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RESEARCH ARTICLE

Increased bird sound diversity in vineyards enhances visitors' tour experience

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Abstract

1. Biodiversity is rapidly declining, reducing the quantity and quality of human interactions with nature and constraining its contribution to human health and well-being. Natural sounds are a key component of our experience of nature, but biodiversity losses are reflected in soundscapes, which are becoming less diverse and quieter.
2. We characterised the soundscapes across 21 English vineyards using acoustic indices and related them to bird species richness and abundance. We found that higher bird species richness, but not abundance, led to more diverse and louder soundscapes, as reflected in higher values of Acoustic Complexity Index (ACI), Bioacoustic Index (BIO) and Normalised Difference Soundscape Index (NDSI), and lower values of Acoustic Entropy Index (H).
3. Secondly, at three of the study vineyards that run vineyard tours, we measured visitors' experience of the tour in terms of *sound enjoyment*, *soundscape connectedness* and *tour satisfaction* and related these to ambient and experimentally enhanced soundscapes, where we used playback recordings of five additional birdsongs to increase the soundscapes' complexity and volume.
4. Under ambient conditions, respondents' ($n=107$) experience was significantly higher at sites with soundscapes that had higher ACI and BIO values, and lower H, Acoustic Diversity Index (ADI) and NDSI values, indicating a positive effect of more diverse and louder soundscapes. Natural sounds formed an important part of the tour experience at these sites, making visitors feel more present and connected to nature.
5. Under experimental soundscape enhancement, respondents ($n=79$) reported hearing significantly more bird species during the tour, and they reported significantly higher scores for *sound enjoyment*, *soundscape connectedness* and *tour satisfaction* than under ambient conditions. This effect was stronger in visitors who engaged more in pro-environmental behaviours, such as purchasing organic foods.

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6. Our study demonstrates (i) the direct contribution of aural modes to our experience of nature and (ii) that the delivery of biodiversity conservation measures aimed at supporting bird diversity could simultaneously enhance the experience and well-being benefits of spending time in nature. Natural soundscapes should therefore be recognised and valued as natural capital, and their protection should be incorporated into conservation planning and policy.

KEYWORDS
aesthetic value, agriculture, birdsong, cultural services, nature connectedness, soundscapes

1 | INTRODUCTION

The Anthropocene is characterised by continual and pervasive biodiversity declines (Díaz et al., 2019; IPBES, 2019), with agriculture being a leading driver (Inger et al., 2015; Reif & Vermouzek, 2019; Rigal et al., 2023). These decline, together with growing urbanisation and changing lifestyles, which have become increasingly sedentary, are reducing the likelihood of human interactions with nature (Díaz et al., 2015; Klepeis et al., 2001; Soga & Gaston, 2016). The growing human disconnect from nature is therefore fuelling an 'extinction of experience' (Cox & Gaston, 2018; Gaston & Soga, 2020), lessening nature's contributions to our physical and psychological health and culture (Bratman et al., 2019; Gaston & Soga, 2020; IPBES, 2019), with potentially serious consequences for human health and well-being. For example, time spent in nature has been shown to lower the risk of developing cardiovascular and respiratory diseases (Richardson & Mitchell, 2010) and diabetes (Astell-Burt & Feng, 2019), and benefitting mental well-being and happiness (Capaldi et al., 2014; Engemann et al., 2019; Joye & Bolderdijk, 2015). In the United Kingdom, 'time in nature' is even prescribed by health professionals (NHS England, n.d.) and considered in governmental policies (DEFRA, 2023) as being crucial for the country's well-being. To maximise the benefits arising from interactions with nature, we need to firstly understand how different modes of experience contribute to human well-being, and secondly, how such benefits could be enhanced through conservation measures.

Landscapes emanate a collection of biological, geophysical and anthropogenic sounds which together form 'soundscapes' (Pijanowski et al., 2011), and soundscapes are in turn experienced and perceived by people (Ratcliffe, 2021). Sounds affect our interactions with nature (Buckley, 2022), with laboratory studies showing greater enjoyment of higher diversity soundscapes (Douglas & Evans, 2022), and that listening to natural sounds promotes mood recovery (Benfield et al., 2014) and perceived restoration (Smalley et al., 2022). Birdsong is a dominant component of natural soundscapes, particularly in temperate regions (Gasc et al., 2017; Uebel et al., 2021), and birdsong diversity has been shown to influence our appreciation of landscapes (Hedblom et al., 2014), and perceived restoration and well-being (Fisher et al., 2021). Ferraro et al. (2020) showed that the experimental enhancement of natural soundscapes using playback of constructed birdsong choruses along hiking routes delivered higher levels of self-reported psychological restoration in hikers. However, a similar laboratory-based study failed to find an improvement in self-reported restoration following a playback of high avian diversity soundscape (Douglas & Evans, 2022), suggesting that perhaps the effects of sounds and the sight of natural landscape interact with the act of physical activity to deliver well-being benefits. The staggering and ongoing declines of bird populations and concurrent homogenisation of assemblages (Burns et al., 2021; Johnson et al., 2017; Olden et al., 2004; Rosenberg et al., 2019), translate to reductions in birdsong abundance and diversity, and underpin reported large-scale declines in natural soundscape quality (Morrison et al., 2021), with associated implications for derived health and well-being benefits.

Farmland bird species have experienced some of the largest population declines (Inger et al., 2015; Reif & Vermouzek, 2019; Rigal et al., 2023). In the United Kingdom, the State of Nature 2023 Report stated that 43% of bird species are threatened with local extinction, based on national IUCN red list assessments (Burns et al., 2023), whilst the Farmland Bird Index shows 60% decline since its 1970 value (DEFRA, 2022). Viticulture is the UK's fastest growing agricultural sector, attributed to global warming improving the climate for grape growing (Nesbitt et al., 2019). European vineyards have been shown to have detrimental effects on bird (Assandri et al., 2016; Pithon et al., 2016), and wider diversity (e.g. Geldenhuys et al., 2022) but the scale of impact is significantly influenced by vineyard practices (Paiola et al., 2020; Zielonka et al., 2024), and the introduction of targeted management can support high abundances of threatened and endemic avifauna within vineyards (Brambilla et al., 2017). Though fundamentally agricultural systems, vineyards are associated with tourism through vineyard tours and tastings events, with tourism contributing 24% of the total revenue across the UK viticulture industry (WineGB, 2023). Earlier this year, *Sussex Modern*, funded by the UK Government, launched a plan to support the development of the wine tourism industry, which it is estimating could be worth £658 million by 2040 and contribute over 26% to the local tourism industry (Sussex Modern, 2023). Soundscapes are an important part of the tourism experience (e.g. Fesenko & García-Rosell, 2019), where higher sound complexity has been shown to correlate positively with improved well-being (Fisher et al., 2021), whilst positive soundscape perception has been linked to higher tourism loyalty (Jiang & Yan, 2022). This presents an opportunity for informing how soundscape conservation could support the development of vineyard tourism and contribute to the wider industry goals of sustainability and protection of the local landscapes and livelihoods (Sussex Modern, 2023; SWGB, 2020).

