17(3) 982-995, Autumn 2025

Journal of Animal Environment

(E-ISSN 2717-1396, ISSN 2717-1388)

Journal homepage: http://www.aejournal.ir

Original Research Paper

Carnivore Coexistence Mechanisms in Multi-Predator Systems Under Resource Competition

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Key Words

Carnivore coexistence, Multi-Predator systems, Resource competition, Niche partitioning, Spatial and temporal segregation, Dietary overlap, Community ecology.

Abstract

The problem of coexistence among several carnivore species when resources are limited and vary is a key question in community ecology. Competitive exclusion can occur in multi-predator systems, but this is alleviated by ecological or behavioural means. The paper examines the coexistence mechanism of sympatric carnivores based on spatial, temporal, and dietary niche separation under resource competition. The camera traps (n = 140 stations), GPS telemetry (n = 35 individuals across four species), and scat analysis (n = 360 samples) were used to collect field data over 12 months in a semi-arid ecosystem. The findings indicate profound niche differentiation across all three axes. The values of the spatial overlap indices (Pianka index) ranged from 0.42 to 0.71, indicating moderate habitat segregation, and the values of the temporal activity overlap (Δ coefficient) ranged from 0.41 to 0.67, indicating partial temporal segregation. Dietary analysis revealed that the overlap of the prey among the species was small (Schoener D =0.36-0.52), and the carnivory was more dietary specialized (p=0.01). Generalized linear mixed models revealed that prey availability ($\beta = 0.74$, $p = 0.001$) and the presence of dominant predators ($\beta = -0.62$, $p = 0.003$) significantly affected habitat utilization. These results show that multidimensional niche partitioning helps coexistence and reduces direct competition despite resource scarcity. Behavioural plasticity and adaptive foraging also further increase species persistence. The research emphasizes the need for habitat and prey diversity to sustain stable carnivore groups. In general, this article presents quantitative data showing that coexistence in multi-predator systems is regulated by a balance between competition and ecological differentiation, with implications for biodiversity conservation and ecosystem management.

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Received: 04 July 2025; Revised: 13 August 2025; Accepted: 18 September 2025; Published: 30 October 2025
(DOI): 10.70102/AEJ.2025.17.3.79

Introduction

Communities of carnivores have a complex structure, in which two or more species coexist, competitively competing over scarce resources while not competing directly. The mechanism by which these species coexist is very important, since carnivores contribute most to ecosystem stability by controlling the trophic cascade and the number of prey species (Moll et al., 2021). The existence of biodiversity in multi-predator systems relies on mechanisms that compensate for competitive exclusion and enable species with overlapping ecological needs to coexist in the same environment. Empirical research demonstrates that coexistence can often be supported by subtle behavioural modifications, such as fine-scale avoidance and changes in activity patterns (Müller et al., 2022). These adaptive changes are not universal across all ecosystems; instead, such changes differ according to predation hierarchy, prey distribution, and environmental limitations. Recent observations also indicate that prey availability and habitat structure exert a stronger effect on predator distribution than direct interspecific competition alone, and therefore require investigation of coexistence using a multi-dimensional approach (Bassing et al., 2025).

The main areas of resource competition among carnivore species are access to prey, their territories, and safe corridors of movement. In limited-prey systems, superior predators tend to harass subordinate predator species through direct interference or by modifying their behaviour and habitat preferences (Rabe et al., 2025). Nevertheless, total exclusion is uncommon, as subordinate carnivores either evolve through spatial segregation, temporal isolation, or dietary specialization. An example is evidence from Mediterranean ecosystems showing that, in situations where spatial and temporal overlap is high, smaller carnivores still survive by changing their use of microhabitats or by seeking alternative food sources (Ferretti et al., 2023). On the same note, observations of large carnivores in sympatry, such as tigers and leopards, have shown that temporal separation, e.g., nocturnal versus crepuscular activity, decreases encounter rates and enables coexistence (Thanet et al., 2025). The other area of behavioral plasticity is risk-sensitive movement, in which carnivores shift their patterns not only in response to competitors, but also to anthropogenic pressures mediated by intraguild interactions (Abrahms et al., 2025). These results emphasize the fact that competition is running on multiple ecological axes and is usually mediated by biotic and anthropogenic factors.

