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REVIEW

A Systematic Review of Anthropogenic Noise Impact on Avian Species

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Abstract

Purpose of review This study aims to investigate anthropogenic noise impact on avian species by means of a systematic review of literature.

Recent findings Based on previous anthropogenic noise impact frameworks, it was possible to: clarify the impacts of noise on birds; optimise the existing frameworks with findings produced over 44 years; recategorise noise impacts into more appropriate categories, indicating which are the positive and negatives, as well as acute and chronic impacts caused by anthropogenic noise; provide a significant cluster model of anthropogenic noise impacts on avian species subdivided into impacts on 'Behaviour' and 'Communication/Perception' (Cluster 1) and 'Physiology' (Cluster 2); and show how avian hearing frequency range overlaps noise source frequency range.

Summary This research adopted the database of Peacock et al. [1, 2] regarding avian species due to its vast coverage across taxa. A systematic literature review of 50 peer-reviewed papers about anthropogenic noise impact on birds was undertaken. A Two-Step Cluster analysis was calculated, showing the data subdivided into two clusters. Cluster 1 (76.9%) showed behavioural responses mainly composed of negative and auditory perception and communication impacts, presenting positive or negative noise impacts. Cluster 2 (23.1%) mainly showed negative impacts on physiological outcomes caused by traffic, anthropogenic, and background noise.

Keywords Noise impact · Birds · Physiology · Behaviour · Communication · Auditory perception

Introduction

Interest in the description of the interaction between anthropogenic and wildlife sounds emerged at the time of Aristotélēs (384 – 322 BC) through underwater acoustics observations [3]. Nearly 2000 years later, Leonardo da Vinci observed the sonic environment of ships and their effect on marine mammals [4]. In 1870, Thomas Edison invented a wax-cylinder recorder, which was used in 1889 for the first animal recordings in Germany [5]. Some years later, in 1892, Richard Lynch Garner recorded primates in a North American zoo [6]. However, anthropogenic noise was not highlighted as a problem until 1960, when the availability of audio cassette recorders made it possible to capture recordings during field studies [7]. In 1978, Flecher & Busnel published one of the first books about the effects of anthropogenic noise on wildlife as a result of the Symposium on the Effects of Noise on Wildlife, organised by ICA-WG4 as part of the 9th International Congress on Acoustics in Madrid, Spain in 1977 [8]. Since then, interest in the topic has increased, especially in recent years, due to the biodiversity crisis and rapid globalisation [9].

Besides wildlife, noise generated, especially on roads, railways, or airports, significantly impacts humans. These effects can transcend nuisance when exposition over a long period becomes a public health issue. The health impacts include annoyance, sleep disturbance, cardiovascular and metabolic problems, and adverse cognitive effects on children during learning [10].

Anthropogenic noise can impact wildlife at individual and population levels on all continents and habitats [11], affecting land and sea wildlife [10]. It can also disrupt ecosystems through changes within populations (e.g.,

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species that use vocalisations for courtship) [12], reducing the ability to reproduce [10] and interactions between species, including prey location and predator detection [12]. In underwater ecosystems, it can affect large mammals' ability to communicate and find food when exposed to the noise of shipping activities [10].

In 2020, the European Environment Agency published Report No. 22/2019 [13], which highlights the potential for anthropogenic noise to impact on both terrestrial and aquatic species. Impacts may be related to physiological and behavioural responses, influencing reproductive success, mortality, emigration and population density. Effects can start at low noise levels (by human definition, e.g. 40 dB(A)) for terrestrial species, such as birds, and the impacts depend on the frequency and noise source [14]. In an area of 1,594,451 km^2 across the EEA-33 (excluding Croatia and Turkey), at least 19% of the Natura 2000 protection areas are affected by noise from roads, railways, and aircraft with levels over the expected sound pressure range for quiet areas established by the European Noise Directive [13]. The Natura 2000 network was established based on European legislation (e.g., the Birds Directive [15] and Habitats Directive [16]), which states how special areas of conservation and special protection areas should be managed [15–17].

In North America, the US Department of Transportation published a report in 2004 report, no. FHWA-HEP-06–016 [18], which provided a "Synthesis of Noise Effects on Wildlife Populations". Regarding birds, it considered their hearing range and sensitivity, also how propagation and attenuation of sounds can affect exposure at different forest heights, and species avoidance of traffic-dominated areas mediated by the quantity of traffic and distance from roads [18]. Subsequently, the US Department of Transportation provided reports about noise control measures, such as noise barriers made of glass, these highlighted the issue of bird collisions with this kind of noise barrier, and proposed solutions to avoid bird collisions [18–21]. The detailed abbreviations and their definitions are listed in Table 1.

Motivation for Avian Species Noise Impact Investigation

According to the IUCN's Red List of Threatened Species [22], the avian class is the only class of animal species that was completely evaluated regarding the number of existing

Table 1 List of abbreviations used in the paper

Abbreviation	Definition	Abbreviation	Definition
Ac	Accipitriformes	DPS	Depends on Predominant Source
An	Anseriformes	EEA	European Environment Agency
Ap	Apodiformes	EEA-33	33 member countries of the European Environment Agency
Ca	Caprimulgiformes	H	Kruskal Wallis Test
Ch	Charadriiformes	Hz	Hertz
Cl	Columbiformes	HPA	Hypothalamic–pituitary–adrenal
Col	Coliiformes	ICA-WG4	International Congress on Acoustics – Work Group 4
Co	Coraciiformes	IOC	International Community of Ornithologists
Cu	Cuculiformes	IUCN	International Union for Conservation of Nature
Fa	Falconiformes	KHz	Kilohertz
Ga	Galliformes	N	Population size
Gr	Gruiformes	n	Sample size
Pa	Passeriformes	PHF	Peak Hearing Frequency
Pe	Pelecaniformes	PSF	Peak Sound Frequency
Ph	Phoenicopteriformes	PTS	Permanent Threshold Shift
Pi	Piciformes	TTS	Temporary Threshold Shift
Po	Podicipediformes	UAS	Unmanned aircraft systems
Ps	Psittaciformes	UAV	Unmanned aerial vehicle
St	Strigiformes	US	United States
Su	Struthioniformes	UK	United Kingdom
CF	Cluster Feature	UKRI	UK Research and Innovation
CFR	Communication frequencies	UAV	Unmanned aerial vehicle
dB(A)	A-weighted decibel	ε^2	Epsilon squared
dB	decibel	$f\Delta$	Frequency variation
DNA	Deoxyribonucleic acid	χ^2	Chi^2 Goodness of Fit

species and species under threat, as observed in Table 2. Therefore, the avian class is the only class allowing a correct anthropogenic impact estimation.

Noise Exposure Characteristics and Effects on Birds

In 2007, a report by the California Department of Transportation explored the effects of highway noise on birds [23]. In this report, Dooling and Popper [23] showed not only the effects caused by highway noise but also the characteristics of the noise source (e.g., their amplitude, frequency range and distance from the receiver, shown as zones (Table 3)). They did not define a distance range for their suggested zones of influence. Instead, they stated that "zone 1" was very near to the sound source and "zone 4" was very far from the source. Other studies regarding traffic noise have also shown the influence of noise amplitudes, the number of vehicles passing per hour and the distance over which effects on birds may be observed [24–26]. Based on these studies, it was possible to suggest some distances for the suggested effect zones, where zones 1–2 could be up to 30 m, zone 3 around 100 m, and zone 4 around 1500 m from the noise source.

As observed in Table 3, the effects on birds depend on noise amplitudes and covered frequency range. Likewise, in humans, the corresponding dose of noise can cause permanent threshold shift (PTS), which is permanent hearing damage, occurring from noise levels over 110 dB(A) in small mammals [27]. Temporary threshold shift (TTS), which is temporary hearing damage, has been observed in birds exposed to noises between 93 and 110 dB(A) in budgerigar (*Melopsittacus undulatus*) and small mammals [23]. Vocalisation masking has been reported when the noise sources have amplitudes between 85 and 125 dB(A). Physiological responses have been observed with noises between 85 and 140 dB(A), while behavioural responses with noises between 38 and 140 dB(A). The negative impacts on birds start with noise levels at 38 dB(A) related to breeding behaviour [25]. This could indicate that the noise source is disturbing rather than the noise level.

Most noise impact responses are acute [11], especially if the frequency content overlaps with the communication frequencies from birds. For example, it can be mentioned species like the Black-billed magpie, with communication frequencies (CFR) ranging from 0.5 to 3 kHz [33] and Rainbow lorikeet, with communication frequencies between 1 and 1.5 kHz [34], that overlap with traffic noise sources, which generally have a sound peak frequency between 0.5 and 1 kHz [35, 36]. Other species, like Common murre (CFR = 0.1 to 10 kHz) [37], Black-crowned night heron (CFR = 1.5 kHz) [38] and Wood duck (CFR = 1.4 to 1.9 kHz) [39], overlap their communication frequencies with aircraft noise sources that generally have a source peak frequency of 1 kHz [40]. However, species differ in communication behaviour in response to anthropogenic noise (e.g., with traffic spectral components). The differences occur due to the auditory thresholds' differentiation between species, where some species react, and others do not react to anthropogenic noise [41]. Over time, noise exposure can have other chronic characteristics, which can also degrade mid- and low-frequency hearing abilities, as has been observed in canaries (*Serius canarius*) [42]. Behavioural responses, such as increased flushing distance during the breeding period [43], have been observed in birds exposed to anthropogenic noise and changes in the frequency and duration of feeding nestlings in playback experiments, which used highway traffic noise around 69.1 dB(A) [44].

Classification of Anthropogenic Noise Impacts on Birds

Over the last two decades, several frameworks, mechanistic schemes and descriptions regarding the impacts of anthropogenic noise on wildlife have been presented [11, 13, 45, 46]. Effects of acoustic stimuli on animal physiology, development, neural function, genetic effects and behavioural changes have been reported in mammals, birds, fish, reptiles and insects [11, 13, 45, 46]. Figure 1 summarises the frameworks and mechanistic schemes regarding the findings about anthropogenic noise impacts on birds. The presented framework is subdivided into four major topics, which are: 1) 'Acoustic perception/Communication and hearing'; 2) 'Physiological response'; 3) 'Behavioural response'; and 4) 'Impact on fitness', which will be detailed in the sequence.

Table 2 Number of terrestrial vertebrate species (adapted from [22])

Group of species	Estimated number of described species in 2023	Evaluated number of species in 2023	Missing number of species to evaluate	Number of species under threat in 2023
Mammals	6631	5980	651	1339
Birds	11,197	11,197	0	1354
Reptiles	12,060	10,254	1806	1848
Amphibians	8707	8020	687	2876
Total	38,595	35,451	3144	7417

Table 3 Characteristics of anthropogenic noise for which impacts on birds have been reported (empty cells indicate data not available)

Order	Species Nominal Name	Species Common Name	Noise source	Acoustic overexposure PTS	Acoustic overexposure TTS	Masking	Physiological response	Behavioural response	Distance of effect	Frequency band (Hz)	Type of noise	Noise Amplitude at the source	Ref.
Ps	*Melopsittacus undulatus*	Budgerigar	Blast	x					Zone 1		Single Impulse	140 dB(A)	[27]
Ps[1,2] Group A[2]	*Melopsittacus undulatus*[1,2]	Budgerigar[1,2]	Jackhammer, pile driver, multiple blasts	x[1]		x[2]					Multiple Impulse	126 dB(A)[1] 50 – 60 dB(A)[2]	[27] [1] [23] [2]
Group A[2]			Highway Noise	x							Continuous noise	<110 dB(A)	
Ga	*G. g. domesticus*	Broiler chickens	Traffic				x			20 - 10 kHz	Continuous noise	110 dB	[28]
Pa	*Taeniopygia guttata*	Zebra finch	Alarms					x		430 – 470 Hz	non-continuous	97 dB	[29]
Ps	*Melopsittacus undulatus*	Budgerigar	Construction noise		x				Zone 2		Non-Strike Continuous	93 dB(A)	[23]
Ps[1,2] Group A[2]	*Melopsittacus undulatus*[1,2]	Budgerigar[1,2]	Highway Noise		x						Continuous noise	93 dB(A)	[27] [1] [23] [2]
Pa	*Sturnus vulgaris*	Common starlings	Traffic					x	Zone 3		Continuous noise	85 dB	[30]
Ps	*Melopsittacus undulatus*	Budgerigar	Construction noise			x					Non-Strike Continuous	50 -60 dB(A)	[23]
Ps[1,2]	*Melopsittacus undulatus*[1,2]	Budgerigar[1,2]								2 - 8kHz	Continuous noise	Below ambinet noise level 50 – 60 dB(A)	[27] [1] [23] [2]
Group A[2]			Highway Noise			x							
Ga	*G. g. domesticus*	Broiler chickens	Traffic					x			Continuous noise	66-76 dB	[31]
Group B			Traffic					x	Zones 3 - 4		Continuous noise	50 - 70 dB(A)	[26]
Pa	*Poeoptera*	Starlings	Traffic					x	Zones 1 - 4	1 - 7.5kHz	Continuous noise	50-100 dB	[32]
Group C			Traffic					x	Zone 4	100 Hz - 10 kHz	Continuous noise	between 38 and 56 dB(A)	[25]
Ps[1,2] Group A[2]	*Melopsittacus undulatus*[1,2]	Budgerigar[1,2]	Highway Noise				x	x			Continuous noise	Below ambient noise level 50 – 60 dB(A)	[27] [1] [23] [2]

Table 3 (continued)

