Diversity and Distributions

WILEY

Diversity and Distributions

RESEARCH ARTICLE OPEN ACCESS

Historical Bird Atlas and Contemporary Citizen Science Data Reveal Long-Term Changes in Geographic Range of Kenyan Birds

Raphaël Nussbaumer[1,2,3] | Améline Nussbaumer[1] | Samuel Guchu[1,4] | Richard Stratton Hatfield[5,6,7] | Erustus M. Kanga[8] | Gladys Nyakeru Kung'u[4,9] | Anthony Kuria[10] | Eliot Miller[3,11] | Paul Kariuki Ndang'ang'a[12] | Peter Njoroge[4] | Darcy Ogada[4,13] | Sidney Shema[4] | Colin Jackson[1,4]

[1]A Rocha Kenya, Watamu, Kenya | [2]Swiss Ornithological Institute, Sempach, Switzerland | [3]Cornell Lab of Ornithology, Ithaca, New York, USA | [4]National Museums of Kenya, Nairobi, Kenya | [5]Wageningen University and Research, Wageningen, The Netherlands | [6]The Bird of Prey Trust, Borssele, The Netherlands | [7]The Kenya Bird of Prey Trust, Naivasha, Kenya | [8]Kenya Wildlife Service, Nairobi, Kenya | [9]University of Salzburg, Salzburg, Austria | [10]Tropical Biology Association, Nairobi, Kenya | [11]American Bird Conservancy, The Plains, Virginia, USA | [12]BirdLife International – Africa Partnership Secretariat, Nairobi, Kenya | [13]The Peregrine Fund, Boise, Idaho, USA

Correspondence: Raphaël Nussbaumer (rafnuss@gmail.com)

Received: 6 June 2024 | **Revised:** 6 September 2024 | **Accepted:** 30 September 2024

Editor: Boris Leroy

Funding: This work was carried out under the Swiss National Science Foundation PostDoc Mobility Grant (2021, grant number #191138) and Mobility Return Grant (2023, grant number #217873). This project was also supported by the UK Government Darwin Initiative through the Tropical Biology Association.

Keywords: conservation | eBird | kenya bird atlas | migration | scavenger | species distribution

ABSTRACT

Aim: Historical bird atlases provide comprehensive datasets for investigating long-term changes in species' distribution. In the context of accelerating biodiversity loss, these datasets can lend critical insights into the state of bird distributions across broad spatio-temporal scales and provide much-needed information for impactful conservation. In Africa, the potential of atlas data to understand changes in avian populations remains largely untapped.

Location: This study mapped changes in national distribution patterns of 1088 bird species found in Kenya.

Methods: Tapping into one of the earliest atlas databases, this study compared Kenyan bird atlas data collected between 1970 and 1984 with recent citizen science data sourced from the Kenya Bird Map project and eBird to determine changes in ranges across 50 years. We produced maps displaying, for every 27 × 27 km square of the country, whether a species appeared, was present throughout both periods, or disappeared. We account for the change in data collection effort between the two periods by quantifying the confidence of the change for each square.

Results: The maps produced for each species are publicly accessible through an interactive website: https://kenyabirdtrends.co.ke/. We found that related species tended to experience similar changes in their distribution ranges. The ranges of Palearctic migrants and scavengers declined drastically, while introduced birds experienced a significant range increase over the past 50 years.

Main Conclusions: This study demonstrates the potential of integrating recent citizen science data with historical atlas data to draw out the changes in range for all species at national level. The range contraction of Palearctic migrants and scavengers echoed corresponding drops in abundance at local, regional and global scales. These findings lend additional weight to the need for an increased conservation focus on migratory and scavenging birds in Kenya.

1 | Introduction

Biodiversity loss stands prominently as one of the most pressing challenges of our time (e.g., Barnosky et al. 2011; Cooke et al. 2023). Notably, an increasing number of bird species are transitioning from relatively low-risk to a high-risk conservation status (Monroe et al. 2019). While conservation strategies have prioritised preventing the extinction of globally threatened species, it is urgent to broaden our scope. By ensuring that species at lower risk do not escalate to higher-risk categories, we can counteract the stark declines observed even among common species (Dirzo et al. 2014; Weeks et al. 2022). Impactful conservation measures will therefore rely on a holistic understanding of shifts in abundance and distribution across all species at broad spatiotemporal scales.

Bird atlases stand out as invaluable resources for monitoring avian populations, offering unparalleled insights into long-term, large-scale trends across a wide range of species (Donald and Fuller 1998). Such atlases have already been instrumental in highlighting long-term trends in Europe and North America (Burns et al. 2021; Keller et al. 2020; Rosenberg et al. 2019). In Africa, the rich history of bird atlas projects—encompassing 30 initiatives across 23 countries (https://birds4africa.org/2020/03/20/african-bird-atlasses/)—provides a robust foundation to quantitatively evaluate shifts in bird distribution (Gibbons et al. 2007). Although these initiatives have not always been replicated using the same protocols, citizen science platforms have emerged as widely used alternatives, offering data at finer spatial and temporal resolutions, albeit with less standardisation and structure (Lee, Brooks, and Underhill 2022; Underhill and Brooks 2014). Comparing historical atlas data with recent citizen science observations offers an opportunity to unlock the full potential of past information and reveal long-term trends in bird distribution. The main challenge in this approach is to appropriately account for change in methodology between the different surveys (Keller 2017).

In East Africa, Kenya boasts one of the continent's most diverse avifauna due to its varied habitats (Fanshawe and Bennun 1991). Yet this rich biodiversity faces threats from rapid anthropogenic changes, including escalating human population growth, climate change, and deforestation (Gudka 2020; Okello and Kiringe 2004). Kenya offers a distinctive vantage point for bird monitoring, with one of Africa's earliest (1970–1984) and most comprehensive bird atlas projects: 'A Bird Atlas of Kenya' (Lewis and Pomeroy 1989). Complementing this, two active citizen science platforms, Kenya Bird Map (kenya.birdmap.africa) and eBird (ebird.org), provide large datasets of more recent bird distributions.

In this study, we compared Kenya's historical atlas data to more recent citizen science data. In particular, we mapped changes in geographic distribution for 1088 bird species found in Kenya, and produced, for each species, an online map identifying which grid squares have been lost (seen only in the historical atlas), kept (seen in both datasets), or gained (seen only in citizen science data) between the two periods considered. These species-level trends were then mapped onto a phylogenetic tree to appraise the degree to which closely related species experienced similar trends. We subsequently identify species or related species groups that have undergone major range shifts and discuss the conservation implications of our results.

2 | Methods

2.1 | Datasets

2.1.1 | Historical Atlas: A Bird Atlas of Kenya (1970–1984)

'A Bird Atlas of Kenya' (Lewis and Pomeroy 1989), subsequently referred to as 'the atlas,' was the third bird atlas produced for tropical Africa, and delineated the distribution of 1065 species identified in Kenya at the time. This exhaustive dataset has served as a foundational reference for species distribution and has informed several subsequent studies (Muriuki et al. 1997; Pomeroy 1989; Pomeroy and Sekabiira 1990).

In alignment with the prevailing methodology of its time (e.g., Ash and Pomeroy 1981), the atlas utilised a spatial resolution of quarter square degree (QSD) ($1/4 \times 1/4 \sim 27 \times 27$ km) which is referred to as 'square' in this paper (Larsen et al. 2009). It predominantly drew upon sightings recorded by approximately 200 volunteer observers, covering 215 of the 228 squares in Kenya. No specific protocol was followed for this atlas; sightings and breeding records were primarily collected incidentally, with the exception of several targeted trips organised to collect data in remote squares. The atlas also incorporated complementary data sources including past literature, museum specimens (mostly collected before 1970), nest record cards, and species captured at ringing stations.

For this study, we consolidated the breeding status recorded for each species per square (i.e., no evidence, probable, or confirmed breeding) into a single species presence value. We did not include pre-1970 data, consisting mostly of past literature and the 22,000 museum specimens, to limit our dataset to a defined temporal window of 14 years. The data used for this study was extracted from the digitised version of this atlas (Nussbaumer et al. 2022).

2.1.2 | Recent Atlas: Kenya Bird Map and eBird (2009–2023)

2.1.2.1 | Kenya Bird Map (KBM). Initiated in 2012, the Kenya Bird Map (kenya.birdmap.africa) has been leading efforts to establish a recent bird atlas for Kenya (Njoroge and Brooks 2023; Wachira, Jackson, and Njoroge 2015). As part of the African Bird Atlas Project (https://www.birdmap.africa/), KBM data are collected by volunteers following the African Bird Atlas protocol (Brooks et al. 2022; Underhill, Brooks, and Loftie-Eaton 2017): observers record a list of all species heard or seen within a given pentad ($1/12° \times 1/12° \sim 9 \times 9$ km square) on a dedicated mobile application. The GPS position is used to automatically record the pentad in which the observation occurred. Cards are considered 'full protocol' when a minimum of 2 h of birding are carried out over a period of five consecutive days. If the duration is lower, the card is considered 'ad-hoc.' We retrieved all data from the start of the initiative to 2023 and derived presence information (i.e., including both full and ad-hoc protocols) for all species recorded at the pentad level. The spatial resolution of the pentads is directly aligned with the squares used in the historical atlas, with each square containing nine pentads (Larsen et al. 2009). Therefore, to allow comparison of KBM data with that of the historical atlas, we upscaled the KBM species' map to a square resolution by considering a species present in a particular square if it was present in any of the nine pentads within that square. The KBM dataset for this study comprised a total of approximately 33,000 cards (10,000 full and 23,000 ad-hoc) collected by 466 volunteers.

2.1.2.2 | eBird. eBird (2023) (ebird.org) is the largest citizen science bird database in the world (Sullivan et al. 2014). Data are organised using several protocols (Travelling, Stationary, Incidental, and Historical) and checklists can be marked as either complete—when all birds observed or heard were recorded—or incomplete when this is not the case (further information on protocols is available at https://support.ebird.org/en/support/solutions/articles/48000950859-guide-to-ebird-protocols). We acquired the eBird Basic Dataset for Kenya eBird (ebird.org) (2023), and, to match the duration of the first atlas (14 years) while utilising the most recent data available, we used all data submitted in Kenya from 2009 to 2023 to produce species presence maps at the square resolution. We included all protocols in our dataset; however, we discarded 4000 travelling and historical checklists for which the distance covered was longer than a square (27 km). We used a total of approximately 91,000 checklists (60,000 complete and 31,000 incomplete) submitted by 3942 observers.

2.1.3 | Taxonomy Matching

Given the taxonomic updates between the two study periods, we aligned all taxa from both eBird Kenya and KBM to their counterparts in the historical atlas taxonomy. Overall, we matched 1152 taxonomic concepts from KBM and 1141 from eBird.

In cases where one species from the historical atlas corresponded to two species in the recent atlas ('split'), we merged the species maps of the recent atlas with the old taxonomy (i.e., combined the presence/absence data for both species into a single map). For the five instances where two different species from the historical atlas corresponded to a single species in the recent atlas ('lump'), we merged the maps of the two species from the historical atlas. We also ignored 17 species that have been rejected since the publication of the historical atlas (Fisher, Pearson, and Hunter 2011; Turner 1985; Zimmerman, Turner, and Pearson 1999), but included 23 new species added to the Kenyan list since then (see http://www.eararities.org/). A total of 1088 species were considered in this study. The exact list is available in File S1.