Here we investigated the relationship between bird diversity and soundscape characteristics in vineyards, and linked these to visitors' experience of vineyard tours to further our understanding of the role that soundscapes play in affecting human experience. Our aims were to (1) quantify the relationships between bird diversity metrics and acoustic indices in UK vineyards; (2) relate visitors' experience of vineyard tours to ambient soundscape conditions; (3) test whether experimental soundscape enhancement affected visitors' perception of vineyards' biodiversity; and (4) test whether experimental soundscape enhancement affected visitors' experience of the vineyard tour. We predicted that bird diversity would be reflected in acoustic indices, and that visitors' experience would be related to soundscape characteristics. We predicted that visitors subjected to soundscape enhancement would perceive the vineyards' biodiversity as being higher and report improved tour experience.

2 | MATERIALS AND METHODS

2.1 | Bird diversity and acoustic monitoring

We performed acoustic monitoring and bird surveys across 21 English vineyards in 2021 and 2022. In each year, data collection took place across the three key seasons of the vine lifecycle: 'budding' (April–May), 'flowering' (June–August), and 'harvest' (September–October). We performed monitoring at 32 locations across the 21 vineyards, with one sampling location across 12 sites (average vineyard size 5.78 ± 2.12 SE ha), two sampling locations across seven sites (45.45 ± 1.68 ha) and three sampling locations across two sites (72.72 ± 6.73 ha). Sampling locations were within vine fields, at least 50 m from boundary habitats and a minimum of 250 m apart (see Supporting Information S1 for a map).

2.1.1 | Active bird surveys

Bird communities in vineyards were assessed with 10-min point counts. At each monitoring location ($n = 32$), we performed one point count in each of the 'budding', 'flowering' and 'harvest' seasons in 2021 and in 2022 (as described in Zielonka et al., 2024). Point count surveys were conducted between 05:00–09:00 and within 3 h of sunrise, and all birds seen and heard within a 50 m radius were recorded, excluding birds flying over. Surveys only took place on dry and still days (Bibby et al., 2000), and were performed by the same observer.

2.1.2 | Acoustic data

At the same monitoring locations as covered by bird surveys, we recorded soundscapes using AudioMoths (Hill et al., 2019), with the sampling rate set to 96 kHz and medium gain. Ten-minute recordings were taken on the hour between 05:00–07:10 ('morning period') and 18:00–20:10 ('evening period') each day, when bird vocal activity was expected to be highest, giving six 10-min recordings in each 24-h period. AudioMoths were placed in clear plastic bags and mounted to metal trellis poles present across all vineyards, at the height of 2 m, with the microphone facing up. This placement ensured that AudioMoths were placed above the vine canopy cover, which could obstruct the clarity of recordings. Devices were deployed twice each year, firstly at 'budding', and then re-deployed at 'flowering', before being collected at 'harvest'. Recordings were collected between 13 April–11 June and 28 June–18 September in 2021 (1553 recording days and 9039 10-min recordings), and between 2 April–16 July 2022 (915 recording days and 5009 10-min recordings). We did not make any recordings beyond 16 July in 2022 as all devices failed due to the extreme heat (Kendon, 2022). On average, data were collected on 50.15 recording days ±1.90 SE per device and per deployment in each year and was mostly dependent on battery life. Over the 2 years, 8 devices were either lost or destroyed.

All sound file processing was performed in R 4.3.0 (R Core Team, 2021). Using the package *seewave* (Sueur et al., 2008), we down-sampled the recordings to 44.1 kHz (following Bradfer-Lawrence et al., 2019) and split the 10-min recordings to 1-min sub-samples (0–59, 60–119 s etc.). Using the packages *seewave* and *soundecology* (Sueur et al., 2008; Villanueva-Rivera & Pijanowski, 2018), we quantified soundscapes using five commonly used indices that capture a range of acoustic characteristics and have been found to be reflective of biodiversity (Alcocer et al., 2022; Bradfer-Lawrence et al., 2023). Specifically, we calculated Acoustic Complexity Index (ACI; Pieretti et al., 2011), where higher values indicate irregularity in acoustic energy across frequencies and time; Acoustic Diversity Index (ADI; Villanueva-Rivera et al., 2011), where higher values indicate greater acoustic evenness (arising from either a 'full' or an 'empty' soundscape); Bioacoustic Index (BIO; Boelman et al., 2007), where higher values indicate higher variation between loud and quiet frequencies; Acoustic Entropy Index (H; Sueur et al., 2008), where a value of 0 indicates a pure tone, and higher values are associated with more even distribution of sound across frequency bands and temporal frames; and Normalised Difference Soundscape Index (NDSI; Kasten et al., 2012), which compares the values of biophony (2–8 kHz) to anthrophony (1–2 kHz), where values closer to +1 reflect soundscapes dominated by biophony. Indices were computed separately for each 1-min sub-sample and using the default settings (as specified in *seewave* and *soundecology* R packages; Sueur et al., 2008; Villanueva-Rivera & Pijanowski, 2018). To facilitate cross-site and cross-index comparison, all indices were standardised prior to analyses to a scale between 0 and 1

(Bradfer-Lawrence et al., 2020): values of ACI, ADI, H and BIO were divided by the maximum value for each index across all recordings to give relative proportions, whilst NDSI, which is on a scale from −1 to +1, was standardised by (NDSI + 1)/2 (following Fairbrass et al., 2017). Following standardisation, and for each acoustic index in turn, we calculated: (1) the median value across 1-min sub-samples of each 10 min recording, and (2) the average of these for the morning and evening period in each season at each sampling location (Bradfer-Lawrence et al., 2020; Fuller et al., 2015).

