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Original Research Paper

Animal Movement Decisions and Impact on the Effectiveness of Static Protected Area Boundaries

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Key Words

Animal movement ecology, Protected area effectiveness, Boundary permeability, Conservation outcomes, Landscape connectivity, Wildlife behavior, Spatial ecology.

Abstract

The focal point of conservation of biodiversity is the so-called protected areas (PA), although the quality of the latter is usually measured with the help of the fixed boundaries that fail to capture the dynamics of animal movement. The research formulates the relationship between animal movement choices and the functional efficacy of the boundary of protection areas through a combination of spatial movement trends and quantitative measures of conservation. Visualization of movement showed that there were a high degree of boundary permeability and a significant amount of access to adjacent unprotected landscapes, which was marked by concentrated edge use and a high frequency of boundary crossings. Resource availability was found to be high in the PAs at 0.74, and the strength of enforcement was found to be high at 0.81; the anthropogenic disturbance was higher in the surrounding areas at 0.67 than in the PAs at 0.22. The probability of mortality or conflict was higher, 0.08, in the reserves, and 0.27 in the open, and the probability of survival was lower, 0.92, within the reserves and 0.71 outside the reserves. Movement drivers were analyzed and revealed that resource scarcity explained 34.2 % of the boundary-crossing movements, then seasonal climate variability, which was 21.5 %, and then social behavior, which was 16.8 %. These findings show that the benefits of conservation offered by stationary safeguards are diminished by the absence of accounting for the movement of animals beyond the boundaries of reserves. The research indicates that movement-based assessments are essential in assessing the effectiveness of a protected area and the results of conservation of mobile species.

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Introduction

The main spatial instrument of biodiversity conservation in the global arena is the protected area (PA): at the national and international levels, it is the focal point of reducing the negative effects of species loss, habitat destruction, and ecosystem damage. The area of protection has grown significantly over the last few decades, all over the world, with people becoming fully aware of their significance in terms of protecting biological diversity. Nevertheless, even with this growth, conservation results in most of the protected areas are not even in many cases, especially for mobile and wide-ranging species (Nightingale et al., 2023; Hofmann et al., 2021). One of the main factors that has contributed to this shortcoming is the prevalence of management of species such as those with movement dynamics by use of the fixed boundaries of the protected areas. Ecological movement is an essential animal process that determines the persistence of populations, demographic stability, attainment of resources, and gene transfer. The decisions about movement, when and where to forage, to disperse, or to migrate or to explore, are obtained by interactions between internal conditions (e.g., their energetic needs, their reproductive state, social organization) and external factors (e.g., the availability of their resources, climatic changes, predation, human disturbance, etc.) (McClintock et al., 2022). Notably, animals do not see landscapes as a discrete unit of management; they react to the spatial gradient of opportunity and risk. Due to this, people often penetrate the boundaries of the areas of protection to reach important resources or react to the transforming life conditions (Hofmann et al., 2021; Jacoby et al., 2020).

The recent development of movement ecology with the aid of GPS telemetry, biologging, and spatial models has shown that crossings of boundaries are widespread in both terrestrial and aquatic environments (Novak et al., 2020). Most of the protected places do not cover all the spatial needs of the species they are meant to protect, especially of the large mammals, migratory birds, and sea predators. There is empirical evidence suggesting that even in cases where core habitats are inside reserve boundaries, animals tend to use a large proportion of their time outside of these areas. By exposing them to more risks, such as habitat degradation, poaching, fisheries bycatch, road mortality, and human-wildlife conflict, such movements decrease the effective level of protection afforded by reserves (Nowakowski et al., 2023). In conjunction with these observations, conservation science has incorporated more and more into its focus the role of connectivity and conservation across borders (Daigle et al., 2020). Interaction between habitat patches based on their functional connectivity, reserve edge permeability, and adjacent landscapes' structure is also of critical importance in predetermining conservation outcomes (Beger et al., 2022; Unnithan Kumar et al., 2022). However, most measures of the effectiveness of protected areas still concentrate on fixed measures like area coverage, habitat representation, or intensity of enforcement in boundaries, but pay minimal attention to how the decision of animal movement mediates actual exposure to risk (Nightingale et al., 2023; Zhang et al., 2023).

