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Recent population changes of common waders and passerines in Iceland's largest lowland region

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ABSTRACT
Capsule: Iceland hosts several internationally important populations of ground-nesting birds in open habitats, particularly waders, but monitoring shows concerning declines among populations of several of these Icelandic land birds.
Aims: To estimate population changes of ground-nesting birds in Iceland's largest lowland region from 2012 to 2024 and compare their densities to important landscape factors.
Methods: Abundance of the nine most common species (seven waders and two passerines) in South Iceland was monitored with point counts in a roadside survey. Data on landscape factors were extracted from aerial photography and their relationships to bird densities were explored.
Results: Redwings *Turdus iliacus* increased over the period (∼12% annual increase), Common Snipes *Gallinago gallinago* did not show significant changes, but seven species declined by ∼2% to 10% annually (European Golden Plover *Pluvialis apricaria*, Eurasian Oystercatcher *Haematopus ostralegus*, Eurasian Whimbrel *Numenius phaeopus*, Black-tailed Godwit *Limosa limosa*, Dunlin *Calidris alpina*, Common Redshank *Tringa totanus* and Meadow Pipit *Anthus pratensis*). Densities of Eurasian Whimbrels and Dunlins increased with distance from permanent settlements while Common Snipe densities decreased, although the abundance change was unaffected.
Conclusion: These rapid changes of open-habitat specialists in Iceland's largest lowland area are a grave cause for concern and call for a concerted effort to explore the drivers.

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Declines of bird populations are prominent in the current global biodiversity crisis, with 48% of the world's birds known or suspected to be declining and only 6% increasing (Lees *et al.* 2022). Species that are vulnerable to human development, such as open-habitat specialists or birds associated with agriculture and wetlands, and also insectivores and migrants, often have an unfavourable conservation status where the most important proximate driver is habitat degradation or loss (Bowler *et al.* 2019, Donald *et al.* 2001, Lees *et al.* 2022, Rosenberg *et al.* 2019). Ground-nesting birds in open habitats, such as waders (*Charadrii*; Piersma & Baker 2000), have been considered especially vulnerable to the expansion of anthropogenic influences, as these species are rarely able to utilize human-altered habitats, such as urban areas or plantation forests (McKinney 2002, Amar *et al.* 2011, Ballantyne & Nol 2015, Jokimäki *et al.* 2016). In addition to unsuitability of the altered habitat, studies have shown that waders often have reduced breeding densities in proximity to anthropogenic structures (Wilson *et al.* 2005, Pearce-Higgins *et al.* 2009, Pálsdóttir 2022, Pálsdóttir *et al.* 2024).

Iceland has a relatively low human population density compared to the rest of Europe, and grazing has left the landscapes open and dominated by short vegetation for centuries (Arnalds 2008, The World Bank 2020). This has made Iceland an ideal nesting area for open-habitat specialists, and it currently holds several internationally important populations of waders, most of which breed in lowland (<300 m a.s.l.) areas. It is estimated that ∼1.5 million pairs of waders breed in Iceland in the summer (Skarphéðinsson *et al.* 2016, Gunnarsson 2020) and consequently an estimated 4–5 million breeding adult and juvenile waders migrate from the country each autumn (Gunnarsson *et al.* 2006, Skarphéðinsson *et al.* 2016). This makes Iceland a major population source for the East Atlantic Flyway, and any substantial changes to the large Icelandic wader populations are likely to impact the non-breeding populations of many countries across Western Europe and West Africa.

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The majority of birds breeding in Iceland's lowland open habitats belong to seven wader species: the Black-tailed Godwit *Limosa limosa*, European Golden Plover *Pluvialis apricaria*, Eurasian Oystercatcher *Haematopus ostralegus*, Dunlin *Calidris alpina*, Eurasian Whimbrel *Numenius phaeopus*, Common Redshank *Tringa totanus* and Common Snipe *Gallinago gallinago*, along with two passerines: the Redwing *Turdus iliacus* and Meadow Pipit *Anthus pratensis* (Jóhannesdóttir *et al.* 2014, Pálsdóttir 2022). For the waders among these birds, between 3% and 51% of the world population of each of these species is estimated to breed in Iceland, making the Icelandic lowlands of international importance for the conservation of these species (Gunnarsson *et al.* 2006, Skarphéðinsson *et al.* 2016). Globally, the majority of these species are estimated to be declining (IUCN 2024), but little is known about the population trends in Iceland as yearly systematic bird counts have only been conducted since 2006 in a few areas (Skarphéðinsson *et al.* 2016).

In Iceland, stochastic environmental events such as volcanic eruptions, flooding, irregular annual snowmelt and adverse weather are all frequent. These may influence wader habitats and bird numbers in the short term through behavioural and demographic responses, and in the longer term through changes to vegetation succession that alters the habitat structure (Gunnarsson *et al.* 2017, Katrinardottir *et al.* 2015, Gunnarsson 2020). In addition to stochastic events, human influence on terrestrial bird habitats is increasing greatly.

