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Research article

Quantifying the effects of road-building on bird communities before and after activities

Yiming Deng[a,*], Juan D. Delgado[b], Yanina Benedetti[a], Federico Morelli[a,c]

[a] Czech University of Life Sciences Prague, Faculty of Environmental Sciences, Kamýcká 129, Prague 6, CZ-165 00, Czech Republic
[b] Ecology Area, Dept. of Physical, Chemical and Natural Systems, Univ. Pablo de Olavide, Ctra. de Utrera Km.1, E-41013, Seville, Spain
[c] Department of Life Sciences and Systems Biology, University of Turin, Via Accademia Albertina 13, 10123 Turin, Italy

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ABSTRACT

Urbanization with a rapid expansion of the road network disrupts ecological processes, fragmenting the landscape, and reducing biodiversity. The frequent machine and human activities involved in road construction led to significant pressure on ecosystems. However, research on the impact of roading building processes in different stages remains lacking information. We performed a bird census for a new highway construction, the SE-40 ring road in Seville, with three-stages: a) active works, b) suspended works stage surrounding, and c) control stage in a natural condition. We analyzed similarities in community composition and bioindicators using the Indicator Value (IndVal) analysis between different stages. Additionally, we calculated several avian biodiversity metrics, including bird species richness, abundance, biodiversity, and diet-specialist species richness (DSR) and abundance (TAB). Road construction significantly impacted species composition (NMDS, ANOSIM $p < 0.001$, $R^2 = 0.1692$); both active (P. adjusted = 0.006) and suspended work (P. adjusted = 0.009) stages display differences compared to the control group. The number of species and bioindicator increases, but diet-specialist species decreased, from active works (bioindicator = 3; mean TAB = 6; mean DSR = 19) to control group (4; 4.89; 12.61) to suspended works (5; 5.67; 14.89), reflecting a higher homogeneity during the active works with lowest biodiversity (mean Shannon = 2.69 and Simpson = 0.92). Our findings highlight the overlooked value of suspended works as provisional habitats for bird assemblages, suggesting that areas with intensive human activity need specific biodiversity monitoring and implications for conservation efforts. Rigorous specific biodiversity monitoring is essential to mitigate long-term impacts and inform adaptive road planning strategies.

1. Introduction

1.1. Impact of roads on ecosystems

Urbanization in the 21st century is characterized by the rapid and poorly planned urban expansion and road management has resulted in considerable land use change, seriously threatening current global biodiversity (Urban et al., 2024), and disrupting various ecological processes (Martínez-Núñez et al., 2023; Morelli et al., 2023). Compared to other processes of urbanization, the expansion of the road network is one of the fastest and transformative human activities on the landscape (Fahrig, 2003; Haddad et al., 2015; Shen et al., 2022). The road network provides an essential link between urban areas and keeps supply chains operational, boosting economical fluxes (Bettencourt and West, 2010; Strano et al., 2012), but keeps supply chains operational, boosting economical fluxesconstruction and expansion pose significant environmental challenges (Quintana et al., 2022; Rezvani et al., 2024). The process of road construction involves extensive land reclamation (Laurance and Balmford, 2013), including the removal of vegetation (Barber et al., 2014; Silva et al., 2023), earth-moving processes, and the installation of infrastructure (Tarolli and Sofia, 2016), all the stages bring different kinds of threats to ecosystems. The construction stage is particularly detrimental (Ametepey and Ansah, 2014; Oke et al., 2021), as it brings in high levels of noise (Madadi et al., 2017), dust, and pollution (Xu et al., 2023), as well as more frequent machinery use and continued human activity (Cervantes-Huerta et al., 2022). All different road construction stages exacerbate varying degrees of ecological stress, including direct mortality by collision and other disturbances that lead to disease (Laurance et al., 2014), as well as indirectly changing species behaviours and traits, in a context of habitat degradation (Johnson et al.,

* Corresponding author.
E-mail addresses: yiming_deng@yeah.net, dengy@fzp.czu.cz (Y. Deng).

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2022; Summers et al., 2011).

1.2. Importance and negative effects of road networks on birds

Birds are often used as indicator species to reflect ecosystem changes (Fraixedas et al., 2020; Kociolek et al., 2011), because of their vulnerability to environmental change and their significant roles in ecosystem services (Whelan et al., 2008). They have high mobility, with greater movement frequencies and larger activity ranges compared to other species. This variation depends on factors such as bird size, reproductive behavior, migratory patterns, and seasonal habitat requirements. Additionally, birds can disperse across larger habitats and are more susceptible to the impacts of infrastructure, making them more likely to overlap with areas affected by roads (Cooke et al., 2020).

The construction and utilization of road networks have been shown to have severe negative impacts on bird species and biodiversity (Benítez-López et al., 2010; Kroeger et al., 2022). Road construction introduces a range of disturbances, including noise, light, chemical pollution, and subsequent utilization, as well as direct vehicle collisions, all of which can negatively impact bird populations (Kociolek et al., 2011). Birds are disproportionately affected by road noise compared to other taxa, as they heavily rely on a viable sound environment for communication (Bottalico et al., 2016; Kociolek et al., 2011), such as territorial announcements, mate attraction and alerts (Laurance, 2015), and traffic noise tends to mask these signals resulting in a significant reduction in the efficiency of mating, foraging and predator alerts (Parris and Schneider, 2009). Bird communities have a larger road-effect zone than mammals, over a far greater distance up to 500–700 m (de Jonge et al., 2022). During active road construction, tree canopy and shrub removal transform closed habitats into open environments, amplifying acoustic and visual disturbances and increasing habitat vulnerability (Lalventluanga, 2019). Once completed, roads contribute to long-term biodiversity loss through habitat fragmentation and vehicle collisions (González-Suárez et al., 2018; S. M. Santos et al., 2016), particularly birds are more vulnerable due to reliance on continuous cover for key life processes (Cooke et al., 2020; Johnson et al., 2022; Kociolek et al., 2011). At various stages of road construction, disruptions significantly contribute to the decline of bird populations, as many species find it challenging to adapt to the altered environment. It is essential to conduct a thorough quantitative analysis that highlights the ecological costs of road infrastructure in urbanization. Furthermore, incorporating conservation measures into urban development planning is crucial for protecting our wildlife.

1.3. Research gaps in the impact of road construction process on biodiversity

Road impact is a long-term and cumulative group of processes, so exhaustive, project-specific biodiversity inventories and quantification should be mandatory from preoperational construction and operative in operational phases (Wu et al., 2023). Ecological studies are currently focused on the effects of completed and operative roads, while the frequent and intense influence of human activities during the construction process and the detailed impact of direct, large-scale destructive acts are often overlooked (Kaja and Goyal, 2023; Li et al., 2022; Oke et al., 2021). Such a baseline survey is crucial for evaluating future biotic changes in the project basin.

In addition, until now, there has been a lack of information regarding the effects of road-building on avian communities. Monitoring is also essential for limiting environmental costs and for making decisions in the environmental impact assessment (EIA) processes of new infrastructure projects, especially because it is relatively easy to quickly carry out an inventory in the field (Mäkeläinen and Lehikoinen, 2021).