2.2 | Effects of soundscape on vineyard visitors' experience

We measured visitors' experience in relation to the soundscape they experienced during vineyard tours at three of our study sites. Data collection occurred between 14 May and 2 July 2022, which overlapped with the 'flowering' season and main vineyard tour period. Following Ferraro et al. (2020), we manipulated the soundscape experienced by visitors in experimental trials, where in 'off' trials, visitors experienced the ambient soundscape, and in 'on' trials, we used audio playback to enhance the soundscape. We ran these trials across 24 vineyard tours (average 7.67 per site, range 6–11), which included 12 'off' trials and 12 'on' trials, with at least three repeats of each trial condition per site. Across all trials, tours followed each vineyards' usual tour route and duration (45–60 min), which varied between sites but remained the same across tours at each site (see Supporting Information S1 for a map). This study was conducted with approval from the University of East Anglia Research Ethics Committee (ETH2122-1782).

2.2.1 | Soundscape enhancement

We constructed our playback sound files using birdsongs of species non-native to the UK to reduce the potential disturbance of playback to breeding native species in vineyards, but we chose songs resembling common UK vineyard birds as it was important that the playback blended in within the natural soundscape. We downloaded high-quality recordings (Quality = A; Type = Song) for five species: American goldfinch (*Spinus tristis*, XC169065), American robin (*Turdus migratorius*, XC293029), Black-capped chickadee (*Poecile atricapillus*, XC465052), Carolina wren (*Thryothorus ludovicianus*, XC248139) and Citrine wagtail (*Motacilla citreola*, XC643079) from an online database (www.xeno-canto.org). The species recordings were overlaid with random start times into an 8 min 51 s (maximum duration of the five downloaded sound files) soundscape using the software GarangeBand (version 10.4.5) and saved as an .mp3 file (available as Digital Supporting Information).

We concealed a pair of WAVE A1 and A2 Portable Bluetooth speakers 15–30 m either side of the tour route at two points (at least 180 m apart) where the guides regularly paused to speak to the visitors about viticulture. We used a Decibel X:dB Sound Level Meter (version 9.4.0) to standardise playback volume at the closest position to each speaker on the tour route at an LAmax of 80 A-weighted dB; this volume was chosen as it is broadly comparable to the LAmax of individual songs in baseline soundscapes (Brumm, 2009; Brumm & Todt, 2002; Luther et al., 2017), and it is the amplitude used by previous similar studies (Ferraro et al., 2020). Playback of constructed soundscapes was initiated before tours assigned to enhanced soundscape ('on') trials began, with speakers set to loop playback of the constructed soundscape continuously. Tour guides were asked not to draw attention to the playback recordings, nor to make direct inferences about birds found across the vineyard.

2.2.2 | Questionnaire

At the end of each tour, the tour guide invited visitors to complete our anonymous questionnaire about their vineyard experience. Participation was voluntary and interested visitors were given an information sheet, asked to give written consent as part of the questionnaire, and they were debriefed afterwards (see Supporting Information S2). To measure the effect of the soundscape on visitors' experience, we devised 15 questions following Ferraro et al. (2020) and Payne (2013), which focused on characterising aspects of the soundscape that may provide psychological restoration. Responses were recorded on a 5-point Likert scale, from 'Strongly disagree' to 'Strongly agree'. We also asked respondents how many bird species they heard during the vineyard tour to measure their perceptions of bird diversity, collected information on respondents' gender and age for descriptive purposes, and asked about their nature-related interests, which may have affected engagement with the soundscape during the tour (Capaldi et al., 2014; Douglas & Evans, 2022). The full questionnaire is available in Supporting Information S2.

2.3 | Statistical analyses

2.3.1 | Relationship between soundscape characteristics and bird communities

We firstly modelled the five acoustic indices as response variables in relation to bird species richness (number of unique species) and total abundance (number of individuals across species). We fitted these models specifying a beta distribution, which is suitable for continuous non-integer data bound between 0 and 1 and that may be skewed and heteroskedastic (Bradfer-Lawrence et al., 2020; Cribari-Neto & Zeileis, 2010; Ferrari & Cribari-Neto, 2004). Across the models, we fitted the recording time (morning or evening) as a fixed effect and included interactions between recording time and (i) bird species richness and (ii) abundance. Deployment season ('budding', 'flowering' or 'harvest' in 2021 or 2022; 6 levels) and sampling location ID (32 levels) nested in Site ID (21 levels) were included as random effects to account for repeated measurements taken at each location. We were not able to model deployment season as a fixed effect due to uneven sampling across the seasons. Species richness and abundance were not collinear; hence, we included them in the same model.

2.3.2 | Effect of soundscape on vineyard visitors' tour experience

We performed explanatory factor analysis (EFA) to test whether questionnaire statements could be reduced to a smaller number of factors, and how the different statements loaded onto these factors. We performed this twice with different sets of statements. Firstly, we performed this for the 15 statements that measured visitors' vineyard tour experience, and secondly for the seven statements that measured respondents' background interest in nature-related activities. Factor analyses were performed using the package *psych* (Revelle, 2024) and prior to starting, we performed initial checks to ensure data was suitable for factor analysis. For the vineyard tour experience statements, the Kaiser-Meyer-Olkin test (KMO-test; Kaiser, 1970) showed overall measure of sampling adequacy (MSA) to be 0.89, with individual MSA values all above 0.83, whilst the Barlett's test of sphericity (Bartlett, 1951) results were $\chi^2(105) = 1633.88$, $p < 0.001$. For the other set of statements, the KMO-test value was 0.71, with individual MSA values all above 0.67, whilst the Barlett's test of sphericity results were $\chi^2(21) = 257.19$, $p < 0.001$. For both sets of statements, these results indicated that there is sufficient correlation in our datasets for factor analysis to be undertaken, and so, we proceeded to use the *fa.parallel* function to determine the number of factors that should be used on the data, applying 'varimax' rotation. We squared the loadings to determine communality, and following similar research (e.g. O'Brien et al., 2024), we used the threshold value of 0.3, which is equivalent to a loading of ~0.55, as the cut off for sufficiently good loading onto a factor. The 5-point Likert scale responses were interpreted as a number of successes, with the lowest answer (Strongly disagree) being scored 0 and highest answer (Strongly agree) being scored 4 (following Mikołajczak et al., 2021). Factor scores were calculated by weighing each Likert score by the communality loading, and then summing these per factor. We then scaled these by dividing each factor sum by that factors' maximum weighted score, which resulted in numbers between 0 and 1.