2.1.4 | Confidence of Change

Given the notable differences in collection practices between the old and recent atlases, we quantified the change in effort across the two periods to assess the level of confidence in our results. We briefly outline the methodology to quantify an index of confidence below and provide more detailed information on the procedure in Appendix A.

To appraise effort in the historical atlas, we used the coverage map variable provided in the atlas (Figure 3, p. 8; Lewis and Pomeroy 1989). This variable was estimated by the atlas authors by first modelling species richness with a linear regression using variables of habitat diversity (altitudinal range and water bodies) and observer effort (scored on a 10-point scale). Then, coverage was quantified as the ratio of the number of species recorded to the modelled richness. In the recent atlas, we quantified effort by summing the duration of all checklists and cards within each square. Using these coverage variables, we modelled the anticipated change in the total number of species per square explained purely by effort fluctuation between the historical and recent atlases (Figure A3). To avoid including squares where the difference in effort was too high to provide reliable data (most notably in the northeast of the country), we excluded from further analysis squares where more than 10% of the species recorded could be explained by a change in effort (Figure A4). This threshold was set visually based on Figure A5 to strike a balance between excluding spurious data and not omitting too much data.

Beyond this threshold, we used the ratio of species change explained by difference in effort as an index of confidence to assess the extent to which a specific square lost or gained can be explained by the underlying change in effort. For instance, a species gaining a new square despite reduced or similar effort is more significant than a gain accompanied by increased effort.

2.2 | Maps of Change in Geographic Range

To visualise the changes in geographic range between the two periods considered, we produced a distribution map for each of the 1088 species (Figure 1). For each square of the map, we indicated whether the species was lost (present in the historical atlas, but absent in the recent atlas), kept (found in both atlases), or gained (absent in the historical atlas, but present in the recent atlas). The index of confidence is displayed by circle size, allowing users to quickly appraise the extent to which a species' trend in a square can be attributed to change in effort. Squares where change in effort is deemed too high (10% threshold described in 4.1.4) are displayed with a small circle size.

All data from both eBird and KBM are vetted by experts on their respective platforms. In addition to this, we manually reviewed each distribution map to identify maps that should be used with caution and identified a total of 112 species maps as follows: 63 species for which identification is challenging (similar species causing potential confusion), 29 species for which at least part of the recent distribution data seemed doubtful based on expert knowledge of the species, nine seabird species for which targeted offshore birding efforts were not reproduced in recent years, seven species for which at least part of the historical atlas species map seemed to include an error of identification or unknown taxonomic change,

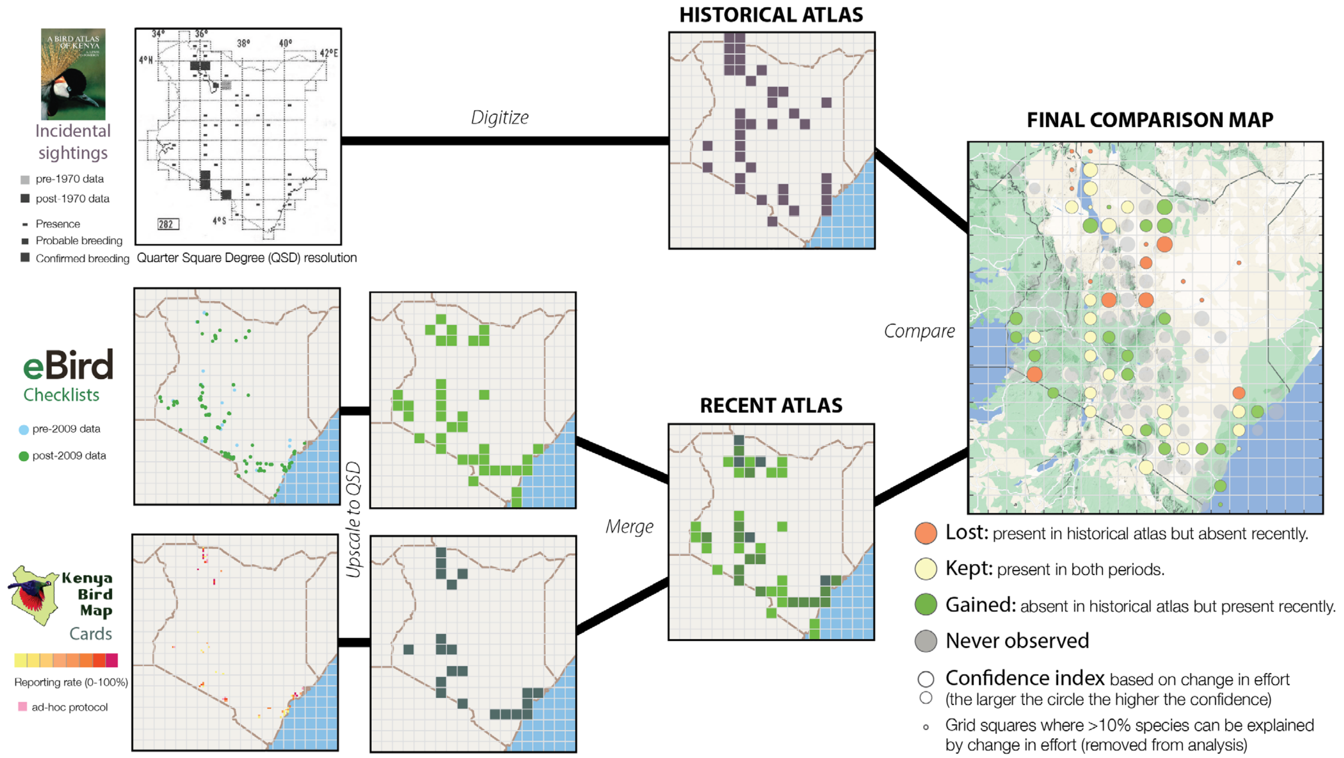

FIGURE 1 | Visual summary of the process followed to convert the original data (left) to the species comparison maps (right) using the example of the Collared Pratincole. Historical atlas data were sourced from Lewis and Pomeroy (1989) and digitised to compare with the map of recent sightings. Recent data were sourced from Kenya Bird Map and eBird citizen science platforms. Data points were upscaled to match the spatial resolution of the historical atlas (quarter square degree) and merged to produce a single map for each species. The final comparison map indicates, for each square, whether the species was lost (seen only in historical atlas), kept (seen in both atlases), gained (seen only in recent atlas), or never observed. The confidence index is visualised through the circle size.

and two species re-introduced in localised parts of the country. For each of these species, a dedicated warning message is displayed on the distribution map to avoid misinterpretation.

2.3 | Species Trends Mapped on Phylogenetic Tree

We obtained a phylogeny of our study species from the Open Tree of Life project (McTavish et al. 2024). We used this evolutionary tree both to visualise species' population trends, in the form of squares lost, kept, or gained (File S2), and to directly quantify the covariance between species trends and their evolutionary history. We measured the correlation between species traits and their evolutionary history using Pagel's lambda value (Münkemüller et al. 2012; Revell 2012). These approaches allow visual and quantitative assessment of whether trends are aligned across larger taxonomic entities such as families.

2.4 | Significant Trends for Palearctic Migrants, Scavengers, and Introduced Birds

To illustrate the conclusions that can be drawn from these maps beyond species-specific analysis, we tested whether significant trends emerged from various groupings and bird traits extracted from Tobias et al. (2022), notably trophic level (Pigot et al. 2020), habitat density (Tobias et al. 2016), migration status (Tobias and Pigot 2019), habitat type, and primary lifestyle. The results of these tests are provided in File S6. Among these, three groupings presented significant trends, which we describe in the results below.

2.4.1 | Palearctic Migrants

We computed the average range change (i.e., difference between total number of squares gained and lost) for Palearctic migrants ($n = 129$), classified based on the Checklist of Birds of Kenya (Bird Committee Nature Kenya—the East Africa Natural History Society 2019) and compared it to non-migrants using a two-sample K-S test. We also compared the average range change between migrant and resident species within families containing at least two species of Palearctic migrants.

2.4.2 | Scavengers

We computed the average range change for each trophic level classified according to Pigot et al. (2020) and provided the map of change in geographic range for seven obligate or mostly obligate scavenger species.

2.4.3 | Introduced Birds

We computed the map of change in geographic range for four species of introduced birds according to the Checklist of Birds of

Kenya (Bird Committee Nature Kenya—the East Africa Natural History Society 2019): House Sparrow, House Crow, Feral Pigeon, and Fischer's × Yellow-collared Lovebird.

3 | Results

The historical atlas constituted the largest dataset, with 39,222 unique records (i.e., the number of unique species per square), followed by eBird (32,975) and KBM (25,738). As some species were recorded in the same square in both eBird and KBM, their combined total of unique records was 37,840—still fewer than the historical atlas. This lower number of records can largely be attributed to the limited coverage of citizen science in the northeast of the country, where geopolitical instability has hindered data collection. Of the 79 squares excluded due to excessive change in effort (as detailed in 4.1.4), 66 were removed because of insufficient coverage during the recent atlas. Once these squares were excluded, the recent atlas contained more unique records—33,308 compared to 29,268 in the historical atlas. In summary, while the historical atlas covered a broader geographic area, the recent atlas provided more concentrated data from a smaller region.

3.1 | Maps of Change in Geographic Range

Maps illustrating range changes for each species—showing squares that have been lost, kept, or gained—were made publicly accessible on an interactive website at https://kenyabirdtrends.co.ke/ (Figure 2) and archived in the Zenodo repository (Nussbaumer 2024). Users can visualise the results either by species (maps of squares lost, kept, and gained) or by grid (list of species lost, kept, and gained for each square). The option to include or exclude squares with poor coverage is available based on user needs. The index of confidence is indicated by the size of the circle (see Appendix A for further details). The website allows users to download species maps as images and export lists of species along with their trends for specific areas, aiding conservation and management strategies in Kenya. The map also highlights areas with poor coverage, offering a practical tool for citizen scientists and researchers to identify priority regions for data collection. Users can choose to display species names according to the taxonomy used in Clements et al. (2023), the Checklist of the Birds of Kenya (Bird Committee Nature Kenya—the East Africa Natural History Society 2019) or following the original names used in A Bird Atlas of Kenya (Lewis and Pomeroy 1989).

