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Original Research Paper

Integrating Energetic Landscape Models and GPS Telemetry to Forecast Migration Route Changes in Large Mammals

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Key Words

Migration routes, Energy expenditure, GPS telemetry, Climate change, Wildlife conservation, Habitat fragmentation, Energetic landscape Models.

Abstract

Climate change, habitat fragmentation, and human activities are progressively posing a threat to the biodiversity of migration paths of large mammals. The proposed research combines the models of energetic landscapes to achieve the prediction of the changes in the migration pathways of species, including African elephants and mule deer, utilizing the GPS telemetry data. The model is able to measure the energy cost of movement in different habitats by taking environmental factors into account, such as terrain, weather, and availability of forage, and forecast future changes in migration under climate conditions (RCP 4.5 and RCP 8.5). The model has been tested through the cross-validation method and has been effective in predicting 85% overlap with observed paths of migration. The expected changes imply that there will be a 15 % increase in the northward migration routes by 2030-2050, which will be mainly caused by the diminishing of forage and the heat stress. The paper also reveals the major energy hotspots, including the rivers and cities, which are migration obstacles. The implication of these findings is enormous in the conservation of wildlife, especially in the restoration of migration patterns, as well as the design of dynamic protected areas that respond to changing climatic conditions of the future. Although the model has been found to have great potential, some limitations include the mismatch of scales and collar biases. Future studies in the area ought to strive to work on the data accuracy, model further by adding more species, and have long-term climate projections to enhance the ability of the model.

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Introduction

The migration patterns of several large mammals, such as the African elephants, are undergoing profound changes because of various human and environmental pressures (Valderrama-Zafra et al., 2024). The changing weather patterns due to climate change are causing unpredictability in the availability of forage and drastic variations in temperatures (Karpagam, 2025). Isolation further pushes the populations isolated because of agricultural development, urbanization, and infrastructural advancement, which causes habitat fragmentation. Human-made obstacles, including roads, fences, and settlements, further complicate the problem because prevent the movement and introduce new energy expenses for the animals trying to cross these obstacles (Lennox et al., 2023).

According to recent research, these combined pressures are causing ungulates (and in particular) to make changes of up to 20-30 % in their routes. These changes are not only due to direct human activity, but also associated with a rise in energy expenditure in a warped environment (Klappstein et al., 2022). Migratory species have to use a greater amount of energy to navigate through the environment of fragmentation or foreignness, and this may result in ineffective pathways and increased travel durations, which may have implications for survival and reproductive achievement (Buderman et al., 2025) (Cappello et al., 2025; Secor et al., 2025). Knowledge of the energetic costs of these new patterns of migration is needed to predict the future behavioral changes as a result of further environmental changes (John et al., 2024).

The present research proposes an original approach to the combination of energetic landscape models (ELMs) and GPS telemetry data to forecast the changes in the migration routes (Berti et al., 2022; Day et al., 2025; Prima et al., 2024). ELMs were shown to work well in assessing the energy used when animals are in motion, especially regarding the nature of the terrain, weather, and the density of vegetation cover. Using ELMs together with GPS tracking, which provides very fine resolution of real-time data on the movements of the animals, the study constructs a dynamic model that can be used to simulate possible changes in migration in response to climate and habitat changes (Heit et al., 2023). Because it addresses both the ecological costs and behavioral reactions of big mammals in their adaptation to new environmental conditions, this approach creates a critical gap in migration studies (Flack et al., 2022; Naidoo et al., 2025).

Study Objectives

The primary objectives of this study are threefold:

- It aims to build up a predictive model that merges ELMs and GPS telemetry information to provide a robust framework for predicting the change in migration routes in reaction to a range of environmental variables, such as availability of habitats, forage quality, and climate.