Legend: **Group A:** Columbiformes (Cl), *Columbia livia,* Pigeon; 2. Passeriformes (Pa), *Molothrus ater,* Brown-headed cowbird; 3. Passeriformes (Pa), *Serinus canarius,* Common canary; 4. Passeriformes (Pa), *Serinus canarius,* Common canary; 5. Passeriformes (Pa), *Sturnus vulgaris,* European starling; 6. Passeriformes (Pa), *Lagonosticta senegala,* Fire finch; 7. Passeriformes (Pa), *Parus major,* Great tit; 8. Passeriformes (Pa), *Agelaius phoeniceus,* Red-winged blackbird; 9. Passeriformes (Pa), *Melospiza melodia,* Song sparrow; 10. Passeriformes (Pa), *Melospiza georgiana,* Swamp sparrow; 11. Passeriformes (Pa), *Taeniopygia guttata,* Zebra finch; 12. Psittaciformes (Ps), *Nymphicus lollandicus,* Cockatiel; 13. Psittaciformes (Ps), *Aratinga canicularis,* Orange-fronted conure; 14. Strigiformes (St), *Tyto alba,* Barn owl. **Group B**: 1. Anseriformes (An), *Cygnus olor,* Mute swan; 2. Anseriformes (An), *Anas platyrhynchos,* Mallard; 3. Anseriformes (An), *Spatula clypeata,* Shoveler; 4. Anseriformes (An), *Aythya fuligula,* Tufted duck; 5. Gruiformes (Gr), *Fulica,* Coot; 6. Charadriiformes (Ch), *American oystercatcher,* Oystercatcher; 7. Charadriiformes (Ch), *Vanellus vanellus,* Lapwing; 8. Charadriiformes (Ch), *Limosa limosa,* Black-tailed godwit; 9. Charadriiformes (Ch), *Tringa totanus,* Redshank; 10. Passeriformes (Pa), *Alauda arvensis,* Skylark; 11. Passeriformes (Pa), *Anthus pratensis,* Meadow pipit; 12. Passeriformes (Pa), *Motacilla flava,* Yellow wagtail. **Group C**: 1. Anseriformes (An), *Anas platyrhynchos,* Mallard; 2. Accipitriformes (Ac), Common buzzard; 3. Phoenicopteriformes (Ph), *Phasianius colchinus,* Ring-necked Pheasant; 4. Cuculiformes (Cu), *Cuculus canorus,* Common cuckoo; 5. Charadriiformes (Ch), *Scolopax rusticola,* Eurasian woodcock; 6. Coraciiformes (Co), *Columba oenas,* Stock dove; 7. Coraciiformes (Co), *Columba palumbus,* Common wood pigeon; 8. Piciformes (Pi), *Picus viridus,* European green woodpecker; 9. Piciformes (Pi), *Dendrocopus minor,* Lesser spotted woodpecker; 10. Piciformes (Pi), *Dendrocopus major,* Great spotted woodpecker; 11. Passeriformes (Pa), *Anthus trivialis,* Tree pipit; 12. Passeriformes (Pa), *Troglodytes troglodytes,* Eurasian wren; 13. Passeriformes (Pa), *Prunella modularis,* Dunnock; 14. Passeriformes (Pa), *Erithacus rubecula,* European robin; 15. Passeriformes (Pa), *Phoenicurus phoenicuris,* Common redstart; 16. Passeriformes (Pa), *Turdus merula,* Common blackbird; 17. Passeriformes (Pa), *Turdus philomenos,* Song thrush; 18. Passeriformes (Pa), *Acrocephalus palustris,* Marsh warbler; 19. Passeriformes (Pa), *Hippolais icterina,* Icterine warbler; 20. Passeriformes (Pa), *Sylvia borin,* Garden warbler; 21. Passeriformes (Pa), *Sylvia atricapilla,* Eurasian blackcap; 22. Passeriformes (Pa), *Phylloscopus sibilatrix,* Wood warbler; 23. Passeriformes (Pa), *Phylloscopus trochilus,* Willow warbler; 24. Passeriformes (Pa), *Regulus regulus,* Goldcrest; 25. Passeriformes (Pa), *Musciapa striata,* Spotted flycatcher; 26. Passeriformes (Pa), *Ficedula hypoleuca,* European pied flycatcher; 27. Passeriformes (Pa), *Aegithalos caudata,* Long-tailed tit; 28. Passeriformes (Pa), *Parus montanus,* Willow tit; 29. Passeriformes (Pa), *Parus palustris,* Marsh tit; 30. Passeriformes (Pa), *Parus caeruleus,* Eurasian blue tit; 31. Passeriformes (Pa), *Parus major,* Great tit; 32. Passeriformes (Pa), *Sitta europea,* Eurasian nuthatch; 33. Passeriformes (Pa), *Certhia brachydactyla;* Short-toed treecreeper; 34. Passeriformes (Pa), *Oriolus oriolus,* Eurasian Golden Oriole; 35. Passeriformes (Pa), *Ganrulus glandarius;* Eurasian jay; 36. Passeriformes (Pa), *Pica pica,* Eurasian magpie; 37. Passeriformes (Pa), *Corvus corone,* Carrion crow; 38. Passeriformes (Pa), *Sturnus vulgaris,* Common starling; 39. Passeriformes (Pa), *Coccothraustes coccothraustes,* Hawfinch; 40. Passeriformes (Pa), *Fringilla coelebs,* Eurasian chaffin

Acoustic Perception/Communication and Hearing

Acoustic perception comprises 'detection of sound stimuli' and 'inhibition of sound stimuli', which are common states of acoustic perception [13]. Bird communication and hearing aspects include: 'vocal plasticity', 'repetition of calls' and 'masking of calls'. The repetition of calls is used to help birds that are not visually in contact with each other, to perceive another bird's approach. Anthropogenic noise interferes with their communication by signal confusion, by overlapping sound signatures from bird's vocalisations with the anthropogenic noise frequency components [47]. Vocal plasticity is an adaptation in birds' vocalisation, such as using higher frequencies to avoid and mitigate masking by low-frequency noise [48, 49]. Masking of calls can inhibit birds' ability to propagate and interpret vocal information since low-frequency noise from the traffic of cars and trains can travel long distances and through vegetation. Depending on the frequency range of the avian vocalisation, the masking of communication frequencies can occur through these noise sources. Another important fact is the observation of tonal components of the noise sources, which, due to the high amplitudes, can also realise a masking process on some bird's vocalisations [50].

Physiological Response

This category has wide ramifications in areas such as: 'community ecology', 'DNA integrity and genes', 'cell structure and signalling', and 'physiological systems' [45].

Concerning the aspects related to community ecology [45, 51], it has been shown that anthropogenic noise can impact birth rate, mortality and survival through a 'decrease of reproductive / breeding success' ([52–62]).

Evidence of 'decrease of reproductive / breeding success' is influenced by heart rate changes, e.g. overexcitation, in Muscovy duck (*Cairina moschata*) embryos in response to acoustic stimulus [63] and reduction in the numbers of great tit (*Parus major*) [64] and eastern bluebirds (*Sialia sialis*) [65] fledglings in response to urban noise. 'Decrease of nesting success' due to noise includes negative alterations of nesting communities' species richness and increasing nest predators' influence on western scrub-jay (*Aphelocoma californica*) [66]. Regarding the 'Decrease of survival success', a study of white-crowned sparrows (*Zonotrichia leucophrys*), shows that noise does not directly influence the survival success of these birds, but predicted a significant negative influence on body condition, which may have long-term consequences for survival [67].

Sound stimuli, when considered unwanted and harmful for humans and wildlife [68], such as anthropogenic noise, may affect 'DNA integrity and genes' by provoking a stress response that leads to DNA damage and gene

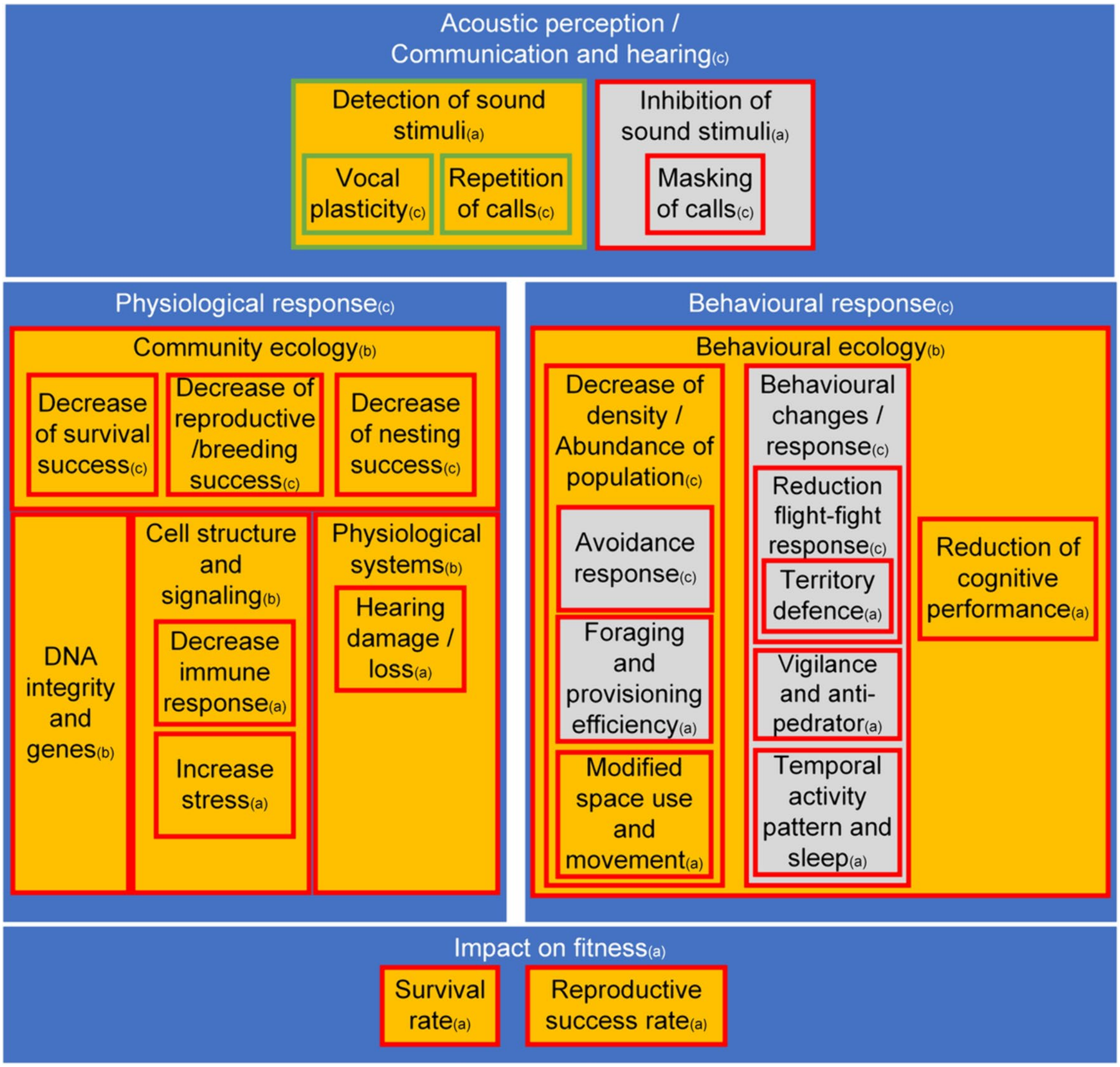

Fig. 1 Framework of anthropogenic noise impact on birds. Items with an (a) were adapted from EEA [13]; Items with a (b) were adapted from Kight and Swaddle [45]; Items with a (c) are suggested in this study. Items with green frames indicate positive impacts and red frames indicate negative ones. Yellow colour indicates chronic impacts, and grey indicates acute impacts. Blue colours indicate the major impact group

alteration [45]. Based on observations of infertile eggs [69], it has been suggested that long-term exposure to loud noise damages DNA because females in louder environments produce a higher number of infertile eggs.

Subcategories of 'Cell structure and signalling' include the effects of 'Decrease of immune response' and 'Increase of stress', being a problem when there is a chronic noise exposure. Cell structure damage can occur due to lesions caused in the avian auditory epithelium by noise with pure-tone and broadband components [70]. However, as soon as the damage occurs, new auditory hair cells around the hair cell damage are stimulated and the growth of support and hyaline cells induce the regeneration of avian auditory cells [71]. Biomarkers of stress, such as glucocorticoids, have been shown to elevate in response to noise exposure [72–75]. Noise as a stressor suppresses the immune function system of young birds, especially during learning periods, due to communication breakdown between adults and their young [45, 76]. House sparrows (*Passer domesticus*) showed an immune reduction in nestlings exposed to noise [77]. Changes in metabolism were observed with increase of cholesterol and protein levels due to noise stress in domestic hens (*G. gallus domesticus*) [78]. Additionally, stress-induced changes in glucocorticoid hormones under noisy conditions can interfere with the fitness of populations [79].

The effects on the 'Physiological systems' can be observed as possible hearing damage or loss. There is a tendency towards auditory thresholds shifts, when birds are exposed to noise levels above 93 dB(A) over 72 h [23, 80]. This is well documented in the work of Wolfenden et al. [81], which investigated the behaviour of chiffchaffs near airports. They observed a lowering of chiffchaff song frequency for individuals living near an airport compared to those from nearby control sites and hypothesised that noise-induced hearing loss may prevent the airport resident birds hearing higher frequencies. However, laboratory experiments indicate that birds are more resistant to hearing loss and auditory damage than humans and other mammals [80, 82], due to their capacity to regenerate their auditory cells following exposure to loud noises [83].

Behavioural Response

Behavioural ecology deals with the ability of animals to reproduce and survive in their natural environment [84]. Noise can impact the behaviour of birds through 'Decrease of density/ Abundance of population' [85–93], 'Behavioural changes/response' [1, 2] and 'Reduction of cognitive performance' [94, 95].