In fact, in environmental impact studies, there is a general lack of data on road construction's "real" impacts on bird communities. Although the potential impacts of road construction on ecosystems have received widespread attention, existing research has generally focused on the impacts of roads on plant communities (Dawazhaxi et al., 2023; Rotholz and Mandelik, 2013), arthropods (Torres-Romero et al., 2020), and mammals (Barrientos et al., 2021; Estrada et al., 2017), while the actual impacts on bird communities have been relatively scarce (Barrientos et al., 2021), with large gaps in understanding the specific impacts on bird communities during road construction (Wu et al., 2023). In particular, what has not been fully explored is the impact of construction activities on bird communities during both the construction phase and the recovery period following construction completion. This lack of information limits our full understanding of the impact of road construction on bird communities at different stages. Filling this knowledge gap is critical to developing effective environmental protection policies, optimizing road construction processes, and preserving biodiversity.

1.4. Study objectives, hypotheses, and analytical scope

This study aims to fill gaps in existing research by providing empirical data on the impact of road construction on bird communities through systematic survey data. We hypothesized that (a) Road construction involves substantial changes in bird communities when comparing these assemblages between different road project phases and with a control area as far as possible from road effects, and (b) the road corridor under construction can still shelter significant bird biodiversity. Evaluation of bird assemblages in habitats affected by road construction helps to understand the environmental impact of roads. By comparing bird biodiversity and community changes at different stages of road construction, we expect to provide strong data support for future research and environmental management practices.

2. Methods

2.1. Field data and avian diversity

2.1.1. Study area

The SE-40 ring road, located in Seville around the city, has a total length of 77.6 km. Work on SE-40 started in 2011 and is scheduled to continue until 2030. The sections located to the southwest and southeast have been opened, leaving three large sections to be completed in the northwest and north, and the closure of the southern arch sections. The SE-40 ring highway is being constructed to serve as a metropolitan traffic distributor around the city of Seville and to fulfill other connecting functions at the national and regional levels. Construction began in May 2007, with a total planned length of approximately 77.6 km. The proposed layout features two carriageways with 2–3 lanes per direction, each 3.5 m wide, and a median of 10–20 m wide, allowing for potential road expansion to a fourth lane. The outer shoulders are 2.5 m, and the interiors are 1 m wide. The berms average 2 m wide. The total surface area for the platform occupation is approximately 44 m wide, not counting slope marginal areas. The route was designed for a speed of 120 km/h.

The construction suffered several delays and suspensions in different sections, a circumstance that allowed large segments of the road to remain abandoned and to be provisionally colonized by vegetation, hence serving as habitats for birdlife. Along the road corridor, temporary small ponds attracted a diverse array of birds from the surrounding areas that would not have been recorded in the project basin otherwise. The official Environmental Impact Statement (EIS) states that the effects on fauna, particularly birds, will be minimal due to the predominance of heavily anthropized environments. However, it also recognizes that in some SW sections, the works and operation of the SE-40 may be impacting, with variable intensities, bird communities associated with riverine and riparian habitats, as well as some steppe species and raptors along the Guadalquivir basin and its tributary, the Guadaira River. A more detailed study of the foreseeable effects on the entire bird community can be beneficial for better integrating the infrastructure into the affected ecosystems. We conducted a bird survey at eight sites, divided into three stages (suspension of construction, resumption of construction, and non-constructive or control areas), around and directly on the SE-40 route as well as in the control group far from the road's effect (Fig. 1).

2.1.2. Data collection

We collected data on bird species composition and abundance through variable length foot itineraries along the SE-40 route segments under construction (suspended works stage) (see Fig. 2), alongside the margins and berms of the route once works were fully reinitiated (2016), and at two control sites relatively unaffected by nearby roads (see in Figs. S1 and S2). These control sites, named "Cerro del Alcor/Mesa del Gandul" (near the elevation called Cerro del Toruño) and "Hacienda Torre de Quinto", were selected in ecologically similar areas to that were affected by the construction of the SE-40, except that in Cerro del Alcor, remnant patches of wild olive trees (*Olea cerasiformis*) and native palms (*Chamaerops humilis*) are still preserved. The control sites were also located as far away as possible from urban centers with respect to the studied segments of the SE-40, located in and around the "Hacienda Torre Doña María" property. We used the approach of the MacKinnon lists (ML), or the species lists technique (MacLeod et al., 2011) to carry out rapid inventories of the avifauna to maximize data capture for biodiversity monitoring in a rapidly changing environment, such as a road under construction. We aimed to collect as much bird data as possible and as quickly as possible in the three treatments before the works resumed. Surveys were carried out in February–March in 2015 and February–May in 2016, in this case after the resumption of constructive road works (see Fig. 2); every site was surveyed at least twice yearly. To account for interannual differences in sampling effort, we applied rarefaction analysis as an unbiased method (using a bootstrapping estimator) to assess species richness from potentially incomplete taxonomic inventories. With this approach, we aimed to identify both common and uncommon species that may be of conservation concern. Bird counts started in the early morning and lasted for 3–4 h, using 8x binoculars. All bird data were taken by only one observer: Juan D. Delgado (see Table S1).

2.1.3. Data analysis

We counted the number of bird species richness (SR) and total abundance of birds (TAB) at each site (Willis, 2019). We calculated the Simpson index to quantify the biodiversity of habitat communities in each site, considering both species richness and evenness, using the

