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RECEIVED 30 November 2025

REVISED 08 January 2026

ACCEPTED 14 January 2026

PUBLISHED 10 February 2026

CITATION

Ringim AS, Muhammad SI and Abubakar HM
(2026) Ecological traits as predictors of avian
reporting rates and monitoring gaps:
a 12-year analysis of iNaturalist in Nigeria.
Front. Bird Sci. 5:1757541.
doi: 10.3389/fbirs.2026.1757541

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Ecological traits as predictors of avian reporting rates and monitoring gaps: a 12-year analysis of iNaturalist in Nigeria

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To prioritise interventions amid the biodiversity crisis, this study applied a vulnerability framework to Nigerian avifauna by analysing 12 years of crowdsourced iNaturalist data (2013–2025). We defined vulnerability as a function of species' sensitivity (extinction risk and specialization) and adaptive capacity (dietary breadth and movement). Analysing 8,751 research-grade records across 631 species, we tested how ecological traits predict IUCN status and reporting rates. Results showed a significant inverse association between adaptability and extinction risk. We identified a specialist penalty and monitoring gap: highly sensitive species contributed only 5% of the dataset, while generalists with high adaptive capacity dominated observations. Despite this bias, the data documented six new country records, including the African Rail (*Rallus caerulescens*) and Ross's Turaco (*Musophaga rossae*), as well as several range extensions. We conclude that while citizen science is a vital tool for monitoring common species and rapid discovery, targeted expert-led surveys remain essential for specialists. This study demonstrates that unstructured iNaturalist data can effectively inform the design of integrated biodiversity monitoring frameworks in West Africa.

KEYWORDS

avian vulnerability, bird conservation, bird migration, citizen science, ecological traits, extinction risk, iNaturalist

Introduction

Citizen science, defined as the collaboration between members of the public and professional scientists (Strasser et al., 2019), has become a vital tool in modern ecological research, making significant contributions across various fields, from urban ecology to invasive species research (Kobori et al., 2016). The rise of digital platforms and information and communication technologies has fundamentally transformed this field, enabling broader public participation and the efficient crowdsourcing of large-scale ecological

datasets (Cooper and Balakrishnan, 2013). Among these platforms, iNaturalist has proven invaluable for biodiversity research, successfully aggregating millions of verifiable species observations used for professional scientific study (Boone and Basille, 2019). While these tools are effective globally in documenting species presence and distribution, their use is especially important in regions where traditional, large-scale ecological monitoring is logistically challenging.

The African continent is known as a biodiversity hotspot, with over 2,000 bird species, representing nearly 20% of the world's avian population (Brooks et al., 2001). However, this rich diversity faces severe and increasing threats, primarily caused by widespread habitat destruction, unsustainable land-use change, and rising human population pressures (Kirby et al., 2008; Buchanan et al., 2009). Evidence shows that agriculture and deforestation impact nearly 80% of threatened bird species, with about 200 African species currently classified as globally threatened (Brooks et al., 2001). This urgent conservation crisis is worsened by a persistent lack of timely and systematic ecological data, which hampers precise conservation efforts and effective monitoring of population trends (Siddig, 2019).

Several regional initiatives, including the bird atlas in Nigeria (Ringim et al., 2022; Tende et al., 2024), Southern Africa (Lee et al., 2022; Brooks et al., 2022), and Kenya (Nussbaumer et al., 2025), have successfully utilised citizen science to produce comprehensive bird distribution records. By mobilising local communities to document sightings, these efforts demonstrate the significant potential of crowdsourced data for avifaunal monitoring, especially in limited-resource contexts (Afrifa et al., 2025). Nonetheless, the potential of generalised crowdsourcing platforms, specifically iNaturalist, to test specific, trait-based vulnerability hypotheses in the African landscape remains underexplored.

To address data gaps and enhance monitoring and conservation strategies, researchers are increasingly analysing species' biological and ecological traits; diet, habitat specialisation, and adaptability—as proxies for resilience to environmental changes (MacLean and Beissinger, 2017; Comte et al., 2024). In this framework, vulnerability is fundamentally defined by three dimensions: sensitivity, exposure, and adaptive capacity (Foden et al., 2013). For avian populations, sensitivity is often reflected in a species' extinction risk status and degree of specialisation, while adaptive capacity is determined by intrinsic traits such as dietary breadth and movement behaviour (Reside et al., 2016).

