Decision-Making During Migration: How Lake Melting and Freezing Affect Caribou Water Crossings in the Arctic

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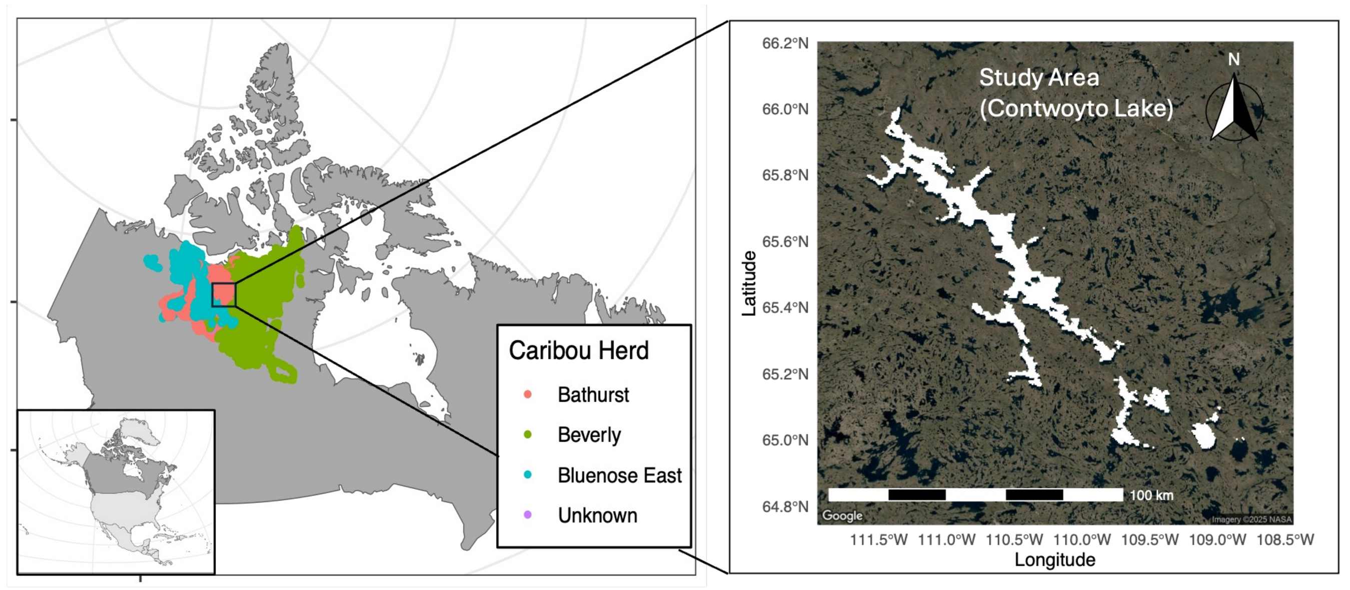
INTRODUCTION

- Seasonal migration allows animals to access food, avoid predators, and reach reproductive habitats. In the Arctic, where lake ice serves as a critical seasonal corridor for movement, rapid warming is reducing ice reliability and disrupting established migratory routes.
- Barren-ground caribou (*Rangifer tarandus*), iconic long-distance migrators, rely on stable ice to cross large lakes efficiently. Deteriorating ice conditions can force detours, increasing energy expenditure, travel time, and risks such as drowning or predation. These challenges are especially critical during spring migration, when pregnant females migrate to calving grounds—a highly synchronized event where delays can compromise reproductive success.
- Contwoyto Lake, a major migratory route for the Bathurst herd, has experienced increasing ice instability. This shift coincides with a dramatic population decline—from 480,000 to fewer than 7,000 individuals over the past 30 years—highlighting the urgent need to understand how changing ice conditions influence caribou lake crossing decisions during migration.

DATA



- **Caribou GPS Data:** 406 adult barren-ground caribou (2001–2021), within 50 km of Contwoyto Lake
- **Remote Sensing Data:** MODIS daily surface albedo (500 m), Days 92–280 (excluding polar night); Land Cover: MODIS land cover (500 m)

