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Short Communication

Effect of low-traffic roads on abundance of ground-nesting birds in sub-Arctic habitats

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Roads are among the most widespread anthropogenic structures, and their presence can impact biodiversity in surrounding landscapes through disturbance and collision risk, particularly when traffic volumes are high. However, the impact of roads with low traffic volumes in open landscapes is much less clear. In the open landscapes of lowland Iceland, road traffic is still relatively low but increasing, and the surrounding landscapes support internationally important populations of several breeding wader species. Here, we used transect counts perpendicular to low-traffic (≤ 15 000 vehicles day^{-1}) roads across the lowlands of southern Iceland to quantify variation in the densities of ground-nesting birds with distance from roads, and to assess how far from the roads any such effects extended. The total abundance of birds increased significantly by 6% per 50 m interval from roads, and densities within 200 m of roads were ~ 20% lower than densities between 200 and 400 m from roads. Four species – whimbrel *Numenius phaeopus*, golden plover *Pluvialis apricaria*, dunlin *Calidris alpina* and meadow pipit *Anthus pratensis* – were found in significantly lower densities closer to roads, while four – black-tailed godwit *Limosa limosa*, redshank *Tringa totanus*, snipe *Gallinago gallinago* and redwing *Turdus iliacus* – showed no change with distance from roads. Redwing was found in higher densities, and dunlin in lower densities, surrounding roads with higher traffic volumes. As approximately 20% of lowland Iceland is within 200 m of roads, the impact of roads on the overall abundance of ground-nesting birds could be substantial. The results show that even relatively low-traffic roads can have a significant impact on adjacent wildlife populations. Road construction, along with other anthropogenic structures, has been shown to have negative effects on bird abundance, and identifying areas for protection from such developments may be the most effective approach to reducing human impacts on the internationally important wildlife of lowland Iceland.

Keywords: anthropogenic changes, bird, conservation, ecology, shorebird, wader

Introduction

There is a growing body of evidence that roads can significantly alter the abundance and distribution of wildlife in surrounding landscapes (Reijnen et al. 1996, Benítez-López et al. 2010, Yoo and Koper 2017, Grilo et al. 2020). Roads differ from many other anthropogenic structures, as they are typically at ground level and can cover relatively small areas, leaving substantial patches of the original habitat still present. However, roads can reduce the amount of native habitat and induce changes in the surrounding habitats, e.g. through changes in hydrology and surrounding vegetation, along with impacts from vehicle emissions and particulate matter spreading from roads (Seiler 2001, Forman et al. 2002, Summers et al. 2011). Roads may also act as barriers in the landscape, if mobile animals are unable or unwilling to cross roads and are therefore constrained to smaller habitat patches than before the road was constructed (Seiler 2001). Roads may also influence patterns of predator distribution and activity in the surrounding habitat, for example as a consequence of barrier effects or if roads aid the access of predators into landscapes and concentrate their activity as they travel along them (Seiler 2001). In addition, collisions with vehicles can be an important cause of animal mortality (Seiler 2001, Benítez-López et al. 2010, Grilo et al. 2020). Traffic noise may also influence the communication of animals in the surrounding landscape, especially species that rely on vocalisations, for example to attract mates and/or alert others to the presence of predators (Rheindt 2003, Kociolek et al. 2011).

