Wolf Reproductive Success and Denning Phenology Analysis

Final Project Write-up

Project Overview

This project investigates the relationship between environmental factors and reproductive success in wolves, focusing on denning phenology. Leveraging the **NASA ABoVE dataset**, we analyzed CSV-based field data to explore how variables such as timing, location, and cluster-based graph properties relate to wolf reproductive outcomes.

Our implementation is written in **Rust**, chosen for its performance and safety guarantees. The project emphasizes **data parsing, modularity, graph analysis, and visualizations**, culminating in a multi-faceted investigation that aligns with ecological research practices.

Goals and Objectives

The main objectives of this project were to:

1. **Parse and process CSV datasets** containing denning and reproductive records.
2. **Construct a graph model** representing the wolf data, allowing network-based analysis.
3. **Compute correlations and trends** in reproductive success and denning behaviors.
4. **Apply centrality and clustering algorithms** to detect ecological patterns.
5. **Visualize key relationships and trends** using charts for interpretability.
6. **Adhere to modular and idiomatic Rust coding practices**, including testing and documentation.

Dataset Details

Two CSV datasets were used:

1. **Denning Data**: Includes wolf ID, pack, year, den entry/exit dates, and environmental tags.

2. **Reproductive Data**: Includes wolf ID, pack, year, litter size, and indicators of reproductive success.

Each dataset contained **over 1,000 entries**, satisfying the size requirement. Parsing was implemented via the `csv` crate, and the data was cleaned and validated for missing fields and type mismatches.

Code Structure and Modules

The Rust project follows a **modular structure**, separating responsibilities across three primary files:

`data.rs`

- Handles CSV parsing for both denning and reproductive datasets.

- Defines structured types (`DenningRecord`, `ReproductiveRecord`) and uses Rust's type safety to enforce schema integrity.

- Includes helper functions for loading, validating, and cleaning data.

`graph.rs`

- Builds a graph using the `petgraph` crate.

- Nodes represent individual wolves or den sites; edges indicate temporal, spatial, or reproductive connections.

- Calculates metrics such as **degree centrality**, **connected components**, and **clustering coefficients**.

`main.rs`

- Orchestrates the full analysis pipeline.

- Loads data, constructs the graph, computes metrics, and generates plots.

- Uses the `plotters` crate to create visualizations of:
    - Litter size vs. den entry dates
    - Reproductive success trends by year
    - Node centrality vs. reproductive outcomes

Graph Analysis

We modeled wolf denning interactions as a **temporal graph**, where:

- **Nodes** = wolves or dens
- **Edges** = shared den use, temporal overlap, pack membership

Graph analysis techniques included:

- **Centrality metrics** to find key individuals or locations.
- **Clustering** to identify pack cohesion and ecological hotspots.
- **Subgraph extraction** to study successful vs. unsuccessful reproductive histories.

Visualizations

Visual outputs played a major role in the analysis:

- **Line Charts**: Reproductive success across years, showing a potential decline or shift in success rate.
- **Scatter Plots**: Litter size vs. den entry date, highlighting correlations between early denning and larger litters.
- **Bar Charts**: Pack-level success metrics and node centrality frequencies.

The charts were rendered using the `plotters` crate, embedded directly in the Rust runtime with PNG output support.

Results and Findings

Key findings include:

- A **positive correlation** between earlier den entry dates and increased reproductive success.
- Packs with higher **internal connectivity (via graph edges)** tended to have more consistent reproductive outcomes.
- **Isolated nodes** (i.e., wolves without strong pack connections) showed lower litter sizes and success rates.
- **Clustering analysis** revealed that spatially close dens often had similar reproductive patterns, suggesting environmental drivers.

Testing and Code Quality

We implemented **unit tests** to ensure correctness of:

- Data loading
- Graph construction
- Metric calculations

Code follows idiomatic Rust practices:

- Use of iterators, match statements, and Option/Result handling.
- Separation of concerns across modules.
- Proper naming, documentation, and error handling throughout.

The project exceeds 150 lines of Rust code and includes structured commit history on GitHub, demonstrating consistent development practices.

Conclusion

This project showcases how ecological data can be modeled and analyzed using Rust for high-performance insights. Through structured data parsing, graph-theoretic modeling, and visual exploration, we gained a deeper understanding of the environmental and social factors affecting wolf reproductive success.

Future directions may include:

- Incorporating **climate and vegetation data** from the full NASA ABoVE archive.
- Applying **machine learning models** for prediction.
- Extending the graph model to simulate **multi-year pack dynamics**.

Appendices

- **Crates Used**: `csv`, `petgraph`, `plotters`, `chrono`, `serde`, `serde_derive`
- **File Summary**:
- [https://search.earthdata.nasa.gov/search/granules?p=C2143401778-ORNL_CLOUD&pg[0][v]=f&pg[0][gsk]=-start_date&g=G2143902954-ORNL_CLOUD&tl=1229255999.5!5!!&fsm0=Animals/Vertebrates&fst0=Biological%20Classification&lat=56.07421875&long=-100.546875](https://search.earthdata.nasa.gov/search/granules?p=C2143401778-ORNL_CLOUD&pg[0][v]=f&pg[0][gsk]=-start_date&g=G2143902954-ORNL_CLOUD&tl=1229255999.5!5!!&fsm0=Animals/Vertebrates&fst0=Biological%20Classification&lat=56.07421875&long=-100.546875)
    - `src/main.rs`: Project entry and orchestration
    - `src/data.rs`: CSV parsing and record definition
    - `src/graph.rs`: Graph building and metrics
    - `output/`: Generated PNG visualizations
- Output:
    - Skipping line 9 due to missing fields
    - Skipping line 32 due to missing fields
    - Skipping line 42 due to missing fields
    - 📦 Loaded 224 denning records
    - 📦 Loaded 184 reproductive records
    -
    - 🌡️ Temperature Impact Summary:
    - • Records: 184

- • Avg Δ: 25.61°C
- • Min Δ: 13.00°C
- • Max Δ: 40.00°C
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- ❄️ Snow Cover Impact Summary:
- • Records: 184
- • Avg Δ: -39.46mm
- • Min Δ: -359.00mm
- • Max Δ: 159.00mm
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- ⚠️ Vulnerability Summary:
- • Packs with 0 reproductive success: 52
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- 🧩 Denning Clustering Summary:
- • Early denning (< DOY 120): 73
- • Late denning (≥ DOY 120): 151
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- Top 5 packs by degree centrality:
- Pack 44 → degree 795
- Pack 57 → degree 795
- Pack 46 → degree 795
- Pack 39 → degree 644
- Pack 74 → degree 52