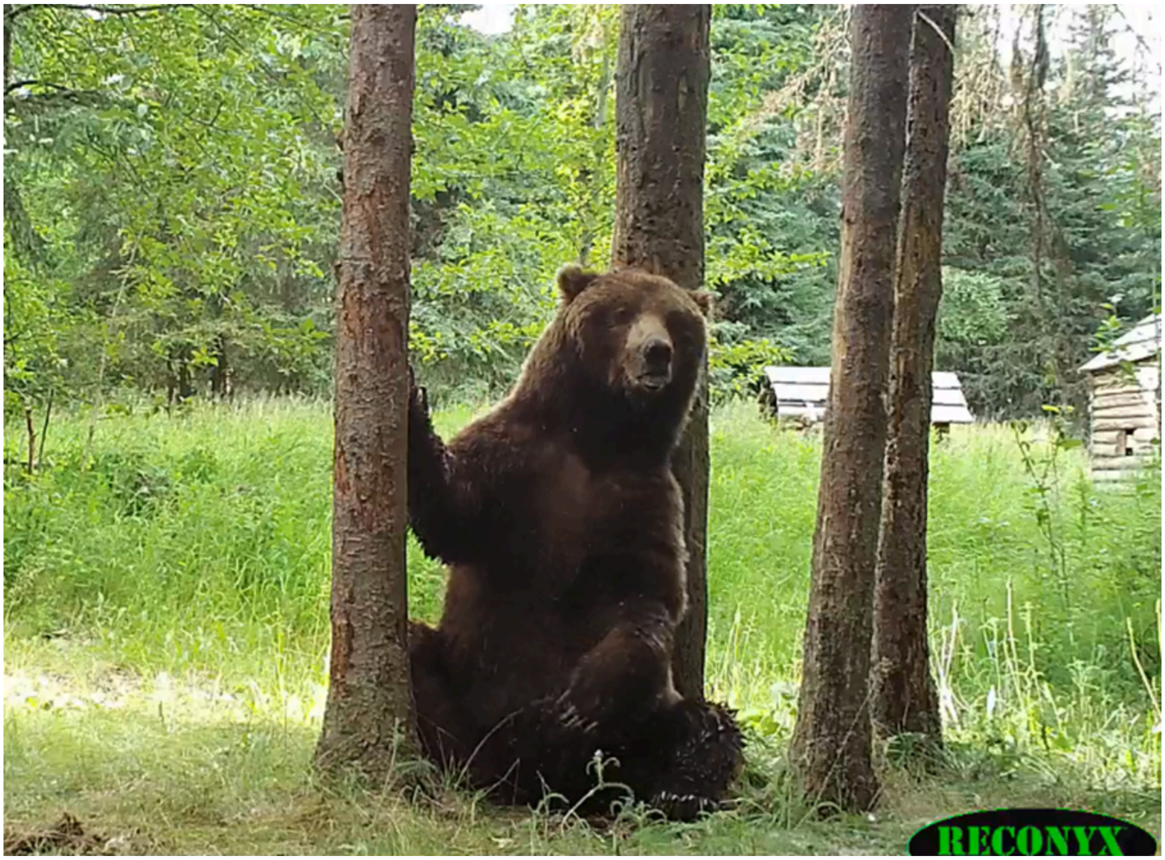
PROJECT OVERVIEW

Testing and Applying an Integrated Machine Learning Workflow as a Novel, Cost-Effective Mark-Recapture Technique to Monitor Brown Bear Population Status, Health, and Behavior on the Kenai National Wildlife Refuge.



Screenshot of a brown bear on the Kenai Peninsula, captured by a remote camera (camera trap).

BACKGROUND AND JUSTIFICATION

Understanding brown bear (Ursus arctos) population trends on the Kenai National Wildlife Refuge (KENWR) is a critical component of meeting the Refuge's purpose of conserving fish and wildlife populations and habitat in their natural diversity and providing opportunities for fish and wildlife–oriented recreation. Brown bears also play a crucial role in redistributing salmon-derived nutrients to the environment. Despite their importance, the remoteness of the Refuge makes it difficult and costly to monitor population trends.

