Spatial Analysis of the Gray Wolf (Canis lupus)

Mohammed Bayati, Suneet D'Silva

Introduction

Wolves (Canis lupus): Apex predators critical for ecosystem balance.

Understanding spatial patterns helps reveal:

- Habitat preferences
- Human-wildlife interactions

Potential influencing factors:

- Topography
- Forest cover
- Human disturbance

Research Questions

- What is the spatial pattern of wolf sightings - random, clustered, or dispersed?
- How do environmental covariates such as elevation, forest cover, human disturbance, and proximity to water influence the intensity of sightings?
- Can spatial variation in sighting intensity be effectively modeled using an inhomogeneous Poisson process?

By addressing these questions, we seek to contribute to the ecological understanding of the wolf habitat preferences in western Canada and provide a statistical framework for analyzing spatial point data in ecological research.

Methods: Data & Workflow

Data

Data for Canis lupus were retrieved from GBIFusing the rgbif package.

Points were filtered to British Columbia, cleaned and retaining only those with valid coordinates.

Covariates included: *Elevation (m), Forest Cover (%), Human Footprint Index (HFI), Distance to Water (m)*

Workflow

Spatial clustering was explored using: Quadrat counts, Kernel Density Estimation, Ripley's K-function and pair correlation function

Point process models were fit using ppm(): First, a linear model with additive/quadratic terms. Then, a more flexible model using B-splines (bs()) to capture non-linear relationships.

Model performance was evaluated using:

Partial residual plots, Fitted intensity surfaces, Likelihood Ratio Test (ANOVA) comparing models

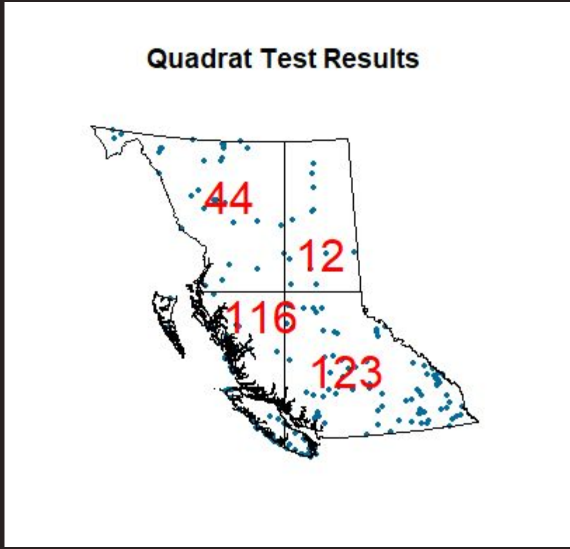
Packages used: `rgbif`, `spatstat`, `sf`, `ggplot2`, `splines`, `raster`, `rnaturalearth`, `rayshader`, `ape`, `gstat`, `gt`.

RQ1: Are Wolf Sightings Random, Clustered, or Dispersed?

Quadrant Test

Are Wolf Sightings Random, Clustered, or Dispersed?

We test whether sightings deviate from Complete Spatial Randomness using quadrat counts.

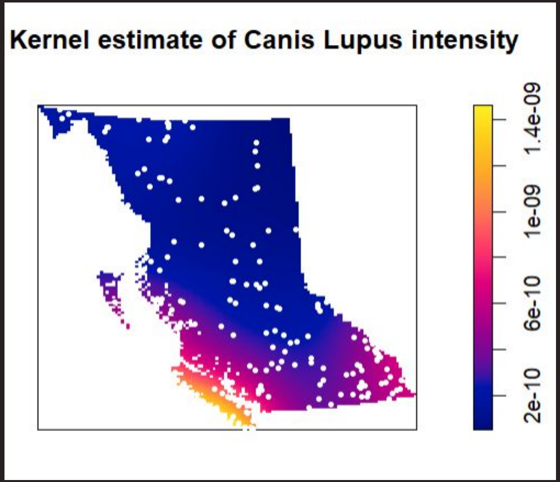


- Quadrats in the southwest show far higher counts, suggesting clustering.
- Sightings are not uniformly distributed across space.

