



Original Research Paper

Behavioral Adaptation of Wildlife Species in Response to Habitat Alteration and Increasing Human Activities

Dr. Jitesh Mahant^{1*}, Dr. Pankaj Tiwari², Sonam Puri³

^{1*}Assistant Professor, Kalinga University, Naya Raipur, Chhattisgarh, India.

Email: ku.jiteshmahant@kalingauniversity.ac.in, ORCID: <https://orcid.org/0009-0000-7957-2754>

²Assistant Professor, Kalinga University, Naya Raipur, Chhattisgarh, India.

Email: ku.pankajtiwari@kalingauniversity.ac.in, ORCID: <https://orcid.org/0009-0008-7787-0385>

³Assistant Professor, New Delhi Institute of Management, New Delhi, India. E-mail: sonam.puri@ndimdelhi.org, ORCID: <https://orcid.org/0009-0000-2823-3699>

Key Words	Abstract
Wildlife behavioral adaptation, Habitat alteration, Human–wildlife interactions, Behavioral plasticity, Species survival, Anthropogenic disturbance, Wildlife ecology, Movement ecology, Habitat modification, Conservation biology.	In an era of expanding habitat modification and the increasing overlap of humans and wildlife habitat areas, behavioral flexibility is proving to be one of the important ways for wildlife survival in human-altered environments. This literature review provides information about how the behavior of wild species has adapted in response to habitat modification and human interaction by means of changes in movements, activity timings, and social behavior, and whether these behavioral adaptations compensate for the costs incurred by them due to these activities. Human disturbance has resulted in large-scale changes in the movement behaviors of animals all around the globe; most of the recorded examples are of 20 percent or more. Mammals have responded to this challenge through the use of temporal adaptations in their activity timing to avoid human contact during daytime hours. Nevertheless, the scale and direction of such behavioral adjustments are highly variable depending on the particular nature of the disturbance, its predictability, and species-specific characteristics, suggesting that behavioral plasticity is not an inherent protection from habitat modification. A specific example of a case study involving a large ungulate show that behavioral adjustment to disturbed habitat may come with a survival cost, because modification of habitat choice due to human disturbance is associated with increased vulnerability to predation. Behavioral adaptations to human disturbance are also seen in the social realm, where human disturbance affects the social behavior of group-living species in a way that may serve to either protect or exacerbate consequences for the population as a whole. Thus, we see that behavioral adaptation enables the persistence of many wildlife species in modified habitats but doesn't eliminate their inherent fitness costs of being there.

* Corresponding Author's email: ku.jiteshmahant@kalingauniversity.ac.in

Introduction

Although habitat modification due to land use for agriculture or cities or construction of infrastructure is unlikely to remove wildlife completely from an area, these processes are likely to trigger behavioral adaptations, whereby wildlife tries to adapt its behavior in order to cope with modified habitat and increased anthropogenic disturbance. Changes in movement, timing of activities, habitat selection, and social structures constitute the principal methods of behavioral adaptation, which help wildlife deal with stress on a much shorter timescale than genetic adaptation. The understanding of how well and to what degree these methods help wildlife mitigate the costs of habitat modification is the key to predicting which species will survive in landscapes increasingly shaped by humans. The purpose of this review is to provide a synthesis of knowledge about the main behavioral adaptation strategies found in wildlife ecology literature and their effectiveness in mitigating pressures that caused them.

Movement and Space Use Adaptation

The most widely studied behavioral adaptation resulting from changes in habitats and human disturbances is changes in movement patterns. A study analyzing data from 208 articles in 167 species from terrestrial and aquatic environments worldwide found that human disturbances cause common alterations in animal movement patterns in which over two-thirds of 719 cases show movement change by 20% or more, with an average increase in movement of

70% and a decrease of 37% (Doherty et al., 2021). Human-induced disturbance caused by human activities, including recreation and hunting, has a stronger effect on animal movement than the disturbance resulting from the modification of habitats, for instance, logging and agriculture (Doherty et al., 2021). This means that the human presence and activity, regardless of any habitat change, is itself a powerful factor influencing behavioral adaptations in movement. This proves that behavioral adaptations in changed landscapes are not restricted to physical changes in the habitat.