The majority of Iceland's human settlements and terrestrial breeding birds are concentrated in the lowlands, which cover about one-third of the country or ~33,000 km^2 (Skarphéðinsson *et al.* 2016, Gunnarsson 2020). However, land-use in these areas is rapidly changing, mainly driven by human impact through, for example, construction of houses, roads and power lines, along with expansion of plantation forests and agricultural areas (EEA 2018, Pálsdóttir *et al.* 2022a). These changes will reduce the amount of open breeding habitat available for ground-nesting birds, but the effects will depend on which habitats are affected and to what extent (Jóhannesdóttir *et al.* 2014, Laidlaw *et al.* 2020). Additionally, these changes may alter the suitability of the remaining habitat by, for example, changes in the number and/or distribution of predators, greater human disturbance and vegetation changes that could then affect the distribution and density of bird populations (Chace & Walsh 2006, Ludlow *et al.* 2015, Yoo & Koper 2017).

Population monitoring of the terrestrial bird populations in Iceland is still undeveloped, and no country-wide monitoring schemes yet exist. However, some regional counts take place annually in various habitat types, which have been developed in various parts of Iceland since 2006, 2009 or 2010, and these will become useful for assessing changes in the near future (Náttúrufræðistofnun Íslands 2019, Kolbeinsson *et al.* 2023, Lárusdóttir *et al.* 2023). Therefore, trends of the most common terrestrial species in Iceland have not yet been quantified, making the current study of high importance for conservation purposes.

Establishing breeding population trends is one of the most important tools for estimating the importance and urgency of habitat conservation and/or management. The aims of this study are: firstly, to establish trends for the most common terrestrial species in southern Iceland, which is the largest lowland basin in the country and an Important Bird Area as identified by BirdLife International (Skarphéðinsson *et al.* 2016); secondly, to attempt to link these trends to landscape factors in the region that have been shown to affect the distribution or demography of the focal species (Pálsdóttir 2022).

Methods

Study area

The study area in the southern lowlands (Figure 1) is characterized by a fine scale mosaic of semi-natural habitats with agricultural patches (Jóhannesdóttir *et al.* 2019). Closer to the coast there are flat plains with abundant wetlands and grasslands, with more elevated land further inland where heathlands are more abundant. The area holds internationally important populations of several species of waders, with numbers of Eurasian Oystercatchers, European Golden Plovers, Dunlins, Black-tailed Godwits and Common Redshanks in the tens of thousands of individuals, while Common Snipes and Eurasian Whimbrels exceed 100,000 individuals, as estimated in 2013 (Jóhannesdóttir *et al.* 2014). Land-use practices are changing rapidly in the area, moving from historical small-scale farming to increasing infrastructure, forestry plantations and housing developments (Wald 2012, Pálsdóttir 2022, Pálsdóttir *et al.* 2024).

Survey methods

The surveys took place annually between 20 and 29 June from 2011 to 2024. The same surveyor carried out the survey in all years. The census was a point count conducted from the roadside (Sauer *et al.* 2017), with all points being at elevations below 300 m a.s.l. In total, the

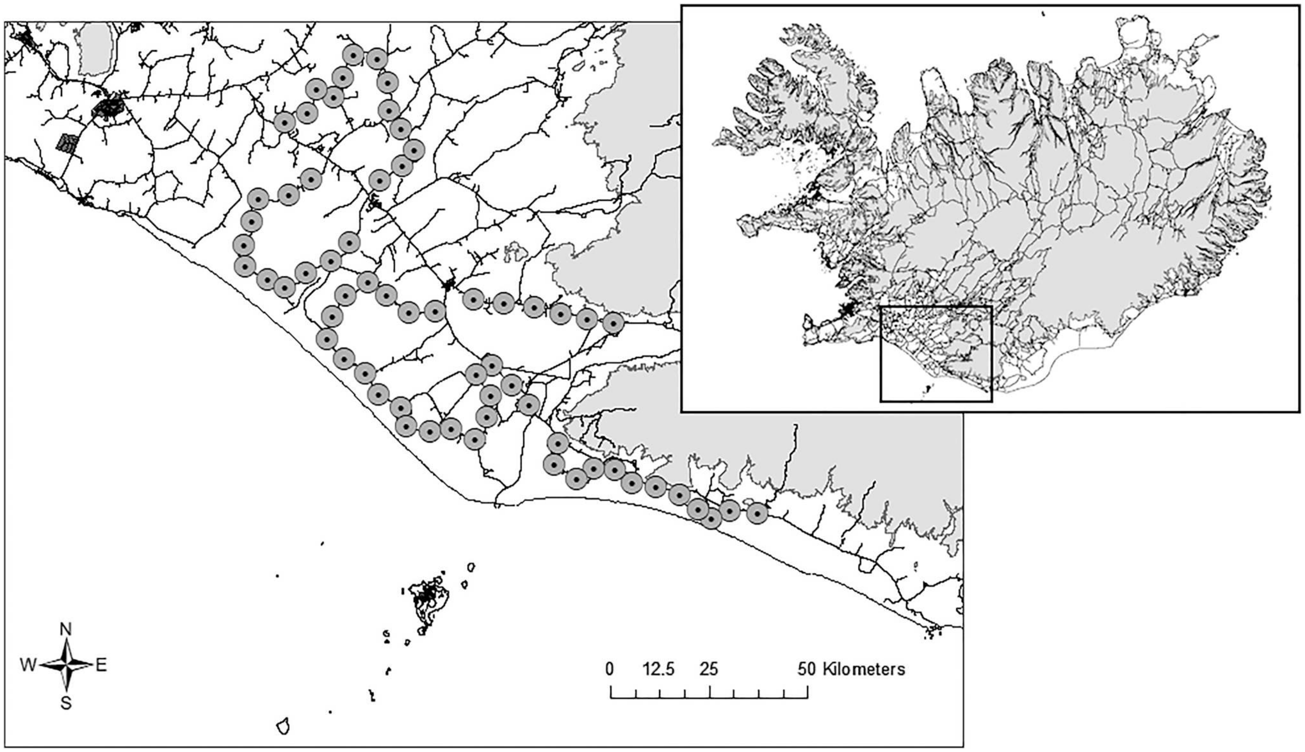

Figure 1. Map of the southern lowlands of Iceland with the survey points shown as black dots surrounded by dark grey circles. The map shows the highlands (>300 m a.s.l.) in grey and roads/towns in black.