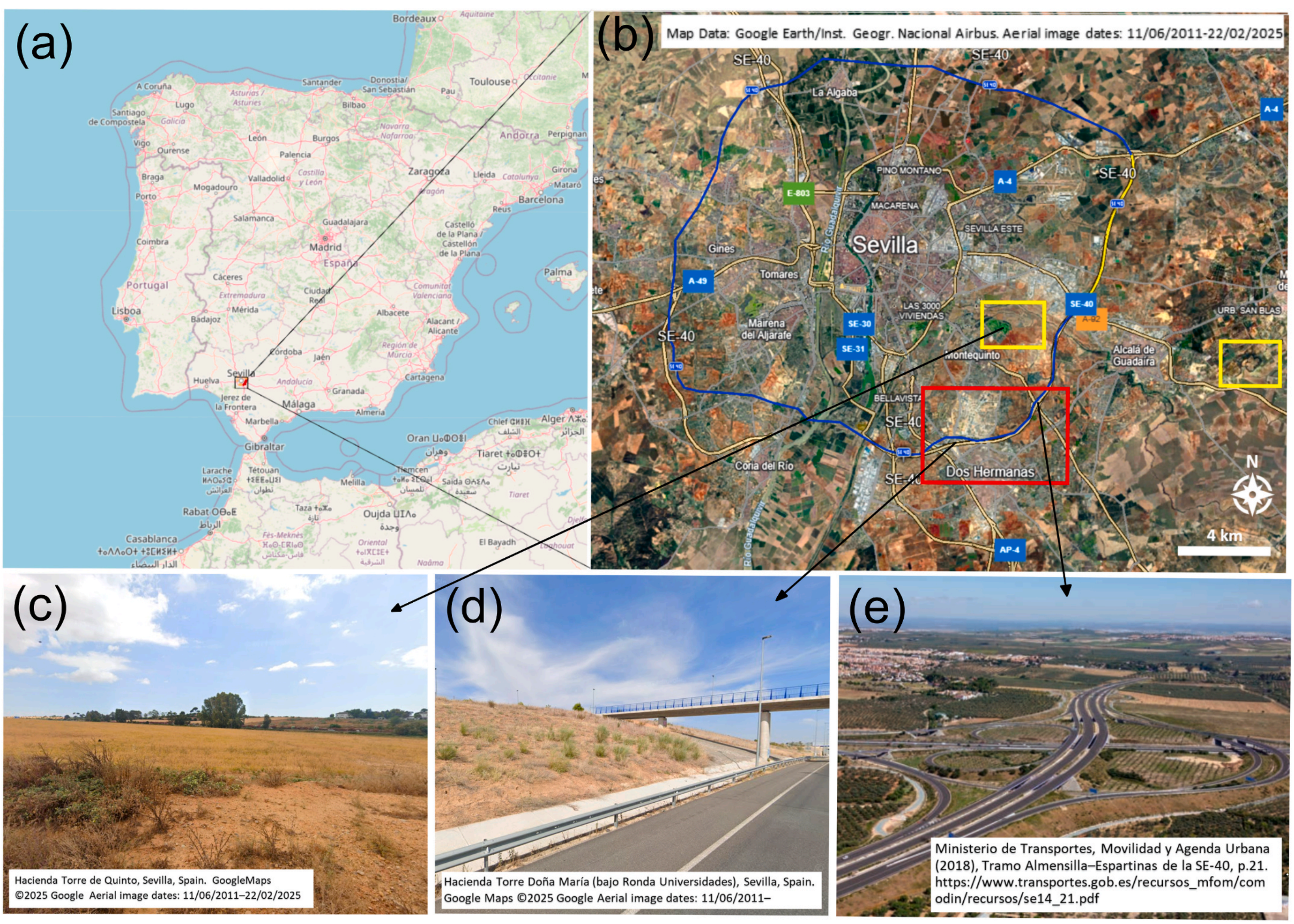

Figure_1. Map of the study area in the SE-40 ring road in Seville. (a) National-level overview of Spain with the study region (data from the OpenStreetMap, and R package "osmextract"); (b) Regional map of the SE-40 motorway and designated sectors marked (The route of the highway (both planned and already built) is highlighted in blue. The Yellow squares indicate bird census areas. Red square: main road corridor, SE of the Seville city. Yellow squares: "control" areas not affected by roadworks, SE of Seville. Data attribution: Google Earth and Inst. Geogr. Nacional Airbus. Aerial image dates: 11/06/2011-22/02/2025.); (c–d) Photographs from field sites within control areas (c: Hacienda Torre de Quinto) and the roadworks (d: Hacienda Torre Doña María (bajo Ronda Universidades)). Data attribution: GoogleMaps. 2025 Google Aerial image dates: 11/06/2011–22/02/2025; (e) View of the SE 40, showing the location of the A 49 junction on the Almensilla–Espartinas section. Source:Ministerio de Transportes, Movilidad y Agenda Urbana (2018), Tramo Almensilla–Espartinas de la SE-40.

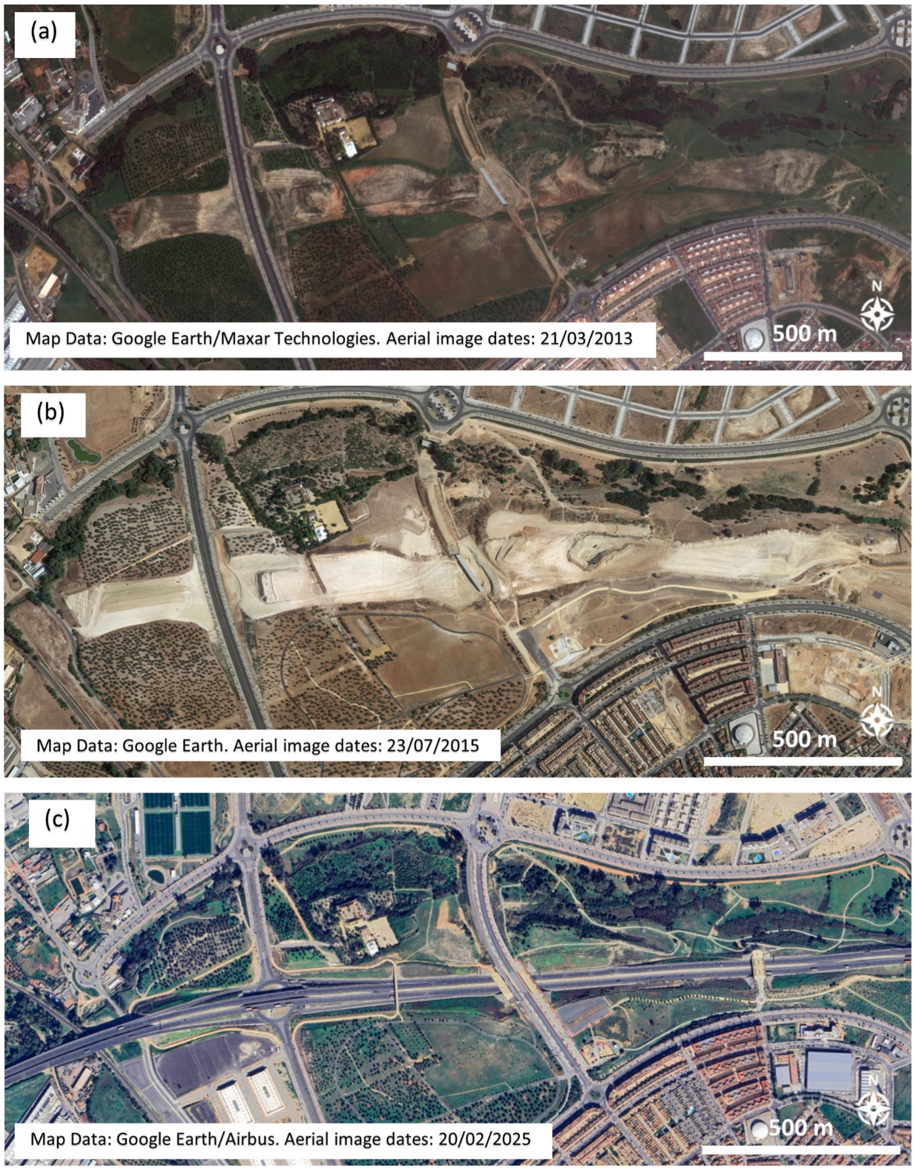

Figure_2. Sequence of aerial photos showing road corridor during the suspension of works phase (a), initial resumption of works (b), and fully operational stage (c) for the SE-30 ring road of Seville in the main bird study area of the affected zone.

package "vegan" (Oksanen et al., 2024). We plotted species richness curves for the treatments and study sites based on the rarefaction analysis (Willis, 2019).