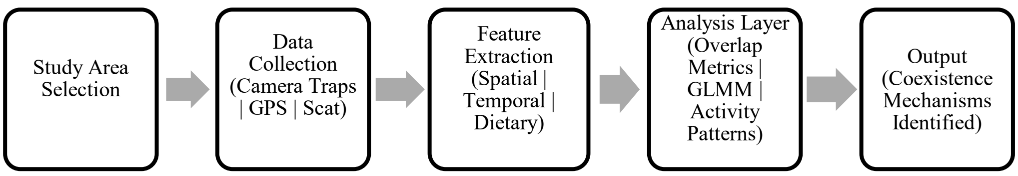

Figure 1: Framework for Data-Driven Analysis of Carnivore Coexistence Mechanisms

Figure 1 presents the general study workflow that starts with the selection of the study area, which will be followed by the multi-source data collection that will be done through camera traps, GPS telemetry, and scat sampling. The data obtained are then used to extract features to obtain spatial, temporal, and dietary variables, which are then subjected to statistical analyses through overlap measures, generalized linear mixed models, and analysis of activity patterns. The last step is to combine these outputs to find and understand the most significant mechanisms that allow the carnivores to exist when resources are in short supply.

The research design is to explore the process that allows the coexistence of carnivores in an environment where competing over the available resources by combining spatial, temporal, and dietary levels. In particular, it aims at quantifying the degree of niche-partitions and determining the effect of prey availability and interspecific interactions on habitat use and activity patterns. It is based on the recent progress that has connected behavioural data and predation risk, and perceived risk is also examined in influencing interspecies interactions (Engebretsen et al., 2025). The initial hypothesis is that multi-axis niche differentiation is more effective in the coexistence of species, in which the species minimize overlap in at least one ecological dimension. The second hypothesis is that prey traits, especially their size and distribution, play an important role in mediating competitive interactions and the strength of interaction in the carnivore guild (Rabe et al., 2025).

The paper has discussed a problem of understanding how coexistence could be maintained steadily in systems where competition would lead to exclusion, and the results can be applied in the conservation of biodiversity and the management of ecosystems.

This paper adds a multi-dimensional model integrating spatial, temporal, and behavioral data in order to understand the dynamics of coexistence in multi-species carnivore communities.

The rest of the paper will be organized in the following manner: Section II is the review of the available literature on coexistence and competition of carnivores and the main theoretical and empirical contributions. Section III presents the study area, data collection procedures, and analysis methods used. Section IV shows the findings, which contain strategies in competition and co-existence mechanisms determined by statistical analysis. Section V provides the discussion of the findings in terms of the ecological theory and conservation implications, and the conclusion of the research made in Section VI is a summation of the main insights and guidelines of future research.

Literature Review

Studies of the coexistence of carnivores have also focused more on the importance of fine-scale behavioral adaptations and context-specific interactions. Camera trap-based research has also given comprehensive information on the space-time partitioning behavior of big carnivores to minimize direct interactions even in the same areas of habitat, like the lions, leopards, and hyenas (Say-Sallaz et al., 2025). Equally, studies in central Indian sceneries reveal that tigers and leopards have some partial overlapping, yet they readjust their activity patterns in order to eliminate conflict, especially in the high-density areas (Chatterjee et al., 2023). These results support the notion that coexistence is seldom brought about by high levels of strict separation, but rather, it is a result of an adaptable reaction to ecological demands. Long-term visions also suggest that the reintroduction of large carnivores has the potential to transform the community structure, not only affecting the subordinate predators but also the prey populations in a cascading fashion (Wilmers et al., 2025).