We used beta models to understand the effect of soundscape characteristics on visitors' tour experience. Firstly, to understand which soundscape characteristics affect visitors' experience we related the three vineyard tour factor scores (*Sound enjoyment*, *Soundscape connectedness* and *Tour satisfaction*; see Section 3) to each of the five acoustic indices. The acoustic indices were averaged across 'morning' and 'evening' periods for each site from 'flowering' season recordings only, as this is when most tours occurred. In the second set of models, we investigated the effect that respondents' characteristics had on their vineyard tour experience by relating each of the three vineyard tour factor score to respondents' gender (female or male, 2 levels), age category (above or below 40 years old, 2 levels) and two factor scores (*Nature-relatedness* and *Pro-environmental behaviours*; see Section 3) that described respondents' background levels of engagement in nature-related activities. These two steps were performed only using the responses from ambient soundscape condition (off trials). Variables that significantly predicted respondents' experience of the vineyard tour (see Supporting Information S6) were used as predictors in the third set of models, which tested the effect that soundscape enhancement had on respondents' vineyard tour experience. Here, we used all responses from across both trials and related the three vineyard tour factor scores to the fixed effects of trial condition (on or off, 2 levels), and age category (2 levels) and the *Pro-environmental behaviours score*, as well as interactions between the condition and the other two predictors. To control for repeated measurements coming from a single tour, all models included Tour group ID ($n = 24$) nested in Site ID (3 levels) as a random effect.

All statistical analyses were performed in R 4.3.0 (R Core Team, 2021) and general(ized) linear mixed models were fitted using the *glmmTMB* package (Brooks et al., 2017). Model fit and residual distribution were assessed, and we proceeded with full models, interpreting predictor significance based on whether the model estimates with 95% confidence intervals overlapped zero, and if $p < 0.05$.

3 | RESULTS

3.1 | Relationship between bird diversity and acoustic indices

In total, we recorded 5731 individuals belonging to 58 species. The average bird species richness per survey was 8.84 ± 0.16 (SE), and the average abundance was 30.43 ± 1.36. Higher species richness was significantly related to higher values of ACI (GLMM *z*-value = 3.898, $p < 0.001$, $R^2 = 0.72$; Figure 1a), BIO (*z*-value = 10.234, $p < 0.001$, $R^2 = 0.76$; Figure 1b) and NDSI (*z*-value = 3.919, $p < 0.001$, $R^2 = 0.23$; Figure 1c), and lower values of H (*z*-value = −2.631, $p = 0.009$, $R^2 = 0.43$; Figure 1d). The values of BIO were significantly higher in the morning than in the evening (*z*-value = 15.000, $p < 0.001$; Figure 1b). There were no significant associations between species richness and ADI, nor between total abundance and any of the acoustic indices, and the interactions of species richness and abundance with recording time were not significant (see full model outputs in Supporting Information S3).

3.2 | Effect of soundscape on vineyard visitors' tour experience

We received 186 (median: 6, range: 1–23 per tour group) questionnaire responses, of which 107 were from the ambient ('off' trials) soundscape tours, and 79 from the enhanced ('on' trials) soundscape tours. Most respondents were female (70%) but the distribution of females and males across the two experimental conditions was

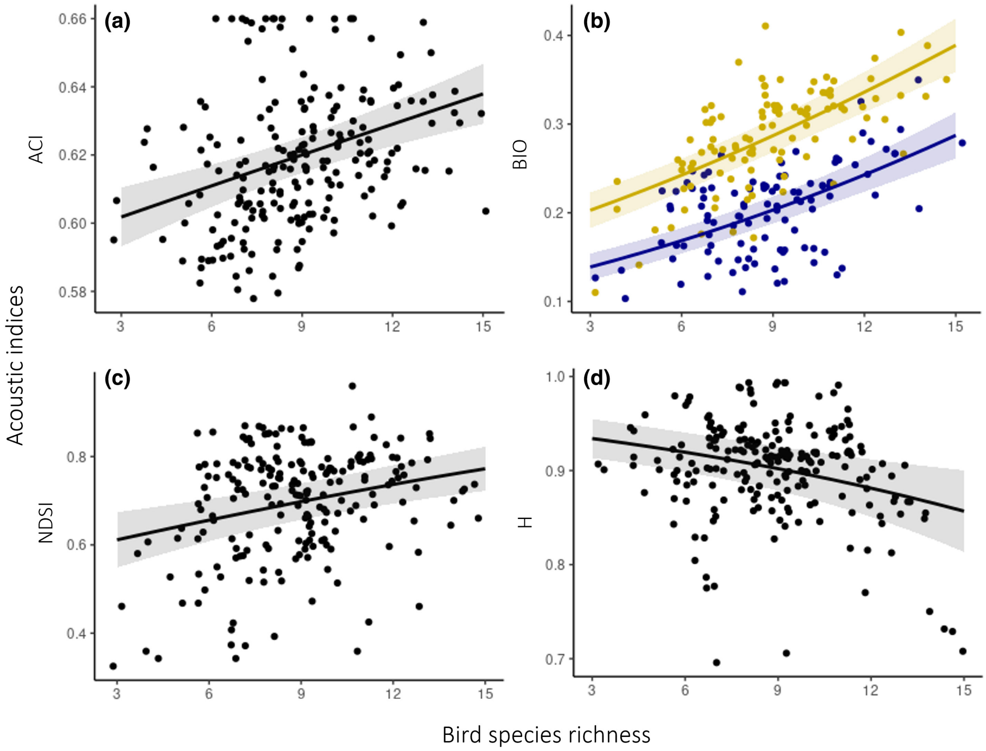

FIGURE 1 Significant relationships between bird species richness and standardised acoustic indices across 21 English vineyards (a) ACI: Acoustic Complexity Index; (b) BIO: Bioacoustic Index; (c) NDSI: Normalised Difference Soundscape Index; and (d) H: Acoustic Entropy Index. Lines represent model predicted values with 95% confidence intervals (shading) from generalised linear mixed models, and the points indicate raw standardised acoustic index values (jittered for clarity, $n=208$ samples). In (b), yellow = 'morning' recordings, and blue = 'evening' recordings, as these were significantly different from each other (see Supporting Information S2).

similar (see Supporting Information S4). An equivalent number of respondents were 18–40 years of age, and 41 and above.