We estimated the degree of ecological specialization in the communities using the Gini index of inequality with multidimensional dietary species traits (Cowell, 2011; Devictor et al., 2010; Gini, 1921). The dietary items were extracted from a published dataset with such information for all birds, named "Eltonian'' niches of species (Wilman et al., 2014). The values of diet specialization ranged from nearly 0 (e.g., generalist species) to 1 (e.g., diet specialist species) (Morelli et al., 2021). The Gini index is the most widely accepted indicator of inequality globally, initially applied in economics, and in the last decade, widely used in ecology (Roberts, 2019),e.g., in habitat conservation areas and characterization in botany and zoology (Morelli et al., 2020; Wang et al., 2024). The Gini coefficient was calculated using the package "DescTools" (Signorell, 2024). Then, we estimated the number or richness of 'specialist' species in each assemblage for each stage of road construction (e.g., active works, suspended works, and control sites).

2.2. Statistical analysis

To evaluate the influence of road activity, we compared the differences in the composition of birds between groups and within groups in each stage of road construction (e.g., active works, suspended works, and control groups), using the package "vegan.

We applied Multidimensional Scaling (MDS) (Jaworska and Chupetlovska-Anastasova, 2009) to display the community ecology graphically for each site, based on a robust, unconstrained ordination method, visualizing similarities or differences between sites through the spatial arrangement of samples (Demaine et al., 2021). MDS is a statistical technique for visualizing data by mapping high-dimensional distances to a low-dimensional space while maintaining the original distances as closely as possible (Demaine et al., 2021; Živadinović, 2011). Our MDS used Bray-Curtis dissimilarity as a similarity metric to construct similarity matrices from species abundance data, which were mapped to a two-dimensional space using classical MDS and Euclidean distance matrices (Dann et al., 2018; Galand et al., 2018; Somerfield et al., 2021a). This approach allows for an initial assessment of clustering patterns. It provides a visual representation for exploring associations between bird communities under the three stages examined in this study.

Additionally, we used ANOSIM (analysis of similarity) for comparisons to statistically test for similarity between and within stage groups to assess significant differences between groups to offset a certain degree of subjectivity possible in the interpretation of the MDS results (Baldwin et al., 1998; Warton et al., 2012). We calculated distance matrices and r-statistics based on species abundance data using the Bray-Curtis distance matrix (Somerfield et al., 2021a). ANOSIM assessed whether the differences observed between groups were greater than expected by chance, with R-value indicating the strength of separation between groups and the relative variability of between and within-group distances within each group. R-values ranged from −1 to 1, where a positive value indicates that the between-group difference is greater than the within-group difference (Chapman and Underwood, 1999). A 999 permutation test assessed statistical significance to confirm the robustness of the observed differences. ANOSIM was especially valuable for assessing whether observed differences in community composition were statistically significant, complementing the visual insights from MDS by providing rigorous statistical validation (Morelli et al., 2019; Somerfield et al., 2021b). Based on significant between-group differences in the condition, we conducted a pairwise multiple comparison analysis considering Bonferroni adjustments to the p-values in the results to control for false-positive rates (Martinez Arbizu, 2020).

We also used the function adonis2 as a more robust support, compensating for the possibility that the ANOSIM analysis may confound differences between groups and dispersion within groups that are hard to interpret (Anderson, 2001; Stevens and Oksanen; Warton et al., 2012). The adonis2 is a framework for ranking-based multivariate analysis of variance techniques to assess group differences in community data and to quantify the influence and contribution to community variance of explanatory variables, i.e., species (Warton et al., 2012). The adonis2 quantifies the relative importance of each variable by fitting a model with multiple explanatory variables, in which we assessed the degree of variance in community composition explained by different species richness using distance matrices computed from Bray-Curtis dissimilarity (Anderson, 2001; Mcardle and Anderson, 2001). The R^2 value was calculated to quantify the proportion of variance explained by each explanatory variable, which ranges from 0 to 1, with a value closer to 1 indicating that the explanatory variable explains more of the community structure (Legendre et al., 2011). The statistical significance of the model was assessed by a permutation test p-value, with 0.05 as the threshold of significance, and less than 0.05 indicating that the explanatory variables have a significant effect on community structure. The adonis2 has a more systematic treatment of the modelling assumptions and explanatory variables of the data, and this approach can provide a detailed analysis of how the explanatory variables, by species, affect the community structure variation in different road stages.

Finally, we used the Indicator Value (IndVal) analysis to provide evidence for the impacts of road construction activity in a species-level analysis and to measure the association between species and the three stages (De Cáceres et al., 2012; McGeoch et al., 2002; Podani and Csányi, 2010). The association gives indicator species related to this type of stage environment (De Cáceres et al., 2010). IndVal analysis is based on the “specificity”, which is the probability of the species as an indicator to be found in the target stage group, and the “sensitivity”, which is the probability that the species be found in sites belonging to the stage group (Podani and Csányi, 2010). A higher specificity value represents a higher possibility that this species belongs to the target group than other groups, and specificity in 1 means that the species only occurs in this stage group. A higher value of sensitivity represents a higher possibility that this species occurs in the site of the target group, and a value of 1 means that this species occurs at all sites in this stage group (Podani and Csányi, 2010). Predicting the biodiversity of communities in different stage conditions through the indicator species (De Cáceres and Legendre, 2009; Morelli et al., 2019).

We compared different avian community metrics across the three stages of road construction using one-way ANOVA. We analyzed the total number of species (i.e., species richness, SR), the total abundance of birds (TAB), and the richness (DSR) and abundance (DSA) of diet specialist birds (Zwanenburg et al., 2011). Additionally, we calculated and compared two biodiversity indices, Simpson's and Shannon's indices, to assess variation in community diversity across stages (Lakićević and Srđević, 2018).

The methodological steps are outlined in the flowchart shown in Fig. 3. All statistical tests were performed with R software version 4.4.1 (R Development Core Team, 2024).

3. Results

We counted 4149 bird individuals, corresponding to 86 species (Table S1, Supplementary Material). Overall bird abundance was comparable in the control areas to the road construction sites for similar sampling efforts (control site Cerro del Alcor: 1366 birds; control site Hacienda Torre de Quinto: 1085 birds; SE-40 grounds: 1698 birds). Additionally, species richness was comparable between control sites and construction areas. By rarefaction analysis, we found that unbiased species richness estimations were similar for both the control site and the road corridor, although the species composition varied significantly. Unbiased or expected species richness was higher in the suspended work stage than in the active road construction (Figs. S1 and S2, Supplementary Material).

Based on the results of the permutational multivariate analysis of variance (adonis2), the factor of the road-building stage significantly contributes ($F = 3.055$, $p < 0.001$) to the variation in species composition. It explains a significant portion of the variation in the data ($R^2 = 0.1692$). NMDS ordination based on the species composition of the small-scale spatial samples showed heterogeneity among the control group and the suspended works group compared to the active works group, suggesting a higher homogeneity in the bird species composition of the active works group (Fig. 4). Active work groups have the densest species distribution, with greater variability in one direction, whereas the species composition of the control group differed significantly from that of the active and suspended work groups (see Fig. 4a).

The NMDS sequencing map based on species provides the ordination of species across space, discriminating between species such as the European Golden Plover (*Pluvialis apricaria*) and Eurasian Skylark (*Alauda arvensis*) on the periphery of the ordination space, related to distinct ecological niches (Fig. 4b). Conversely, species grouped near the center, such as the Rock Dove (*Columba livia*) and House Martin (*Delichon urbicum*), exhibit a broader ecological tolerance (see Fig. 4b).

