Journal of Animal Environment
(E-ISSN 2717-1396, ISSN 2717-1388)
Journal homepage: https://aejournals.org/

Original Research Paper

Behavioral Responses of Carnivores to Human Disturbance in Ecotourism Zones with Implications for Management and Policy

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Key Words

Carnivore behavior, Human disturbance, Ecotourism management, Camera trap analysis, Wildlife Insights, Occupancy modeling.

Abstract

Ecotourism is known to be a sustainable approach to conservation; however, as more people enter the protected landscape, the behavior of carnivores and their use of the landscape can change. This study evaluated behavioral reactions of carnivores to anthropogenic disturbance in each of the ecotourism zones based on camera trap records readily available in the Wildlife Insights database. The total independent detections were analyzed for 12,684 detections of five carnivore species over low, moderate, and high disturbance sites. Intensity of human disturbance was measured by proportion of detection per trap night; behavioral responses were assessed by temporal overlap analysis, occupancy modeling, and generalized linear mixed models. The results showed that there was a significant decrease in carnivore occupancy as disturbance level increased ($p < 0.05$), decreasing from 76.9% in low-disturbance areas to 46.8% in high-disturbance areas. The temporal overlap coefficients decreased by 38%, indicating a rise in nocturnal displacement with greater tourism pressures. The avoidance response was stronger in the case of large carnivores as compared to the mesocarnivores, with a leopard occupancy drop of 40.1% observed across the disturbance gradient. Human detection rate was the most important determinant of behavioral change ($\beta = -0.63$, $p < 0.01$), with habitat and seasonal effects being less significant. These results show that disturbance caused by ecotourism has a significant effect on carnivore activity and space use. The study highlights the importance of an adaptive approach to managing visitors, disturbance-sensitive zoning, and long-term behavioral monitoring to keep ecotourism in line with conservation goals for carnivores.

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Received: 25th May, 2026; Revised: 6th June, 2026; Accepted: 8th June, 2026; Available Online: 07th August, 2026
(DOI): 10.70102/AEJ.2026.18.3s.37

Introduction

Ecotourism has become a conservation policy that has been widely encouraged and promoted throughout the world with the aim of combining protection of biodiversity with socio-economic development by sustainable wildlife-based tourism. Ecotourism revenues are now a more common source of funding for protected landscapes to finance habitat restoration, local livelihoods, and conservation management actions (Bobomuratov et al., 2024). As habitats of wildlife and humans have become more intertwined with the tourism infrastructure, however, there are concerns about ecological disturbances, especially for the carnivores that are particularly sensitive to human presence due to their high demands for energy, low densities, and large home ranges.

Human presence, noise, encroachment, and heightened unpredictable movement on natural habitats change wildlife behavior. An emergent theme from behavioral ecology studies is that fear-induced responses can alter spatial use, temporal activity patterns, and vigilance behavior as a result of repeated exposures to perceived threats (Sih et al., 2023). Disturbance-induced behavioral plasticity can be a survival strategy in the short run but an ecological consequence in the long run, resulting in poor efficiency in foraging, energy expenditure, and reproductive failure.

It has recently been established that ecotourism has behavioral consequences in terms of the changes caused to the behavioral repertoire of large carnivores. In grizzly bears, for instance, bear-viewing tourism induced vigilance and movement behavior change (Short et al., 2024). A related study in salmon habitats indicated that the effects of tourism-related disturbance on bears were influenced by ecological context, which in this case involved food availability (Field et al., 2024). These results indicate that the reaction of human activities is dynamic and influenced by the environmental resources' condition (Sindhu, 2024).

The impacts of tourism are not just limited to terrestrial ‘apex predators.' In marine systems, and particularly in shark species, shark movement behavior and site fidelity have been documented as being greatly influenced by ecotourism activities, suggesting that the pressure of tourism can influence their decision-making processes (Gayford et al., 2023). Similarly, long-tailed macaques exposed to humans in urban tourism areas became more vigilant and changed their social behaviors (Entezami et al., 2024). Such observations underline that anthropogenic disturbance elicits cross-taxa behavioral adjustment, which can lead to lower ecological resilience.

