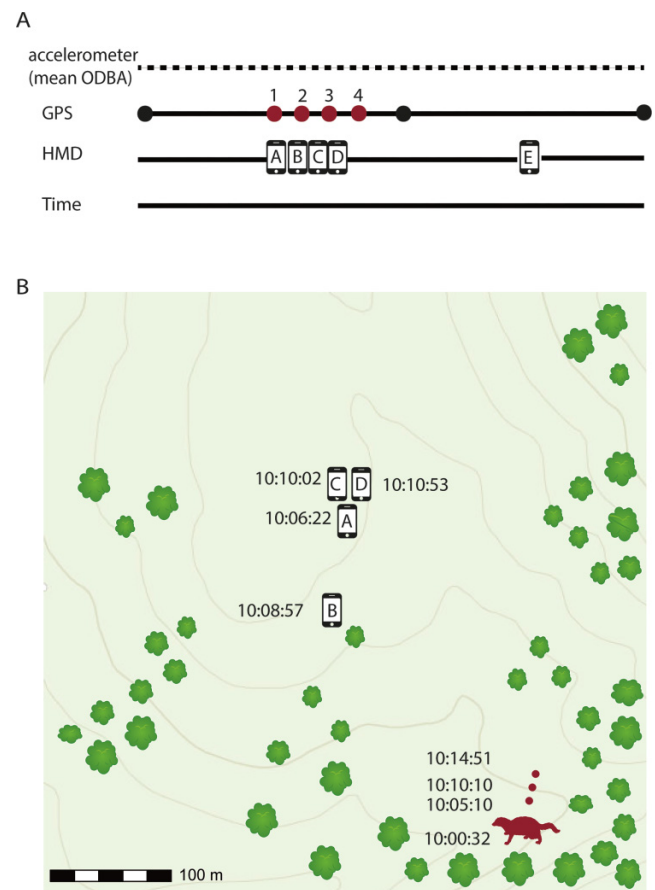
Collars collected ODBA six times a second, but stored measurements as 5 min averages (Fig. 1). Per manufacturing defaults, ODBA was recorded such that 1 ODBA unit = 2 milli-Gs. More intuitively, this can be understood as 500 ODBA units being equivalent to acceleration due to gravity (1G). Collars also collected swift fix GPS locations on a fixed schedule, 2–6 times per day depending on the study year and site. Additional GPS locations were collected when animal activity levels exceeded a set ODBA threshold to balance competing objectives of prolonging collar battery life and capturing high resolution data when animals were moving. We provide a detailed description of collar programming across years and sites in Table S1. All ODBA and GPS data were cleaned by trimming 24 h of data surrounding trapping events and unrealistic values (e.g., those arising from corrupted files during downloads). Positional error quantified in static laboratory testing is 10–15 min (Lotek 2024).

Human mobility data

Fisher GPS fixes were used in conjunction with anonymized, commercially available, human mobility data (HMD) to identify instances when fishers were in close proximity to humans. The HMD managed by Unacast Inc. are sourced from software development kits integrated into smartphone applications that collect GPS locations from consenting users. The smartphone applications are sampled to be geographically representative of an estimated ~10%–15% of users in the United States of America. Importantly, HMD can acquire a GPS fix in the absence of cellular service and can collect data from backcountry users. The HMD complies with the California Consumer Privacy Act and the European General Data Protection Regulation.

We filtered data to include only fixes that occurred within 300 m and ± 10 min of a fisher GPS location to create 20 min sampling windows. This 300 m boundary represented an extreme outer limit for which we thought fishers might detect humans (e.g., hear noise from a highway), but it is likely that fishers might not detect all humans within that 300 m boundary (e.g., solitary hiker). Next, we categorized locations into three classes of smartphone users: (1) inside buildings, (2) on

Fig. 1. (A) Conceptual figure depicting the relationship between accelerometer, GPS, and human mobility data (HMD). Overall dynamic body acceleration (ODBA) data from accelerometers were recorded every 5 min throughout collar deployment. GPS data came from both fixed (black dots) and ODBA dependent (red dot) collar programs. To minimize pseudo-replication, records associated with GPS point 1 would be included in the analysis, but GPS points 2–4 would be filtered out (see the “Materials and Methods” section). Pings from cell phone detections A, B, and C would be associated with GPS point 1 because they occurred within 10 min and 300 m of this fix (see the “Materials and Methods” section). Data from cell phone D and E would not be included. (B) Stylized figure illustrating pings from smartphone user(s) and fisher (*Pekania pennanti*) GPS locations.



