

Outer Banks Coyote Project - Additional Deliverables Overview

NC State University Collaboration w/National Park Service Inventory & Monitoring Division

Grant # 533759

1. General Project Overview

These additional deliverables package documents the analytical outputs, spatial data, and R code produced for a multi-season study of coyotes (*Canis latrans*) on the barrier islands of the Outer Banks, North Carolina. The study was conducted at North Carolina State University in partnership with the National Park Service to address two interrelated objectives: (1) estimating coyote density and population dynamics, and (2) describing individual coyote movement and behavior.

Data collection spanned three sampling seasons — Winter 2024, Summer 2024, and Winter 2025 — across multiple barrier islands including Bodie, Pea, Hatteras, Ocracoke, North Core Banks, South Core Banks, and Shackleford Banks. Methods integrated non-invasive scat-based multi-state robust design mark-recapture models using microsatellite genotyping, accelerometer-informed GPS collars on five coyotes across Cape Lookout National Seashore, and experimental testing of fladry as a non-lethal coyote deterrent.

2. Top-Level Folder Structure

Each folder corresponds to a distinct analytical component of the study.

File / Folder	Description
Activity_Analysis_and_Visualizing_Results	Accelerometer-derived activity (VeDBA) data and visualizations for all collared individuals; includes raw sensor files, the combined VeDBA output, and the R visualization script.

All_scat_locations	Spatial data (shapefile and Excel) for all scat collection locations across all sampling seasons; coordinate system NAD 1983 StatePlane NC FIPS 3200 (Meters).
Calculating_Population_Growth_Rates_from_MSJS_Posterior_Samples	R scripts and JAGS model workspace for deriving population growth rates (λ) from the posterior distributions of the multi-state Jolly-Seber model.
Coyote_GPS_data	GPS collar fix data for five collared individuals (Azula, Cruella, Ed, Martha, Rahzar), organized by individual with both CSV and shapefile formats.
Custom_Island_Boundaries_w_Density_Per_Season_Appended	Custom OBX island boundary shapefile used for density calculations, with density estimates appended by season.
Describing_Inter_Island_Movements_w_Azula_GPS_Data_and_Time_Spent_Per_Island	R script analyzing and describing Azula's documented movement between Shackleford Banks and South Core Banks
Fladry_Analysis	R script and associated data for the fladry avoidance analysis, testing fladry as a non-lethal deterrent. We used the South Core Banks north/south partition shapefile to assign each GPS fix to either the north or south of the island prior to this Rscript using ArcGIS Pro.
Population_Modeling	Core population modeling folder: contains the complete robust design Jolly-Seber multi-state mark-recapture R script, density visualization script, and

	associated data and output subdirectories.
South_Core_Banks_Shapefile_w_North_South_Partitioned	Shapefile of South Core Banks with the island partitioned into northern and southern zones, used specifically to support the fladry spatial analysis.
Data_Dictionary.xlsx	Data dictionary documenting the variables and what they mean across the datasets produced by this study.

3. Analytical Components

3.1 Population Modeling: Robust Design Jolly-Seber Multi-State Model

Our population analysis uses an open-population robust design Jolly-Seber (RDJS) multi-state mark-recapture framework. Coyotes were individually identified through microsatellite genotyping of non-invasive scat samples collected across four replicate sampling rounds (survey round AKA secondary occasions) within each season (primary period). The model was implemented in R interfacing with JAGS for Bayesian estimation and simultaneously estimates apparent survival, recruitment, population size, and state-specific detection probabilities across islands and seasons. Posterior distributions from the fitted model are then passed to a separate script to calculate population growth rates (λ) and associated credible intervals.

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Input Data (Population_Modeling/data/)

- `obx_coyote_matrix_nathan - updated.xlsx` — The individual recapture history matrix. Each row is a genetically confirmed coyote (identified by `recapture_id`); columns represent each sampling round across Winter 2024 (w11–w14), Summer 2024 (s11–s14), and Winter 2025 (w21–w24). Cell values indicate which island the individual was detected on in a given round, with zero representing no detection. This is the primary capture history input to the RDJS model.
- `obx_coyote_island_key - Sheet1.xlsx` — Island-level sampling effort lookup table. Records which barrier islands were sampled in each broad season (w1 = Winter 2024, s1 = Summer 2024, w2 = Winter 2025) using binary indicators, and provides the mapping between numeric island codes and island names (Bodie, Pea, Hatteras, Ocracoke, etc.). Main purpose is to show the model we did not survey Bodie in Winter 2024.
- `trapping_matrix_complete.xlsx` — Island-level trapping effort matrix. Records whether each island received physical trap deployment across two inter-season trapping sessions (t1 = the interval between the end of Winter 2024 and the start of Summer 2024; t2 = the interval between Summer 2024 and Winter 2025) and whether road-based surveys were conducted (`roads_det`). Used to model detection probability and effort covariates in the RDJS framework.