Traffic intensity has been shown to affect population density of animals in surrounding areas (van der Vliet et al. 2010). Birds may be particularly vulnerable to the presence of roads, as in both Europe and North America it is estimated that millions of birds die each year from collisions with cars (Trombulak and Frissell 2000, Loss et al. 2015). In addition to higher mortality rates, birds may be sensitive to the increased disturbance and habitat changes, which have been shown to affect physical processes such as stress levels, survival, vigilance and reproductive success (Trombulak and Frissell 2000, Kociolek et al. 2011, Morán-López et al. 2017). Densities of ground-nesting birds are often reduced in landscapes surrounding roads (Reijnen et al. 1997, Forman et al. 2002, Benítez-López et al. 2010, Kociolek et al. 2011). How far this effect extends from roads may vary between species (van der Vliet et al. 2010) and with road characteristics, but disturbance distances, where the density of birds is reduced, have been identified as small as 100 m from cycle paths and small roads, up to > 2 km for highways (van der Vliet et al. 2010, Thompson et al. 2015). Bird density may also be affected by traffic volume, but a study from the Netherlands found that surrounding high-traffic roads (> 50 000 vehicles day^{-1}), the disturbance distance was larger and more species showed lowered densities compared to low-traffic roads (< 500 vehicles day^{-1}) (Reijnen et al. 1996). However, a meta-analysis found no effect of traffic volume on the mean species abundance close to roads (Benítez-López et al. 2010). Hitherto, most studies on densities of ground-nesting birds surrounding roads have focused on areas where roads are large and traffic volume is high.

The Icelandic lowlands are an important breeding area for a variety of ground-nesting birds, and Iceland is a signatory to multiple international agreements under which the country has committed to protect these species (Schmalensee et al. 2013). The majority of ground-nesting birds in Iceland nest between May and June, and raise their chicks in June–July (Gunnarsson et al. 2017, Alves et al. 2019, Carneiro et al. 2019, Méndez et al. 2022), which is also a time when people, both residents and tourists, tend to travel more within Iceland. The Icelandic transportation system is currently not extensive compared to the rest of Europe (Torres et al. 2016), and traffic volume is much lower, with no roads surpassing 100 000 vehicles day^{-1}, and the majority of roads outside the capital region having fewer than 1000 vehicles day^{-1} (Vegagerðin 2024). However, traffic has been increasing steadily in recent years, driven primarily by an increasing number of tourists (Helgadóttir et al. 2019, Statistics Iceland 2021). For example, traffic on the road leading from Reykjavik to Keflavík International Airport (the major international airport in the country) increased from ~ 5000 vehicles day^{-1} in 2006 to ~ 20 000 vehicles day^{-1} in 2023 (Vegagerðin 2024). In Iceland, previous studies on the effects of roads have primarily focused on environmental impact assessments in areas prior to roads being constructed (Albertsson et al. 2004, Hreinsdóttir et al. 2006). Consequently, little is known about the effects of traffic on Icelandic biodiversity, particularly on ground-nesting bird populations for which Iceland has international responsibilities. In this study, we use transect surveys of ground-nesting birds across the lowlands of southern Iceland to quantify: 1) variation in densities with distance from roads with moderate-to-low traffic volumes (≤ 15 000 vehicles day^{-1}) and estimate how far from roads any such effects extend, and 2) the area of the Icelandic lowlands that is currently within those distances from roads.

Material and methods

Data collection

This study was conducted between 24 May and 27 June, which spans the majority of the nesting season of ground-nesting birds in Iceland and is the period when the focal species are most visible (Davíðsdóttir 2010), in the years 2018 and 2019. Transects were not conducted in wind speeds exceeding 7 m s^{-1} or during heavy rain, as these conditions have been shown to affect the activity of the target species (Hoodless et al. 2006). All transects were located in areas below 300 m a.s.l. (Fig. 1). Potential survey areas were identified by searching the Icelandic Road and Coastal Administration (IRCA) database (Vegagerðin 2019) for low-traffic roads (on average ≤ 15 000 vehicles day^{-1} in the summertime) located below 300 m a.s.l. (Fig. 1). The selected areas were then visited by car, and transect locations were randomly selected from within the areas of homogeneous semi-natural habitat that were > 100 m away from other anthropogenic structures such as houses

