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Associations Between Land-Use and Land-Cover Change and Waterbird Community Structure in a Coastal Ramsar Wetland, Ghana

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Abstract

Wetland ecosystems are increasingly affected by land-use change and urban expansion, with important implications for biodiversity and ecosystem functioning. Understanding how habitat dynamics are associated with ecological communities is therefore critical for effective environmental monitoring and management. This study examined associations between land-use and land-cover (LULC) change and waterbird community structure at the Densu Delta Ramsar Site in Ghana using an integrated remote sensing and ecological monitoring approach. Sentinel-2 satellite imagery was used to classify LULC into four classes: open water, wetland vegetation, agriculture/degraded wetland, and built-up/bare land, using a Random Forest classification method in Google Earth Engine. Waterbird data from the International Waterbird Census (2020–2023) were analysed to assess patterns in abundance, species richness and functional guild composition. A total of 62 waterbird species were recorded, with peak abundance observed in 2021. Shorebirds dominated the assemblage across all years. Exploratory analysis indicated positive associations between wetland vegetation extent and wader abundance, and moderate associations between open water and both piscivorous birds and waterfowl. These findings suggest that variation in wetland habitat composition may be associated with differences in waterbird community structure. While the limited temporal dataset constrains causal inference, the study demonstrates the value of integrating satellite-derived environmental data with biodiversity monitoring to support wetland assessment and management.

Introduction

Wetlands are among the most productive ecosystems on Earth and provide essential ecological services, including water purification, flood regulation, nutrient cycling, shoreline stabilisation and carbon sequestration (Davidson, 2014; Finlayson et al., 2011). Despite these benefits, wetlands are declining globally due to land-use transformation, hydrological alteration, pollution and climate change. Global assessments indicate that more than 35% of the world's wetlands have been lost since 1970, with coastal wetlands experiencing particularly rapid declines (Davidson, 2014; Pekel et al., 2016). These losses have significant implications for biodiversity, especially for waterbirds that depend on wetlands for feeding, breeding and migration (Amano et al., 2010).

Waterbirds are widely recognised as reliable indicators of wetland ecological condition because their populations respond sensitively to changes in hydrology, vegetation structure and food availability (Bolduc & Afton, 2008; Ma et al., 2010). Variations in water depth, sediment exposure and vegetation cover influence the accessibility of feeding habitats and the distribution of aquatic prey. As a result, changes in wetland extent or habitat quality can strongly influence waterbird abundance and community composition. Many species migrate along established flyways and depend on networks of wetlands for refuelling and resting during long-distance movements (Newton, 2007).

Wetlands in West Africa are particularly important within the East Atlantic Flyway, which links breeding grounds in Europe and northern Asia with wintering areas across West Africa (Nagy et al., 2022). Coastal lagoons, estuaries and floodplains in this region support large populations of migratory shorebirds, herons and terns and are recognised as critical habitats for Palearctic migrants (Cresswell, 2012; Ntiamoa-Baidu et al., 2000). In Ghana, coastal wetlands such as the Densu Delta, Sakumo Lagoon and Keta Lagoon Complex provide essential feeding and roosting sites for both resident and migratory waterbirds and contribute significantly to regional biodiversity conservation (Gbogbo & Attuquayefio, 2010; Ntiamoa-Baidu et al, 2000). However, these ecosystems

are increasingly threatened by urban expansion, resource extraction, pollution and hydrological modification, all of which alter wetland structure and reduce habitat quality (Ekumah et al., 2020).

Ghana contains several wetlands of international importance designated under the Ramsar Convention, including the Densu Delta, Sakumo Lagoon, Songor Lagoon and Keta Lagoon Complex. These wetlands support diverse assemblages of resident and migratory waterbirds and provide essential ecosystem services for surrounding communities. However, increasing anthropogenic pressures such as urban expansion, sand mining, agriculture and pollution threaten their ecological integrity (Gbogbo & Attuquayefio, 2010).

The Densu Delta Ramsar Site, located near Accra, represents one of the most important coastal wetlands in southern Ghana and provides feeding and roosting habitats for numerous species of waders, terns and herons. Compared to other coastal Ramsar sites in Ghana, the Densu Delta is particularly suitable for examining habitat–waterbird relationships due to its proximity to a rapidly expanding urban centre, which has resulted in pronounced land-use and land-cover changes over relatively short time scales. In addition, the site comprises a heterogeneous mosaic of habitats, including open water, mudflats, vegetated wetlands and degraded areas, which support diverse waterbird guilds and provide an opportunity to assess differential ecological responses to habitat variation. The availability of consistent waterbird census data further enhances its suitability for analysing temporal changes in bird community dynamics in relation to habitat change.

Remote sensing has become an essential tool for monitoring wetland dynamics and detecting environmental change. Satellite imagery, particularly from the Landsat archive, provides long-term spatial data that enable the mapping of changes in water extent, vegetation cover and surrounding land use (Adam et al., 2010; Rebelo et al., 2009). Spectral indices such as the Normalised Difference Water Index improve the detection of surface water and wetland vegetation, facilitating accurate monitoring of wetland environments (McFeeters, 1996; Xu, 2006). These approaches have been widely applied in wetland studies to understand landscape-scale ecological change.