Spatial Intensity: Kernel Density Estimate

Are Wolf Sightings Random, Clustered, or Dispersed?

We estimate the intensity of sightings across the landscape, independent of covariates.

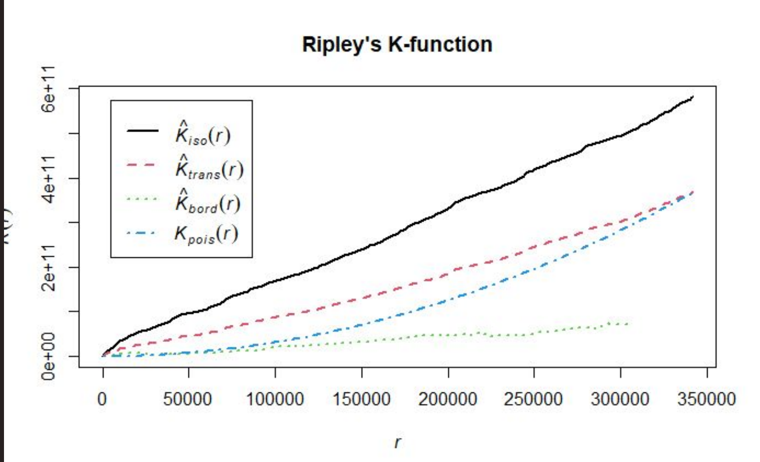


- Bright regions (e.g. southwest BC) show dense clusters of sightings.
- Other regions have few or no sightings.
- Confirms large-scale spatial inhomogeneity.
- But how statistically significant is this pattern?

Ripley's K-function: Detecting Clustering at Multiple Scales

Are Wolf Sightings Random, Clustered, or Dispersed?

We compare the observed spatial clustering of sightings against the null model of Complete Spatial Randomness (CSR).

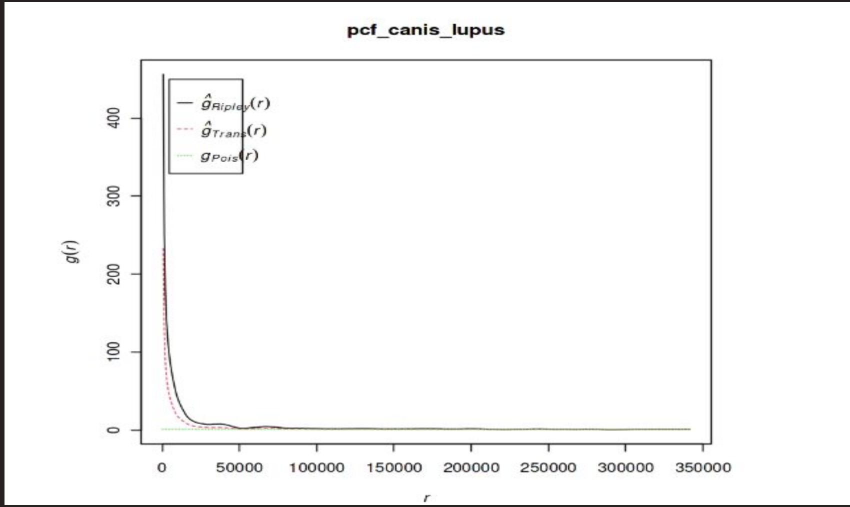


- Multiple K-function estimates (e.g., isotropic, translation) all lie above the theoretical CSR curve.
- This indicates clustering of wolf sightings over a broad range of distances.
- Isotropic correction shows the strongest departure from CSR, reinforcing the finding.
- Confirms non-randomness in wolf occurrence patterns.

Pair Correlation Function: Detecting Local Clustering

Are Wolf Sightings Random, Clustered, or Dispersed?