Concerning the 'Decrease of density/Abundance of population', the effects of 'Avoidance response', 'Foraging and provisioning efficiency', can cause 'Modified space use and movement', changing the number of species in areas which are affected by anthropogenic noise [13]. The other 'Behavioral changes/response' are commonly associated with 'Flight-fight response' due to 'Territory defence', where during bird fights, they cannot hear their neighbour's territorial calls, mediated by physiological stress hormone changes (e.g. [81]). Additional behavioural changes are related to 'Vigilance and anti-predator' and 'Temporal activity pattern and sleep' [13].

Animals move through space due to the use of dead reckoning, landmarks, and cognitive maps, which facilitate their navigation through a mental map-like representation of the environment [96]. Anthropogenic noise can cause a 'Reduction of cognitive performance' since the birds affected by noise can have smaller brain regions related to vocal learning; due to altered brain anatomy, they are also more distracted, affecting avoidance or vigilance behaviour [97, 98]. Other cognitive alterations have been observed in Zebra finch (*Taeniopygia guttata*). Following exposure to noise (110 dBA for > 100 d), the vocal skills learning of juvenile Zebra finches were altered, but these vocal skills subsequently recovered [99].

Impact of Fitness

Anthropogenic noise can have an 'Impact on fitness' (e.g., [100, 101]); that is, impacts on 'Survival' and 'Reproductive success rate' [13]. This happens due to severe hearing frequencies overlapping through anthropogenic noise, called acoustic masking. Birds would not hear significant acoustic signals in the environment, such as predators, competitors or mates, causing them to lose important information about environmental quality, safety, and competition [100]. Another important fact is the overproduction of glucocorticoids, activating the hypothalamic–pituitary–adrenal (HPA) axis, causing the perception of stress in the brain, directly affecting eggs' hatching success [100, 102].

Aim

This systematic review uses the mechanisms of impact framework described above to organise and evaluate the available evidence on noise impacts on birds. The meta-analysis is based on avian species investigated by Peacock et al. [103, 104], which provided a knowledge baseline regarding avian hearing curves, including peak hearing frequency – which is the frequency at maximum amplitude [105] – and dimensions of the hearing system. The information on Peak Hearing frequencies is essential for the verification of how the avian hearing frequencies overlap with and are influenced by anthropogenic noise frequencies, which could cause noise impact on birds, as observed by Engel et al. [106]. A Two Step-Cluster Analysis will provide an optimised noise impact structure considering parameters such as: the main category of impacts, sub-categories of impacts and noise sources. Avian order, species and peak hearing frequencies provide information to characterise impacts across taxa.

Methodology

A PRISMA diagram flow was adopted as a systematic review methodology [107]. Keywords "noise impact" + "noise effect" with species "nominal name" + "common name" were used to structure search of Google Scholar, Pub-Med, SCOPUS, Taylor and Francis, Springer, Wiley online library, Elsevier, ResearchGate, and Academia. The database of Peacock et al. [103, 104] was used to provide names of specific avian species to include within searches. Across the various search engines, a total amount of $N = 701{,}575$ candidate papers were identified up to 31st July 2023 using the keywords reported above. Of these, 920 documents which were identified for screening. Duplicate paper exclusion, unmatched topics and keywords or provision of partial information resulted in a pre-selection of 85 papers. After the removal of outputs that had not been subject to a rigorous peer review process prior to publication, 50 papers were carried forward

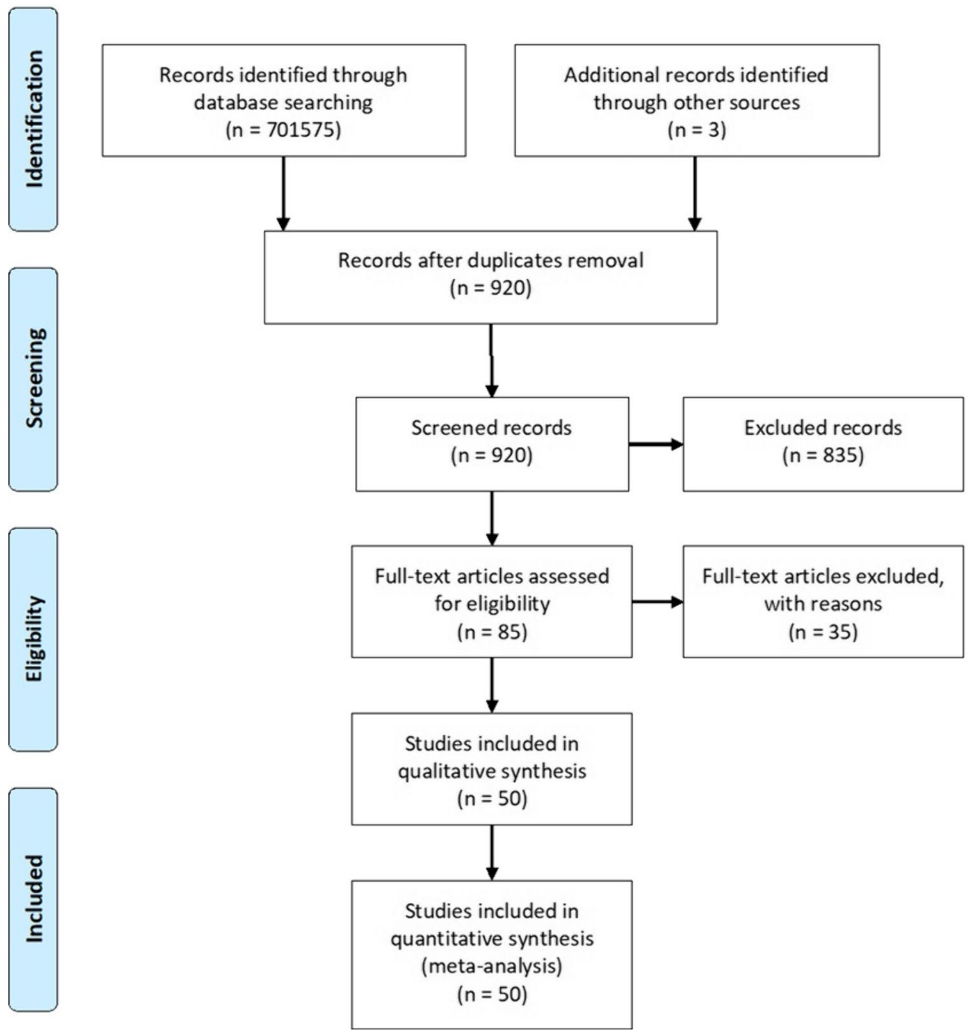

Fig. 2 PRISMA flow diagram for anthropogenic noise impact on birds

for further analysis (Fig. 2). These papers, which were all published within the last 44 years, provide insights into anthropogenic sound sources that are negatively impacting birds and what the physiological, behavioural, and acoustic (hearing and communication) responses are (Table 4). The classification of noise impacts on birds follows the suggested framework presented in Fig. 1.

Extracted data from 'impact', 'Impact category' and 'noise source' were analysed using a Two-Step Cluster analysis, which consists of a pre-clustering and a clustering [133]. In the first step, a cluster feature (CF) tree checks if the cluster can be merged with other clusters through a distance criterion. The second step allows the adjustment of clusters according to the desired number of clusters, considering the removal of outliers and considering descriptive, cross-tabulation analysis and correlation results. Afterwards, Chi-squared goodness of fit was calculated to confirm that the generated clusters do not have a random component, validating the result [134].

The Akaike Information Criterion was applied as a Clustering criterion on imputed variables (Table 4), using the Log-likelihood measure of distance. As inputs of the clustering, the following parameters were used: 1) 'Impact category' subdivided into 'physiological', 'communication and perception', and 'behavioural'; 2) 'Impact' which are subcategories from each 'impact category', e.g., 'behavioural changes/responses', 'decrease density/abundance of population', 'repetition of calls', 'masking of calls', 'vocal plasticity', 'decrease reproductive/breeding success', 'reduction cognitive performance', 'decrease survival success', and 'decrease of nesting success'; 3) noise source, e.g., 'background', 'Drone/UAV/UAS', 'white noise', 'aircraft/jet', 'mining', 'human', 'fireworks', 'anthropogenic', 'drilling', 'traffic', 'wind farm', 'construction', 'snowmobile', and 'military activity'. Parameters such as 'order', 'species' and 'peak hearing frequency' serve as evaluation fields, helping to characterise the receiver (birds) but not influencing the cluster's power.

Table 4 Anthropogenic noise impact on birds – metanalysis of 50 peer-reviewed works regarding 25 of the 39 avian species cited in Peacock et al. [103, 104] (empty cells in the table indicate data not available)

Order	Species Nominal Name	Species Common Name	Noise source	Classification of avian noise impact – Quantity of works – Referred work								
				Physiological response			Animal behaviour			Acoustic perception - Communication and hearing		
				Decrease of survival success	Decrease of reproductive/ breeding success	Decrease of nesting success	Reduction of cognitive performance	Decrease Density/ Abundance of population	Behavioural changes/ response	Vocal plasticity	Repetition of calls	Masking of calls
An	*Anas platyrhynchos*	Mallard duck	Background [108], Drone [1], White noise [109]					1 [108]	1 [1]	1 [109]		
	Aix sponsa	-Wood duck	Aircraft [110], Jet [111]						2 [110, 111]			
	Mergus merganser	Common merganser	-									
Su	*Struthio camelus*	Common ostrich	-									
Ga	*Pavo cristatus*	Indian peafowl	Background [112], Mining [113]						1 [113]	1 [112]		
Ph	*Phoenicopterus chilensis*	Chilean flamingo	UAV [114], Human [115]						2 [114, 115]			
Po	*Aechmophorus occidentalis*	Western grebe	Background [47]								1 [47]	
	Podilymbus podiceps	Pied-billed grebe	-									
Cl	*Streptopelia decaocto*	Eurasian collared dove	Urban background [2]						1 [2]			
Ca	*Chordeiles minor*	Common nighthawk	-									
Ap	*Aeronautes saxatalis*	White-throated swift	-									
Cu	*Coccyzus americanus*	Yellow-billed cuckoo	-									

Table 4 (continued)

Order	Species Nominal Name	Species Common Name	Noise source	Classification of avian noise impact – Quantity of works – Referred work								
				Physiological response			Animal behaviour			Acoustic perception - Communication and hearing		
				Decrease of survival success	Decrease of reproductive/ breeding success	Decrease of nesting success	Reduction of cognitive performance	Decrease Density/ Abundance of population	Behavioural changes/ response	Vocal plasticity	Repetition of calls	Masking of calls
Gr	*Fulica americana*	American coot	Fireworks [93], Anthropogenic [60]	1 [60]	1 [60]			1 [93]				
Pe	*Ardea herodia*	Great blue heron	Human steps [61], Anthropogenic ([54, 55])		2 [54, 55]	1 [61]						
	Plegadis chihi	White-faced ibis	Drilling [53]		1 [53]							
	Nycticorax nycticorax	Black-crowned night heron	Aircraft [92], Human [52]		1 ([52]			1 [92]				
Ch	*Uria aalge*	Common murre	Aircraft [56], Traffic, human speech, airplanes [116]		1 [56]							1 [116]
	Charadrius vociferus	Killdeer	-									
	Larus delawarensis	Ring-billed gull	-									
	Larosterna inca	Inca tern	Background [94]				1 [94]					
Ac	*Cathartes aura*	Turkey vulture	Traffic ([90], Wind farm [117, 118], UAV [119], UAS [120]					1 [90]	4 [117–120]			
St	*Bubo virginianus*	Great horned owl	-									
Col	*Urocolius macrourus*	Blue-naped mousebird	-									

Table 4 (continued)

Order	Species Nominal Name	Species Common Name	Noise source	Classification of avian noise impact – Quantity of works – Referred work								
				Physiological response			Animal behaviour			Acoustic perception - Communication and hearing		
				Decrease of survival success	Decrease of reproductive/ breeding success	Decrease of nesting success	Reduction of cognitive performance	Decrease Density/ Abundance of population	Behavioural changes/ response	Vocal plasticity	Repetition of calls	Masking of calls
Co	*Megaceryle alcyon*	Belted kingfisher	-									
	Dacelo novaeguineae	Laughing kookaburra	-									
Pi	*Colaptes auratus*	Northern flicker	-									
	Leuconotopicus villosus	Hairy woodpecker	Construction, traffic, human [59], Traffic [85]		1 [59]			1 [85]				
	Sphyrapicus nuchalis	Red-naped sapsucker	-									
Fa	*Falco sparverius*	American kestrel	Traffic and/or human [62, 121], Traffic [58]		1 [58]	1 [62]		1 [121]				
Ps	*Trichoglossus moluccanus*	Rainbow lorikeet	Traffic [91]					1 [91]				
	Melopsittacus undulatus	Budgerigar	Traffic [122]						1 [122]			

Table 4 (continued)

Order	Species Nominal Name	Species Common Name	Noise source	Classification of avian noise impact – Quantity of works – Referred work								
				Physiological response			Animal behaviour			Acoustic perception - Communication and hearing		
				Decrease of survival success	Decrease of reproductive/ breeding success	Decrease of nesting success	Reduction of cognitive performance	Decrease Density/ Abundance of population	Behavioural changes/ response	Vocal plasticity	Repetition of calls	Masking of calls
Pa	*Taeniopygia guttata*	Zebra finch	Traffic [116, 123, 124], Anthropogenic [95], Background [57, 125]		1 [57]		3 [95, 123, 124]		2 [116, 125]			
	Sturnus vulgaris	European starling	Traffic [126], Background [127]				1 [126]		1 [127]			
	Quiscalus quiscula	Common grackle	Anthropogenic [128]						1 [128]			
	Corvus corax	Common raven	Urban [88], Traffic [86], Snowmobile [50]					2 [86, 88]				1 [50]
	Corvus brachyrhnchos	American crow	Anthropogenic [129], Military activity [89]					1 [89]	1 [129]			
	Pica hudsonia	Black-billed magpie	Traffic [130]						1 [130]			
	Cyanocitta stelleri	Steller's jay	Traffic [131]					1 [131]				
	Cyanocitta cristata	Blue jay	White noise [132]						1 [132]			