same 63 points were surveyed each year (Figure 1). All adult birds seen and heard up to 200 m from the observer were recorded and a laser range finder was used to determine the distance to the bird. All birds and their behaviour were marked on a map of the point to give an overview of their position and avoid double counting. Birds flying high and purposefully over the point were omitted from the analysis but birds on the ground and those showing breeding behaviour (displaying, alarm calling, fighting, mobbing, etc.) were included. The survey duration at each point was five minutes, which is a frequent practice in point counts that is a trade-off between accuracy and efficiency (Fuller & Langslow 1984, Bonthoux & Balent 2012).

The timing of the surveys coincided with the peak breeding season of the most common focal species (Gunnarsson *et al.* 2006, Laidlaw *et al.* 2020). Detectability is usually high during this time of the breeding season. Counts were carried out in dry weather and wind speeds of <7 m/s, and took place between 07:00 and 21:30 local time. Visibility of birds may vary throughout the day for individual species (Figure S1) and so the same points were counted during the same part of the day each year to give an interannual comparison. In a few cases, however, points had to be moved in time due to unsuitable weather conditions (Figure S2).

When surveying long-lived and philopatric species, like most of the focal species, it is preferable to prioritize counting in more places rather than censusing fewer sites more intensively (Rhodes & Jonzén 2011), so the survey was based on roads and tracks to maximize coverage in the region at a similar time of the breeding season. Tracks and roads varied in their traffic and surfacing, from rarely used mud tracks to some of the busiest roads in rural Iceland, but which still have low traffic volume in an international context (mean 457 cars/day in summer, range: 15–4,402). A total 198 km of roads and tracks were driven each year, and birds were counted at points that were selected by a pre-determined rule of stopping every 3 km to get a proportionate coverage of main habitats along the transect. Roads were selected so they would cover the coastal plains (<30 m a.s.l.; 39 points) and heathland dominated hills (30–200 m a.s.l.; 24 points) further inland.

Relating trends to landscape factors

To explore how certain landscape factors affected bird abundances and trends, five factors that have previously been shown to correlate with variation in breeding density of open habitat species (Jóhannesdóttir *et al.* 2014, Thompson *et al.* 2015, Davíðsdóttir *et al.* 2016, Torres *et al.* 2016, Morán-López *et al.* 2017, Alfreðsson 2018, Jóhannesdóttir *et al.* 2018, Pálsdóttir *et al.* 2022a) were estimated for each point within a 200 m radius of the observer. These factors were: distance to nearest permanent settlement (DPS), area of trees, habitat type class, presence of non-residential buildings, and traffic volume.

Data for the DPS, along with house and tree presence, were extracted from aerial photography captured in 2022 (Loftmyndir ehf 2022) and thus describe the recent condition of these attributes but not changes during the study period, which were not readily available. The DPS was measured (in metres) from the centre of the point/observer. Towns, farmsteads and residential houses without farming activities were classified as permanent settlements. To explore how human impact in the point counts related to the rest of the southern lowlands, a GIS was used to generate additional 100 random points in the study area (longitude: −19.51912 to −20.69147, latitude: 63.51607–63.98312, altitude: <300 m a.s.l.) and the DPS was measured at these points.

The area of trees, either as patches or shelterbelts, was extracted from aerial photography as they have previously been shown to have an effect on densities of the focal species (Davíðsdóttir *et al.* 2016, Alfreðsson 2018, Pálsdóttir *et al.* 2022a). However, the data lacked variance in the area covered by trees (Figure S3) and the distribution of trees varied between points, with some having tree patches (approximately circular, range: 0–7.2 ha) and others shelterbelts (linear in one or more lines with an average width of 6.2 m and total length ranging over 30–700 m). These different formations will vary in regard to their visibility and length of edge, with possible subsequent effects on bird densities. Therefore, only presence of trees was included in the final model.

The presence of houses and buildings, other than permanent settlements that were already accounted for within the DPS variable, was also recorded. The majority of the buildings were summer cottages, and the number of houses per point ranged from 0 to 16. In total, 22 (35%) of points contained one or more houses. For the habitat type classes, the percentage of cultivated, forestry, wetland, freshwater, grassland, humid, moss, heathland (poor/rich) and semi vegetated land per point (within 200 m) was extracted from the Icelandic farmland database, 'Nytjaland', which was established between 2001 and 2014 (Gísladóttir *et al.* 2014).

For the variable of traffic volume, at each point in each year we extracted cars/day in summer (start of June until the end of September) from the nearest (<1 km) traffic counter on the respective road from official records (The Icelandic Road and Coastal Administration 2022). For roads that did not have individual traffic counters, the traffic volume of the nearest road of similar structure was used. However, this only applied to roads or tracks with very little traffic (<300 cars/day in summer). Sometimes the same traffic counter was used for up to four points, as it was the nearest to all of them. Traffic in Iceland increased steadily with increased tourism during 2011–2019, followed by low traffic numbers in 2020–2021 due to the Covid-19 pandemic, so temporal variation in traffic volume was considered as well as spatial variation (Jóhannesson & Huijbens 2010, The Icelandic Road and Coastal Administration 2022).