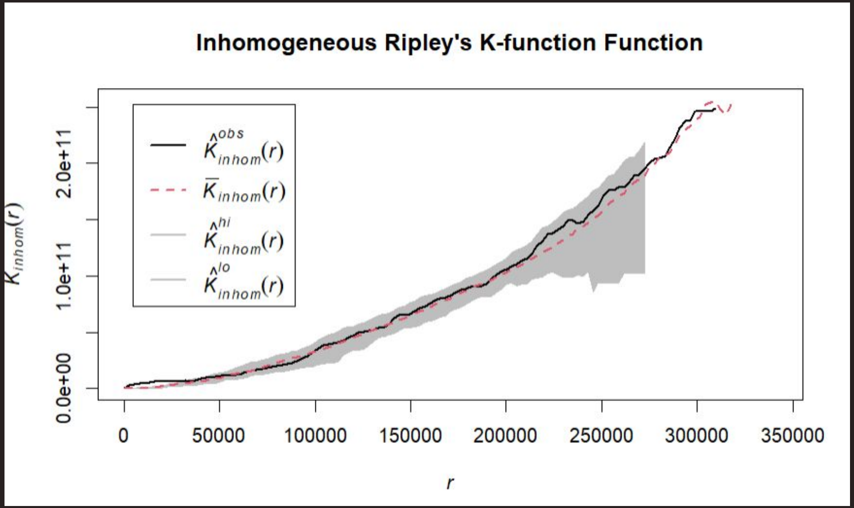
We use the PCF to measure how likely wolves are to occur at specific distances from one another.

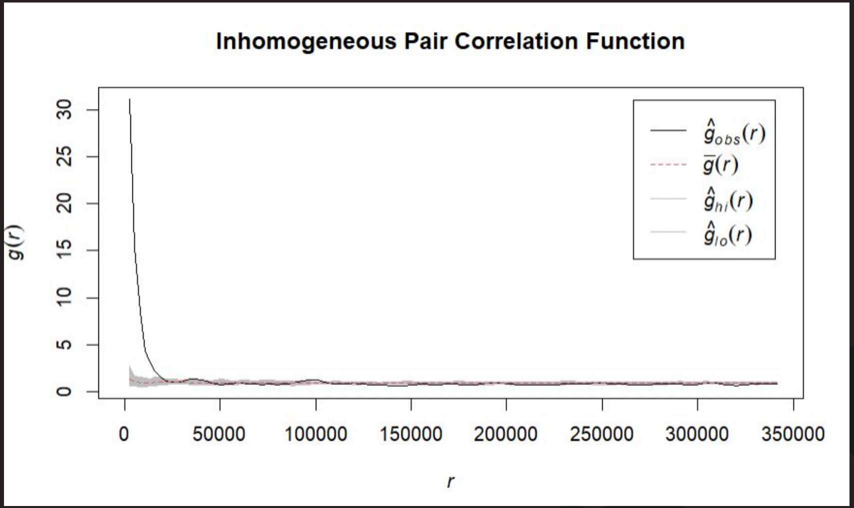


- Observed PCF > 1 at small distances → strong local clustering
- PCF < 1 at medium distances → possible territorial spacing
- PCF ~ 1 at large distances → pattern consistent with randomness
- Reinforces that clustering is most intense at fine spatial scales

Inhomogeneous Ripley's K-function and PCF

Are Wolf Sightings Random, Clustered, or Dispersed?





The observed K_inhom(r) rises above the simulated envelope - suggesting wolf clustering is not fully explained by the covariates.

At small r the pair correlation exceeds 1 → wolves cluster closely, even after accounting for spatial inhomogeneity.

Answering RQ1: Are Wolf Sightings Clustered?