The EFA highlighted three factors that summarised the 15 vineyard tour experience statements and 13/15 statements loaded strongly (communality >0.3) onto one of the three factors (Figure 2a). These three factors were interpreted as: *Sound enjoyment* (explained 24.4% variance), *Soundscape connectedness* (17.5% variance) and *Tour satisfaction* (15.4% variance). The three factors combined explained 57.3% of the variance. The EFA suggested that the seven statements measuring respondents' pro-environmental behaviours and nature-relatedness should be summarised to two factors with 4/7 of the statements loading strongly onto one of the two factors (Figure 2b). These two factors were interpreted as *Pro-environmental behaviours* (explained 23.5% of variance) and *Nature-relatedness* (17.8%).

Under ambient soundscape conditions ('off' trials), *sound enjoyment* and *soundscape connectedness* factor scores were significantly higher at sites with higher ACI and BIO values, and with lower H and ADI values (Figure 3). *Sound enjoyment* factor scores were also significantly higher in sites with lower NDSI values (Figure 3). There were no significant relationships between the *Tour satisfaction* factor score and any of the acoustic indices. Full model outputs are in Supporting Information S5.

Respondents with higher *pro-environmental behaviours* scores rated their vineyard tour experience more positively, as indicated by significantly higher *Sound enjoyment* (z-score = 3.087, p-value = 0.002) and *Tour satisfaction* (z-score = 4.210, p-value <0.001) scores. Younger respondents (below 40 years old) scored lower on vineyard *soundscape connectedness* than older respondents (above 40 years old; Supporting Information S6). Respondents who experienced the enhanced soundscape reported that they heard a significantly higher number of bird species during the tours (3.57 ± 0.22 SE species; z-value = 4.252, p-value <0.001; Supporting Information S7) compared to respondents who experienced the ambient soundscape (2.22 ± 0.18). Soundscape enhancement resulted in significantly higher *sound enjoyment*, *soundscape connectedness* and *tour satisfaction* factor scores in respondents who engaged in more *pro-environmental behaviours* (Figure 4; Supporting Information S8).

4 | DISCUSSION

We demonstrate the link between bird species richness and soundscape complexity and volume in UK vineyards and show that soundscape characteristics can have a positive effect on vineyard visitors' experience, increasing levels of reported *soundscape connectedness* and *sound enjoyment*. Our experimental soundscape enhancement demonstrates the direct contribution of the aural mode to improving our experiences of nature.

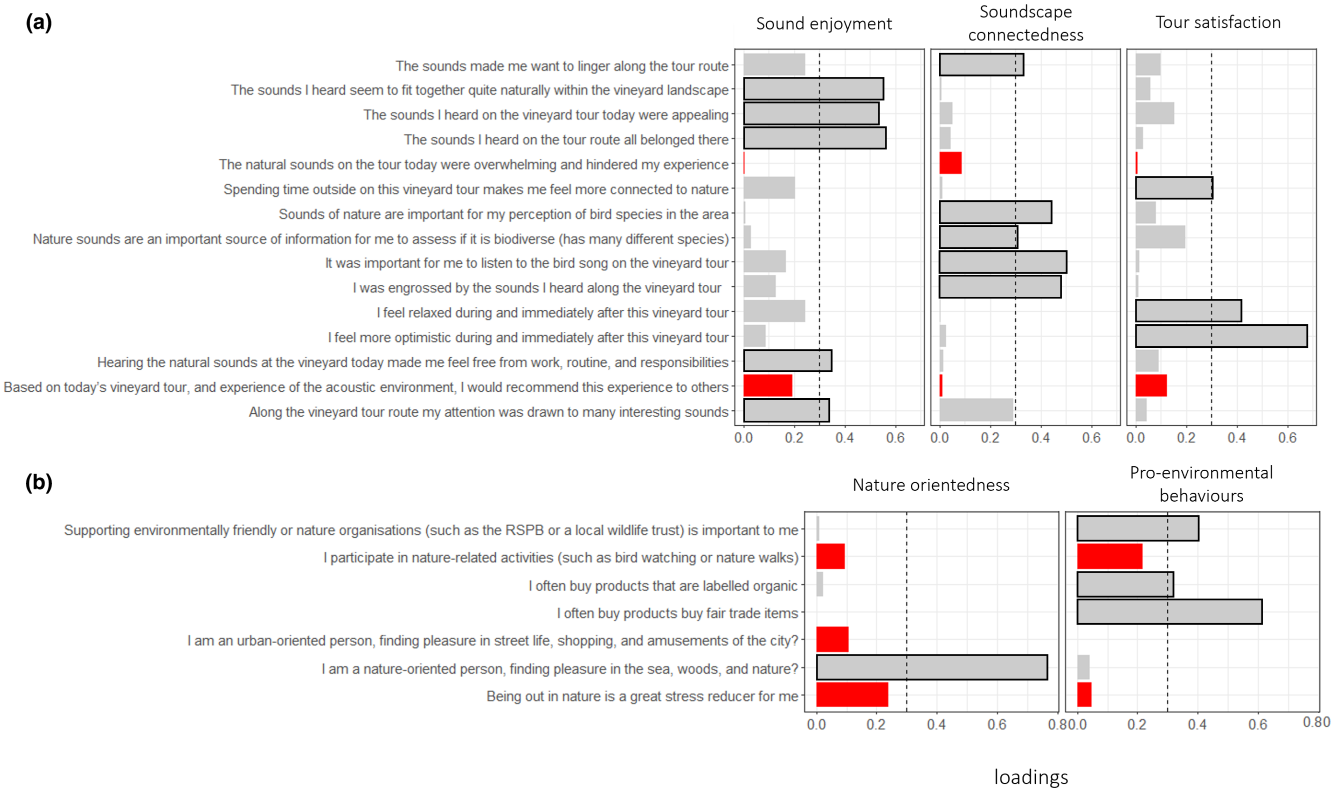

FIGURE 2 Explanatory factor analysis showing the factors (panel columns) and the associated communalities (loading squared) of each of the 15 statements that measured respondents' vineyard tour experience (a), and the seven statements that measured respondents' background interest in nature-related activities (b). Statements that loaded well (communality >0.3) onto one of the factors are marked by a black outline, and the red bars indicate statements that did not load well onto any other factors.