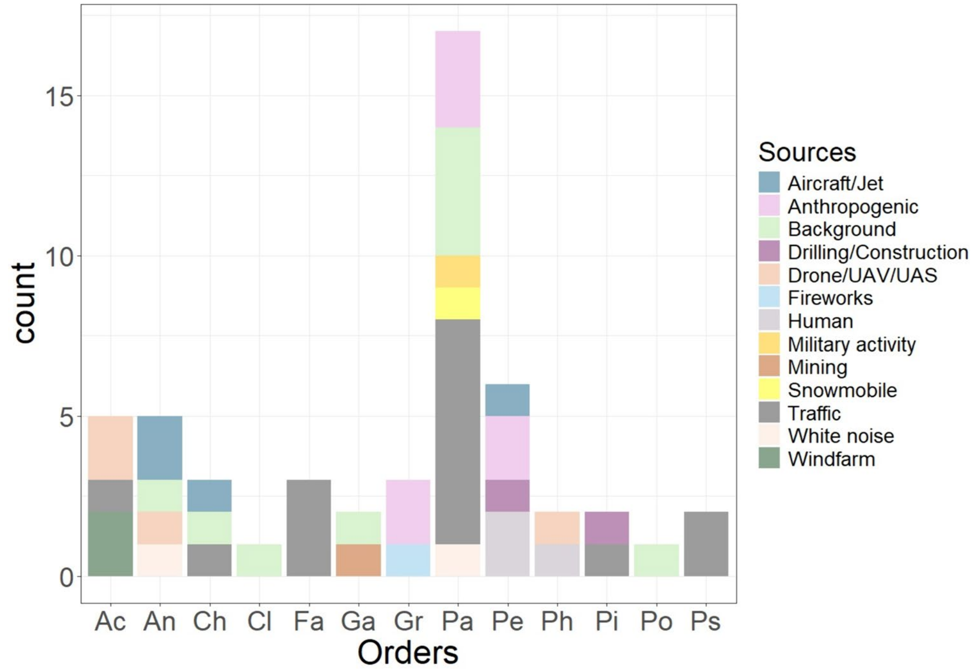

Fig. 3 Quantification of reported sound sources that impact avian orders

Results

The identified noise impacts were categorised using the framework presented in Table 4. The results highlight impacts within the blue coloured section of the framework; that is, 'Physiological response' ('Decrease of survival success', ' Decrease of reproductive/breeding success', 'Decrease of nesting success'); 'Animal behaviour' ('Reduction of cognitive performance', 'Decrease of density/abundance of population', 'Behavioural changes/response'); 'Acoustic perception – communication and hearing' ('Vocal plasticity, 'Repetition of calls', 'Masking of calls'). A descriptive overview of the noise sources and impacts on avian species is presented in Sect. "Descriptive Analysis of the Anthropogenic Noise Impacts on Birds". The Two-Step Clustering (Sect. "Two-step Cluster Analysis of the Anthropogenic Noise Impacts on Birds") groups avian orders, species, noise sources, impacts and peak hearing frequency.

The systematic review yielded data for 20 avian orders and 39 species following the species sampled in Peacock et al. [103, 104] (Table 4). However, of the 39 species, only 25 presented information about anthropogenic noise impact, gathered in 50 peer-reviewed papers and 52 noise impact reports on avian species. The following fourteen species did not present studies related to anthropogenic noise impact during the period of data collection for this systematic review: common merganser (*Mergus merganser*), common ostrich (*Struthio camelus*), pied-billed grebe (*Podilymbus podiceps*), common nighthawk (*Chordeiles minor*), white-throated swift (*Aeronautes saxatalis*), yellow-billed cuckoo (*Coccyzus americanus*), kildeer (*Charandrius vociferus*), ring-billed gull (*Larus delawarensis*), great horned owl (*Bubo virginianus*), blue-naped mousebird (*Urocolius macrourus*), belted kingfisher (*Megaceryle alcyon*), laughing kookaburra (*Dacelo novaegineae*), northern flicker (*Colaptes auritus*), and red-naped sapsucker (*Sphyrapicus nuchalis*). Considering the IOC World Bird List [135], the reference work of Peacock et al. [103, 104] does not present all avian orders. The following eight orders were not represented within the analysis of Peacocock et al. [103, 104] and consequently in this analysis: Phaethontiformes, Pterocliformes, Otidiformes, Gaviiformes, Procellariiformes, Ciconiiformes, Trogoniformes, Bucerotiformes.

Descriptive Analysis of the Anthropogenic Noise Impacts on Birds

Results related to descriptive statistics are presented in Figs. 3 and 4. Results concerning sound sources and responses to anthropogenic-generated sounds were not available for two orders: Cuculiformes and Suliformes.

Figure 3 shows the sound sources that have been observed to change bird behaviour in different environments. These sources were: 'background', 'drone/UAV/AUS', 'white noise', 'aircraft/jet', 'mining', 'human', 'fireworks', 'anthropogenic', 'drilling', 'traffic', 'windfarm', 'construction', 'snowmobile', and 'military activity'. As a matter of definition, background noise is classified as the opposite of foreground noise or principal sound signal under investigation [106, 136]. Anthropogenic noise is equivalent to human-produced noise, which is considered unwanted and harmful [106, 137], and human noise is related to human-related

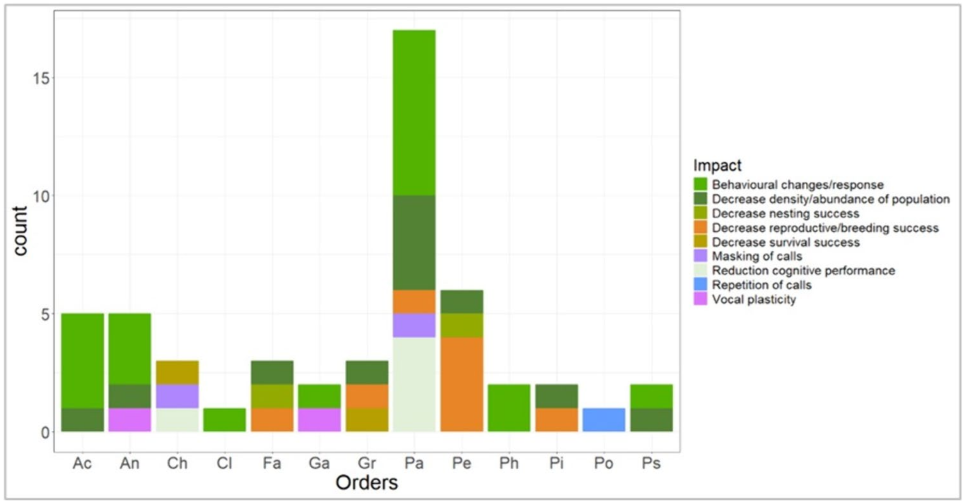

Fig. 4 Quantification of anthropogenic noise impacts on birds subdivided according to avian orders

noises (voice—communication, body—movement and clothing) [106, 137]. The plot from Fig. 3 shows the number of studies related to each sound source, subdivided by avian order. The avian order which has been most studied in relation to different sound sources is Passeriformes (Pa), with 17 studies covering anthropogenic, traffic, snowmobile, and military activity sound sources.

Figure 4 shows the impacts of noise on avian populations that were identified through the Systematic Review. These impacts are 'decrease of survival success', 'reduction of cognitive responses', 'vocal plasticity', 'decrease of reproductive/breeding success', 'density/abundance of population', 'repetition of calls', 'decrease of nesting success', 'behavioural changes/responses', and 'masking of calls'. The avian order with the greatest number of studies reporting behavioural changes is Passeriformes (Pa) with 17 studies highlighting 'decrease of reproductive/breeding success', 'reduction of cognitive performance', 'density/abundance of population', 'behavioural changes/responses', and 'masking of calls'.

Two-step Cluster Analysis of the Anthropogenic Noise Impacts on Birds

The Two-Step Clustering results are presented in Fig. 5 and Table 5. As observed in Fig. 5, Cluster 1 had 40 observations (76.9%), and Cluster 2 had 12 observations (23.1%). The ratio between the largest and smallest cluster was 3.33. To confirm the significance of the extraction of these two clusters, a Chi^2 goodness of Fit of the clusters was calculated, which confirmed their significance $\chi^2(1) = 15.077$, $p < 0.001$, indicating that the clusters were not formed randomly. The Silhouette measure of cohesion showed good cluster quality (0.6).

The Two-Step Cluster analysis also indicates the importance of each predictor, where 1.0 indicates a high importance and 0.00 is a low importance. The 'Impact category' variable presented high importance (1.0), the 'Impact' indicated moderate importance (0.69) and the 'sources' presented low importance (0.07).

To verify the effect size of the clusters, a Kruskal–Wallis test was used because the sample was not homogeneous. Additionally, the effect size was estimated through epsilon squared (ε^2) [138]. The interpretation of the epsilon-squared effect size corresponds to $0.00 < 0.01$ (negligible), $0.01 < 0.04$ (weak), $0.04 < 0.16$ (moderate), $0.16 < 0.36$ (relatively strong), $0.36 < 0.64$ (strong) and $0.64 < 1.00$ (very strong) [139].

The Kruskal-Walis test and the epsilon-squared effect size confirmed the findings of predictor importance of the Two-Step Cluster Analysis, where for 'Impact category' $H(1) = 39.830$, p-value < 0.001, $\varepsilon^2 = 0.781$ (very strong), 'Impact' $H(1) = 28.986$, p-value < 0.001, $\varepsilon^2 = 0.568$ (strong) and 'Sources' $H(1) = 0.000$, p-value $= 0.982$, $\varepsilon^2 = 0.000$ (negligible).

Regarding the cluster composition, Fig. 5 shows a sunburst graph with the categories of each cluster. Cluster 1 concentrated 'Impact category' observations on 'behavioural' ($n = 35$, 87.5%) and 'communication and perception responses' ($n = 5$, 12.5%). The sub-categories from 'behavioural' are 'behavioural changes/response' ($n = 19$, 47.5%), 'decrease density/abundance of population' ($n = 11$, 27.5%), and 'reduction cognitive performance' ($n = 5$, 12.5%). 'Communication and perception' are subdivided into 'masking of calls' ($n = 2$, 5%), 'repletion of calls' ($n = 1$, 2.5%) and 'vocal plasticity' ($n = 2$, 5%). Related to the noise sources that are causing these impacts, the majority was associated with traffic ($n = 11$, 27.5%), followed by background ($n = 8$, 20%), anthropogenic ($n = 6$, 15%), drone/UAV/UAS ($n = 4$, 10%), aircraft/jet ($n = 3$, 7.5%), wind farm ($n = 2$, 5%), and white noise, mining, human, fireworks, snowmobile, military activity ($n = 1$, 2.5% each). Cluster 2 observations concentrated on 'physiological' responses ($n = 12$, 23.1%), with

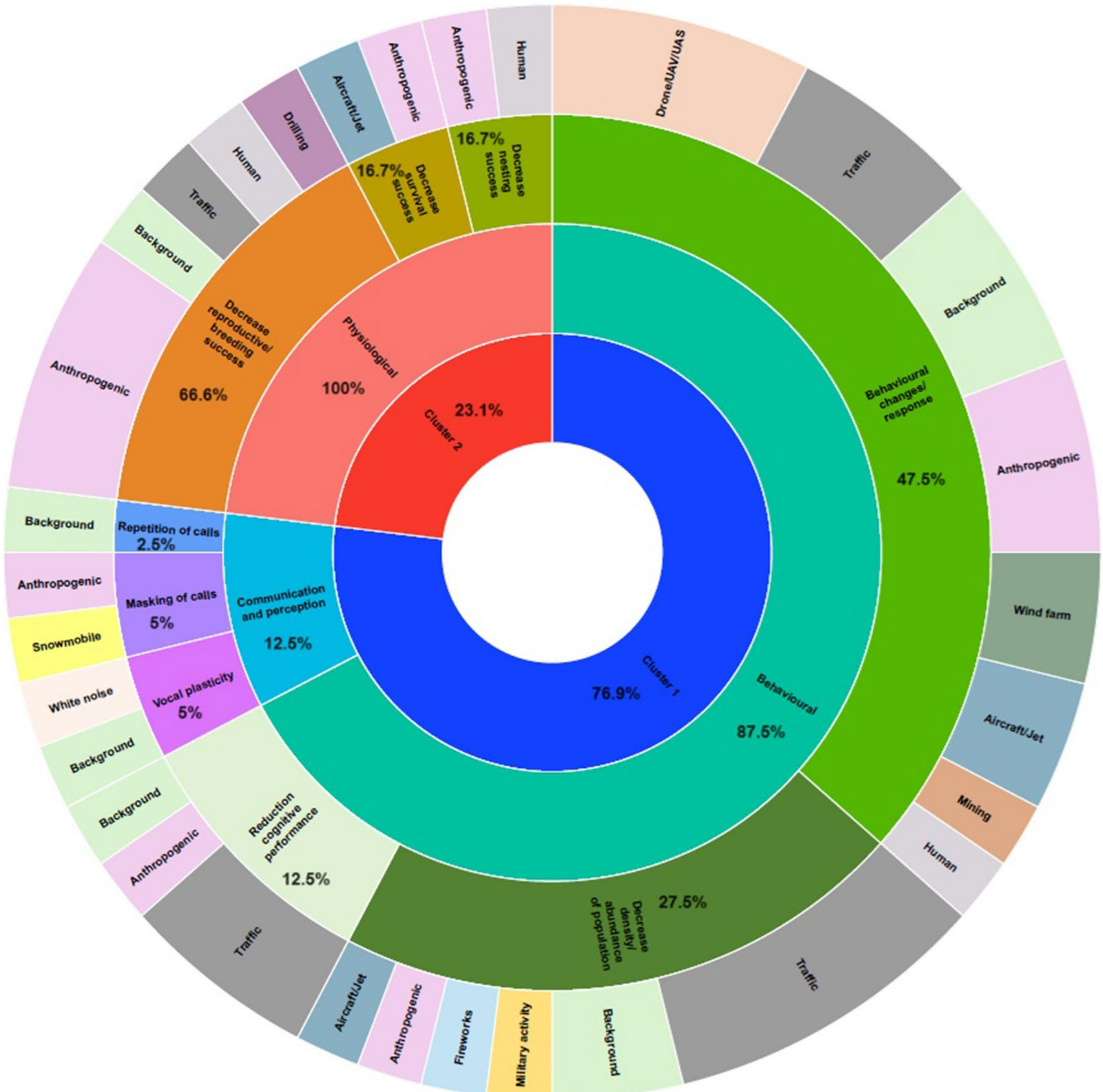

Fig. 5 Clusters of noise impact on birds and related noise sources

100% of the observations related to 'Physiological' aspects subdivided into 'decrease of nesting success' ($n=2$, 16.7%), 'decrease of reproductive/breeding success' ($n=8$, 66.6%), and decrease of survival success' ($n=2$, 16.7%). The related noise sources to these impacts are anthropogenic ($n=6$, 50%), human ($n=2$, 16.8%), and background, aircraft/jet, drilling, and traffic with $n=1$ (8.3%) each.