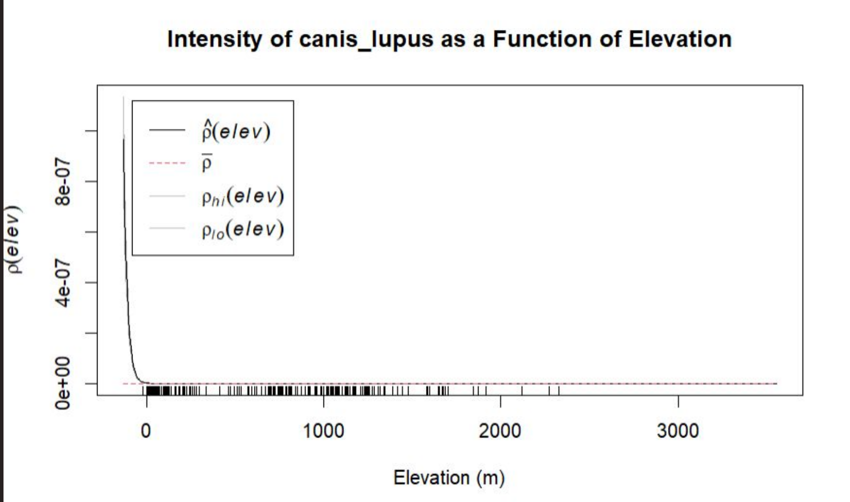
Across multiple methods, we find consistent evidence of spatial clustering in wolf sightings.

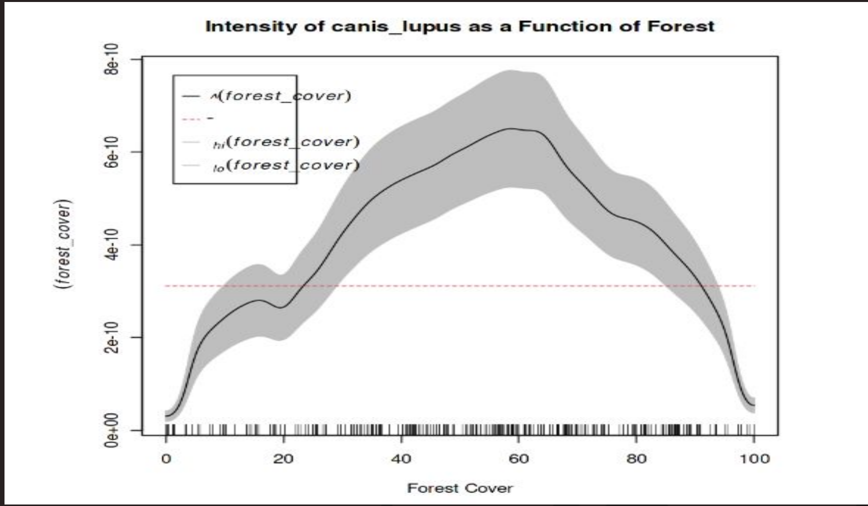
- Quadrat test shows far higher counts in the southwest quadrant.
- Kernel density estimation reveals distinct high-intensity clusters.
- Ripley’s K-function and pair correlation function exceed CSR expectations at most distances.
- Inhomogeneous models show clustering persists even after adjusting for environmental covariates.

RQ2: How do environmental covariates (elevation, forest, HFI, distance to water) influence wolf sightings?

Covariate Effects: Elevation and Forest Cover

How do environmental covariates influence wolf sightings?



