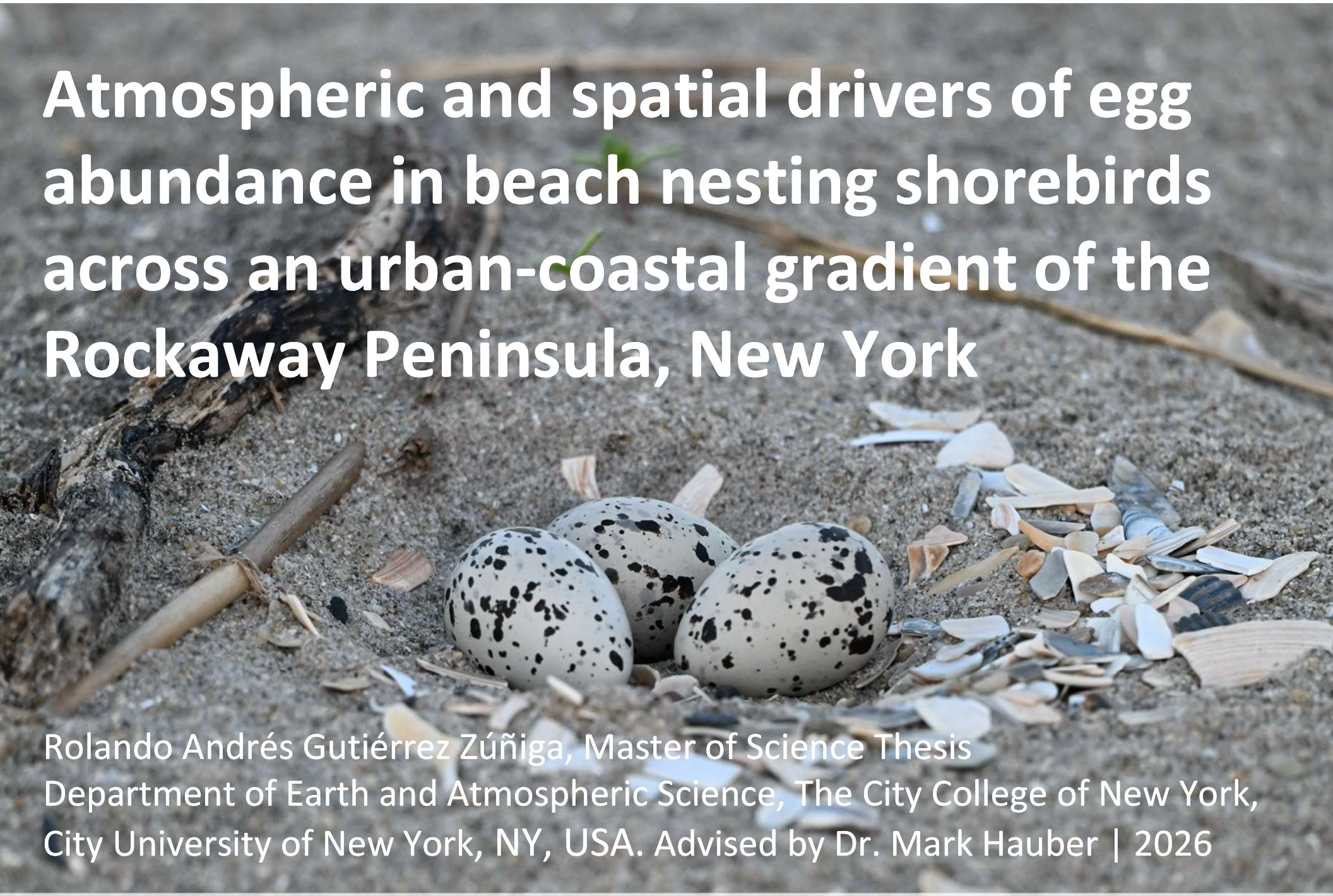
Atmospheric and spatial drivers of egg abundance in beach nesting shorebirds across an urban-coastal gradient of the Rockaway Peninsula, New York



Rolando Andrés Gutiérrez Zúñiga, Master of Science Thesis
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2026©All pics by Rolando Gutierrez

Acknowledgments

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Decline of the North American avifauna

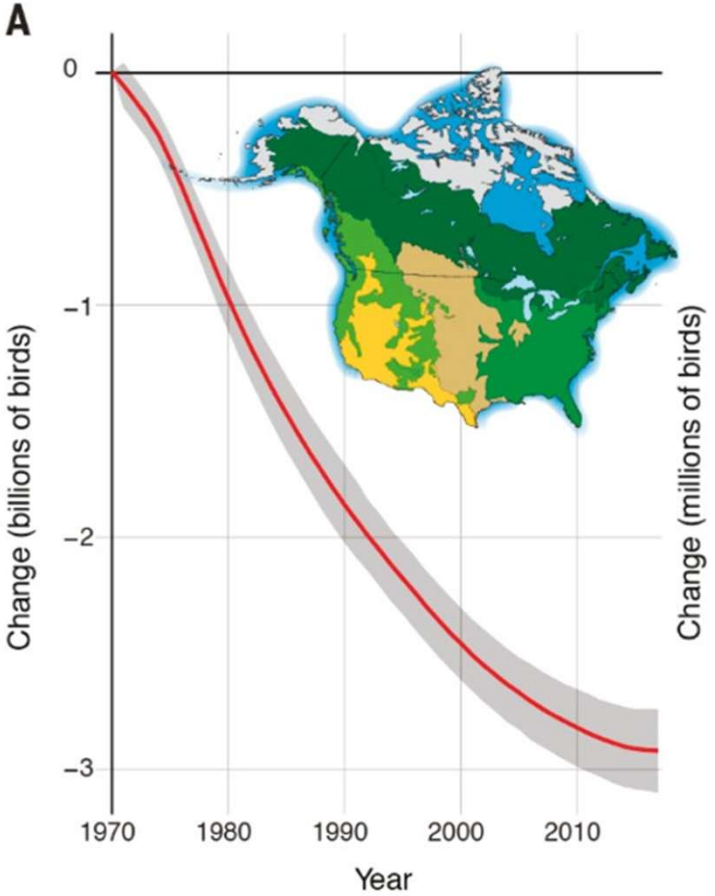


Figure A. North American bird populations have declined by approximately 2.9 billion individuals since 1970 across 529 species.*

