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

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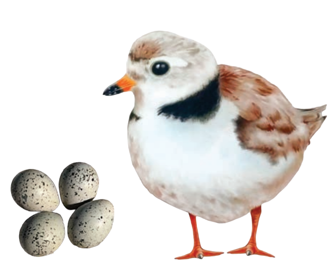
1 Introduction

Beach-nesting shorebirds are increasingly threatened by climate change and coastal urbanization. This study identifies how temperature and microtopography shape egg abundance across the Rockaway Peninsula, highlighting critical habitat features and vulnerability to flooding, and informing conservation strategies for sustaining shorebird populations in rapidly changing urban coastal systems.



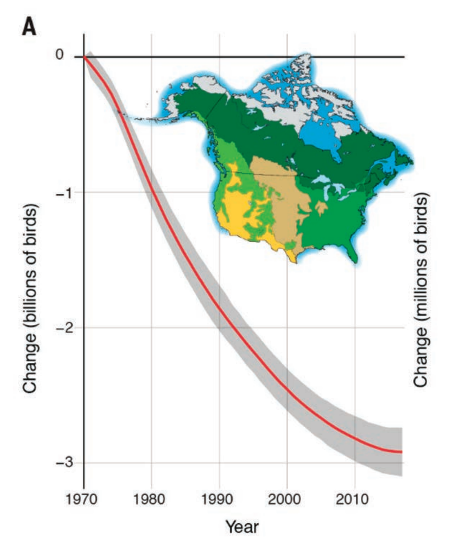


Figure 1. North American bird populations have declined by approximately 2.9 billion individuals since 1970 across 529 species. The red trend line shows cumulative losses, with gray shading indicating uncertainty (±95% credible intervals). The map highlights biome-specific patterns, emphasizing widespread declines across diverse breeding regions and habitats. *

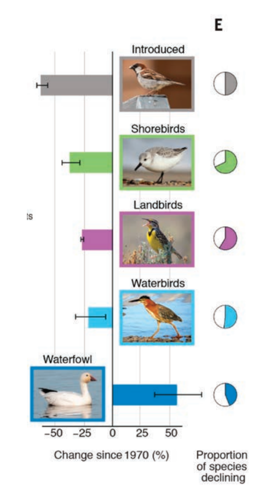


Figure 2. Bird population trends vary across groups, with many species declining over the past half century. Shorebirds and landbirds show substantial losses, while waterfowl exhibit population gains. The figure contrasts percentage population change and the proportion of declining species, highlighting uneven conservation outcomes across North American avifauna.*

*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

2 Study Area

This study was conducted on the Rockaway Peninsula, a dynamic barrier island in New York City shaped by coastal processes and urbanization, creating diverse habitats influenced by human infrastructure and activity.

Four sites represent a gradient of urbanization and geomorphology (Fig. 3.): urban Beach 37–56th Streets, semi-natural Fort Tilden, exposed Ocean Side, and sheltered Bay Side estuarine habitat with tidal flats and marshes.

Figure 3. Nesting points at: a) Beach 37th St.-56th St., b) Fort Tilden, c) Breezy Point Ocean Side, and d) Breezy Point Bay Side*

3 Data and Methods

Field data were collected during the 2025 breeding season through weekly surveys across four sites. Nests were identified, egg counts recorded, and locations georeferenced using GPS with minimal disturbance.

Spatial variables included distances to tide, vegetation, infrastructure, and nests, analyzed using geospatial tools. Beach slope (Fig. 4.) captured microtopography, and atmospheric data were obtained from NOAA records at JFK Airport.

Statistical analyses were conducted in Python, applying generalized linear models (Poisson), generalized additive models, and Random Forest to evaluate linear and nonlinear relationships and identify key drivers of egg abundance.