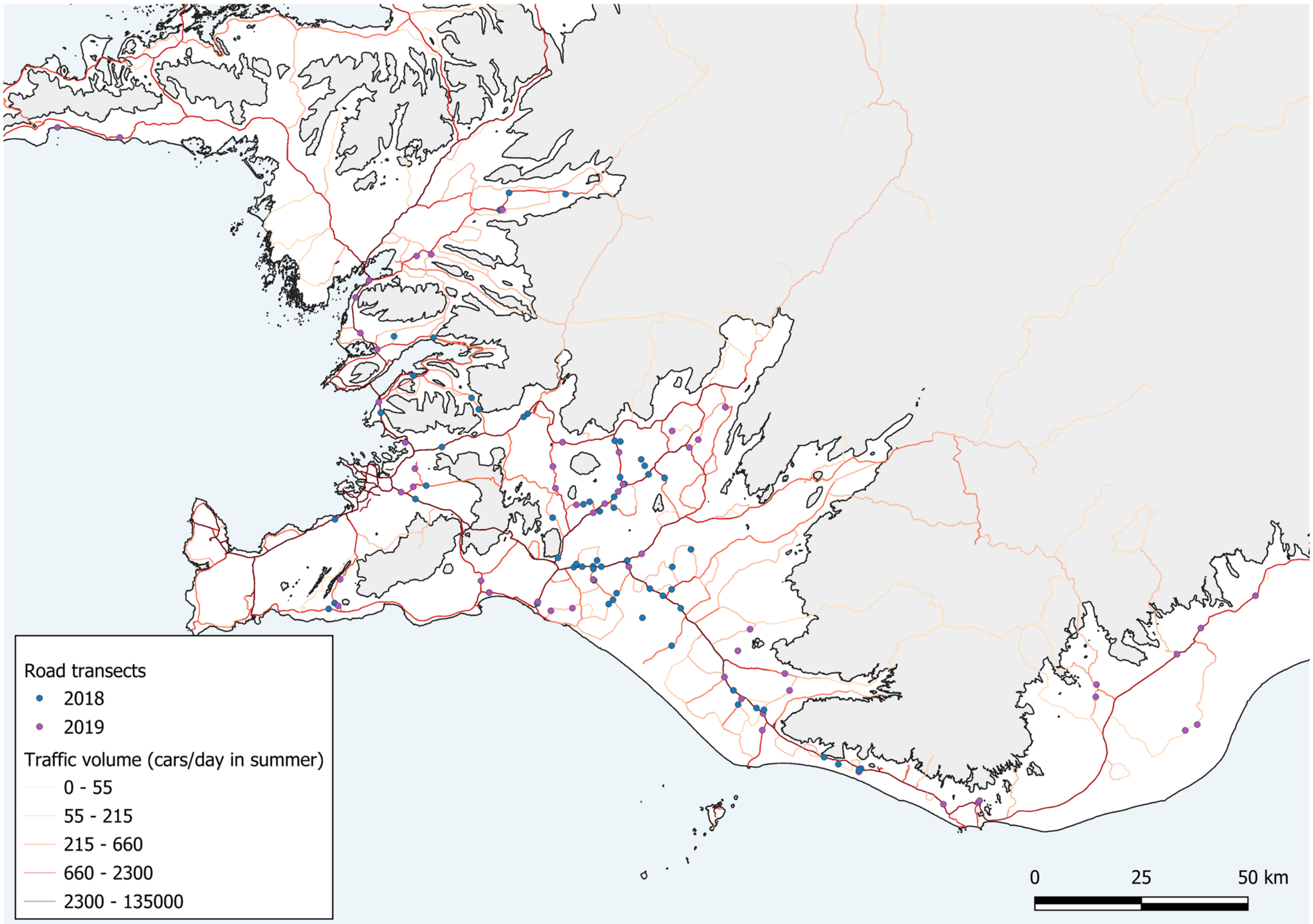

Figure 1. Locations of transects of 400 m length surrounding roads in areas below 300 m a.s.l. (shown in white) where bird counts were conducted in the summers of 2018 (blue) and 2019 (purple). All roads with traffic counters and their relative traffic numbers (average number of cars per day during June–September) are shown (data from Vegagerðin 2019).