3.2 | Related Species Experienced Similar Trends

We summarised trends for each species by tallying the number of squares each species has lost, kept, or gained between the two periods. These data are available as a spreadsheet in File S2 and as a Figure in File S3. We illustrated and quantified these changes using a phylogenetic tree (Figure 3, with a higher resolution version including species name in File S4). We identified a strong phylogenetic signal in the trends: entire clades of related species exhibited similar shifts in their ranges (Pagel's lambda = 0.42, $p < 0.001$). For instance, the 10 species that have lost the most squares are all either scavenger or migratory birds, while the 10 species that have gained most squares are either

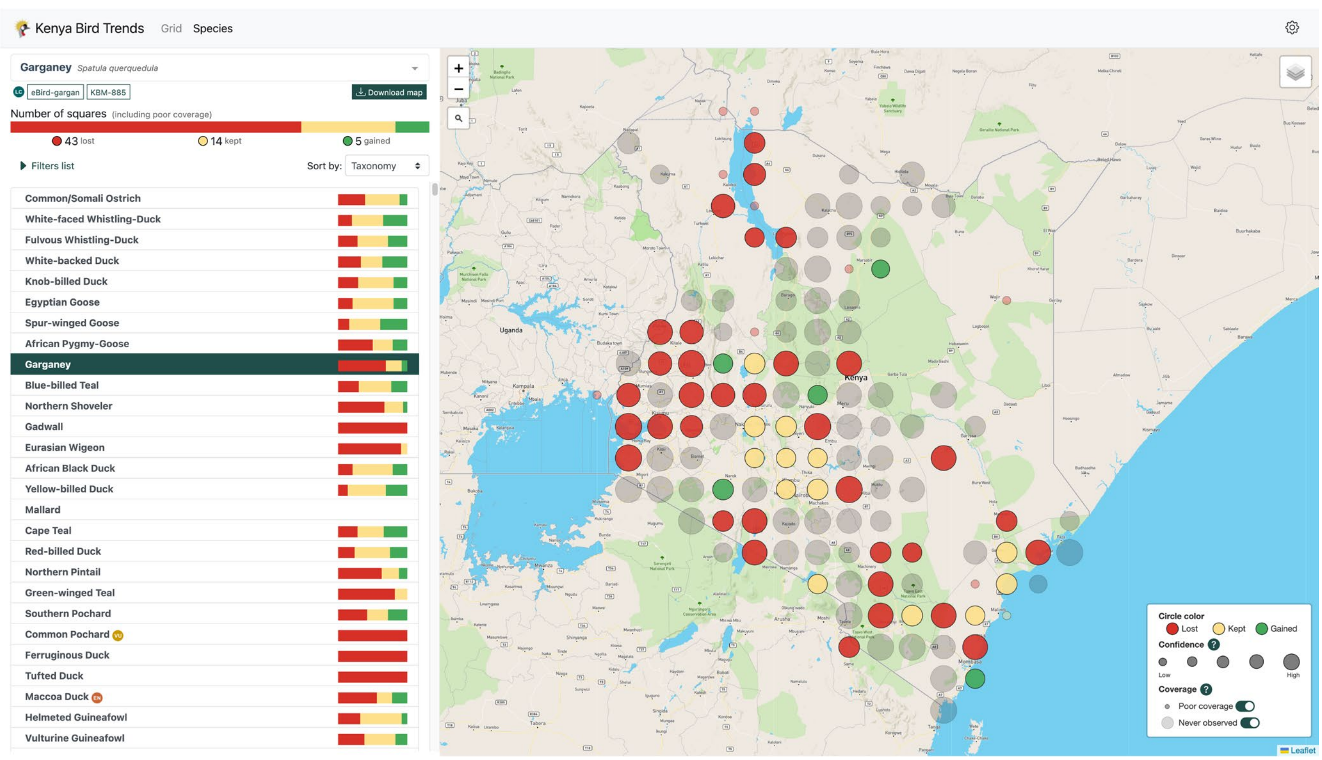

FIGURE 2 | Screenshot of the interactive public website designed to share the results from this comparison work (https://kenyabirdtrends.co.ke/). Users can visualise the change in distribution for all 1088 species. Each grid square is coloured to indicate whether it has been lost (red), kept (yellow), or gained (green). To highlight variations in data collection effort, the size of the circles represents the level of confidence for each grid square.

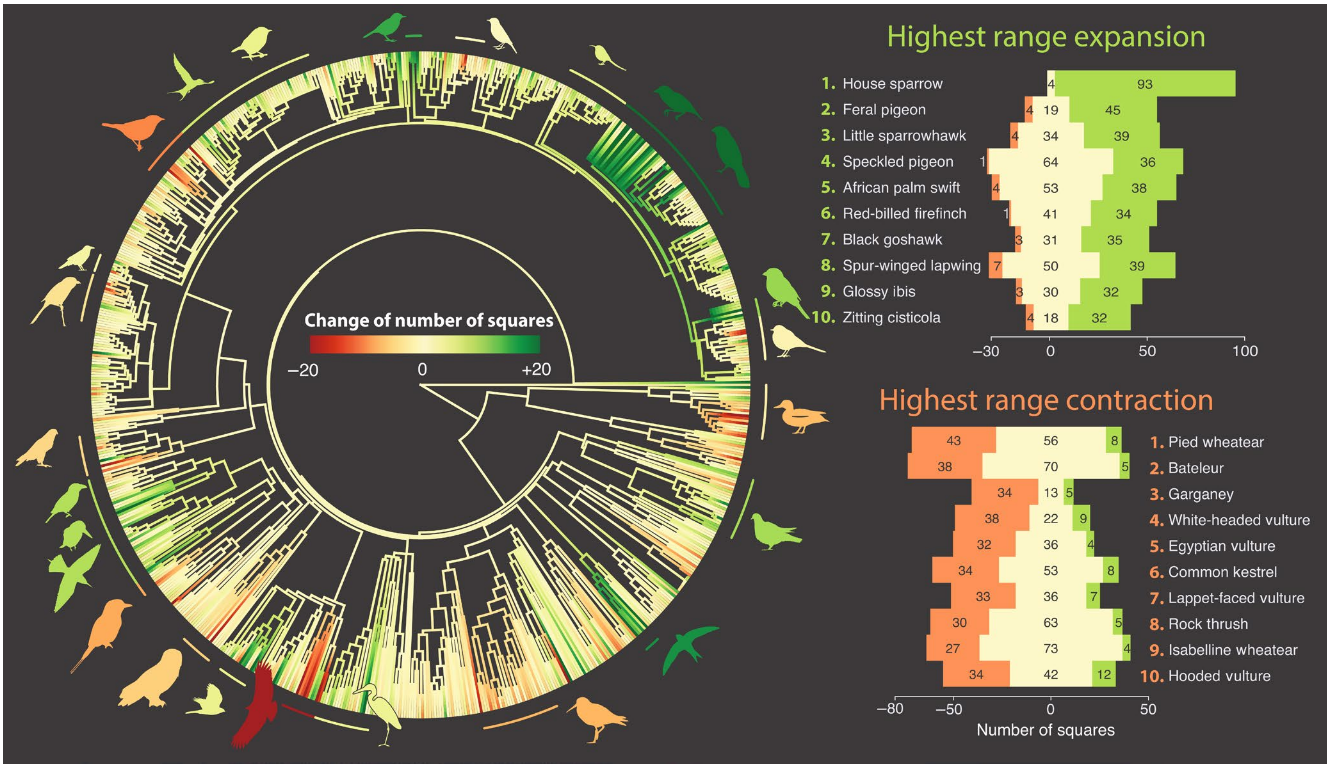

FIGURE 3 | Phylogenetic tree depicting the overall change in species range (squares gained minus lost) for all 1088 species. The pictograms highlight key families which showed unified trends among related species. A higher-resolution version with species names can be found in File S5. The right-hand panel shows the top 10 species with the most squares gained (top) and lost (bottom).

introduced or resident species (Figure 3). This aligns with the broader trends described in the following section.

3.3 | Significant Trends for Palearctic Migrants, Scavengers, and Introduced Birds

3.3.1 | Marked Range Contractions for Palearctic Migrants

The 129 long-distance Palearctic migrants experienced a significant contraction in their distribution, losing an average of 6.4 squares, which is notably greater than the average gain of four squares observed among non-migratory species (two-sample K-S test, $p < 0.001$). This range contraction amounts to a 16% loss in the cumulative range of Palearctic migrants between the two periods. Furthermore, when individual species were categorised at the family level (see File S6), migratory species exhibited a more pronounced range decline compared to their non-migratory (resident) counterparts, with the exception of raptors and bee-eaters (Figure 4).

3.3.2 | Significant Range Losses Among Scavengers

We found substantial range reductions among avian scavengers: all six vulture species and the Bateleur—each listed in threatened categories on the IUCN Red List—have experienced losses ranging from 14% to 48% of their historical ranges (Table 1). Compared to other trophic levels, scavengers are the group most affected by a shrinking distribution (Figure 5).

3.3.3 | Expanded Ranges for Introduced Birds

The four introduced species present in Kenya have experienced substantial range expansions between the two periods: House Sparrow (from 4 to 97 squares), Indian House Crow (from 5 to 23 squares), Feral Pigeon (from 23 to 64 squares), Fischer's × Yellow-collared Lovebird (from 9 to 36 squares) (Figure 6).

4 | Discussion

4.1 | The Potential of Bird Atlas and Citizen Science Data

To curb biodiversity losses with effective conservation actions, data gaps and biases must urgently be addressed, particularly in data-poor contexts. By providing standard trends for 1088 species in Kenya at the national scale and across 53 years, this dataset directly contributes to this effort. It offers a powerful tool to identify species which have experienced range reductions and where, and thereby inform conservation strategies. We lend strong support to previous studies that have reached similar conclusions about worrisome population declines in Palearctic migrants and scavengers (Burns et al. 2021; Shaw et al. 2024) and describe new trends for the many species where no abundance data are available. While we have highlighted some initial results, this dataset and its dedicated web interface should act as a starting point to trigger deeper investigation into specific species and uncover the causes driving these changes. For instance, drawing on existing literature to introduce additional data points for specific species would help to detail the fine-scale patterns of trends described here.

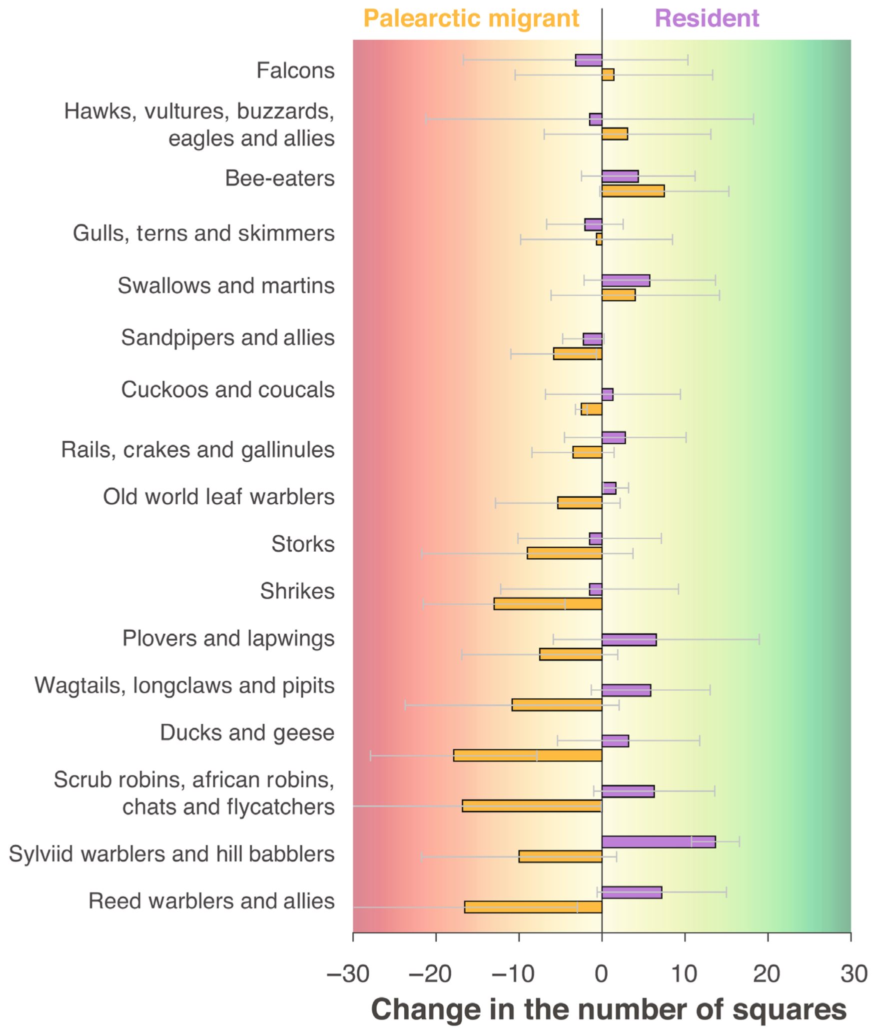

FIGURE 4 | Number of squares lost and gained for all families with at least two migratory species. See File S6 for more details per family.