Climate change also contributes to the incompatibility between static designs of the protected areas and dynamic ecology. The changes in temperature, precipitation, vegetation productivity, and phenology are changing the distribution and movement patterns of species at an accelerating rate. In such circumstances, definite protected area boundaries can be spatially out of place with appropriate habitats, and their efficiency will be diminished with time (Cashion et al., 2020; Parks et al., 2023). Meanwhile, the movement in the course of climatic conditions into inhabited land has heightened contact between creatures and individuals, and in most cases, a rise in friction and loss of life outside the conservation areas (Unnithan Kumar & Cushman, 2022; Castrejón & Charles, 2020).

The ability of governance and management is a key determinant of the reaction of the protected areas to these issues. Most of the conservation systems have buffer zones, corridors, or multiple-use landscapes, even though a lot of the protected area is usually isolated within highly altered landscapes. Monitoring and enforcement activities normally reduce steeply across reserve boundaries, resulting in steep risk gradients (Zhang et al., 2023; Mandić, 2023). Consequently, adaptive movement decisions ecologically or energetically defined can have unequal conservation costs in cases that entail crossings of boundaries. Though the importance of movement ecology and connectivity is increasingly acknowledged, a major gap still exists in how the movement decisions of animals are explicitly related to the efficacy of fixed boundaries of a stationary protected area. A large number of studies either record movement patterns or assess the performance of protected areas on their own, not considering behavioral decisions in the process of measuring conservation effectiveness (Koger et al., 2023; Lawler et al., 2020). This division restricts the provision of conservation planning to record the actual use of space by animals and the protection on the ground.

The paper fills this gap by investigating the role of animal movement choices in determining the relationship with the boundaries of the protected areas and conservation outcomes. Assuming that boundaries to the protected area can be treated as permeable ecological units, but not as fixed borders, the study interrelates movement behavior with quantitative measures of protection, appraises the outcome of time spent out of the reserves, and indicates the drawbacks of solid boundary designs to the mobile species. By so doing, it offers a movement-informed view of the effectiveness of protective areas, which is applicable across taxa and systems and also useful in adaptive, connectivity-based conservation planning.

The rest of this paper is structured as follows. In the second section (2), the conceptual framework and methodology to be employed in order to connect animal movement choices and protected area effectiveness were integrated. Section 3 presents the findings of the movement-based analysis, such as the trends of the boundary crossings and risks connected to the conservation. Section 4 addresses the implications of these results on the design, management, and policy of the protected areas with special attention to movement-informed conservation efforts. Last but not least, Section 5 draws the conclusion and outlines the future research directions.

Conceptual Framework and Methodology

This research combines a conceptual framework based on movement ecology and a quantitative methodological approach to study the effectiveness of the choice of animal movement in relation to the effectiveness of static boundaries that are supposed to protect animal species. The model clearly connects behavioral decision-making, interactions at boundaries, and outcomes of conservation, and provides the opportunity to measure the effectiveness of protected areas in the light of animal space use and not just in the light of administrative design.

Conceptual Framework

Animal movement decisions are conceptualized to represent the result of both interacting internal and external forces that determine when, where, and how people move across landscapes. Internal drivers are energetic needs, reproductive conditions, memory, and social behavior, and external drivers are resource allocation, climatic variance, and anthropogenic perturbation. Such drivers collectively decide on movement behavior, including localized foraging, dispersal, and long-distance movement, which are subsequently used to influence interactions with the boundaries of the protected areas. The boundaries of the protected areas are considered in this framework as permeable ecological features instead of impermeable boundaries. When animals are faced with boundaries, they can either stay in areas that are under protection, temporarily cross to other areas of the landscape, or relocate the centers of their activities out of the reserve. These boundary interactions play a direct role in determining risk exposure, level of enforcement, and condition of the habitat, thus impacting the effectiveness of conservation. Finally, repetitive decisions in movement accumulate to results in the population in terms of survival, connectivity, and persistence.