and plantation forests (Pálsdóttir et al. 2022, 2024) and > 1 km away from urban areas (to avoid confounding effects of these structures). Roads were all single roads with two-way traffic. Transects were conducted in homogeneous habitats and each transect was in a single habitat type. Transect habitat type class was classified as wetland, semi-wetland, grassland, rich heathland and poor heathland according to the Icelandic Farmland Database (Gísladóttir et al. 2014). Subsequently count transects of 400 m perpendicular to the roads were initiated at each chosen site, starting at the road edges and walked at a steady pace. Each transect was counted once, between 06:00 and 19:00 h by one of three experienced observers. The same region of the country was monitored in both years, although each transect was only counted once. Transects each year were chosen with the aim of sampling a similar range of traffic numbers in both years (2018: mean 2274 (SD 3746) and range 40–14 612 cars day^{-1}; 2019: mean 2159 (SD 2793) and range 39–15 664) All individual birds seen within 100 m in each direction of the transect line were recorded when first seen, along with species and distance from the road, measured with a range finder. Bird locations and their behaviour were mapped to provide spatial context and avoid double-counting. Traffic volume for the start of each transect in each year (average number of cars day^{-1} during summer (June–September)) was extracted from the nearest traffic counter (distance < 1 km from each transect) from the Icelandic Road and Coastal Administration (Vegagerðin 2024). For roads without individual traffic counters, traffic volume was estimated from the nearest road of similar structure. However, this only applied to roads or tracks with very low traffic (< 300 cars day^{-1} during summer). Although the period for summer day traffic (June–September) does not match perfectly with the period the study was conducted (May–June), these numbers should give a relative estimate of traffic volume in each area, assuming the road use is similar throughout the study and traffic-counting period.

Statistical analysis

All transects were divided into intervals of 50 m, and subsequently bird abundance – both on a species level and combined for the most abundant species (Supporting information) – was used as a response variable in a generalized linear mixed model (GLMM) with a Poisson distribution. In the model, which contained multiple species, species was

Table 1. Variables included in the models and structures of models exploring the variation in densities of ground-nesting birds along transects perpendicular to roads in lowland Iceland.

Variable	Unit	Definition
Bird abundance	Birds ha^{-1}	Total number of birds counted per interval (1 ha)
Interval	1–8	Distance bands of 50 m on transects from closest 1) to furthest away 8) from roads. Measured with a GPS tracker.
Transect	Transect number	Transect identity
Traffic	Vehicles day^{-1}	Traffic on the road (range 39–15 664) corresponding to each transect (Vegagerðin 2019).
Habitat	Poor heathland/rich heathland/grassland/semi-wetland/wetland	Classification of transect habitat type, from the Nytjaland database (Gísladóttir et al. 2014)
Model structure		
Model A	Bird abundance ~ Interval × Traffic + Year + (1|Habitat/Transect)	
Model B	Bird abundance ~ Interval + Traffic + Year + (1|Habitat/Transect)	
Model C	Bird abundance ~ Interval × Traffic + (1|Habitat/Transect)	
Model D	Bird abundance ~ Interval + Traffic + (1|Habitat/Transect)	
Model E	Bird abundance ~ Interval + Year + (1|Habitat/Transect)	
Model F	Bird abundance ~ Traffic + Year + (1|Habitat/Transect)	
Model G	Bird abundance ~ Interval + (1|Habitat/Transect)	
Model H	Bird abundance ~ Traffic + (1|Habitat/Transect)	
Model I	Bird abundance ~ Year + (1|Habitat/Transect)	
Model J	Bird abundance ~ 1 + (1|Habitat/Transect)	

included as a random factor, as the sample size and response to roads may differ between species. As bird densities were low, the majority of intervals had a value of 0, and R package 'glmmTMB' was used to add a zero-inflation parameter to all models (*ziformula* = ~ *1*) (Brooks et al. 2017). Nine models were constructed, along with a null model, using all combinations of distance from roads (interval), traffic volume and an interaction term between them to estimate if changes in bird densities vary with traffic volume. Year was also included as a fixed effect to account for the effects of varying bird abundance between years (Table 1). Transect number nested within habitat type was included as a random factor to account for non-independence of intervals within the same transect and transects within each habitat. The constructed models were subsequently compared, and the model with the lowest AIC value was chosen (Supporting information), when it provided a significantly better fit (ΔAIC $\geq$ 2) than a more parsimonious model (Sutherland et al. 2023).