Avian adaptability is a multifaceted process involving genetic, physiological, and ecological mechanisms that enable birds to modify their traits in response to challenges, such as urbanisation (Wong and Candolin, 2015; Richards et al., 2021). These adaptive capacities determine ultimate vulnerability; for instance, species with narrower resource needs, termed specialists, are generally more sensitive to habitat loss than generalists (Ramiadantsoa et al., 2018; Mills et al., 2020). Furthermore, key determinants of adaptive capacity include habitat specificity, with species restricted to narrow geographic ranges often facing the greatest risk (Khaliq et al., 2014). Also, adaptability involves genetic variations and introgression that facilitate survival in new conditions (Campagna and Toews, 2022), with avian genomes showing significant

evolutionary changes that correlate with adaptations (Zhang et al., 2014). Adaptability manifests through several physiological strategies, such as unique metabolic or water-handling mechanisms (Laverty and Skadhauge, 2008), and behavioural shifts, particularly in response to urbanisation (Garcia et al., 2017; Tryjanowski et al., 2020).

Global assessments indicate that 6–9% of bird species are already highly climate-vulnerable and threatened with extinction (Foden et al., 2013), with specific groups such as wetland-associated birds (Gardali et al., 2012), grassland species (Conkling et al., 2022), and tropical savanna birds (Reside et al., 2016) showing distinct patterns of susceptibility. However, this vulnerability is context-dependent and influenced by population size, body size, and geographic distribution (Purvis et al., 2000; Gaston, 2003).

Gaining insight into these relationships, particularly how sensitivity and adaptive capacity correlate with observed reporting rates and IUCN extinction risk assessments, is vital for identifying gaps in monitoring programs and initiatives. This study leverages 12 years of research-grade iNaturalist data (2013–2025) across Nigeria to test how these traits predict vulnerability in a fast-changing West African context. Specifically, we test three hypotheses:

1. Adaptive capacity vs. sensitivity (extinction risk): Is there a significant inverse association between a species' adaptability level and its IUCN extinction risk status?
2. Sensitivity (specialist diet) vs. reporting rate: Does a specialist diet predict significantly lower observation counts compared to a generalist diet?
3. Adaptive capacity (movement) vs. detectability: Do resident species demonstrate significantly higher predicted observation counts than migrants, indicating that stable, year-round populations have higher detectability in citizen science efforts?

Ultimately, this study aims to shed light on how ecological traits relate to avian vulnerability and the value of large, unstructured iNaturalist data as a tool for designing integrated biodiversity monitoring frameworks in West Africa.

Materials and methods

Nigeria's location on the Gulf of Guinea has provided the country with a diverse and rich ecosystem. These include wetlands, savannas, grasslands, montane forests, and lowland rainforests, with some bird fauna found nowhere else in the world, such as the Ibadan malimbe (*Malimbus ibadanensis*) (IUCN, 2025). The country experiences a tropical climate with a well-defined wet and dry season. Annual rainfall varies between southern regions (Figure 1); the Niger Delta receives more than 2,000 mm annually, while the savanna-dominated northern region (Figure 1) receives 600 to 1,200 mm annually (Eruola et al., 2021). Nigeria's population of over 240 million is driving land use change, with deforestation and agriculture being key drivers of the global decline of biodiversity (Hirsch, 2010).



Data extraction

We compiled the available data on the iNaturalist platform between January 2013 and August 2025, the first compilation on this database for Nigeria, which includes the authors' field observations of 444 bird species in Nigeria (Figure 2). Our search and download parameters include all bird species that were classified as "Research Grade." Research-grade observations are those that have been confirmed as genuine by a significant number of citizen scientists, enabling their use in scientific research (Jacobs, 2019). Certain key criteria associated with the research grade are a date, georeferenced coordinates, photos or sounds, and wild organisms (not cultivated or captive). These desired elements were exported from the Data Export page. We specifically queried species name, common name, family, locality, date and time, and coordinates. The data was downloaded as a CSV file, and we used Microsoft Excel for data cleaning and descriptive analysis. Data on species conservation status and movement patterns were primarily compiled from the IUCN (2025). To determine the biological traits of the bird species, namely foraging guild-diet, range, we used the available information from the Birds of the World (Birds of the World, 2025).

Trait classification and vulnerability dimensions

In this study, we utilise an established vulnerability assessment framework to evaluate Nigerian avifauna. We define sensitivity as

the inherent traits that make a species susceptible to decline (such as diet specialisation and extinction risk), while adaptive capacity represents the intrinsic ability of a species to persist in or escape changing environments (Reside et al., 2016). By categorising the bird's ecological traits into these functional pillars, we can more accurately predict which species are at the greatest risk of being overlooked by current monitoring efforts.