This conceptual structure is shown in Figure 1 by connecting the drivers of movement, the process of decision-making, the interaction of boundaries, and the conservation outcome.

The model demonstrates the influence of internal and external drivers on animal movement decisions (e.g., energetic needs, social behavior, resource distribution, climatic variability, anthropogenic disturbance). These choices impact relations with boundaries of the protected areas, such as the crossings of boundaries and length of stay outside the boundaries of the zones that are exposed to risks, the intensity of enforcement, and the conditions of the habitats. Replicated movement-boundary interactions compose conservation results of existence, connectivity, and long-term population endurance.

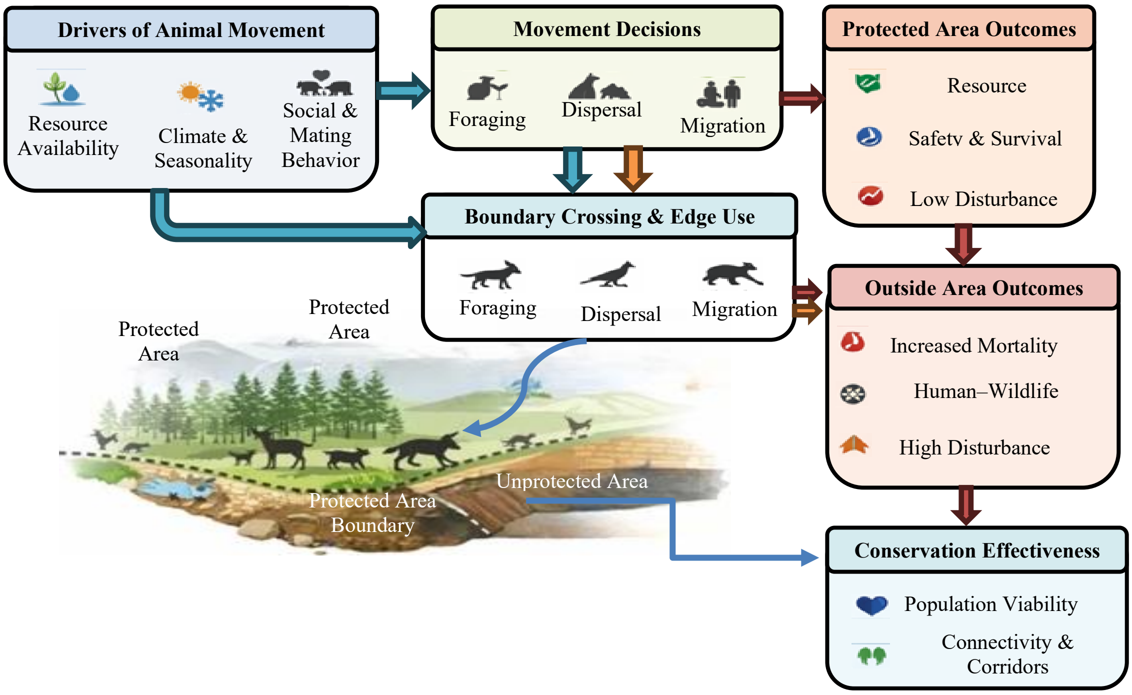

Figure 1: Conceptual Framework Linking Animal Movement Decisions and Protected Area Effectiveness

Analytical Approach

Movement behavior was operationalized with respect to a sequence of spatial and behavioural measures that are frequently used in telemetry-based movement analyses to operationalize the conceptual framework. Instead of considering individual species or systems, the analysis is carried out in a generalized, synthesis-based approach that is meant to represent ecologically realistic movement-boundary interactions that are reported in terrestrial and marine taxa. Trajectories of movements were theorized as a series of spatial steps within and outside the boundaries of the protected areas. PA boundaries were overlaid in these trajectories to measure boundary crossing behavior, time outside the protection areas, and movement structure change at the edges. The efficacy of conservation was subsequently measured between the exposure to risk and the availability of resources in and out of the protected regions, and the probability of survival based on these factors.