To explore how far any effect of roads on abundance of ground-nesting birds reaches, segmented linear regression with total bird abundance as a response and interval as predictor was subsequently used to identify distances from roads over which densities changed before plateauing (Muggeo 2008).

Road coverage in the Icelandic lowlands

In an attempt to estimate how much of the Icelandic lowlands are currently affected by roads, three buffers (50, 100 and 200 m) were placed around all roads below 300 m a.s.l. using ArcGIS and percentage cover calculated.

Results

In total, 1887 individuals belonging to 20 species were counted on 121 transects: 60 transects in 2018 and 61 in 2019 (Fig. 1; Supporting information). Approximately 93% of individuals counted belonged to eight species: common redshank, redwing, European golden plover, black-tailed, dunlin, Eurasian whimbrel, common snipe and meadow pipit, which were retained for the statistical analysis (Supporting information). Traffic volume ranged from 39–15 644 cars day^{-1} (mean 2216 cars day^{-1} (SD 3309)) in summer (Supporting information).

The total abundance of the eight bird species combined increased with distance from road by 6% per 50 m interval (Table 2, Fig. 2). Densities of four of the species (whimbrel, golden plover, dunlin and meadow pipit) increased with distance from roads, while the other four showed no effect (godwit, snipe, redwing and redshank; Fig. 2). Meadow pipit showed the smallest increase (~ 4% increase per 50 m interval), and whimbrel the largest (~ 24% increase per 50 m interval; Table 2). Additionally, densities of dunlin declined significantly with traffic volume, and densities of godwit and snipe were lower on the transects surveyed in 2019 compared to those in 2018 (Table 2). Redwing abundance increased with traffic.

Segmented linear regression indicated a breaking point in total abundance of the eight species between 150–200 m (interval 4) away from the road, after which bird numbers plateaued (mean ± SE: birds km^{-2} within 200 m = 161 ± 6; beyond 200 m = 200 ± 7).

From the buffers surrounding roads we see that 5.2% of lowland Iceland is within 50 m from roads, 9.6% within 100 m and 17.4% within 200 m from roads.

Discussion

In the Icelandic lowlands, road construction is rapidly expanding into areas previously unaffected by anthropogenic structures. Most of these roads have relatively low

Table 2. Estimates from best GLMMTMB models on the effects (± SE) of distance from roads (interval), traffic volume and year on densities of birds of eight species, separately and all combined. Significant effects are indicated with letters ($p < 0.05^{A}$; $p < 0.01^{B}$; $p < 0.001^{C}$). Transect ID nested in habitat was included as a random factor in all models and species was also included as a random effect in the model for total bird abundance for which variance (± SE) is given. Model selection is shown in the Supporting information.