Despite the availability of satellite imagery and long-term waterbird census data, relatively few studies in Ghana have integrated remote sensing analysis with ecological monitoring to examine how wetland habitat dynamics influence waterbird communities. Most existing research has focused on species inventories or site-specific ecological descriptions rather than linking habitat change with patterns of waterbird abundance and community structure. However, the use of aggregated census data limits the ability to infer causal relationships, highlighting the need for cautious interpretation of habitat–waterbird associations.

This study, therefore, examines the relationship between wetland habitat change and waterbird abundance at the Densu Delta Ramsar Site using remote sensing and waterbird census data. Specifically, the study analyses land-use and land-cover dynamics and evaluates how variations in wetland habitat structure correspond with patterns of waterbird abundance, species richness and community composition. By integrating satellite-derived environmental data with ecological monitoring records, the study provides new insight into habitat–waterbird relationships in a rapidly changing coastal wetland and contributes evidence to support conservation and management of Ramsar wetlands in Ghana.

Study Area

The study was conducted at the Densu Delta Ramsar Site (Fig. 1), a coastal wetland located near Accra in the Greater Accra Region of Ghana. The site lies between approximately 5°30'–5°33' N and 0°18'–0°20' W and covers an area of about 5,893 ha (Ramsar Convention Secretariat, 2024). The wetland forms part of the lower basin of the Densu River, where the river enters the Gulf of Guinea, creating a complex mosaic of lagoon waters, tidal flats, marshes, and mangrove vegetation. The site was designated as a wetland of international importance under the Ramsar Convention due to its ecological significance and its role in supporting diverse communities of resident and migratory waterbirds.

The area experiences a coastal savanna climate, characterised by mean annual rainfall ranging between approximately 750 and 1,000 mm, with a bimodal rainfall pattern consisting of major rains from April to July and minor rains between September and November (Dickson & Benneh, 2004; Ramsar Convention Secretariat, 2024). Mean annual temperatures range between 24°C and 30°C, with relatively low seasonal variability typical of coastal West Africa. Hydrological conditions within the wetland are influenced by both freshwater inflows from the Densu River and tidal exchange with the Gulf of Guinea, resulting in dynamic fluctuations in water levels and salinity gradients across the lagoon system. Seasonal rainfall and river discharge influence the extent of inundation, while tidal processes periodically expose intertidal mudflats that are critical feeding habitats for migratory shorebirds (Ntiamoa-Baidu et al., 2000; Cresswell, 2012).

The wetland contains a variety of habitats, including open water, seasonal wetlands, mudflats and mangrove stands dominated by *Rhizophora racemosa* and *Avicennia germinans*. These habitats provide feeding and roosting grounds for numerous waterbird species, particularly waders, herons, egrets and terns, many of which are associated with migratory flyways along the West African coast (Gbogbo & Attuquayefio, 2010; Ntiamoa-Baidu et al., 2000). Coastal wetlands in Ghana, including the Densu Delta, are recognised as important sites for migratory waterbirds within the East Atlantic Flyway (Nagy et al., 2022).

Despite its ecological importance, the wetland faces increasing pressure from human activities such as urban expansion, sand mining, agriculture and pollution from surrounding settlements. These pressures have contributed to habitat modification and degradation of wetland ecosystems, as noted in several studies of coastal wetlands in Ghana (Gbogbo & Attuquayefio, 2010; Ekumah et al., 2020), highlighting the need for continuous monitoring of wetland dynamics and waterbird populations.

Materials and Methods

Data Sources

Two main datasets were used in this study: satellite-derived land-use and land-cover data and waterbird census records from the Ramsar Information Sheet (RIS). Satellite imagery from the Sentinel-2 mission of the European Space Agency was used to analyse land-use and land-cover (LULC) dynamics within the study area. Sentinel-2 provides multispectral imagery at 10 m spatial resolution with frequent revisit intervals, making it suitable for monitoring environmental change in wetland ecosystems. Surface reflectance Level-2A products were used to ensure radiometric consistency and comparability across multiple years.

Satellite Image Processing

Satellite imagery was processed using the Google Earth Engine cloud computing platform. Images were filtered to retain scenes with less than 20% cloud cover, and cloud contamination was removed using the Sentinel-2 Scene Classification Layer. For each year, images acquired during the dry season (January–March) were combined using median compositing to minimise atmospheric noise and seasonal variability. To enhance wetland feature detection, three spectral indices were calculated: the Normalised Difference Vegetation Index (NDVI), the Normalised Difference Water Index (NDWI) and the Modified Normalised Difference Water Index (MNDWI). These indices improve the discrimination of vegetation, water bodies and non-vegetated surfaces in wetland environments.

Land-Use and Land-Cover Classification

Land-use and land-cover classification was performed using a supervised machine learning approach based on the Random Forest algorithm implemented in Google Earth Engine. The classification scheme consisted of four major land-cover classes: open water, wetland vegetation, agriculture/degraded wetland, and built-up/bare land. Training samples were generated through visual interpretation of Sentinel-2 imagery and spectral index layers. Classification accuracy was evaluated using confusion matrices and standard accuracy metrics, including overall accuracy, producer's accuracy, user's accuracy and the Kappa coefficient.

Waterbird Population Data

Waterbird data used in this study were obtained from the Ramsar Sites Information Service (RSIS), which compiles data from the International Waterbird Census (IWC) coordinated by Wetlands International. The IWC is a globally standardised monitoring programme in which waterbird counts are conducted annually during the mid-winter period (January), when bird populations are relatively stable and less influenced by migration movements (Wetlands International, 2020).