R Scripts (Population_Modeling/)

- `OuterBanksCoyote_MarkRecapture_Complete_Script.R` — The complete RDJS model. Handles all data preparation (reading and formatting the recapture history and trapping matrices), JAGS model specification, MCMC sampling (1 million iterations, 200 burn-in), convergence diagnostics, and extraction of posterior estimates for abundance, survival, recruitment, and detection probability by island and season.
- `Calculating_Population_Growth_Rate_from_MSJS_Model.R` — Takes the saved JAGS posterior workspace as input and calculates population growth rates ($\lambda = N_{t+1}/N_t$) with 95% Bayesian credible intervals using two complementary approaches: (1) abundance-based λ derived directly from posterior draws of N ($N[2]/N[1]$ for interval 1→2, $N[3]/N[2]$ for interval 2→3), and (2) vital-rate-based λ derived from posterior apparent survival (ϕ , averaged across seven islands) plus per-iteration recruitment.
- `Visualizing_Density_Across_Islands_and_Seasons_Plus_Generating_Table_w_Abundances_w_95CrI.R` — Reads the posterior abundance and density outputs and produces spatial density maps across islands by season and a formatted summary table of abundance estimates with 95% credible intervals.

Model Outputs (Population_Modeling/output/)

- `jags_model_out_onemiliter_twohundburnin.RData` — Saved R workspace containing the full JAGS posterior sample object from the RDJS model run (1 million iterations, 200 burn-in). This is the master checkpoint file; the growth rate and visualization scripts load this object directly, so the computationally intensive MCMC chain does not need to be re-run.
- `jags_model_out_onmiliter_twohundburnin.xlsx` — Tabular export of key posterior summaries (means, credible intervals) from the JAGS model run, provided in Excel format for review without requiring R.
- `Robust_Design_Posterior_Distribution_Output_of_Abundance_to_Density.xlsx` — Derived density estimates converted from posterior abundance estimates using island area. Provides per-island, per-season coyote density with associated credible intervals; the direct source data for the density visualization script and maps.

3.2 Activity Analysis — VeDBA from Accelerometer Collar Data

Five individual coyotes were GPS collared which contained accelerometers on board that recorded tri-axial accelerometer bursts at 20 Hz. Vectorial Dynamic Body Acceleration (VeDBA) was calculated for each 3.4-second burst (68 samples per burst) as the mean Euclidean magnitude of dynamic acceleration across all three axes, where dynamic acceleration is the per-sample deviation from the burst-mean static acceleration.

Individual sensor files were processed through a common R pipeline and combined into a single output file (`vedba_all_individuals.csv`) covering all five collared animals: `coyote_12542`, `coyote_12547`, Ed, Martha, and Rahzar. The `visualizing_results.R` script performs the full activity analysis using that combined file. Key analyses include:

- Diel activity patterns: mean VeDBA by hour of day, plotted by season (summer = April–September; winter = October–March), both pooled across individuals and faceted per individual.
- Solar-normalized diel curves: timestamps are converted to a solar-normalized time axis (0 = sunrise, 0.5 = sunset, 1 = next sunrise) using actual daily sunrise and sunset times from the `suncalc` package at Cape Lookout coordinates (34.8141°N, 76.3606°W). Each burst is classified as day, crepuscular, or night. Seasons are labeled “Nesting/visitor (Apr–Sep)” and “Off-season (Oct–Mar)” in final figures.
- Nocturnality index: daily activity-weighted proportion of VeDBA occurring at night is computed per individual and summarized per season. A linear mixed model (`lmer: daily nocturnality ~ season + (1|individual)`) and a paired t-test (summer vs. winter, per individual) are used to test for seasonal differences in nocturnality.

- Nighttime VeDBA comparison: mean nighttime VeDBA (solar time $s \in [0.5, 1)$) is calculated per period with 95% confidence intervals, and the absolute and percent difference between nesting/visitor season and off-season is reported.

3.3 GPS Collar Data — Spatial Fix Records

All GPS fix locations are provided for all five collared individuals. Each individual's data is stored in a dedicated subfolder within `Coyote_GPS_data/` containing both a CSV of raw fix records and a projected shapefile (NAD 1983 StatePlane North Carolina FIPS 3200, Meters) for direct use in GIS.