Statistical analysis

As DPS was negatively correlated with two of the other aforementioned factors, i.e. the presence of houses (Wilcoxon $W = 825$; $P < 0.001$) and presence of trees (Wilcoxon $W = 661$, $P < 0.01$) (Figure S4 and Figure S5), the DPS and traffic volume were the only landscape factors included in the final models. The amount of each habitat type class at the points correlated with each other, as the area of the point is a fixed size, and so an increase in one type will inevitably lead to a decrease in others (Figure S5). Therefore, only the habitat type class that showed the most variation (cultivated land) was included in the final models. Although the amount of cultivated habitat was negatively correlated with DPS (Figure S5), the strength of the relationship was modest (GLM: $t = -2.87$; $P < 0.01$, correlation coefficient = −0.34).

To test for changes in bird numbers through the years, GLMMs with a Poisson distribution and a log-link function were constructed. Bird abundance, for each species and all birds combined (overall bird density), was the dependent variable, with all possible combinations of year, DPS (with and without an interaction with year), traffic (with and without an interaction with year) and amount of cultivated habitat as independent variables, along with a null model (Table S1). Due to convergence problems, an interaction between year and cultivated habitat was not included in the final model, but, as it correlated with DPS (which also correlated with tree and house presence), some of the variation caused by the amount of cultivated land was already accounted for. Year (see Daskalova *et al.* 2019) and point were included as random intercepts to account for non-independence of the same points in different years. In the model for all species, the number of individuals of each species per point per year was the dependent variable, and species was included as a random intercept. The best model for each species and all individuals together were defined as the models with the lowest AIC value, unless $\Delta AIC < 2$ from a model with fewer explanatory variables, which was then selected. Estimates of yearly density changes for all birds and individual species were derived by back-transforming the model estimates. All statistical analyses were performed in R (R Core Team 2017) and the package 'performance' was used to check that all model assumptions were met (Lüdecke *et al.* 2021), and the package 'terra' was used to extract habitat variables (Hijmans 2024).

Results

In total, 9,381 birds were counted over the course of 14 years. The vast majority of birds counted (92%) belonged to nine species, involving two passerines (Redwing and Meadow Pipit) and seven waders (Dunlin, European Golden Plover, Black-tailed Godwit, Eurasian Oystercatcher, Eurasian Whimbrel, Common Snipe and Common Redshank), which were the focal species for analyses (Table S2).

During the 2011 breeding season a volcano erupted in south-east Iceland, causing ash to spread over the southern lowlands (Moxnes *et al.* 2014). Previous studies have shown that wader productivity in the area was greatly reduced in that year (Katrinardottir *et al.* 2015, Gunnarsson *et al.* 2017). Therefore, the detectability of certain species, such as the Black-tailed Godwit, Dunlin, European Golden Plover and Eurasian Whimbrel, may have been reduced in that year compared to others, due to failed or aborted breeding attempts (Figure S6). As such, 2011 was removed from our main analysis as it may have caused an underestimation of abundance changes. Results including counts from 2011 are reported in discussion.

The total bird abundance of the focal species decreased throughout the study period, by an average of around 2% each year (Table 1, Figure 2). On a species level, the Redwing increased by ~12% annually while the abundance of European Golden Plovers, Common Redshanks, Dunlins, Meadow Pipits, Eurasian Oystercatchers, Black-tailed Godwits and Eurasian Whimbrels decreased by between 2% and 10% annually (Table 1, Figure 2). Common Snipes did not show a significant change in abundance throughout the study period.

Greater traffic volumes had a negative effect on the abundance of Dunlins, Eurasian Whimbrels and Eurasian Oystercatchers, while the opposite was true for Common Redshanks, which were more abundant at points with higher traffic volumes (Figure 3(A)). The abundance of Common Snipes was higher at points closer to permanent settlements, but densities of Dunlins and Eurasian Whimbrels were lower (Figure 3(B)). The DPS measured at 100 random points (mean: 1,365 ± 144 m) in the study area was higher (two sample t-test; $t = -4.91$, $P < 0.001$) compared to the road-based point counts (595 ± 18 m).

Discussion

Global bird diversity and abundance are declining. Waders are a vulnerable group of (generally) open-habitat specialists that have shown widespread declines (International Wader Study Group 2003, Amar *et al.* 2011, Pearce-Higgins *et al.* 2017). Iceland holds several internationally important populations of waders breeding in its lowland areas, but trends of those populations have hitherto remained unexplored in areas undergoing rapid land-use changes. In this study we carried out systematic counts of common land birds in Iceland's largest lowland region over a 13-year period. The overall abundance of common species declined, and more species were declining (seven of nine) than increasing (one of nine), which may negatively affect species diversity and lead to a more homogenous bird community.

Although the time series of the study had a limited duration with respect to the longevity of most of the focal species, there were significant declines of between 2% and 10% each year that were already apparent (Table 1). As the majority of these species are still abundant in Iceland, and are widespread in the wider countryside, their protection has not been a priority. Our results strongly suggest that population declines may be underway across large areas of southern Iceland, which is the single most important breeding area for waders in the country. Here, the first year of counts (2011) was excluded due to a volcanic eruption in the area, but even if that year was included in our analysis there were significant negative trends of the seven declining species, for all but the Black-tailed Godwit. These estimates were more conservative, however, at between 2% and 7% population declines each year (Figure S6).