TABLE 1 | Range reduction of scavenging species (ranked from highest to lowest) over a 53-year period between 1970 and 2023. Their current IUCN Red List status is indicated in red/orange circles.

Common name	Distribution loss
White-headed vulture CR	48%
Egyptian vulture EN	41%
Hooded vulture CR	29%
Bateleur EN	31%
Lappet-faced vulture EN	38%
White-backed vulture CR	14%
Rüppell's vulture CR	14%

Bird atlas data offers invaluable insights into species distribution and relative abundance across vast spatial scales (Dunn and Weston 2008). Yet, nearly half of historical atlas initiatives have not been repeated with a similar protocol (Gibbons et al. 2007), making it difficult to use these data to determine long-term trends. This represents a missed opportunity for advancing ecological understanding and conservation. By using citizen science data as a modern alternative, this method makes it possible to utilise the original atlas data, with no additional field effort required. This approach is adaptable to other under-studied regions with available early atlas data, as is the case in several African countries.

4.2 | Methodological Considerations

Our results use presence-only data, and as such cannot be used to directly quantify population trends. However, an increase/decrease in population is generally associated with a similar trend in distribution range (Borregaard and Rahbek 2012; Bart and Klosiewski 1989; Donald and Fuller 1998; Gaston, Blackburn, and Lawton 1997), suggesting that distribution change can be used as

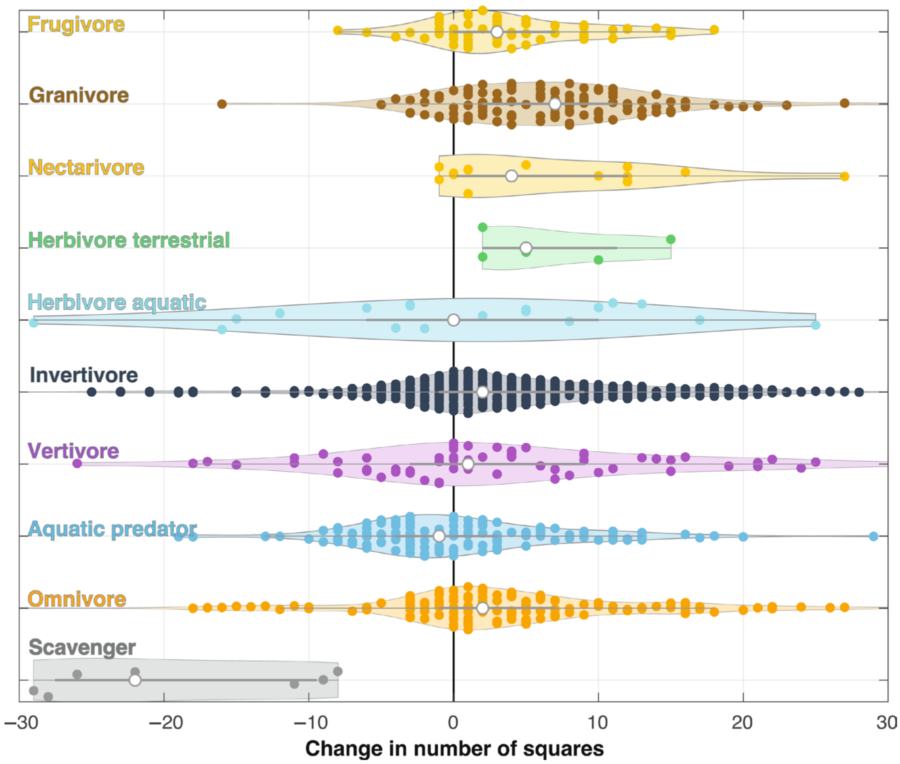

FIGURE 5 | Distribution changes by trophic level highlighting the comparatively higher loss of range that scavengers have undergone.

a proxy for population trends. Note that the nature of this relationship is expected to vary depending on a range of factors such as the species' distribution and habitat changes within its range.

In addition to the known biases inherent to citizen science data (Bird et al. 2014; Johnston et al. 2021), comparing datasets from distant time periods comes with several challenges due to the different conditions and protocols under which the data were collected. Technology, communication, equipment, information on identification, and taxonomy have all evolved between the two study periods. In addition, spatial coverage has decreased in the northeast of the country due to geopolitical instability, while the number of records has increased around cities and national parks (Figure A1). To minimise the impact of these variations, we quantified the change in effort using an index of confidence (Appendix A) and discarded squares where the change in effort was deemed to be too drastic. Furthermore, to avoid spurious conclusions, we manually reviewed each map and flagged species maps for which the distribution change might not reflect the overall population trend, such as endemic and threatened species which may be subject to specific observation biases (see File S1 for a list of species concerned). For example, while the Malagasy Pond Heron is known to have declined across the continent (Rabarisoa et al. 2020), our map suggests its range is stable, most likely due to the funding of targeted searches for this species in recent years, which has led to the discovery of 16 new sites in Kenya (Ndithia and Muchai 2012).

Despite the limitations inherent to using data from a distant period with little effort information, this method remains a useful and effective approach to leverage available datasets on past bird distributions. As such, it has a unique ability to paint a broad picture of changes in bird distributions across several decades.

4.3 | Trends at Group Level

The significant range contractions of migrants are a sobering yet unsurprising result, as population declines have already been reported in several other regions worldwide (e.g., Robbins et al. 1989; Sanderson et al. 2006). This trend is well documented for Afro-Palearctic migrants across west and central Europe using data collected in Europe (Berthold et al. 1998; Burns et al. 2021; Sanderson et al. 2006; Vickery et al. 2014). Comparatively, there is little information on population trends in more eastern breeding areas (Pearson, Backhurst, and Jackson 2014). This study helps fill this gap, as migrants wintering in Kenya tend to breed in eastern Europe, Siberia, and central and southwestern Asia. A key source of data collected in Kenya for nocturnal passerines is the long-term monitoring scheme of Palearctic and Afro-tropical migrants at Ngulia Ringing Station (Pearson and Backhurst 1976). Although determining absolute long-term trends remains a challenge due to changes in protocol over time, data seem to suggest similar decreases among migrating passerines (Pearson, Backhurst, and Jackson 2014; Nagy and Langendoen 2020; Bennun and Nasirwa 2000; Nasirwa and Bennun 2000; Owino et al. 2002). In line with existing abundance trends, our findings add weight to calls for urgent conservation measures to protect migrant species in Kenya (Wong et al. 2024; Adamík et al. 2024).

The decrease in ranges of scavengers supports known trends of declining populations among vultures and large eagles in

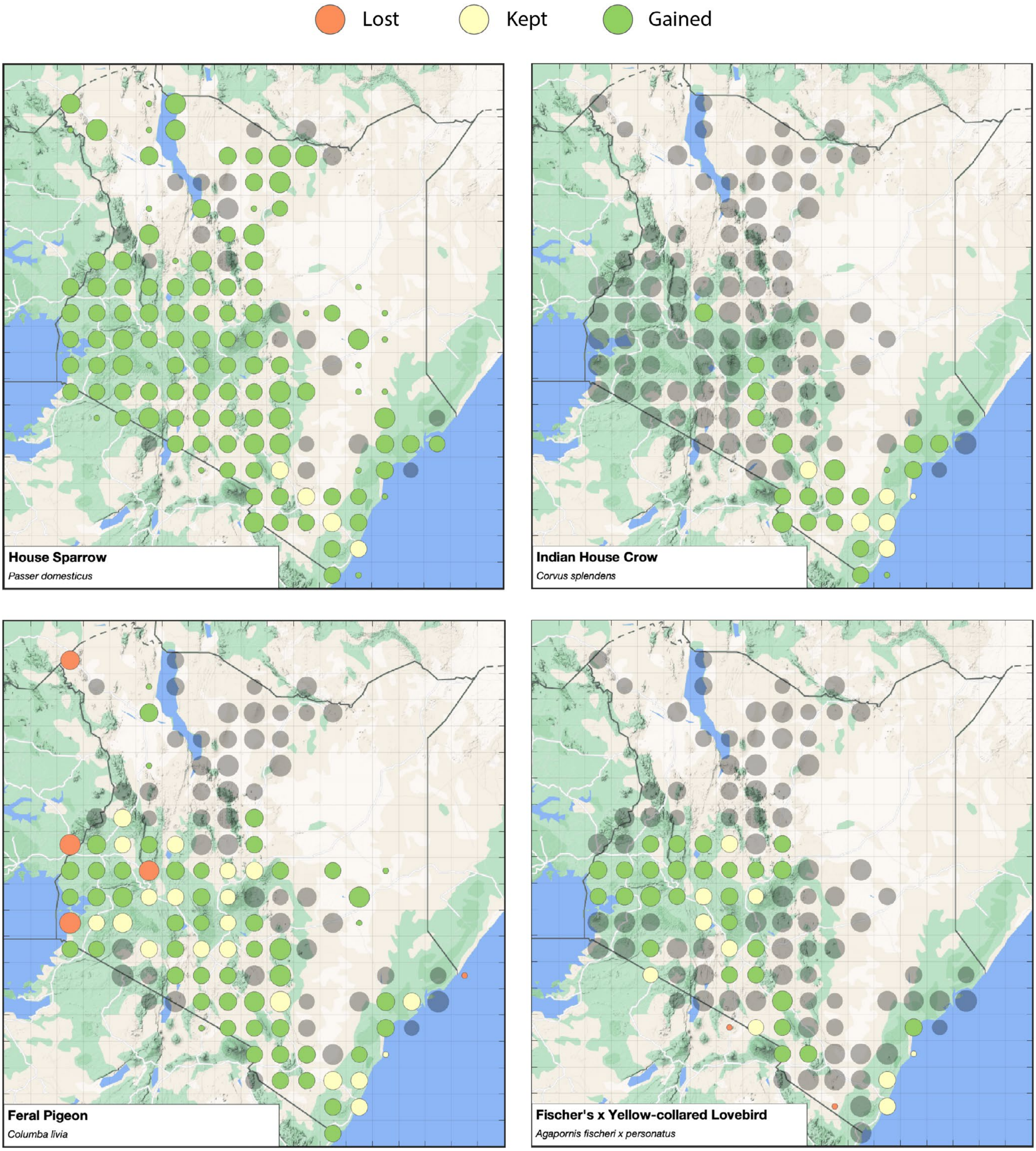

FIGURE 6 | Distribution maps showing the marked increases in the ranges of four introduced species.