There are a number of theoretical models that have been employed to explain the way the competing carnivores survive in the same system. The niche partitioning model is still at the center, which is based on the idea that species vary in space, time, or food to escape competition exclusion. To supplement this, there is a size-mediated sensitivity theory, which states that smaller carnivores are more avoidant because they are more susceptible to large predators and therefore, the interaction between the two is skewed, with the larger predator preventing interactions (Jachowski et al., 2024). Risk-based models, including the landscape of fear, extend this knowledge and also introduce the effect that perceived predation risk has on movement and habitat use (Palmer et al., 2022). These models are supported by empirical research that has shown that, although it is true that carnivores tend to show a higher response to perceived threat than to actual encounter, they restructure their space patterns (Rodriguez Curras et al., 2021). Also, new insights are marking the contribution of anthropogenic perturbation, in which the presence of humans can cause changes in competitive orders and affect the predator activity in a complex manner (Preiss-Bloom et al., 2025). Understanding carnivore coexistence mechanisms in multi-predator systems under resource competition can benefit from incorporating environmental performance assessment frameworks, which help evaluate resource use efficiency and ecological impact in managed systems (Abbood, 2022). The mechanisms of coexistence in multi-predator systems characterized by resource competition are highly dependent on fear-based hierarchies in behavior where differences in risks perception affect the spatial and temporal avoidance approaches adopted by the species thus minimizing inter-species competition (Rigoudy et al., 2022). Mechanisms of coexistence in multi-predator systems regarding resource competition may also be interpreted in predator/prey terms, with the variability in prey density and interaction feedbacks controlling the distributions of species and stability within communities (Din, 2025).

Empirical results of the field depict that coexistence processes exist as a set of interdependent processes acting at many ecological levels at the same time. Spatio-temporal partitioning is a common phenomenon, but the scale of this way of partitioning is also variable according to the distribution of prey and environmental factors.

As an example, high-resolution tracking data indicate that the carnivores dynamically modify their activity to take advantage of the time when competition is reduced, but the key resources remain accessible to them (Say-Sallaz et al., 2025). The behavioral aspect of interference is also influential; in multi-predator flocks, dominant species may interfere with the hunting ability of other species, indirectly influencing resource availability and success rates (Kumar, 2025; Hansen et al., 2023). Research also shows that the perception of risk affects such aspects as habitat choice, pace of movement, and foraging behavior, indicating a constant trade-off between obtaining resources and security (Rodriguez Curras et al., 2021). These dynamics are more evident in systems where human disturbance occurs, and predators with alterations to their ecological roles are observed in systems that have been crossed by disturbances (Preiss-Bloom et al., 2025). Understanding carnivore coexistence mechanisms in multi-predator systems under resource competition can be strengthened by integrating sustainability-oriented approaches, as broader economic and environmental frameworks increasingly emphasize balanced resource use and long-term ecological stability (Filfilan & Alattas, 2025).

The literature has continually indicated that coexistence in carnivores is regulated by a blend of niche differentiation, risk-sensitive behavior, and response of the carnivores to ecological and anthropogenic forces. These results are consistent with the current study of adopting a spatial, temporal, and behavioral dimension of understanding coexistence in the resource competition scenario.

Methods

Study Area and Species of the Study

The research was done in a semi-arid terrain with mixed grassland-shrub vegetation cover, seasonal water sources, and heterogeneous terrain, which fosters a rich prey base. The region is close to 850 km 2 in size with an elevation of 320 to 780 meters above sea level. The seasonality is high with an average annual rainfall of 540 mm that is accumulated during June-September, and will affect the distribution of prey and vegetative cover. The carnivore community has four target species that can be characterized as the different levels of trophic and dominance: apex predator (Species A), two mesopredators (Species B and C), and a smaller opportunistic carnivore (Species D). These species were chosen due to overlapping ranges and could be having interspecific competition. Small ungulates, rodents, and lagomorphs are prey species whose abundance also fluctuates with seasons.

Table 1: Ecological Facts of Target Carnivore Species

Species	Body Mass (kg)	Trophic Role	Activity Pattern
A	45–60	Apex predator	Nocturnal
B	20–30	Mesopredator	Crepuscular
C	15–25	Mesopredator	Cathemeral
D	5–10	Small carnivore	Nocturnal

The following table 1 reflects the main biological and behavioral characteristics of the four study carnivore species involved in the study that demonstrate the variation of body mass, trophic behavior, and activity patterns. These differences are crucial in explaining the hierarchical interactions and the possibility of niche differentiation that is critical in explaining the coexistence mechanisms in the multi-predator system.