For each bird species, we followed the nominate subspecies found in Nigeria, where taxonomic variations or multiple populations exist. We recorded a suite of ecological traits, primarily using habitat breadth—the variety of ecosystems a species can occupy, as a measurable proxy for adaptive capacity (MacLean and Beissinger, 2017). While adaptability is fundamentally a complex physiological and genetic trait (Campagna and Toews, 2022), for this study, we categorised species as having high adaptability if they occupy diverse ecosystems (e.g., a mix of wetlands, savannas, and forests) and low adaptability (specialists) if restricted to specific environments, such as montane forests.

Similarly, we classified each species diet based on its primary foraging guild from Birds of the World (2025, www.birdsoftheworld.org). Species were defined as dietary specialists if they forage on specific sources (e.g., nectivores or piscivores) and generalists if they utilise a diverse array of food sources. These biological traits, alongside geographic range and occurrence status, were cross-referenced with Birds of the World (2025) to ensure taxonomic and ecological consistency across the dataset.

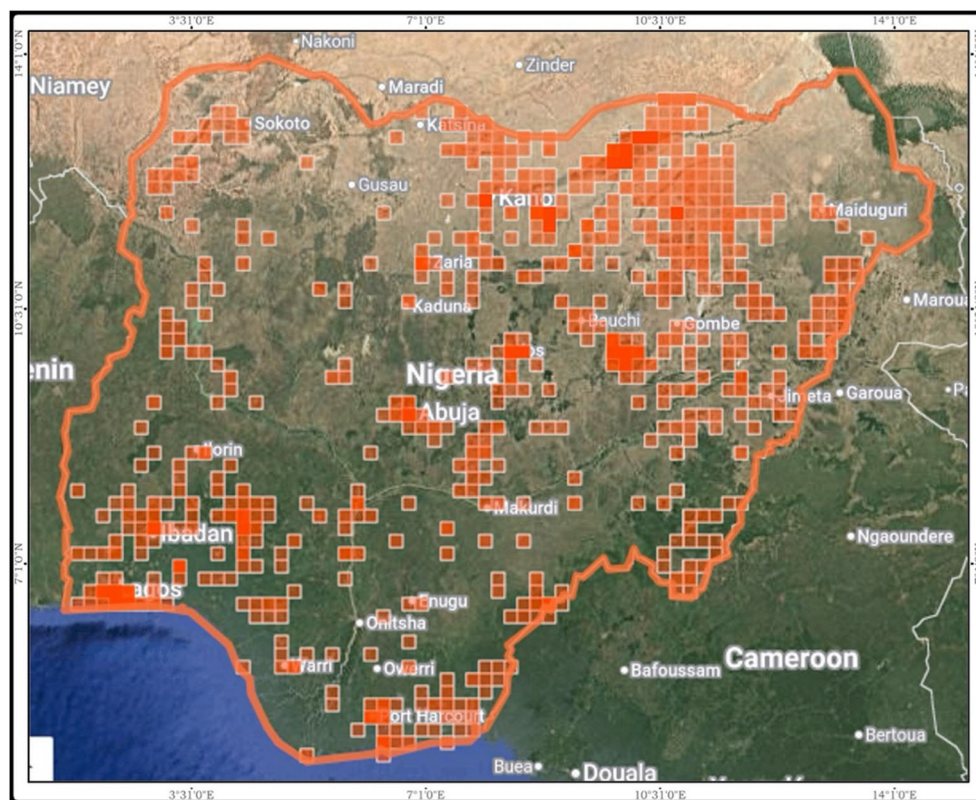


FIGURE 2
Distribution of bird observation counts on iNaturalist in Nigeria (2013–2025).

Reporting rate

We classified bird species into five frequency categories based on the total number of photographic records, or ‘observation counts’, within the iNaturalist dataset. These categories serve as a proxy for a species’ observation count rather than absolute biological abundance. Species were categorized as: Very frequent (more than 100 observations), Frequent (51–100), Common (11–50), Uncommon (2–10), and Rare (1 observation over the 12-year study period).

Location variables

Location variables include geographic distribution (restricted to northern or southern Nigeria, or found nationwide), range restriction, and movement patterns, classified as resident or migratory. Resident species are present year-round. Migratory species undertake long-distance movements during or outside their breeding periods, including intra-African migrants (breeding and migrating within Africa) and Palearctic migrants, which breed in Europe and spend the post-breeding period in Africa (Borrow and Demey, 2014). Range restriction follows BirdLife International’s (1998) criteria, assigning a score of 1 to species with a global range of less than 50,000 km² and 0 to those with a larger range.