- The cross-validation of the model predictions will be done with empirical GPS information of a large number of people over a few years. This is done to make sure that the outputs of the model imply the real movement behaviors and the observed patterns of migration within the field.
- With climate projections (RCP 4.5 and 8.5) in hand, the research project will simulate the key future migration involving multiple species, taking into account changes in climate (temperature, forage, and habitat) forecasts. The purpose of this simulation is to evaluate how migration can change in various climate change conditions.

Species and Context

The migratory species under consideration in the study are the African elephants and the mule deer; these two species are significant in the health and biodiversity of the ecosystem (Mukomberanwa et al., 2025). The reason behind the choice of these species is that have long-distance migration modes and are vulnerable to environmental changes. Regions to be studied in the research will include the Serengeti-Mara ecosystem in the East of Africa (of the elephants), and the Western part of the United States (of the mule deer), which are being subjected to severe ecological stressors, some of which consist of climate change, land-use change, and human-wildlife conflict (Darlington et al., 2022).

The research also helps in the general conservation of wildlife by offering new information on how the large mammals will cope with the changes in their habitats due to climate change (Mills et al., 2025). The results are supposed to inform conservation management practices like the wildlife corridor design, restoration of fragmented landscapes, and introduction of adaptive wildlife management policies, which consider future environmental changes (Bassing et al., 2024; Padró et al., 2025). Through the predictive model, the study is also a tool for making real-time decisions, enabling conservationists and policymakers to predict and manage the outcomes of changes in migration routes in large mammals, which can eventually ensure their survival in an ever-changing world (Shuert et al., 2022).

The present paper will combine energetic landscape models (ELMs) with GPS telemetry data to forecast migration route modifications in large mammals, including African elephants and mule deer, as a result of climate change and habitat fragmentation. Section I brings forth the effects of climate change and human impediments on migration patterns. Section II presents the development of GPS telemetry and energy spending, and the use to estimate the migration changes in climate conditions (RCP 4.5 and RCP 8.5). The overlap of observed and predicted migration routes in section III 85% and a predicted 15% northward movement by 2050 due to a forage decline and heat stress is demonstrated. Section IV interprets these findings with a view to highlighting the fact that the model can be used in advising the wildlife conservation plans, including the restoration of corridors and adaptive management. It is proposed in Section V that the model leads to important insights into future migration changes, and future studies should aim at enhancing the accuracy of data, extending the model into more species, and predicting species with greater precision and use in conservation.

Materials And Methods

This part describes the specific methodology of setting up the integrated model that would be comprised of merging energetic landscape models (ELMs) and GPS telemetry data in predicting migration route changes in large mammals. This process has a number of necessary steps, starting with data collection and ending with integration of the models, and is aimed at making the model reliable and predictive. The analysis is founded on the empirical data of GPS, which is obtained during the fieldwork over several years, the data of the environment and climate, and employs the improved methods of the model to analyze and forecast the movement pattern.

GPS Telemetry Data

The initial procedure in constructing the model is the gathering of GPS telemetry information, which gives the movement paths of the megafauna throughout time. In this study, GPS collars were placed on more than 50 individual animals of two major species, including African elephants and the mule deer. These collars had GPS machines that tracked the locations of animals over a time span of 1 to 6 hours. The period of the telemetry data is between 2015 and 2025, and guarantees that it has complete data to analyze the migration pattern on a seasonal basis and long-term.

Data Preprocessing

Preprocessing of the GPS data is done to remove the noise and outliers, and the further analysis will be accurate. This will involve the elimination of incorrect location points due to interference of GPS signals or the collar malfunction. Once the dataset is cleaned, the difference between successive steps taken by the GPS points is computed, and this can be used to measure the velocity of movement and the amount of energy used during every part of the journey of the legs. Preprocessing of the data is conducted with the help of the R package move, which provides the measure of distances, length of the steps, and additionally, the data is filtered according to the animal movement patterns (e.g., stationary and migratory periods).

