Modeling African Lion Movements and ecological corridor using MaxEnt and Grid Based clustering

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Motivation

- African lion populations have experienced **severe long-term decline and range contraction**
- Remaining populations are **highly fragmented**, increasing risks of isolation and local extinction
- Conservation priorities have shifted from population counts to **landscape connectivity**
- Available monitoring data is **presence-only, opportunistic, and spatially uneven**
- Conservation planning must therefore operate **under incomplete and uncertain information**

Nicholson (2024); Africa Geographic (2023)

Core problem

- Lion occurrence data is presence-only
- True absences are not observable (non-detection ≠ absence)
- Sampling effort is spatially uneven and clustered
- Classical presence–absence or likelihood-based models are poorly justified
- The task is to infer spatial probability under incomplete information

Move bank; Arcgis

Why MaxEnt?

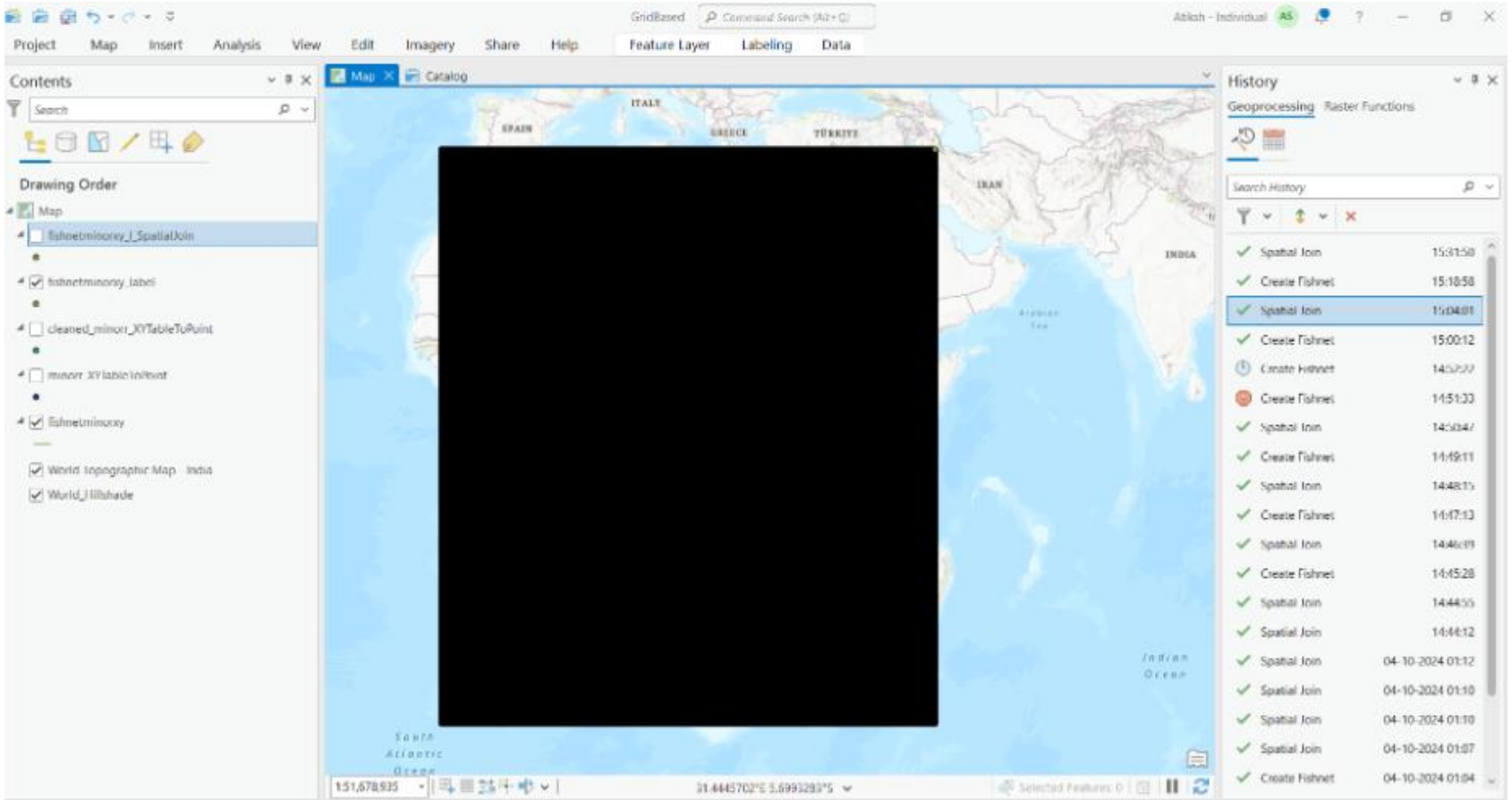
- To infer a probability distribution under incomplete information
- Choose the distribution that is maximally non-committal beyond known constraints
- Constraints encode ecological knowledge, not assumptions about absence
- Avoids unjustified likelihoods or deterministic structure
- Provides a principled probabilistic baseline for spatial inference