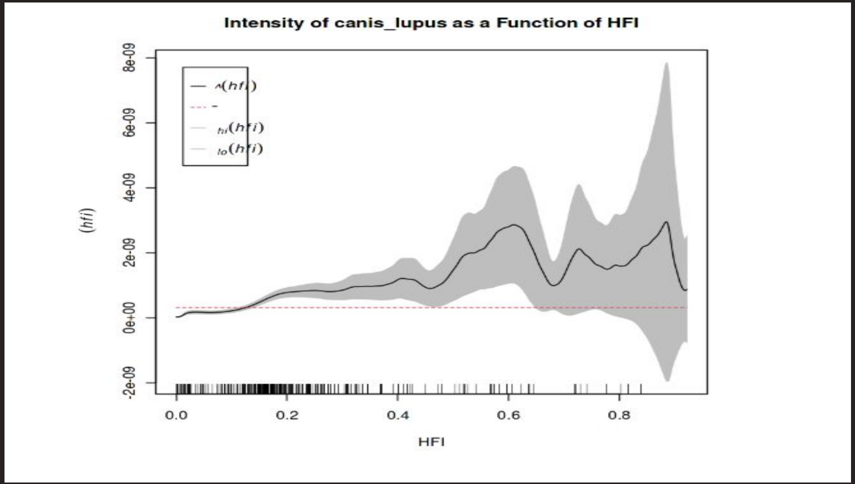


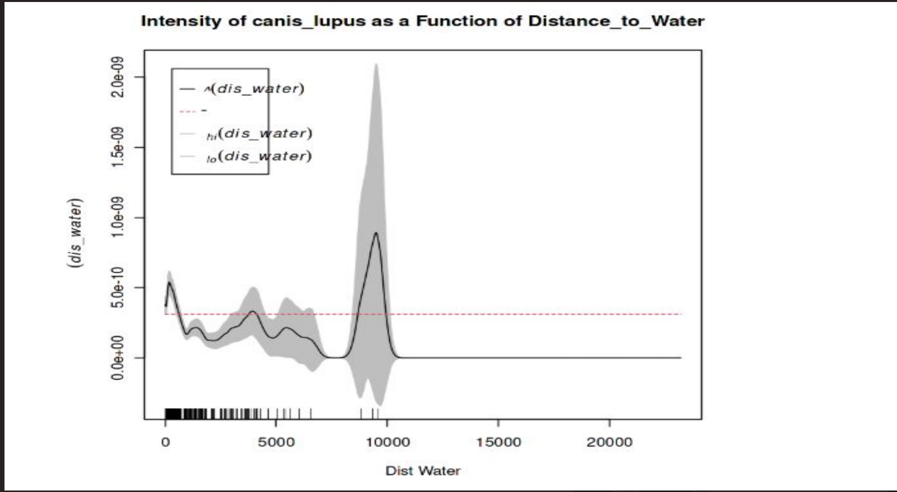
Wolf sightings drop rapidly with elevation, suggesting strong preference for low-altitude terrain

Sightings peak at ~60–70% forest cover – wolves may favour moderate cover over dense forest.

Covariate Effects: Human Disturbance and Water Proximity

How do environmental covariates influence wolf sightings?





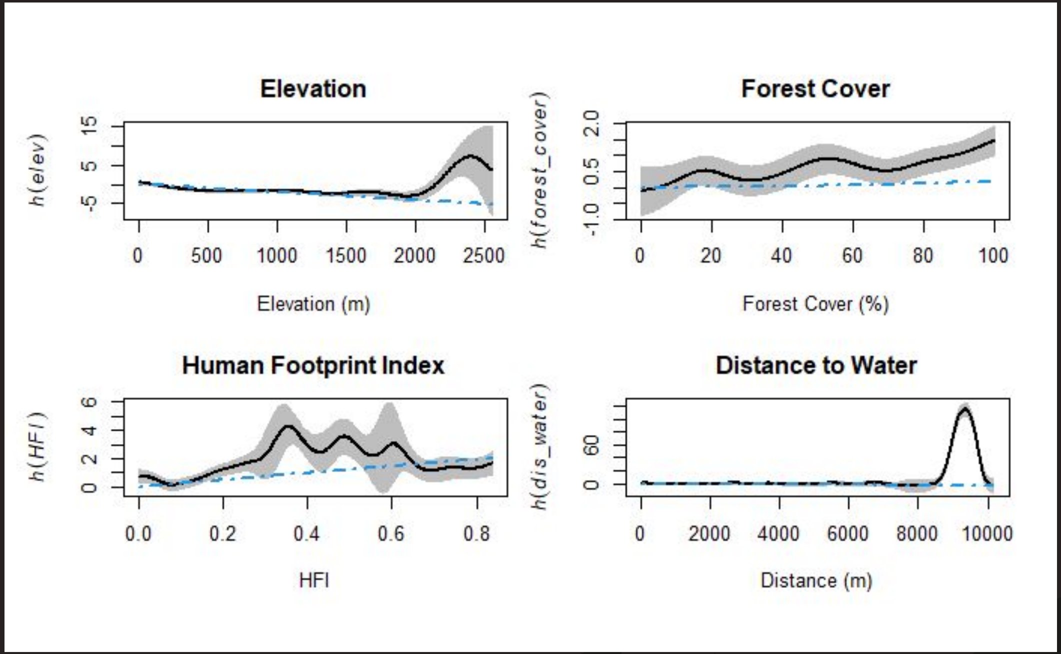
Sightings increase slightly with human presence, but drop under high disturbance.