Counts are conducted using total count methods within defined wetland boundaries by trained observers, following standardised protocols to ensure comparability across sites and years. The Densu Delta is part of this global monitoring network, and the data used in this study represent aggregated annual counts reported through the RSIS database (https://rsis.ramsar.org).

For this study, annual census records from 2020 to 2023 were used to examine broad temporal patterns in waterbird abundance, species richness and community composition. While the dataset provides valuable insight into general trends, it does not represent continuous or fine-scale monitoring, and therefore interpretations are limited to exploratory analysis.

Waterbird Community Analysis

Waterbird census data were used to assess patterns in bird community structure. Three ecological indicators were derived from the census dataset: total waterbird abundance, species richness and guild composition. Species were further grouped into functional guilds based on their primary feeding ecology to evaluate ecological responses of waterbird communities to wetland habitat conditions.

Statistical Analysis

To evaluate relationships between wetland habitat variables and waterbird community metrics, Spearman's rank correlation analysis was used. Spearman correlation is a non-parametric method that assesses monotonic relationships between variables and does not assume normal distribution of data. This approach is particularly suitable for ecological datasets with small sample sizes and potential non-linear relationships.

Correlation analysis was performed between land-use and land-cover variables and waterbird abundance and guild metrics. Descriptive statistics and graphical comparisons were used to examine temporal trends in waterbird abundance, diversity and guild composition. All statistical calculations and data summarisation were performed using Microsoft Excel and standard ecological diversity formulas. Due to the limited number of temporal observations (n = 4), correlation results are interpreted as indicative of general ecological patterns rather than statistically robust relationships.

Results

Land-use and land-cover were classified into four dominant classes (Table 1): open water, wetland vegetation, agriculture/degraded wetland, and built-up/bare land to capture the principal ecological components of Ghana's wetland systems and the major forms of anthropogenic pressure affecting them.

Table 1
Description of LULC Classes Used in This Study

Class Code	LULC Class	Description
1	Open water	Permanent or seasonal surface water bodies, including lagoons, reservoirs, rivers, and ponds, with high water reflectance and low vegetation cover
2	Wetland vegetation	Natural and semi-natural wetland vegetation, such as mangroves, reeds, grasses, and marsh vegetation, within Ramsar sites
3	Agriculture / bare / degraded wetland	Cultivated lands, fallow areas, exposed soil, sand flats, and degraded wetland zones with sparse or no vegetation cover
4	Built-up / bare land	Settlements, infrastructure, roads, compacted surfaces, and non-vegetated developed areas

The LULC maps for the Densu Ramsar Site (Fig. 2) show that built-up and bare land occupy a substantial proportion of the site throughout the study period. This class is widely distributed across the western and central areas in all mapped years.

Open water is concentrated mainly in the southern and south-eastern sections, corresponding to the Densu Lagoon and associated water bodies. The overall spatial extent of open water remains broadly similar across years, although minor shifts are visible along lagoon margins.

Wetland vegetation occurs primarily along lagoon edges and drainage channels, forming a transitional belt between open water and adjacent terrestrial land cover. Across the mapped years, this class shows areas of discontinuity, particularly along borders between built-up and agricultural land.

Agriculture and degraded wetland classes are located mainly in the site's eastern and north-eastern portions. These areas appear as interspersed patches within the broader wetland matrix and are present in each reference

year.

In summary, the mapped outputs indicate that built-up and bare land constitute a dominant component of the Densu site, while wetland vegetation and open water remain spatially concentrated around the lagoon system.

Accuracy Assessment

The classification results showed high accuracy across all land-use and land-cover classes, with both user's and producer's accuracies approaching or equal to 1.0 for most classes in 2020 and 2023 (Table 2).

Table 2
Accuracy Assessment of LULC Classification

Site		Water		Wetland Veg		Agri/Bare		Built-up	
	Year	User's	Producer's	User's	Producer's	User's	Producer's	User's	Producer's
Densu	2020	1	1	1	1	1	1	1	1
Densu	2023	1	0.95	1	1	1	1	0.96	1

Overall classification performance was similarly high, with overall accuracy exceeding 98% and Kappa coefficients above 0.98 for both years, indicating strong agreement between classified and reference data (Table 3).

Table 3
Overall accuracy and Kappa

Site	Year	Overall Accuracy	Kappa
Densu	2020	1	1
Densu	2023	0.989	0.985

Waterbird Abundance Trends and Species Richness

Community Composition

Waterbird assemblages were dominated by a relatively small number of species that accounted for a large proportion of individuals recorded during the study period (Table 4). Several of the most abundant species were migratory shorebirds associated with coastal mudflats, including the *Charadrius hiaticula* and *Calidris ferruginea*. Other dominant species included piscivorous birds such as *Microcarbo africanus* and aerial foragers such as *Sterna hirundo*.