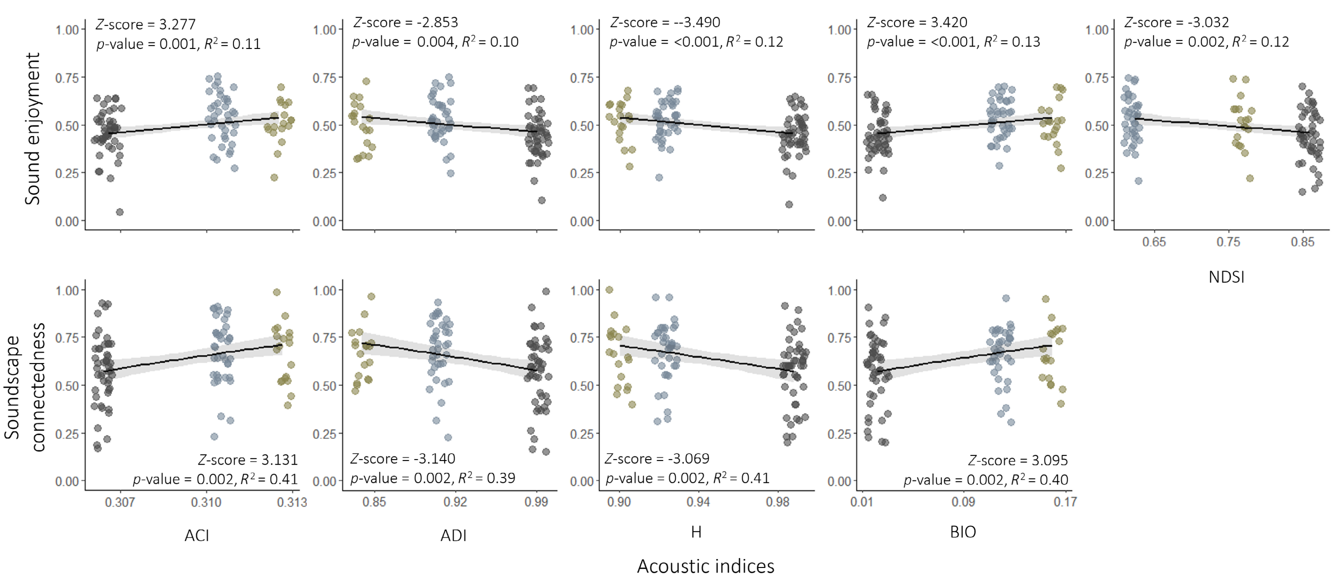

FIGURE 3 The relationship between five standardised acoustic indices (column panels—ACI: Acoustic Complexity Index; BIO: Bioacoustic Index; NDSI: Normalised Difference Soundscape Index; H: Acoustic Entropy Index; ADI: Acoustic Diversity Index), measured in the flowering season under ambient conditions, and two factor scores (row panels) describing respondents' experience of vineyard tours: *Sound enjoyment* and *Soundscape connectedness*, where higher values indicate more positive experiences. Lines represents model predicted values with 95% confidence intervals (shading) from generalised linear mixed models. Points indicate raw factor scores ($n = 107$) and are coloured per study site where the soundscape enhancement experiment took place, and they are jittered for clarity. Summary model outputs are given.