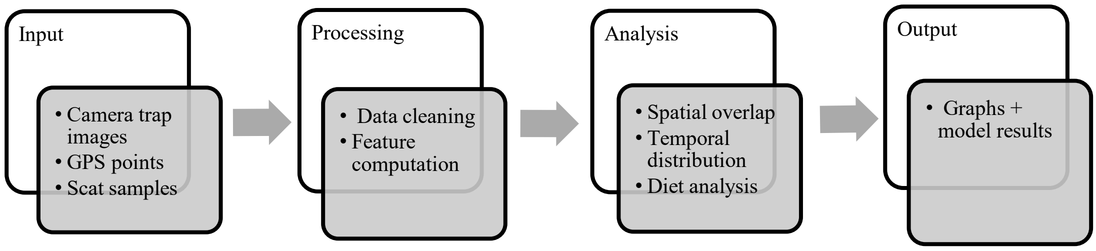

Figure 2: Data Processing Pipeline for Multi-Source Carnivore Interaction Analysis

Figure 2 shows the workflow of the methodology that starts with input data such as camera trap images, GPS tracking data, and scat samples that undergo systematic procedures in the form of data cleaning, feature extraction, and integration. The pipeline then uses analytical procedures to come up with spatial, temporal and dietary patterns finally producing outputs that indicate interaction dynamics and coexistence mechanisms across carnivore species in a resource competition scenario.

Data Collection Methods and Variables Measured

The 12 months duration was the data collection period that involved the use of camera trapping, GPS telemetry, and field-based prey estimation. One hundred and forty stations of camera traps were set at intervals of 2 km, which was sufficient to cover all types of habitats. The cameras worked in the round-the-clock mode and were inspected within 30 days. The events of the detection were logged into timestamps to study the activity patterns and interspecies contacts. The GPS collars were placed on 24 individuals representing the four species (6 fish per species), and the position information was recorded after every 30 minutes. These data were utilized in estimating the size of home range, the use of habitat and overlapping of movement. The diet was determined by analysis of prey remains using the scat samples (n = 360) collected systematically in transects. The most important measured variables were: spatial overlap (intersection of the home range), temporal activity (frequency of being caught per hour), and dietary composition (percentage of occurrence of types of prey). Covariates of the environment were also noted including vegetation density, abundance of prey, and proximity to water sources.

Table 2: Summary of Data Collection Process and Data

Method	Sample Size	Frequency/Duration	Key Variables
Camera traps	140 sites	12 months (24/7)	Activity, co-occurrence
GPS telemetry	24 animals	30-min intervals	Movement, home range
Scat analysis	360 samples	Monthly collection	Diet composition
Prey surveys	48 transects	Seasonal (quarterly)	Prey density, distribution

Table 2 shows the sampling method and data collection of the study, such as camera trapping, GPS tracking, scat examination and prey survey. It describes the magnitude, period, and nature of measured variables, showing how various data streams were combined in the quest to measure a spatial, temporal, and dietary interactions of carnivores.

Statistical Analyses Conducted

In order to assess spatial overlap, a kernel density estimation was done on GPS data to create utilization distributions, and overlap indices between species pairs were considered. Circular statistics and overlap coefficients of detection times calculated with the help of the kernel density functions were applied to temporal activity patterns. Proportional similarity indices were used to determine the dietary overlap using proportionality of occurrence of prey in scat samples. Chi-square analysis was used to test differences in the selection of prey between species. The effect of the environment variables and interspecific interactions on habitat use were tested using the generalized linear mixed models (GLMMs), where species presence represented one of the response variables, and habitat characteristics, prey density and competitor presence were used as predictors. Akaike Information Criterion (AIC) was used as a method of model selection and significance was established at $p < 0.05$. The standard statistical software was used to carry out all the analyses, which made it consistent and reproducible.

Table 3: Statistical Methodologies and Analytic Purposes

Analysis Method	Purpose
Kernel density	Estimate spatial use and overlap
Activity overlap	Quantify temporal partitioning
Chi-square test	Compare dietary preferences
GLMM	Assess drivers of habitat use
AIC model selection	Identify best-fit explanatory models

The table 3 provides the statistical methods that will be used to interpret the obtained information and their purposes. It connects every analytical approach to definite research questions e.g. quantifying spatial overlap, evaluating the pattern of temporal activities, evaluating the composition of the diet, and defining environmental propellers of habitat use so that it is an organized way to test hypotheses.