Kenya (Ogada et al. 2022; Virani et al. 2011), Africa (Ogada, Botha, and Shaw 2016; Ogada et al. 2016; Shaw et al. 2024; Thiollay 2006), and more globally (e.g., Prakash 2003). This is to be expected as birds at higher trophic levels are known to be more sensitive to anthropogenic disturbance (McClure et al. 2018). By comparing linear encounter rates between 1970–1977 and 2002–2020, Ogada et al. (2022) found that the median encounter rate dropped by 70% for 19 of the 22 raptor species studied. Virani et al. (2011) found a relatively higher decline of Hooded and Egyptian Vultures compared to Rüppell's Vulture or Tawny Eagle within the Mara ecosystem, which is consistent with our results. Contrary to our findings, they observed that Bateleurs had increased, though this may be restricted to the Mara ecosystem, as Ogada et al. (2022) also reported a decline of Bateleurs. The 30% range contraction we found for Hooded Vultures supports the 40% abundance decline reported between 1989–1999 and 2000–2010 (Ogada and Buij 2011).

The range expansion of the four bird species introduced in Kenya is to be expected, as they are typically associated with urban habitats, which have widely expanded between the two periods considered: the urban human population in Kenya rose from 10% to 28%, and total human population size quintupled (World Bank 2023). We found a similar trend of range expansion across many urban birds such as Little Swift, Cattle Egret, and African Pied Wagtail. Using the 11 species classified as using a human-modified habitat by Tobias et al. (2022), we find an average increase of 18.5 squares (see Figure S6). The House Sparrow experienced a rapid range expansion from Mombasa in 1979 (Lewis 1983; Turner, Britton, and Pearson 1980) and reached Nairobi for the first time in 1993 (Pearson and Turner 1998; Liebl and Martin 2012; Schrey et al. 2014, 2019). This expansion stands in contrast to the more recent declines of House Sparrows recorded in North America (Berigan, Greig, and Bonter 2020), Europe (Burns et al. 2021), India (Sharma and Binner 2020), Australia (Olsen et al. 2003) and South Africa (Underhill and Brooks 2014). The expansion of the House Crow follows a similar pattern, originally introduced from India to the East African coast. Despite the species being subject to eradication efforts in both Kenya and Tanzania, our map confirms the known trajectory of this species, with a large expansion on the coast, reaching into Tsavo, and nearly reaching Nairobi (Ryall 1992, 2010, 2016).

4.4 | Implications for Conservation

The webtool associated with this study can directly serve as an awareness-raising and educational tool for conservation. Participatory, volunteer-based data collection schemes are known to improve attitudes towards science and bolster a sense of regional awareness and ownership over local conservation action (von Gönner et al. 2023). By providing a platform where atlassers and volunteers can visualise a concrete product based on the data they collected, we hope this study further incentivises data collection. The webtool enables users to easily familiarise themselves with the birds found in their local area, explore which species have been gained or lost in the past 50 years, and thereby confront local ecological challenges. Importantly, the platform can help users identify, and subsequently fill, the gaps in spatial coverage, which are known to persist in citizen science data (e.g., Hugo and Altwegg 2017).

Overall, this study demonstrates the potential of leveraging existing datasets on bird distribution to learn about changes in geographic range in areas where such long-term monitoring is otherwise absent. The maps resulting from this study can be used for species-to-species comparison and to inform practical conservation action. To further improve the reliability of the analysis and design well-informed conservation strategies, establishing and maintaining long-term monitoring schemes with a consistent protocol should be a priority. While such schemes are already well-established in Kenya, future monitoring of bird populations would benefit from increased collaboration between citizen science platforms and alignment of protocols.

Author Contributions

R.N. and C.J. conceptualised the study. S.G., G.N.K., and S.S. oversaw data collection and curation, managed by A.K., C.J. and P.N. R.N. designed the methodology and performed the analyses. R.N. led the writing of the the manuscript with significant input from A.N. R.N. and A.N. created the visualisations. R.S.H. and C.J. reviewed all species maps and flagged suspicious species. R.S.H., C.J., E.M., D.O., and P.K.N. contributed critically to the drafts. A.K. secured funding for the project. All authors reviewed the final manuscript and gave approval for publication.

Acknowledgements

We thank colleagues for providing valuable feedback on the paper's findings and structure: Wesley Hochachka from the Cornell Lab of Ornithology and Barbara Helm, Yann Rime, Crinian Jarrett and Elizabeth Yohannes from the Swiss Ornithological Institute. Dr. Mathieu Gravey contributed to the digitisation of the historical atlas, which was instrumental in carrying out this analysis.

Finally, this work could not have been possible without the contributions of the thousands of citizen scientists who submitted bird observations through the Kenya Bird Map and eBird citizen science platforms. We recognise the hard work of the Kenya Bird Map platform manager and eBird reviewers to review sightings and ensure data quality. We also thank the teams working hard to create and maintain the Kenya Bird Map initiative and eBird platforms.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The raw citizen science data is available through the African Bird Atlas API for Kenya Bird Map (kenya.birdmap.africa) and through https://ebird.org/data/download for the eBird Basic Dataset for Kenya (*EBird Basic Dataset. Version: EBD_relNov-2023*, 2023). The code and data that support the findings of this study are openly available at https://github.com/Rafnuss/KenyaAtlasComparison. The website source code is openly available at https://github.com/Rafnuss/KenyaBirdTrends.

Peer Review

The peer review history for this article is available at https://www.webofscience.com/api/gateway/wos/peer-review/10.1111/ddi.13935.

References

Adamík, P., J. B. Wong, S. Hahn, and A. Krištín. 2024. "Non-Breeding Sites, Loop Migration and Flight Activity Patterns Over the Annual Cycle in the Lesser Grey Shrike Lanius Minor From a North-Western Edge of Its Range." *Journal für Ornithologie* 165: 247–256. https://doi.org/10.1007/s10336-023-02102-7.

Ash, J. S., and D. E. Pomeroy. 1981. "Mapping Schemes in the Afrotropical Region." *Ibis* 5, no. 523: 552.

Barnosky, A. D., N. Matzke, S. Tomiya, et al. 2011. "Has the Earth's Sixth Mass Extinction Already Arrived?" *Nature* 471: 51–57. https://doi.org/10.1038/nature09678.

Bart, J., and S. P. Klosiewski. 1989. "Use of Presence-Absence to Measure Changes in Avian Density." *Journal of Wildlife Management* 53: 847. https://doi.org/10.2307/3809224.

Bennun, L., and O. Nasirwa. 2000. "Trends in Waterbird Numbers in the Southern Rift Valley of Kenya." *Ostrich* 71: 220–226. https://doi.org/10.1080/00306525.2000.9639917.

Berigan, L. A., E. I. Greig, and D. N. Bonter. 2020. "Urban House Sparrow (*Passer domesticus*) Populations Decline in North America." *Wilson Journal Of Ornithology* 132: 248–258. https://doi.org/10.1676/1559-4491-132.2.248.

Berthold, P., W. Fiedler, R. Schlenker, and U. Querner. 1998. "25-Year Study of the Population Development of Central European Songbirds: A General Decline, Most Evident in Long-Distance Migrants." *Science of Nature* 85: 350–353. https://doi.org/10.1007/s001140050514.

Bird Committee Nature Kenya—The East Africa Natural History Society. 2019. *Checklist of the Birds of Kenya*, 5th ed. Nairobi, Kenya: Nature Kenya.

Bird, T. J., A. E. Bates, J. S. Lefcheck, et al. 2014. "Statistical Solutions for Error and Bias in Global Citizen Science Datasets." *Biological Conservation* 173: 144–154. https://doi.org/10.1016/j.biocon.2013.07.037.

Borregaard, M. K., N. J. Gotelli, and C. Rahbek. 2012. "Are Range-Size Distributions Consistent with Species-Level Heritability?" *Evolution* 66: 2216–2226. https://doi.org/10.1111/j.1558-5646.2012.01581.x.

Brooks, M., S. Rose, R. Altwegg, et al. 2022. "The African Bird Atlas Project: A Description of the Project and BirdMap Data-Collection Protocol." *Ostrich* 93: 223–232. https://doi.org/10.2989/00306525.2022.2125097.

Burns, F., M. A. Eaton, I. J. Burfield, et al. 2021. "Abundance Decline in the Avifauna of the European Union Reveals Cross-Continental Similarities in Biodiversity Change." *Ecology and Evolution* 11: 16647–16660. https://doi.org/10.1002/ece3.8282.

Clements, J. F., P. C. Rasmussen, T. S. Schulenberg, et al. 2023. "The eBird/Clements Checklist of Birds of the World: v2023b."

Cooke, R., F. Sayol, T. Andermann, et al. 2023. "Undiscovered Bird Extinctions Obscure the True Magnitude of Human-Driven Extinction Waves." *Nature Communications* 14: 8116. https://doi.org/10.1038/s41467-023-43445-2.

Dirzo, R., H. S. Young, M. Galetti, G. Ceballos, N. J. B. Isaac, and B. Collen. 2014. "Defaunation in the Anthropocene." *Science* 345: 401–406. https://doi.org/10.1126/science.1251817.

Donald, P. F., and R. J. Fuller. 1998. "Ornithological Atlas Data: A Review of Uses and Limitations." *Bird Study* 45: 129–145. https://doi.org/10.1080/00063659809461086.

Dunn, A. M., and M. A. Weston. 2008. "A Review of Terrestrial Bird Atlases of the World and Their Application." *Emu* 108: 42–67. https://doi.org/10.1071/MU07034.

eBird. 2023. "eBird Basic Dataset Version: EBD_relNov-2023." Cornell Lab of Ornithology, Ithaca, New York. Oct 2023.

Fanshawe, J. H., and L. A. Bennun. 1991. "Bird Conservation in Kenya: Creating a National Strategy." *Bird Conservation International* 1: 293–315. https://doi.org/10.1017/S0959270900000642.

Fisher, D., D. Pearson, and N. Hunter. 2011. "East African Rarities Committee (EARC) Special Report Species Included for East African Countries in Britton (1980) Which Have Since Been Considered Unacceptable." 55–67.

Gaston, K. J., T. M. Blackburn, and J. H. Lawton. 1997. "Interspecific Abundance-Range Size Relationships: An Appraisal of Mechanisms." *Journal of Animal Ecology* 66: 579. https://doi.org/10.2307/5951.

Gibbons, D. W., P. F. Donald, H.-G. Bauer, L. Fornasari, and I. K. Dawson. 2007. "Mapping Avian Distributions: The Evolution of Bird Atlases." *Bird Study* 54: 324–334. https://doi.org/10.1080/00063650709461492.

Gudka, M. S. 2020. "Kenya National Biodiversity Threat Assessment: Direct Human Threats Impacting Kenya's Biodiversity." IUCN–BIODEV2030, Gland, Switzerland.

Hugo, S., and R. Altwegg. 2017. "The Second Southern African Bird Atlas Project: Causes and Consequences of Geographical Sampling Bias." *Ecology and Evolution* 7: 6839–6849. https://doi.org/10.1002/ece3.3228.

Johnston, A., W. M. Hochachka, M. E. Strimas-Mackey, et al. 2021. "Analytical Guidelines to Increase the Value of Community Science Data: An Example Using eBird Data to Estimate Species Distributions." *Diversity and Distributions* 27: 1265–1277. https://doi.org/10.1111/ddi.13271.

Keller, V. 2017. "Atlases as a Tool to Document Changes in Distribution and Abundance of Birds." *Vogelwelt* 137: 43–52.