The results from our survey closely resemble species-specific distribution patterns from other recent studies in Iceland that showed Redwings and Common Snipes, which readily breed amongst taller vegetation and in urban areas, seemed to show a neutral or positive response to the current landscape changes associated with increased shrub growth, forestry,

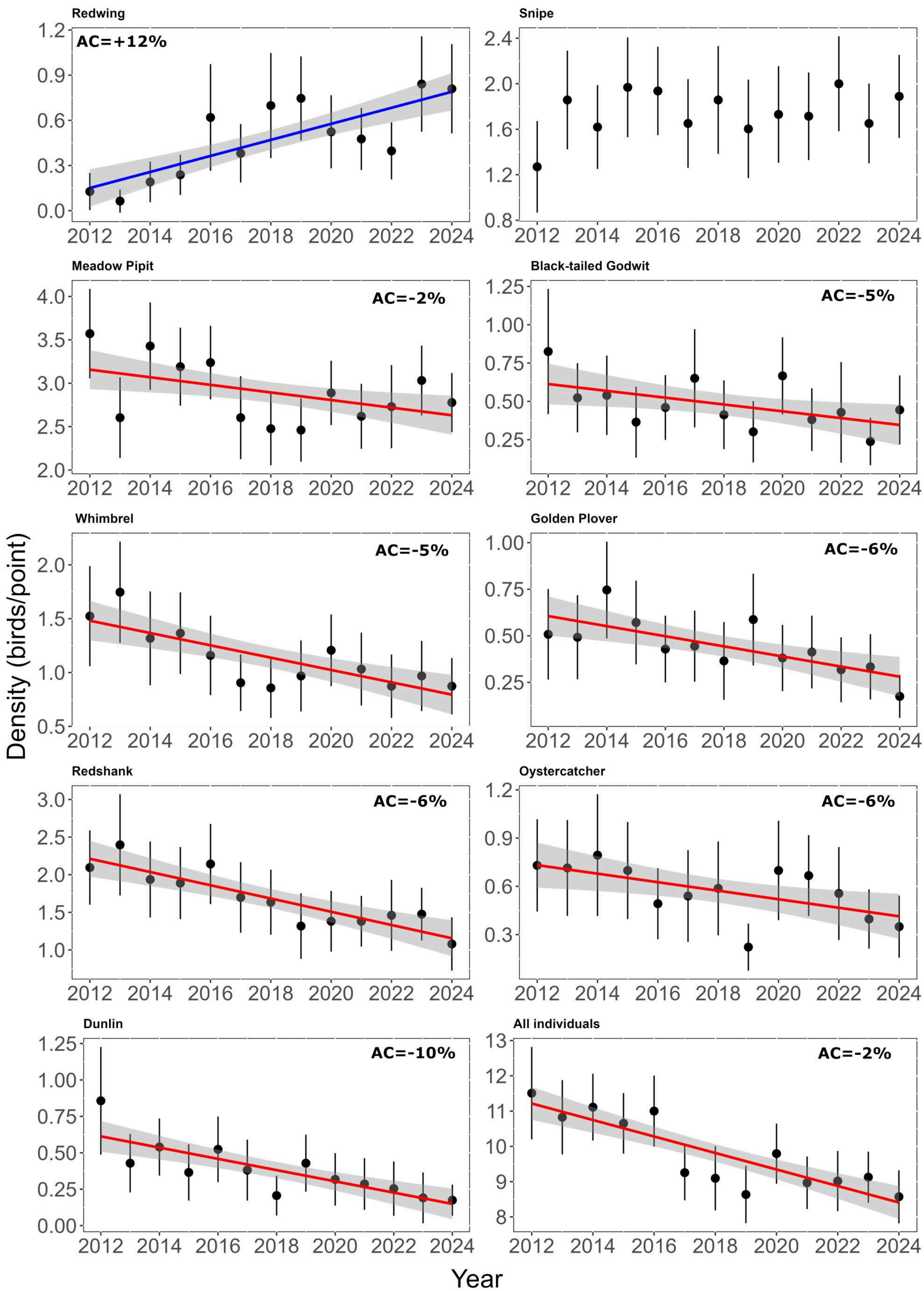

Figure 2. The mean (±SE) density of nine species and the total number of birds on point counts in south Iceland during the years 2012–2024. Each point is 12.56 ha (radius 200 m). Regression lines of observed densities are shown for significant relationships. Annual rate of change (AC) calculated from estimates from the best model (Table 1) is included in relevant plots.

Table 1. Estimates (±SE) from models predicting changes in bird abundance in south Iceland during 2012–2024. Letters represent significance ($^{A}P < 0.05$, $^{B}P < 0.01$, $^{C}P < 0.001$). Model selection is shown in Table S1. Point ID and year were included as a random factor in all models, and species as a random factor in models for all individuals. Each point is made up of ~555 pixels and the unit of cultivated habitat is the number of pixels per point. DPS is the distance to a permanent settlement.