Table 4
Dominant Community Composition

Scientific Name	Common Name	Total Individuals
Charadrius hiaticula	Common ringed plover	13,734
Calidris ferruginea	Curlew sandpiper	13,343
Himantopus himantopus	Black-winged stilt	8,566
Microcarbo africanus	Long-tailed cormorant	7,488
Tringa nebularia	Common greenshank	5,962
Sterna hirundo	Common tern	5,344
Calidris minuta	Little stint	4,214
Thalasseus sandvicensis	Sandwich tern	4,162
Thalasseus maximus	Royal tern	3,990
Dendrocygna viduata	White-faced whistling duck	3,710

Functional Guild Structure

Waterbird species were grouped into four ecological guilds based on feeding behaviour and habitat use: shorebirds, waders, piscivores, and waterfowl. Guild composition varied across the study period (Fig. 4).

Shorebirds represented the dominant guild in all years, accounting for more than half of all individuals recorded annually. Waders and piscivores were consistently present but in lower numbers, while waterfowl showed strong interannual variation, with substantial increases in 2021 and 2022.

Relationships Between Habitat Change and Bird Guilds

To explore potential ecological relationships between habitat dynamics and waterbird guild composition, *Spearman's rank correlation analysis* was used to assess associations between land-use and land-cover variables and waterbird guild abundance (Table 5). Given the short temporal dataset (2020–2023), the analysis is interpreted as *exploratory*, focusing on identifying general ecological patterns rather than establishing statistical significance.

Table 5
Habitat Dynamics and Bird Guild Relationship

Summary Table of Results		
Relationship	**Spearman ρ**	**Strength**
Shorebirds vs degraded wetland	0.15	Very weak
Waterfowl vs open water	0.44	Moderate
Waders vs wetland vegetation	**0.9**	**Very strong**
Piscivores vs open water	0.61	Moderate–strong

The strongest association was observed between wader abundance and wetland vegetation extent (ρ = 0.90), suggesting that vegetated wetland habitats may be important for supporting wading bird species. Moderate positive associations were also observed between piscivores and open water (ρ = 0.61) and between waterfowl and open water (ρ = 0.44), indicating the relevance of aquatic habitats for these groups. In contrast, the relationship between shorebirds and degraded wetland areas (ρ = 0.15) was weak, suggesting that additional factors, such as tidal dynamics, prey availability, and migratory timing, may influence shorebird distribution.

The similarity between correlation values across habitat variables reflects consistent patterns in the relative ranking of habitat extent and bird abundance over the study period. Since the data spanned four years, these relationships are interpreted as indicative of general ecological associations rather than statistically robust ones.

Discussion

Land-Use and Land-Cover Dynamics in the Densu Delta Ramsar Site

The land-use and land-cover analysis indicates that built-up and bare land occupy a substantial proportion of the landscape within the Densu Delta Ramsar Site. This pattern suggests that urban expansion may be an important driver of landscape change within the wetland. Rapid urbanisation and land-use transformation are widely recognised as key drivers of wetland degradation and habitat fragmentation globally (Davidson, 2014; Hu et al., 2017). Urban development around wetlands may alter hydrological processes and increase pollution loads, potentially reducing habitat quality for aquatic species.

Wetlands are highly sensitive ecosystems whose ecological functioning depends strongly on hydrology, vegetation structure, and surrounding land uses (Mitsch & Gosselink, 2015). Changes in land cover, particularly conversion to built-up areas or agriculture, can alter water flow patterns and sediment dynamics, thereby affecting habitat quality for wetland organisms. Similar patterns have been reported in coastal wetlands worldwide, where increasing human activities have significantly altered natural wetland landscapes and reduced their ecological integrity (Hu et al., 2017).

The spatial distribution of wetland vegetation around the lagoon margins further highlights the ecological structure of the Densu Delta wetland. Vegetated marsh zones typically serve as transitional habitats between open water and terrestrial landscapes, providing feeding and breeding habitats for many aquatic species (Mitsch & Gosselink, 2015). The persistence of these vegetation zones, therefore, remains important for maintaining ecological functions within the wetland.

Waterbird Abundance and Community Structure

Substantial interannual variation was observed in both waterbird abundance and species richness between 2020 and 2023. The highest abundance and species richness recorded in 2021 may reflect more favourable environmental conditions during that period. Waterbird populations are known to fluctuate across years due to changes in hydrological conditions, climatic variability, and food availability within wetland ecosystems (Kingsford & Norman, 2002).

Wetlands are globally recognised as critical habitats for waterbirds because they provide feeding, nesting, and resting areas for both resident and migratory species (Ramsar Convention Secretariat, 2016). The dominance of

migratory shorebirds such as *Charadrius hiaticula* and *Calidris ferruginea* in the dataset highlights the importance of the Densu Delta wetland as a feeding and stopover site for migratory birds along international flyways. Migratory shorebirds depend heavily on coastal wetlands to replenish energy reserves during long-distance migrations (Newton, 2007).

Shorebirds were the most abundant guild throughout the study period, accounting for more than half of all individuals recorded annually. This pattern is consistent with observations from other coastal wetlands, where exposed mudflats and shallow-water habitats support large populations of wading birds due to the abundance of benthic invertebrates (Colwell, 2010). The dominance of shorebirds likely reflects the availability of suitable feeding habitats, particularly shallow sediments and mudflats.

Piscivorous birds such as cormorants and kingfishers were also well represented in the community. The presence of these species indicates the availability of fish resources within the wetland ecosystem. Waterbirds are often considered useful indicators of wetland ecological conditions because their abundance and distribution respond to habitat quality and food availability (Kingsford et al., 2017).