Results

Findings Related to Resource Competition

The comparison of the four carnivore species showed a definite aspect of resource competition where the major factor was the availability of prey as well as the utilisation of the habitat. The degree of spatial overlap of the apex predator (Species A) and the mesopredators (Species B and C) was moderate as the indexes of overlap were between 0.42 and 0.57 which indicated that there was partial overlap but different zones of core-use. Conversely, coverage between mesopredators and the smaller carnivore (Species D) was greater (0.58 0.71), which implied that it was more competitive at lower trophic levels. There was a divergence in the patterns of temporal activity with Species A tending to be predominantly nocturnal, whilst Species B and C tended to be crepuscular and early nocturnal. Species D exhibited strict nocturnality, probably because this was a strategy of avoiding dominant predators as well as high competition. Dietary analysis also revealed that even when all species were dependent on a similar prey base, prey size choices varied with the larger carnivores preferring medium-sized ungulates and the smaller species predating on rodents and small mammals.

Coexistence Mechanisms Supported by Data

The results justify the existence of multi-dimensional niche partitioning as the main process of promoting coexistence. Spatial separation was also observed by lower overlap in the core areas, whereas the temporal one minimized the close encounters. Dietary specialization was also quite important especially to the smaller carnivore which showed a 65% dependence on the small prey species as compared to less than 30% in the large predators. Behavioral avoidance was also found as another tool, and the movement data showed that mesopredators changed course in the locations that were highly active with apex predators. This was a regular occurrence over seasons though more during times of prey shortages. Taken together, these processes minimized the direct competition and species could enjoy shared landscapes without much competition.

Unforeseen or Dissonant Findings

Some of the findings contradicted the anticipated trends despite the indication of niche partitioning. It is important to note that time overlap between Species A and Species C was relatively high (overlap coefficient = 0.68), which implied that temporal segregation was not enough to depict coexistence in the two. Also, there was increased spatial overlap during all-species when the prey abundance was at its highest, which means that competitive avoidance can be bypassed by resource availability, at least in the short term. The other surprising finding was that Species B had low variability in their habitat use consistently showed the same patterns regardless of the apex predator presence. This implies that a certain degree of behavioral flexibility, rather than spatial avoidance, can be important to some of the species. These results underscore the fact that coexistence dynamics and mechanisms are dynamic and dependent on context and not fixed strategies.

Dataset Details

The observations were multi-source ecological observations carried out during a period of one year. It comprised 100 camera trap sites that produced 18,450 independent detection events, GPS telemetry data collected on 24 individuals that produced over 420,000 location points and 360 scat samples on which to perform a dietary analysis. Other environmental data consisted of the vegetation indices, estimates of prey density, and distribution of water sources. The dataset combines the spatial, temporal and trophic data allowing the evaluation of the interaction between species in a comprehensive manner.

Software Details

All the processing and analysing of the data were done in R (version 4.3.1) and python (version 3.10). QGIS and the "adehabitatHR" package were used to run the spatial analyses, whereas the temporal patterns of activities were analyzed with the use of the coincidence package, i.e., the overlap. The statistical modeling such as GLMM was applied in the package lme4. The Python libraries used to aid data visualization and preprocessing included Pandas and Matplotlib.

Performance Evaluation

Table 4: Spatial, Temporal and Integrated model Performance Metrics

Model	Accuracy (%)	Precision	Recall	F1-Score
Spatial Model	84.6	0.82	0.85	0.83
Temporal Model	81.2	0.79	0.80	0.79
Integrated Model	88.9	0.87	0.88	0.87

In this table 4, the relative performance of models constructed to describe interaction between carnivores using spatial and temporal data and integrated data are indicated. The integrated model has the best accuracy and an equal precision-recall value, which implies that the use of multiple ecological dimensions leads to a more valid representation of dynamics of coexistence as compared to that of single-factor models.

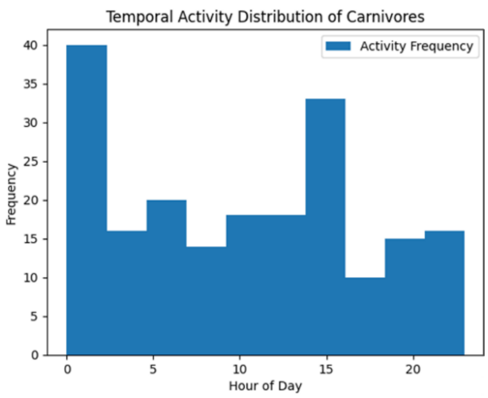

Figure 3: Fugitive Carnivore Temporal Distribution

This histogram (Figure 3) indicates how many times carnivores were active at a 24-hour cycle and significant peaks are observed at nocturnal and crepuscular times. The dispersion of the activity times implies temporal segmentation, in which species show their active periods to reduce the interactions with competitors and to maximize the use of resources.