What we are actually inferring?

- A probability distribution over geographic space
- Random variable: lion presence conditioned on environment
- Constraints: empirical averages of environmental predictors at presence locations
- Output: relative habitat suitability, not observed occupancy
- Interpretation is probabilistic, not deterministic

Key Contribution: Spatial Regularization

- To reduce redundant information, not remove ecological signal
- Enforce spatial representativeness of presence records
- One representative occurrence per occupied grid cell
- No pseudo-absences introduced
- Preserves overall geographic coverage while stabilizing constraints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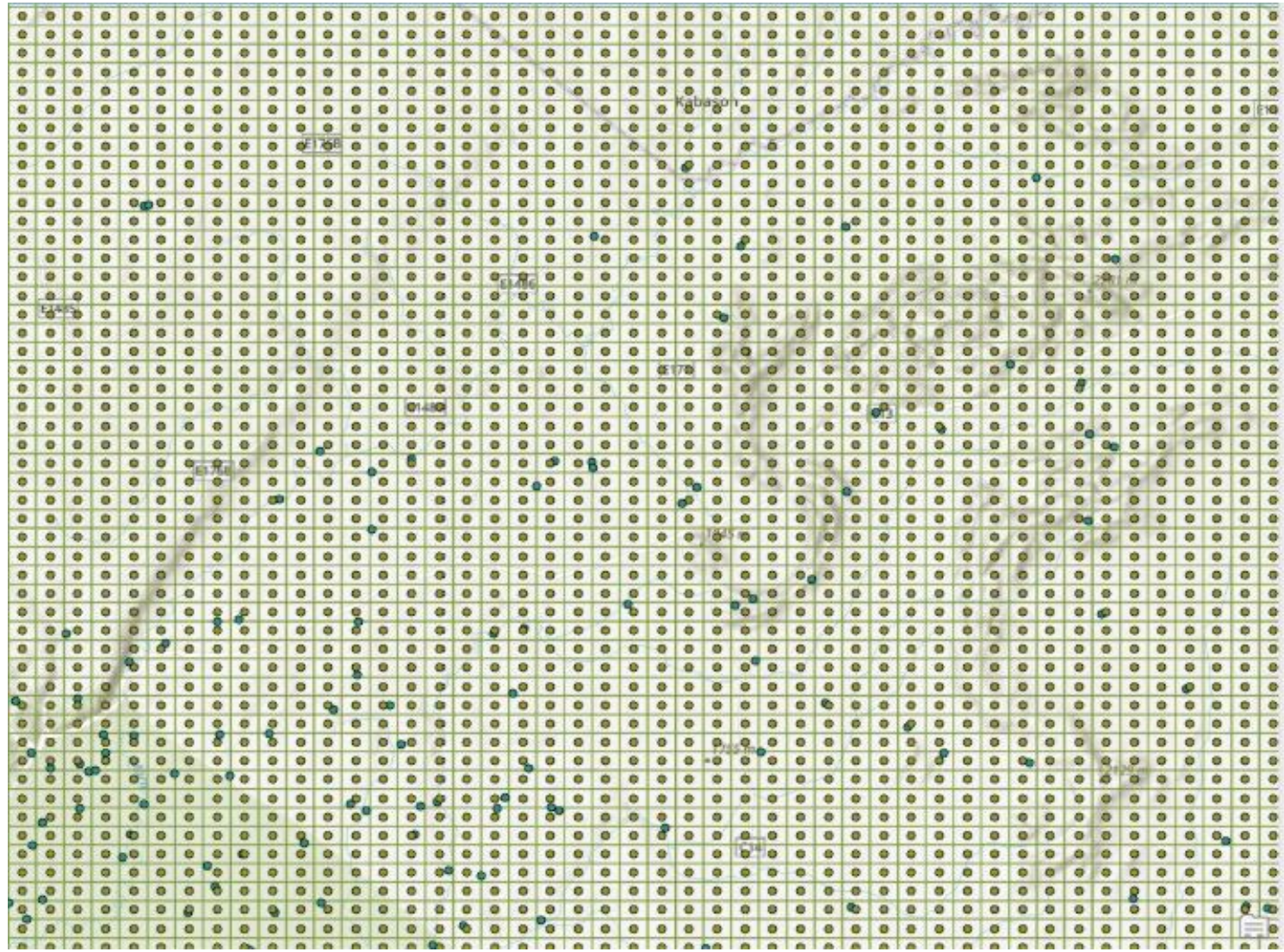
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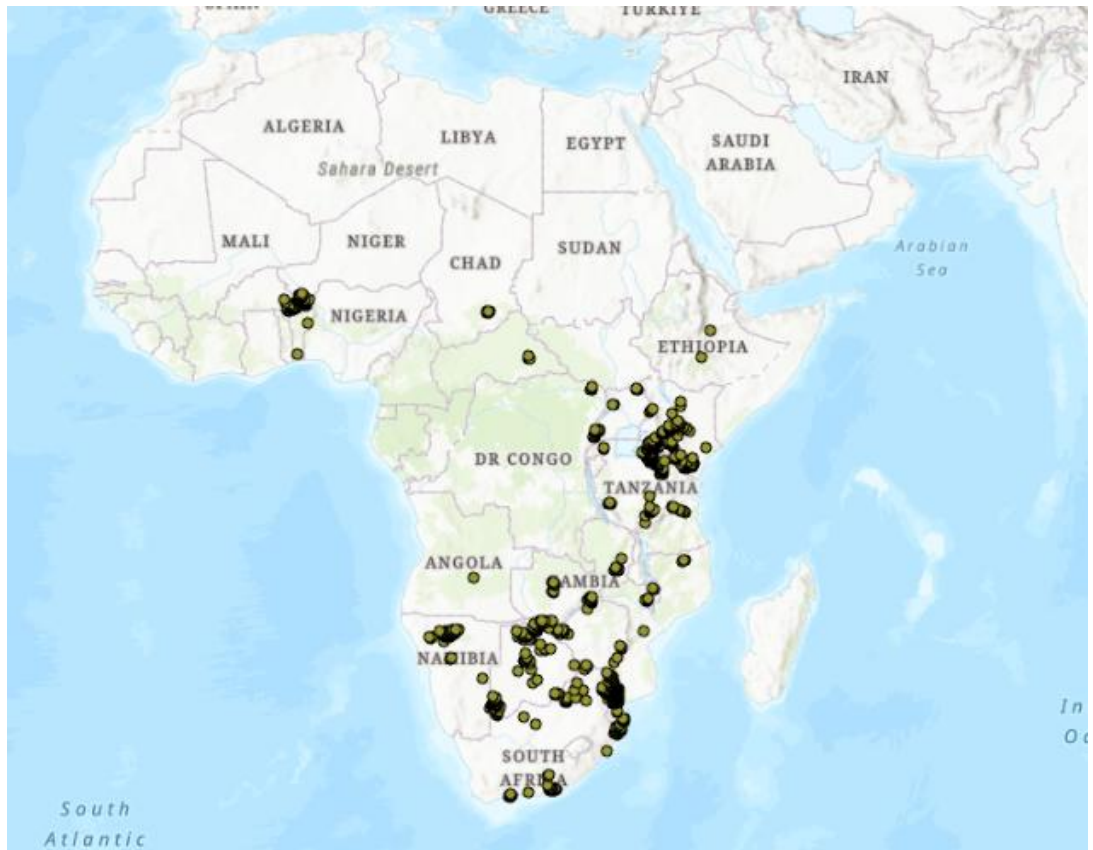
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Why this is MaxEnt-Consistent