Wolves cluster near water – sightings spike close to rivers and lakes.

Residuals from Linear Model

How do environmental covariates influence wolf sightings?

Do linear and quadratic terms explain variation in wolf intensity?



Elevation
Misses sharp increase above ~2000m - underfits high elevations.

Forest Cover
Fails to capture the nonlinear dip around 60% - curve too rigid.

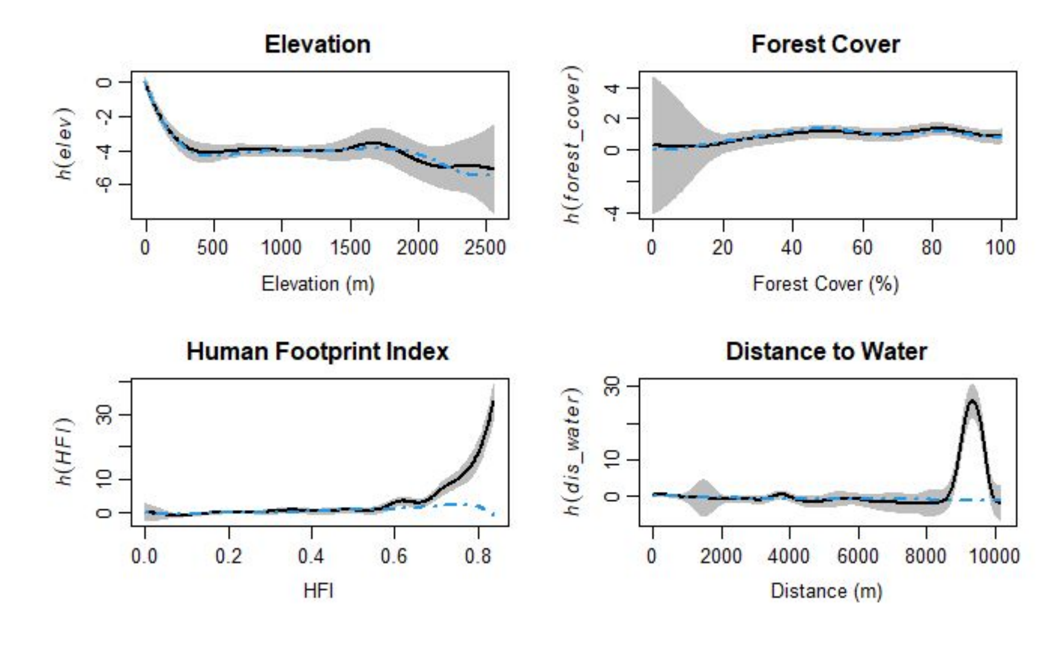
Human Footprint Index
Underfits mid-range HFI fluctuations - linear model too smooth.

Distance to Water
Ignores spike near 9000m - fails to capture clustering near water.

Refining the Model with Splines

How do environmental covariates influence wolf sightings?

Flexible spline terms better capture complex relationships.



Elevation
Captures nonlinear increase above ~2000m - previously missed by linear fit.