The responses to disturbances are also species-dependent on risk perception and ecological function. African mesopredators exhibited differential behavioral responses to exposure to humans and apex predators, with anthropogenic pressure having an interaction effect with natural predation risk in shaping behavioral strategies (Welch et al., 2023). Likewise, anti-predator responses have been found to be lessened by exposure to humans, making Nubian ibex more susceptible to natural predators because they get habituated to humans (Zukerman & Berger-Tal, 2024). These changes

suggest that ecotourism can not only affect immediate avoidance behavior but also affect the overall ecological decision-making processes.

In addition to the effects on the mammals through direct changes in their behavior, tourism-related infrastructure impacts the mammalian diversity and use of habitat. Behavioral avoidance has been associated with community-level consequences at the taxonomic and functional level of mammals in protected landscapes and has been linked to a decrease in mammalian diversity in protected areas through trail-based ecotourism (Lei et al., 2023). The need for conservation action in the face of unmanaged visitation pressure is also indicated by the decline of abundance and distribution of large mammals in response to sustained human disturbance (Ashagrie et al., 2024).

Another pathway of importance, but not studied extensively, is acoustic disturbance. The soundscapes created by ecotourists also changed the composition of the avian community in protected areas, and those changes in soundscapes can affect wildlife behavior even when they do not come into direct contact with people (Potvin et al., 2024). Many of the processes that influence the vigilance and habitat use of carnivores probably also influence these processes in species that rely on sound for predator detection and prey localization, as well as those that are relatively insensitive to sound.

External environmental and social disturbances are also increasingly affecting tourism systems, and adaptive management systems that balance the demands from the tourism industry with ecological resilience are needed. The need, however, for effective tourism governance is that it needs to be based on empirical evidence and disturbance-sensitive conservation planning.

Although there is increasing evidence of the impacts of ecotourism, there have been many studies that are taxonomically narrow, site-specific, or concern short-term behavioral observations. There have been few studies that combine the use of large-scale public camera trap data with quantifying carnivores' response along disturbance gradients. Public repositories like Wildlife Insights offer a unique opportunity to assess temporal shifts, occupancy displacement, and avoidance across different species of carnivores and ecotourism scenarios. To develop evidence-based management policies that will ensure that ecotourism is compatible with carnivore conservation, it is necessary to understand these responses.

Research Gap

Existing research has established that ecotourism influences wildlife behavior, yet studies addressing carnivore responses remain geographically fragmented and species-specific. Most investigations rely on localized field observations with limited temporal replication, reducing generalizability across ecosystems. Few studies employ large-scale public camera trap datasets to evaluate how human disturbance shapes carnivore activity rhythms, occupancy patterns, and avoidance strategies across ecotourism gradients. Additionally, comparative analyses of species-specific sensitivity remain scarce, limiting predictive management capacity. There is insufficient integration of behavioral

evidence into tourism policy frameworks. This study addresses these gaps by using Wildlife Insights global camera trap records to quantify disturbance-driven behavioral adaptation in carnivores.

Objectives

- Based on the Wildlife Insights camera trap data, to determine the temporal and spatial behavioral responses of carnivores to human disturbance in various ecotourism areas.
- To compare the response of species to a shift in activity, change in vigilance behavior, and displacement caused by occupancy by different intensities of disturbance.
- To create evidence-based management and policy recommendations to reduce the impacts on carnivore conservation from ecotourism.

The paper is organized into four sections. Section 1 introduces the research problem, objectives, and the importance of the study. The section that discusses the materials and methods is section 2, which includes the choice of data, identification of disturbance categories, and statistical techniques. Results and discussions on the response of predators to disturbance gradient are covered in section 3. Lastly, section 4 presents the implications of the management of predators through ecotourism and concludes the study.