roadways or inside vehicles, and (3) outdoors. We used the Microsoft Building Dataset (Microsoft 2018) to assign locations ≤ 30 m from a building footprint as a user inside of a building. HMD locations ≤ 50 m of any public roadway (U.S. Geological Survey and National Geospatial Technical Operations Center 2023) were classified as on a roadway. All other locations were considered outdoor users. Distances were selected to account for positional error in spatial feature delineations and smartphone locations and the desire to be parsimonious in assigning smartphone users as outdoor recreationists. When fishers were in proximity to smartphone users, they sometimes were near multiple cell phone detections (pings) during the 20 min sampling window. As such, each fisher sampling window is

associated with the total number of pings across that 20 min span. Pingcounts are strongly correlated with the number of unique users. We verified this relationship for Yosemite and Sequoia & Kings Canyon National Parks by placing a 600 m grid over the entire region covered by fisher GPS data in July 2022 and calculating the correlation between pingcounts and unique users for each cell. The correlation was 0.878 in Yosemite and 0.869 in Sequoia & Kings Canyon. In addition to calculating the total number of pings, we also calculated the number of pings for each of the three user classes and the minimum distance recorded between each fisher and smartphone location for each unique user category.

Statistical analyses

We used all ODBA data to evaluate daily and seasonal activity patterns of fishers and, in combination with HMD, evaluate the impact of proximity to humans on fisher activity. We report sample sizes for analyses in Tables S2 and S3. We report all models in Table S4 and also describe them below.

To evaluate daily activity patterns, we classified each 5 min ODBA measurement as representing either an active or inactive animal using a threshold of 100 units, which corresponds to one-fifth the acceleration due to gravity. Unfortunately, activity values from other fisher studies cannot be used to set an appropriate activity thresholds due to differences in collar type and collar units (Olson et al. 2024; Ganoe et al. 2025). As such, we set an activity threshold informed by resting ODBA values reported in other terrestrial mammals (Ryan et al. 2013; Chimienti et al. 2021) and a histogram of the raw data (we expected a bimodal distribution with a large portion of acceleration measures collected when fishers were at rest). We aggregated data to the hourly timescale, with an animal being classified as “active” for the hour if any 5 min average ODBA measurement within it exceeded our threshold. We built generalized additive models (GAMs) in mgcv (v. 1.8-40) to model daily activity patterns with cubic-cyclic splines (Wood 2011). We followed the methods of Iannarilli et al. (2025) to model activity with a binomial distribution, random intercepts, and slopes for individual id, a smooth term for hour of the day, a main effect for sex-specific life history stages, and factor smooth for hour of the day by sex-specific life history stages (Table S4). For males, these stages were winter (1 October to 28 March), mating (29 March to 6 May), and summer (7 May to 30 September). For females, these life history stages were winter (1 October to 16 March), lactation (17 March to 10 June), and summer (11 June to 30 September) (Spencer et al. 2015; Green et al. 2018). We used the traditional hypothesis set within the R package Diel niche (Gerber et al. 2024) to assign a specific diel phenotype (e.g., nocturnal, crepuscular, etc.) for each life history stage. Under the traditional hypothesis set, an animal is considered cathemeral if its probability of being active exceeds 0.2 for more than one diel period (daytime, nighttime, twilight).

We modeled seasonal activity by summing 5 min average ODBA measures for each animal for each day of collar deployment to create a total daily ODBA score. We modelled total daily ODBA using a GAM with a Gaussian distribution and thin-plate splines. Our model included random inter-

cepts and slopes for individual id, a smooth term for day of year, a main effect for sex, and a factor smooth for day of year by sex (Table S4).

To evaluate the impact of human presence on fisher activity, we aligned 20 min fisher-HMD interaction windows with 5 min mean ODBA data (Fig. 1). We averaged all ODBA measurements from each 20 min interaction window for each fisher and calculated average ODBA in the 60 min before and after interaction windows. We used lme4 (Bates 2004) to build a linear mixed effect model with a random effect for individual ID, a covariate for the three timepoints, and a timepoint*sex interaction (Table S4). To avoid pseudo-replication, we included only the first 20 min “interaction” within a 140 min period for each fisher (Fig. 1). Given that most GPS fixes were collected when fisher were moving, data are best interpreted as showing how active fisher change behavior when they are in proximity with humans.