	All birds	Whimbrel	Dunlin	Golden plover	Meadow pipit	Godwit	Redshank	Snipe	Redwing
Model	G	G	D	G	G	I	J	I	H
Intercept	−2.14 (± 0.28)	−3.38 (± 0.30)	−3.16 (± 0.49)	−3.16 (± 0.36)	−0.63 (± 0.10)	−1.89 (± 0.56)	−3.00 (± 0.40)	−0.32 (± 0.26)	−3.66 (± 0.35)
Interval	0.06 (± 0.01)^{C}	0.22 (± 0.04)^{C}	0.12 (± 0.04)^{B}	0.09 (± 0.04)^{A}	0.05 (± 0.02)^{B}				
Year						−0.61 (± 0.30)^{A}		−0.54 (± 0.15)^{C}	
Traffic			−0.24 (± 0.09)^{B}						0.10 (± 0.05)^{A}
Habitat	0.03 (± 0.18)	0.07 (± 0.26)	0.59 (± 0.77)	0.24(± 0.49)	1.86×10^{-9} (± 4.30×10^{-5})	0.48 (± 0.69)	0.52 (± 0.72)	0.07 (± 0.26)	1.72×10^{-9} (± 4.15×10^{-5})
Transect:habitat	0.13 (± 0.36)	0.72 (± 0.85)	1.18 (± 1.09)	0.64 (± 0.80)	0.21 (± 0.46)	0.85 (± 0.92)	1.09 (± 1.04)	0.30 (± 0.54)	2.35 (± 1.5)
Species	0.53 (± 0.72)								

traffic volumes (≤ 15 000 vehicles day^{-1}) compared to more densely populated countries (Torres et al. 2016, Vegagerðin 2024). However, our findings show that even these low-traffic roads impact birds in the surrounding landscapes, with overall densities ~ 20% lower within 200 m of roads, compared to further away. The reduced densities were primarily driven by three wader species (dunlin, whimbrel and golden plover) and one passerine (meadow pipit), all of which declined significantly closer to roads, and for dunlin densities also declined with increasing traffic volume. These reduced densities in the surrounding landscapes, in addition to the loss of habitat resulting from road construction, suggest that the cumulative impacts of building roads in these open habitats can be significant. Given that ~ 17% of lowland Iceland lies within 200 m of roads, the impacts are also likely to be widespread and substantial.

The main road in Iceland, which surrounds the island, is 1322 km long and traffic speed is limited to 90 km hour^{-1}. Causes of reductions in densities of ground-nesting birds close to roads could include high rates of mortality from vehicle collisions, as bird carcasses were often encountered on roads during this study. Birds may also avoid roads because of traffic noise and human presence, particularly if cars stop frequently as is often the case for tourist-based traffic in Iceland and, as the roads are generally slightly elevated with adjacent ditches or fences, they may also reduce visibility of approaching predators or other sources of disturbance. Although little is currently known about predator distribution in Iceland and how it may be related to roads and other anthropogenic structures, predator activity and abundance may potentially be affected by roads, which could result in higher or lower predation rates. Additionally, roads may alter the surrounding vegetation structure, e.g. by drainage and protection from grazing by livestock, which can encourage taller vegetation on road verges, which are generally not used by most of the study species.

Whimbrel and golden plover usually nest in open areas and the nest has little if any concealment (Laidlaw et al. 2020). These species may therefore rely on having good visibility around the nest to reduce the risk of predation on eggs or incubating adults, which could explain why their densities are particularly reduced close to roads, which are elevated and may limit the view of individuals on the nest. Among the species that conceal their nests in vegetation, only dunlin had reduced densities close to roads, while godwit, redshank and snipe showed no effect of distance to roads. Species that hide their nest in tall vegetation may be less likely to show an effect of distance to roads as they rely less on visibility around the nest than open nesting species. Dunlin in lowland Iceland are most frequently found in wetland habitats, while the other nest-concealing species occur in a wider range of habitats including grasslands and agriculture (Laidlaw et al. 2020, Jóhannesdóttir et al. 2014). The drainage associated with road construction may therefore make the immediate surrounding habitat particularly unsuitable for dunlin, which were found in the overall lowest densities in the first interval (0–50 m from roads). It is possible this may also affect