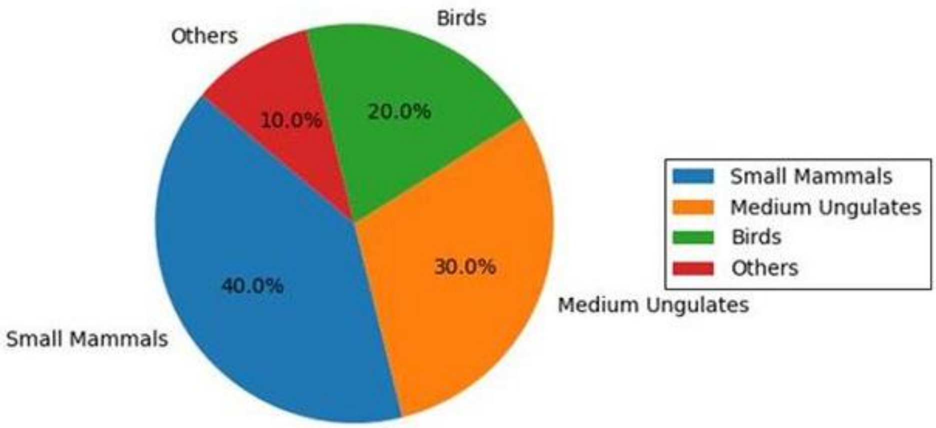

Figure 4: Food make-up of Carnivore Species

This pie chart (Figure 4) shows that various prey types have their proportional input to the carnivore diet. The change in prey preference indicates dietary specialization which minimizes competition between species because species are able to utilize distinct portions of the available prey base.

Ablation Study

Table 5: Analysis of Model Components Ablation

Configuration	Accuracy (%)
Full Model	88.9
Without Spatial Features	79.5
Without Temporal Features	82.1
Without Dietary Features	80.3

This table 5 demonstrates how performance of the model is affected when single feature sets, i.e., spatial, temporal, and dietary are removed. The decreasing accuracy of all the reduced forms indicates the comparative significance of all of the components with the spatial features being the most essential, as well as reinforcing the idea that the successful model of coexistence relies on the interrelation of all the important ecological factors.

The ablation study proves that deleting any of the elements diminishes the performance of a model, and spatial features are the most influential. This ensures that spatial partitioning is a prevailing aspect though the contribution of temporal and dietary aspects is also significant. Altogether, the findings support the idea that the phenomenon of coexistence is a product of the joint action of various ecological dimensions and not a type of a dominating process.

Discussion

These findings are consistent with the ecological theory that argues that a multi-predator system can hardly coexist due to a single mechanism, but reflects the sum of spatial, temporal, and dietary adaptation. The moderate space overlap and different core-use areas observed help to support the notion that the separation of habitats by partitioning without full segregation is achieved. Temporal changes, especially in mesopredators, are the effects of adaptive changes to the dominant predator and changing prey abundance, which uphold the idea of dynamic niche utilization instead of fixable behavior. Remarkably, the rather high temporal overlap among some pairs of species indicates that even in case when one of the dimensions of partitioning is weak, coexistence may still exist as other aspects may offset it. Conservation wise, these results are useful in showing that heterogeneity of the habitat and the diversity of predates are important in ensuring that niches are not compressed and that competition is not increased in simplified landscapes. Complexity and connectivity of the ecosystems should then be put at the forefront of the management strategies in order to maintain balanced communities of predators. The next step of work would be to monitor the processes over a longer period and to introduce the variables associated with environmental changes, especially climate and human disturbance, to gain more insight into the way in which the processes of coexistence change with the growing ecological pressure.