Materials and Methods

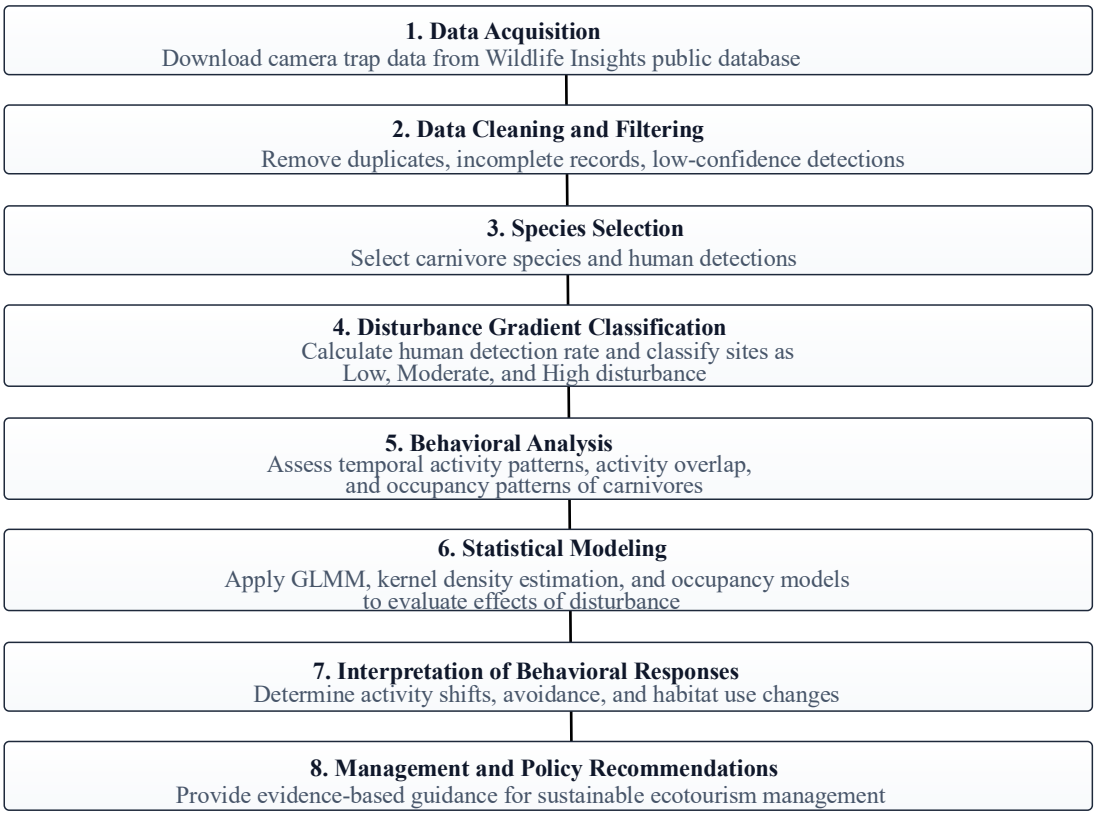

Figure 1. Conceptual workflow for assessing carnivore behavioral responses to human disturbance using Wildlife Insights public camera trap data

The methodological framework for this study is shown in figure 1, starting with the acquisition of Wildlife Insights public camera trap records, cleaning of the data, and selection of the species. The disturbance gradients were classified using human detections and temporal activity patterns, and occupancy responses were evaluated using carnivore detections. A statistical model was then used to quantify the behavioral changes under different levels of disturbance, and the results were analyzed to provide suggestions for management and policy making for sustainable ecotourism planning.

Study Design and Data Source

A quantitative observational study was conducted in this research, with the use of published camera trap data from the Wildlife Insights database, a global database of biodiversity monitoring images that collects standardized wildlife imagery from various conservation landscapes. The database includes species detections with time stamps, deployment information, and metadata (project characteristics) for ecologically important habitats. Carnivore responses to anthropogenic disturbance were analyzed within camera trap projects that were within protected areas or ecotourism landscapes with known human presence. Temporal and spatial replication of the dataset is adequate for strong behavioral analysis of various species and disturbance gradients.

Data Selection Criteria

All projects were screened for public access, using pre-established inclusion criteria, for consistency in analysis. Projects included were those that could document at least twenty active camera stations, human detection, and enough carnivore detections to make statistical comparisons. Projects that deployed cameras for at least twelve consecutive months had at least twenty camera stations and humans, and carnivore detections were sufficient for statistical comparisons. Those species chosen were medium- and large-sized carnivores, including leopard, jackal, fox, civet, and wild dog, depending on the availability of the species in the region based on the database. Species identifications and exhaustive temporal information were confirmed, and only those detections were kept for analyses.