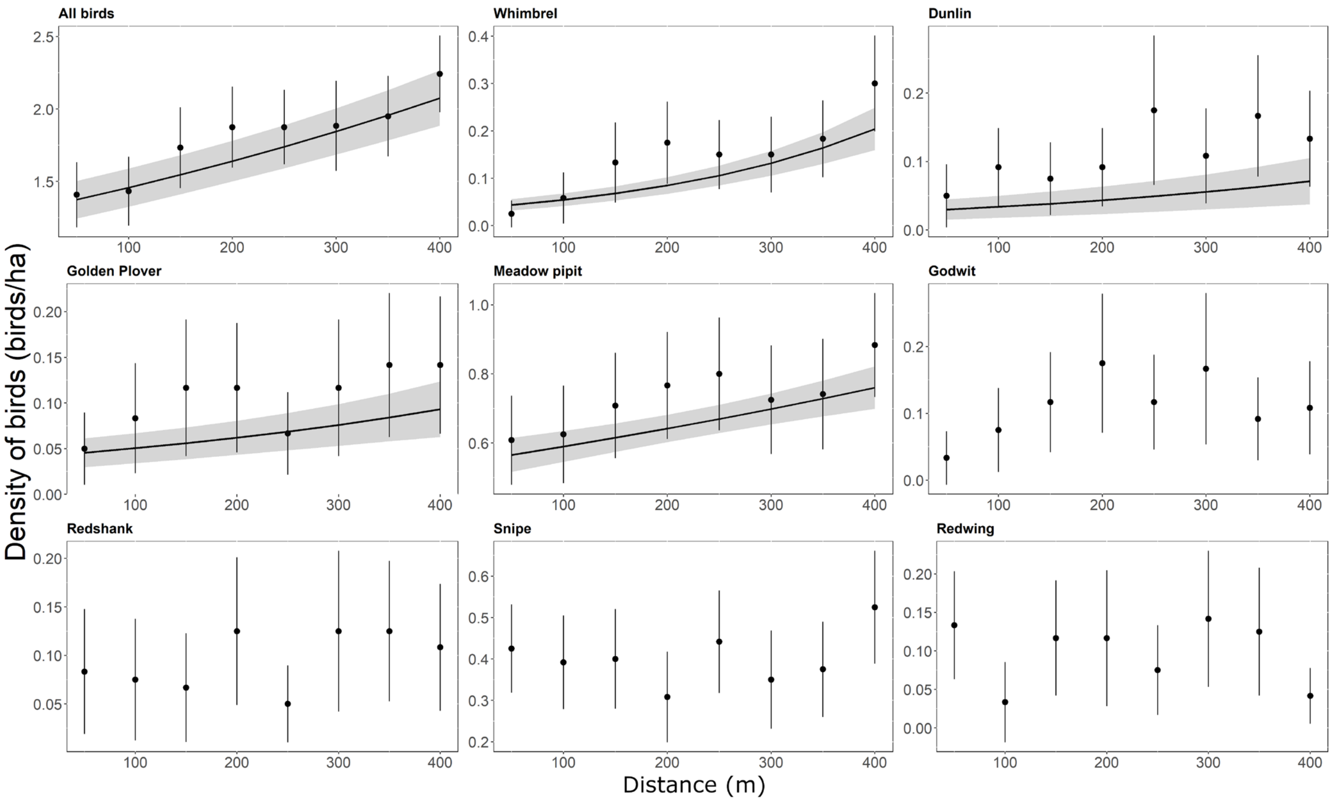

Figure 2. Mean (± SE) numbers of birds at 50 m intervals with increasing distance from roads for the eight most abundant species, combined and individually. Lines represent model predictions (± SE) and are shown for species with significant trends (Table 2). Currently 5.2% of lowland Iceland is within 50 m from roads, 9.6% within 100 m and 17.4% within 200 m from roads.

redwing densities, which were higher surrounding roads with higher traffic volume. Redwings have been shown to be in higher densities surrounding both summer houses and forests in Iceland (Pálsdóttir et al. 2022, 2024). It is possible the elevation of the roads or associated structures, and possibly taller vegetation on road verges, attracted more redwings, but these features are usually more prominent on roads with higher traffic volume. However, as all roads in the habitats in the study require some modification of the immediate surroundings, the vegetation structure in the 1–2 m next to the road is often slightly different from the rest of the transect.