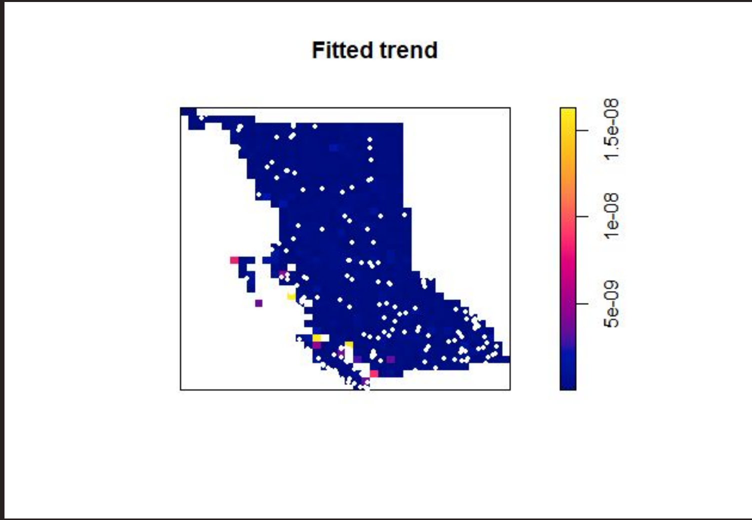
Forest Cover
Smoother dip and rise near 60–80% cover - spline adapts to curvature.

Human Footprint Index
Models rapid rise at high HFI - spline reflects steep behavior.

Distance to Water
Picks up spike near 9000m - spline reveals clustering near water.

Fitted Spatial Intensity – Spline Model

How do environmental covariates influence wolf sightings?



Likelihood Ratio Test: Model Comparison

Model	Formula	# Parameters	Residual DF	Deviance	p-value
1	~ elev + I(forest_cover^2) + hfi + dis_water	5	NA	NA	NA
2	~ bs(elev,7) + bs(forest_cover,8) + bs(hfi,9) + bs(dis_water,8)	33	28	366.08	< 2.2e-16

Predicted spatial variation in wolf sightings using spline-smoothed environmental covariates.

Spline model significantly outperforms linear model ($p < 2.2e-16$) - confirms importance of nonlinear covariate effects.

Answering RQ2: How do environmental covariates influence wolf sightings?

Across all covariates, we find clear nonlinear relationships shaping wolf intensity:

Elevation:
Intensity drops with elevation - sightings concentrated below ~2000m.

Forest Cover:
Wolves prefer 60–70% cover - intensity declines in sparse and dense areas.

Human Footprint Index (HFI):
Moderate rise across HFI, but intensity spikes in high-human areas.

Distance to Water:
Sightings show peaks around 9000m, suggesting preference for indirect proximity rather than shoreline adjacency.

Spline model substantially improved fit over linear terms, capturing these complex effects.

References

Main Data Source:

1. GBIF.org (2025). GBIF Occurrence Download for Canis lupus in British Columbia. https://www.gbif.org/occurrence/search?taxon_key=5219173&state_province=British%20Columbia&has_coordinate=true

Elevation and Forest Cover Covariate Interpretation:

2. Person, D. K., & Ingle, M. (2000). Wolf den site selection and characteristics in coastal British Columbia. BioEcon and the Raincoast Conservation Society. Retrieved from https://www.wellbeingintlstudiesrepository.org/context/bioeopp/article/1006/

Human Activity Covariate Interpretation (UBCO):

3. Dickie, M., Serrouya, R., Avgar, T., & Ford, A. T. (2022). Resource exploitation efficiency collapses the home range of an apex predator. Ecology, 103(1), e3642. https://doi.org/10.1002/ecy.3642

Distance From Water Covariate Interpretation:

4. Citation: Natural Habitat Adventures. (2021, November 9). The secret world of Canada's coastal wolves. Retrieved from https://www.nathab.com/blog/the-secret-world-of-canadas-coastal-wolves

References

Introduction:

5. Muñoz-Fuentes, V., Darimont, C. T., Paquet, P. C., & Leonard, J. A. (2009). Ecological factors drive differentiation in wolves from British Columbia. Journal of Biogeography, 36(8), 1516–1531.

6. British Columbia Ministry of Environment. (2014). Management Plan for the Grey Wolf (Canis lupus) in British Columbia. https://www2.gov.bc.ca/assets/gov/environment/plants-animals-and ecosystems/wildlife-wildlife-habitat/management_plan_for_the_grey_wolf_in_british_columbia.pdf

7. Darimont, C. T., Reimchen, T. E., Bryan, H. M., & Paquet, P. C. (2017). Resource selection by coastal wolves reveals seasonal importance of mature forest and open land cover. Forest Ecology and Management, 405, 56–65.