- No absence or pseudo-absence information introduced
- Constraints remain empirical averages at presence locations
- Reduces redundant information, not ecological signal
- Improves stability of entropy maximization
- Acts before inference, not as model modification

Environmental Constraints

- Constraints derived from climatic conditions at presence locations
- Focus on seasonal precipitation regimes
- This model provides a parsimonious baseline for future constraint enrichment
- Variables selected for ecological relevance and parsimony
- Avoid over-parameterization under presence-only data
  - BIO16 – Precipitation of Wettest Quarter
  - BIO17 – Precipitation of Driest Quarter
  - BIO18 – Precipitation of Warmest Quarter
  - BIO19 – Precipitation of Coldest Quarter

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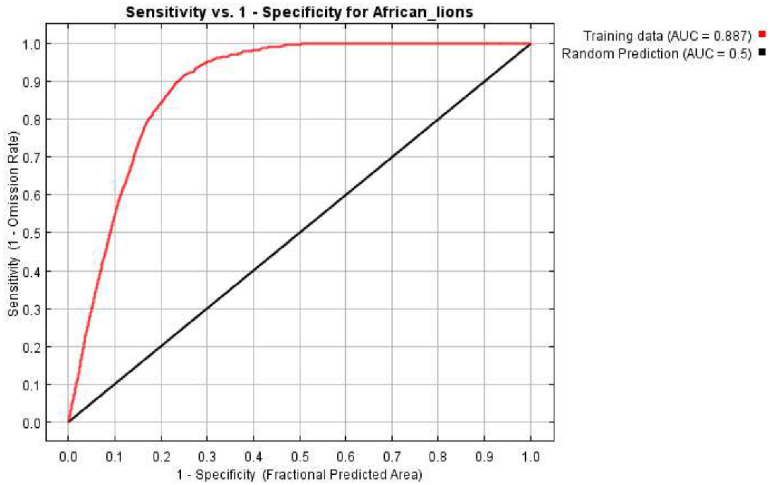
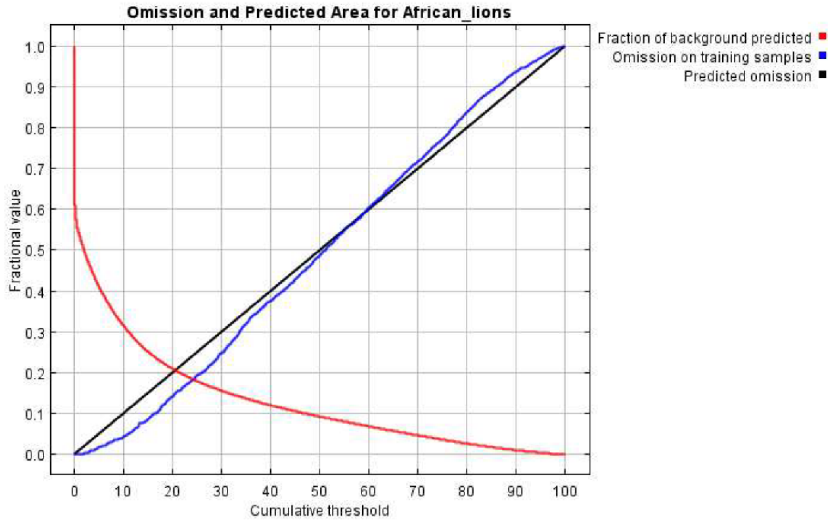
Model Performance