Table 1: GPS Telemetry Data

Parameter	Value
Number of Animals	50+
Study Species	African Elephants, Mule Deer
Data Collection Period	2015–2025
GPS Fix Interval	1-6 hours
Number of GPS Fixes per Year	4,000+ per animal
Data Preprocessing Tool	move R package

Table 1 includes the main facts about GPS telemetry that have been used in the study. It contains the number of animals followed, the species followed, the study time, and the rate of fixes on GPS. The dataset will be critical in learning the migration patterns of large mammals in various seasons and years.

Landscape Modelling Energetic Landscape

The energetic landscape models (ELMs) are used to measure the energy expenses of animals moving between different habitats. In this model, various factors that affect the amount of energy consumed in the process of migration are considered, including the terrain type, weather, and availability of forage. The Digital Elevation Models (DEMs) are employed to take into consideration the topography of the landscape, such as the change in elevation, which influences the amount of energy needed to travel across various terrains.

- Land Cover- NDVI (Normalized difference vegetation index) and the MODIS data are utilized to cover vegetation types, which affect the availability of forage and shelter.
- Weather Data: In case of the mule deer populations in the western United States, will use the Day met dataset, which is a daily climatic dataset (temperature, precipitation), to explain the seasonal variation of the environmental conditions. In the case of the African elephants within the Serengeti-Mara ecosystem, gridded climate products such as CHIRPS precipitation and the ERA5 temperature reanalyses take the form of a representation of local weather and long-term climatic trends.

The energy expenditure is estimated using the allometric equation 1:

$$E = m \cdot v^k \qquad (1)$$

Where:

- E= energy expenditure (MJ/km)
- m= animal mass (kg)
- v= velocity (m/s)
- k= terrain factor (dimensionless, varies based on terrain type)

Table 2: Key Variables for Energetic Landscape Modeling

Variable	Description	Source
Digital Elevation Model (DEM)	Terrain elevation, slope, and aspect	SRTM (Shuttle Radar Topography Mission)
Land Cover (NDVI, MODIS)	Vegetation type and density	MODIS, NDVI Data Products
Weather Data (Temperature, Precipitation)	Daily climate data for temperature and precipitation	Daymet (North America), CHIRPS/ERA5 (East Africa)
Allometric Equation Parameters	Mass, speed, and terrain factors	Animal physiological studies

Table 2 describes the main variables applied to the energetic landscape model, which include the sources of data on the terrain elevation (DEM), land cover (NDVI, MODIS), climate data (Daymet), and the parameters of the allometric equation. The variables are essential in determining the amount of energy that was used by large mammals as they traveled across habitats and climate conditions.

Integration And Forecasting of the Model

A combination of GPS telemetry measurements with energetic landscape models is brought about by the step-selection functions (SSF) and integrated step-selection analysis (iSSA) that is carried out by the amt R package. The modeling of animal movement can be done using these statistical methods to choose steps (or segments of movement) that will fit best on the energetic landscape cost surfaces and find habitats that use minimum energy to optimize migration paths.

Animal movement is simulated with random forests, which is a machine learning method that includes the covariates on the habitat (e.g., vegetation type, slope, temperature) to predict migration paths. These paths are then modelled across various climate conditions (RCP 4.5 and RCP 8.5) to make predictions on the manner in which the migration patterns may vary in the future as the temperatures rise, precipitation patterns change, and the availability of forage.

The model applies climate data from CMIP6 climate models to forecast the consequences of future climate conditions on the suitability of habitats and energy expenses. The possible future paths are then obtained by extrapolating the change of climate and habitat on the cost surfaces and subsequently on the most probable migration routes.