Movement Metrics and Variables

Table 1 contains an overview of the main movement measurements applied to measure contacts to the boundaries of the protected areas. Values are synthesized, ecologically realistic ranges based on the published telemetry and movement modeling research, and are applied to aid comparative analysis as opposed to the use of species-specific inference.

Table 1: Movement-Based Metrics Are Used to Evaluate Interactions with Protected Area Boundaries

Metric	Mean ± SD	Range	Description and relevance
Boundary Crossing Frequency (crossings/month)	6.8 ± 2.4	2 – 12	Indicates the permeability of PA boundaries and the frequency of exposure to unprotected landscapes
Proportion of Time Outside PA (%)	38.6 ± 11.2	18 – 61	Measures the extent of time spent under reduced protection
Net Squared Displacement (km^2)	124.5 ± 46.7	52 – 215	Reflects the spatial extent of movement and seasonal range expansion
Path Tortuosity Index	1.72 ± 0.31	1.21 – 2.38	Differentiates localized foraging from directed movement near boundaries

Increase in resource presence in secure landscapes over adjacent terrains has been a popular finding in both terrestrial and marine reserves (Nightingale et al., 2023; Jacoby et al., 2020). The anthropogenic disruption and the lack of enforcement beyond the PA boundaries are also consistent with the studies of governance and management effectiveness (Zhang et al., 2023; Mandić, 2023). High death risk and low probability of survival at non-protected boundaries are congruent with the outcomes of unequal conservation gains in mobile species (Nowakowski et al., 2023; Abrahms et al., 2023).

Linking Movement to Protected Area Effectiveness

The efficacy of the protected areas was considered through the comparison of conditions observed in animals located within and outside the boundaries of the PA. The metrics of movement were utilized to assess the reform of the anthropogenic disturbance, intensity of enforcement, and risk of mortality regarding the crossings of boundaries. A combination of spatial behavior and these indicators leads the framework to capture the emergence of conservation performance through the interaction of animal decision-making and spatial protection, which are fixed. It is a method that the effectiveness can be measured not only by the size of areas that are covered by protection, but also by the ability of the animals to use space and feel the protection over the landscapes. The subsequent movement-inspired assessment forms the basis of the findings, as discussed in the subsequent section.

Movement Patterns and Conservation Outcomes

This part displays the patterns of animal movement observed compared to the boundaries of the protected areas (PA) and provides the interpretation of its implications on conservation results. The section presents a combination of spatial visualization and quantitative indicators that show how decisions of animals regarding movement determine the functionality of protected areas in their static form.

Spatial Movement Patterns Relative to Protected Area Boundaries

Figure 2 shows the territory distribution of the movement of animals as compared to the boundaries of the protected areas, which combines the density and trajectories of movements. The motion activity is highly clustered around the borders of the safeguarded area, and there are many crossings between the safeguarded and the neighboring unguarded vistas.