Keller, V., S. Herrando, P. Voříšek, et al. 2020. *European Breeding Bird Atlas 2: Distribution, Abundance and Change*. Barcelona: European Bird Census Council & Lynx Edicions.

Larsen, R., T. Holmern, S. D. Prager, H. Maliti, and E. Røskaft. 2009. "Using the Extended Quarter Degree Grid Cell System to Unify Mapping and Sharing of Biodiversity Data." *African Journal of Ecology* 47: 382–392. https://doi.org/10.1111/j.1365-2028.2008.00997.x.

Lee, A. T. K., M. Brooks, and L. G. Underhill. 2022. "The SABAP2 Legacy: A Review of the History and Use of Data Generated by a Long-Running Citizen Science Project." *South African Journal of Science* 118: 12030. https://doi.org/10.17159/sajs.2022/12030.

Lewis, A., and D. Pomeroy. 1989. *A Bird Atlas of Kenya*. United Kingdom: CRC Press. https://doi.org/10.1201/9781315136264.

Lewis, A. D. 1983. "Range Extension and Population Increase of the House Sparrow in Kenya." *Scopus: Journal of East African Ornithology* 7: 23–26.

Liebl, A. L., and L. B. Martin. 2012. "Exploratory Behaviour and Stressor Hyper Responsiveness Facilitate Range Expansion of an Introduced Songbird." *Proceedings of the Royal Society B: Biological Sciences* 279: 4375–4381. https://doi.org/10.1098/rspb.2012.1606.

McClure, C. J. W., J. R. S. Westrip, J. A. Johnson, et al. 2018. "State of the world's Raptors: Distributions, Threats, and Conservation Recommendations." *Biological Conservation* 227: 390–402. https://doi.org/10.1016/j.biocon.2018.08.012.

McTavish, E. J., J. A. Gerbracht, M. T. Holder, et al. 2024. "A complete and dynamic tree of birds." *BioRxiv*: 595017. https://doi.org/10.1101/2024.05.20.595017.

Monroe, M. J., S. H. M. Butchart, A. O. Mooers, and F. Bokma. 2019. "The Dynamics Underlying Avian Extinction Trajectories Forecast a Wave of Extinctions." *Biology Letters* 15: 1–5. https://doi.org/10.1098/rsbl.2019.0633.

Münkemüller, T., S. Lavergne, B. Bzeznik, et al. 2012. "How to Measure and Test Phylogenetic Signal." *Methods in Ecology and Evolution* 3: 743–756. https://doi.org/10.1111/j.2041-210X.2012.00196.x.

Muriuki, J. N., H. M. De Klerk, P. H. Williams, L. A. Bennun, T. M. Crowe, and E. Vanden Berge. 1997. "Using Patterns of Distribution and Diversity of Kenyan Birds to Select and Prioritize Areas for Conservation." *Biodiversity and Conservation* 6: 191–210. https://doi.org/10.1023/A:1018340002756.

Nagy, S., and T. Langendoen. 2020. *Flyway Trend Analyses Based on Data From the African-Eurasian Waterbird Census From the Period of 1967–2018. Online publication*. Wageningen, the Netherlands: Wetlands International. http://iwc.

Nasirwa, O., and L. A. Bennun. 2000. "Co-Ordinated Waterbird Counts: The Kenyan Experience." *Ostrich* 71: 99–101. https://doi.org/10.1080/00306525.2000.9639881.

Ndithia, H. K., and M. Muchai. 2012. "Distribution and Wetland Habitat Preference of Madagascar Pond-Heron Ardeola Idae in Its Kenyan Non-Breeding Range." Nairobi.

Njoroge, P., and M. Brooks. 2023. "Kenya Bird Map Full Protocol and Adhoc Records." https://doi.org/10.15468/2lrl79.

Nussbaumer, R. 2024. "Kenya Bird Trends." https://doi.org/10.5281/zenodo.13710124.

Nussbaumer, R., S. Shema, S. Kennedy, and C. Jackson. 2022. "A Bird Atlas of Kenya." https://doi.org/10.15468/2ga3wk.

Ogada, D., A. Botha, and P. Shaw. 2016. "Ivory Poachers and Poison: Drivers of Africa's Declining Vulture Populations." *Oryx* 50: 593–596. https://doi.org/10.1017/S0030605315001209.

Ogada, D., P. Shaw, R. L. Beyers, et al. 2016. "Another Continental Vulture Crisis: Africa's Vultures Collapsing Toward Extinction." *Conservation Letters* 9: 89–97. https://doi.org/10.1111/conl.12182.

Ogada, D., M. Z. Virani, J. M. Thiollay, et al. 2022. "Evidence of Widespread Declines in Kenya's Raptor Populations Over a 40-Year Period." *Biological Conservation* 266: 109361. https://doi.org/10.1016/j.biocon.2021.109361.

Ogada, D. L., and R. Buij. 2011. "Large Declines of the Hooded Vulture *Necrosyrtes monachus* Across Its African Range." *Ostrich* 82: 101–113. https://doi.org/10.2989/00306525.2011.603464.

Okello, M. M., and J. W. Kiringe. 2004. "Threats to Biodiversity and Their Implications in Protected and Adjacent Dispersal Areas of Kenya." *Journal of Sustainable Tourism* 12: 55–69. https://doi.org/10.1080/09669580408667224.

Olsen, P., M. Weston, R. Cunningham, and A. Silcocks. 2003. "The State of Australia's Birds 2003." *Supplement to Wingspan* 15: 1–32.

Owino, A. O., L. A. Bennun, O. Nasirwa, and J. O. Oyugi. 2002. "Trends in Waterbird Numbers in the Southern Rift Valley of Kenya, 1991–2000." *Waterbirds* 25: 191–201. https://doi.org/10.1675/1524-4695(2002)025[0191:tiwnit]2.0.co;2.

Pearson, D., G. Backhurst, and C. Jackson. 2014. "The Study and Ringing of Palaearctic Birds at Ngulia Lodge, Tsavo West National Park, Kenya, 1969–2012: An Overview and Update." *Scopus* 33: 1–80.

Pearson, D., and D. A. Turner. 1998. "Review of Kenya Bird Records 1992–1996." *Scopus* 20: 65–83.

Pearson, D. J., and G. C. Backhurst. 1976. "The Southward Migration of Palaearctic Birds Over Ngulia, Kenya." *Ibis* 118: 78–105. https://doi.org/10.1111/j.1474-919X.1976.tb02012.x.

Pigot, A. L., C. Sheard, E. T. Miller, et al. 2020. "Macroevolutionary Convergence Connects Morphological Form to Ecological Function in Birds." *Nature Ecology & Evolution* 4: 230–239. https://doi.org/10.1038/s41559-019-1070-4.

Pomeroy, D. 1989. "Using East African Bird Atlas Data for Ecological Studies." *Annales Zoologici Fennici* 26: 309–314.

Pomeroy, D., and D. Sekabiira. 1990. "An Analysis of the Distributions of Terrestrial Birds in Africa." *African Journal of Ecology* 28: 1–13. https://doi.org/10.1111/j.1365-2028.1990.tb01131.x.

Prakash, V., D. J. Pain, A. A. Cunningham, et al. 2003. "Catastrophic Collapse of Indian White-Backed *Gyps bengalensis* and Long-Billed *Gyps indicus* Vulture Populations." *Biological Conservation* 109, no. 3: 381–390. https://doi.org/10.1016/S0006-3207(02)00164-7.

Rabarisoa, R., J. Ramanampamonjy, F. Razafindrajao, et al. 2020. "Status Assessment and Population Trends of the Madagascar Pond-Heron (*Ardeola idae*) From 1993 to 2016." *Waterbirds* 43: 45–54. https://doi.org/10.1675/063.043.0105.

Revell, L. J. 2012. "Phytools: An R Package for Phylogenetic Comparative Biology (and Other Things)." *Methods in Ecology and Evolution* 3: 217–223. https://doi.org/10.1111/j.2041-210X.2011.00169.x.

Robbins, C. S., J. R. Sauer, R. S. Greenberg, and S. Droege. 1989. "Population Declines in North American Birds That Migrate to the Neotropics." *Proceedings of the National Academy of Sciences* 86: 7658–7662. https://doi.org/10.1073/pnas.86.19.7658.

Rosenberg, K. V., A. M. Dokter, P. J. Blancher, et al. 2019. "Decline of the North American Avifauna." *Science* 1979, no. 366: 120–124. https://doi.org/10.1126/science.aaw1313.

Ryall, C. 1992. "Predation and Harassment of Native Bird Species by the Indian House Crow *Corvus splendens*, in Mombasa, Kenya." *Scopus: Journal of East African Ornithology* 16: 1–8.

Ryall, C. 2010. "Further Records and Updates of Range Expansion in House Crow *Corvus splendens*." *Bulletin of the British Ornithologists Club* 130: 246–254.

Ryall, C. 2016. "Further Records and Updates of Range Expansion in House Crow *Corvus splendens*." *Bulletin of the British Ornithologists Club* 136: 39–45.

Sanderson, F. J., P. F. Donald, D. J. Pain, I. J. Burfield, and F. P. J. van Bommel. 2006. "Long-Term Population Declines in Afro-Palearctic Migrant Birds." *Biological Conservation* 131: 93–105. https://doi.org/10.1016/j.biocon.2006.02.008.

Schrey, A. W., A. L. Liebl, C. L. Richards, and L. B. Martin. 2014. "Range Expansion of House Sparrows (*Passer domesticus*) in Kenya: Evidence of Genetic Admixture and Human-Mediated Dispersal." *Journal of Heredity* 105: 60–69. https://doi.org/10.1093/jhered/est085.

Schrey, A. W., A. K. Ragsdale, K. L. Adams, et al. 2019. "Evidence That Kenyan House Sparrows *Passer domesticus* Invaded From Multiple Sites." *Ibis* 161: 915–921. https://doi.org/10.1111/ibi.12756.

Sharma, P., and M. Binner. 2020. "The Decline of Population of House Sparrow in India." *International Journal of Agricultural Science* 5: 1–4.

Shaw, P., D. Ogada, L. Dunn, et al. 2024. "African Savanna Raptors Show Evidence of Widespread Population Collapse and a Growing Dependence on Protected Areas." *Nature Ecology & Evolution* 8: 45–56. https://doi.org/10.1038/s41559-023-02236-0.

Sullivan, B. L., J. L. Aycrigg, J. H. Barry, et al. 2014. "The eBird Enterprise: An Integrated Approach to Development and Application of Citizen Science." *Biological Conservation* 169: 31–40. https://doi.org/10.1016/j.biocon.2013.11.003.

Thiollay, J.-M. 2006. "The Decline of Raptors in West Africa: Long-Term Assessment and the Role of Protected Areas." *Ibis* 148: 240–254. https://doi.org/10.1111/j.1474-919X.2006.00531.x.

Tobias, J. A., and A. L. Pigot. 2019. "Integrating Behaviour and Ecology Into Global Biodiversity Conservation Strategies." *Philosophical Transactions of the Royal Society, B: Biological Sciences* 374: 20190012. https://doi.org/10.1098/rstb.2019.0012.

Tobias, J. A., C. Sheard, A. L. Pigot, et al. 2022. "AVONET: Morphological, Ecological and Geographical Data for All Birds." *Ecology Letters* 25: 581–597. https://doi.org/10.1111/ele.13898.