We were concerned that ODBA might be higher in the minutes surrounding any fisher GPS fix due to the ODBA-dependent GPS fix schedules used in collar programming. Therefore, we conducted a “matched case” analysis to assess this potential for sampling bias. First, for each 20 min interaction window we identified “matched-case” GPS records collected on other days at the same circadian time of day. We filtered these records to include only those collected in the absence of an HMD record and selected the record with the closest temporal match to the interaction window (within ± 3 days). We calculated average ODBA measures during the matched case GPS fix and used a linear mixed effects model with a random effect for individual id and a fixed effect for case type (matched/interaction) and an interaction with sex to test for the possibility of sampling bias (Table S4).

We also evaluated whether fisher ODBA during the 20 min interaction window was associated with the number of pings and the minimum distance between the fisher and the smartphone user(s). Since we were interested in the impact of “extreme” encounters on fisher activity but were also worried about extreme observations exerting inappropriate leverage on continuous analyses, we treated these covariates as discrete categories. High versus low was set at the 75th percentile for number of pings and close/far was set at the 25th percentile for distance. We analyzed the data using linear mixed effects models with fixed terms for distance, pingcount, and the interaction of those covariates with sex (Table S4). We conducted the same analyses on subsets of the data restricted to 20 min interaction windows with only one class of smartphone user (Table S4). We also selected all cases where interactions were restricted to one class of smartphone user and tested whether the user type or the interaction between user type and fisher sex influenced activity levels during the interaction.

Finally, we assessed the cumulative impact of encounters with large numbers of pingcounts across the entire day. For this analysis, we took observed daily ODBA for each day and each individual and subtracted predicted daily ODBA from our sex-specific seasonal activity model (described above) to calculate residual ODBA. We used linear mixed effects models to evaluate whether residuals were explained by a discrete predictor indicating whether the number of smart-

phone pings near the fisher were high or low (thresholded at the 75th percentile) across the day (Table S4).

For each of these analyses, we ran the full models described above, which included sex-specific interactions as well as reduced models and null models with a random effect for individual id and/or slope as appropriate (Table S4). We took this exploratory approach because we had a general interest in identifying factors affecting activity for future investigation. We compared these models using Akaike information criterion (AIC). For linear mixed effects analyses, we used the emmeans package in R (Lenth 2019) to explore interactions when they were present in the most informative model.

Results

We recovered activity and GPS information from 56 fishers (24 males and 32 females) across the two study sites over 3 years. Our final dataset included ODBA data on 2906 unique animal days in the first capture season, 2106 in the second, and 2063 days in the third (Tables S2 and S3). Importantly, the number of observation days differed dramatically across individuals and across years, limiting our ability to pursue analyses such as the functional response of fisher to human recreation. Combining these records with the HMD, we detected fishers in proximity to humans during 341 events across the study (~5% of animal days). Out of our study group, 40 out of the 56 fishers came into proximity with a human smartphone user at least once.

The probability that male and female fishers were active changed across the 24 h day in a season-specific manner (Table S4; Fig. 2). Female fishers showed the highest probability of being active at the beginning and end of the day during winter and summer but had different diel activity patterns during the lactation period. During lactation, females had relatively flat probability of being active across the entire day, except for a peak at the end of the day. Diel niche models classified females as cathemeral for all life history stages. Male fishers showed the highest probability of being active at the beginning and end of the day (Fig. 2), yet probability of being active was sufficiently high across all hours of the day that their diel patterns were also classified as cathemeral for all life history stages. Total daily ODBA also varied by day of the year and by sex (Table S4). Females had lower total daily ODBA during early spring and higher total ODBA during late summer. Males had highest ODBA in early January and early spring (Fig. 3).