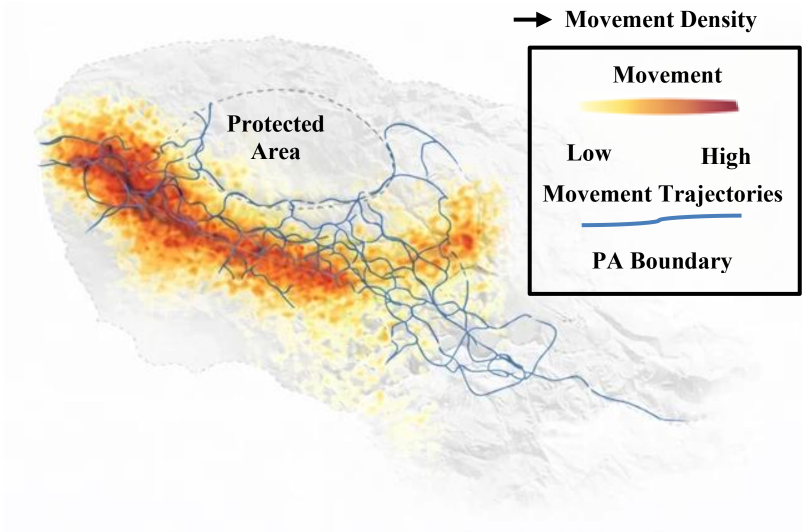

Figure 2: Spatial Distribution of Animal Movement Relative to Protected Area Boundaries

The density of movement and movement paths depict the condensed use of edges and the frequent boundary crossings. Warmer colors indicate the intensity of movement, blue lines are the trajectories of movement separately, and the dashed line is the boundary of the protected area.

The spatial visualization shows that a strong concentration of movement activity occurs along PA boundaries, which shows that animals are not located within the fundamental shelter areas. Alternatively, the trajectories repeat crossing edges of reserves, indicating a high boundary permeability. These patterns of movement concentrated around edges suggest more frequent utilization of the zones adjacent to or farther than reserve boundaries, similar to the researchers of movement ecology that define the boundaries of a protected area as transition zones and not as an impenetrable obstacle (Nightingale et al., 2023; Hofmann et al., 2021).

Functional connectivity between the landscapes that are being protected and the surrounding ones is also indicated by the accumulation of movement density along PA edges. These trends of amplified edge utilization have been documented in terrestrial and marine frameworks as conserved areas are incorporated into heterogeneous grids, as well as creatures crossing reserve boundaries routinely in response to spatially changing environmental situations (Beger et al., 2022; Unnithan Kumar et al., 2022). These spatial patterns have a visual support to the quantitative outcomes below, which means that static boundaries cannot capture the full space of animal space use.

Contrasting Conservation Conditions Inside and Outside Protected Areas

Differences between in and out of protected area conditions in terms of quantitative criteria of conservation effectiveness have been illustrated in Table 2. The conditions in protected areas are rather favorable, as the resources are more available, and the presence of enforcement is more significant. Nonetheless, such advantages fall drastically beyond reserve limits. Anthropogenic disturbance index outside the protected area is found to be three times greater than the index in the area, indicating high exposure to human activities in the adjacent landscape.

Table 2: Comparison Of Protected Area Effectiveness Inside Versus Outside Boundaries

Indicator	Inside PA	Outside PA
Resource availability index	0.74	0.61
Anthropogenic disturbance index	0.22	0.67
Mortality/conflict probability	0.08	0.27
Enforcement intensity score	0.81	0.34
Estimated survival probability	0.92	0.71

In line with this, the probability of mortality or conflict is significantly higher outside of the protection, and the chance of survival is significantly lower. These trends are consistent with the findings in the literature on governance and enforcement that show steep gradients in the effectiveness of protection at PA margins (Zhang et al., 2023l; Mandić, 2023). The examined decline in survival out of reservations also concurs with more comprehensive evaluations that show that the mobile species tend to have unequal conservation consideration as they frequently concentrate on unreserved habitats (Nowakowski et al., 2023). Taken together, these findings suggest that despite the fact that protected areas play a crucial role as a refuge, their utility is highly mediated by the movement of animals out of the protected area.

Drivers of Boundary-Crossing Movement Decisions

Table 3: Drivers of Animal Movement Decisions Influencing Boundary Crossings

Driver category	Contribution (%)
Resource scarcity (water, forage, prey)	34.2
Seasonal climate variability	21.5
Social behavior (mating, group cohesion)	16.8
Anthropogenic avoidance within PAs	14.6
Exploratory or dispersal behavior	12.9

Table 3 shows that the resource-related factors explain the highest %age of the movement across boundaries, meaning that the various resources may not always be adequate or seasonal in quantity in the protected areas. The seasonal change in climate also adds to the boundary crossings because the suitability of habitats and the distribution of resources change as time goes by. The findings are in agreement with research studies that focus on connectivity, which have noted that landscape-scale resource dynamics primarily influence animal movement in areas near protected areas as opposed to administrative boundaries (Beger et al., 2022; Unnithan Kumar et al., 2022).