Table 5 shows which 'noise sources' are associated with each 'impact' and the characteristics of the impacted species through the indication of 'order', 'species' name and 'peak hearing frequency'. Cluster 1 is formed by impacts on 'behavioural responses' such as 'behavioural changes/responses' occurred in association with 'aircraft/jet' (2 observations), 'anthropogenic' (3 observations), background (3 observations), drone/UAV/UAS (4 observations), 'human' (1 observation), 'mining' (1 observation), 'traffic' (3 observations) and 'wind farm' (2 observations) on birds with peak hearing frequency varying from 862 to 2018 Hz. These birds include Anseriformes (An) – wood duck, mallard duck, Passeriformes (Pa) – common grackle, American crow, blue jay, zebra finch, European starling, black-billed magpie, Columbiformes (Cl)—Eurasian collared dove, Phoenicopteriformes (Ph) – Chilean flamingo, Galiformes (Ga) – Indian peafowl, Psittaciformes (Ps) – Budgerigar, and Accipitriformes (Ac) – Turkey Vulture.

There was evidence that 'Decrease density/population abundance' was happening due to noises generated by aircraft/jet (1), anthropogenic (1), background (2), fireworks (1), military activity (1) and traffic (5). The birds which presented this form of impact were birds with peak hearing

Table 5 Clusters subdivision of birds impacted by noise

Order	Species	Noise source	Impact	Peak Hearing Frequency—PHF (Hz)	Cluster
An	Wood duck	Aircraft/Jet	Behavioural changes/response	1106	Cluster 1 $n=40$
An	Wood duck	Aircraft/Jet	Behavioural changes/response	1106	
Pa	Common grackle	Anthropogenic	Behavioural changes/response	1604	
Pa	American crow	Anthropogenic	Behavioural changes/response	1062	
Pa	Blue jay	Anthropogenic	Behavioural changes/response	1480	
Pa	Zebra finch	Background	Behavioural changes/response	1879	
Pa	European starling	Background	Behavioural changes/response	2018	
Cl	Eurasian collared dove	Background	Behavioural changes/response	1269	
An	Mallard duck	Drone/UAV/UAS	Behavioural changes/response	1138	
Ph	Chilean flamingo	Drone/UAV/UAS	Behavioural changes/response	973	
Ac	Turkey vulture	Drone/UAV/UAS	Behavioural changes/response	1165	
Ac	Turkey vulture	Drone/UAV/UAS	Behavioural changes/response	1165	
Ph	Chilean flamingo	Human	Behavioural changes/response	973	
Ga	Indian peafowl	Mining	Behavioural changes/response	862	
Ps	Budgerigar	Traffic	Behavioural changes/response	1672	
Pa	Zebra finch	Traffic	Behavioural changes/response	1879	
Pa	Black-billed magpie	Traffic	Behavioural changes/response	1426	
Ac	Turkey vulture	Wind farm	Behavioural changes/response	1165	
Ac	Turkey vulture	Wind farm	Behavioural changes/response	1165	
Pe	Black-crowned night heron	Aircraft/Jet	Decrease density/abundance of population	677	
Fa	American kestrel	Anthropogenic	Decrease density/abundance of population	1174	
An	Mallard duck	Background	Decrease density/abundance of population	1138	
Pa	Common raven	Background	Decrease density/abundance of population	793	
Gr	American coot	Fireworks	Decrease density/abundance of population	1301	
Pa	American crow	Military activity	Decrease density/abundance of population	1062	
Ac	Turkey vulture	Traffic	Decrease density/abundance of population	1165	
Pi	Hairy woodpecker	Traffic	Decrease density/abundance of population	1706	
Ps	Rainbow lorikeet	Traffic	Decrease density/abundance of population	1764	
Pa	Common raven	Traffic	Decrease density/abundance of population	793	
Pa	Steller's jay	Traffic	Decrease density/abundance of population	1257	
Ch	Common murre	Anthropogenic	Masking of calls	1928	
Pa	Common raven	Snowmobile	Masking of calls	793	
Po	Western grebe	Background	Repetition of calls	1906	
An	Mallard duck	White noise	Vocal plasticity	1138	
Ga	Indian peafowl	Background	Vocal plasticity	862	
Ch	Inca tern	Background	Reduction cognitive performance	1801	
Pa	Zebra finch	Anthropogenic	Reduction cognitive performance	1879	
Pa	Zebra finch	Traffic	Reduction cognitive performance	1879	
Pa	Zebra finch	Traffic	Reduction cognitive performance	1879	
Pa	European starling	Traffic	Reduction cognitive performance	2018	

Table 5 (continued)

Order	Species	Noise source	Impact	Peak Hearing Frequency—PHF (Hz)	Cluster
Pe	Great blue heron	Human	Decrease nesting success	895	Cluster 2 $n=12$
Fa	American kestrel	Anthropogenic	Decrease nesting success	1174	
Gr	American coot	Anthropogenic	Decrease reproductive/breeding success	1301	
Pe	Great blue heron	Anthropogenic	Decrease reproductive/breeding success	895	
Pe	Great blue heron	Anthropogenic	Decrease reproductive/breeding success	895	
Pi	Hairy woodpecker	Anthropogenic	Decrease reproductive/breeding success	1706	
Pe	White-faced ibis	Drilling	Decrease reproductive/breeding success	1076	
Pe	Black-crowed night heron	Human	Decrease reproductive/breeding success	677	
Fa	American kestrel	Traffic	Decrease reproductive/breeding success	1174	
Pa	Zebra finch	Background	Decrease reproductive/breeding success	1879	
Gr	American coot	Anthropogenic	Decrease survival success	1301	
Ch	Common murre	Aircraft/Jet	Decrease survival success	1928	

frequencies from the species ranging from 677 to 1764 Hz from the following orders: Pelecaniformes (Pe) – black-crowned night heron; Falconiformes (Fa) – American kestrel; Anseniformes (An) – mallard duck; Passeriformes (Pa) – common raven; American crow (reported with two observations impacts) and Steller's jay; Gruiformes (Gr) – American coot; Accipitiformes (Ac) – turkey vulture; Piciformes (Pi) – hairy woodpecker; Psittaciformes (Ps) – rainbow lorikeet (Table 4).

'Reduction of cognitive performance' occurs due to background (1), anthropogenic (1), and traffic noise (3). The affected birds, with frequencies from the species ranging from 1801 to 2018 Hz, were from the orders Charadriformes (Ch)—inca tern and Passeriformes (Pa)—zebra finch (three observed impacts) and European starling (Tab4).

Other impacts on 'Communication and hearing', such as 'Masking of calls', were associated with anthropogenic (1) and snowmobile (1) noise sources. The species which presented this output were from the orders Charadriformes (Ch) – common murre, and Passerifomes (Pa) – common raven with peak hearing frequencies from the species of 1928 Hz and 793 Hz, respectively. 'Repetition of calls' was observed with the association of background noise (1) for Podicipediformes (Po) – western grebe, which has a peak hearing frequency of 1906 Hz. 'Vocal plasticity' was observed when there is white noise (1) and background noise (1), for the following orders Anseriformes (An) – mallard duck and Galiformes (Ga) – Indian peafowl, with 1138 Hz and 862 Hz as respective peak hearing frequencies from the species (Tab4).

In Cluster 2, 'Physiological response', such as 'decreased nesting success', is related to human and anthropogenic noise. The orders for which impacts were reported are Pelecaniformes (Pe)—great blue heron (PHF = 895 Hz) and Falconiformes (Fa)—American kestrel (PHF = 1174 Hz). 'Decrease reproductive/breeding success' occurred due to anthropogenic (4), drilling (1), human (1), traffic (1), and background (1). The birds for which this type of impact was reported were birds Gruiformes (Gr) – American Coot, Pelecaniformes (Pe) – great blue heron (two impact observations), white-faced ibis and black-crowed night heron, Falconiformes (Fa) – American kestrel, Piciformes (Pi) – hairy woodpecker and Passeriformes (Pa) – zebra finch, with a variation of peak hearing frequencies from the species from 677 to 1879 Hz. 'Decrease of survival success' was reported in relation to aircraft/jet noise (1) and anthropogenic noise (1). The following orders are Gruiformes (Gr) – American coot (PHF = 1301 Hz), and Charadriformes (Ch) – common murre (PHF = 1928 Hz) (Tab5).

Figures 6-8 show the hearing frequency range and peak hearing frequency of the investigated avian species [103], noise source frequency and peak sound frequency [125, 126, 128, 140–142] of the observed noise sources that are causing impacts on these avian species. Figure 6 is showing the species, which reported 'behavioural' responses and Fig. 7 shows 'communication and perception' impacts regarding to noise observed in Cluster 1. Figure 8 shows the species and noise sources which caused 'physiological' impacts observed in Cluster 2. As observed in all figures, part of the spectral content of the noise sources overlaps with the

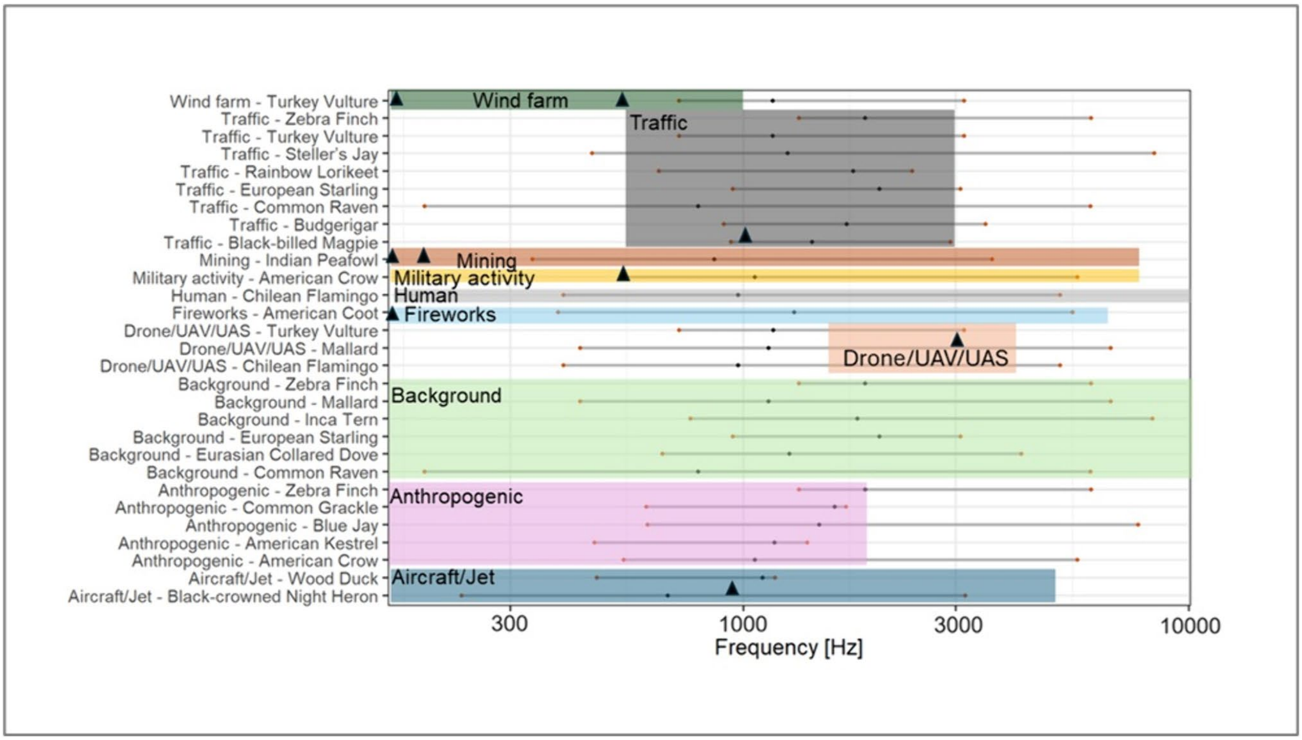

Fig. 6 Overlapping of avian frequency range and noise source spectra observed in the behavioural impacts of noise. Legend: ● Peak Hearing Frequency (PHF); ▲ Peak Sound Frequency (PSF); Depends on Predominant Source (DPS); PSF1 = Anthropogenic; PSF2 = Background; PSF3 = Drone/UAV/UAS; PSF4 = Human; PSF5 = Military activity; PSF6 = Traffic; PSF7 = Wind farm; PSF8 = Aircraft/Jet; PSF9 = Fireworks; PSF10 = Mining; Black-crowned Night Heron – PHF = 677 Hz, PSF8 = 1000 Hz; Wood duck – PHF = 1106 Hz, PSF8 = 1000 Hz; American Crow—PHF = 1062 Hz, PSF1 = DPS, PSF5 = 500 Hz; American Kestrel—PHF = 1174 Hz, PSF1 = DPS; Blue Jay—PHF = 1480 Hz, PSF1 = DPS; Common Grackle—PHF = 1604 Hz, PSF1 = DPS; Zebra Finch—PHF = 1879 Hz, PSF1 = DPS, PSF2 = DPS, PSF6 = 500–1000 Hz; Common Raven—PHF = 793 Hz, PSF2 = DPS, PSF6 = 500 – 1000 Hz; Eurasian Collared Dove—PHF = 1269 Hz, PSF2 = DPS; European Starling—PHF = 2018 Hz, PSF2 = DPS, PSF6 = 500 – 1000 Hz; Inca Tern—PHF = 1801 Hz, PSF2 = DPS; Mallard—PHF = 1138 Hz, PSF2 = DPS, PSF3 = 3000 Hz; Chilean Flamingo—PHF = 973 Hz, PSF3 = 3000 Hz, PSF4 = DPS; Turkey Vulture—PHF = 1165 Hz, PSF3 = 3000 Hz, PSF6 = 500 – 1000 Hz, PSF7 = 1–30 Hz / 500-1000 Hz / 10–200 Hz; American Coot—PHF = 1301 Hz, PSF9 = 20 Hz; Indian Peafowl—PHF = 862 Hz, PSF10 = 63 to 125 Hz; Black-billed Magpie—PHF = 1426 Hz, PSF6 = 500 to 1000 Hz; Budgerigar—PHF = 1672 Hz, PSF6 = 500 to 1000 Hz; Rainbow Lorikeet—PHF = 1764 Hz, PSF6 = 500 to 1000 Hz; Steller's Jay—PHF = 1257 Hz, PSF6 = 500 to 1000 Hz

hearing frequencies or at least the peak hearing frequencies of the investigated species.