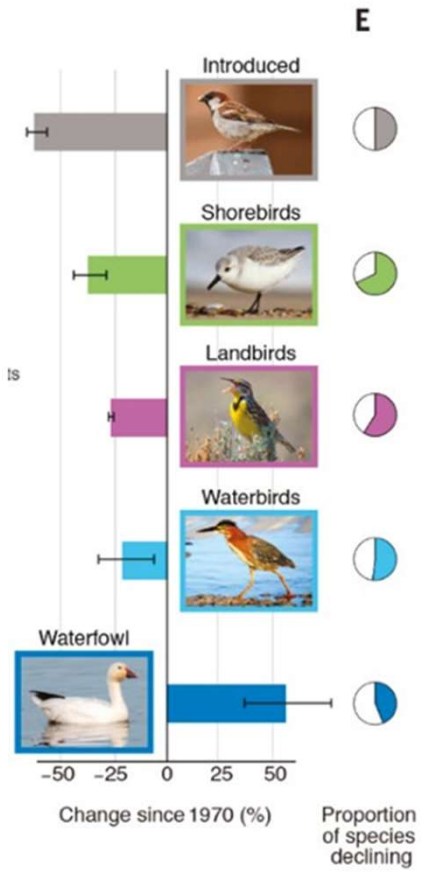
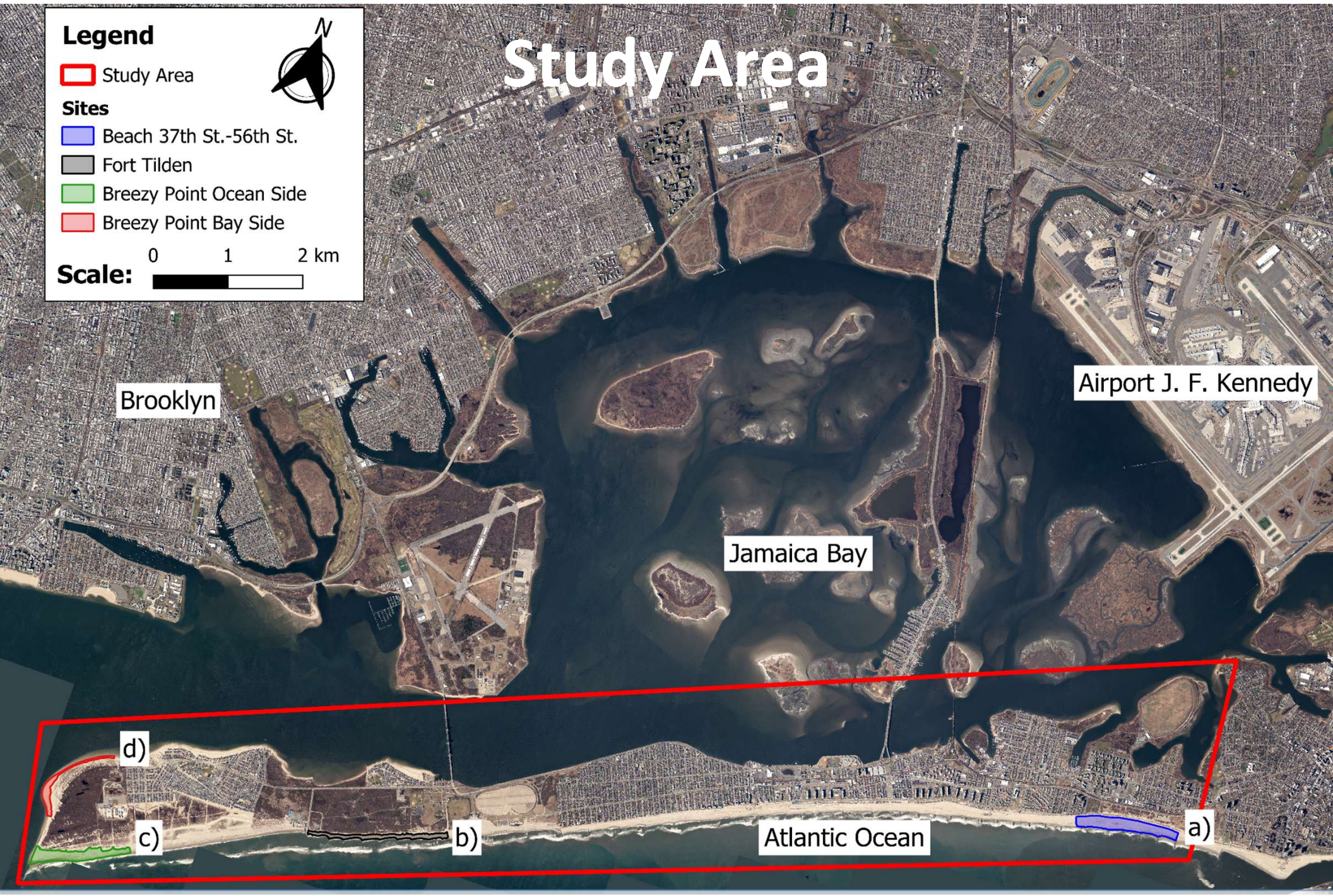