Functional Guild Structure and Habitat Associations

The functional guild analysis revealed clear differences in the abundance of different feeding groups. Shorebirds dominated the community across all years, while waders, piscivores, and waterfowl occurred in lower but variable numbers.

A strong positive association was observed between wader abundance and wetland vegetation extent ($\rho = 0.90$), suggesting that vegetated wetland habitats may play an important role in supporting wading bird species. Vegetated wetlands provide structurally complex foraging environments for herons, egrets and other waders, which typically feed on fish, amphibians and aquatic invertebrates in shallow water habitats (Colwell, 2010).

Moderate positive associations between piscivorous birds and open water ($\rho = 0.61$), as well as between waterfowl and open water ($\rho = 0.44$), further indicate the ecological importance of aquatic habitats for species dependent on fish and open-water resources (Kingsford et al., 2017).

However, these relationships should be interpreted with caution due to the limited temporal dataset ($n = 4$), and are therefore indicative of general ecological patterns rather than statistically robust relationships. In addition, the use of aggregated waterbird census data limits the ability to establish causal relationships between habitat change and bird community responses, and the observed associations should therefore be interpreted as exploratory rather than mechanistic.

The weak association observed between shorebirds and degraded wetland areas ($\rho = 0.15$) suggests that additional factors, including tidal dynamics, prey availability and migratory timing, may influence shorebird distribution beyond habitat extent alone (Newton, 2007).

Implications for Wetland Conservation

The results of this study provide indicative evidence of the ecological importance of the Densu Delta wetland for supporting diverse waterbird communities. The presence of large numbers of migratory shorebirds and other waterbird guilds suggests that the site likely plays an important role within regional wetland networks.

Wetlands designated under international frameworks such as the Ramsar Convention are recognised for their importance in maintaining biodiversity and supporting migratory species (Ramsar Convention Secretariat, 2016). Protecting the ecological integrity of these wetlands is therefore essential for sustaining waterbird populations and maintaining ecosystem services.

However, the dominance of built-up areas within the surrounding landscape indicates potential pressure from urban expansion and land-use change. Continued monitoring of both habitat dynamics and waterbird populations is therefore necessary to evaluate the effectiveness of wetland conservation measures. Integrating remote sensing techniques with biodiversity monitoring provides a valuable approach for understanding how environmental changes influence ecological communities in wetland ecosystems.

Limitations of the Study

This study provides an exploratory assessment of associations between land-use and land-cover dynamics and waterbird community structure at the Densu Delta Ramsar Site. However, several limitations should be acknowledged. First, the waterbird dataset was based on aggregated annual census records covering a relatively short temporal period (2020–2023), which limits the ability to establish robust long-term ecological trends or infer causal relationships between habitat change and bird community responses. Second, the use of annual census data from the International Waterbird Census programme does not capture seasonal variation in bird abundance and habitat use within individual years. In addition, other ecological factors such as hydrological variability, tidal fluctuations, food availability and climatic conditions were not explicitly incorporated into the analysis, although these variables may influence waterbird distribution and abundance. Consequently, the observed relationships should be interpreted as indicative of general ecological patterns rather than definitive mechanistic relationships. Future studies incorporating longer-term monitoring datasets and additional environmental variables would help provide a more comprehensive understanding of habitat–waterbird interactions in coastal wetland ecosystems.

Conclusion

This study examined the relationship between land-use and land-cover dynamics and waterbird community structure at the Densu Delta Ramsar Site between 2020 and 2023 using remote sensing analysis and waterbird census data. The results showed notable interannual variation in waterbird abundance and species richness, with the highest counts recorded in 2021. A total of 62 waterbird species were documented during the study period, with shorebirds constituting the dominant ecological guild across all years.

The land-use and land-cover analysis indicated that built-up and bare land occupy a significant proportion of the study area, reflecting increasing anthropogenic influence on the wetland landscape. Despite these pressures, the wetland continues to support diverse waterbird communities, including migratory species that depend on coastal wetlands for feeding and resting.

Exploratory analysis further indicated that variation in wetland habitat structure may be associated with differences in waterbird guild abundance. In particular, wader abundance showed a strong positive association with wetland vegetation extent, while piscivorous birds and waterfowl exhibited moderate associations with open water habitats. However, these relationships should be interpreted with caution due to the limited temporal dataset.

Overall, the study underscores the ecological importance of the Densu Delta wetland and demonstrates the value of integrating remote sensing with biodiversity monitoring to improve understanding of habitat–waterbird relationships in dynamic coastal ecosystems.

Recommendations

Based on the findings of this study, several measures are recommended to support the conservation and sustainable management of the Densu Delta Ramsar Site. Given the increasing dominance of built-up land within the surrounding landscape, regulating urban expansion and land-use development in areas adjacent to the wetland is essential to minimise further habitat degradation. Conservation efforts should prioritise the protection and restoration of wetland vegetation, which appears to play an important role in supporting wading bird populations. Maintaining the ecological integrity of vegetated marsh habitats will therefore be critical for sustaining waterbird communities.

In addition, long-term ecological monitoring programmes should be strengthened to enable more robust assessment of habitat change and waterbird dynamics over time. Integrating satellite-based remote sensing with field-based biodiversity monitoring offers a valuable approach for detecting environmental change and informing adaptive wetland management strategies. Continued implementation of conservation measures under the Ramsar Convention framework will also be important for ensuring the long-term protection of the wetland and the migratory bird species that depend on it.