Species	Predictors	Year	Traffic (per 1000 cars/day in summer)	DPS (km)	Cultivated (per 100 pixels)	Year:Traffic
European Golden Plover *Pluvialis apricaria*	Year	$-0.06\ (\pm0.02)^{C}$				
Dunlin *Calidris alpina schinzii*	Year, Traffic, DPS	$-0.10\ (\pm0.02)^{C}$	$-0.89\ (\pm0.32)^{B}$	$1.50\ (\pm0.39)^{C}$		
Common Snipe *Gallinago gallinago faeroensis*	DPS			$-0.33\ (\pm0.14)^{A}$		
Black-tailed Godwit *Limosa limosa islandica*	Year, Cultivated	$-0.05\ (\pm0.01)^{C}$			$1.59\ (\pm0.65)^{A}$	
Redwing *Turdus iliacus coburni*	Year	$0.12\ (\pm0.01)^{C}$				
Common Redshank *Tringa totanus robusta*	Year, Traffic, Cultivated	$-0.06\ (\pm0.01)^{C}$	$0.20\ (\pm0.06)^{B}$		$1.66\ (\pm0.42)^{C}$	
Eurasian Oystercatcher *Haematopus ostralegus*	Year, Traffic, Year:Traffic	$-0.06\ (\pm0.01)^{C}$	$-0.66\ (\pm0.22)^{A}$			$4.67*10^{-5}\ (\pm1.76*10^{-5})^{B}$
Meadow Pipit *Anthus pratensis*	Year	$-0.02\ (\pm0.01)^{B}$				
Eurasian Whimbrel *Numenius phaeopus islandicus*	Year, Traffic, DPS, Cultivated	$-0.05\ (\pm0.09)^{C}$	$-0.24\ (\pm0.09)^{B}$	$0.68\ (\pm0.23)^{B}$	$-1.24\ (\pm0.01)^{A}$	
All individuals	Year	$-0.024\ (\pm0.01)^{C}$				

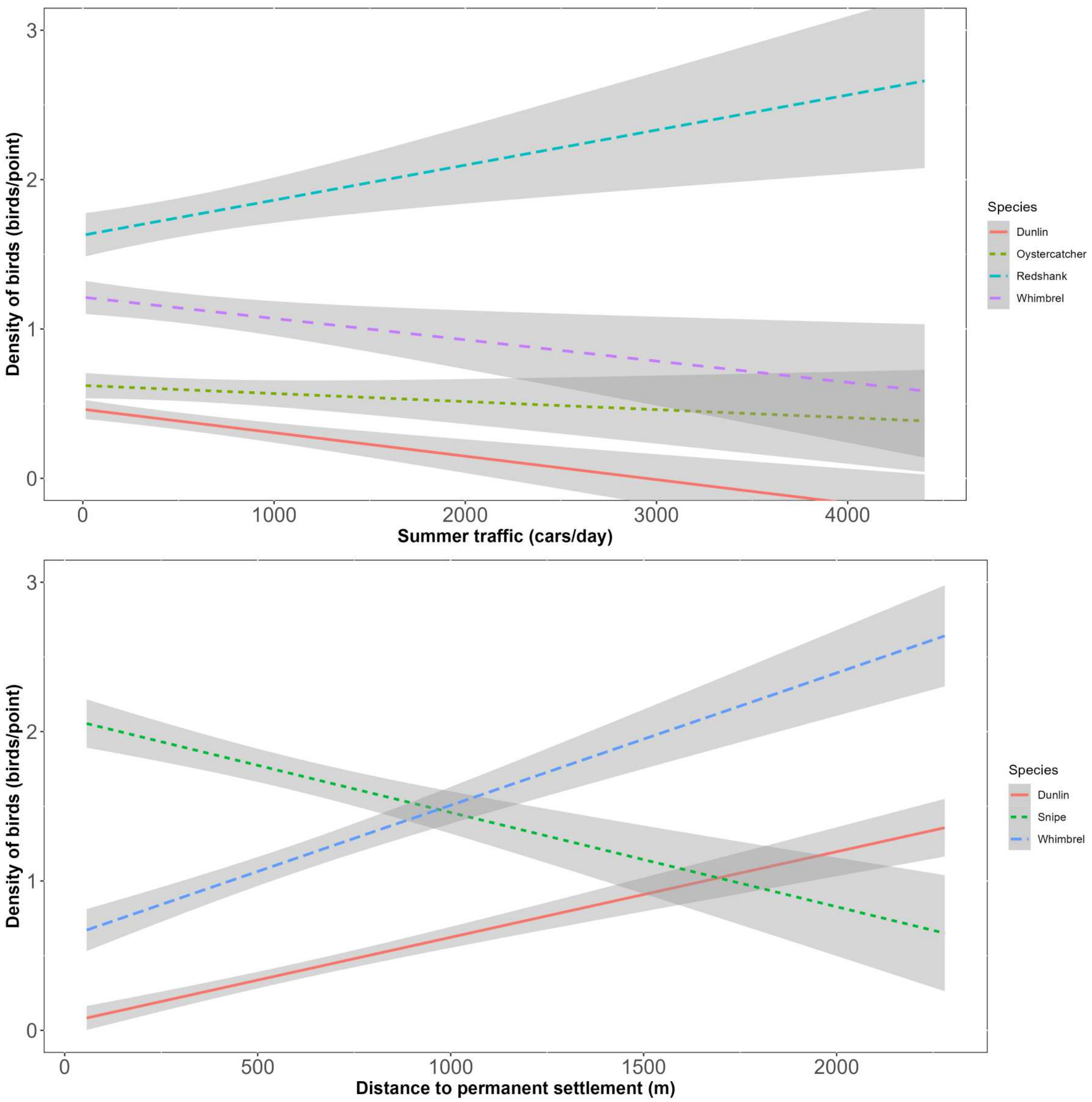

Figure 3. Regression lines showing the mean density (±SE) of four bird species that showed a significant correlation with traffic volume (A) and distance to permanent settlements (B) in point counts in south Iceland during 2012–2024.