The analysis of variability across different road construction stages revealed that between-group differences were higher than within-group differences, with a positive R-value ($R = 0.19$), which was statistically significant ($p = 0.028 < 0.05$) (Fig. 5). The active work group has significantly lower within-group variability than other groups, indicating a more homogeneous species composition in this group. Control was significantly different from both other groups, with significantly and relatively higher differences compared to active works (P. adjusted = 0.006) and significantly different from suspended works (P. adjusted = 0.009). The adjusted P-value between suspended works and active works was 0.063, indicating a minimal difference (see Fig. 5).

We found that some bird species were the strongest indicators associated with each stage of the road construction. Barn Swallow was associated with the active works stage (Table 1); Sardinian Warbler was associated with the control stage (Table 1); while White Wagtail was associated with the suspended works stage (Table 1). In the active group, there are species with relevant lower stat values but significantly low P-values (<0.01), which can distinguish between groups. Each of these species exhibits a high degree of specificity (A-value) or fidelity (B-value) as an indicator of the road target stage group (Table 1).

All road construction stage groups achieved 100 % indicator

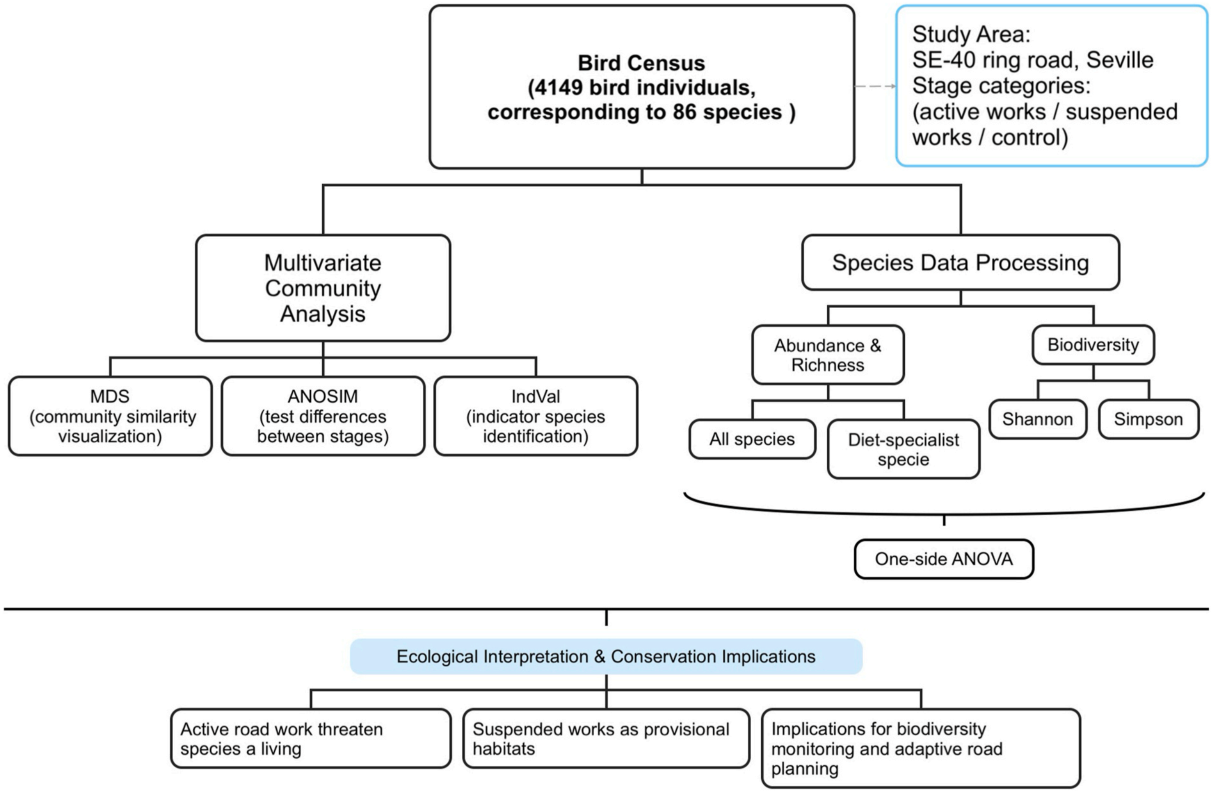

Figure_3. Flowchart of data collection, processing, analysis, and conclusion.

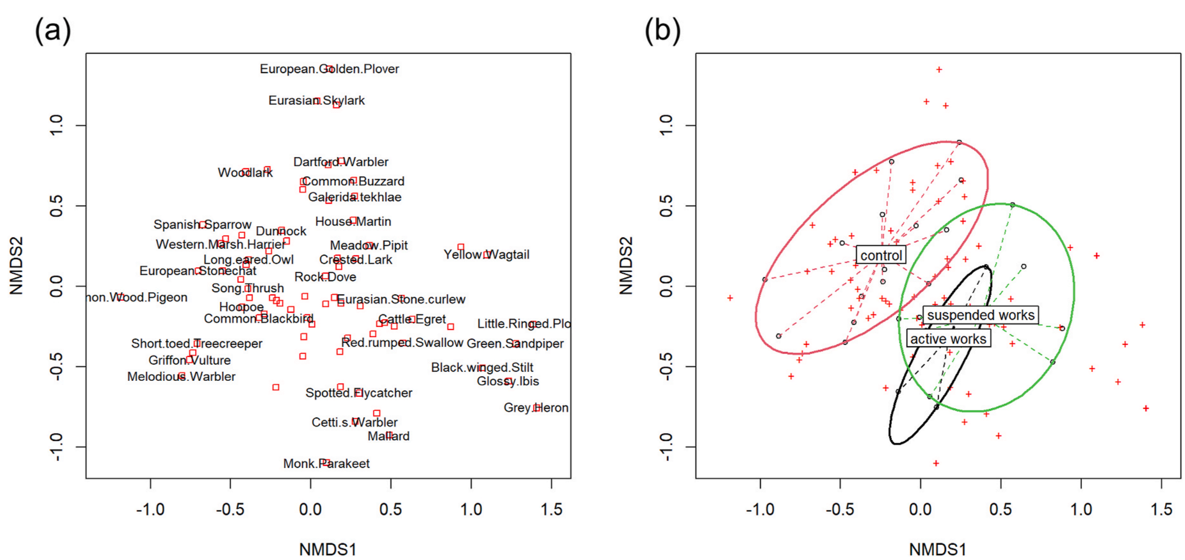

Figure_4. Two-dimensional Non-metric Multidimensional Scaling (NMDS) ordination represents species composition across road-building stages. (a) NMDS plot of sample sites, with each site connected by dotted lines to the centroid of its group and grouped into three categories in ellipsoid, reflecting intra-group variability. (b) NMDS plots individual species across the same two-dimensional ordination space, with each species labelled.

coverage at an IndVal threshold below 0.6, with many species contributing to group representation (Table 1). As the threshold increases, coverage for the active work group declines sharply, indicating a reduction in the number of indicator species or the weaker characteristics of species traits. The active work group is characterised by a smaller number of indicator species or a limited number of key indicator species (Table 1). In contrast, the control group shows a more gradual decline in coverage, suggesting the presence of a greater number of important species combinations within the group (see Fig. 6).