Both godwit and snipe were found in lower densities in 2019 as compared to 2018. This aligns with studies from the same area which show the results of bird counts in the area from 2011 to 2024 (Pálsdóttir et al. 2025a). These yearly fluctuations are a common pattern in Iceland due to weather conditions between years which can affect the nest survival and hence visibility of certain species.

Although the study presents important results on how low-traffic roads can negatively affect bird densities in the surrounding areas, there are some caveats. The period for which summer day traffic is estimated (June–September) does not match exactly with the study period (May–June), although there is considerable overlap. However, these traffic numbers are a good indicator of relative traffic volume on each respective road. Because of this, the estimates of traffic volume may not be precise and should be considered as a relative rather than an exact measure. Similarly, the numbers of birds presented here do not give an accurate estimate of total abundance, as variation in species' visibility is not incorporated in the analyses (Supporting information).

The introduction of anthropogenic infrastructure into open landscapes can have considerable negative effects on ground-nesting birds in the surrounding landscape (van der Vliet et al. 2010, Thompson et al. 2015, Fernández-Bellon et al. 2018, Pálsdóttir et al. 2024). In an effort to reduce potential bias from other anthropogenic structures, transects were always > 100 m away from such structures. Previous studies have shown that the influence of various structures on bird densities may extend beyond this distance (Benítez-López et al. 2010, van der Vliet et al. 2010, Thompson et al. 2015), which could cause a potential bias in our data. However, this would only be relevant if the direction of the effect was always in the same direction, i.e. if all the structures were at the end or beginning of the transect. Additionally, transects were always > 1 km away from urban areas, which are likely to have a large effect on bird densities and species composition (van der Vliet et al. 2010).

Iceland has overall one of the lowest densities of transportation infrastructure in Europe (Torres et al. 2016), and consistently low traffic volume, with roads outside of the capital region primarily being single-track format. However, the majority of roads are currently situated in the Icelandic lowlands, and the majority (~ 85%) of the estimated

~ 1.5 million pairs of waders in Iceland breed in the lowlands (Skarphéðinsson et al. 2016, Gunnarsson 2020). Considering that the effects of roads extend up to 200 m into the surrounding landscape, 17.4% of Iceland's lowlands already fall within this distance from a road. Assuming bird densities are 20% lower within this zone compared to areas further away, overall bird abundance in lowland Iceland may already be reduced by approximately 3.5% due to proximity to roads, a figure that is likely to increase as the road network expands. As road construction along with other anthropogenic structures, such as power-lines, houses and associated planting of non-native trees have been shown to have negative effects on bird abundances (Pálsdóttir et al. 2022, 2024), identifying (large) areas for protection from all such developments may be the most effective approach to reducing human impacts on the internationally important wildlife of lowland Iceland.

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Author contributions

Aldís Erna Pálsdóttir: Conceptualization (equal); Data curation (equal); Formal analysis (equal); Funding acquisition (equal); Methodology (equal); Writing – original draft (equal). **Jenny A. Gill**: Conceptualization (equal); Funding acquisition (equal); Project administration (equal); Supervision (equal); Writing – review and editing (equal). **José A. Alves**: Conceptualization (equal); Supervision (equal); Writing – review and editing (equal). **Snæbjörn Pálsson**: Conceptualization (equal); Supervision (equal); Writing – review and editing (equal). **Verónica Méndez**: Conceptualization (equal); Formal analysis (equal); Writing – review and editing (equal). **Böðvar Þórisson**: Conceptualization (equal); Data curation (equal); Writing – review and editing (equal). **Tómas G. Gunnarsson**: Conceptualization (equal); Funding acquisition (equal); Investigation (equal); Methodology (equal); Project administration (equal); Supervision (equal); Writing – review and editing (equal).

Transparent peer review

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Data availability statement

Data are available from the Dryad Digital Repository: https://doi.org/10.5061/dryad.qfttdz0w5 (Pálsdóttir et al. 2025b).

Supporting information

The Supporting information associated with this article is available with the online version.

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