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POLICY BRIEF

Birds as Indicators of Carbon and Ecosystem Health

Roadside hawk, Parita Bay.

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Introduction

Mangroves are vital ecosystems that support biodiversity and play a crucial role in carbon sequestration. Unfortunately, mangroves face growing threats from climate change and human activities. While acoustic studies of mangroves have been carried out extensively in the Old World, there is limited knowledge about these ecosystems in the Neotropics.

This study, which is part of the Blue Natural Heritage project, addresses this gap by employing acoustic monitoring and profiling to study bird populations within the mangroves of Panama and Parita Bays. Since birds serve as indicators of ecosystem health, the data collected and methodologies developed may contribute to the sustainable management and conservation of these critical habitats.

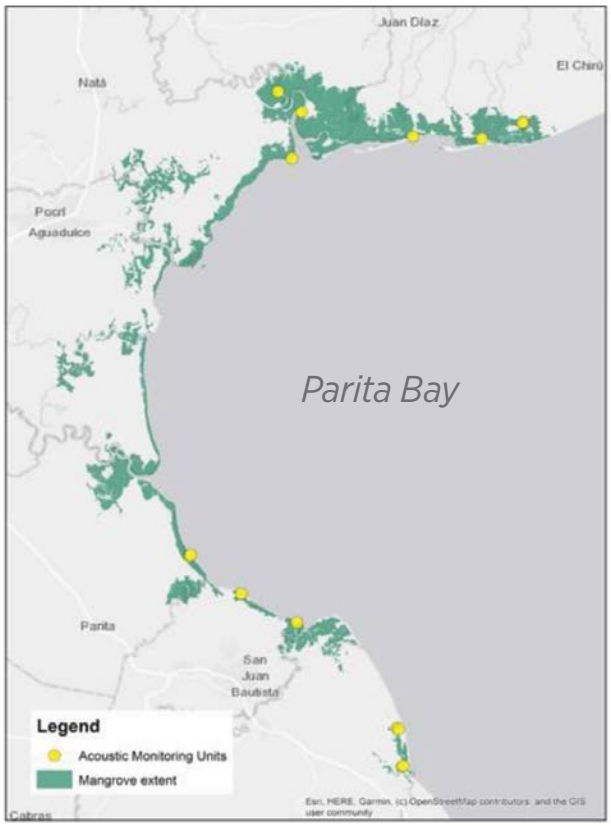
The goal of this pilot study was to estimate the relationship between bird species density and various habitat factors, in particular carbon stocks, across mangrove forest sites on Panama's Pacific coast. Estimates of bird species abundance were derived from recordings collected via passive acoustic monitoring and analyzed using machine learning models, human listening, and Bayesian hierarchical statistical models.

Objectives

- Establish a baseline of bird composition and diversity in the mangroves of Parita and Panama Bays.
- Analyze the relationship between the richness of bird species and carbon sequestration at sampling points in mangroves.
- Examine the relationship between bird diversity and indices related to ecosystem health.

Breanna Wilson / National Audubon Society

Yellow Warbler.



Mangrove cover and locations where autonomous recording units were deployed at Parita Bay and Panama Bay.

Methodology

The study was coordinated by Audubon Americas (Jorge Velásquez), fieldwork was conducted by Panama Audubon Society (Oscar López, Christian Torres, Yenifer Díaz) and Audubon Americas (Jorge Velásquez & Diego Lizcano). Audio annotation was performed by Santiago Muñoz Bolaños and Juan David Garcia (ICESI University). Statistical analyses were conducted by Justin Kitzes, Cameron Fiss, and Santiago Ruiz Guzman at U Pitt. GIS support was provided by Jorge Velásquez, Daniela Linero, and José Miguel Guevara (Audubon Americas).

1. Data Collection

AudioMoths are low-power, open-source acoustic monitoring devices that allow passive recording of sounds for long periods of time. A total of 30 AudioMoths collected recordings (16 in Parita Bay and 14 in Panama Bay); they were deployed in an even distribution between estuarine or riparian areas and coastal or beach areas. Researchers collected acoustic recordings from each survey point, obtained habitat covariates for each point from the carbon team and remote sensing data, and gathered secondary information on the conservation status and functional traits of detected bird species.

2. Review and Validation

Researchers used BirdNET, an open-source bird song classifier from the Cornell Lab of Ornithology, to identify species in acoustic recordings. BirdNET splits long recordings into three-second clips and predicts which bird species are present in each clip. Because BirdNET, like other bird song classifiers, has high rates of false positives (incorrect detections) and false negatives (missed detections), further expert review was required. Experts corrected false positives, and statistical models accounted for false negatives. A total of 29,255 audio recordings were manually analyzed and validated.