All bird community metrics were lowest during active construction, and during the suspended works stage, they were high. Species richness was high during suspended works (mean = 23), compared to 21.33 in the control and 18.67 in active works (see Table 2 and Fig. 7). Similarly, the biodiversity indices were highest in the suspended stage (mean: Shannon = 2.88; Simpson = 0.93), followed by the control (mean: Shannon = 2.74; Simpson = 0.917) and active works (mean: Shannon = 2.69; Simpson = 0.91). But the abundance is highest in control group (mean = 57.7), decline to suspended in 52.22 and active I 48.83 (see

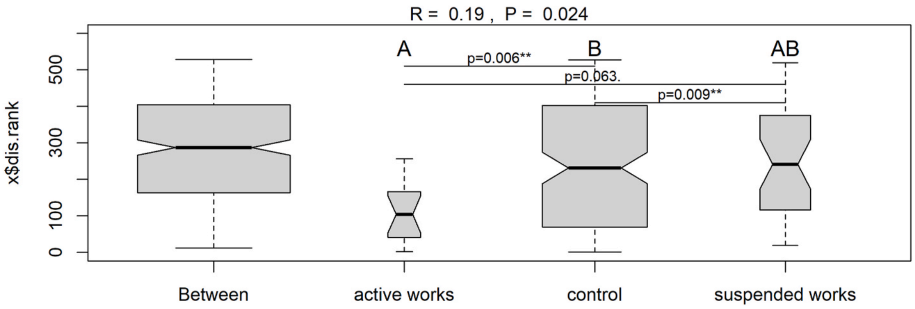

Figure_5. Analysis of similarities (ANOSIM) comparing species composition between different road-building stages. The box shows the between-group and within-group dissimilarity ranks in different groups. The width of the columns is proportional to the number of samples in the group. Columns with the same letter are not significantly different in pairwise multiple comparisons.

Table_1
The indicator species statistics (stat) and associated p-values for each species across different treatments, with statistically significant species ($p < 0.05$), are indicated. Indicator value A (specificity) shows the relative abundance in a given environment, and indicator value B (sensitivity) shows the statistical significance of habitat association.

Species	A (specificity)	B (sensitivity)	stat	P
Group active works				
Barn Swallow	0.5275	1	0.726	0.017*
House Sparrow	0.6045	0.8333	0.71	0.029*
Rose-ringed Parakeet	0.6	0.8333	0.707	0.007**
Spotted Flycatcher	1	0.5	0.707	0.007**
Group control				
Sardinian Warbler	0.6379	0.9444	0.776	0.003**
European Robin	0.7778	0.7222	0.749	0.008**
Eurasian Blackcap	0.6183	0.8889	0.741	0.022*
Common Linnet	0.8462	0.5556	0.686	0.022*
Common Kestrel	0.7647	0.6111	0.684	0.021*
Group suspended works				
White Wagtail	0.6914	0.8889	0.784	0.006**
Red legged Partridge	0.6316	0.8889	0.749	0.013*
Cattle Egret	0.64	0.7778	0.706	0.008**
Common Moorhen	0.7	0.5556	0.624	0.02*
White Stork	0.8	0.4444	0.596	0.044*
Yellow legged Gull	1	0.3333	0.577	0.02*

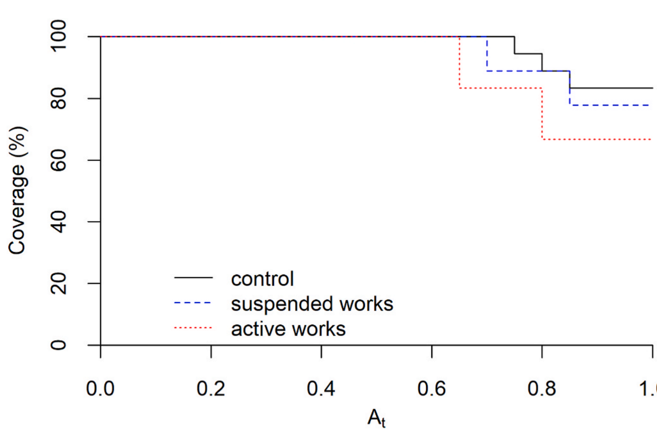

Figure_6. Coverage of species richness against the threshold At, at different stages of EIA based on valid indicators from multi-level pattern analysis. The proportion of coverage within the range of species indicated on the At.

Table 2 and Fig. 7).

Of the 86 bird species observed, 20 were classified as diet-specialist species (e.g., had a dietary Gini value of 1). The richness of diet specialist species varied across the road stage, with the highest value in the active work stage area (mean = 6), the suspended works stage (mean = 5.67), and the lowest in the control stage (mean = 4.89) (see Table 2 and Fig. 7). The abundance varied across the stages, consistent with the level of bird diversity, with averages of 19, 14.89, and 12.61, respectively (see Table 2 and Fig. 7).

4. Discussion

Road construction can significantly impact the composition of the species community, and even though species richness may revert after a construction suspension, the composition of the species is very different from the original natural ecosystem conditions (see Fig. 4). The control stage areas far from the road, which were surveyed in this work, sheltered a higher species richness and biodiversity of ecological niches compared to those along the SE-40 construction sites, reflecting that the ecological environment quality in this area is relatively better (see Fig. 7). Most species in control have a wide range of diet preferences and a wider range of ecological niches (see Fig. 7). They may have better adaptability to such areas because providing good habitat conditions and a more resource-rich environment (Navarro-López and Fargallo, 2015).

The active process of road building will impact avian communities, resulting in a more specialized and homogenous species composition. Construction also significantly reduces the biodiversity and abundance of bird communities (see Fig. 5), and also the indicator species (see Fig. 6). In addition, we observed a decline in the number of indicator species (De Cáceres et al., 2010), and with higher diet specialization, all kinds of indices reflect the severity of environmental change (see Table 2 and Fig. 7). The reactivation of works may affect species directly by modifying nesting areas and foraging habitats or eliminating previous refuges (see Fig. 2), and indirectly through ongoing increased human presence and mechanized, imposing considerable survival pressure on bird communities. In particular, acoustic and visual disruptions during road development have been shown to interfere with breeding behavior, territory defense, and long-term population viability. Our findings regarding human disturbance are consistent with previous studies, which show lower species biodiversity (Murphy and Romanuk, 2014) Although landscape structure and noise levels were not explicitly measured in this study, the patterns align with well-established pathways of road impacts on birds. Future studies should incorporate these environmental variables to better disentangle the mechanisms underlying avian responses to infrastructure development.

The availability of diverse food resources can drive birds to develop more generalized feeding strategies, reducing their reliance on specific foods. This ecological flexibility minimizes interspecific competition and offers a high potential with a wider ecological niche (Irschick et al., 2005). Conversely, in resource-scarce habitats, heightened specialization often emerges as an adaptive response to effectively exploit niche-specific resources effectively (Ravigné et al., 2009). The specialization of bird diet could reflect to some extent the environmental conditions (Morelli et al., 2020; Reif et al., 2016).