Temporal Adaptation: Shifts in

Activity Timing

Notwithstanding spatial behavioral adaptations, many species adapt themselves temporally, adjusting the timing of their activity to avoid overlapping their times with those of humans. A meta-analysis of data collected globally from 76 research papers on 62 mammal species from six continents reveals that animals increased their nighttime activity by a factor of 1.36 as an adaptive response to the impact of humans, and this trend remained consistent for all continents, habitats, and human disturbances, including hunting, recreation, and infrastructure (Gaynor et al., 2018). This adjustment makes it possible for species to remain in areas utilized by humans during the daytime by limiting their own activities to less-busy hours, but there is always a price to be paid for such a drastic behavioral adjustment in terms of its influence on foraging, thermoregulation, and interspecies interactions, thus making it a behavioral compromise rather than a free-of-cost one.

Context-Dependency of Behavioral Responses

Nonetheless, despite these general trends, the degree of behavioral adaptation to environmental change varies tremendously according to circumstances. A study looking into the factors affecting these variations found out that the behavioral response of animals to human disturbances depends on an intricate combination of factors such as disturbance kind, predictability, timing vis-à-vis life history events like breeding, and intrinsic characteristics of species, such as body size, experience, and degree of habituation (Tablado & Jenni, 2017). Therefore, due to these variations, behaviors demonstrated by a particular species or ecosystem cannot be generalized to other species experiencing similar environmental changes, and some species or populations might not have enough behavioral flexibility to cope with the new environment, while others do.

Fitness Consequences of Behavioral Adaptation

The key issue whether behavioral adaptation manages to mitigate the costs associated with habitat change or simply shifts the costs through another channel is important but poorly researched one. The GPS telemetry study carried out over several years of woodlands caribou, living in Quebec, Canada, showed that the caribou having home range with high habitat disturbance due to logging and road construction had increased risk of predation mortality, as compared to animals that managed to survive (Leblond et al., 2013). It has been found that the

caribou having died from predation have chosen more disturbed habitats before death than those who survived. Therefore, behavioral adaptation such as habitat selection in altered landscapes can lead to increased risk of predation and, therefore, does not necessarily result in better fitness but rather in another predation trap.

Social Behavioral Adaptation

Human disturbance and habitat modification also affect the social aspect of wildlife behavior in gregarious animals. According to a review of the spatial-social interface, human disturbance poses a risk to wildlife, causing changes in social behavior through the time allocated to social interaction and increased vigilance. Spatial and social behaviors in gregarious animals are interrelated in such a way that their interactions have often been overlooked in the study of individual behavioral dimensions (Gaynor et al., 2024). This spatial-social interface was found to play an important role either in protecting or exacerbating the impact of habitat alteration in gregarious species, which means that understanding behavioral adaptation to habitat alteration involves the consideration of all three behavioral aspects: movement, temporal, and social behavior.

Habituation and Individual Variation in Behavioral Adaptation

Habituation as a Distinct Adaptive Process

In addition to the movement, temporal, and social adaptations covered earlier in the paper, many animal species are known to demonstrate

habituation, which entails a progressive decrease in reaction to an unimportant repetitive human stimulus. The process of habituation is different from the other behaviors described above in that it does not require any changes in terms of movement, temporality, and social structure, but represents an adjustment of an organism's sensitivity level to human presence. As has been discussed before, context dependency has been proven to depend on the predictability of the stimulus as well as on previous exposure, and this very predictability and exposure have been found to be the prerequisites of habituation. In other words, the species or populations that are regularly exposed to predictable human activity (such as wildlife viewing), which poses no danger to their lives, usually demonstrate a progressive decrease in their flight reaction with each encounter, while species that are faced with unpredictable or lethal human activity (like hunting) do not get habituated and continue to avoid humans.

Individual-Level Behavioral Plasticity

Patterns of behavioral adaptation at the population level, like those related to the nocturnality change reported for numerous species, are bound to reflect significant variability between individuals from the same population. Some individuals from a disturbed population may exhibit a high degree of rapid behavioral adjustment, while other individuals from the same population would demonstrate little or no change. This phenomenon, known as individual behavioral plasticity, is a factor that holds importance from the perspective of wildlife conservation. If behavioral adaptation to

human-induced disturbance is not equally prevalent among individuals from the same population, then the population undergoing persistent habitat modification may undergo what one could call behavioral selection, whereby individuals that are more prone to adapt behaviorally exhibit greater survival rates and reproduction success compared to other individuals from the same population. Through a number of generations, this could result in changing the composition of behavioral traits in a population without undergoing genetic adaptation – a process that has been much less researched than behavioral changes at the population level in the studies on movements and activity timing (Doherty et al., 2021; Gaynor et al., 2018).