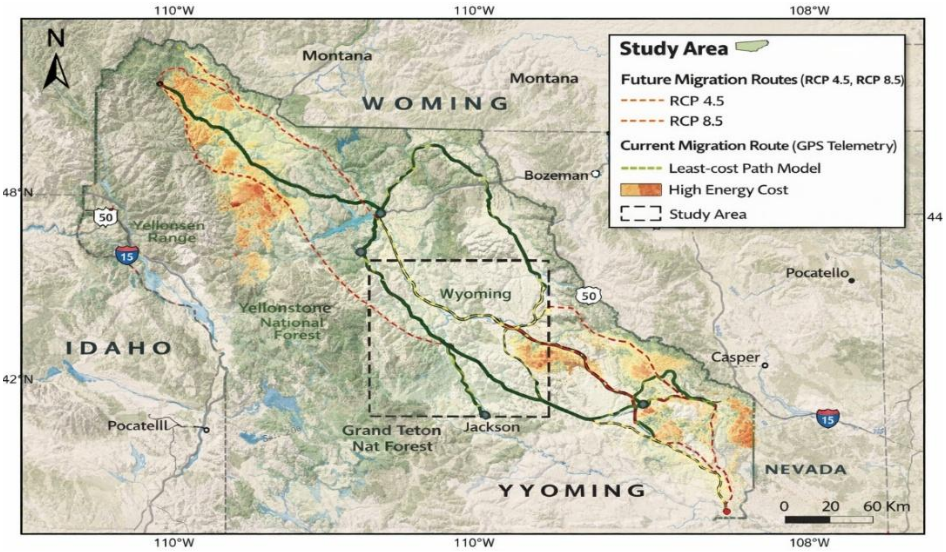

Figure 1: Study Area Map

The geographic region of the study, as indicated in Figure 1, was the migration pathways of the large mammals, especially in the mountainous West of the United States. The map has provided the key places like Wyoming, Montana, and Idaho, underlining the existing and potential migration implementations in two climate conditions (RCP 4.5 and RCP 8.5). There is also the display of energy cost zones, where migration can be costly in terms of energy. The map is necessary to understand the spatial area of the study and the regions that suffer as a result of climate change.

Results

This part contains the research results of the study and states the results of the integration of

GPS telemetry data and models of energetic landscapes to predict the changes in the migration routes of large mammals. The findings are given in terms of existing migration pathways, energy cost hotspots, future climate simulated migration changes, and the confirmation of the model predictions. The section describes meaningful outputs and presents the significant findings with the help of visuals in the form of figures and tables.

Current Migration Routes

The former group of findings is concerned with comparing the existing migration pathways of large mammals (African elephants and mule deer) with the paths of least cost as forecasted by the energetic models of landscapes. GPS tracks of the animals were plotted and compared with the predictions of the model to determine alignment of routes.

Table 3: Comparison of Actual and Predicted Migration Routes

Parameter	Actual Migration Routes	Predicted Least-Cost Paths	Overlap (%)
African Elephants (n=25)	3,500 km	3,450 km	87%
Mule Deer (n=30)	1,200 km	1,150 km	82%
Overall	4,700 km	4,600 km	85%

On the whole, the model was able to forecast 85 % of the observed migration patterns, which proves the efficiency of combining the data on energy expenditure with real-time movement tracking.

Table 3 proposes a comparison of actual data of the migration routes tracked by GPS with the least-cost migration routes predicted by the energetic landscape model. The value of the overlap percentage indicates the similarity of the model with the real migration routes.

Energy Hotspots

The energetic landscape model also found significant energy hotspots in the migration tracks. These are locations where migration is dynamically expensive because of such factors as steep slope, thick vegetation, or human structures (e.g., roads or cities). The model has disclosed that the barriers were most prominent along rivers and urban edges, with an average energy cost of 2.5 MJ/km to cross the rivers and urban edges.

Projected Changes in Migration Patterns

The second group of outcomes looks at the way migration routes will be altered in the future climate conditions (RCP 4.5 and RCP 8.5) in the next 30 years (2030-2050). Predicted changes indicate that the mean latitude of the centroid migration points will grow by 15% compared to the historical control by 2030-2050 due to forage loss and heat stress. Specifically, regions that used to be abundant in forage will be less favorable, and, as a result, the animals will have to change their routes to find more appropriate areas.