Figure E. Bird population trends vary across groups, with many species declining over the past half century.*

Rosenberg, K. V., Dokter, A. M., Blancher, P. J., Sauer, J. R., Smith, A. C., Smith, P. A., Stanton, J. C., Panjabi, A., Helft, L., Parr, M., & Marra, P. P. (2019). Decline of the North American avifauna. Science, 366(6461), 120–124.https://doi.org/10.1126/science.aaw1313



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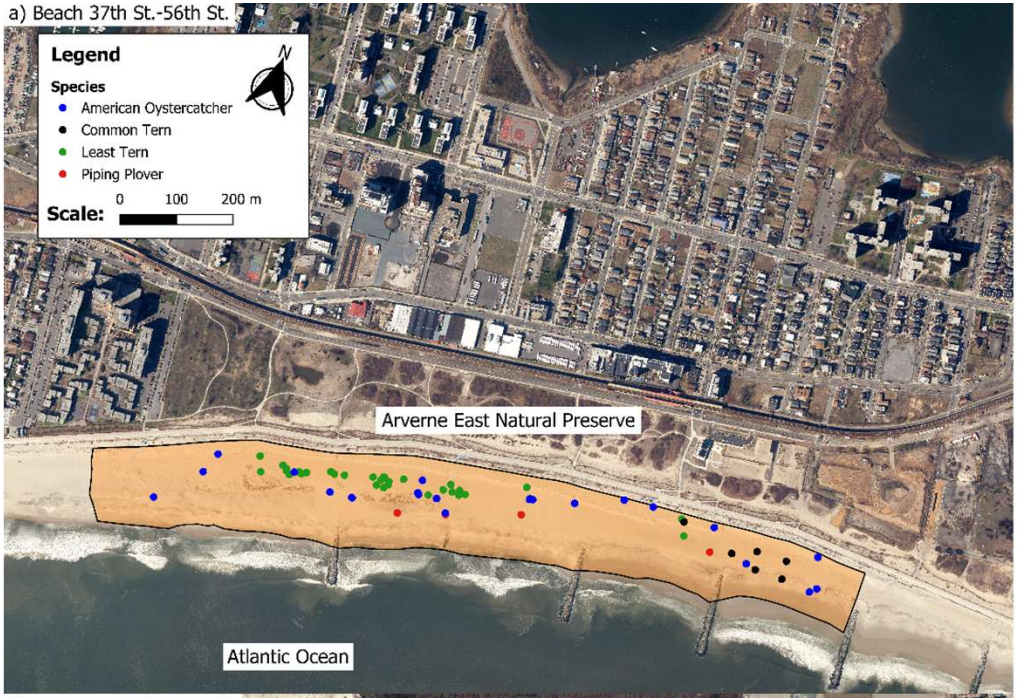
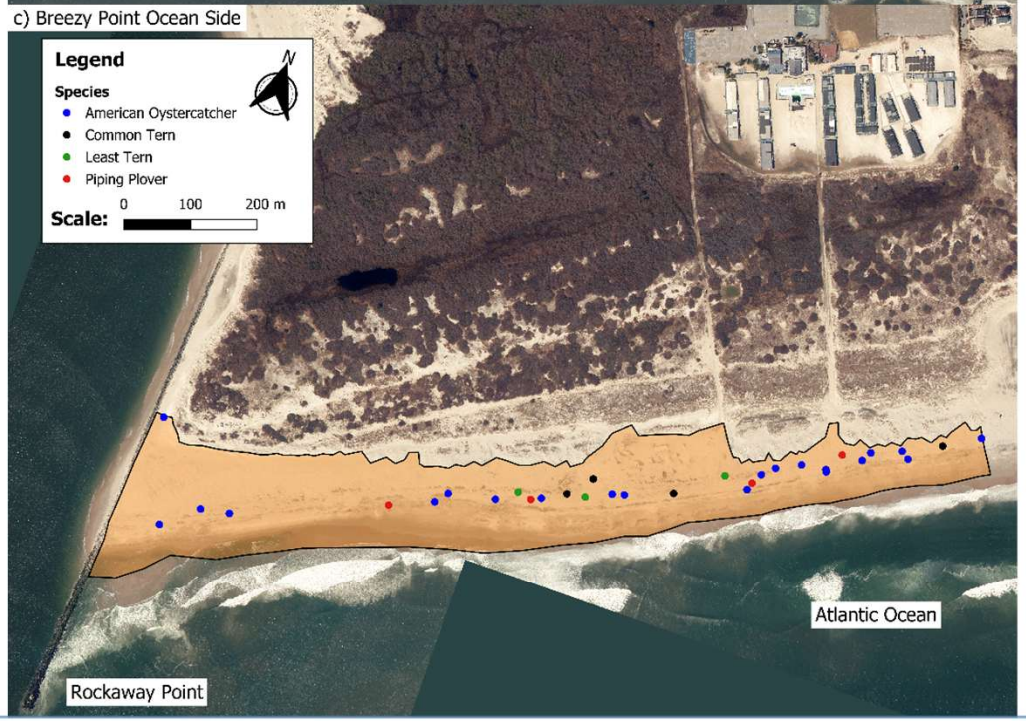
a) Beach 37th St.-56th St.