METHODS

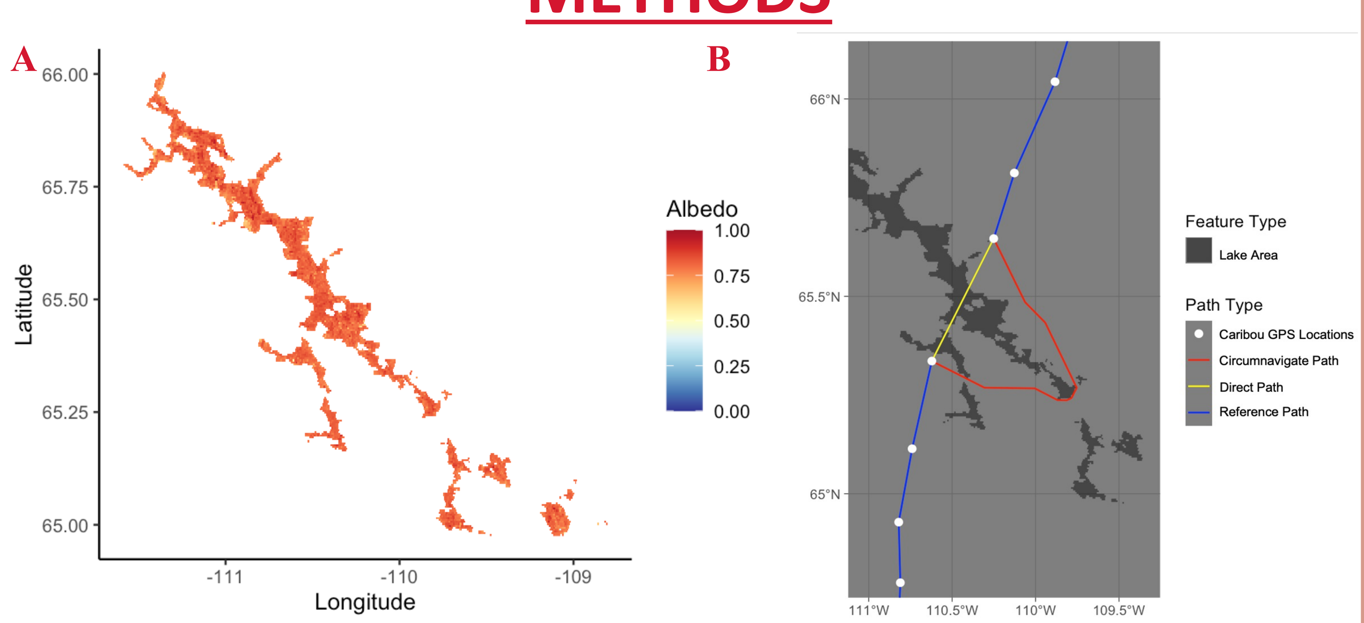
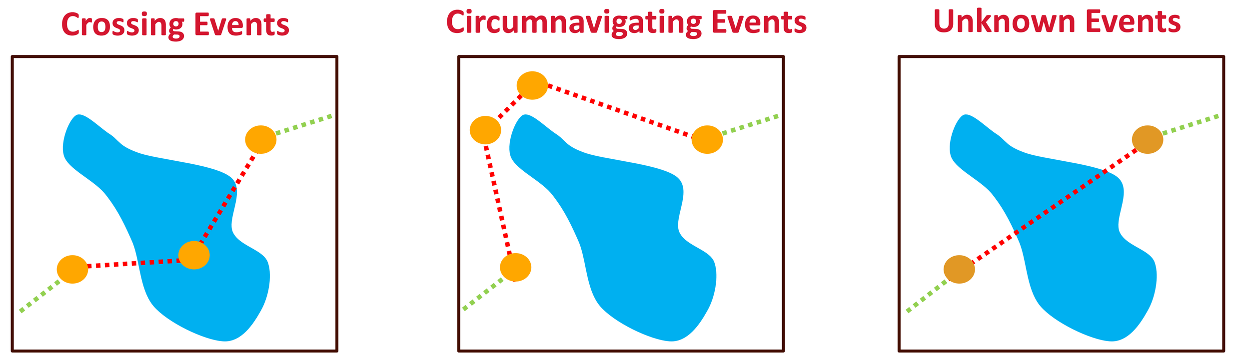


Figure 1. (A) Albedo of Contwoyto Lake on April 2, 2019 (Day 92), after gap-filling via climatology-informed spatiotemporal interpolation and Kalman filtering. Pure water surfaces were masked using land cover data. (B) Defined movement paths: direct (yellow), circumnavigate (red), and reference (blue, ±3 steps), with start/end points in white. The lake boundary is shown in dark grey.