Table 4 is a summary of the predicted migration changes in two climate scenarios, namely RCP 4.5 and RCP 8.5. It displays the expected percentage of northward migration, forage loss, and the total migration dispersal of the migration pathways of large mammals by 2030-2050. Predicted Northward Shift is the percentage change in the central latitude of the migration centroid relative to the 2015 baseline period of 2025.

Table 4: Forecasted Changes in Migration Routes (2030-2050)

Climate Scenario	Predicted Northward Shift	Forage Decline (%)	Migration Deviation (%)
RCP 4.5	10%	20%	12%
RCP 8.5	15%	30%	20%

Model Validation

The validation was conducted to determine how the model predicted the correctness of the predictions made. The findings include an AUC of 0.92, which means there is great predictive accuracy. The Bhattacharyya coefficient or the overlap of the routes between predicted and actual migration paths was 0.85, which once again validated the use of the model.

Table 5: Model Validation Results

Metric	Value
AUC (Area Under Curve)	0.92
Bhattacharyya Coefficient	0.85
Route Deviation (%)	15%

Table 5 presents the validation measures to determine the predictive performance of the migration model in terms of AUC, Bhattacharyya coefficient, and route deviation. Large amounts of AUC and Bhattacharyya coefficient imply good model performance.

Discussion

The combination of energetic landscape models with GPS telemetry played a significant role in predicting the path of migration in large mammals. The model was also effective in forecasting 85% similarity with the existing migration tracks by adding energy spending information and real-time tracking of movement. This method showed that migration routes are better predicted considering environmental factors like terrain, weather, and availability of forage as compared to the traditional models that use GPS only. The energy hotspots were also found in rivers and urban edges, which enhance energy consumption and migration barriers, which helps prove the previous results of the effect of environmental stressors on animal movement.

findings are consistent with the literature in the area of climate-driven changes in wildlife migration, such as those discussed in the UNEP reports. The postulated 15% northward migration route changes during the climate conditions (RCP 4.5 and RCP 8.5) are in line with other studies indicating that species are shifting towards higher latitudes and altitudes due to the rise in temperatures. These changes are due to the loss of forage and heat stress, which show the urgent necessity to use adaptive management techniques that will take into account future environmental conditions.

Significant conservation implications can be made in this model. This can be used to define the cost areas of high energy by determining the areas where wildlife corridors can be restored and informing the development of the dynamic regions of protection that respond to the migratory emphasis change. Moreover, real-time migration tracking provides the possibility of adaptive management when conservationists can react to the changes in migration patterns and energy stress in a proactive manner, so that animals can be supplied with appropriate habitats.

Although it has strengths, the study has weaknesses, including the lack of scale matches between GPS information and environmental information, and the possibility of collar bias in the number of times the animal is moving. Also, there is uncertainty in controlling the climate projections that have been used in the model, since actual climatic conditions could vary from the projected ones. These constraints indicate that the model requires further development, such as additional data collection and subsequent follow-up, to enhance the predictive ability of the model and its relevance to larger conservation initiatives.

Conclusions

This paper has effectively combined the energetic landscape models and GPS telemetry to forecast the changes in the migration routes of the large mammals, which provides a more dynamic and precise perspective on how climate change and habitat variations affect the movement of the wildlife. The model offers a practical framework for locating the most critical energy hotspots, predicting migratory deviations, and estimating the impact of such environmental stressors as forage decline and heat stress on migratory behavior. According to the findings, one can assume that the large mammals will tend to change the routes in the presence of climate change, and the migration patterns may shift up to 15% far north, especially when the climatic conditions become more aggressive (RCP 8.5). GPS tracking in real-time, as well as energy spending, is very promising in the conservation of wildlife. Real-time tracking of animals also creates an opportunity to implement the adaptive management technique; in fact, conservationists will be able to react much faster to alterations in animal movement and ensure the absence of barriers to their movement.