Discussion

Anthropogenic Noise Impacts on Birds

Anthropogenic noise has been shown to impact on physiological responses, behavioural responses and acoustic perception – communication and hearing (Table 5). The reported noise sources' associated with the classified impacts on birds are discussed below.

a. Anthropogenic noise

This category of noise is human-produced noise, which is unwanted and maybe harmful. This kind of noise can cause: 1) a decrease in the survival success of birds due to antipredator responses, e.g., vigilance or flight on American coot [60]; 2) a decrease in reproductive/breeding success through energetic costs due to disturbance by flight activities related to feeding, therefore there is no energy or motivation for reproductive activities in the American coot [60]. Another reason for the decrease in reproductive/breeding success is the presence of humans near colonies, as observed in great blue heron studies [55]; 3) a reduction of cognitive performance was observed in zebra finch studies through the reduced performance of learning of novel motor skills, as well as fewer copy demonstrations [124]; 4) behavioural changes were observed in zebra finch, common grackle, and American crow due to foraging difficulties [125, 128, 129]; and 5) masking of calls on common murre studies, by the observation that sensitive hearing frequencies overlap with anthropogenic noise [116].

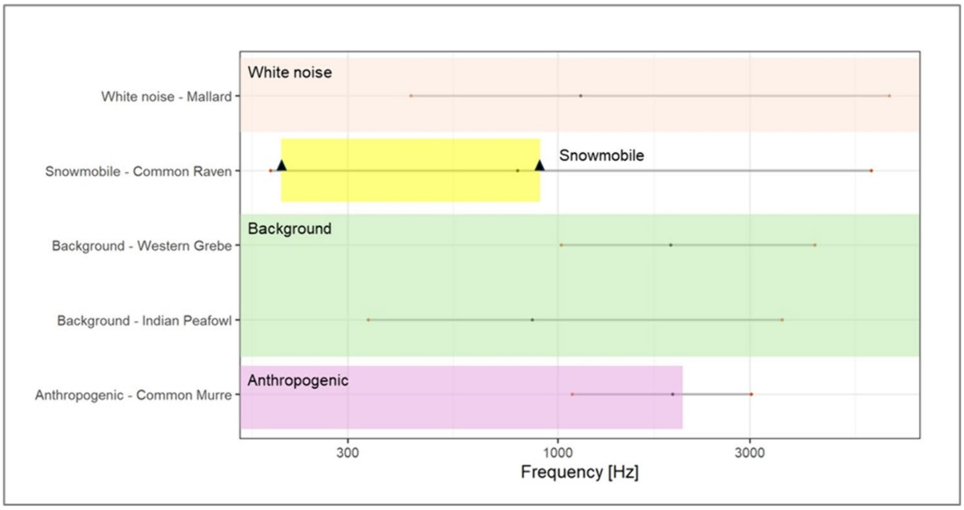

Fig. 7 Overlapping of avian frequency range and noise source spectra observed in communication and perception noise impacts. Legend: ● Peak Haring Frequency (PHF); ▲ Peak Sound Frequency (PSF); Depends on Predominant Source (DPS); PSF1 = Anthropogenic; PSF2 = Background; PSF3 = Snowmobile; PSF4 = White noise; Common Murre—PHF = 1928 Hz, PSF1 = DPS; Indian Peafowl – PHF = 862 Hz, PSF2 = DPS; Western Grebe—PHF = 1906 Hz, PSF2 = DPS; Common Raven—PHF = 793 Hz, PSF3 = 200 to 800 Hz; Mallard – PHF4 = 1138 Hz, PSF = same amplitude in all frequencies

b. Human noise

This noise is generated by human communication, clothing and movement, which can affect birds through 1) a decrease in reproductive/breeding success, observed in black-crowed night heron studies, the disturbance and destruction of eggs, chicks and adults [52]; 2) a decrease of nesting success was evident on investigations related to great blue heron, where there was an increase of young chicks exposure predation, causing abandonment of the colony

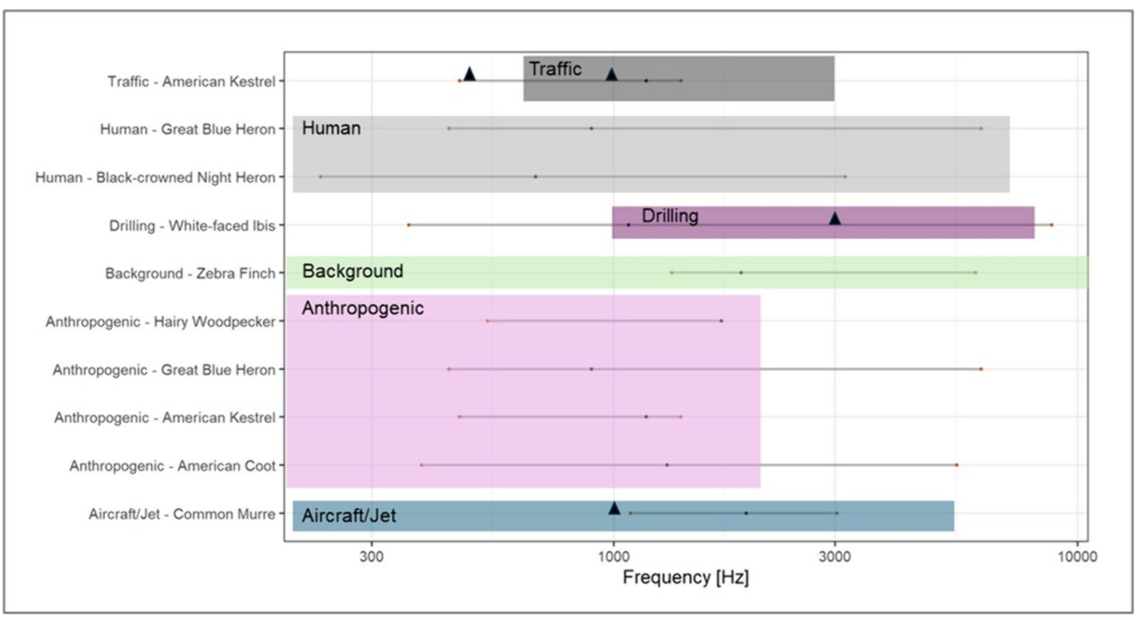

Fig. 8 Overlapping of avian frequency range and noise source spectra observed in the physiological noise impacts. Legend: ● Peak Haring Frequency (PHF); ▲ Peak Sound Frequency (PSF); Depends on Predominant Source (DPS); PSF1 = Aircraft/Jet; PSF 2 = Anthropogenic; PSF3 = Background; PSF4 = Drilling; PSF5 = Human; PSF6 = Traffic; Common Murre—PHF = 1928 Hz, PSF1 = 1000 Hz; American Coot – PHF = 1301 Hz, PSF2 = DPS; American Kestrel—PHF = 1174 Hz, PSF2 = DPS, PSF6 = 500 -1000 Hz; Great Blue Heron—PHF = 895 Hz, PSF2 = DPS, PSF5 = DPS; Hairy Woodpecker—PHF = 1706 Hz, PSF2 = DPS; Zebra Finch—PHF = 1879 Hz, PSF3 = DPS; White-faced Ibis—PHF = 1076 Hz, PSF4 = 3000 Hz; Black-crowned Night Heron—PHF = 677 Hz, PSF5 = DPS

[61]. In the American kestrel, human disturbance caused nesting failure [62].

c. Fireworks

The use of fireworks caused alterations in animal behaviour in the American coot [93].

d. Military activity noise

Noises generated by military activities (e.g., firing guns, artillery, and explosive ordinances) caused the foraging disruption of American crows, and consequently, this species is observed less frequently near military areas [89].

e. Drilling/Construction noise

Drilling adversely affected white-faced ibis' breeding, as reported by Mueller and Glass [53]. There was also a 'decrease in reproductive/breeding success in hairy woodpeckers, affecting their mating rituals dependent on song, especially for the "song birds" [59].

f. Urban/Background noise

Urban and background, the opposite of foreground sound signal, are noises which influenced the: 1) 'decrease of reproductive/breeding success' (e.g., the pair bond of zebra finch [57]); 2) 'reduction of cognitive performance' where chicks of inca tern altered their begging calls in dangerous environments, which is normal behaviour and a way to adapt to the environment, however in noisy environments, they tend not to hear the alarm calls produced by their parents when there is a predator in the proximities [94]; 3) 'density/abundance of population' of mallard ducks [87]; 4) 'behavioural changes' were observed in Eurasian collared dove by increase of distances from urban noisy environments [2], increased song level on European starlings [127]; 5) the 'vocal plasticity' changed on Indian peafowl by the alteration of male signals [112]; 6) 'repetition of calls' in the western grebe [47].

g. Traffic noise

Several noise impacts on birds are associated with traffic noise, such as: 1) the 'decrease of reproductive/breeding success' in American kestrel due to the difficulty in incubation related to the perception of greater predation risk [58]; 2) 'reduction of cognitive performance' of European Starlings, which are emitting more begging calls due to difficulties on communication [126]; 3) alteration on 'density/abundance of population' observed in black-crowed night heron [92], turkey vulture [90], hairy woodpecker [85], American kestrel [85], rainbow lorikeet [91], common raven [86], Steller's jay [85]; 4) 'behavioural changes' in budgerigar in which the social behaviour was affected by masking of signals [122], and the black-billed magpie changed the selection of sites for nest choice [130].

h. Aircraft/Jet noise

Aircraft and jet noise affected the 1) 'decrease of reproductive/breeding success' observed in common murre, which felt disturbed by low-flying aircraft noise during the breeding season [56]; 2) 'behavioural changes' in wood duck and observation of sensitiveness [110].

i. Drones/UAV/UAS noise

Regarding drone noise, it was observed 1) 'behavioural changes' by foraging or head and tail movement of mallard duck [1]; continuous flapping due to stress caused by UAVs in Chilean flamingo [114], in turkey vultures caused disturbance [119] and increased their reaction time to reproductions of UAS noise [120].

j. Snowmobile noise

This kind of noise influenced the 'masking of calls', which inhibited the propagation and interpretation of animal vocalisations of common raven [50].

k. Mining noise

Mining noise affected the behavioural responses of Indian peafowls, as observed in Rathoure [113].

l. Wind farm noise

Regarding wind farm noise, 'behavioural changes' were observed through the avoidance behaviour [118] and disturbance [117] of turkey vultures.

m. White noise

This kind of noise, which shows the same amplitude over all frequencies, caused 'behavioural changes' such as foraging in the blue jay [132] and 'vocal plasticity' by regulating call amplitude and increasing peak frequency in mallard ducks [109].