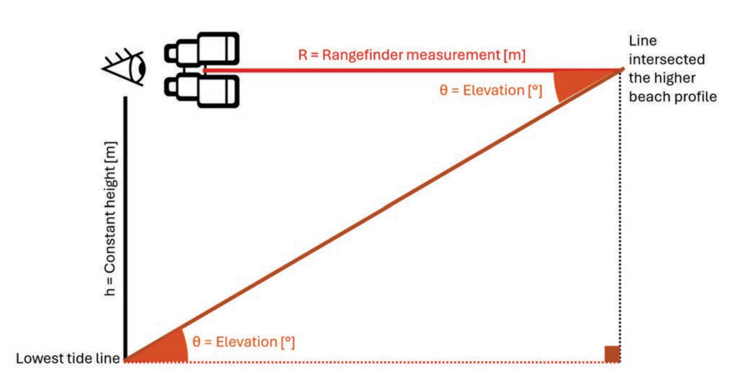


Figure 4 Conceptual diagram of beach slope measurement of nesting sites

4 Descriptive Analysis

A total of 121 nests and 269 eggs were recorded, (Fig. 5.) dominated by American Oystercatchers. Nesting was highest at Beach 37–56th Streets, indicating favorable conditions. Clutch sizes were species-specific and consistent: OC (2–3 eggs), LT (2), CT (1–2), and PP (4). Spatial variation suggests habitat quality and constraints influence reproductive investment across sites.

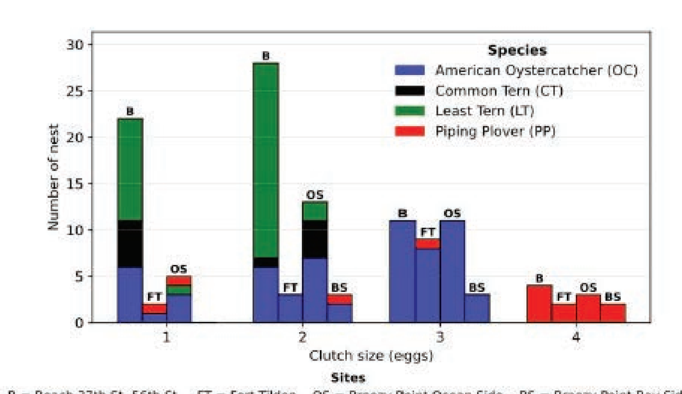


Figure 5. Number of eggs per nest by species and site.

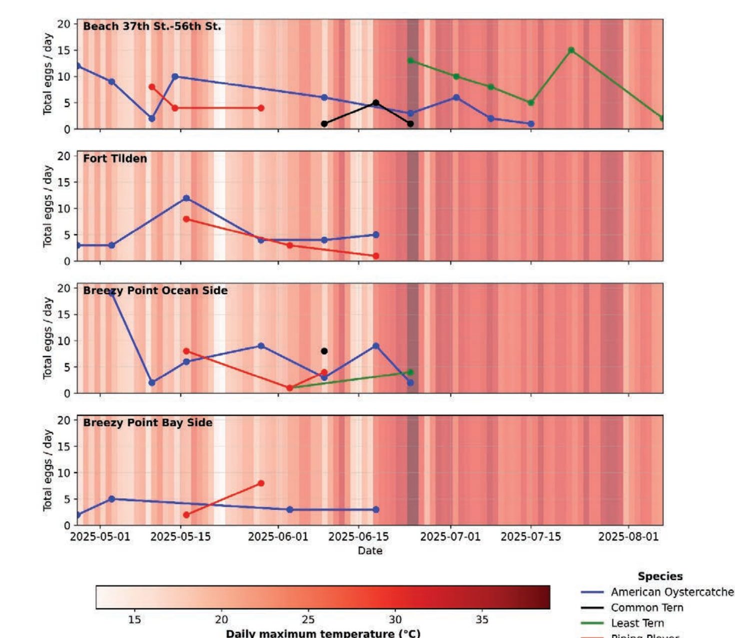


Figure 6. Daily total number of eggs by species and site, with maximum daily temperature.

Egg production (Fig. 6.) was seasonal, peaking May–July at 18–28°C and declining above 30°C. Urban sites showed prolonged activity, others shorter periods. Staggered peaks suggest temporal partitioning, with temperature and habitat shaping breeding timing.

5 Descriptive Analysis

Nest distances to tide and vegetation (Fig. 7.) varied across sites. Urban areas allowed farther placement, while constrained sites showed closer nests, reflecting geomorphology-driven habitat selection and trade-offs among flooding, predation, and disturbance risks.

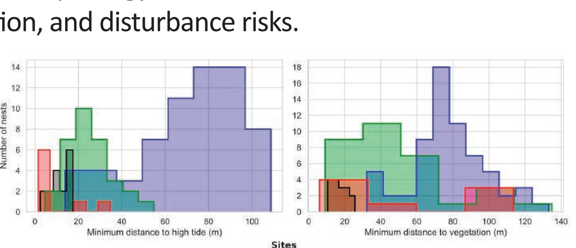


Figure 7. Minimum distance from nests to the high tide line and vegetation by site.