In 2010, the KENWR established a baseline population estimate of 624 individuals using non-invasive DNA-based mark-recapture from hair samples. While this method is a significant improvement over invasive physical capture and radio-collaring, its reliance on frequent helicopter travel and lab analysis makes it cost-prohibitive to repeat for tracking population trends over time.

To address this challenge, we are moving beyond simplistic, single-method AI solutions. Initial concepts exploring facial recognition proved to be unreliable. Therefore, this project will pioneer a more robust and sophisticated integrated machine learning workflow to build a more reliable "digital fingerprint" for each individual bear.

PROPOSED METHODOLOGY AND WORKFLOW

This project will employ a state-of-the-art, multi-modal workflow that integrates a suite of machine learning tools. This process is designed to be a robust pipeline, moving from raw data to actionable ecological insights.

Step 1: Detection and Pre-processing

Tool: MegaDetector (Timelapse2 and EcoAssist).

Purpose: All remote camera trap imagery will first be processed using MegaDetector. Implemented through a powerful image management platform like Timelapse2, MegaDetector will automatically detect wildlife, filter out the vast number of non-animal images, and provide initial classifications. This creates an efficient, manageable dataset of bear-only images and videos.

Step 2: Core Data Extraction

Tool: DeepLabCut.

Purpose: For all bear videos, we will use DeepLabCut to perform markerless pose estimation. This involves training a model to identify the precise pixel coordinates of specific anatomical keypoints (e.g., nose, ears, shoulders, hips, paws) in each frame. The result is a quantitative, time-series dataset of each bear's unique posture, kinematics, and gait.

Step 3: Automated Individual Re-Identification

Tools: DeepLabCut-ReID and Miew v3 (WildNorth)

Purpose: This step uses two independent AI models to automatically suggest the identity of a bear. DeepLabCut-ReID uses the kinematic data to identify bears based on their unique "gait signature." In parallel, MiewID v3 analyzes visual data to identify individuals based on their unique pelage patterns and scars.

Step 4: Human-in-the-Loop Verification

Tool: WildCLIP.

Purpose: This vision-language model serves as the critical quality control step. It empowers researchers to use plain-text descriptions (e.g., "bear with a torn right ear") to search the image database. This is used to verify automated suggestions, resolve conflicts, and confirm new individuals.

Step 5: Potential Downstream Ecological Analysis

Tools: AmadeusGPT, 3D Pose and Volumetric Analysis models, and Social Network Analysis software (e.g., NetworkX)

Purpose: Once individuals are confidently identified, the workflow enables deeper ecological analysis. AmadeusGPT can classify behaviors (e.g., foraging, traveling). 3D Pose and Volumetric Analysis can be applied to estimate Body Condition Score (BCS), tracking health. Finally, Social Network Analysis tools can use co-occurrence data to map social structures.

PROJECT OBJECTIVES

Phase 1: Workflow Development & Validation (Years 1-2)

- Establish a "Gold Standard" catalog of individuals that can be identified with 100% certainty by human experts.
- Train and validate the integrated machine learning workflow against the "Gold Standard" catalog, with the objective of achieving an F1-Score of >0.90 for re-identification.
- Develop a probabilistic framework that assigns a quantifiable Identification Certainty Score to each observation to formally handle uncertainty.

Phase 2: Population & Ecological Analysis (Years 3-5)

- Apply the validated workflow to the full dataset to perform mark-recapture analysis using modern probabilistic models (e.g., Bayesian models) that incorporate the Certainty Score.
- Produce a robust population estimate and track trends from the 2010 baseline.
- Analyze novel data streams to assess population health via Body Condition Score (BCS) estimates and to map social dynamics.
- Disseminate all findings through reports to partners and peer-reviewed publications.

PROJECT DURATION

October 2025 - September 2030

ACTIVITIES AND TIMELINE

Project Phase	Key Activities	Major Deliverable(s)
Year 1: Setup & Validation	Procure all equipment. Finalize study design. Deploy cameras in a	- Fully operational camera trap grid.

	targeted area to create a "Gold Standard" photo-ID catalog of bears that can be identified with 100% certainty by human experts.	- "Gold Standard" catalog report.
Year 2: Model Training	Full field season of data collection. Train and validate the Re-ID models (DeepLabCut-ReID, MiewID v3) against the Gold Standard catalog. Develop the Identification Certainty Score framework.	- Internal report on model performance (e.g., Precision, Recall, F1-Score). - Validated Certainty Score methodology.
Years 3-4: Full Implementation	Expand camera grid. Apply the full workflow to the entire dataset. Begin preliminary population modeling using probabilistic models that incorporate the certainty scores.	- First preliminary population estimate with confidence intervals. - Technical paper on the workflow.
Year 5: Final Analysis & Dissemination	Final season of data collection for trend analysis. Conduct downstream ecological analyses (Health, Social). Final reports and publications.	- Final report with population trends. - Peer-reviewed publications on ecological findings.