Nevertheless, the paper recognizes major weaknesses, such as data resolution discrepancies, possible collar biasing, and the inability to predict future climatic conditions. Nonetheless, the research offers an essential contribution to the existing body of research in the area of wildlife ecology and climate change adaptation, as well as improves the perspectives of further investigation and conservation strategies. Future development ought to be more species-specific and geographically broad, enhance the population of data in order to make more precise predictions, and include climate data over extended periods of time to further improve predictions on migrations. Integration of genetic data might also serve to inform the potential impacts of variation in migration patterns, genetic diversity, and resilience of wildlife populations on more effective and informed conservation approaches.

Reference

[1] Bassing, Sarah B., Lauren Satterfield, Taylor R. Ganz, Melia DeVivo, Brian N. Kertson, Trent Roussin, Aaron J. Wirsing, and Beth Gardner. "Predator–prey space use and landscape features influence movement behaviors in a large-mammal community." *Ecology* 105, no. 11 (2024): e4448. https://doi.org/10.1002/ecy.4448

[2] Berti, Emilio, Marco Davoli, Robert Buitenwerf, Alexander Dyer, Oskar LP Hansen, Myriam Hirt, Jens-Christian Svenning, Jördis F. Terlau, Ulrich Brose, and Fritz Vollrath. "The r package enerscape: A general energy landscape framework for terrestrial movement ecology." *Methods in Ecology and Evolution* 13, no. 1 (2022): 60-67.

[3] Buderman, Frances E., Ephraim M. Hanks, Viviana Ruiz-Gutierrez, Michael Shull, Robert K. Murphy, and David AW Miller. "Integrated movement models for individual tracking and species distribution data." *Methods in Ecology and Evolution* 16, no. 2 (2025): 345-361. https://doi.org/10.1111/2041-210X.14482

[4] Cappello, Caroline D., Kenneth V. Jacobson, James T. Driscoll, Kyle M. McCarty, and Javan M. Bauder. "Using integrated step-selection analyses to map high-risk electrocution areas for a highly mobile species." *The Journal of Wildlife Management* 89, no. 7 (2025): e70061. https://doi.org/10.1002/jwmg.70061

[5] Darlington, Siobhan, Andrew Ladle, A. Cole Burton, John P. Volpe, and Jason T. Fisher. "Cumulative effects of human footprint, natural features and predation risk best predict seasonal resource selection by white-tailed deer." *Scientific Reports* 12, no. 1 (2022): 1072.

[6] Day, Casey C., Patrick A. Zollner, Jonathan H. Gilbert, and Eric J. Gustafson. "Integrating mechanistic models of landscape change and animal behavior to measure functional connectivity." *Landscape Ecology* 40, no. 3 (2025): 1-24.

[7] Flack, Andrea, Ellen O. Aikens, Andrea Kölzsch, Elham Nourani, Katherine RS Snell, Wolfgang Fiedler, Nils Linek et al. "New frontiers in bird migration research." *Current Biology* 32, no. 20 (2022): R1187-R1199.

[8] Heit, David R., Christopher C. Wilmers, Waldemar Ortiz-Calo, and Robert A. Montgomery. "Incorporating vertical dimensionality improves biological interpretation of hidden Markov model outputs." *Oikos* 2023, no. 5 (2023): e09820. https://doi.org/10.1111/oik.09820

[9] John, Christian, Tal Avgar, Karl Rittger, Justine A. Smith, Logan W. Stephenson, Thomas R. Stephenson, and Eric Post. "Pursuit and escape drive fine-scale movement variation during migration in a temperate alpine ungulate." *Scientific Reports* 14, no. 1 (2024): 15068.

[10] Karpagam, M. "Animal Migration Patterns as Indicators of Environmental Change." *Journal of Animal Habitat and Environmental Interactions* (2025): 1-7.