b) Fort Tilden



c) Breezy Point Ocean Side



d) Breezy Point Bay Side



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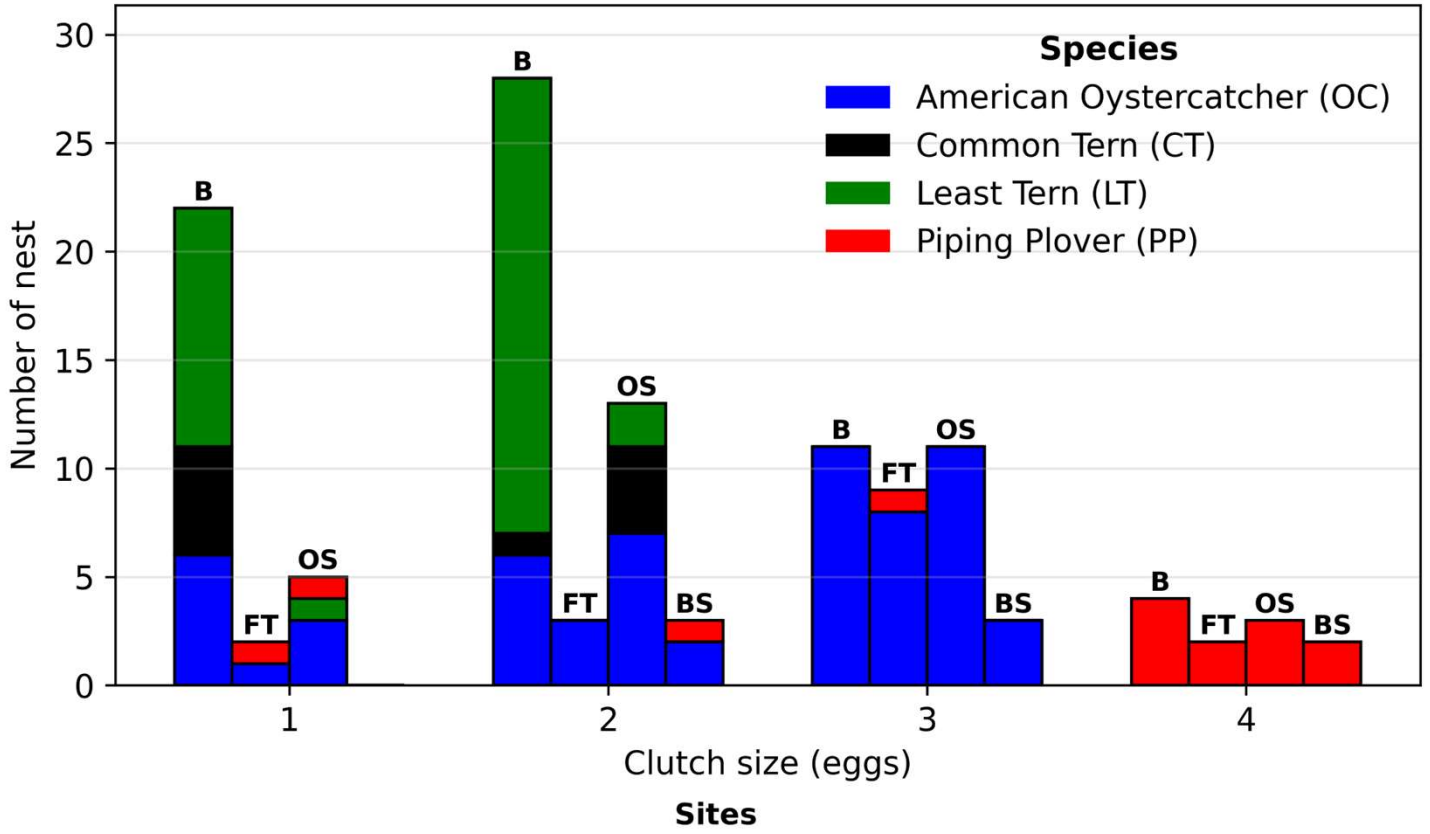
Contrasting reproductive strategies

American Oystercatcher (OC)
61 nests (145 eggs)

Least Tern (LT)
35 nests (58 eggs)

Piping Plover (PP)
15 nests (51 eggs)

Common Tern (CT)
10 nests (15 eggs)



Sites

B = Beach 37th St.-56th St. FT = Fort Tilden OS = Breezy Point Ocean Side BS = Breezy Point Bay Side

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Study questions

1. Which spatial, environmental, and atmospheric factors most strongly explain variation in egg abundance?
2. How do these relationships reflect differences in habitat suitability among nesting sites?
3. Does a dominant driver emerge when relationships are evaluated using both parametric and non-parametric modeling frameworks?

Hypothesis

Climatic and geomorphological factors, particularly temperature and elevation, exert measurable effects on egg abundance through both physiological constraints and habitat-mediated mechanisms.

Data capture

A multi-scale, zero-disturbance data capture protocol



Step 1: Field Measurement

15 weeks of weekly monitoring. Rangefinders used relative to pre-established markers.

Initial GPS coordinates recorded only after the nesting season to ensure absolute zero disturbance to active incubators.



Step 2: Spatial Structuring

QGIS analysis utilizing 2024 NYC orthoimagery.

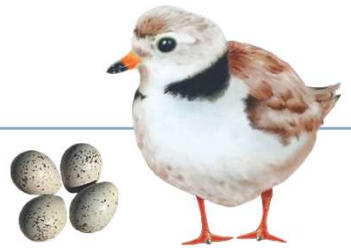
Haversine geodesic distance estimations to infrastructure, vegetation, and the highest GPS-registered seasonal tide line.



Step 3: Atmospheric Integration

Integration of daily NOAA summaries of daily NOAA summaries from the JFK International Airport weather station (temperature, wind, precipitation, cloud cover) synced to individual nest initiation proxies.

Microtopography Metric: Local beach slope calculated via vertical elevation differential and horizontal distance.