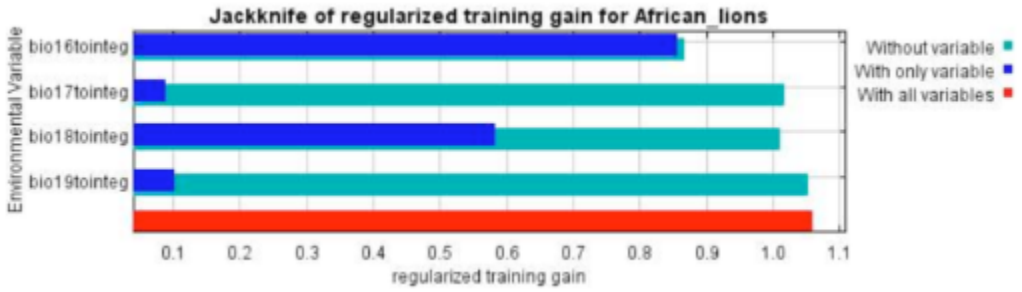
- Model discrimination evaluated using **ROC framework**
- Training AUC = **0.887**
- Indicates strong separation between presences and background
- Omission rates closely follow expected values
- No evidence of severe overfitting under regularization





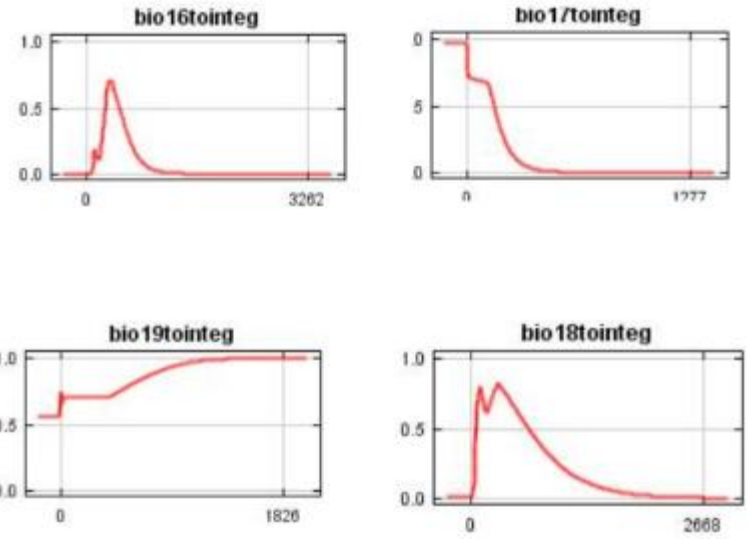
Predictor contribution

- Variable contribution assessed via training gain
- Jackknife analysis used to evaluate unique information
- BIO16 (Precipitation of Wettest Quarter) shows highest contribution
- Removing BIO16 causes the largest drop in model gain
- Other precipitation variables provide complementary but partially redundant information