Tobias, J. A., C. Sheard, N. Seddon, A. Meade, A. J. Cotton, and S. Nakagawa. 2016. "Territoriality, Social Bonds, and the Evolution of Communal Signaling in Birds." *Frontiers in Ecology and Evolution* 4: 00074. https://doi.org/10.3389/fevo.2016.00074.

Turner, D. A. 1985. "On the Claimed Occurrence of the Spike-Heeled Lark *Chersomanes albofasciata* in Kenya." *Scopus* 9: 146.

Turner, D. A., P. L. Britton, and D. J. Pearson. 1980. "Species Report. Ethiopian and Malagasy Region Birds and Oceanics." *Scopus* 3: 107–115.

Underhill, L., and M. Brooks. 2014. "Preliminary Summary of Changes in Bird Distributions Between the First and Second Southern African Bird Atlas Projects (SABAP1 and SABAP2)." *Ornithological Observations* 5: 258–293.

Underhill, L. G., M. Brooks, and M. Loftie-Eaton. 2017. "The Second Southern African Bird Atlas Project: Protocol, Process, Product." *Vogelwelt* 137: 64–70.

Vickery, J. A., S. R. Ewing, K. W. Smith, et al. 2014. "The Decline of Afro-Palaearctic Migrants and an Assessment of Potential Causes." *Ibis* 156: 1–22. https://doi.org/10.1111/ibi.12118.

Virani, M. Z., C. Kendall, P. Njoroge, and S. Thomsett. 2011. "Major Declines in the Abundance of Vultures and Other Scavenging Raptors in and Around the Masai Mara Ecosystem, Kenya." *Biological Conservation* 144: 746–752. https://doi.org/10.1016/j.biocon.2010.10.024.

von Gönner, J., T. M. Herrmann, T. Bruckermann, et al. 2023. "Citizen Science's Transformative Impact on Science, Citizen Empowerment and Socio-Political Processes." *Socio-Ecological Practice Research* 5: 11–33. https://doi.org/10.1007/s42532-022-00136-4.

Wachira, W., C. Jackson, and P. Njoroge. 2015. "Kenya Bird Map: An Internet-Based System for Monitoring Bird Distribution and Populations in Kenya." *Scopus* 34: 58–60.

Weeks, B. C., S. Naeem, J. R. Lasky, and J. A. Tobias. 2022. "Diversity and Extinction Risk Are Inversely Related at a Global Scale." *Ecology Letters* 25: 697–707. https://doi.org/10.1111/ele.13860.

Wong, J. B., P. Adamík, M. Bažant, and S. Hahn. 2024. "Migration and Daily Flight Activity Patterns in the Barred Warbler *Curruca nisoria* Over the Annual Cycle." *Journal of Vertebrate Biology* 73: 23085. https://doi.org/10.25225/jvb.23085.

World Bank. 2023. "World Development Indicators." Accessed January 23, 2024. https://data.worldbank.org/indicator/SP.POP.TOTL?end=2010&locations=KE&start=1977.

Zimmerman, D. A., D. A. Turner, and D. J. Pearson. 1999. *Birds of Kenya and Northern Tanzania*. Princeton, New Jersey: Princeton University Press.

Supporting Information

Additional supporting information can be found online in the Supporting Information section.

Appendix A

Correction for Effort

In this appendix, we present a map that illustrates the expected change in the number of species reported in a square based on the change in effort between the historical and recent data. This map quantifies how increased effort (i.e., more time spent) is anticipated to result in a higher total number of species observed.

A.1. | Change in Effort

In this study, we quantified the change in sampling effort between the two atlas periods (Figure A1). We used the following measures of effort for each atlas:

– Historical atlas: Coverage. For the historical atlas, the effort variable used is the modelled coverage category provided in figure 3, p. 8 of Lewis and Pomeroy (1989). This coverage value is estimated as the percentage of the number of species recorded over the expected number of species present (i.e., richness). The richness was determined by modelling the number of species recorded based on (1) number of types of water body, (2) altitude range and (3) observer effort (score from 1 to 10).

– Recent atlas: total duration. For the recent atlas, we computed the cumulative hours of observation from all full cards for KBM data and from all checklists for eBird data. This does not take into account ad-hoc protocols in the KBM data and incidental checklists in eBird, as no duration is available from this data.

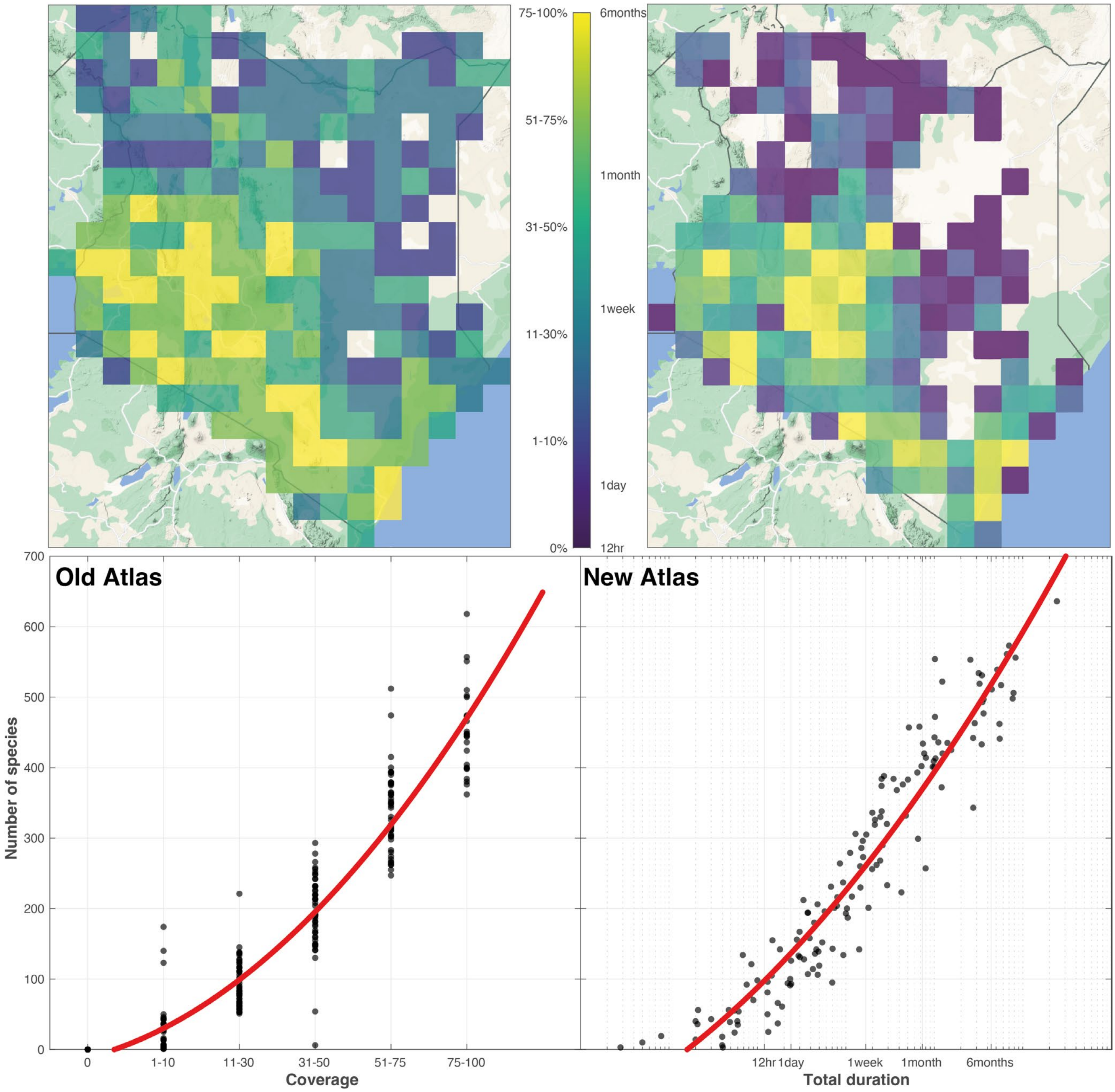

FIGURE A1 | The relationship between the total number of species recorded on a square and the effort spent (quantified by coverage category in the historical atlas and total duration in the recent atlas) shows a similar pattern between both periods.

Both metrics show a similar influence on the total number of species observed (Figure A1). Additionally, the same squares tend to have similar level of effort between the two periods as suggested by the alignment of the dots with the black dotted line in Figure A2. Furthermore, any discrepancy from this general tendency is linked to an overall change in the total number of species observed. For example, in squares where

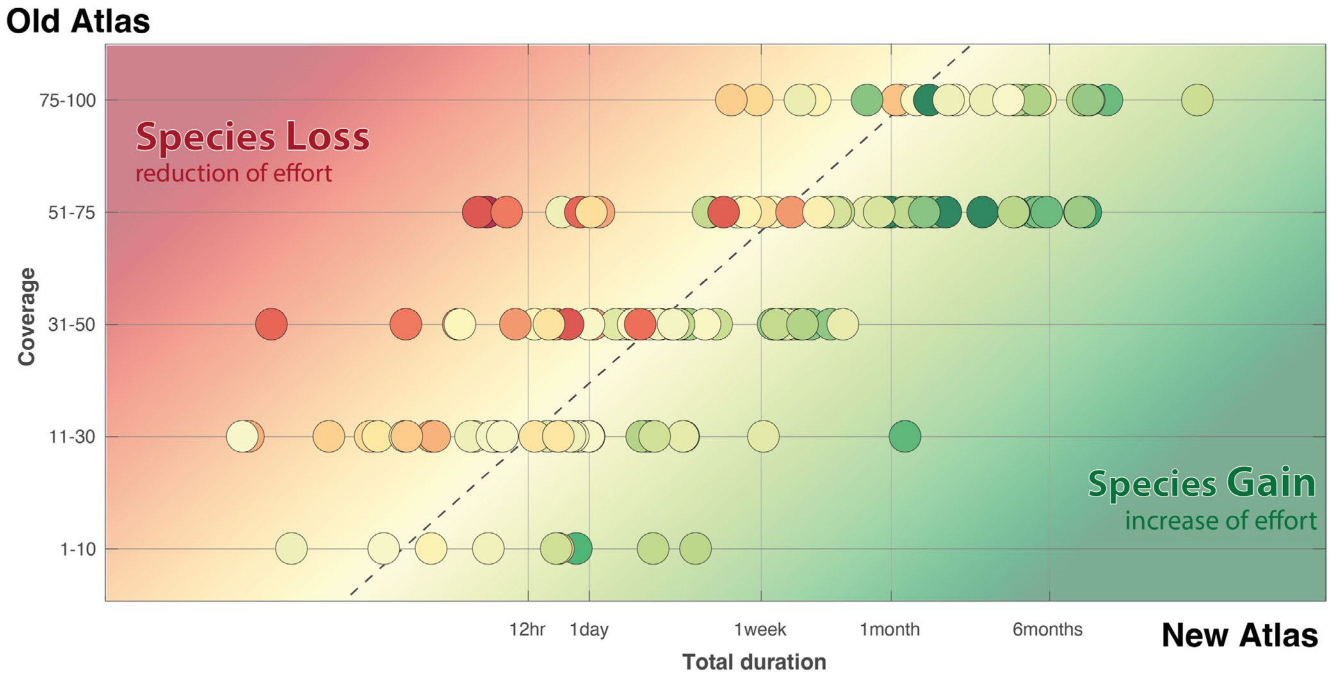

FIGURE A2 | The difference in the number of species observed in each square (colour) is strongly influenced by the change in effort (coverage or total duration). An increase in effort (e.g., low coverage of historical atlas and high total duration in recent atlas) is correlated with an increase in the number of species.