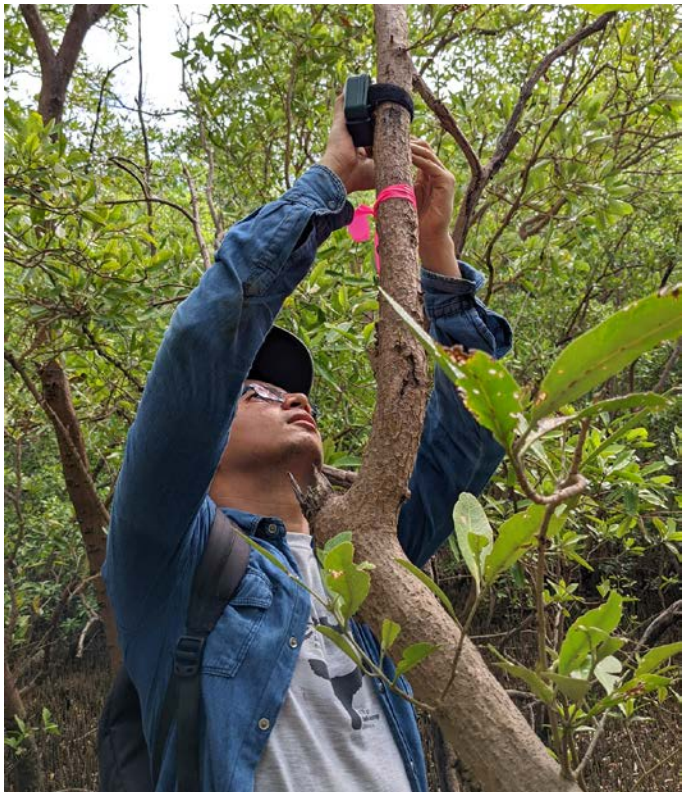
3. Estimation of species abundance and its relationship to habitat variables

Researchers used the Royle-Nichols hierarchical abundance model, which uses detection history (presence or absence), to estimate abundance. Researchers then analyzed how 13 habitat factors influenced species abundance and community metrics at each site. These factors included vegetation structure variables (above-ground biomass, mean diameter at breast height, mean canopy height, vegetation greenness-NDVI and mangrove type), soil variables (nitrogen, phosphorus, below-ground carbon, pH, conductivity), and human disturbance as measured by the Human Footprint Map.

4. Calculation of community-level diversity metrics and habitat relationships

To assess how habitat factors influence bird diversity, researchers calculated three community diversity metrics at each survey point and assessed their relationship to habitat variables.

- Bird Friendliness Index (BFI): Developed by the National Audubon Society, BFI accounts for species abundance, conservation status, and functional diversity. Functional diversity was calculated using traits such as diet and foraging behavior.
- Call rate: The number of three-second audio clips with species calls.
- Species richness: The number of species at each point from validated audio recordings.



Jorge Velásquez / National Audubon Society

AudioMoths are small recorders that use open-source technology and allow passive recording for long periods of time.