Conservation status

The conservation status of each bird species in our dataset is based on the IUCN Red List of Threatened Species (IUCN, 2025, www.iucnredlist.org). The categories are Data Deficient (DD), Least Concern (LC), Near Threatened (NT), Vulnerable (VU), Endangered (EN), and Critically Endangered (CR). For analysis, we classified species as *lower* extinction risk if their status is DD or LC, and as *higher* extinction risk if their status is NT, VU, EN, or CR. iNaturalist provides conservation status for these species in our dataset, which complements the recently published Nigerian Bird Atlas Project dataset (NiBAP, Tende et al., 2024). It also includes trait classification data and vulnerability dimensions for known and rarely encountered species, as well as photographic evidence of several range extensions on the iNaturalist platform.

Data quality

Previous studies (e.g., Hochmair et al., 2020; López-Guillén et al., 2024) have examined concerns regarding the quality and reliability of the iNaturalist dataset. Therefore, it is important to thoroughly review the dataset to ensure that each bird species is accurately identified and confirmed to occur in Nigeria. We found several issues and removed many records from the dataset that did not occur in Nigeria, such as the African Hill Babbler (*Sylvia abyssinica*), Long-tailed Starling

(*Aplonis magna*), African Penduline-tit (*Anthoscopus caroli*), and the Gabon Woodpecker (*Dendropicos gabonensis*). Several species were misidentified. For example, the Azure-winged magpie (*Cyanopica cyanus*) is native to eastern Europe and Asia, and the Brown pelican (*Pelecanus occidentalis*) is found in the Americas. Other misidentifications include the Laughing Dove, which was incorrectly identified as Socotra Laughing Dove (*Spilopelia senegalensis sokotrae*). A record of Sandgrouse in Yankari Game Reserve was mistakenly identified as the Double-banded Sandgrouse (*Pterocles bicinctus*), which is not found in Nigeria. Based on the location of the sighting, the correct identification is the Four-banded Sandgrouse (*Pterocles quadricinctus*).

There is no photographic evidence for the presence of Cooper's Hawk (*Astur cooperii*) in Nigeria, as it is primarily an American species. Similarly, the Brown-breasted flycatcher (*Muscicapa muttui*) is an Asian species, and its observation lacks photographic support. Some records are duplicated because some were identified at the species level and others at the subspecies level. For example, Great Egret (*Ardea alba*) versus African Great Egret (*A. a. melanorhynchos*); we retain the latter as it is the species found in Africa. Similarly, African Thrush (*Turdus pelios saturatus*) versus African Thrush (*Turdus pelios*). In some cases, records were identified as subspecies found elsewhere, such as West African Helmeted Guineafowl (*Numida meleagris galeatus*), which is found mainly in western Africa, versus Saharan Helmeted Guineafowl (*Numida meleagris meleagris*), which ranges from eastern Chad to east Africa.

We maintain the bird names (taxonomic names) in the iNaturalist dataset, which may differ from those used by other taxonomic authorities, such as the English names available on the IUCN RedList. For example, the Black-and-white-casqued Hornbill (*Bycanistes subcylindricus*) is listed on iNaturalist as the Western Black-and-white-casqued Hornbill. Additionally, we did not include 10 introduced or domesticated bird species in our analyses. These species include the Greylag Goose (*Anser anser domesticus*), Muscovy Duck (*Cairina moschata*), Red Junglefowl (*Gallus gallus*), Feral Pigeon (*Columba livia*), Domestic Chicken (*Gallus gallus domesticus*), Domestic Guineafowl (*Numida meleagris domesticus*), Indian Peafowl, Common Ostrich (*Struthio camelus*), and Marabou Stork (*Leptoptilos crumenifer*).

Analysis

To examine the association between adaptability and extinction risk, we performed a Chi-square test of independence. Given that the response variable (reporting rate) did not follow a normal distribution even after log transformation, non-parametric methods were utilised. Specifically, we employed a Poisson Generalized Linear Model (GLM) without a log-linked function, which is the standard approach for analysing non-normal count data. To ensure the suitability of the Poisson model, we conducted diagnostic tests for overdispersion and zero-inflation. As the data showed no significant overdispersion, a negative binomial model was not warranted. Furthermore, while some species had low encounter rates, the frequency of zero-counts did not exceed

levels expected in large-scale ecological datasets; therefore, we did not utilise zero-inflated models. Additionally, Kruskal-Wallis tests were used to assess differences in reporting rates across habitat types, adaptability levels, geographic locations, and frequency occurrence categories. All analyses were performed in RStudio (Version 2025.09.2 + 418, [Posit team, 2025](#)).