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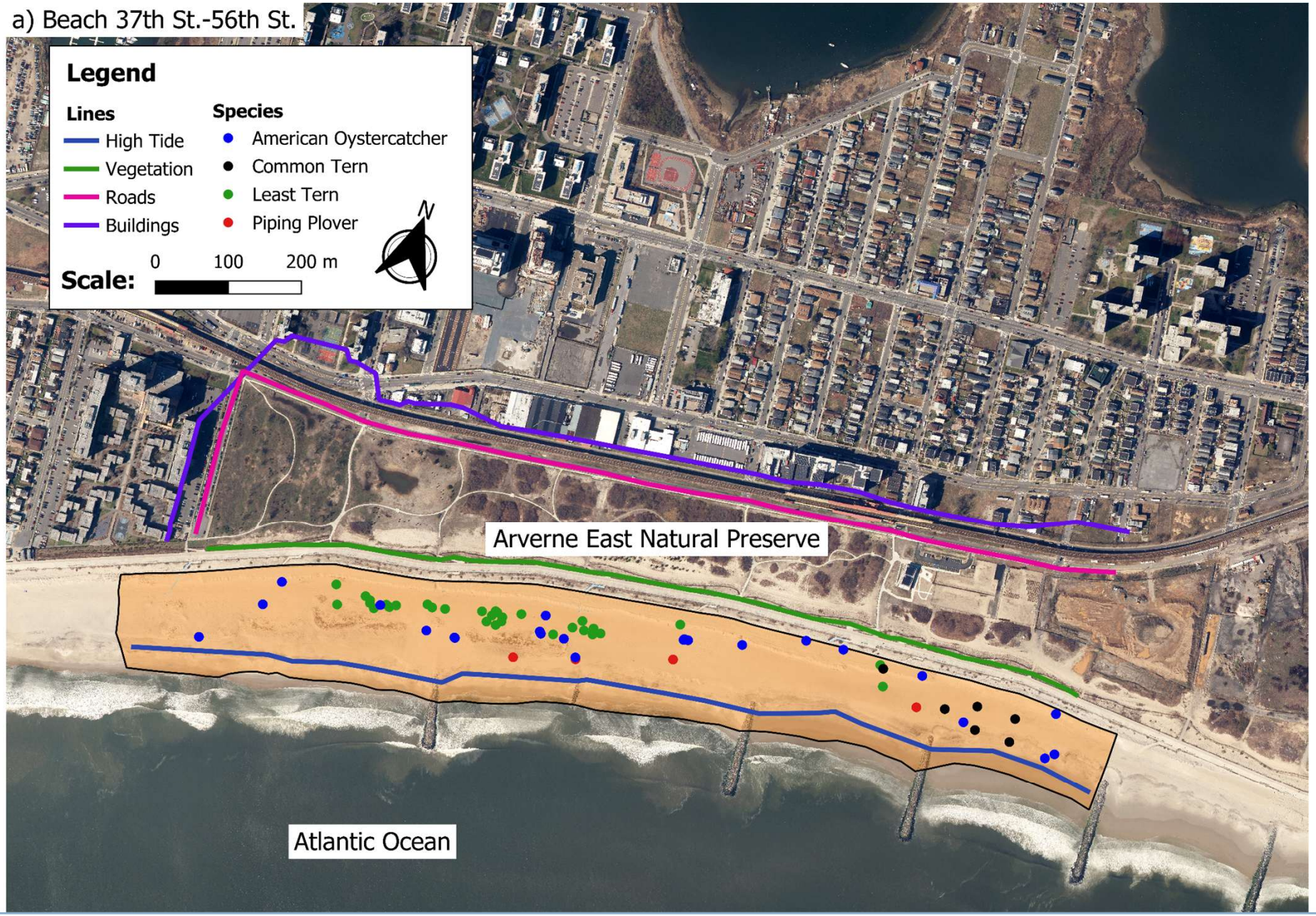
Results-Study Area

a) Beach 37th St.-56th St.



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Results-Study Area



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Results-Study Area



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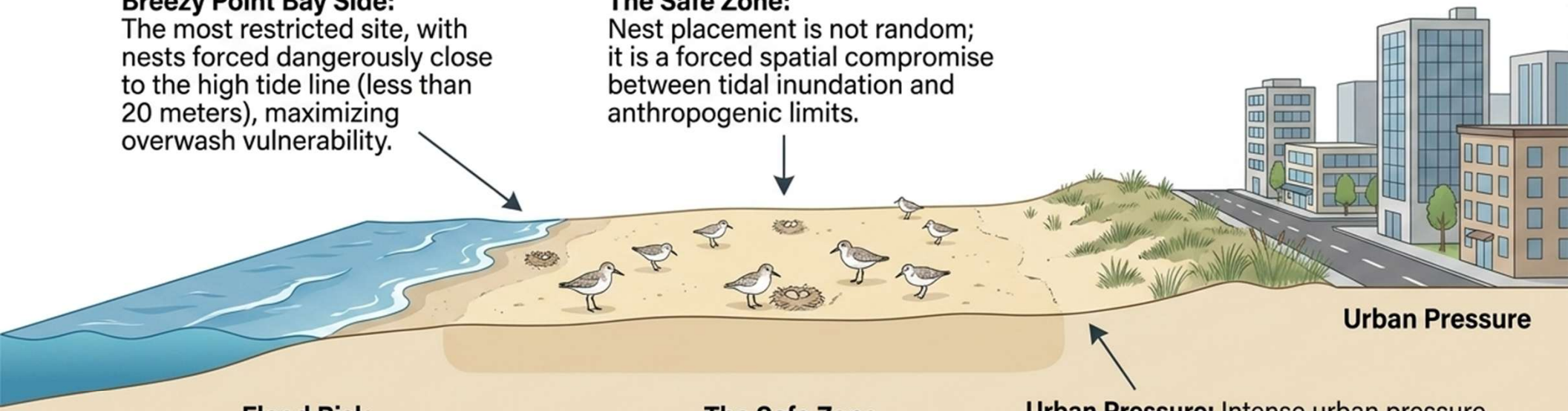
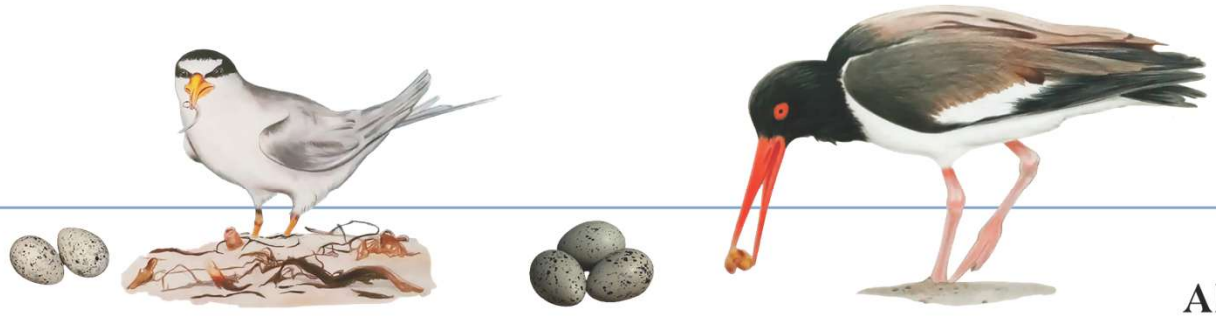
The Coastal Squeeze: Balancing flooding risk and urban disturbance.