RESULTS

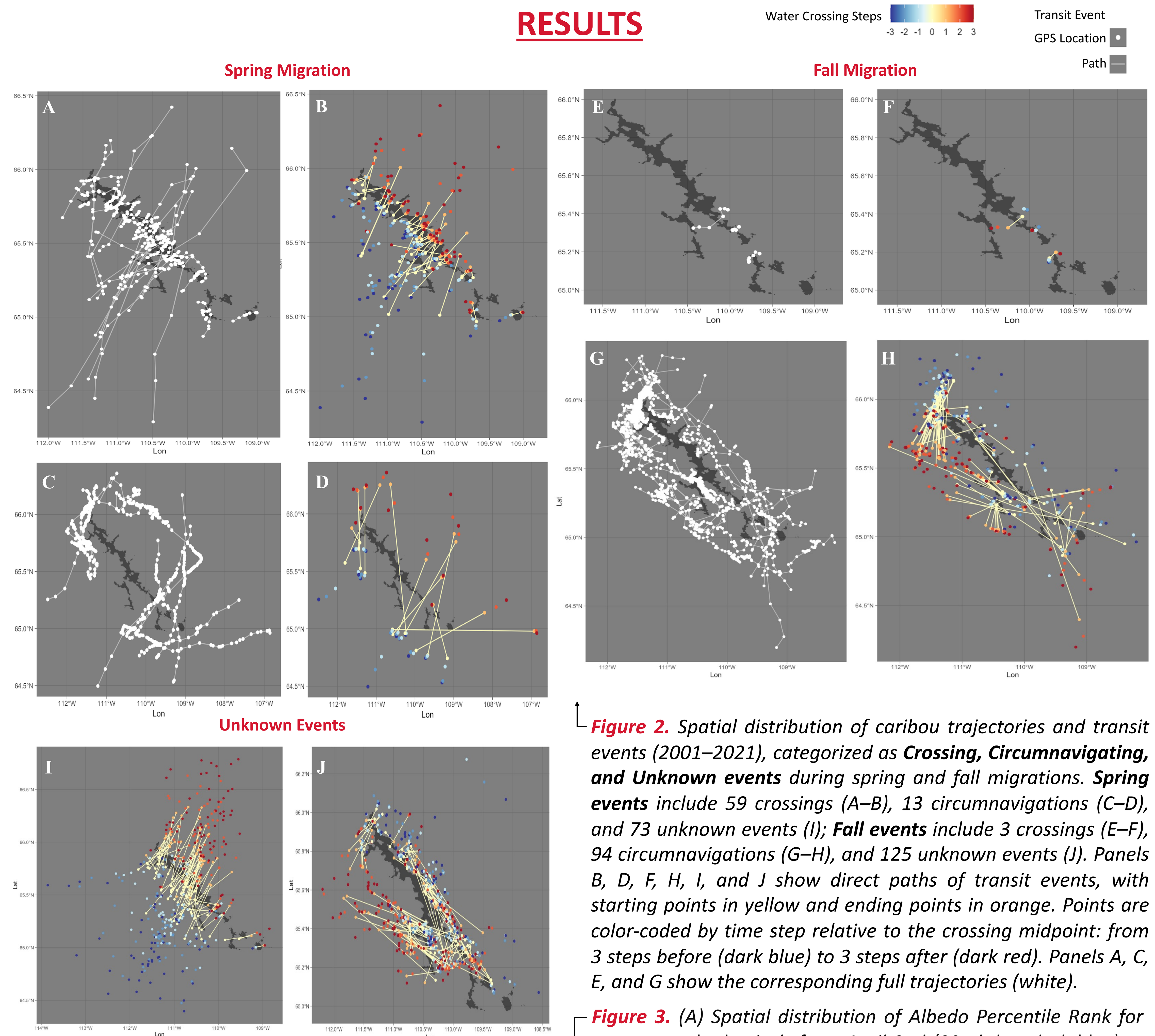
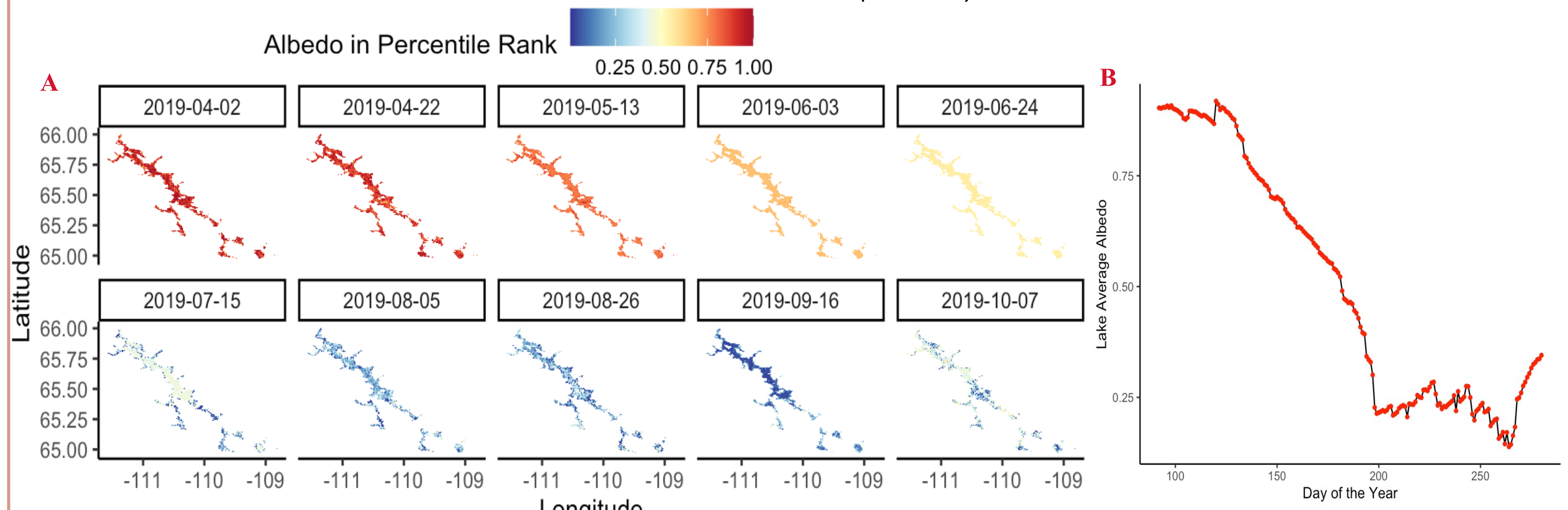