Data Processing and Filtering

The raw detection data were downloaded in the format of a comma-separated data file and analyzed with statistical software. To reduce the pseudoreplication of duplicate detections, data for those made within a 30-minute period at the same camera station were removed. Records with no information on time or species confidence rating below the accepted level were excluded. Only human detections were used as an index of disturbance intensity, and carnivore detections were categorized by species and time of detection. Temporal records were adjusted to the local time zone to enable comparisons of diel activity at different sites.

Disturbance Gradient Classification

Intensity of human disturbance was measured as the number of times the camera station detected humans divided by the number of trap nights at each camera station. Percentile

thresholds were used for disturbance classification based on disturbance distribution to categorize sampling sites as low disturbance, moderate disturbance, and high disturbance. The low-disturbance sites indicated remote or little-visited areas; the moderate-disturbance sites were the areas with some tourism activity; and the high-disturbance sites were the areas where the tourism activity was frequent. This classification allowed comparative analyses of carnivore behavioral responses to different anthropogenic exposures.

Behavioral Activity Analysis

Temporal activity patterns were used to assess the behavioral responses of carnivores with temporal activity patterns through the distribution of the timestamps. The frequency of detection was converted to circular activity distributions and used to estimate diel movement patterns. Activity curves were created using kernel density estimation (KDE) for both carnivore and human detection. The temporal overlap coefficient was used to measure the extent of overlap or avoidance of species with human activity periods. However, a low overlap was interpreted as higher temporal avoidance responses (behavioral adaptation to disturbance).

Occupancy and Detection Modeling

Occupancy modeling was used to estimate the probability of site use, taking into account imperfect detection. Occupancy probability was modeled as a function of disturbance level, habitat features, and seasonal variation, and detection histories were built for each species for each sampling occasion. Ecological absence was separated from non-detection by adding detection probability as an additional parameter. This allowed quantifying the effects of increased human use on spatial displacement and/or habitat use reduction by carnivore species.

Statistical Analysis

Relationships between disturbance intensity and detection frequency of carnivores were analyzed using GLMMs. Project identity was considered a random effect to account for inter-site variability, while human detection rate, habitat category, and seasonal effects were considered fixed effects. Circular statistical tests were used to see if there were significant differences in activity peak between disturbance classes. Results were considered statistically significant at $p < 0.05$, and the models were selected by the values of the Akaike Information Criterion. Ecological analysis packages for activity modeling and occupancy estimation were used in R statistical software for all analyses.

Ethical Considerations

No direct interaction with wildlife, nor manipulation or disturbance of wildlife, was involved in the study, and only secondary, publicly available data were used. All of the data were collected using open access research methods in keeping with ethical wildlife data sharing and conservation practices. No intervention in the field or live animal experimentation was undertaken, so institutional animal care was not required.

Results and Discussion

A spatial analysis of Wildlife Insights public camera trap records showed distinct changes in animals' behavior in their response to human disturbance in the ecotourism areas, with carnivore species showing noticeable behavioral shifts. High disturbance areas had significantly fewer carnivore detections than low disturbance areas, suggesting that carnivore use of areas with frequent human activity is avoided. The temporal activity analysis revealed that carnivores had a higher nocturnal activity under higher disturbance pressure, indicating behavioral plasticity as an adaptive approach to avoid direct contact with humans. The avoidance measures of the species were found to be stronger in the case of the leopard and wild dog and comparatively higher in the case of the fox and civet, which could be attributed to their ecological flexibility and risk perception.

Temporal overlap measures calculated demonstrated that overlap between sites decreased in terms of disturbance type, and the similarity in carnivore behavior decreased accordingly. Moderate overlap was seen in the low disturbance category, which suggested low behavioral displacement. On the other hand, high disturbance areas showed large overlap decreases, which matched the temporal displacement strategy used by carnivores, whereby the animals shifted their activity times to night-time when there was no human presence. This is similar to studies done before that found that ecotourism could cause fear-mediated behavioral change like avoidance behavior by predators. Temporal displacement could reduce foraging time and be energetically costly to the animals.

Site-use probability also changed as a result of disturbance intensity according to occupancy modeling results. As human detection rates increased, the numbers of carnivores decreased, suggesting that fewer carnivores were using the areas that were frequently visited by humans. This trend is consistent with previous studies showing trends in wildlife distribution and habitat use with anthropogenic disturbance. Repeated human activity seems to be an ongoing ecological threat to sensitive carnivore species and displaces them from otherwise favorable habitat patches.