When fishers were in proximity to smartphone users, mean ODBA was elevated during the 20 min interaction window (mean = 313, SE = 8.74, df = 600, 95% CI [296, 330]) relative to the preceding (mean = 255, SE = 8.74, df = 600, 95% CI [238, 272]) or following (mean = 269, SE = 8.75, df = 603, 95% CI [252, 287]) hours. We report marginal means here because the impact of sex on activity across timepoints was negligible for this analysis, although inclusion of a sex by timepoint interaction did improve model performance. For the matched case analysis, the best fit model included both main effects for sex and the measurement timepoint as well as their interaction ($\beta = 50.41$, SE = 19.77, df = 254, 95% CI [11.671, 89.150]). Females had higher ODBA during an inter-

action (mean = 326, SE = 14.6, df = 421, 95% CI [297, 354]) than during a matched case record (mean = 294, SE = 14.6, df = 421, 95% CI [265, 322]). If anything, males near cell phones (mean = 299, SE = 12.0, df = 421, 95% CI [276, 323]) compared to matched case records (mean = 318, SE = 12.0, 95% CI [294, 342]) showed the opposite pattern. Mean ODBA during the 20 min interaction window was somewhat sensitive to the intensity and proximity of smartphone use. Inclusion of an interaction for total number of cell phone pings and sex consistently improved models predicting ODBA during the interaction window (Table S4). Even though model performance improved with the inclusion of these covariates (Table S4), confidence intervals for this interaction overlapped zero ($\beta = -59.31$, SE = 47.71, df = 336.54, 95% CI [-153.661, 33.001]). A model with an interaction between smartphone user proximity and sex also performed well, but confidence intervals for this interaction also overlapped zero ($\beta = -25.817$, SE = 40.214, df = 329.995, 95% CI [-104.910, 52.602]; Table S4). We observed similar findings when data were analyzed for specific user groups (Table S4)—models with interactions between proximity or pingcount and sex performed well but confidence intervals overlapped zero. Similarly, while models including an interaction between fisher sex and user class outperformed those with a single covariate and null model (Table S4), the confidence intervals for all interactions and main effects overlapped zero.

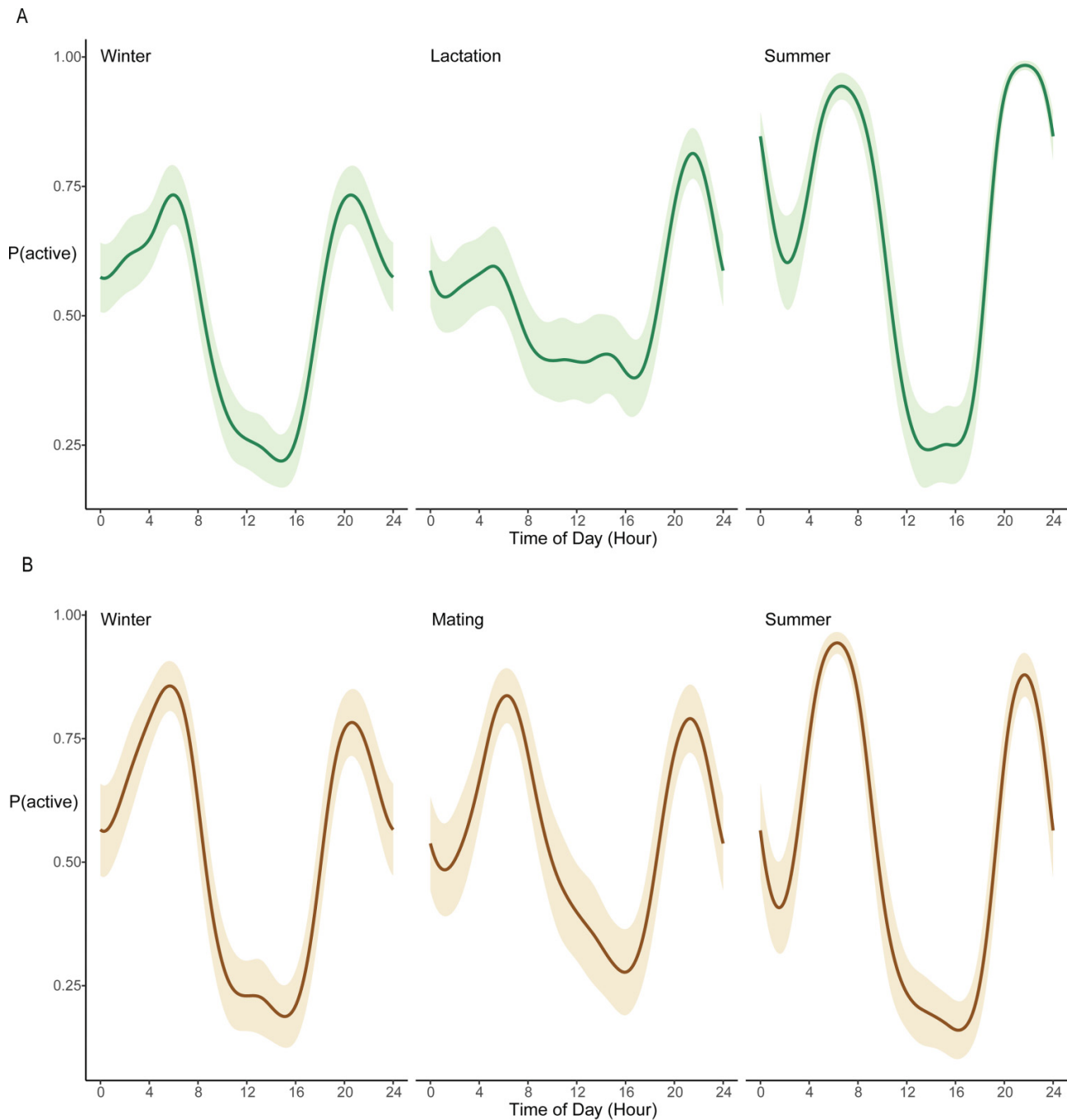
When we compared residual total daily ODBA for fishers that had more intense exposure to humans over the course of an entire day, there was a significant sex by number of users interaction ($\beta = -10905.79$, SE = 4675.72, df = 291.74, 95% CI [-20178.526, -1851.091]; Fig. 4) whereby residual ODBA in females exposed to high levels of smartphone detections (mean = 12408, SD = 4110, df = 154.7, 95% CI [4285, 20531]) was elevated compared to females exposed to low levels of smartphone detections (mean = 4111, SE = 2310, df = 28.7, 95% CI [-623, 8846]), with no clear differences in residual ODBA between males exposed to high (mean = 4638, SE = 2850, df = 54.7, 95% CI [-1084, 10359]) or low (mean = 7247, SE = 2360, df = 28.1, 95% CI [2405, 12089]) numbers of smartphone detections.