Declarations

All authors have read, understood, and complied as applicable with the statement on “Ethical responsibilities of Authors” as found in the Instructions for Authors

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Competing Interests

The authors have no relevant financial or non-financial interests to disclose.

Author Contributions

D.T.O = Conceptualisation and study design, data collection and analysis, wrote the main manuscript.

A.M.K = Conceptualisation and study design, manuscript review and editing.

R.A = manuscript review and editing.

All authors read and approved the final version of the manuscript.

Data Availability

The Waterbird data used in this study were obtained from the Ramsar Sites Information Service (RSIS) database (https://rsis.ramsar.org), which compiles International Waterbird Census (IWC) records. Satellite imagery

(Sentinel-2) is publicly available through the European Space Agency and was accessed via Google Earth Engine. Processed datasets are available from the corresponding author upon reasonable request.

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Figures

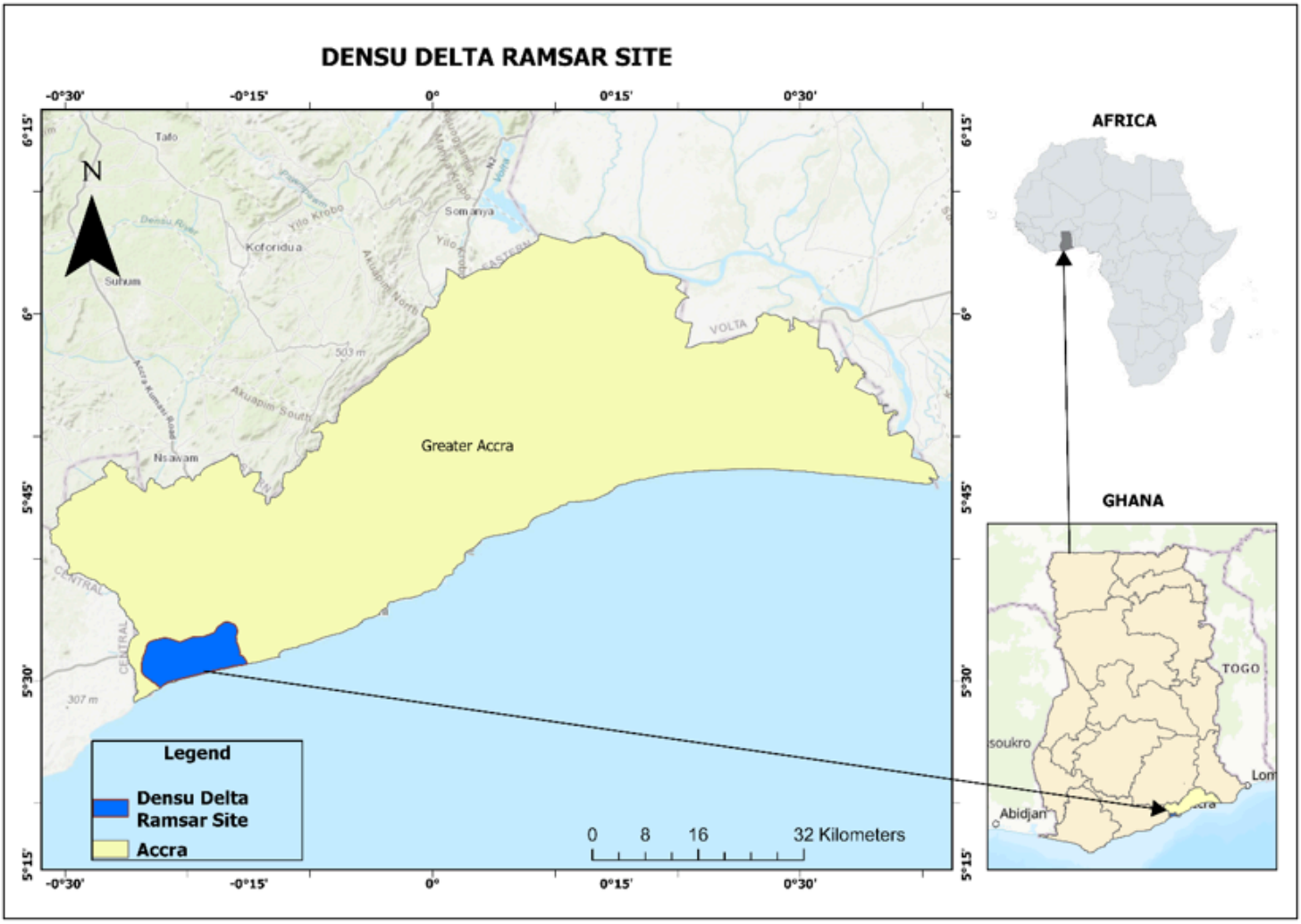


Figure 1

illustrates the location of the Densu Delta Ramsar Site in the Greater Accra Region of Ghana.