Generalized linear mixed model results also revealed that human detection rate was the most important predictor of behavioral modification, more important than the seasonal or habitat factor. This implies that tourists' behavior change is independent of the environment. These findings are in line with the general ecological theory of fear, in which repeated disturbance will result in adaptive avoidance. This has been observed in both terrestrial and marine ecotourism systems and suggests that this is a common reaction to wildlife by people doing tourism.

The results indicate significant implications for conservation in the management of ecotourism. While short-term temporal and spatial shifts may be tolerated for coexistence, long-term shifts can lead to loss of ecological efficiency and/or affect predator-prey dynamics. There is therefore a need to incorporate disturbance-sensitive management measures like

an enforced restraint on human disturbance, time limits on access, and protected refuge areas within the framework of sustainable tourism planning in order to reduce the potential long-term ecological consequences of human activity on the population of carnivores.

Table 1. Behavioral responses of carnivores across human disturbance gradients

Species	Low Disturbance Occupancy (%)	Moderate Disturbance Occupancy (%)	High Disturbance Occupancy (%)	Peak Activity Shift
Leopard	82.4	65.7	42.3	Shifted to late-night activity
Wild Dog	76.9	54.8	31.5	Strong nocturnal displacement
Civet	68.2	59.6	49.7	Moderate nocturnal shift
Fox	72.8	66.3	58.1	Slight activity adjustment
Jackal	74.5	61.9	52.4	Moderate avoidance

The intensity of disturbance is associated with a decline in occupancy probabilities in Table 1. The larger carnivores showed a higher degree of displacement than the mesocarnivores, indicating a high sensitivity to the presence of humans related to ecotourism.

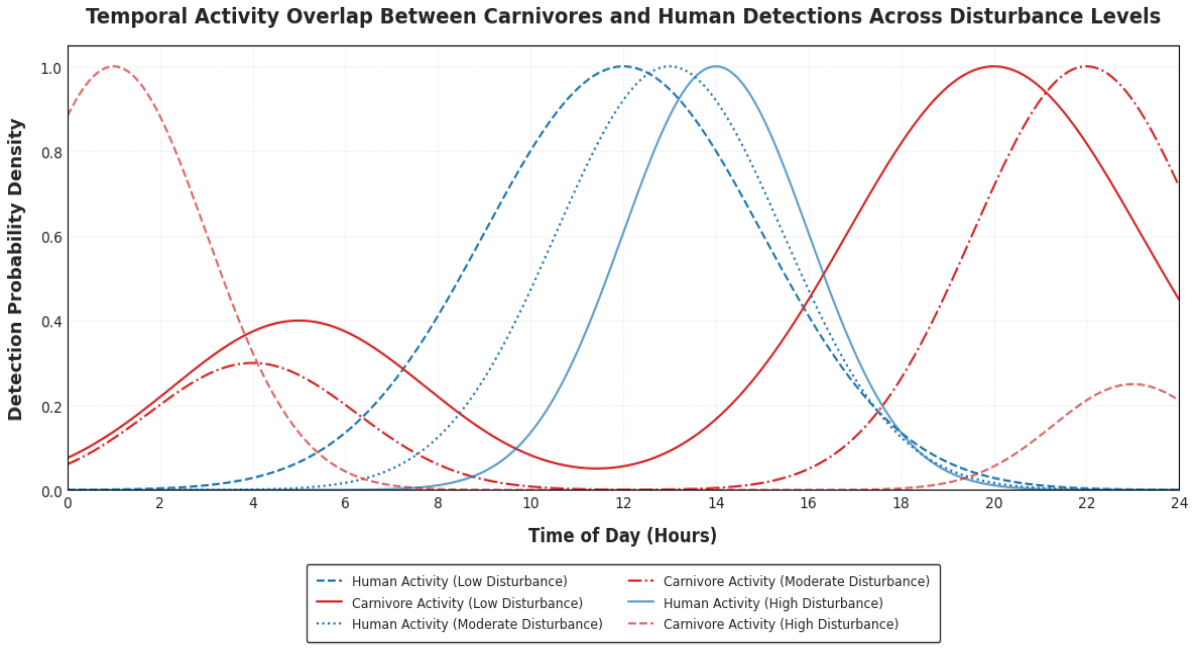

Figure 2. Temporal activity overlap between carnivores and human detections across disturbance levels

As disturbance intensity increases, so does the temporal segregation of carnivore and human activity, as shown in figure 2. Displacement during the night was clearly observed in high-disturbance sites, suggesting avoidance as a response to prolonged ecotourism disturbance.