Results

iNaturalist dataset composition

As of August 4, 2025, a total of 8,751 bird observation counts, representing 631 species (approximately 70% of Nigeria's documented bird fauna), have been uploaded by 223 citizen scientists (*see* supplementary material). The data set comprises resident and migratory species, including very notable records, as well as new country additions (Table 1). The results on diet show that generalist species have a dramatically higher reporting rate (count: 6,897; 448 species, 71%) compared to specialist species (count: 1,860, 182 species, 29%).

On the extinction risk, the species classified as having a lower extinction risk (DD and LC) account for most of the reporting rate (8,592, 599 species, 95%). The combined observation count of species classified in the higher extinction risk category (NT, VU, EN, and CR) is negligible in comparison (count: 219, 32 species, 5%). Conversely, species requiring the most urgent attention (NT, VU, EN, CR) are so scarce in the dataset that they contribute minimally to the reporting rate (5%), reinforcing the challenge of monitoring threatened species through opportunistic data collection.

The analysis of the bird's habitat specialisation shows that species with a generalist habitat classification account for 90% of the reporting rate (count: 8,489, 567 species), while habitat specialist species account for 10% (count: 262, 64 species). The analysis of the occurrence indicates that the highest reporting rate is concentrated in the common category (4,276, 192 species, 30%), followed by the frequent category (count: 2,623, 45 species, 7%), and the uncommon category (count: 942, 209 species, 33%). The very frequent and rare categories contribute the lowest reporting rates (count: 697, 5 species, 1%; 213, 180 species, 29%, respectively).

New national records and range extensions

The dataset revealed several notable records. Importantly, the platform documented the first confirmed national records for African Rail (*Rallus caerulescens*) and Ross's Turaco (*Musophaga rossae*, Table 1, Figure 3) among others, along with several range extensions, including House Sparrow (*Passer domesticus*), Grey-backed Fiscal (*Lanius excubitoroides*), Red-pate Cisticola (*Cisticola ruficeps*), Black-headed Weaver (*Ploceus melanocephalus*), Blue-breasted Kingfisher (*Halcyon malimbica*), Sun Lark (*Galerida modesta*), Tree Pipit (*Anthus trivialis*), West African Seed-eater (*Crithagra canicapilla*), and Yellow-throated Longclaw (*Macronyx croceus*). Additionally, leucistic individuals were recorded among

TABLE 1 List of bird species representing new records or special status and ornithological significance recorded on iNaturalist in Nigeria.

Species	Observed count	Special status/significance
Ross's Turaco (<i>Musophaga rossae</i>)	1 record, https://www.inaturalist.org/observations/137381515	New country record. A distinct, forest-dwelling species. Its photographic record in Nigeria via iNaturalist citizen science is a major ornithological event.
Golden-tailed Woodpecker (<i>Campethera abingoni</i>)	1 record, https://www.inaturalist.org/observations/18391143	New country record. Its presence, likely a localised northern population or vagrant, is critical for understanding its northern distribution limit in Nigeria.
African Rail (<i>Rallus caerulescens</i>)	1 record, https://www.inaturalist.org/observations/137390130	New country record. A highly cryptic, wetland-dependent species. Its first confirmed record via the iNaturalist is a significant ornithological addition to Nigeria.
African Grass Owl (<i>Tyto capensis</i>)	1 record, https://www.inaturalist.org/observations/139206036	New country record. Its record in Obudu represents a vital expansion of ornithological knowledge in the country. The adult birds were photographed by Terso Leventis (Kevin Eyos, per. comm.).
African Swift (<i>Apus barbatus</i>)	2 records, https://www.inaturalist.org/observations/293728292	New country record. The verifiable record in Adamawa State constitutes a new country record for Nigeria, representing a localised population previously thought to be endemic to the Bamenda Highlands in Cameroon.
Ursula's Sunbird (<i>Cinnyris ursulae</i>)	1 record, https://www.inaturalist.org/observations/36742103	New country record. Its observation in Obudu confirms the presence of this small, specialised species, likely at the edge of its range. The iNaturalist observation was confirmed by Nik Borrow.
Ibadan Malimbe (<i>Malimbus ibadanensis</i>)	Very rare, 4 records, https://www.inaturalist.org/observations/7498927	This species is endemic to Nigeria, highly localised, and globally threatened on the IUCN RedList (Endangered).
Jos Plateau Indigobird (<i>Vidua maryae</i>)	Very rare, 1 record, which may further be validated by other citizen scientists due to sympatry, https://www.inaturalist.org/observations/143934620	Near endemic. Its geographic range are largely restricted to the Jos Plateau.

Long-tailed Glossy Starling (*Lamprotornis caudatus*), African Thrush (*Turdus pelios*), Village Weaver (*Ploceus cucullatus*), and White-billed Buffalo Weaver (*Bubalornis albirostris*).

species' sensitivity (extinction risk and specialisation) and adaptive capacity (dietary breadth and movement behaviour) predict reporting rates across the 12-year iNaturalist dataset.