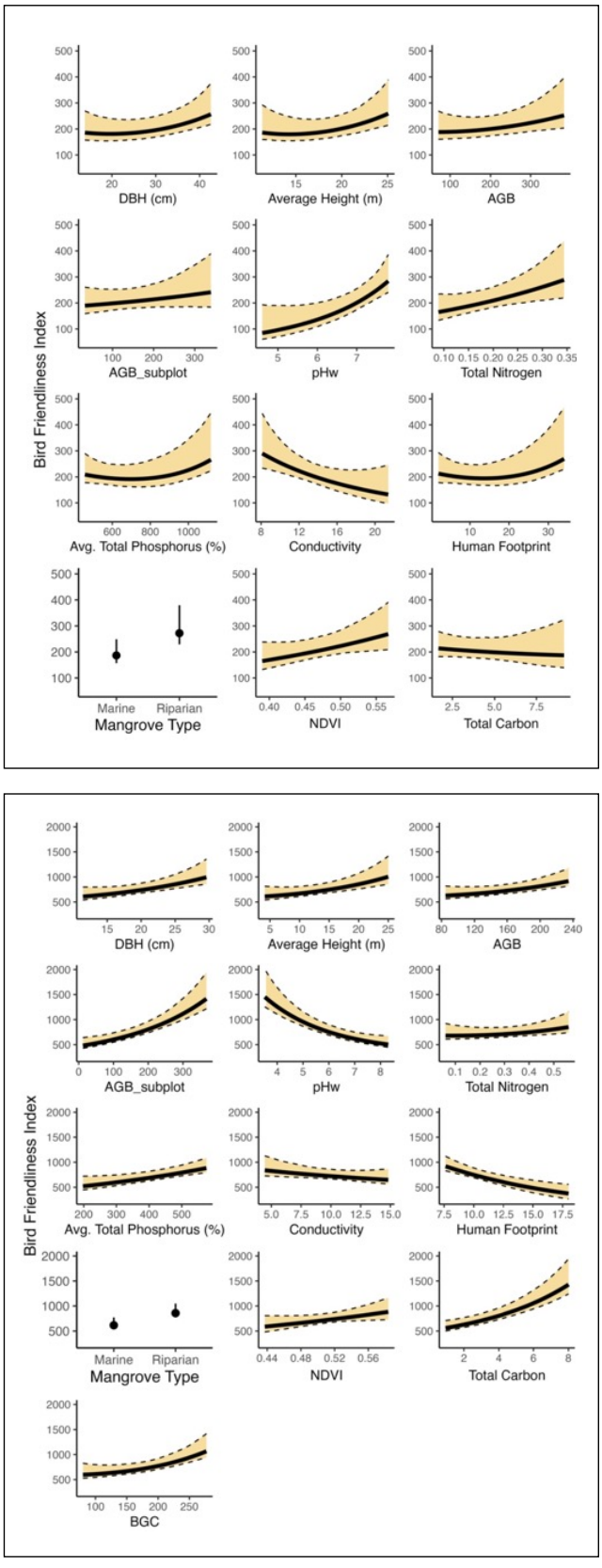
Results – Key Findings

A Promising New Methodology

- The first study of its kind focusing on mangroves in a neotropical region documented 85 bird species — 61 in Parita Bay and 53 in Panama Bay — including 27 and 8 species at each site that were detected in each respective area for the first time.
- The study generated key information for the conservation of mangroves. It also demonstrated a scalable and effective workflow for using automated recording units to assess bird species, community characteristics, and their relationships with habitat drivers. This approach could expand biodiversity surveys without relying solely on field technicians.

Complex Habitat-Bird Relationships

- Habitat variables such as carbon, biomass, and mangrove type show complex, species-specific relationships with bird abundance. The abundance of certain bird species appears to be an indicator of carbon and other measures of vegetation structural complexity.
- Although species exhibited idiosyncratic responses to different habitat variables, the responses of bird communities to these variables were generally consistent across the three community metrics that were analyzed. Nevertheless, most habitat variables did not show statistically significant effects on bird communities, due to the limited sample sizes available. Notable potential effects included positive relationships at Parita Bay between BFI and both total carbon and above-ground biomass at the subplot level, as well as negative relationships between BFI and both soil pH and human footprint.
- Although the statistical power of the analysis was limited, the results largely support the hypothesis that greater structural complexity — indicated by variables such as DBH (diameter at breast height), vegetation health, and tree height — correlate with higher diversity, for mangrove-associated bird species.
- A positive relationship (though not statistically significant) was also observed between aboveground carbon and the diversity measures, consistent with the findings for DBH and tree height.



Relationship between habitat variables and the Bird Friendliness Index (BFI) at Panama Bay (top) and Parita Bay (bottom).

Community Metric Results

- When analyzed at the community level, the effects of habitat variables vary widely but were generally consistent across the three community metrics that were assessed: observed richness, total calls, and BFI. Due to the limited number of survey points per site, the statistical models often lacked sufficient power to identify significant relationships between community metrics and habitat variables.
- Notable exceptions were observed at Parita Bay, where BFI shows positive relationships with both total carbon and above-ground biomass at the subplot level, and negative relationships with soil pH and human footprint. In the future, larger sample sizes and a broader range of habitat variables across survey points could enhance the statistical power of such analyses.

Other Insights

- Soil carbon levels are stable and may not reflect short-term changes in bird communities. Birds may respond indirectly to habitat features such as carbon through these features' influence on nesting sites or food availability.
- The human footprint shows the expected relationship with diversity in Parita, but not in Panama Bay. This discrepancy could be due to statistical power or an ecotone effect at the western edge of the bay, which differs significantly from the other sampled sites.
- A higher BFI was observed in riparian mangroves compared to marine mangroves. This may be linked to the greater structural and compositional complexity of riparian mangroves.
- Species detection differences may stem from detectability issues such as sound propagation or background noise, requiring larger samples for clearer analysis.
- The validation protocol of one audio per sampling day per recorder is efficient for developing occupancy models.
- Validating 100 audio recordings per species at each site helps establish specific detection thresholds, making it more effective for studies focused on analyzing daily detection counts.

Adriana Moreno / National Audubon Society

Training workshop on passive acoustic monitoring methods with Panamanian environmental authorities, non-profits and academics.

Conclusions

The study succeeded in increasing the baseline knowledge of birds in Panama and Parita Bays, and in establishing a replicable methodology for low-cost bird monitoring that can be implemented in other applications.

Passive acoustic monitoring proved to be an effective and non-invasive method for studying biodiversity in remote and hard-to-access areas. Integrating autonomous recording units with expert field technicians has the potential to greatly enhance the scope and scale of biodiversity surveys in these and similar ecosystems. In the future, larger sample sizes and a broader range of habitat variables across survey points could enhance the ability of studies like this to more accurately evaluate the relationships between bird communities and habitat drivers.

Northern Waterthrush.

The results indicate that the relationship between avian abundance and habitat variables, including carbon, is complex in this ecosystem. The findings reveal that habitat variables such as carbon, biomass, mangrove type, and soil properties influence bird species differently, with most variables showing both positive and negative correlations across different species. Future analyses could focus on specific species or groups of species that exhibit notable responses to particular habitat variables.

Avian abundance and diversity are unlikely to respond directly to many of the habitat variables measured in this study (e.g., total carbon, NDVI, soil properties). Instead, they are more likely influenced indirectly by factors such as forest or canopy structure, availability of nesting sites, and forage resources.

Anthony Barsotti / National Audubon Society

Field installation of AudioMoths.

Jorge Velásquez / National Audubon Society

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