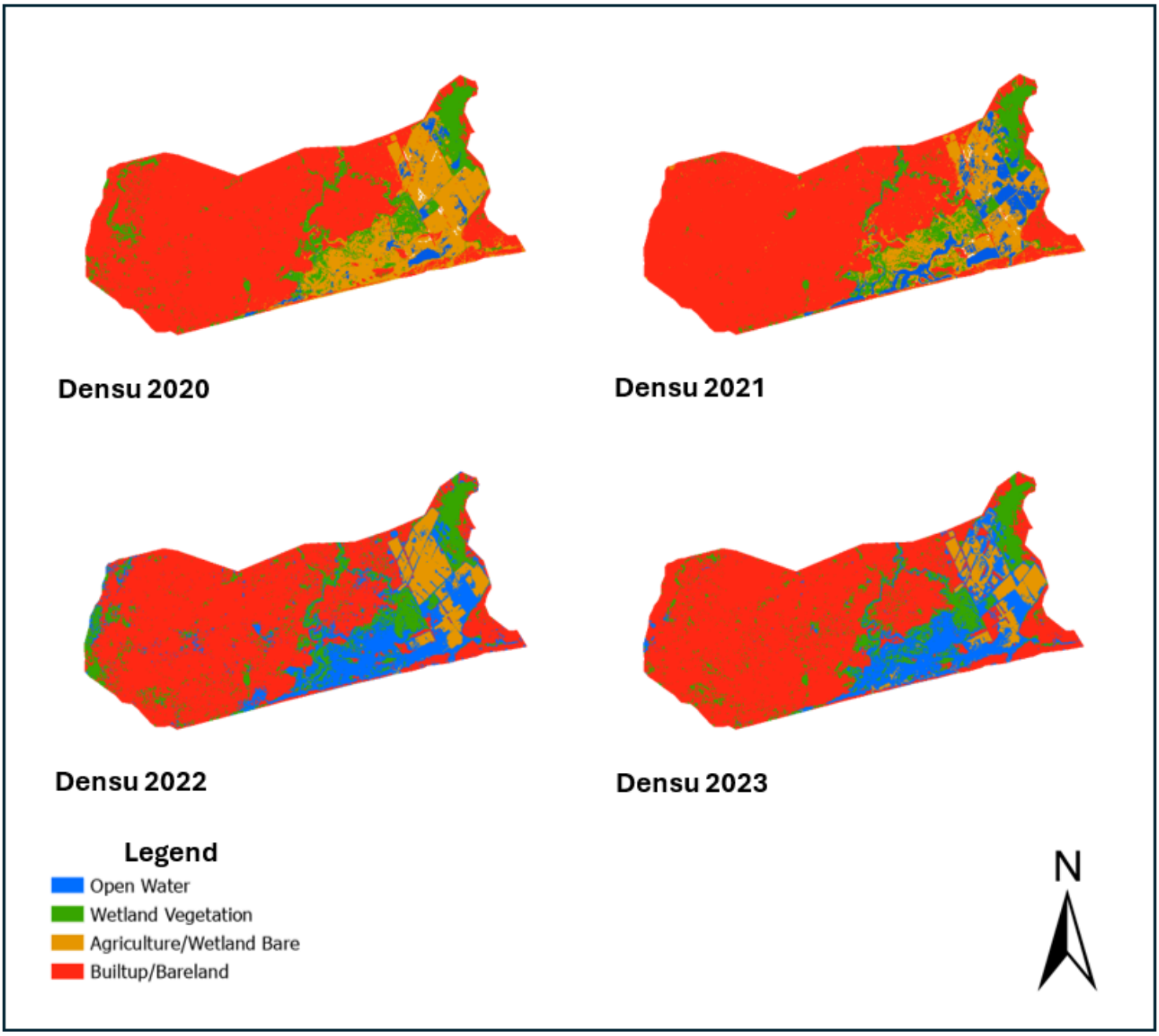


Figure 2

Spatio-temporal Land-use and Land-cover map of Densu Delta Ramsar Site

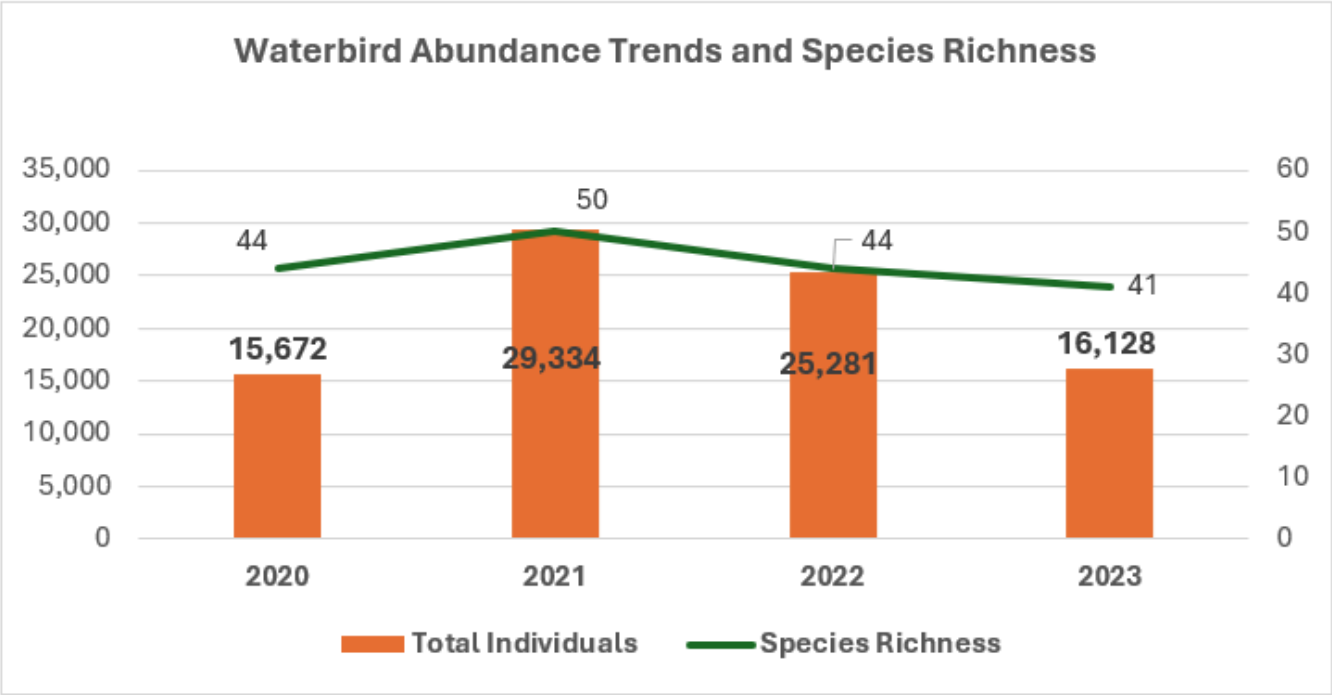