GLM analysis of trait-based vulnerability and reporting rates

The analysis utilized a Chi-square test of independence to assess the relationship between adaptability and extinction risk. Subsequently, a Generalised Linear Model (GLM) was employed to determine how

Adaptive capacity vs. sensitivity (extinction risk)

The initial analysis addressed the hypothesis that there is a significant inverse association between a bird species' adaptability level and its IUCN extinction risk status. The Chi-square test of



FIGURE 3

(A) African Rail (*Rallus caerulescens*) in Dikwa, Borno State, and (B) Ross's Turaco (*Musophaga rossae*) in Yebbi, Adamawa State, representing new country records in Nigeria. Photo Credit (HMA).

independence revealed a highly significant association between bird species' adaptability levels and their classification into IUCN extinction risk categories ($\chi^2 = 343.95$, $df = 6$, $p < 0.001$). This finding supports the hypothesis and confirms that low adaptability is statistically linked to higher threat classifications (NT, VU, EN, and CR). Furthermore, Table 1 details the initial non-parametric comparison of reporting rate across several ecological traits using the Kruskal-Wallis test, revealing highly significant differences in observed counts across all tested ecological traits (Table 2).

Sensitivity (specialist diet) vs. reporting rate

The second hypothesis, which predicted that species with a specialist diet status would show significantly lower predicted abundance compared to generalists ($\beta = -0.19$, $p < 0.001$; Table 3). This negative estimate indicates that being a specialist results in a predicted observation count that is substantially lower than that of generalist species. Furthermore, the model suggested that species in the lower observation count categories (rare, uncommon, and common) had highly significant negative coefficients relative to the most frequent

TABLE 2 Kruskal-Wallis test assessing the influence of habitat, adaptability, geographic location, and reporting rate recorded on iNaturalist in Nigeria.

Variables	Chi-square	df	p value
Habitat	19.163	1	$p < 0.001$
Adaptability	20.796	1	$p < 0.001$
Geographic location	41.091	2	$p < 0.001$
Reporting rate	216.69	4	$p < 0.001$

groups (frequent and very frequent). Specifically, rare ($\beta = -3.52$, $p < 0.001$) and uncommon ($\beta = -2.32$, $p < 0.001$) categories showed the strongest negative effects, confirming that specialist species (which drive these low observation count categories) are the least recorded and most difficult to monitor through iNaturalist.

Adaptive capacity (movement) vs. detectability

The third hypothesis, predicting that resident species would demonstrate significantly higher predicted observation count than migrant species, was supported by the GLM results (Table 3). The coefficient for the Resident bird species was positive and significant ($\beta = 0.11$, $p = 0.0105$). This positive estimate confirms that resident species have a statistically higher predicted observation count/detectability compared to migrant species. Conversely, the Vagrant bird species showed no significant difference ($\beta = 0.42$, $p = 0.6754$).

Discussion

By testing three hypotheses on species resilience, our findings identify specific biases inherent in citizen science data while demonstrating its potential for trait-based vulnerability analysis in data-poor regions. Our analysis confirms that ecological traits are the primary determinants of both a species' reporting rate and its conservation risk. The highly significant inverse association between adaptability and extinction risk aligns with established global ecological theory (Jetz and Freckleton, 2015), underscoring that generalised threats, such as habitat fragmentation and land-use change, disproportionately impact species with low adaptive

TABLE 3 GLM coefficients showing the effects of ecological traits on avian reporting rates in the Nigerian iNaturalist dataset.

Predictor	Estimate	Std. error	z-value	p-value
Intercept	3.463	0.145	23.90	<0.001
Extinction risk (Lower)	0.410	0.131	3.12	0.002
Movement pattern (Resident)	0.114	0.045	2.56	0.010
Movement pattern (Vagrant)	0.423	1.009	0.42	0.675
Diet (Specialist)	-0.187	0.046	-4.06	<0.001
Habitat (Specialist)	0.343	1.014	0.34	0.736
Adaptability (Low)	-0.558	1.006	-0.55	0.579
Geographic location (Northern & Southern)	0.088	0.045	1.95	0.052
Geographic location (Southern)	-0.591	0.097	-6.10	<0.001
Occurrence (Common)	-0.854	0.048	-17.96	<0.001
Occurrence (Rare)	-3.518	0.115	-30.58	<0.001
Occurrence (Uncommon)	-2.320	0.068	-34.23	<0.001
Occurrence (Very frequent)	0.934	0.059	15.93	<0.001

Model coefficients were derived from a Poisson GLM without a log-link function. Diagnostic tests were performed for the response variable; overdispersion and zero-inflation were tested and found to be non-significant, justifying the use of the Poisson distribution over negative binomial or zero-inflated alternatives.

capacity (Sweeney and Jarzyna, 2022). This finding is important, as it supports the use of easily compiled trait data as a vital early-warning system for vulnerability in regions lacking the systematic long-term monitoring required for direct population trend analysis.