From Figs. 5-8 and Table 5, it was observed that the composition of two clusters had a clear subdivision of the impacts of noise on birds. Cluster 1 showed 'behavioural' and 'communication and perception' impacts. The 'behavioural' outcomes affecting birds with peak hearing frequency ranging from 677 to 2018 Hz. The associated sound sources are 'aircraft/jet' ($f\Delta = 50\ Hz - 5\ kHz, SPF = 1000\ Hz$) [40], 'anthropogenic' ($f\Delta = below\ 2\ kHz$) [143], 'background', 'drone/UAV/UAS' ($f\Delta = 2\ kHz - 4\ kHz, SPF = 3kHz$) [144, 145], 'human' ($f\Delta = 63\ Hz - 20\ kHz$) [146–148], 'mining' ($f\Delta = 31.5\ Hz - 8\ kHz, SPF = 63\ Hz; - 125\ Hz$) [149], 'traffic' ($f\Delta = 500\ Hz - 3\ kHz, SPF = 500\ Hz - 1kHz$) [35, 36] and 'wind farm' ($f\Delta = 20 - 200\ Hz$) [150]. Since most of the observations were related to traffic, background, anthropogenic and done/UAV/UAS, it is possible to realise that the frequency range of the emitted noise sources overlaps with the peak hearing range of the affected birds, which presented behavioural outcomes. Regarding the 'communication and perception' outcome, Table 5 shows that affected birds presented peak hearing frequency ranging from 793 to 1928 Hz. The related noise sources that provoke this outcome are 'anthropogenic' ($f\Delta = below\ 2\ kHz$) [143], 'background', 'snowmobile' ($f\Delta = 1\ kHz - 1.5\ kHz$) [151] and 'white noise'. For this outcome, the most reported noise sources were 'anthropogenic' and 'background' noise, which also have emission frequencies which overlap with the peak hearing frequencies of the affected bird species. Cluster 2 showed physiological-related outcomes on bird species with peak hearing frequency range between 677 and 1928 Hz. These outcomes were associated with 'human' ($f\Delta = 63\ Hz - 20\ kHz$) [146–148], 'anthropogenic' ($f\Delta = below\ 2\ kHz$) [143], construction – 'drilling' ($f\Delta = below\ 800\ Hz$) [152], 'traffic' ($f\Delta = 500\ Hz - 3\ kHz$) [35, 36], 'background', 'aircraft/jet' ($f\Delta = 50\ Hz - 5\ kHz$) [40] noise sources. Again, the most reported noise sources in the investigated studies which inform physiological outcomes on birds are 'anthropogenic', 'traffic', 'background noise' and 'human' noise, in which the emission frequency comprehends the peak hearing frequencies of the affected bird species.

Limitations

The main limitations observed in this study are finding works with a complete dataset of the investigated species. As observed in the quantity of screened works, the literature review screened 701,575 and we extracted 50 publications, which corresponded to the species investigated by Peacock et al. [103, 104]. Besides, there are around 11,000 bird species, so our data are a very small sample with many missing orders. This means it is difficult to generalise findings.

Additionally, it was observed that several authors presented their frameworks regarding the classification of anthropogenic noise impact on wildlife ([11], [45], [46], [13]), but there is no specific work defining the framework for impacts on avian species. The classification of impacts on this work was more demanding and uncertain due to the possibility of new findings related to the topic since there as orders which were not investigated regarding the impacts of anthropogenic noise.

Conclusion

Based on an extensive literature review on noise's impact on birds, it was possible to present a framework which classifies the major impacts in different levels, e.g., 'acoustic perception—communication and hearing', 'physiological response', 'behavioural response' and 'impact on fitness' which is the consequence of the three first levels of impacts. As observed in the limitations, this framework is the first attempt to present a classification method on impacts on avian species and could be adapted in the future, according to the progress of findings related to the topic.

Negative and positive noise impacts were highlighted through a Two-Step Cluster Analysis. Two Clusters subdivided the noise impacts. Cluster 1 (76.9%), showed negative impacts on birds' behaviour, and negative as well as positive impacts were shown on the category 'communication and sound perception'. These were caused mainly by traffic, background, anthropogenic, and done/UAV/UAS noise sources. In Cluster 2 (23.1%), most impacts were negative, where physiological responses caused by 'anthropogenic', 'traffic', 'background noise', and 'human' noise sources were highlighted.

The presented systematic review categorises the main impacts caused by anthropogenic noise on avian species based on datasets of species that already have information about their hearing capacities, such as hearing frequency range. It also shows how the demonstrated species' hearing frequency range overlaps with the noise sources' frequency range. This information can be used for an effective noise control action plan, ensuring a better sonic environment for humans and wildlife.

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Data Availability No datasets were generated or analysed during the current study.

Declarations

Conflict of Interest The authors declare that they have no conflict of interest.

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References

1. Vas E, Lescroël A, Duriez O, Boguszewski G, Grémillet D. Approaching birds with drones: first experiments and ethical guidelines. Biol Let. 2015;11(2):20140754. https://doi.org/10.1098/rsbl.2014.0754.
2. Eddajjani A, Hanane S, Kandry AE, Qninba A. The association strength of landscape composition and spatial structure governs occurrence of invasive Eurasian collared-doves and expanding woodpigeons in a Mediterranean urban environment. Landscape Ecol. 2022;37(8):2007–24. https://doi.org/10.1007/s10980-022-01462-4.
3. Bjørnø L. Features of underwater acoustics from Aristotle to our time. Acoust Phys. 2003;49(1):24–30. https://doi.org/10.1134/1.1537384.
4. University of Rhode Island (2002). The discovery of underwater acoustics: Pre-1800s. Accessed at: https://dosits.org/people-and-sound/history-of-underwater-acoustics/the-discovery-of-underwater-acoustics-pre-1800s/
5. Pavan G, Budney G, Klinck H, Glotin H, Clink D J, & Thomas JA. History of sound recording and analysis equipment. *Exploring Animal Behavior Through Sound: Volume 1: Methods*, 2022: 1–36. https://doi.org/10.1007/978-3-030-97540-1.
6. Garner RL. The speech of monkeys. London: William Heinemeann; 1892.
7. Krause B. Bioacoustics, habitat ambience in ecological balance. Whole Earth Review. 1987;57(472):14–8.
8. Fletcher JL, Busnel RG. Effects of noise on wildlife. Academic Press, New York, 1978. ISBN 978-0-12-260550-5
9. Waddington D, Wood M, Davies B, & Young R. Habitats: Managing the ecological impacts of noise on wildlife habitats for sustainable development. In *I*NTER-NOISE and NOISE-CON Congress and Conference Proceedings (Vol. 265, No. 2, pp. 5247–5251). Institute of Noise Control Engineering, 2022.
10. European Environment Agency. Noise. Does noise stress animals too? EEA, 2024. Accessed at: https://www.eea.europa.eu/en/topics/in-depth/noise#:~:text=Noise%20negatively%20impacts%20wildlife%2C%20both,other%2C%20especially%20during%20mating%20season.
11. Blickley JL, Patricelli GL. Impacts of anthropogenic noise on wildlife: research priorities for the development of standards and mitigation. J Intl Wildlife Law Policy. 2010;13(4):274–92. https://doi.org/10.1080/13880292.2010.524564.
12. U.S. Environmental Protection Agency - USEPA Report No. NTID 300.5. Effects of noise on wildlife and other animals. Washington, DC, USA, 1971. Accessed at https://nepis.epa.gov/Exe/ZyNET.exe/9100ONX4.TXT?ZyActionD=ZyDocument&Client=EPA&Index=1976+Thru+1980&Docs=&Query=&Time=&EndTime=&SearchMethod=1&TocRestrict=n&Toc=&TocEntry=&QField=&QFieldYear=&QFieldMonth=&QFieldDay=&IntQFieldOp=0&ExtQFieldOp=0&XmlQuery=&File=D%3A%5Czyfiles%5CIndex%20Data%5C76thru80%5CTxt%5C00000022%5C9100ONX4.txt&User=ANONYMOUS&Password=anonymous&SortMethod=h%7C-&MaximumDocuments=1&FuzzyDegree=0&ImageQuality=r75g8/r75g8/x150y150g16/i425&Display=hpfr&DefSeekPage=x&SearchBack=ZyActionL&Back=ZyActionS&BackDesc=Results%20page&MaximumPages=1&ZyEntry=1&SeekPage=x&ZyPURL. https://nepis.epa.gov/Exe/ZyNET.exe/9101NNCV.TXT?ZyActionD=ZyDocument&Client=EPA&Index=Prior+to+1976&Docs=&Query=&Time=&EndTime=&SearchMethod=1&TocRestrict=n&Toc=&TocEntry=&QField=&QFieldYear=&QFieldMonth=&QFieldDay=&IntQFieldOp=0&ExtQFieldOp=0&XmlQuery=&File=D%3A%5Czyfiles%5CIndex%20Data%5C70thru75%5CTxt%5C00000024%5C9101NNCV.txt&User=ANONYMOUS&Password=anonymous&SortMethod=h%7C-&MaximumDocuments=1&FuzzyDegree=0&ImageQuality=r75g8/r75g8/x150y150g16/i425&Display=hpfr&DefSeekPage=x&SearchBack=ZyActionL&Back=ZyActionS&BackDesc=Results%20page&MaximumPages=1&ZyEntry=1&SeekPage=x&ZyPURL
13. European Environment Agency – EEA. Report No. 22/2019. Environmental noise in Europe – 2020. Luxembourg: Publication Office of the European Union, 2020. https://doi.org/10.2800/686249.
14. Shannon G, McKenna MF, Angeloni LM, Crooks KR, Fristrup KM, Brown E, ... & Wittemyer G. A synthesis of two decades of research documenting the effects of noise on wildlife. Biological Reviews, 91(4), 2016: 982–1005. https://doi.org/10.1111/brv.12207.
15. European Union Council. Directive 2009/147/EC. Birds Directive, 1979. Accessed at https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1561459564543&uri=CELEX:32009L0147
16. European Union. Council Directive 92/43/EEC. Habitats Directive, 1992. Accessed at https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A01992L0043-20130701
17. European Commission. Natura 2000. Catalogue number: KH-78–09–728-EN-C. Publications Office of the European Union, 2009. https://doi.org/10.2779/36584. Accessed at: https://op.europa.e/en/publication-detail/-/publication/eac01534-07a3-4231-9eed-f3e539a354fb/language-en/format-PDF/source-297754186
18. U.S. Department of Transportation, Federal Highway Administration Publication No. FHWA-HEP-06–016. Synthesis of noise effects on wildlife populations. Kaseloo. P. A. (author), 2004. Accessed at https://www.fhwa.dot.gov/environment/noise/resources/noise_effect_wildlife/effects.pdf
19. Binette N. Bird deterrent markings on transparent noise barrier panels. Evonik Industries, 2008. Accessed at http://www.adc40.org/presentations/summer2008/BinetteTRB08.pdf
20. Rössler M, Laube W, Weihs P. Avoiding bird collisions with glass surfaces. Experimental investigations of the efficacy of markings on glass panes under natural light conditions in Flight Tunnel II. BOKU-Met Report, 10: 2009.