Discussion

We used accelerometry and HMD to explore the activity patterns of SSN fishers living in two popular National Parks and adjacent National Forests. We found that fishers show sex-specific activity patterns on daily and seasonal timescales, as well as sex-specific responses to human proximity. The pairing of these two datasets allowed us to assess the potential for human fisher interactions in this landscape. Given that ODBA is linked with energy expenditure (Halsey et al. 2009), our finding suggests that human interactions may not only cause behavioral alterations, but also physiological costs for female fishers, who increase ODBA by approximately one-third on days with high numbers of human interactions.

Accelerometry data showed that fishers in this geographic area have a cathemeral activity pattern and are active during multiple periods of day. A recent global, multi-species camera trapping study that included data from fisher pop-

Fig. 2. Daily activity patterns for female (top; panel A) and male (bottom; panel B) fisher (*Pekania pennanti*) for key seasonal periods. Seasonal periods for females shown in panel A are winter, lactation, and summer. Seasonal periods for males in panel B are winter, mating, and summer. Data represent generalized additive model predictions $\pm$ 95% confidence intervals.

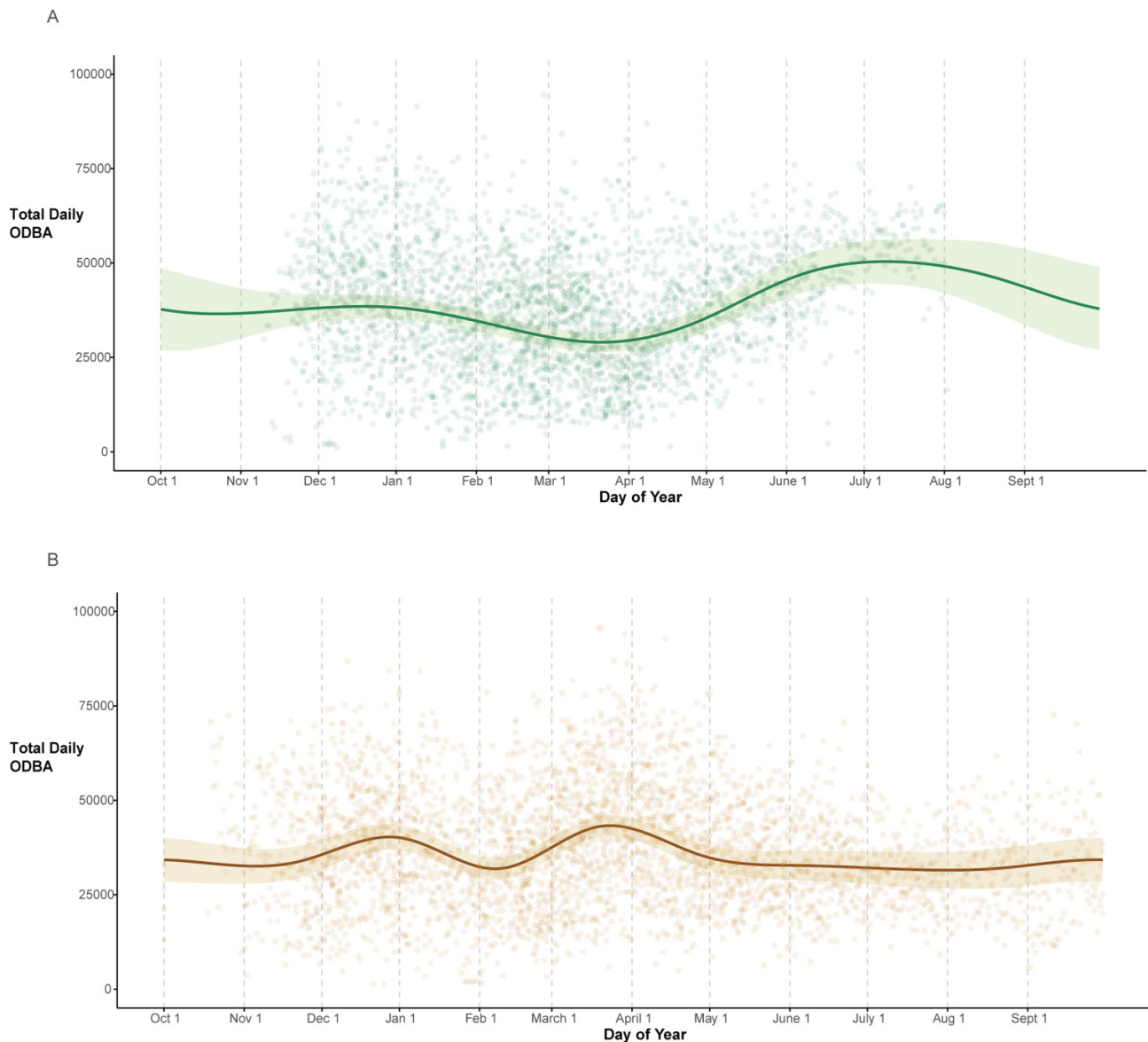


ulations in multiple regions of the United States found that while fishers were most commonly classified as cathemeral, there were individual datasets that classified fishers as diurnal or nocturnal during specific seasons (Devarajan et al. 2025). Within species variation in diel phenotype appears to be common in mammals, and may be associated with basic species/population traits (e.g., distribution, distance from latitude), seasonality in light availability, or landscape factors such as degree of human modification (Devarajan et al. 2025). Diet and activity cycles of prey may also shape diel pheno-

types; notably, SSN fishers may rely more on small prey items than fisher in other portions of their range where snowshoe hare and porcupine are available (Pilgrim et al. 2023). While we are not aware of a study that has formally tested this, it is also possible that accelerometry and camera trap studies may arrive at different assessments of diel phenotypes.

Despite all being classified as cathemeral, fisher activity patterns looked fairly different between males and females and across seasonal periods. In our study, male activity patterns, during mating, and female activity patterns, during