Table_2
The richness (DSR) and abundance (DSA) of diet-specialist species and for all species in SR (species richness) and TAB (abundance) in each stage condition, and the information for each site.

year	zone	site	#count	stage EIA	Ecosystem/Macrohabitat	SR	TAB	DSR	DSA	Shannon	Simpson
2015	Alcor/ Gandul	Cerro del Alcor	3	control	Olive grove, holm oaks and palm hearts	20	49	4	9	2.69	0.92
2015	Alcor/ Gandul	Cerro del Alcor	3	control	Chamaerops humilis palmital	10	22	1	2	2.09	0.85
2015	Alcor/ Gandul	Cerro del Alcor	3	control	Meadows and stony plains	8	9	1	1	2.04	0.86
2015	Alcor/ Gandul	Mesa del Gandul	2	control	Meadows and stony plains	19	48	4	7	2.68	0.92
2015	Alcor/ Gandul	Mesa del Gandul	7	control	Olive grove, holm oaks and palm hearts	19	43	5	7	2.68	0.92
2015	Alcor/ Gandul	Mesa del Gandul	7	control	Meadows and stony plains	16	23	3	4	2.65	0.92
2015	Alcor/ Gandul	Mesa del Gandul	10	control	Olive grove, holm oaks and palm hearts	28	116	6	22	2.76	0.91
2015	Alcor/ Gandul	Mesa del Gandul	11	control	Acebuchal, palm hearts, olive trees, brooms	19	30	4	7	2.78	0.93
2015	Alcor/ Gandul	Mesa del Gandul	11	control	Pasture/crop plateau	21	30	4	7	2.95	0.94
2015	Torre de Quinto	Hacienda Torre de Quinto	4	control	Olive grove and open land removed	26	99	6	22	2.96	0.94
2015	Torre de Quinto	Hacienda Torre de Quinto	13	control	Olive grove and open land removed	28	90	6	15	3.03	0.94
2015	Torre de Quinto	Hacienda Torre de Quinto	15	control	Olive grove and open land removed	30	96	6	16	3.03	0.93
2015	Torre de Quinto	Hacienda Torre de Quinto	16	control	Olive grove and open land removed	32	75	9	15	3.2	0.95
2015	SE-40	Hacienda Torre Doña María (bajo Ronda Universidades)	6	suspended works	Olive grove and open land removed	13	23	4	8	2.45	0.9
2015	SE-40	Hacienda Torre Doña María (sobre Ronda Universidades)	6	suspended works	Olive grove and open land removed	24	52	7	16	2.95	0.94
2015	SE-40	Hacienda Torre Doña María (Ronda Arco Norte-Adolfo Suárez)	1	suspended works	Olive grove and open land removed	29	102	6	28	3.03	0.94
2015	SE-40	Hacienda Torre Doña María (Ronda Arco Norte-Adolfo Suárez)	5	suspended works	Olive grove and open land removed	18	42	2	5	2.74	0.93
2015	SE-40	Hacienda Torre Doña María (Ronda Arco Norte-Adolfo Suárez)	8	suspended works	Olive grove and open land removed	22	52	7	18	2.83	0.93
2015	SE-40	Hacienda Torre Doña María (Ronda Arco Norte-Adolfo Suárez)	17	suspended works	Olive grove and open land removed	24	60	7	19	2.97	0.94
2015	SE-40	Motilla_Ctra. Vieja de Bellavista	9	suspended works	Ruderal meadows, wheat fields, reed fields and stony plains	34	72	6	18	3.28	0.95
2015	SE-40	Motilla_Ctra. Vieja de Bellavista	12	suspended works	Ruderal meadows, wheat fields, reed fields and stony plains	12	20	5	9	2.39	0.9
2015	SE-40	Motilla_Ctra. Vieja de Bellavista	14	suspended works	Ruderal meadows, wheat fields, reed fields and stony plains	31	47	7	13	3.3	0.96
2016	Alcor/ Gandul	Mesa del Gandul	4	control	Acebuchal, palm hearts, olive trees, brooms	27	77	8	26	2.79	0.91
2016	Alcor/ Gandul	Mesa del Gandul	6	control	Acebuchal, palm hearts, olive trees, brooms	24	87	7	30	2.79	0.92
2016	Alcor/ Gandul	Mesa del Gandul	8	control	Shrub-Crop Edge	20	45	6	15	2.81	0.93
2016	Alcor/ Gandul	Mesa del Gandul	8	control	Pasture/crop plateau	16	27	3	7	2.62	0.92
2016	Torre de Quinto	Hacienda Torre de Quinto	1	control	Olive grove and open land removed	21	72	5	15	2.72	0.92
2016	SE-40	Hacienda Torre Doña María (Ronda Arco Norte-Adolfo Suárez)	2	active works	Olive grove and open land removed	25	74	9	27	3.02	0.94
2016	SE-40	Hacienda Torre Doña María (Ronda Arco Norte-Adolfo Suárez)	3	active works	Olive grove and open land removed	19	51	5	19	2.72	0.92
2016	SE-40	Hacienda Torre Doña María (Ronda Arco Norte-Adolfo Suárez)	5	active works	Olive grove and open land removed	18	45	4	11	2.61	0.91
2016	SE-40	Hacienda Torre Doña María (Ronda Arco Norte-Adolfo Suárez)	7	active works	Olive grove and open land removed	13	26	5	10	2.42	0.9
2016	SE-40	Hacienda Torre Doña María (Ronda Arco Norte-Adolfo Suárez)	9	active works	Olive grove and open land removed	17	52	5	27	2.61	0.91
2016	SE-40	Hacienda Torre Doña María (Ronda Arco Norte-Adolfo Suárez)	10	active works	Olive grove and open land removed	20	45	8	20	2.77	0.92

In this particular case, we deal with a new road infrastructure in the construction phase, that due to a temporary suspension of the works (halted long enough to favour the attraction and settlement of bird species and other wildlife), generates a favourable habitat that attracts a high diversity of species from the surrounding ecosystems (Fig. 2). The SE-40 is not far from the Doñana National Park and is included in the Guadalquivir Basin, a migratory passage area between Europe and Africa. Many bird species were observed using the study area, possibly on a provisional basis, because small, improvised wetlands and patches of ruderal vegetation were left behind as a result of the work. These