Breezy Point Bay Side:
The most restricted site, with nests forced dangerously close to the high tide line (less than 20 meters), maximizing overwash vulnerability.

The Safe Zone:
Nest placement is not random; it is a forced spatial compromise between tidal inundation and anthropogenic limits.



Urban Pressure: Intense urban pressure dictates a strict 200-300 meter buffer from buildings at Beach 37th-56th Street. In contrast, birds maintain vast buffers of greater than 600 meters from roads at natural sites sites like Fort Tilden and Breezy Point Ocean Side.



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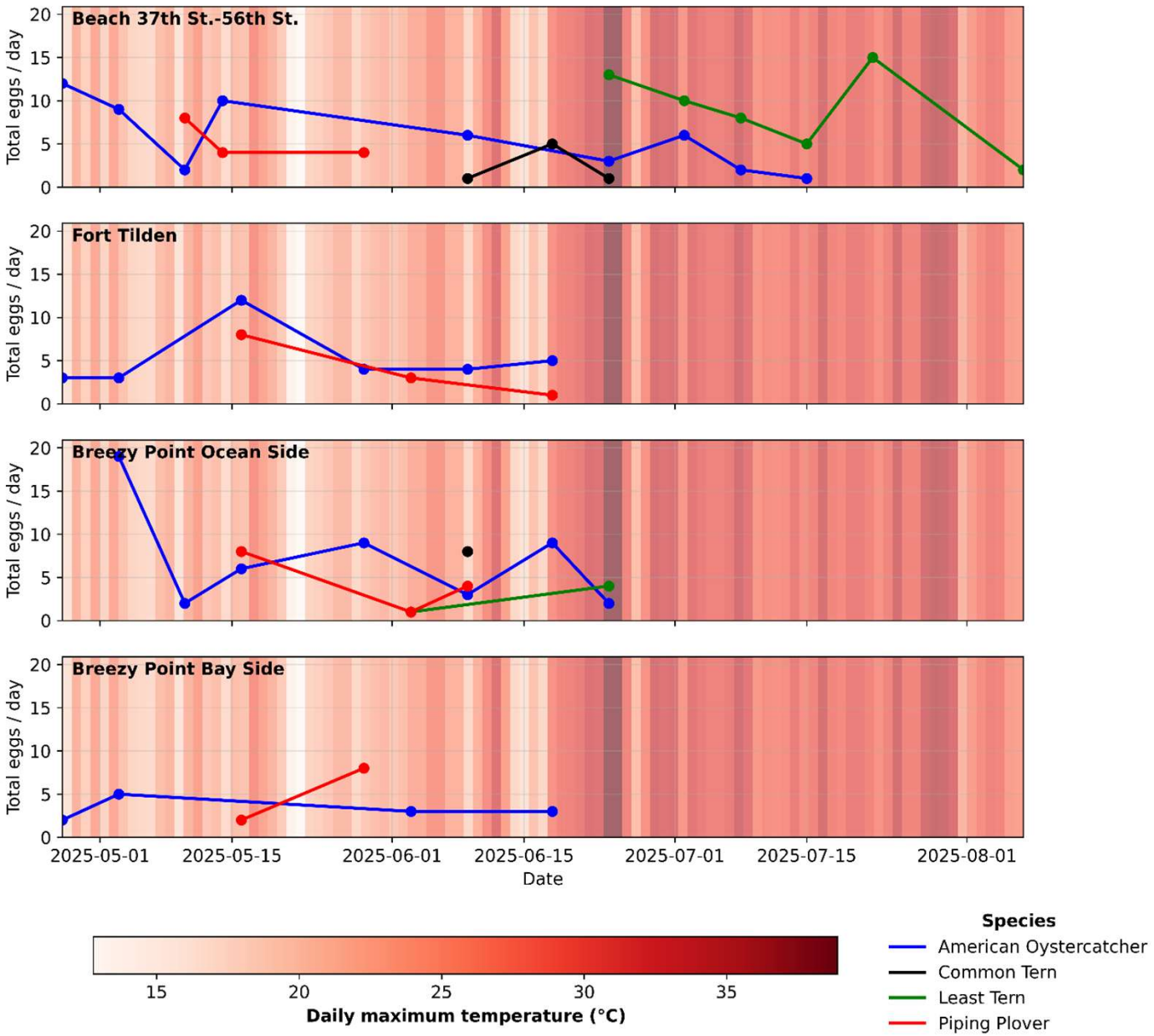
Reproductive timing is strictly constrained by a phenological thermal window