housing developments and infrastructure, while most other open-habitat species responded negatively (Davíðsdóttir *et al.* 2016, Alfreðsson 2018, Pálsdóttir *et al.* 2022a, Pálsdóttir *et al.* 2022b). The rapid increase of Redwing abundance may be driven by an increase in nesting opportunities related to anthropogenic structures and tree planting. These coherent species-specific responses in different studies suggest that habitat change on the breeding grounds may be a likely driver of population change, although the contribution of different drivers cannot be separated at present, and they are also likely to vary between species.

Although Dunlins showed the steepest population decline (10% per year), this may be an overestimate due to the species' high numbers in the initial year; if 2012 was removed then the decline would be ~8% per year, which is still a cause for concern. For a better understanding of the underlying drivers of this decline, information on how the measured landscape factors have changed over time would be needed, along with an increased number of point counts that better capture different habitat factors. Hopefully, in the future, more widely distributed monitoring studies and improved data for land-use change will make these patterns clearer.

Densities of Eurasian Whimbrels and Dunlins, which are both currently declining, were lower at points closer to permanent settlements, while Common Snipes, whose numbers are stable, were found in higher densities at points closer to permanent settlements (Figure 3(B)). There was no evidence of a more rapid decline of Eurasian Whimbrels and Dunlins closer to permanent settlements. These patterns are likely driven by differences in the habitat composition of the survey points, but with increasing distance from a permanent settlement (town, farm, etc.) the presence of trees and non-residential houses became less frequent, and the amount of cultivated habitat decreased (Figure S4, Figure S5). Additionally, points that contained houses and trees within the counted area (200 m radius) were more likely to have houses and trees in the habitat surrounding the point up to 400 m distant (Figure S7, Figure S8) which could also affect bird densities at the points. Densities of Common Snipes in Iceland have been shown to be higher in areas closer to forest edges, while densities of Eurasian Whimbrels and Dunlins are lower (Pálsdóttir *et al.* 2022a). Similarly, Common Snipe densities are not affected by the presence of summer houses in the proximate habitat, while Eurasian Whimbrels respond negatively (Pálsdóttir *et al.* 2024).

One caveat to our results was that the point counts were performed next to roads, which are closer than average to permanent settlements in the southern lowlands. Therefore, it is possible that the patterns described here may differ from those further away from roads, where bird densities tend to be higher. Additionally, the areas close to roads may be different to the lowlands in general, although previous studies have shown that the frequency of habitat type classes does not differ greatly between areas nearer or further from roads (Gunnarsson *et al.* 2006).

Human influence is considered a primary driver behind global biodiversity changes, and the Icelandic lowlands, which have been open landscapes for centuries, are now rapidly changing towards landscapes that are under more anthropogenic pressure from diverse sources (EEA 2018). Monitoring breeding numbers and mitigating the negative effects of habitat loss is imperative. Comparable counts in the west and north-east of Iceland do not show consistent abundance declines across species, unlike those that are apparent from southern Iceland, but those study areas are overall less developed (Náttúrufræðistofnun Íslands 2019, Kolbeinsson *et al.* 2023, Lárusdóttir *et al.* 2023). However, counts from eastern Iceland show similar results to those presented here, with four wader species showing significant declines (Eurasian Whimbrel, Black-tailed Godwit, European Golden Plover and Common Redshank) while Redwing is increasing (Lárusdóttir *et al.* 2023). Those counts were partially undertaken in areas that have experienced, or are currently changing due to, anthropogenic pressure from various factors, such as plantation forests, summer houses, agriculture and increased tourism. This suggests that the trends presented here may not represent countrywide changes, but rather regional declines in areas where land-use pressures are increasing, such as the southern and parts of eastern Iceland.

However, with half of the counts currently being performed in Iceland showing similar patterns of decline for ground-nesting birds in open habitats, while those species that prefer taller vegetation and are more tolerant to human influence are increasing (Pálsdóttir *et al.* 2022a, Pálsdóttir *et al.* 2024), there is considerable urgency for further investigation and management. It is highly likely that these patterns have started emerging in more areas of the country, and more widespread monitoring should be a priority. Even if the declines are limited to the areas identified here, the importance of these large areas for bird populations cannot be understated, and as more of lowland Iceland becomes developed these patterns are likely to develop across the country.

The affected species have a broad range on their wintering grounds. The waders winter coastally from

West Africa (Eurasian Whimbrel and Dunlin), through Western Europe from Iberia to Britain and Ireland, while part of the Eurasian Oystercatcher population is sedentary in Iceland (Gunnarsson & Tómasson 2011, Þórisson *et al.* 2018) and Meadow Pipits winter in North Africa and Southern Europe (Boyd 2003). These species use a variety of coastal and inland habitats in different countries and are on different migration schedules (Gunnarsson & Tómasson 2011). A common denominator for the declining species, driven by non-breeding season processes, is therefore not obvious.