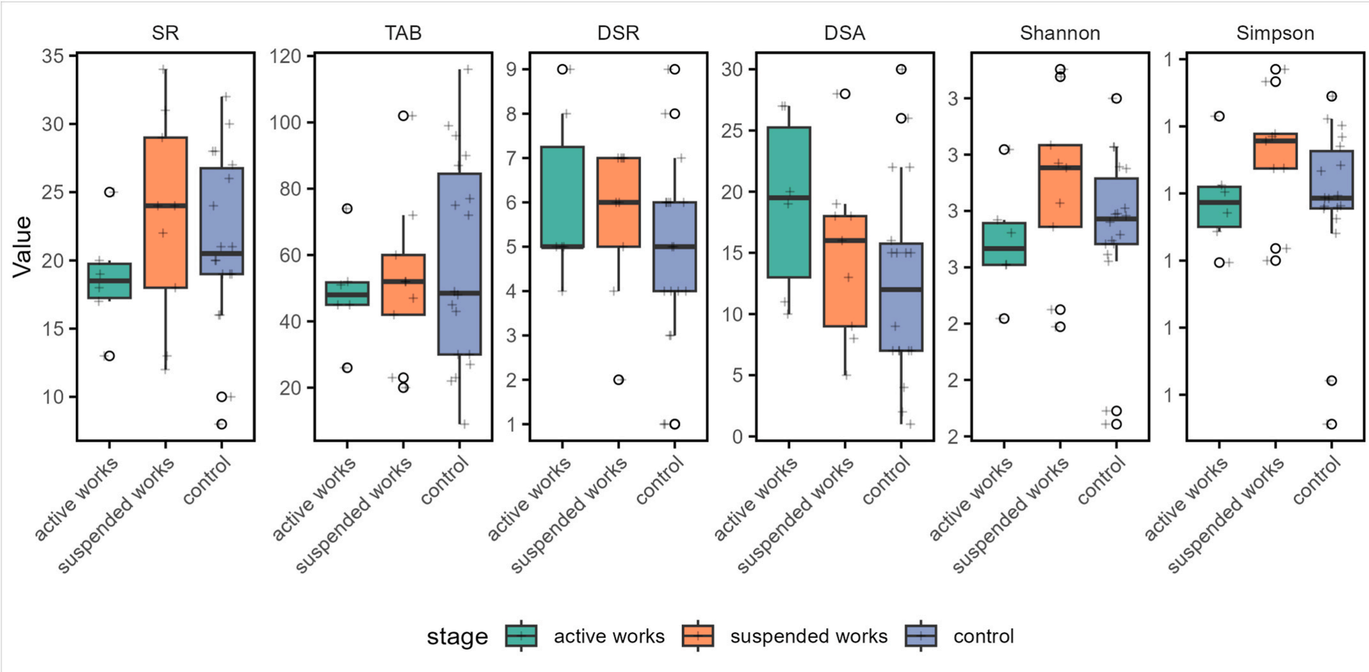

Figure_7. The boxplot of species abundance and richness diet-specialist species and biodiversity in different stages (Con = control, sus = suspended works, and act = active works). The black dots are the mean values for each group, and the grey diamonds are the outliers.

biotopes disappeared when construction resumed, forcing the birds to move or die. Many nests of already breeding species might have been destroyed or deserted by parents. Especially when water resources become scarce, these temporary habitats are also crucial for birds, and they are forced to look for new locations to survive (Crispim-Mendes et al., 2024). The presence of wintering and breeding or resting areas in disturbed peri-urban areas is of great interest for the conservation of birds (Canedoli et al., 2018). Far from representing areas without ecological value, these patchy areas serve as supplementary habitats to the protected natural spaces and, as a whole, provide an important refuge.

Environmental impact statements of road projects, as produced by environmental authorities, frequently fail to provide updated and detailed inventories of the biodiversity in the affected areas (Kopnina et al., 2024). Moreover, these assessments often neglected to thoroughly evaluate the potential impacts of new roads on ecosystems and biodiversity (Charlotte et al., 2017). Instead, they typically rely on data from previously published sources regarding the presence or absence of key species, which is inadequate. Fieldwork specifically conducted at the project site and its surrounding ecosystems, which is necessary, but is rarely undertaken. Unfortunately, it has been common practice in environmental impact assessment resolutions to include statements about the low value for bird species because the areas affected by the projects were heavily altered. Hence, a lack of interest causes environmental impact assessments and official impact statements from environmental authorities to rely on partial inventories of the biodiversity of the problem area. Often, the data come from other sources that have already been published on the presence or absence of taxa of interest and are not updated (Laurance, 2022). More rarely, they rely on fieldwork carried out specifically for the site of the work in question and the affected ecosystems in its surroundings; actualized baseline studies are usually scarce for any given project area (Mäkeläinen and Lehikoinen, 2021).

Without further verification, assumptions about the low diversity and absence of species of interest in anthropized areas lead to biased verdicts and the granting of building permits in areas of true ecological value. This leads to sustaining the reactive nature of the EIA process at the expense of an adaptive attitude, which fails to incorporate corrective measures for impacts after they have occurred (Morrison-Saunders et al., 2024).

The use of the SE-40 as a provisional habitat for many bird species indicates a high interest in the study area for maintaining regional biodiversity. The great proportion of ground-nesting taxa (such as the Red-legged partridge, or the Stone Curlew), a remarkable presence of nocturnal raptors with a high known incidence of roadkill (Little Owl), and intensive use by passerines and aquatic birds along the SE-40 corridor, reveal that this project site is a high-diversity bird area and that it deserves further monitoring (see Table S1). We have shown that even. Species richness is comparable between the construction area and the control sites when all taxa (N = 86 species) are considered (see rarefaction analysis in Supplementary Material Table S1). The road under construction provided a diverse array of biotopes for different bird guilds, including some species of higher conservation concern. Two near-threatened taxa (NT, according to IUCN, 2024) were found at the control site (Dartford Warbler and Red-legged Partridge), two at the active works stage (Red-legged Partridge and Woodchat Shrike) and one at the suspended works stage, where one endangered species was also detected at the suspended works stage (Common Snipe). The remaining taxa (82 species) were catalogued as Least Concern by the IUCN (2024), although several of these birds exhibit contrasting population trends in the region and on the European scale. We did not detect, however, the presence of other important taxa mentioned in the SE-40 Environmental Impact Statement, such as the Squacco heron (*Ardeola ralloides*) or the Collared Pratincole (*Glareola pratincola*), which are located in other segments of the infrastructure. In addition, several introduced and naturalized bird species have been detected in the SE-40 grounds, and we have found that these species are more frequent in these altered areas than in the control sites (see Table S1).

As the SE-40 Environmental Impact Statement mentioned, “The effects on the fauna will not be important due to the predominance of heavily anthropized biotopes” (BOE núm. 181, July 30, 2001, p. 27,905). The fact that the SE-40 environments are already deeply anthropized should not serve as an unscientific justification for applying a scorched earth policy to infrastructure construction. There is a high environmental cost for evaluating the degree of ecosystem conservation and biodiversity based on premises without a scientific foundation. This practice does not favour conserving an environment that is already extremely transformed in a geographical region of high biological diversity and has been secularly occupied by human activities. Mitigation and road adaptation measures, along with impact monitoring, must minimize chronic effects, particularly during the operational phase (including noise, mortality due to collisions, and the barrier effect) for birds and other fauna.

CRediT authorship contribution statement

Yiming Deng: Writing – original draft, Visualization, Formal analysis, Data curation, Conceptualization. **Juan D. Delgado:** Writing – review & editing, Resources, Investigation, Data curation. **Yanina Benedetti:** Writing – review & editing, Supervision, Project administration, Methodology. **Federico Morelli:** Writing – review & editing, Supervision, Project administration, Methodology, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvman.2025.126694.

Data availability

Data will be made available on request.

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