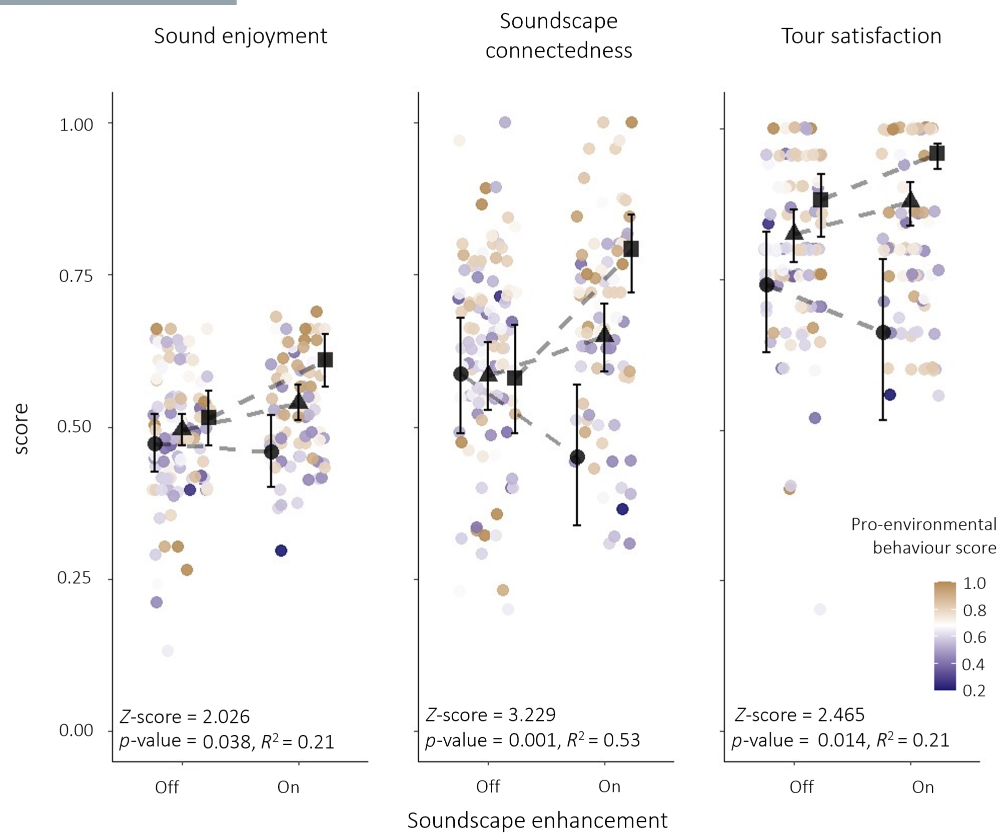

FIGURE 4 Impact of soundscape enhancement on respondents' experience of vineyard tours, as summarised by three factor scores (panel columns). Coloured points indicate raw scores for the two conditions ($n=107$ for 'off' and $n=79$ for 'on') and the colour gradient relates to respondents' *pro-environmental behaviour* factor score, with orange indicating higher scores, white indicating the mean, and blue indicating lower scores. Black points show model predicted scores (with 95% CI error bars) for the first quartile (circle, 0.31), mean (triangle, 0.68) and third quartile (square, 0.80) value of the *pro-environmental behaviours* factor score, with the dashed line connecting the predictions between the 'on' and 'off' conditions. Summary model outputs of the interaction between the condition and *pro-environmental behaviour* score are included in each panel.

4.1 | Relationship between bird diversity and acoustic indices

Sites and sampling seasons with higher avian species richness had more diverse and louder soundscapes. This closely mirrors patterns reported in similar studies from both tropical (Bradfer-Lawrence et al., 2019) and temperate systems (Eldridge et al., 2018), with larger bird communities resulting in a higher diversity of frequency bands being occupied and greater temporal variation in the sound energy across the soundscape. Bird activity is greatest in early mornings, so dawn soundscapes are expected to be louder and more diverse (Dröge et al., 2021). In support of this, we found higher BIO values in the mornings, which indicates higher amplitude of sounds (Boelman et al., 2007; Fuller et al., 2015; Pieretti et al., 2011). ADI, which measures soundscape evenness, did not predict species richness well. This could be because the relationship between soundscape evenness and species richness is not linear, with both quiet soundscapes with little song, and diverse soundscapes with continuous song, being characterised by high evenness; some studies have reported a weak decline in evenness with greater richness (e.g. Bradfer-Lawrence et al., 2019; Eldridge et al., 2018), with others reporting evenness to increase with species richness (e.g. Fuller et al., 2015; Mammides et al., 2017).

Contrary to other research (Boelman et al., 2007; Bradfer-Lawrence et al., 2019), we found no relationship between acoustic indices and bird abundance. This could be because abundance holds a comparatively weaker relationship with acoustic indices than species richness (Bradfer-Lawrence et al., 2020). Additionally, the species likely contributing most to soundscape complexity in our system are territorial and occur at low density, whilst the most abundant species, such as Woodpigeons *Columba palumbus* and Rooks *Corvus frugilegus*, are less vocal and have simple calls that are less likely to contribute to soundscape complexity. The difference may also arise from methodological differences between studies. For example, Boelman et al. (2007) and Bradfer-Lawrence et al. (2019) compared acoustic indices with diversity data collected at the same point in time, whilst we related bird diversity from a single point count to acoustic index values calculated across recording periods stretching weeks. Relative abundance can change rapidly over short periods of time, as animals move in relation to the recorders, whilst species richness stays more stable (Alcocer et al., 2022;

Bradfer-Lawrence et al., 2023), and so, a snapshot measure of richness is more likely to be representative of avian contributions to local soundscapes over longer periods of time than an equivalent snapshot of abundance.

4.2 | Effects of soundscape on vineyard visitors' experience

We found a clear link between soundscape characteristics and vineyard visitors' experience. The increase in reported *soundscape connectedness* and *sound enjoyment* with BIO indicate a positive association with soundscape volume, whilst the differences in responses with varying ACI, H and ADI values indicate a positive effect of soundscape complexity. Vineyard visitors who experienced the enhanced soundscapes showed stronger agreement with statements like '*hearing natural sounds at the vineyard today made me feel free from work, routine and responsibilities*', which demonstrates that increased soundscape volume and complexity positively affect our well-being and contribute to a mindful experience of nature. This aligns with earlier findings that showed that bird diversity and birdsong have a positive effect on life satisfaction and well-being (Dallimer et al., 2012; Hammoud et al., 2022; Methorst et al., 2021; Schebella et al. 2017), support restoration from stress and fatigue (Ratcliffe et al., 2013), and alleviate feelings of anxiety and paranoia (Stobbe et al., 2022). A sense of familiarity with sound can also enhance enjoyment and connectedness with soundscapes (Ednie & Gale, 2021), which could explain why vineyard visitors reported higher *sound enjoyment* at sites with lower NDSI values, indicative of lower ratios of biophony and anthrophony.

Soundscape enhancement had a significantly positive effect on both *sound enjoyment*, *soundscape connectedness* and *tour satisfaction* scores, crucially highlighting the direct contribution of the aural mode to visitors' experiences. Our soundscape enhancement with birdsongs increased agreement with statements such as '*the sounds I heard on the vineyard tour today were appealing*', '*I was engrossed by the sounds I heard along the vineyard tour*' and '*I feel relaxed during and immediately after this vineyard tour*', which showcases that natural sounds are an important part of the experience of nature and are noticed, even if subconsciously. Whilst similar effects of soundscape enhancement have been demonstrated on hiking trials (Ferraro et al., 2020), the patterns were not replicated under a laboratory setting that isolated the effect of aural stimuli (Douglas & Evans, 2022), raising questions as to whether sounds and sights associated with nature interact to deliver well-being benefits. Indeed, the results from the 'off' trials could arise because sound is a proxy for other habitat characteristics that can directly benefit well-being, such as the presence of hedgerows and woodland patches that host birds, or the perceived beauty of green spaces (Joye & Bolderdijk, 2015; Zhang et al., 2022). However, the experimental soundscape enhancement ensured only aural characteristics changed, and whilst it is noteworthy that there may have been minor variation in the exposure to playback for each participant due to differences in their standing position, speed of approach to the speaker or wind direction, our study kept any major additional modalities for nature engagement and physical activity stable. Regardless of the baseline and background sound levels, introducing additional birdsong into the ambient soundscape increased its complexity and volume, and the resultant increases in *sound enjoyment*, *soundscape connectedness* and *tour satisfaction* reinforce the specific contribution of birdsong to perceptions of biodiversity and delivery of benefits from nature engagement (Buckley, 2022; Douglas & Evans, 2022; Ferraro et al., 2020; Hammoud et al., 2022; Smalley et al., 2022; Stobbe et al., 2022). Importantly, we found the effect of soundscape enhancement to be supported across sites, regardless of their ambient soundscape characteristics, suggesting that there is capacity to improve health and well-being benefits from natural soundscapes through vineyard management practices that increase bird diversity (Paiola et al., 2020; Winter et al., 2018). We enhanced our soundscapes through the addition of songs from five species and further investigation could also identify whether the associated benefits continue to increase, level off, or even decline (Chmiel & Schubert, 2017), as more species are added, whilst also considering the interaction of birdsong with other sources of biophony and geophony, which were not measured in this study but have previously been shown to elicit feelings of connectedness (Ednie & Gale, 2021; Hallmann et al., 2017; Sharif et al., 2023).