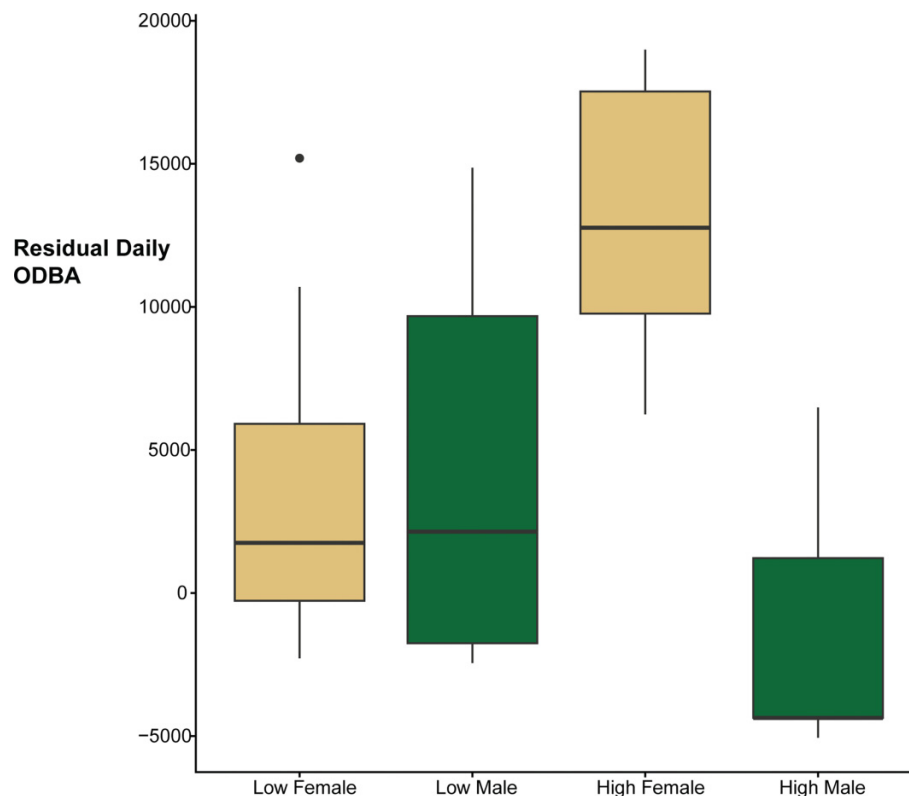
Fig. 3. Seasonal patterns of daily energy expenditure (total daily overall dynamic body acceleration (ODBA)) for female (panel A; top) and male (panel B; bottom) fisher (*Pekania pennanti*). Points represent raw data, solid lines represent generalized additive model predictions, and shaded regions represent 95% confidence intervals.



lactation, looked different than activity patterns at other times of year. During lactation, females showed an elevated absolute probability of being active during the middle of the day, to such an extent that the probability of being active was relatively consistent at all hours, except for an increased probability of activity at the end of the day. This is qualitatively similar to results from previous work in a fisher population in Maine, which found that denning females had a higher probability of being active than non-denning females (Arthur and Krohn 1991), which may be related to the need to hunt and acquire energy to support lactation and kit rearing. To a lesser extent, males showed a slightly elevated probability of being active midday during the mating period, which is consistent with increased movement to find and acquire mates (Arthur and Krohn 1991).

As fisher diel activity patterns changed seasonally, total daily ODBA also changed. In females, total daily ODBA was depressed in late March/early April, coincident with parturition dates in this population (Green et al. 2018). Total daily ODBA increased across April and May during later phases of lactation when females may spend more time away from the den and travel farther to obtain food for themselves and for kits as they mature (Powell and Leonard 1983; Cummins 2016). Males, in contrast, showed two smaller activity peaks—one coinciding with mating, which is consistent with the need to travel to locate mates (Arthur and Krohn 1991). The second modest peak in male ODBA occurred in late December/early January and is more difficult to explain. Previous analyses have suggested that fisher activity is lower in the winter than in the summer (Arthur and Krohn 1991); however, it is possible that male activity and home range may in-

Fig. 4. Residual total daily overall dynamic body acceleration (ODBA) differed by sex and the relative (high/low) number of smartphone detections in proximity to fisher (*Pekania pennanti*). High numbers of cell phone detections were those that exceeded the 75th percentile.



crease if prey becomes scarce during winter months (Lofroth et al. 2010), as they are expected to have higher energetic requirements than females. Juvenile and sub-adult males may also make exploratory movements at this time. Times of year with high total daily ODBA are also periods of high energy expenditure and, while we did not apply an explicitly energetics framework to this analysis, it serves as an important reminder that movement costs of larger winter home ranges, late lactation, and mating translate to increased energetic costs.

Collar-mounted accelerometers in combination with HMD allowed us to explore how fisher activity is affected by proximity to humans. While our datasets did not allow us to definitively conclude that fishers saw or heard humans, changes in fisher activity levels suggest that some aspect of human presence—whether it be the presence of the human themselves or the presence of human associated infrastructure (cars, buildings)—affected fishers. We found some evidence that female fishers elevated activity levels in the minutes surrounding exposure to a human smartphone user, and also showed that more intrusive exposures to humans, for example, exposures to a greater number of users across the day, led them to increase total daily ODBA. While this analysis presents the first assessment of fisher responses to direct human presence, other studies looking at the relationship between human-altered landscapes and fisher movement or