PARTNERS

Alaska Department of Fish and Game: providing technical advice and support for the project.
Kenai NWR: will deploy camera traps and collect data.
Chugach National Forest: will provide access to the study area and support for the project.

BUDGET

The total budget for this project is $62,500.
- Camera traps: $12,500
- Mounts and solar panels: $5,000
- Software and computing resources: $15,000
- Personnel: $20,000
- Travel expenses and miscellaneous: $10,000

Budget Justification

The total budget of $62,500 is allocated to cover the full 5-year project duration. The Personnel funds ($20,000) are essential to support the field staff needed for camera deployment and data management. The Camera traps ($12,500) and Mounts/solar panels

($5,000) cover the core hardware for data collection. Crucially, the Software and computing resources ($15,000) are allocated for the necessary cloud computing credits (e.g., on AWS or Google Cloud) to train and run the computationally intensive AI models on our large video dataset, as well as for long-term data storage. Travel and miscellaneous funds ($10,000) will cover vehicle/boat transport and other essential field supplies.

RESOURCES

Field Staff: The project will be supported by a Lead Biotech, one seasonal biotech, two volunteer interns (at 25% time), and a pilot biologist (at 6 hrs/mo).
Aircraft and Fuel: Flights may be required for the deployment of camera traps to remote locations.
Boat: Boats will be required to transport equipment and crew to certain camera trap locations.

RISK ASSESSMENT AND CONTINGENCY PLAN

Risk Category	Specific Risk	Mitigation Strategy
Technical	Re-ID models underperform on Kenai bears.	Our multi-modal approach is the primary mitigation. If pattern-matching fails, we rely on gait, and vice-versa. The WildCLIP human-in-the-loop component ensures expert oversight and allows for manual correction.
Logistical	Gaps in data collection due to camera trap failure or damage.	Budget includes spare camera units for rapid replacement. Solar panels will minimize power-related failures. Sites will be checked periodically to ensure functionality.
Analysis	The volume of video data proves too large for available computing resources.	The workflow is designed to be efficient; MegaDetector drastically reduces the number of files needing intensive analysis. The budget for software and computing is specifically allocated for cloud computing credits to handle peak processing loads.

DATA MANAGEMENT PLAN

All data will be managed according to a formal DMP. Raw images and videos will be stored on secure Refuge servers with a secondary backup on a separate cloud platform. All processed data, including model outputs and individual bear IDs, will be stored in a structured database with standardized metadata. In accordance with data sharing policies, anonymized data products and final reports will be made publicly available through an appropriate repository.

STUDY AREA

The study area for this project is the Kenai National Wildlife Refuge, located in southcentral Alaska. The refuge covers over 2 million acres and includes a diverse range of habitats, including boreal forests, wetlands, rivers, and glaciers.

ETHICS AND PERMITS

This project will be conducted in accordance with all applicable state and federal laws and regulations regarding the use of non-invasive techniques to study wildlife. All research activities will be reviewed and approved by the Institutional Animal Care and Use Committee (IACUC). Permits will be obtained from the Alaska Department of Fish and Game, Chugach National Forest, and the U.S. Fish and Wildlife Service.

CONCLUSION

This project leverages powerful advances in artificial intelligence to move beyond the limitations of traditional monitoring methods. By implementing an integrated workflow designed to handle the real-world challenge of identification uncertainty, we can non-invasively identify individual bears and assign a confidence level to each identification. The use of modern probabilistic models will produce a more accurate and defensible estimate of population size. Furthermore, the rich, multi-faceted data on animal health and social dynamics will allow for the development of highly targeted and effective conservation strategies tailored to the specific needs of the Kenai brown bear population.