At the individual level, the degree to which soundscapes alleviate mental fatigue and improve well-being can be influenced one's connection with nature (Ratcliffe et al., 2013). Vineyard visitors who reported higher willingness to purchase organic or fair-trade foods scored higher for *sound enjoyment* and *tour satisfaction*. These individuals likely had higher levels of care for and awareness of nature, which in turn could have enhanced how much they connected to the vineyard soundscapes during tours (Barbaro & Pickett, 2016; Soga & Gaston, 2016). Individual's ability to be mindful and experience nature is positively correlated with their reported well-being and happiness (Barbaro & Pickett, 2016; Capaldi et al., 2014; Capstick et al., 2022) and may explain why our experimental soundscape enhancement had a more strongly positive effect on vineyard visitors with higher levels of pro-environmental behaviours. On the flip side, this highlights that individuals with lower levels of nature connectedness may benefit less from spending time in nature and from experiencing soundscapes, which is a cause for concern. Lower levels of nature connectedness are characteristic of the younger generations (Kesebir & Kesebir, 2017; Schweizer et al., 2007; Soga & Gaston, 2016), and our research reinforces that this patterns holds true for soundscapes, as vineyard visitors below 40 years of age connected less strongly to the vineyard soundscape than older visitors. It would be interesting to further research whether different groups of people benefit differently from exposure to soundscapes, and to better understand if efforts to improve biodiversity could be optimised to maximise the benefits for people arising from nature.

5 | CONCLUSIONS

As biodiversity losses continue, particularly in agricultural areas (Rigal et al., 2023), and people's access to greenspaces becomes more limited (Buxton et al., 2021; Morris et al., 2011), creating new and accessible opportunities to experience natural soundscapes, whilst also delivering biodiversity conservation, is vital. Given the importance of the tourism industry within viticulture (Sussex Modern, 2023), and given the positive link between soundscape complexity and visitors' perception and experience, it is of particular value to vineyard managers to create complex natural soundscapes. At one extreme, this could potentially be achieved through artificial birdsong playback. However, this would require significant investment in technology and maintenance and would come without any conservation benefit. Furthermore, research has demonstrated that real-life experiences of nature lead to greater improvements in our mood and well-being compared to virtual or laboratory-based settings (Browning et al., 2020; Douglas & Evans, 2022). Instead, the ambition should be to increase bird richness in vineyards through, for example, diversification of habitats and ground cover, reduced chemical use (Barbaro et al., 2021; Zielonka et al., 2024), and the provision of nest boxes (Caprio & Rolando, 2017; Jedlicka et al., 2011). There could be potential monetary gains associated with investing in bird conservation measures in vineyards. Tourism loyalty (Jiang & Yan, 2022) and tourists' well-being (Fisher et al., 2021) increase with positive soundscape perception and higher sound diversity, whilst natural sounds have been shown to alter consumer behaviour and affect food choices and sales (Kontukoski, 2018; Peng-Li et al., 2022). We hypothesise that complex and diverse vineyard soundscapes which enhance visitors' experience could lead to them recommending their experience to others and translate to increased wine sales. This could lead to a win-win-win for biodiversity conservation, visitors' well-being and business prosperity.

Biodiversity loss and the extinction of experience are linked and, together, they have serious consequences for our health and well-being (Bratman et al., 2019; IPBES, 2019). Natural soundscapes play an important role, and we argue that they should be recognised as natural capital and further incorporated into existing conservation policy (e.g IPBES Conceptual Framework—connecting nature and people; Díaz et al., 2015) to support actions required to protect and enhance natural soundscapes. Governmental agri-environment schemes are a major source of conservation funding across '*working landscapes*' (Batáry et al., 2015) and support diversification practices that can effectively enhance diversity and the provision of regulating ecosystem services (e.g. biological pest control) within agricultural landscapes and positively affect production (Albrecht et al., 2020). We argue that these funding schemes, or indeed industry-specific sustainability schemes (Sigwalt et al., 2012; SWGB, 2020), should be extended to support management to conserve and enhance natural soundscapes, thus enriching nature's contributions to visitors' well-being and experience across vineyard landscapes.

AUTHOR CONTRIBUTIONS

Natalia B. Zielonka, Victoria Tubman and Simon J. Butler conceived the study; Natalia Zielonka and Victoria Tubman collected the data; Natalia B. Zielonka and Simon J. Butler curated and analysed the data; Natalia B. Zielonka wrote the first draft of the manuscript; Lynn V. Dicks and Simon J. Butler reviewed and supported the writing; Natalia B. Zielonka, Victoria Tubman, Lynn V. Dicks and Simon J. Butler acquired the funding; Lynn V. Dicks and Simon J. Butler provided supervision. All authors have read and agreed on the published version of the manuscript.

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CONFLICT OF INTEREST STATEMENT

The authors declare that they have no conflict of interest.

DATA AVAILABILITY STATEMENT

Data are publicly available on Dryad: https://doi.org/10.5061/dryad.j0zpc86pm.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

Data S1.

Appendix 1. Map of study site.

Appendix 2. Questionnaire.

Appendix 3. Model outputs–acoustic indices and bird diveristy.

Appendix 4. Demographic information about participants.

Appendix 5. Model outputs–acoustic indices and factor scores.

Appendix 6. Model outputs–factor scores and participants' demographics.

Appendix 7. Model outputs–experimental soundscape enhancement and predicted species.

Appendix 8. Model outputs–experimental soundscape enhancement, factor scores and participants' demographics.

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