*Figure 2. Spatial distribution of caribou trajectories and transit events (2001–2021), categorized as **Crossing, Circumnavigating, and Unknown events** during spring and fall migrations. **Spring events** include 59 crossings (A–B), 13 circumnavigations (C–D), and 73 unknown events (I); **Fall events** include 3 crossings (E–F), 94 circumnavigations (G–H), and 125 unknown events (J). Panels B, D, F, H, I, and J show direct paths of transit events, with starting points in yellow and ending points in orange. Points are color-coded by time step relative to the crossing midpoint: from 3 steps before (dark blue) to 3 steps after (dark red). Panels A, C, E, and G show the corresponding full trajectories (white).*

Figure 3. (A) Spatial distribution of Albedo Percentile Rank for pure water body pixels from April 2nd (92nd day, dark blue) to October 7th (280th day, dark red) in 2019. (B) Average Albedo Percentile Rank of the lake from April 2nd (dark blue) to October 7th (dark red) in 2019.



Unknown Events Classification

Model predictions for unknown events were compared between Random Forest (RF) and Binomial Logistic (BL) models using a 50% threshold. Evaluation metrics also included accuracy, sensitivity, F1 score, AUC, delta AIC (BL), and OOB error (RF).

Model	Most Important Variables in Classification	Prediction Consistency	Accuracy (Test Data)
RF (Spring)	Albedo Along the Potential Crossing Path Circumnavigate Speeds/Direct Speeds (log) Circumnavigate Speeds/Reference Speeds (log)	100%	100%
BL (Spring)	Albedo Along the Potential Crossing Path*		95.80%
RF (Fall)	Circumnavigate Speeds/Reference Speeds (log) Proportion of Time Spent in Lake Area Direct Speeds/Reference Speeds (log)	98.40%	95%
BL (Fall)	Circumnavigate Speeds/Reference Speeds (log) **		97.94%
RF (Whole)	Albedo Along the Potential Crossing Path Albedo at the Nearest Pixel Albedo of the Entire Lake Area	70.71%	91.18%
BL (Whole)	Albedo Along the Potential Crossing Path*** Proportion of Time Spent in Lake Area* Circumnavigate Speeds/Reference Speeds (log)*		98.82%

Note: Variables listed for RF models represent the top three predictors ranked by Gini Importance Index