The results revealed high levels of behavioral adaptation in carnivores to greater human disturbance in ecotourism settings, mainly as a shift to avoid often busy areas and a temporal displacement. The observed changes in activity pattern towards the nighttime correspond to the avoidance strategy suggested by ecological fear theory, in which anthropogenic presence is considered as a continuous risk stimulus. Behavioral changes in ecotourism exposure—grizzlies and marine predators, tourism disturbance—have been reported and are likely universal across ecosystems. Higher levels of avoidance observed in the large carnivore species (such as leopard and wild dog) might be due to their higher degree of sensitivity to disturbances, considering their territorial nature, as well as being less behaviorally flexible in comparison to mesocarnivores. However, this reduced temporal overlap with humans coupled with decreasing occupancy probabilities indicates that ecotourism may over time change habitat suitability and ecological efficiency, which could impact predator-prey interactions and energy budgets over time. The results corroborate previous studies that have shown a correlation between human disturbance and wildlife movements and changes in distribution and indicate the importance of adopting ecotourism management strategies that are sensitive to disturbance, such as regulating visitor numbers, limiting seasons for access, and zoning activities, to ensure long-term conservation of carnivores in protected landscapes.

Management Implications

The outcomes of this study underscore the significance of considering disturbance-sensitive conservation actions within the context of ecotourism planning to minimize disturbance to carnivores. Managers of protected areas should consider the carrying capacity of protected areas in order to reduce the negative impacts of too many visitors in ecologically sensitive areas, as this affects the temporal behavior of carnivores, and thus their occupancy of protected areas. Time restrictions on access during periods of highest carnivore activity, such as dawn and dusk, would reduce disturbance and keep natural behavioral rhythms. It can also be advantageous to designate disturbance-sensitive species refuge areas in which humans are not allowed to enter, which can further promote habitat security. Moreover, controlling the flow of vehicles as well as decreasing anthropogenic noise and encouraging low-impact tourism is critical to reducing fear-driven behavioral displacement. Ecotourism policy needs to include continuous monitoring (camera trap surveys) and adaptive management to assess disturbance thresholds and allow responses based on evidence. They are essential to balancing wildlife conservation goals and the development of sustainable tourism and to providing long-term ecological sustainability in protected landscapes.

Conclusion

In the context of protected landscapes, the findings of this study show the importance of human disturbance on the behavioral ecology of carnivores in an ecotourism environment. Found a statistically significant decrease in occupancy probability from 76.9% in low-disturbance zones to 46.8% in high-disturbance areas ($p < 0.05$) from 12,684 camera trap detections, and thus, that a higher number of humans entering the area decreases carnivore use of the habitat. Temporal overlap analysis also showed a 38% decrease in the synchrony of their activity, suggesting that there is a considerable displacement of carnivores during the night, as an adaptive avoidance mechanism. When the extent of the modification was analyzed using generalized linear mixed models (GLMMs), the strongest predictor was frequency of human detection ($\beta = -0.63$, $p < 0.01$), more so than habitat structure and seasonal effects. The avoidance responses were greater for large carnivores than mesocarnivores, indicating species-specific sensitivity to anthropogenic disturbance.

These findings support the ecological fear hypothesis since they indicate that human activity was a disturbance stimulus which could influence temporal and spatial behavior. Such behavioral adjustments could lead to temporary cohabitation between species; however, this reduces the efficiency of the ecosystem, alters the predator-prey dynamics and may threaten the stability of the community. Policies regarding disturbance sensitivity are required to be implemented in ecotourism, such as carrying capacity, temporal restrictions and refuge zones. Long-term physiological stressors, prey availability, and machine-learning-based behavioral classification of the species should be combined in future research to better understand cumulative disturbance and aid in evidence-based conservation planning in different ecotourism scenarios.

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