Figure 3

Waterbird Abundance Trends and Species Richness

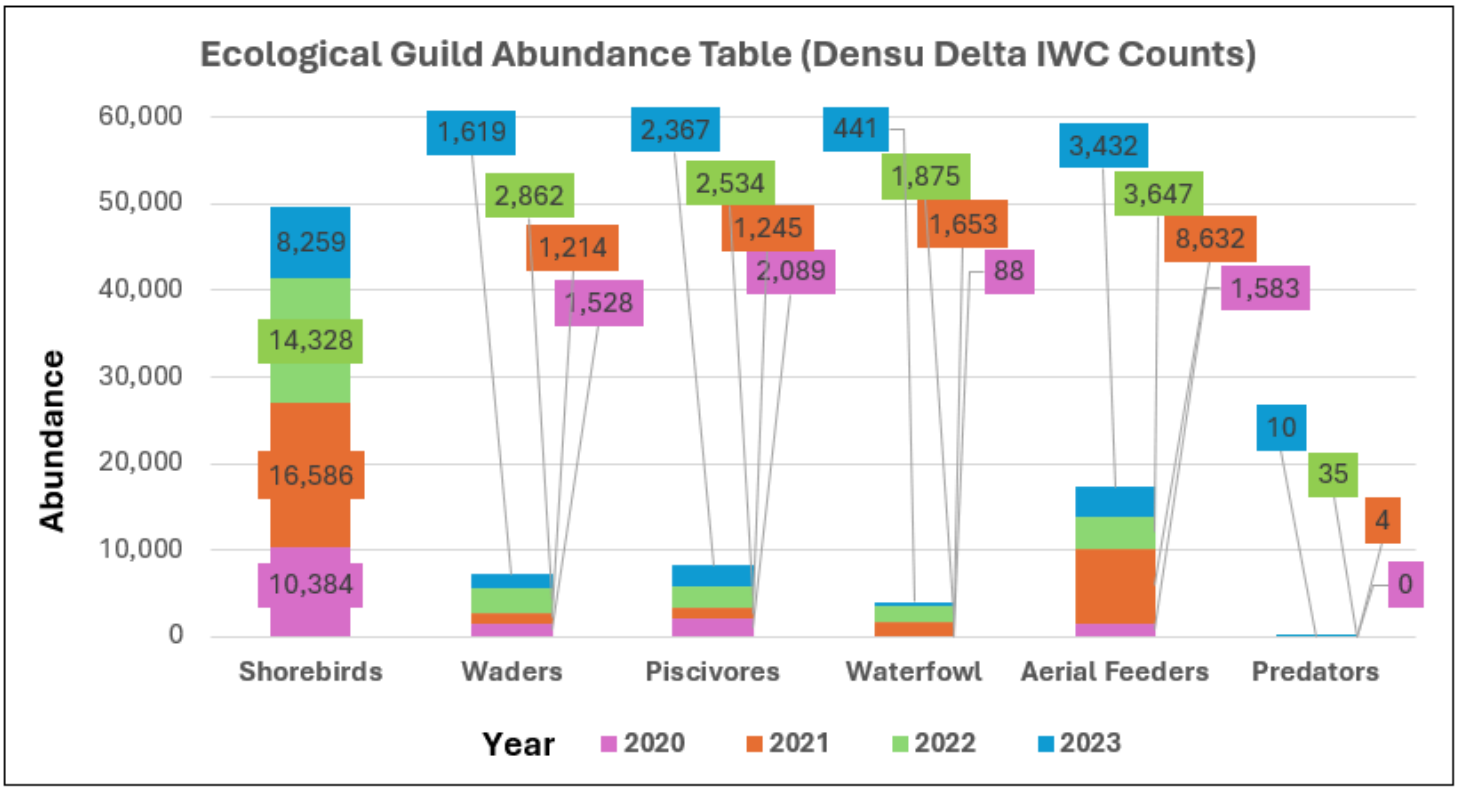


Figure 4

Community Guild Structure.