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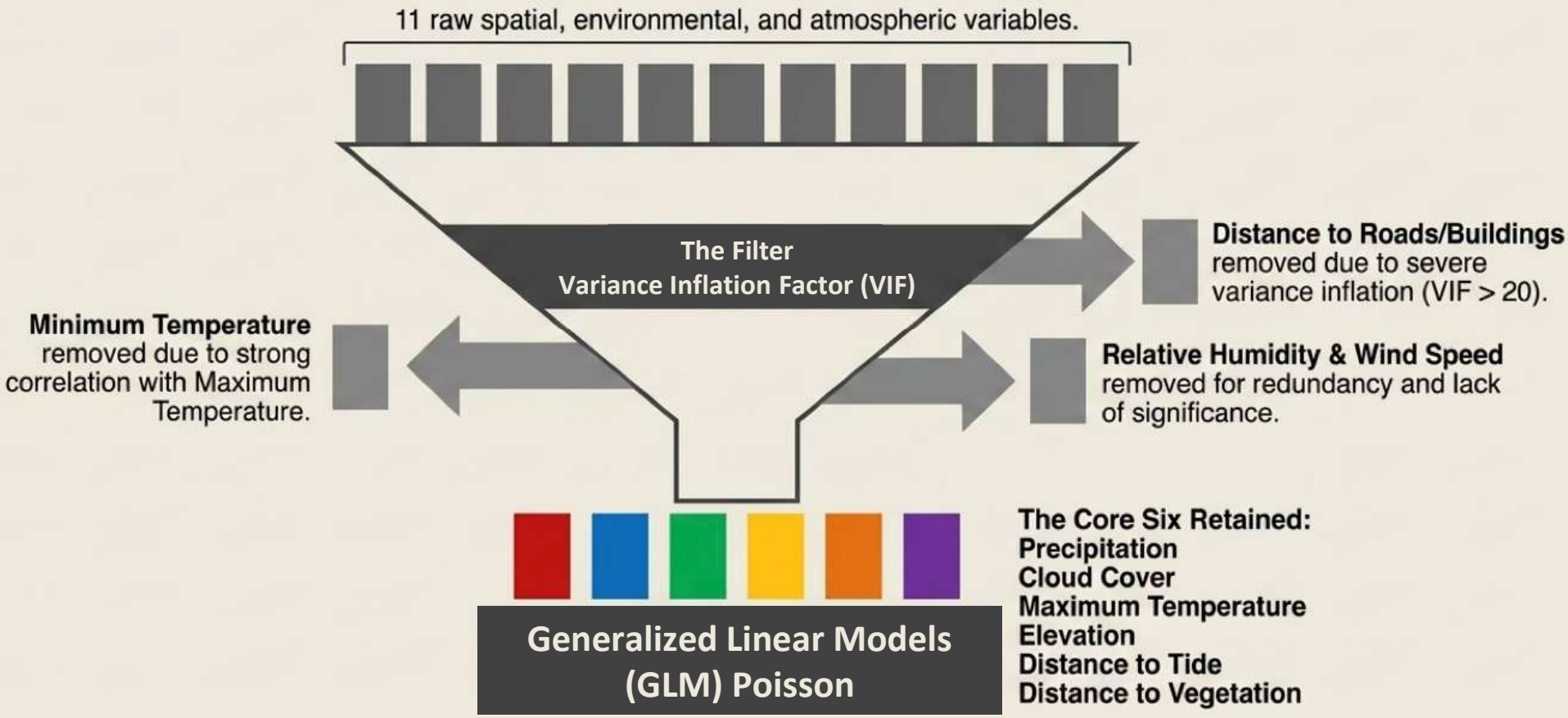
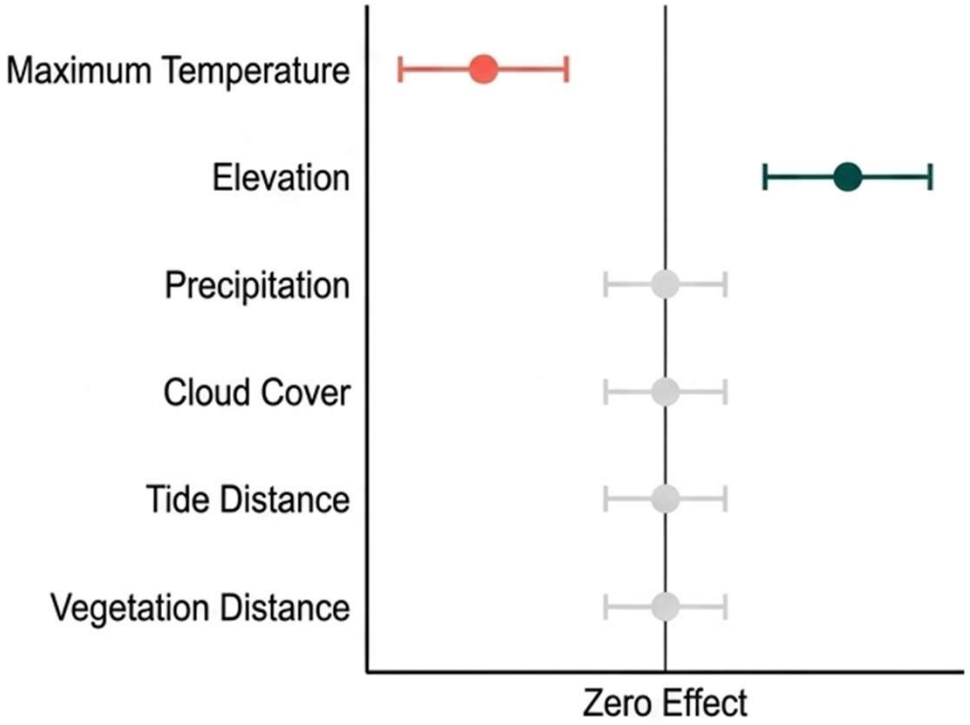
Refining the noise to isolate true ecological signals





Maximum temperature acts as the dominant regional ceiling on reproduction.