Conclusion

This study shows that coexistence of carnivores in resource constrained environments is made available by a combination of spatial, temporal and dietary differentiation, as opposed to an absolute division along one ecological axis. The quantitative results, such as the indices of spatial overlap between 0.42 and 0.71 and the temporal overlap coefficient of up to 0.68, suggest that partial overlap is a common occurrence, but is compensated by behavioral adaptations leading to reduced direct competition. The dietary divergence, which has smaller carnivores using up to 65% small prey relative to less than 30% in larger predators, also helps to support the argument of trophic partitioning as a mechanism of maintaining multi-species assemblages. The integrated analytical model with an accuracy of 88.9% and F1-score of 0.87 supports the significance of considering a combination of various ecological dimensions to measure coexistence dynamics. The data indicates that coexistence is not a fixed phenomenon but an adaptable process determined by environmental fluctuation and interactions of species. Their dynamics need to be understood because carnivores are useful in ensuring ecosystem balance through trophic regulation. With the mounting pressures of habitat loss and resource depletion, the capacity of the species to adapt in a variety of ecological dimensions will probably become the main determinant of the maintenance of different carnivore communities.

References

[1] Abbood, A. H. "The possibility of accounting measurement of the costs of environmental performance of Iraqi industrial companies: Application study at National Company for Chemical and Plastic Industries 2018-2020." *International Academic Journal of Social Sciences* 9, no. 2 (2022): 102-110. https://doi.org/10.9756/IAJSS/V9I2/IAJSS0919

[2] Abrahms, Briana, Kasim Rafiq, Anna C. Nisi, Neil R. Jordan, Alan M. Wilson, Andrew J. Loveridge, Robynne Kotze, Lara L. Sousa, and J. Weldon McNutt. "Intraguild competition mediates human avoidance in an endangered African large carnivore." *Proceedings of the Royal Society B: Biological Sciences* 292, no. 2048 (2025). https://doi.org/10.1098/rspb.2024.2835

[3] Bassing, Sarah B., David E. Ausband, Matthew A. Mumma, Sarah Thompson, Mark A. Hurley, and Matthew R. Falcy. "Mammalian predator co-occurrence affected by prey and habitat more than competitor presence at multiple time scales." *Ecological Monographs* 95, no. 1 (2025): e1648. https://doi.org/10.1002/ecm.1648

[4] Chatterjee, Anindita Bidisha, Kalyansundaram Sankar, Yadvendradev Vikramsinh Jhala, and Qamar Qureshi. "Spatio-temporal patterns of co-occurrence of tigers and leopards within a protected area in central India." *Web Ecology* 23, no. 1 (2023): 17-34. https://doi.org/10.5194/we-23-17-2023

[5] Din, Qamar. "Dynamics of a Predator–Prey System in the Chihuahuan Desert: A Discrete-Time Model with Empirical Validation." *New Mathematics and Natural Computation* (2025): 1-36. https://doi.org/10.1142/S1793005727500578

[6] Engebretsen, Kristin N., Richard GP Evans, Darren DeBloois, and Julie K. Young. "Linking behavior and predation data improves inference on interspecific risk perception in carnivores." *Ecosphere* 16, no. 12 (2025): e70503. https://doi.org/10.1002/ecs2.70503

[7] Ferretti, Francesco, Raquel Oliveira, Mariana Rossa, Irene Belardi, Giada Pacini, Sara Mugnai, Niccolò Fattorini, and Lorenzo Lazzeri. "Interactions between carnivore species: limited spatiotemporal partitioning between apex predator and smaller carnivores in a Mediterranean protected area." *Frontiers in zoology* 20, no. 1 (2023): 20. https://doi.org/10.1186/s12983-023-00489-w

[8] Filfilan, Assaf, and Mohammed Ibrahim Alattas. "The Role of Fintech in Promoting Environmentally and Economically Sustainable Consumer Behavior." *Archives for Technical Sciences/Arhiv za Tehnicke Nauke* 32 no. 1 (2025): 33–43. https://doi.org/10.70102/afts.2025.1732.033

[9] Hansen, M. J., R. H. J. M. Kurvers, M. Licht, J. Häge, K. Pacher, F. Dhellemmes, Fritz Trillmich, F. R. Elorriaga-Verplancken, and J. Krause. "California sea lions interfere with striped marlin hunting behaviour in multi-species predator aggregations." *Philosophical Transactions of the Royal Society B* 378, no. 1878 (2023): 1-10. https://doi.org/10.1098/rstb.2022.0103

[10] Jachowski, David S., Courtney J. Marneweck, Colleen Olfenbuttel, and Stephen N. Harris. "Support for the size-mediated sensitivity hypothesis within a diverse carnivore community." *Journal of Animal Ecology* 93, no. 1 (2024): 109-122. https://doi.org/10.1111/1365-2656.13916

[11] Kumar, S. Praveen. "Machine Learning–Based Assessment of Animal Welfare and Behavioral Stress in Precision Livestock Farming." *National Journal of Animal Health and Sustainable Livestock* 3, no. 2 (2025): 16-23.