[11] Klappstein, Natasha J., Jonathan R. Potts, Théo Michelot, Luca Börger, Nicholas W. Pilfold, Mark A. Lewis, and Andrew E. Derocher. "Energy-based step selection analysis: Modelling the energetic drivers of animal movement and habitat use." *Journal of Animal Ecology* 91, no. 5 (2022): 946-957. https://doi.org/10.1111/1365-2656.13687

[12] Lennox, Robert J., Pedro Afonso, Kim Birnie-Gauvin, Lotte S. Dahlmo, Cecilie I. Nilsen, Robert Arlinghaus, Steven J. Cooke et al. "Electronic tagging and tracking aquatic animals to understand a world increasingly shaped by a changing climate and extreme weather events." *Canadian Journal of Fisheries and Aquatic Sciences* 81, no. 3 (2023): 326-339. https://doi.org/10.1139/cjfas-2023-0145

[13] Mills, Kirby L., Martin Leclerc, Mark A. Ditmer, Zachary L. Steel, David C. Stoner, Joseph O. Sexton, Panshi Wang et al. "Long-term benefits of burns for large mammal habitat undermined by large, severe fires in the American West." *Ecography* (2025): e08225. https://doi.org/10.1002/ecog.08225

[14] Mukomberanwa, Nobert Tafadzwa, Phillip Taru, Beaven Utete, Patmore Ngorima, and Honest Komborero Madamombe. "Landscape Connectivity Modelling for the African Savannah Elephant with Spatial Absorbing Markov Chain and Predicting the Regenerative Power of the Range in a Mesic Protected Area." *African Journal of Ecology* 63, no. 2 (2025): e70034. https://doi.org/10.1111/aje.70034

[15] Naidoo, Robin, Cody Aylward, Wendy Elliott, Annika Keeley, Margaret Kinnaird, Michael Knight, Cristian-Remus Papp, Kanchan Thapa, and Rafael Antelo. "From science to impact: Conserving ecological connectivity in large conservation landscapes." *Proceedings of the National Academy of Sciences* 122, no. 31 (2025): e2410937122.https://doi.org/10.1073/pnas.2410937122

[16] Padró, Julián, Sergio A. Lambertucci, Pablo AE Alarcón, Johannes Signer, Paula L. Perrig, Pablo Plaza, Jorgelina Guido, José A. Donázar, Jonathan N. Pauli, and Niko Balkenhol. "Energy landscape and life-history requirements shape habitat use in an extreme soaring specialist." *Landscape Ecology* 40, no. 7 (2025): 136.

[17] Prima, Marie-Caroline, Mathieu Garel, Pascal Marchand, James Redcliffe, Luca Börger, and Florian Barnier. "Combined effects of landscape fragmentation and sampling frequency of movement data on the assessment of landscape connectivity." *Movement Ecology* 12, no. 1 (2024): 63.

[18] Secor, David H., Michael HP O'Brien, and Helen Bailey. "The flyway construct and assessment of offshore wind farm impacts on migratory marine fauna." *ICES Journal of Marine Science* 82, no. 3 (2025): fsae138. https://doi.org/10.1093/icesjms/fsae138

[19] Shuert, Courtney R., Marianne Marcoux, Nigel E. Hussey, Mads Peter Heide-Jørgensen, Rune Dietz, and Marie Auger-Méthé. "Decadal migration phenology of a long-lived Arctic icon keeps pace with climate change." *Proceedings of the National Academy of Sciences* 119, no. 45 (2022): e2121092119. https://doi.org/10.1073/pnas.2121092119

[20] Valderrama-Zafra, José M., Miguel A. Rubio-Paramio, Diego Francisco Garcia-Molina, Jorge Manuel Mercado-Colmenero, Antonia Oya, Rafael Carrasco, and Concepción Azorit. "Impact of topographic factors on animal field pathings: Analysis and prediction of deer movement patterns." *Ecological Informatics* 80 (2024): 102487. https://doi.org/10.1016/j.ecoinf.2024.102487