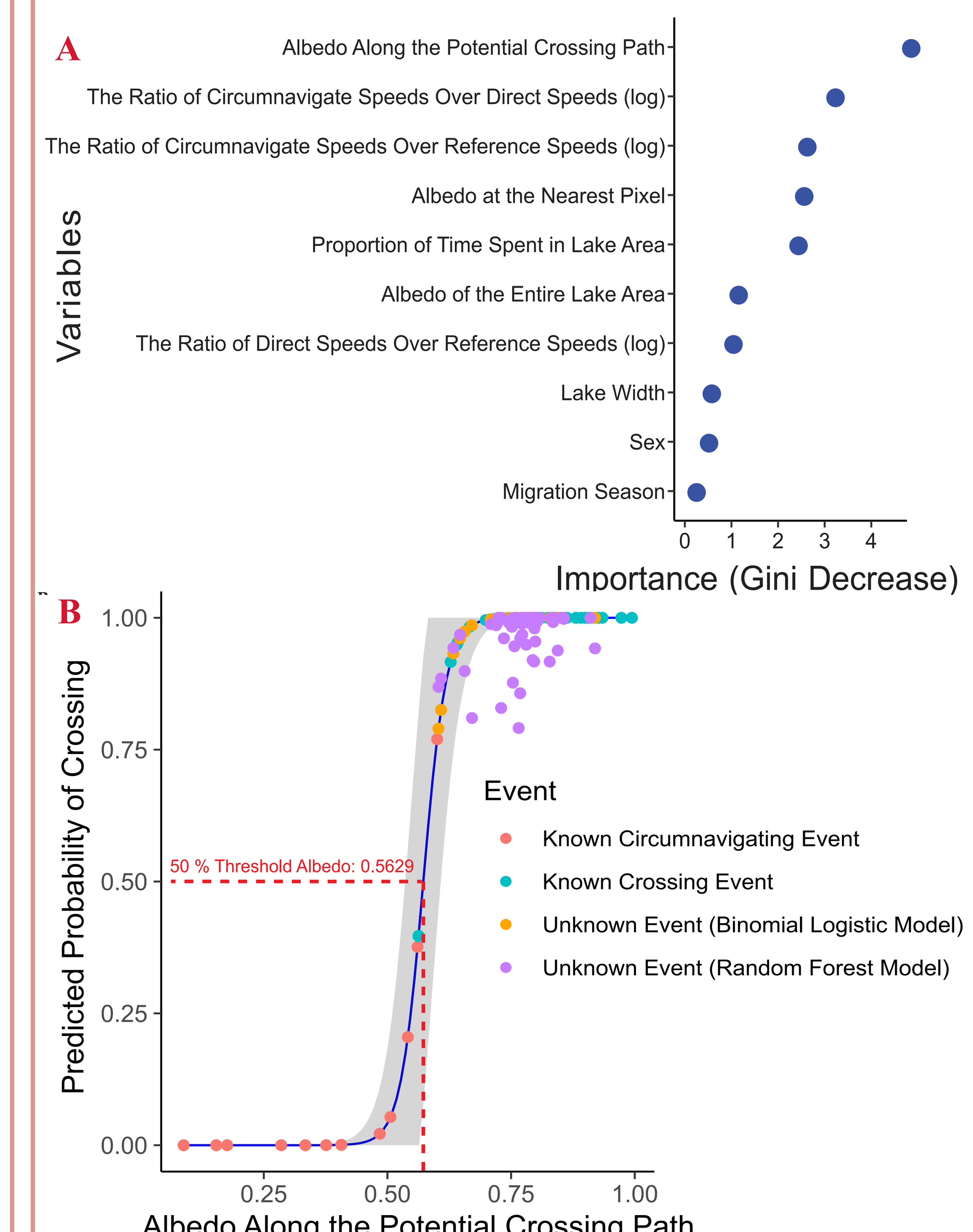


Figure 4. Model results from the "Spring Only" dataset. (A) Gini importance from the RF model classifying spring events. (B) BL model showing crossing probability increasing with albedo along potential paths trained on crossing (green) and circumnavigating(red) events. Both models (RF: purple; BL: yellow) predicted a crossing probability of more than 50% for most unknown events, indicating strong agreement during spring migration.

CONCLUSIONS

Our study shows that caribou water-crossing behavior is shaped by seasonal shifts in lake ice conditions. In spring, surface albedo—a proxy for ice condition—was the strongest predictor, with crossings more likely when albedo exceeded the 56th percentile. In fall, when lakes were ice-free, movement-based metrics dominated. These findings suggest that caribou respond to environmental cues at intermediate spatial scales and adjust their strategies accordingly. As Arctic warming accelerates, traditional crossing routes may become less accessible, threatening migratory connectivity. Our framework links fine-scale behavioral thresholds to landscape-scale patterns and offers a transferable tool for anticipating climate impacts on migration across ice-dominated ecosystems.

ACKNOWLEDGEMENTS

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