activity suggest that this relationship is context dependent (Kordosky et al. 2021; Ganoe et al. 2025). While previous studies have not reported results by sex, one fisher study in Rhode Island suggested that fishers inhabiting areas with high levels of human disturbance avoided roads during the daytime, but selected for areas with roads at night (Ganoe et al. 2025). This behavior was in contrast to movement patterns of fishers inhabiting areas with low levels of human disturbance, which avoided roads at all times (Ganoe et al. 2025). Research in the SSN fisher population has suggested that fishers minimize human development within core habitat, but that their broader home ranges may include more human development than the core (Kordosky et al. 2021). Importantly for those making management decisions and planning conservation activities that affect the SSN population of fishers, our analysis suggests that fishers are active during times of day when humans are abundant on portions of the landscape and that many of the fishers collared in this study are coming into proximity with humans multiple times a year. Even though this only represented approximately 5% of animal collar-days, given that the HMD used in this analysis only represents 10%–15% of smartphone users in the US, the frequency and intensity of fisher encounters with humans reported in this analysis likely underestimate reality.

Female fishers may be especially sensitive to “high intensity” direct human presence. While more data are needed to

understand the mechanisms behind, and consequences of, elevated female activity on days with higher levels of human exposure, this contributes to a growing literature that suggests responses to humans recreating and in vehicles may differ between the sexes. Some previous studies on the impact of recreation on wildlife have also found that females respond more strongly than males, showing greater avoidance of recreating humans (Pacific marten: [Slauson et al. 2017](#); wolverine: [Heinemeyer et al. 2019](#)). Reproductive females may be especially affected by recreation as disturbance from recreation may decrease reproductive output (elk; [Shively et al. 2005](#); bighorn sheep; [Wiedmann and Bleich 2014](#)). In such systems, evidence suggests that reproductive individuals select for habitat farther from roads (bighorn sheep; [Brushett et al. 2023](#)) than non-reproductive individuals. There are, however, some studies that show a greater response to recreation (capercaille; [Thiel et al. 2007](#)) and risk of vehicle collision in recreational areas (kangaroo; [Forrester et al. 2025](#)) in males. Understanding sex-specific impacts of recreation on wildlife, and how those impacts may change with duration of exposure, will continue to be an important area of research moving forward. While our analysis suggested that information about type of human exposure (building, car, outdoor) and its interaction with sex improved predictions of fisher activity levels during an encounter, our sample size was not robust enough to detect strong differences across these categories. Despite this, recent findings in other systems have shown that species' behavioral responses vary depending on the type of recreation exposure, which suggests the potential for managers to design targeted interventions for the most disruptive forms of recreation ([Zeller et al. 2024](#)), especially at sensitive times of year.

The range of tools that can be brought to bear on studies investigating interactions from wildlife and human recreationists is expanding rapidly. For example, accelerometers have also been used to study impacts of recreationists on mountain lions ([Bolas et al. 2025](#)) and heart rate loggers have been used to study the impacts of specific types of recreation, such as the impact of drones ([Ditmer et al. 2015](#)) and hunting ([Le Grand et al. 2019](#)), on bears. Similarly, while HMD provides the fine resolution locations of humans across broad scales ([Abernathy et al. 2025b](#)), a variety of unique recreation datasets derived from smartphone applications like Strava ([Thorsen et al. 2022](#)), handheld GPS trackers ([Olson et al. 2018](#); [Heinemeyer et al. 2019](#)), images ([Papafitsoros et al. 2021](#)), and geo-referenced social media posts ([Procko et al. 2024](#)) are changing the way that data on human recreation are being incorporated into wildlife research studies (see [Ellis-Soto et al. \(2023\)](#) for an overview). Studies, such as ours, highlight the value in combining biologging data from wildlife with large-scale recreation datasets to extend inference on the impact of human-wildlife interactions beyond occupancy, to behavior, that changes dynamically on daily and seasonal timescales. Dynamic datasets such as these give managers a nuanced view of the temporal dynamics of human-wildlife interactions and may help managers design temporally refined interventions, when necessary.

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Data availability

Fisher data are not available because they are a federally listed population segment within the United States. Human mobility data are not available because they are a commercially available data product with data sharing restrictions.

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Competing interests

The authors disclose no competing interests.

Supplementary material

Supplementary data are available with the article at <https://doi.org/10.1139/cjz-2025-0099>.

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