Distances to roads and buildings (Fig. 8.) revealed an urban gradient: nests were closer to infrastructure in urban areas and farther in less disturbed sites, showing human disturbance and habitat availability shape nest-site selection.

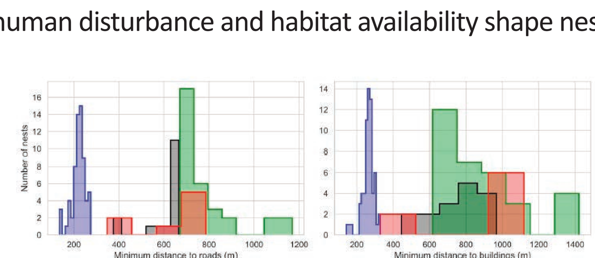


Figure 8. Minimum distance from nests to roads and buildings by site.

Nesting occurred under stable conditions with moderate winds, high humidity, warm temperatures, and little precipitation (Fig. 9.), indicating favorable weather strongly influences reproductive timing and reduces environmental risks for shorebirds.

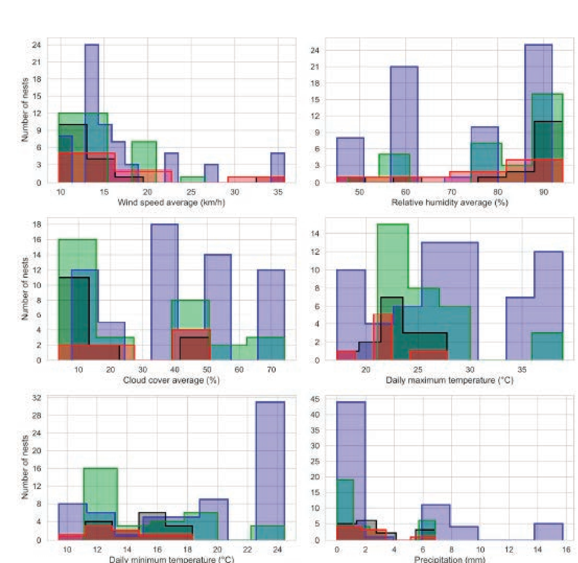


Figure 9. Atmospheric conditions by site.

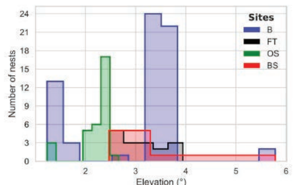


Figure 10. Elevation by site.

Nesting elevation varied across sites (Fig. 10.), reflecting geomorphology and flooding risk. Nests clustered at intermediate elevations, while wider beaches allowed optimal placement and constrained sites limited elevation choice, increasing vulnerability to flooding.

6 Statistical Analysis

Exploratory regression identified key drivers of egg abundance (Table 1.), with stable performance after removing collinear variables. Improved parsimony and diagnostics supported validity, highlighting temperature and spatial factors as primary influences.

Criterion	Test 1	Test 2	Test 3
R^2	0.375	0.374	0.368
AIC	288.6	284.9	279.9
Shapiro-Wilk test p	0.531	0.664	0.580
Breusch-Pagan test p	0.190	0.178	0.277
Durbin-Watson statistic	1.595	1.584	1.581
VIF			
Minimum distance to vegetation	1.270	1.190	1.180
Minimum distance to high tide	2.930	2.252	1.660
Minimum distance to roads	**24.050**	-	-
Minimum distance to buildings	**20.907**	-	-
Wind speed	5.418	**5.254**	-
Relative humidity	6.830	**6.603**	-
Cloud cover	6.892	6.625	2.335
Maximum temperature	7.883	7.790	1.619
Minimum temperature	8.698	**8.286**	-
Precipitation	2.235	2.232	1.572
Elevation	1.244	1.118	1.074

Table 1. Model fit statistics. diagnostic tests. and variance inflation factors (VIF) for the three regression specifications.

The final model explained 36.8% of egg abundance (Table 2.). Temperature showed a strong negative effect, elevation a positive effect, while others were weak, highlighting temperature and microtopography as key drivers.