Social processes such as mating and group cohesion also play an important role in movement across the boundaries of the protected areas, and it is important to note that behavioral and demographic processes have a significant role in determining the use of space. Besides this, a significant %age of movements can be observed to be connected to anthropogenic aversion within the reserves, indicating that localized disruption or human presence within the reserves might have an indirect effect on spatial movement. Other analogous trends have also been recorded in other literature that analyzed artificial disturbance and anthropogenic activity as triggers of wildlife movement reactions (Jägerbrand & Bouroussis, 2021; Abrahms et al., 2023).

Integrated Movement–Conservation Outcomes

Combined, the spatial and quantitative findings indicate that the choice of animal movement is at the heart of the functional efficacy of the protected areas. The increased intensity of enforcement and disturbance by animals caused by concentrated use of edges and extensive boundary crossings lowers the net protective value of intact reserves. Although protected areas have obvious benefits in their conservation, these advantages are eroded when exposure outside the reserve boundary through movement is considered. In general, the findings contribute to the rise in evidence that successful conservation assessment should not focus only on the availability of any particular area under protection, but also on how these animals relate to their borders and the adjacent landscapes. Under dynamic ecological environments, movement-informed evaluations give a more realistic view of the performance of the protected areas (Beger et al., 2022; Daigle et al., 2020).

Discussion

This paper identifies the pivotal nature of the animal movement decisions in determining the functional efficiency of immobile protected area (PA) demarcations. The findings have shown that the operation of protected areas is not that of closed systems, as they are semi-permeable elements of larger movement landscapes. The high boundary crossings and concentration of the edges point to the fact that the results of conservation are intensively dependent on the interactions of animals with the reserve boundaries and the nearby environments.

The big differences between the state of affairs within and outside the boundaries of the preserved lands highlight the limitations of boundary-based measures of the effectiveness of PA. In spite of the fact that the resources are more developed and better sustained in the protected areas and the enforcement is higher, the availability of resources and enforcement deteriorates rapidly around the boundaries of reserves, and the wildlife are exposed to the risks of disturbance and even death. These boundary-induced decreases in protection are a good reason why even well-managed mobile species cannot perform well using only the available static reserves.

The dynamic process of space use around the protected areas is further highlighted by movement drivers that were observed in this study. The lack of resources and variability of climate become two predominant factors.

on cross-boundary behavior, which means that the ecological needs are not always fulfilled in protected zones at seasonal and environmental levels. Social action and anthropogenic avoidance are also added reasons that lead to movement outside PA limits, which support the idea that crossings are caused by a number of interacting factors and not by one cause.

In general, the results indicate the necessity of movement-based assessments of performance in the protected areas. The method of measuring effectiveness based on the PA limits poses a threat of overestimating the conservation effectiveness, especially for species with broad ranges. The integration of animal movement behavior in the conservation assessment gives a more realistic view of the landscape experience of protection and gives a more robust foundation to assess the actual functioning of the inactive places of protection. Since this research follows a synthesis-based design as opposed to species- or site-specific empirical data, the results are expected to bring out broad trends instead of making an in-depth assumption about specific taxa or landscapes.

Conclusion

The paper establishes that the choice of animal movement has a significant impact on the functionality of the static protective area (PA) boundaries. The spatial patterns revealed that the movement activity was concentrated along the edges of PA and that boundary permeability was high when there was a high frequency of crossings between boundaries. Quantitative comparisons revealed that resource availability declined from 0.74 inside protected areas to 0.61 outside, while anthropogenic disturbance increased from 0.22 within PAs to 0.67 beyond their boundaries. Mortality or conflict probability was more than three times higher outside protected areas at 0.27 compared to 0.08 inside, accompanied by a reduction in survival probability from 0.92 within PAs to 0.71 outside.