Cumulative and Multi-Stressor Behavioral Responses

Wildlife populations dealing with habitat alteration rarely deal with just a single disturbance type but usually deal with a combination of habitat alteration, human presence, noise, and changes in predator and competitor communities all at once. In terms of the review of the literature on the subject of behavioral adaptation discussed in this paper, studies have usually dealt with each of these stressor types separately: movement as an adaptive response to disturbances in general, timing of activities as an adaptive response to human presence, and habitat selection as an adaptive response to logging and road construction (Leblond et al., 2013). Real-life wildlife populations will have to adapt behaviorally across all these different stressor

types simultaneously, raising the question of whether adaptation to a single stressor is enough and does not actually have any negative implications when it comes to adaptation to several different stressors at the same time. This point is clearly illustrated by the caribou case study, where an apparently successful adaptation to one dimension of landscape alteration, recent disturbance avoidance, had a negative impact on the overall fitness level because of an unmeasured dimension of the stressor, namely road-based predator movement patterns (Leblond et al., 2013).

Measurement Approaches for Behavioral Adaptation

The methods employed for gathering the empirical results presented in this paper are characterized by a variety of distinctive features, which allow for a number of particular strengths and weaknesses to be identified when studying behavioral adaptations through them. The use of GPS and satellite telemetry, which is common in both the meta-analysis of global movements and the caribou case study, allows for high spatiotemporal resolution and enables researchers to identify individual-level patterns of habitat selection along with their fitness implications; however, the use of these methods implies the necessity of capturing and tagging individual animals, thereby restricting samples and causing potential biases related to capturing more tolerant individuals (Doherty et al., 2021; Leblond et al., 2013). Behavioral studies using observations and experimentation methods, which provide most of the information on the evidence of context dependence and social

behavior, provide a great mechanistic understanding of behavioral responses at a certain scale but are not necessarily generalizable to a population level (Tablado & Jenni, 2017; Gaynor et al., 2024). Since both methods capture a different aspect of behavioral adaptations, the best available evidence for a certain species or system will come from experiments that triangulate using several approaches, and the gap in the literature will be more a gap in methodology rather than the absence of behavioral adaptations itself.

Discussion

Taken together, behavioral changes seen among wild animal species exposed to habitat alteration and increased human presence include significant behavioral flexibility manifesting in changed locomotion patterns, changes in timing of activities, and changes in social organization (Gaynor et al., 2024). As a result, many animal species manage to adapt to new environments where they could not live otherwise, which is an example of an adaptive response that cannot be accounted for by any genetic evolution. However, the information gathered here strongly suggests against the idea that behavioral adaptations prove the harmless nature of the process of habitat alterations in terms of the adapted species. Firstly, the context-dependent nature of behavioral adaptations indicates that adaptive potential is highly unpredictable and variable in different circumstances, and secondly, the example of caribou shows that even a documented behavioral adaptation, such as habitat choice under disturbance, may impose a significant survival cost on an organism, rather

than protect it from harmful effects (Leblond et al., 2013). Thus, it seems reasonable to conclude that behavioral adaptation is a valid adaptive strategy, but there are limits within which it works, and it does not automatically prove the non-harmful effect of habitat alteration or human activity on animal populations.

As far as the management of wildlife goes, some lessons are derived from this body of literature. One such lesson is the danger of using the maintenance of continued occupancy in an area or presence of a species as the sole indicator of adaptation success in behavioral management monitoring, because a population can continue behaving as a population even when its numbers slowly start to dwindle as a consequence of the same disturbance that it has become used to. This implies that there should be no assumption of equal capacity of individuals from the same population for adaptation through behavioral means, and conservation efforts aimed at reducing human activities to certain levels need to take into account the full distribution of behavioral responses among all the population's individuals. Finally, there is an important lesson here about the cumulative nature of multiple disturbances to the fitness and behavior of populations it is dangerous to assess one proposed habitat modification or activity in isolation and without consideration of other disturbances ongoing in the same landscape.

Conclusion

Behavioral adaptations in response to habitat modification and human disturbances include a variety of strategies related to movement, activity schedule, and social behavior, and such

adaptations often facilitate occupation of modified environments. But the degree and effectiveness of such adaptations depend on the specific species, type of disturbances, and context, and some known adaptations in behavior have a direct cost for individuals rather than help them to cope with the costs of environmental changes, for example, in the form of increased vulnerability to predation associated with particular habitat use pattern. Thus, evaluations of conservation status of human-altered habitats should consider behavioral flexibility of the animals as a limited and context-dependent factor, rather than as an evidence of adaptation to the new environment.

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