The overwhelming dominance of habitat and dietary generalists in the iNaturalist dataset, which accounts for 90% and 71% of observations, respectively, carries significant implications for biodiversity monitoring in West Africa. This specialist penalty confirms that birds with a diverse diet are observed approximately 3.7 times more frequently than specialists. This statistical confirmation suggests that species restricted by narrow dietary or habitat requirements are intrinsically less detectable or exist at lower densities, making them more susceptible to population collapse when their specific niche is degraded (Scheele et al., 2017).

The negligible reporting rate (5%) for species in higher IUCN extinction risk categories (NT, VU, EN, and CR) underscores a structural monitoring gap. The rarity of near-endemics like the Ibadan Malimbe (*Malimbus ibadanensis*) and Jos Plateau Indigobird (*Vidua maryae*), along with species restricted to the Obudu Plateau, is statistically explained by this specialisation penalty. While opportunistic data provide an effective early warning system for common species, they remain an insufficient standalone tool for monitoring Nigeria's most sensitive avifauna. These findings provide a necessary quantification of bias within the context of digital monitoring in Nigeria, offering a roadmap for where traditional conservation resources must be most urgently directed.

Our third hypothesis confirmed an inherent methodological constraint: resident bird species showed significantly higher predicted observation counts than migrants. This result is consistent with other large-scale monitoring efforts (Sauer et al., 2012) and highlights the need for statistical correction when using raw iNaturalist counts to compare seasonal migrants with year-round residents. While our study shed light on identifying relative patterns of visibility across ecological guilds, it is not intended for determining fine-scale distribution or the population health of highly localised specialists, which still require systematic, expert-led surveys.

Despite these biases, iNaturalist proves to be a high-value tool for conservation ornithology through its capacity for rapid discovery and documentation. The recorded presence of the new bird records for Nigeria (e.g., African Rail and Ross's Turaco), along with several range extensions for species such as the House Sparrow (*Passer domesticus*) (Ringim et al., 2019), Grey-backed Fiscal (*Lanius excubitoroides*) (Ringim et al., 2020), Red-pate Cisticola (*Cisticola ruficeps*) (Abubakar and Ringim, 2020), and Yellow-throated Longclaw (*Macronyx croceus*) (Muhammad et al., 2025a; 2025b), among others, provides updates to the Nigerian avifaunal checklist. These qualitative discoveries, which often come from single, verifiably photographed sightings, demonstrate the unique utility of citizen science in filling critical knowledge gaps along ecological boundaries, such as the transboundary link between the Bamenda Highlands in Cameroon and the high-altitude forests of Adamawa in Nigeria.

The perceived contradiction between data bias and conservation relevance is resolved when citizen science is viewed as a diagnostic tool. Identifying which species are digitally invisible provides the empirical basis for why citizen science should be viewed as a complementary tool

for common species tracking rather than a surrogate for systematic surveys of threatened specialists. For policymakers, this study offers a methodological framework for integrating citizen science into national biodiversity strategies, ensuring that limited conservation resources are directed toward the specialists most at risk.

Conservation implications and recommendations

The link between ecological traits and avian vulnerability demonstrated in this study provides a useful framework for enhancing biodiversity monitoring in West Africa. By quantifying the relationship between sensitivity (specialisation) and adaptive capacity (diet and movement), we offer a useful insight into how conservation agencies can prioritise species based on measurable intrinsic risks.

Our findings carry two primary implications for conservation strategy. First, the documented specialist penalty serves as a diagnostic tool for identifying species at risk of digital omission on iNaturalist. Relying solely on opportunistic data risks leaving range-restricted specialists, namely Ibadan Malimbe (*Malimbus ibadanensis*) and Jos Plateau Indigobird (*Vidua maryae*), invisible to national monitoring frameworks. Second, the unique capacity of iNaturalist to rapidly document new country records and range extensions proves that citizen science is an unparalleled tool for updating national biodiversity registers in real-time, outpacing traditional formal surveys.