A study of wader population trends in Fennoscandia, one of the closest landmasses to Iceland that hosts species that share migratory routes and wintering areas with the Icelandic populations, showed that Eurasian Whimbrels were declining, while Common Snipes and Common Redshanks showed no change, and Eurasian Oystercatchers and Dunlins were increasing (Lindström *et al.* 2015). This study was at a large scale, covering almost three countries, which may further strengthen our hypothesis that the Icelandic results were driven by changes in the southern lowlands, rather than global factors.

Local factors may influence certain species and/or populations, in addition to global changes. Predation rates in certain regions may be a contributing factor for the population sizes of ground-nesting birds (Macdonald & Bolton 2008, Roos *et al.* 2018). Only two wild mammalian predators are found in Iceland, the non-native American Mink *Neovison vison* and the Arctic Fox *Vulpes lagopus*, along with Domestic Cats *Felis catus*. Arctic Foxes are common predators of wader nests and chicks in Iceland (Pálsdóttir *et al.* unpublished data), and the Arctic Fox population seems to be increasing after a historical low in 1979 (Unnsteinsdóttir 2021). Therefore, it is possible that the predation pressure on nests, chicks and even adult birds has increased throughout the study period, which could contribute to the declining bird abundance. However, the hunting statistics for Arctic Foxes collected from around Iceland, which are strongly related to population size, do not show a different pattern in the study area compared to other parts of the country where bird declines are not evident (Pálsson *et al.* 2016). Nevertheless, regional differences in predation rates cannot be excluded, with anthropogenic influence possibly altering the distribution of foxes.

Traffic volumes had negative effects on the densities of Dunlins, Eurasian Whimbrels and Eurasian Oystercatchers (Figure 3(A)). Previous studies have identified lower densities of birds closer to roads with high traffic volumes, so our results were not surprising (Benítez-López *et al.* 2010, Kociolek *et al.* 2011, Grilo *et al.* 2020, Pálsdóttir 2022). Here, we found no evidence that birds were declining or increasing more rapidly closer to roads, suggesting that traffic is not a driver of the current declines. Despite this, the lower bird densities near roads suggested that they may have been higher in the area before high-traffic roads appeared. A caveat for this is that all points were counted next to roads, and we lacked a comparison with bird trends in undisturbed landscapes.

The positive effects of higher-traffic roads on the abundance of Common Redshanks could have been driven by nest-site selection; in Iceland this species generally conceals its nests in patches of tall vegetation, such as tussocks (Laidlaw *et al.* 2020). In other European studies, Common Redshanks and Eurasian Oystercatchers have been shown to be relatively insensitive to land-use intensity (Silva-Monteiro *et al.* 2021). High-traffic roads in Iceland are often elevated, fenced off and have ditches and strips of un-grazed grassland running alongside, which may provide suitable nest sites. Mean traffic volumes at each point showed no correlation with habitat type classes that are known to have higher densities of Common Redshanks (wetland, grassland and agricultural fields; Jóhannesdóttir *et al.* (2018), Jóhannesdóttir *et al.* (2014)), suggesting that this was not driven by habitat variation between points with higher or lower volumes of traffic (Table S3).

Currently, it is not possible to identify a single environmental factor as the driver behind the observed abundance changes, which are probably driven by a combination of factors combined with the life history traits of individual species. Nevertheless, we have identified steep declines in regional populations of seven ground-nesting species in an area under high anthropogenic pressure, compared to the rest of the country. Although the estimates presented here may not be representative of Iceland as a whole, they may suggest what is to be expected with increased human impact. Currently, the area of forests, housing and agricultural fields are increasing around the country (EEA 2018, Statistics Iceland 2022, Registers Iceland 2023) at the cost of dry and wetland habitats, which are important breeding habitats of the focal species (Jóhannesdóttir *et al.* 2014). Most of these changes are taking place in lowland areas, where the vast majority of Redwings and Meadow Pipits breed, along with 85% of all Icelandic breeding waders (Skarphéðinsson *et al.* 2016, Gunnarsson 2020). The loss of open landscapes will inevitably result in habitat loss for ground-nesting birds by occupying space that could potentially have been used for breeding and/or chick-rearing. Additionally, these changes may create edge effects that further intensify the negative impacts on the abundance, species composition and behaviour of surrounding wildlife (Ditchkoff *et al.* 2006, Kociolek *et al.* 2011, DeGregorio *et al.* 2014, Wilson *et al.* 2014, Torres *et al.* 2016, D'Amico *et al.* 2018, Pálsdóttir 2022).

The Icelandic human population is growing, creating increased demand for housing, infrastructure and food production, in addition to a huge increase in tourism, so further loss of open semi-natural habitats seems inevitable (Helgadóttir *et al.* 2019, Statistics Iceland 2021). Waders are generally declining globally (International Wader Study Group 2003, Pearce-Higgins *et al.* 2017, Rosenberg *et al.* 2019), and local populations in more densely populated countries have frequently shown steep declines and even local extinctions, with attempts at restoring lost habitats or increasing densities in remaining habitats often proving unsuccessful (Melman *et al.* 2008, Bell & Calladine 2017, Bentzen *et al.* 2018). It is therefore imperative that Iceland adopts an early intervention strategy to fulfil international commitments for species and biodiversity conservation. Designating large areas of Iceland for the conservation of waders and open-habitat species, which is organized and integrated into land-use, seems essential. Additionally, further research to understand the drivers of the declines observed in this study is essential to inform conservation action and site protection policy.

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