Collared individuals and their study relevance:

- Azula — The only individual documented making inter-island movements traveling between Shackleford Banks and South Core Banks. Her GPS data is the subject of a dedicated movement analysis (see Section 3.4).
- Cruella — Resident individual
- Ed — Resident individual
- Martha — Resident individual
- Rahzar — Resident individual

3.4 Inter-Island Movement — Azula

Azula (coyote_12547) is the sole collared individual confirmed to have traveled between islands during the study period, moving among Shackleford Banks, South Core Banks, and Morgan Island. The R script `Exploring_Azulas_Inter_Island_Movements.R` documents the full detection and characterization of these movements using her GPS fix sequence and a custom island boundary shapefile (`azula_boundary.shp`; which is just a shapefile containing our custom boundaries shapefile for the Outer Banks only including the South Core and Shackleford polygons and an additional one named Morgan Island representing the islet) covering all three islands.

The analytical workflow proceeds as follows:

- GPS fixes are assigned to islands (Shackleford Banks, South Core Banks, Morgan Island) or Ocean via spatial join. Fixes with missing coordinates (31 rows, <1% of total) are removed prior to analysis.
- A bout-collapse algorithm reassigns short ocean excursions flanked by the same island ($A \rightarrow \text{Ocean} \rightarrow A$) back to that island, to avoid counting near-shore fixes as true crossings. Only ocean bouts flanked by two different islands ($A \rightarrow \text{Ocean} \rightarrow B$) are counted as inter-island crossings.
- Residency summaries are computed per island: total time (hours and days), total fixes, and proportional time and fix shares.

- Crossing events are tabulated with departure time, arrival time, crossing duration, and directional route. A transition matrix records crossing counts by origin–destination pair.
- Crossings are aligned to NOAA CO-OPS tide predictions (station 8656483, Beaufort, NC). A one-sided binomial test evaluates whether crossings occur at low tide more often than expected by chance (null expectation: 2/12.4 given semidiurnal tides and a ± 1 -hour low-tide window).
- The Morgan Island section isolates and summarizes the longest continuous Morgan Island bout, including its GPS fix sequence and duration in days.
- Multiple CSVs are exported: island residency summary, bout statistics, crossing events, tide alignment, crossing frequency by hour of day, and transition matrix.

3.5 Fladry Analysis — Non-Lethal Deterrent Testing

Fladry is a traditional livestock protection tool consisting of flagging hung along a rope perimeter. We tested it as a non-lethal coyote deterrent by setting up a fladry line across the width of South Core Banks during the deployment period June 17 – August 16, 2024. Three collared residents on South Core Banks (Ed, Martha, Rahzar) provided the GPS tracking data for this analysis.

GPS fixes for each individual were pre-processed in ArcGIS Pro: the South Core Banks island boundary shapefile was split into north and south zones along the fladry line, and each fix was spatially assigned to either the north or south side. The R script `Fladry_Analysis.R` then:

- Assigns each fix a period label (pre, during, or post deployment) relative to the deployment window.
- Computes weekly observation effort per individual (inter-fix hours, capped at 0.5 h to limit gaps) and detects southward-to-northward (S→N) crossings of the fladry line.
- Calculates crossing rates per 24 animal-hours by period, both pooled across individuals and per individual.
- Applies a robust crossing criterion requiring ≥ 30 minutes of consecutive north-side residence before a S→N transition is counted, reducing false positives from brief incursions.
- Performs Poisson rate tests comparing crossing rates during vs. pre and during vs. post deployment to assess whether fladry significantly reduced northward movement.

3.6 Scat Collection Locations

All scat sample collection locations are compiled in `All_scat_locations/`, provided as both a Microsoft Excel file and a full ESRI shapefile set. Locations are projected in NAD 1983 StatePlane North Carolina FIPS 3200 (Meters). Each point represents a scat collection event in

the field, identified by a globally unique GPS waypoint name (Bipoop[N], sequentially numbered across the entire study with no reset between seasons). Note that multiple scats were occasionally found at the same location, so the total number of rows in the CSV and shapefile does not exactly equal the total number of individual scat samples collected. The dataset includes the field collection timestamp (cmt_dt), season classification (Summer 2024, Winter 2024, or Winter 2025), and projected coordinates (X, Y).

4. Data Dictionary

A separate Data Dictionary (Data_Dictionary.xlsx) is included in the deliverables folder to describe all these additional deliverables. It documents the variables for each dataset provided in this additional deliverables folder, including field definitions, data types, units if applicable, and value ranges. Datasets covered include:

- OBX Island Key (island sampling effort by season)
- Individual recapture history matrix (microsatellite-based mark-recapture)
- Trapping effort matrix (per-island trapping sessions and road detection)
- All scat collection locations (GPS waypoints with survey season classification added)
- VeDBA all individuals (accelerometer-derived activity per collar burst)