Model Specifications: Robust Poisson Generalized Linear Model (GLM) utilizing Heteroskedasticity-Consistent (HC3) standard errors.



The Primary Culprit: Maximum Temperature

Beta: -0.036, $p < 0.001$

A highly significant, consistent negative relationship across all species and sites.

The Secondary Buffer: Elevation

Beta: 0.075, $p = 0.008$

A significant positive effect, confirming microtopography acts as a localized buffer against environmental stress.

Non-Significant Variables

Precipitation, Cloud Cover, Tide Distance, and Vegetation Vegetation Distance yielded negligible direct statistical effects on final egg counts.



Machine learning validates the absolute dominance of thermal stress

Model: Random Forest (RF) Regression Model measuring permutation importance



The Verdict: Maximum temperature accounts for an overwhelming 0.81 of the model's predictive importance.

Synthesis: The RF fundamentally corroborates the GLM: thermal conditions unilaterally dictate reproductive investment. Elevation falls away as a primary macro-driver, confirming its role as a strictly secondary, micro-spatial buffer.



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Translating mathematical coefficients into ecological reality

The Cost of Heat



Equation: exp(-0.036)

Impact: Every 1°C increase in maximum daily temperature results in an approximate 3.6% decrease in expected egg counts.

Mechanism: As thermal stress rises, adults must divert critical energy from reproductive investment into survival thermoregulation (shading eggs, posture adjustments), drastically reducing incubation efficiency.

The Value of Microtopography



Equation: exp(+0.075)

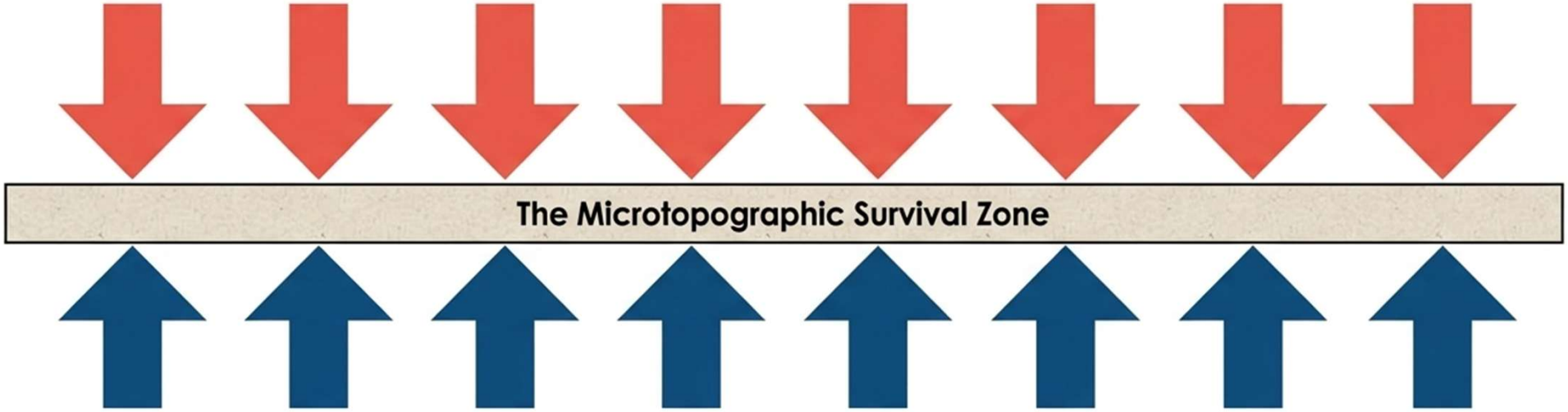
Impact: Every 1 unit (degree) increase in elevation yields a 7-8% increase in expected clutch size.

Mechanism: Elevational gains drastically reduce overwash risk, stabilize nesting substrate, and provide slight thermal wind buffering.



Synthesis: Regional climatic stress meets local microtopography

The Macro Ceiling: Ambient maximum temperature operates as an unavoidable regional ceiling, biologically capping reproductive investment and limiting phenological windows.



The Micro Floor: Highly specific micro-elevations serve as the only localized defense mechanism, providing a fragile spatial floor against rising tides and overwash.

The overarching narrative of the Rockaway Peninsula shorebirds is defined by a vertical and horizontal vice grip. As global temperatures rise and extreme weather intensifies, the viable "Survival Zone" between these two forces is rapidly compressing.



Ecosystem-based management in a rapidly warming world

Preserve Thermal Heterogeneity



We cannot just fence off flat sand. Management must preserve complex micro-habitats that offer subtle thermal variations and sheltering options for incubating adults facing heat stress.

Allow Dynamic Geomorphology



Over-engineering dunes or strict coastal stabilization destroys necessary habitat. We must permit natural sediment dynamics and overwash events that create early-successional, elevated nesting substrates.

Absolute Disturbance Mitigation



Given the extreme physiological cost of thermal stress, forcing birds to expend additional energy fleeing from pedestrians or off-road vehicles guarantees reproductive failure. Expanding buffer zones during heatwaves is critical.



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Final Defense Statement

Shorebird reproduction on the Rockaway Peninsula is ultimately dictated by the precise intersection of thermal extremes and local microtopography. Sustaining these populations requires managing not just for space, but for thermal resilience and dynamic coastal geomorphology.



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Questions?

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