Based on the findings of this study, we propose the following strategic recommendations:

1. *Trait-informed prioritization*: conservation funding and site protection should be targeted toward habitats supporting species with low adaptive capacity and high sensitivity. These guilds are statistically confirmed as the most difficult to detect and the most susceptible to population collapse following land-use change.
2. *Hybrid monitoring frameworks*: national biodiversity reporting, specifically for the Convention on Biological Diversity (CBD) and the Nigerian Biodiversity Strategy and Action Plan (NBSAP), should adopt a hybrid approach in biodiversity monitoring. This involves leveraging iNaturalist for broad-scale distribution mapping of generalist species while maintaining dedicated funding for systematic, expert-led surveys for threatened and specialist guilds.
3. *Methodological integration*: to mitigate detectability biases, future research must integrate unstructured iNaturalist data with effort-corrected, systematic datasets, specifically the Nigerian Bird Atlas Project (NiBAP) and eBird. Such integration improves distribution modelling for scarce or migratory species that are currently underrepresented on iNaturalist.
4. *Expansion of citizen science in data-poor regions*: strengthening iNaturalist participation in under-sampled regions will be a cost-effective, integrative approach to

African bird conservation. Expanding the digital footprint of observers in high-altitude and transboundary forests like the Mambila and Obudu Plateaus will bridge critical knowledge gaps regarding range shifts driven by climate and land-use change.

Study limitations

While this study demonstrates the significant potential of iNaturalist for monitoring West African avifauna, our findings must be interpreted alongside several limitations inherent to opportunistic datasets.

First, record counts derived from iNaturalist are sourced from an unstructured framework and are inevitably influenced by observer behaviour, habitat accessibility, and species-specific detectability (Johnston et al., 2018). Consequently, these data are treated as measures of relative reporting frequency rather than formal biological abundance. Variations in reporting rates reflect a combination of a species' actual population density and its visibility to the average citizen scientist, which is a common challenge in crowdsourced monitoring (Callaghan et al., 2019).

While these biases make the dataset unsuitable for estimating absolute population densities, our comparative trait-based analysis remains very useful. By analysing the difference in reporting rates between ecological groups (e.g., generalists vs. specialists, residents vs. migrants), we are not measuring absolute population sizes, but rather the efficacy of the platform to detect specific guilds and habitat breadth. This distinction assists in identifying monitoring gaps and validating which ecological traits lead to digital invisibility, even if it cannot yet serve as a standalone census tool.

Furthermore, the uneven spatial sampling effort evident in Figure 2 is a characteristic of opportunistic platforms, where observations typically cluster around urban centres, accessible road networks, and regions with high concentrations of observers (Geldmann et al., 2016). This is especially true in Nigeria's cities with high citizen science activities like Plateau, Lagos, Jigawa, Oyo, and Abuja. In this analysis, we utilised raw occurrence data without applying spatial thinning or explicit sampling effort models. We did not differentiate between urban and rural detectability, which can skew reporting frequencies in areas with concentrated human activity (Mair and Ruete, 2016).

Finally, we acknowledge a degree of conceptual overlap between our measure of adaptability (habitat breadth) and the criteria used for IUCN Red List assessments. The IUCN frequently incorporates habitat specificity and geographic restriction as primary indicators of extinction risk (Jetz and Freckleton, 2015). Consequently, the significant inverse relationship found between adaptability and threat status may partially reflect these shared underlying attributes.

However, our results provide evidence of how these traits translate into actual reporting frequencies on opportunistic platforms. Even if low adaptability is a pre-defined risk factor for extinction, our findings demonstrate that it simultaneously results in a significant monitoring gap, where ecological specialists are consistently under-recorded. This confirms that the observed

relationship is not merely a taxonomic artifact of the IUCN classification system, but a reflection of real-world ecological scarcity and reduced detectability within the fast-changing West African landscape.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material. Further inquiries can be directed to the corresponding author.

Ethics statement

Ethical approval was not required for the study involving animals in accordance with the local legislation and institutional requirements.

Author contributions

AR: Conceptualization, Methodology, Data Curation, Writing – original draft, Writing – review & editing. HA: Writing – review & editing. SM: Formal Analysis, Writing – review & editing.

Funding

The author(s) declared that financial support was not received for this work and/or its publication.

Acknowledgments

We thank the citizen scientists for their observations on the iNaturalist platform, which provided the foundation for this study. We are grateful to Dr. Ulf Ottosson for reviewing the checklist of bird species downloaded from iNaturalist. We also thank Dr. Ottosson for encouraging the primary author to contribute to this special issue of *The Science of Birding in Africa*.

Conflict of interest

The author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The author(s) declared that generative AI was used in the creation of this manuscript. We acknowledge the use of AI generators (Grammarly) in grammar correction and rewriting sections for clarity.

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Supplementary material

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/fbirs.2026.1757541/full#supplementary-material>

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