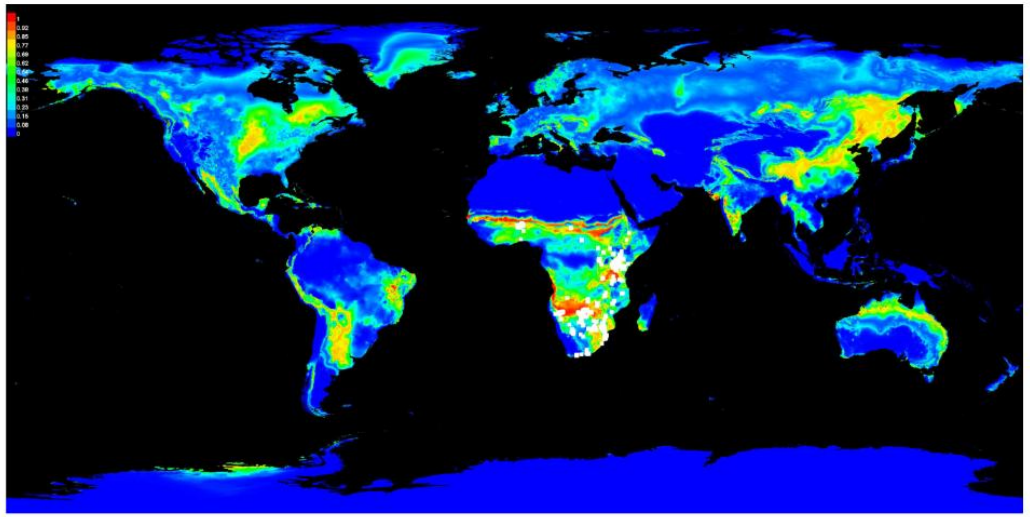
Response Curves

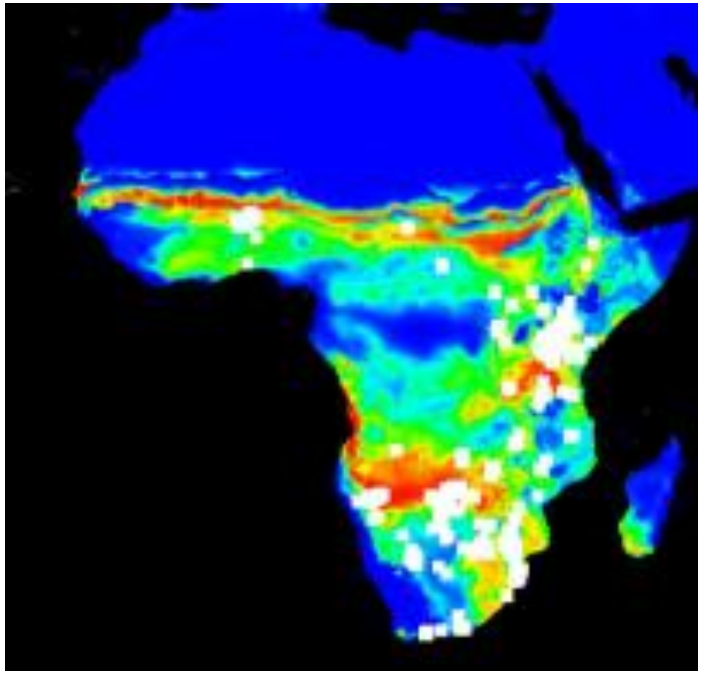
- Response curves show how suitability varies with each constraint
- Relationships are non-linear and unimodal
- Suitability peaks at intermediate precipitation ranges
- Extremely low or high values reduce suitability
- Patterns are consistent with known ecological expectations



Spatial Distribution

- Continuous regions of high relative suitability observed
- Patterns align with known lion strongholds
- Extended zones suggest potential connectivity corridors
- Interpretation is probabilistic, not deterministic





What this contributes

- Frames lion corridor identification as a probabilistic inference problem
- Demonstrates MaxEnt-consistent handling of presence-only data
- Introduces spatial regularization to stabilize information entering MaxEnt
- Produces interpretable suitability gradients, not hard classification.
- Provides a transparent, reproducible framework for conservation-oriented analysis

Limitations and Extensions

- Analysis based on climatic constraints only
- Does not explicitly model land use, prey density, or human pressure
- Suitability reflects environmental consistency, not observed movement

- Incorporate anthropogenic and land-use variables
- Integrate prey availability and vegetation structure
- Combine with movement or genetic data where available

Take-Home Message

- Lion conservation operates under severely incomplete information
- Maximum Entropy provides a principled framework for such settings
- Constraint quality matters as much as the inference method
- Spatial regularization improves robustness without adding assumptions
- Probabilistic suitability supports connectivity reasoning, not certainty