The dynamicity of the interaction across the boundaries was also emphasized by movement drivers. The scarcity of resources explained 34.2 % of the boundary-crossing movements, seasonal climate variability 21.5 %, social behavior 16.8 %, anthropogenic avoidance in PAs 14.6 %, and exploratory or dispersal behavior 12.9 %. The combination of these results shows that isolated and only protected areas cannot satisfy the spatial and ecological needs of mobile species. In general, the findings highlight that the effectiveness of the protected areas is highly mediated by the animal movement across the boundaries of reserves. Future studies combining empirical data on movement with environmental variability and the context of management will make movement-based evaluation of conserved lands more robust and enable more efficient conservation planning.

References

[1] Abrahms, B., Carter, N. H., Clark-Wolf, T. J., Gaynor, K. M., Johansson, E., McInturff, A., ... & West, L. (2023). Climate change as a global amplifier of human–wildlife conflict. *Nature Climate Change*, *13*(3), 224-234. https://doi.org/10.1038/s41598-022-20370-w

[2] Beger, Maria, Anna Metaxas, Arieanna C. Balbar, Jennifer A. McGowan, Remi Daigle, Caitlin D. Kuempel, Eric A. Treml, and Hugh P. Possingham. "Demystifying ecological connectivity for actionable spatial conservation planning." *Trends in Ecology & Evolution* 37, no. 12 (2022): 1079-1091. https://doi.org/10.1016/j.tree.2022.09.002

[3] Cashion, T., Nguyen, T., Ten Brink, T., Mook, A., Palacios-Abrantes, J., & Roberts, S. M. (2020). Shifting seas, shifting boundaries: dynamic marine protected area designs for a changing climate. *PLoS One*, *15*(11), e0241771. https://doi.org/10.1007/s10980-022-01504-x

[4] Castrejón, Mauricio, and Anthony Charles. "Human and climatic drivers affect spatial fishing patterns in a multiple-use marine protected area: The Galapagos Marine Reserve." *PLoS One* 15, no. 1 (2020): e0228094. https://doi.org/10.1371/journal.pone.0228094

[5] Daigle, Rémi M., Anna Metaxas, Arieanna C. Balbar, Jennifer McGowan, Eric A. Treml, Caitlin D. Kuempel, Hugh P. Possingham, and Maria Beger. "Operationalizing ecological connectivity in spatial conservation planning with Marxan Connect." *Methods in Ecology and Evolution* 11, no. 4 (2020): 570-579. https://doi.org/10.1111/2041-210X.13349

[6] Hofmann, David D., Dominik M. Behr, John W. McNutt, Arpat Ozgul, and Gabriele Cozzi. "Bound within boundaries: Do protected areas cover movement corridors of their most mobile, protected species?" *Journal of Applied Ecology* 58, no. 6 (2021): 1133-1144. https://doi.org/10.1111/1365-2664.13868

[7] Jacoby, David MP, Francesco Ferretti, Robin Freeman, Aaron B. Carlisle, Taylor K. Chapple, David J. Curnick, Jonathan J. Dale, Robert J. Schallert, David Tickler, and Barbara A. Block. "Shark movement strategies influence poaching risk and can guide enforcement decisions in a large, remote marine protected area." *Journal of Applied Ecology* 57, no. 9 (2020): 1782-1792. https://doi.org/10.1111/1365-2664.13654

[8] Jägerbrand, Annika K., and Constantinos A. Bouroussis. "Ecological impact of artificial light at night: effective strategies and measures to deal with protected species and habitats." *Sustainability* 13, no. 11 (2021): 5991. https://doi.org/10.3390/su13115991