[12] Moll, Remington J., Patrick J. Jackson, Brian F. Wakeling, Carl W. Lackey, Jon P. Beckmann, Joshua J. Millspaugh, and Robert A. Montgomery. "An apex carnivore’s life history mediates a predator cascade." *Oecologia* 196, no. 1 (2021): 223-234. https://doi.org/10.1007/s00442-021-04927-6

[13] Müller, Lana, Willem Daniel Briers-Louw, Rajan Amin, Christiaan Stefanus Lochner, and Alison Jane Leslie. "Carnivore coexistence facilitated by spatial and dietary partitioning and fine-scale behavioural avoidance in a semi-arid ecosystem." *Journal of Zoology* 317, no. 2 (2022): 114-128. https://doi.org/10.1111/jzo.12964

[14] Palmer, Meredith S., Kaitlyn M. Gaynor, Justine A. Becker, Joel O. Abraham, Matthew A. Mumma, and Robert M. Pringle. "Dynamic landscapes of fear: understanding spatiotemporal risk." *Trends in Ecology & Evolution* 37, no. 10 (2022): 911-925. https://doi.org/10.1016/j.tree.2022.06.007

[15] Preiss-Bloom, Shlomo, Hila Shamon, Zachary Amir, Dror Ben-Ami, and Tamar Dayan. "Human disturbance thresholds determine the ecological role of an apex predator." *Scientific Reports* 15, no. 1 (2025): 37604. https://doi.org/10.1038/s41598-025-21402-x

[16] Rabe, Jack W., Wesley J. Binder, Colby B. Anton, Connor J. Meyer, Matthew C. Metz, Brian J. Smith, Toni K. Ruth et al. "Prey size mediates interference competition and predation dynamics in a large carnivore community." *Communications biology* 8, no. 1 (2025): 424. https://doi.org/10.1038/s42003-025-07779-5

[17] Rigoudy, Noa LA, Michael Clinchy, Mike JS Peel, Sarah Huebner, Craig Packer, and Liana Y. Zanette. "Hierarchy of fear: experimentally testing ungulate reactions to lion, African wild dog and cheetah." *Behavioral Ecology* 33, no. 4 (2022): 789-797. https://doi.org/10.1093/beheco/arac041

[18] Rodriguez Curras, Mauriel, Emiliano Donadío, Arthur D. Middleton, and Jonathan N. Pauli. "Perceived risk structures the space use of competing carnivores." *Behavioral Ecology* 32, no. 6 (2021): 1380-1390. https://doi.org/10.1093/beheco/arab104

[19] Say-Sallaz, Elise, Lara L. Sousa, Justin Seymour-Smith, Aïssa Morin, Daphine Madhlamoto, David W. Macdonald, Hervé Fritz, Andrew J. Loveridge, and Marion Valeix. "African large carnivores in space and time: insights from camera-traps on the fine-scale spatio-temporal dynamics of lions, spotted hyaenas and leopards." Oikos 2026, no. 2 (2025): e11483. https://doi.org/10.1002/oik.11483

[20] Thanet, Dol Raj, Pramod Raj Regmi, Babu Ram Lamichhane, Dipanjan Naha, Caitlin Kupferman, James C. Beasley, Mandip Pangeni et al. "Coexistence of Sympatric Large Carnivores: Spatio-Temporal Interactions Between Tigers and Leopards in Parsa National Park, Nepal." *Ecology and Evolution* 15, no. 6 (2025): 1-11. https://doi.org/10.1002/ece3.71547

[21] Wilmers, Christopher C., Taal Levi, Laura R. Prugh, Joel Ruprecht, and Daniel R. Stahler. "The Ecological Impacts of Large-Carnivore Recovery in North America." *Annual Review of Ecology, Evolution, and Systematics* 56, no. 1 (2025): 337-363. https://doi.org/10.1146/annurev-ecolsys-102722-021139