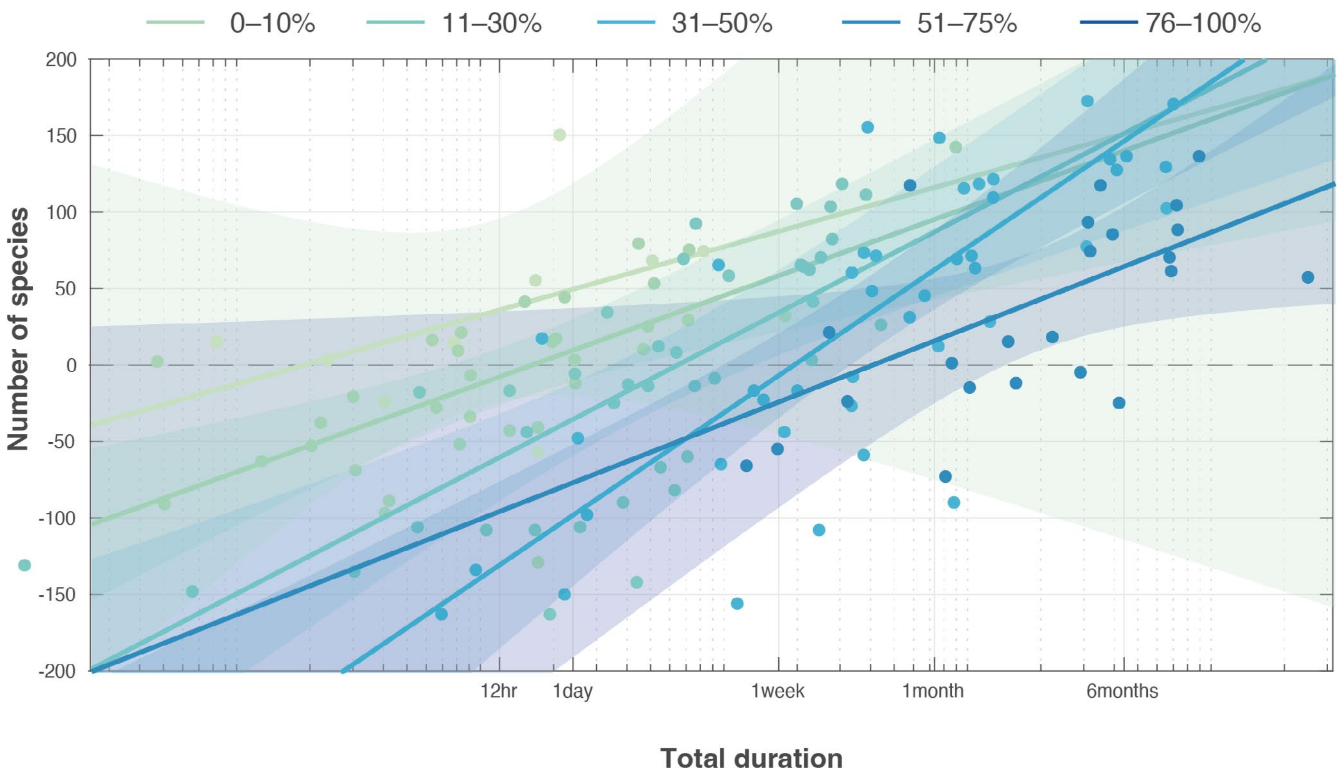

FIGURE A3 | Linear fits between the change in number of species and total duration (recent atlas) for each coverage (historical atlas). These fits are used to estimate an expected change in number of species based on total duration and coverage category. The interception of each fit provides the correspondence between the historical and recent atlas effort variables. For instance, a coverage of 31%–50% (historical atlas) is roughly equivalent to a total duration of 5 days (recent atlas).

the effort has increased between the two periods (i.e., dots to the lowest right of the dotted line), the number of species also generally increased (i.e., green dots). This suggests that change in effort is a significant factor explaining the change in number of species observed.

A.2. | Modelling Species Number Change

To be able to account for the change in effort, we fit linear models between the change in the total number of species and the total duration for each coverage category (Figure A3). These models can then be used to predict the change in the number of species that would be expected given a change in effort. Note that this approach assumes a net-zero overall change in the number of species per square.

A.3. | Estimate of Confidence

The main goal of computing the expected change in number of species per square is to assess how confident we can be that a square was lost or gained because of increased or decreased effort in that square. Indeed, the gain of a species in a square where effort has decreased is more significant than if the effort had increased (in which case the species might have been present but undetected in the historical atlas).

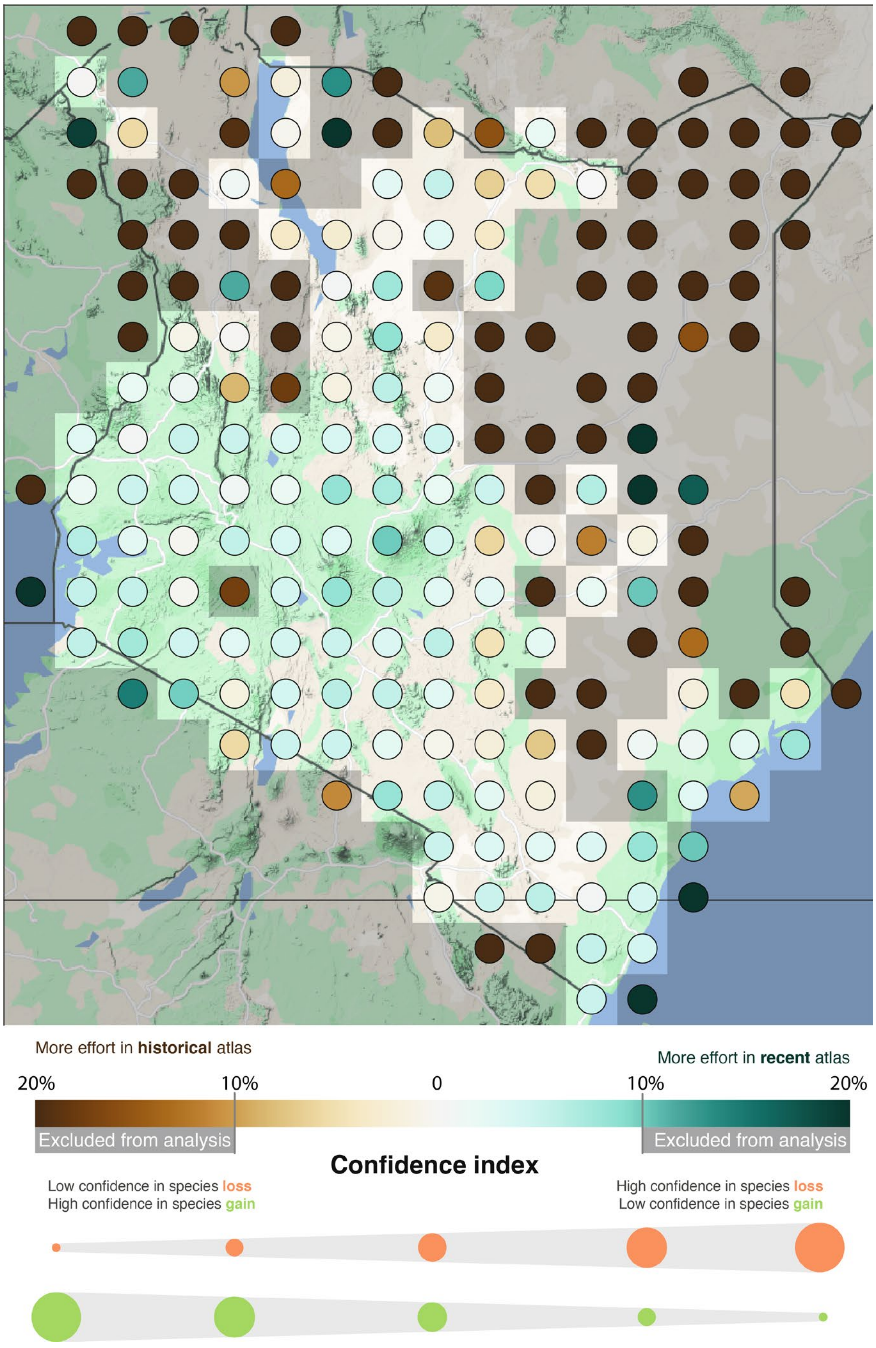

FIGURE A4 | Map of the confidence index (i.e., expected proportion of species lost or gained due to change in effort). The grey mask shows the 10% threshold used for the analysis. Below the map, we show how the confidence index is then displayed on the species map with varying circle sizes reflecting levels of confidence in the result.

For each square, we quantify a confidence index measured as the ratio of the expected change in species due to change in effort divided by the total number of species average between the historical and recent atlases. It essentially quantifies the proportion of all species recorded that can be attributed to the change of effort. This confidence index is visualised on each species map using the size of the circle (Figure A4).

A.4. | Threshold of Use

In the analysis, we discarded squares where the confidence index exceeded 10%. This threshold was chosen to avoid including spurious data in the analysis while seeking to keep as much data as possible. It was manually determined based on the inflection points of the curves in Figure A5.

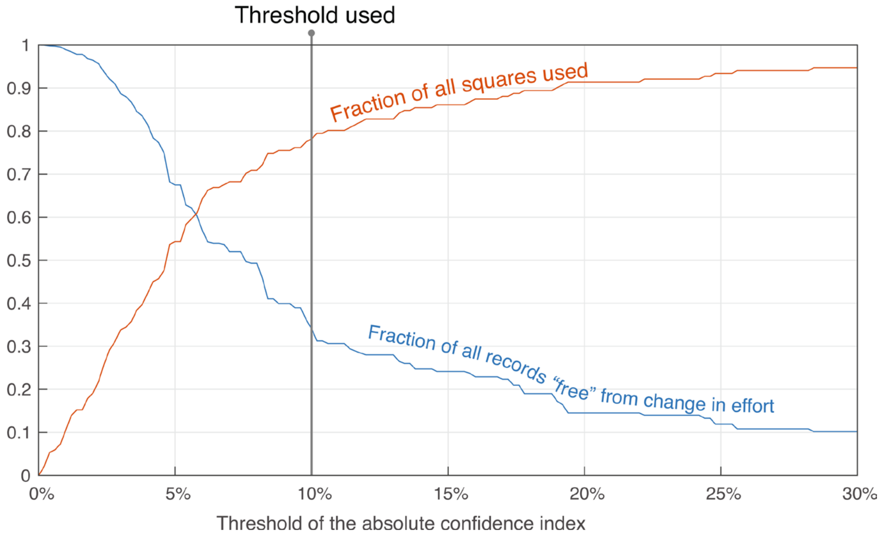

FIGURE A5 | Illustration of the effect of varying the threshold of the confidence index to include in the analysis. As the threshold increases, more squares are used in the analysis but more records (i.e., a species per square) are expected to be caused by change in effort (as quantified by the models presented above). The 10% threshold chosen aims to avoid including spurious data in the analysis while seeking to keep as much data as possible.