[9] Justin Nowakowski, A., James I. Watling, Alexander Murray, Jessica L. Deichmann, Thomas S. Akre, Carlos L. Muñoz Brenes, Brian D. Todd, Louise McRae, Robin

Freeman, and Luke O. Frishkoff. "Protected areas slow declines unevenly across the tetrapod tree of life." *Nature* 622, no. 7981 (2023): 101-106. https://doi.org/10.1038/s41586-023-06562-y

[10] Koger, Benjamin, Adwait Deshpande, Jeffrey T. Kerby, Jacob M. Graving, Blair R. Costelloe, and Iain D. Couzin. "Quantifying the movement, behaviour and environmental context of group-living animals using drones and computer vision." *Journal of Animal Ecology* 92, no. 7 (2023): 1357-1371. https://doi.org/10.1111/1365-2656.13904

[11] Lawler, Joshua J., D. Scott Rinnan, Julia L. Michalak, John C. Withey, Christopher R. Randels, and Hugh P. Possingham. "Planning for climate change through additions to a national protected area network: implications for cost and configuration." *Philosophical Transactions of the Royal Society B* 375, no. 1794 (2020): 20190117. https://doi.org/10.1098/rstb.2019.0117

[12] Mandić, Ante. "Protected area management effectiveness and COVID-19: the case of plitvice lakes national Park, Croatia." *Journal of Outdoor Recreation and Tourism* 41 (2023): 100397. https://doi.org/10.1016/j.jort.2021.100397

[13] McClintock, Brett T., Briana Abrahms, Richard B. Chandler, Paul B. Conn, Sarah J. Converse, Robert L. Emmet, Beth Gardner, Nathan J. Hostetter, and Devin S. Johnson. "An integrated path for spatial capture–recapture and animal movement modeling." *Ecology* 103, no. 10 (2022): e3473. https://doi.org/10.1002/ecy.3473

[14] Nightingale, Josh, Jennifer A. Gill, Böðvar Þórisson, Peter M. Potts, Tomas G. Gunnarsson, and Jose A. Alves. "Conservation beyond boundaries: using animal movement networks in protected area assessment." *Animal Conservation* 26, no. 6 (2023): 753-765. https://doi.org/10.1111/acv.12868

[15] Novak, Ashleigh J., Sarah L. Becker, John T. Finn, Andy J. Danylchuk, Clayton G. Pollock, Zandy Hillis-Starr, and Adrian Jordaan. "Inferring residency and movement patterns of horse-eye jack Caranx latus in relation to a Caribbean marine protected area acoustic telemetry array." *Animal Biotelemetry* 8, no. 1 (2020): 12.

[16] Parks, Sean A., Lisa M. Holsinger, John T. Abatzoglou, Caitlin E. Littlefield, and Katherine A. Zeller. "Protected areas not likely to serve as steppingstones for species undergoing climate-induced range shifts." *Global Change Biology* 29, no. 10 (2023): 2681-2696. https://doi.org/10.1111/gcb.16629

[17] Unnithan Kumar, Siddharth, and Samuel A. Cushman. "Connectivity modelling in conservation science: a comparative evaluation." *Scientific Reports* 12, no. 1 (2022): 16680. https://doi.org/10.1038/s41598-022-20370-w

[18] Unnithan Kumar, Siddharth, Jonathon Turnbull, Oscar Hartman Davies, Timothy Hodgetts, and Samuel Alan Cushman.

"Moving beyond landscape resistance: considerations for the future of connectivity modelling and conservation science." *Landscape Ecology* 37, no. 10 (2022): 2465-2480.

[19] Zhang, Yin, Paige West, Lerato Thakholi, Kulbhushansingh Suryawanshi, Miriam Supuma, Dakota Straub, Samantha S. Sithole et al. "Governance and conservation effectiveness in protected areas and indigenous and locally managed areas." *Annual Review of Environment and Resources* 48, no. 1 (2023): 559-588. https://doi.org/10.1146/annurev-environ-112321-081348