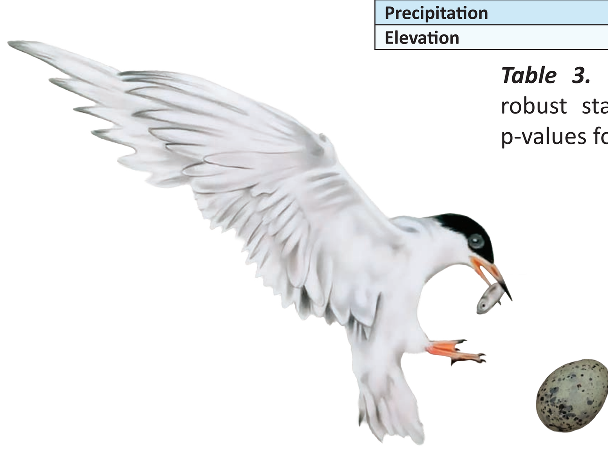
	β	std err	p
Constant	3.997	0.368	<0.001
Minimum distance to vegetation	0.001	0.002	0.681
Minimum distance to high tide	-0.004	0.003	0.099
Cloud cover	-0.002	0.005	0.583
Maximum temperature	-0.073	0.014	<0.001
Precipitation	-0.035	0.022	0.100
Elevation	0.177	0.076	0.022

Table 2. Parameter estimates (ß), standard errors, and p-values for the final regression model (Test 3).

A Poisson GLM showed temperature negatively and elevation positively influenced egg counts (Table 3.). Robust errors improved inference, confirming temperature and microtopography as consistent drivers across sites and species.

	β	std err	p
Constant	1.674	0.156	<0.001
Minimum distance to vegetation	0.001	0.001	0.527
Minimum distance to high tide	-0.001	0.001	0.094
Cloud cover	-0.001	0.002	0.290
Maximum temperature	-0.036	0.006	<0.001
Precipitation	-0.016	0.009	0.069
Elevation	0.075	0.029	0.008

Table 3. Parameter estimates (ß), robust standard errors (HC3), and p-values for the robust Poisson GLM.



7 Machine Learning (RF)

GLMMs and GAMs tested hierarchical and nonlinear effects; GLMMs failed to converge, while GAMs confirmed temperature's negative effect without added structure. Results matched the Poisson GLM, supporting it as the most reliable model.

Random Forest identified maximum temperature as the dominant predictor of egg abundance (Fig. 11.). Vegetation and tide distances contributed moderately, others minimally, confirming temperature as the primary driver and consistent across methods.

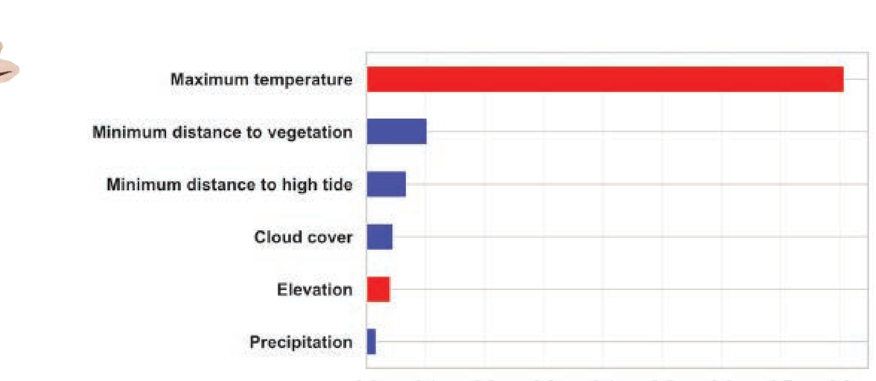


Figure 11. Permutation importance of main study predictors from the RF model. Variables highlighted in red indicate those identified as statistically significant in the Poisson GLM analysis.

8 Conclusions

Shorebird reproduction on the Rockaway Peninsula is primarily shaped by temperature and elevation, with thermal stress reducing egg abundance and higher elevations lowering flooding risk. Habitat structure and urbanization further influence nest distribution. These findings highlight climate and geomorphology as key drivers, with important implications for conservation in rapidly changing coastal systems.

Management and conservation implications

This study highlights key implications for conserving beach-nesting shorebirds in urban coastal systems. Temperature limits reproduction, while elevation reduces flooding risk. Maintaining natural processes like overwash and open habitats is critical. Human disturbance requires management through access restrictions and buffers. Integrating habitat conservation, disturbance mitigation, and long-term monitoring is essential for sustaining shorebird populations.

Acknowledgments

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