21. Klem D Jr, Saenger PG. Evaluating the effectiveness of select visual signals to prevent bird-window collisions. Wilson J Ornithol. 2013;125(2):406–11. https://doi.org/10.1676/12-106.1.
22. International Union for Conservation of Nature – IUCN. The IUCN Red List of Threatened Species. IUCN Red List version 2023–1: Table 1a – Last update: 11 December 2023. Accessed at https://www.iucnredlist.org/resources/summary-statistics#Summary%20Tables
23. Dooling RJ & Popper AN. The Effects of Highway Noise on Birds. California Department of Transportation, Division of Environmental Analysis. Sacramento, CA, USA, 2007.
24. Frings H, Jumber J. Preliminary studies on the use of a specific sound to repel starlings (Sturnus vulgaris) from objectionable roosts. Science. 1954;119:318–9. https://doi.org/10.1126/science.119.3088.318.
25. Reijnen R, Foppen R, Ter Braak C. Thissen J. The effects of car traffic on breeding bird populations in woodland. III. Reduction in the density in relation to the proximity of main roads. J Appl Ecol 32: 187–202, 1995. https://doi.org/10.2307/2404428.
26. Reijnen R, Foppen R, Meeuwsen H. The effects of car traffic on the density of breeding birds in Dutch Agricultural Grasslands. Biol Cons. 1996;75:255–60. https://doi.org/10.1016/0006-3207(95)00074-7.
27. Hashino E, Sokabe M, Miyamoto K. Frequency-specific susceptibility to acoustic trauma in the budgerigar. J Acoust Soc Am. 1988;83:2450–2. https://doi.org/10.1121/1.396325.
28. Stadelman WJ. The effect of sounds of varying intensity on hatchability of chicken egg. Poult Sci. 1958;37(1):166–9. https://doi.org/10.3382/ps.0370166.
29. Corbani TL, Martin JE, Healy SD. The impact of acute loud noise on the behavior of laboratory birds. Front Veterin Sci. 2021;7. https://doi.org/10.3389/fvets.2020.607632.
30. Frings H, Jumber J. Preliminary studies on the use of a specific sound to repel starlings (Sturnus vulgaris) from objectionable roosts. Science. 1954;119(3088):318–9. https://doi.org/10.1126/science.119.3088.318.
31. Scott GB, Moran P. Effects of visual stimuli and noise on fear levels in laying hens. Appl Anim Behav Sci. 1993;37:321–9. https://doi.org/10.1016/0168-1591(93)90121-5.
32. Langowski DJ, Wight HM, Jacobson JN. Responses of instrumentally conditioned starlings to aversive acoustical stimuli. J Wildl Manag. 1969;33:669–77. https://doi.org/10.2307/3799392.
33. Riede T, Goller F. Morphological basis for the evolution of acoustic diversity in oscine songbirds. Proc Royal Soc B: Biol Sci. 2014;281(1779):20132306. https://doi.org/10.1098/rspb.2013.2306.
34. Hu Y, Cardoso GC. Which birds adjust the frequency of vocalizations in urban noise? Anim Behav. 2010;79(4):863–7. https://doi.org/10.1016/j.anbehav.2009.12.036.
35. Rochat JL. Highway Traffic. Noise Acoustics Today. 2016;12(4):38–47.
36. Carley M, Kennedy J, Walker I, Holt N. The experimental measurement of motorcycle noise. Proc Mtgs Acoust. 2011;12:040002. https://doi.org/10.1121/1.3602214.
37. Smith AB, Fischer-McMorrow I, Kolbeinsson Y, Rasmussen M, Shero MR, McElwaine JN, ... & Mooney TA. Sensitive aerial hearing within a noisy nesting soundscape in a deep-diving seabird, the common murre Uria aalge. Marine Ecology Progress Series, 2023; 714, 87–104. https://doi.org/10.3354/meps14346
38. The Sound Approach. Black-crowned Night Heron: Nycticorax nycticorax, 2019. Accessed on: https://soundapproach.co.uk/species/black-crowned-night-heron/
39. Miller DB. Two-voice phenomenon in birds: further evidence. Auk. 1977;94(3):567–72. https://doi.org/10.1093/auk/94.3.567.
40. Oakland International Airport. Aircraft Noise. Oakland International Airport Masterplan – Update. 2006. Accessed at https://flyquietoak.com/wp-content/uploads/2022/04/aircraft_noise_fundamentals.pdf. Retrieved on 13/07/2023.
41. Liu Y, Zollinger SA, Brumm H. Chronic exposure to urban noise during the vocal learning period does not lead to increased song frequencies in zebra finches. Behav Ecol Sociobiol. 2021;75:1–9. https://doi.org/10.1007/s00265-020-02942-w.
42. Marler P, Konishi M, Lutjen A, Waser MS. Effects of continuous noise on avian hearing and vocal development. Proc Natl Acad Sci. 1973;70(5):1393–6. https://doi.org/10.1073/pnas.70.5.1393.
43. Meillère A, Brischoux F, Angelier F. Impact of chronic noise exposure on antipredator behavior: an experiment in breeding house sparrows. Behav Ecol. 2015;26(2):569–77. https://doi.org/10.1093/beheco/aru232.
44. Liu Q, Gelok E, Fontein K, Slabbekoorn H, Riebel K. An experimental test of chronic traffic noise exposure on parental behaviour and reproduction in zebra finches. Biology Open. 2022;11(4). https://doi.org/10.1242/bio.059183.
45. Kight CR, Swaddle JP. How and why environmental noise impacts animals: an integrative, mechanistic review. Ecol Lett. 2011;14(10):1052–61. https://doi.org/10.1111/j.1461-0248.2011.01664.x.
46. Francis CD, Barber JR. A framework for understanding noise impacts on wildlife: an urgent conservation priority. Front Ecol Environ. 2013;11(6):305–13. https://doi.org/10.1890/120183.
47. Nuechterlein GL, Buitron D. Advertising by western grebes: bout-length variability and signal confusion in a multiple-use call. Behaviour. 2006;1547–1562. https://doi.org/10.1163/156853906779367008.
48. Slabbekoorn H, Peet M. Birds sing at a higher pitch in urban noise. Nature. 2003;424:267. https://doi.org/10.1038/424267.
49. Potvin DA, Parris KM, Mulder RA. Geographically pervasive effects of urban noise on frequency and syllable rate of songs and calls in silvereyes (*Zosterops lateralis*). Proc R Soc B. 2011;278:2464–9. https://doi.org/10.1098/rspb.2010.2296.
50. Mullet TC, Morton JM, Gage SH, Huettmann F. Acoustic footprint of snowmobile noise and natural quiet refugia in an Alaskan wilderness. Nat Areas J. 2017;37(3):332–49. https://doi.org/10.3375/043.040.0315.
51. Nielsen UF. Community Ecology. The Nature Education: Knowledge project – library, 2014. Accessed at https://www.nature.com/scitable/knowledge/community-ecology-13228209/#:~:text=Community%20ecology%20is%20an%20expanding,interactions%20that%20occur%20between%20species.
52. Burger J. Effects of human disturbance on colonial species, particularly gulls. Colonial Waterbirds. 1981;28–36. https://doi.org/10.2307/1521108.
53. Mueller AJ, Glass PO. Disturbance tolerance in a Texas waterbird colony. Colonial Waterbirds. 1988;119–122. https://doi.org/10.2307/1521181.
54. Carlson BA, McLean EB. Buffer zones and disturbance types as predictors of fledging success in great blue herons, Ardea herodias. Colonial Waterbirds. 1996;124–127. https://doi.org/10.2307/1521816.
55. Butler RW, Baudin P. Status and conservation stewardship of the Pacific Great Blue Heron in Canada. In Proc. Conf. on the biology and management of species and habitats at risk. LM Darling (editor). Kamloops, BC. 1999;247–250.
56. Rojek NA, Parker MW, Carter HR, McChesney GJ. Aircraft and vessel disturbances to Common Murres Uria aalge at breeding colonies in central California, 1997–1999. Mar Ornithol. 2007;35:61–9.
57. Swaddle JP, Page LC. High levels of environmental noise erode pair preferences in zebra finches: implications for noise pollution. Anim Behav. 2007;74(3):363–8. https://doi.org/10.1016/j.anbehav.2007.01.004.

58. Strasser EH, Heath JA. Reproductive failure of a human-tolerant species, the American kestrel, is associated with stress and human disturbance. J Appl Ecol. 2013;50(4):912–9. https://doi.org/10.1111/1365-2664.12103.
59. Harding BC. An Urban-Wildland Interface in Claremont Canyon, Berkeley, CA: Change in Avian Species Richness Over Time, 2015.
60. Novčić I. Behavioural responses of grey herons Ardea cinerea and great egrets Ardea alba to human-caused disturbance. J Vertebrate Biol. 2022;71(22026), 22026–1. https://doi.org/10.25225/jvb.22026.
61. Vos DK, Ryder RA, Graul WD. Response of breeding great blue herons to human disturbance in northcentral Colorado. Colonial Waterbirds. 1985;13–22. https://doi.org/10.2307/1521190.
62. Strasser EH, Heath JA. Effects of developmental conditions on nestling American Kestrel (Falco sparverius) corticosterone concentrations. Gen Comp Endocrinol. 2011;173(1):164–70. https://doi.org/10.1016/j.ygcen.2011.05.010.
63. Hochel J, Pirow R, Nichelmann M. Development of heart rate responses to acoustic stimuli in Muscovy duck embryos. Comp Biochem Physiol. 2002;131:805–16. https://doi.org/10.1016/S1095-6433(02)00018-1.
64. Halfwerk W, Hollemann LJM, Lessells CM, Slabbekoorn H. Negative impact of traffic noise on avian reproductive success. J Appl Ecol. 2011;48:210–9. https://doi.org/10.1111/j.1365-2664.2010.01914.x.
65. Kight CR. Acoustics of anthropogenic habitats: the impact of noise pollution on eastern bluebirds. PhD Dissertation, Applied Science Department, College of William and Mary, Williamsburg, VA, 2010.
66. Francis CD, Ortega CP, Cruz A. Noise pollution changes avian communities and species interactions. Curr Biol. 2009;19(16):1415–9. https://doi.org/10.1016/j.cub.2009.06.052.
67. Phillips JN, Gentry KE, Luther DA, Derryberry EP. Surviving in the city: higher apparent survival for urban birds but worse condition on noisy territories. Ecosphere. 2018;9(9):e02440. https://doi.org/10.1002/ecs2.2440.
68. Kok ACM, Berkhout BW, Carlson NV, Evans NP, Khan N, Potvin DA, Radford AN, Sebire M, Shafiei Sabet S, Shannon G, Wascher CAF. How chronic anthropogenic noise can affect wildlife communities? Front Ecol Evol. 2023;11:1130075. https://doi.org/10.3389/fevo.2023.1130075.
69. Kight CR, Saha MS, Swaddle JP. Anthropogenic noise is associated with reductions in the productivity of breeding Eastern Bluebirds (Sialia sialis). Ecol Appl. 2012;22(7):1989–96. https://doi.org/10.1890/12-0133.1.
70. Cotanche DA. Regeneration of the tectorial membrane in the chick cochlea following severe acoustic trauma. Hear Res. 1987;30(2–3):197–206. https://doi.org/10.1016/0378-5955(87)90136-5.
71. Stone JS, Rubel EW. Cellular studies of auditory hair cell regeneration in birds. Proc Natl Acad Sci. 2000;97(22):11714–21. https://doi.org/10.1073/pnas.97.22.11714.
72. Crino OL, Johnson EE, Blickley JL, Patricelli GL, Breuner CW. Effects of experimentally elevated traffic noise on nestling white-crowned sparrow stress physiology, immune function and life history. J Exp Biol. 2013;216:2055–62. https://doi.org/10.1242/jeb.081109.
73. Cyr NE, Earle K, Tam C, Romero LM. The effect of chronic psychological stress on corticosterone, plasma metabolites, and immune responsiveness in European starlings. Gen Comp Endocrinol. 2007;154:59–66. https://doi.org/10.1016/j.ygcen.2007.06.016.
74. Kleist NJ, Guralnick RP, Cruz A, Lowry CA, Francis CD. Chronic anthropogenic noise disrupts glucocorticoid signaling and has multiple effects on fitness in an avian community. Proc Natl Acad Sci U S A. 2018;115:E648–57. https://doi.org/10.1073/pnas.1709200115.
75. Wasser SK, Bevis K, King G, Hanson E. Noninvasive physiological measures of disturbance in the Northern spotted owl. Conserv Biol. 1997;11:1019–22.
76. Brumm H, Goymann W, Derégnaucourt S, Geberzahn N & Zollinger SA. Traffic noise disrupts vocal development and suppresses immune function. Sci Adv. 2021;7(20): eabe2405. https://doi.org/10.1126/sciadv.abe2405.
77. Moreno-Rueda G. An immunological cost of begging in house sparrow nestlings. Proc Roy Soc B-Biol Sci. 2010;277:2083–8. https://doi.org/10.1098/rspb.2010.0109.
78. Chloupek P, Vosla´rˇova´ E, Chloupek J, Beda´nˇova´ I, Pisˇteˇkova´ V & Vecˇerek V. Stress in broiler chickens due to acute noise exposure. Acta Vet Brno. 2009;78:93–98. https://doi.org/10.2754/avb200978010093.
79. Bonier F, Moore IT, Martin PR, Robertson RJ. The relationship between fitness and baseline glucocorticoids in a passerine bird. Gen Comp Endocrinol. 2009;163(1–2):208–13. https://doi.org/10.1016/j.ygcen.2008.12.013.
80. Ryals BM, Dooling RJ, Westbrook E, Dent ML, MacKenzie A, Larsen ON. Avian species differences in susceptibility to noise exposure. Hearing Res. 1999;131:71–88. https://doi.org/10.1016/S0378-5955(99)00022-2.
81. Wolfenden AD, Slabbekoorn H, Kluk K, de Kort SR. Aircraft sound exposure leads to song frequency decline and elevated aggression in wild chiffchaffs. J Anim Ecol. 2019;88(11):1720–31. https://doi.org/10.1111/1365-2656.13059.
82. Saunders JC, Dooling RJ. Characteristics of temporary and permanent threshold shifts in vertebrates. In H. Slabbekoorn, R. J. Dooling, A. N. Popper, and R. R. Fay (Eds.), Effects of Anthropogenic Noise on Animals. Springer-Verlag, New York. 2018;83–108. https://doi.org/10.1007/978-1-4939-8574-6_4.
83. Dooling RJ, Buehler D, Leek MR, Popper AN. The impact of urban and traffic noise on birds. Acoustics Today. 2019;15(3):19–27. https://doi.org/10.1121/AT.2019.15.3.19.
84. Halkin SL, Bray AM. Chapter 11 - Are squirrels and ants smart shoppers? How foraging choices may meet current and future needs. In: Exploring Animal Behavior in Laboratory and Field (Second Edition). Zimbler-DeLorenzo H., Margulis S.W. (editors). Academic Press, pp.193–230, 2021. ISBN 9780128214107. https://doi.org/10.1016/B978-0-12-821410-7.00027-3
85. Rottenborn SC. Predicting the impacts of urbanization on riparian bird communities. Biol Cons. 1999;88(3):289–99. https://doi.org/10.1016/S0006-3207(98)00128-1.
86. Helldin JO, Seiler A. Wildl Biol. 2003;6:111–20.
87. Gunnarsson G, Elmberg J, Sjöberg K, Pöysä H, Nummi P. Experimental evidence for density-dependent survival in mallard (Anas platyrhynchos) ducklings. Oecologia. 2006;149:203–13. https://doi.org/10.1007/s00442-006-0446-8.
88. Patón D, Romero F, Cuenca J, Escudero JC. Tolerance to noise in 91 bird species from 27 urban gardens of Iberian Peninsula. Landsc Urban Plan. 2012;104(1):1–8. https://doi.org/10.1016/j.landurbplan.2011.09.002.
89. Barron DG, Brawn JD, Butler LK, Romero LM, Weatherhead PJ. Effects of military activity on breeding birds. J Wildl Manag. 2012;76(5):911–8. https://doi.org/10.1002/jwmg.355.
90. Watson KA, Simpson TR. Relationship of vehicular traffic flow and roadside raptor and vulture abundance in South-Central Texas. Texas Ornithol Soc. 2014;47:17–23.
91. Uebel K, Bonn A, Marselle M, Dean AJ, & Rhodes JR. Park and Landscape Features Influence Urban Park Soundscapes. People & Nature. 2021;3(3). Accessed at SSRN 3969910. https://doi.org/10.2139/ssrn.3969910.
92. Wang J, Liu W, Lin Q, Hou J. Effects of Flight Disturbance on Bird Communities at Airports: Predatory Birds Rise to the

Challenge, 2022. https://doi.org/10.17582/journal.pjz/20220913080930.
93. Rodríguez-Casanova AJ, Zuria I, Hernández-Silva DA. Effect of Firework Festivities on Bird Richness and Abundance at a Natural Protected Wetland in Central Mexico. Waterbirds. 2023;45(3):277–86. https://doi.org/10.1675/063.045.0307.
94. Lima SL. Predators and the breeding bird: behavioral and reproductive flexibility under the risk of predation. Biol Rev. 2009;84(3):485–513. https://doi.org/10.1111/j.1469-185X.2009.00085.x.
95. Daria C, Slevin MC, Anderson RC. Effects of anthropogenic noise on cognition, bill color, and growth in the zebra finch (Taeniopygia guttata). acta ethologica. 2022;1–15. https://doi.org/10.1007/s10211-022-00406-0.
96. Stevens ANP, Stevens JR. Animal Cognition. Nature Educ Knowl. 2012;3(11):1.
97. Templeton CN, O'Connor A, Strack S, Meraz F, Herranen K. Traffic noise inhibits inhibitory control in wild-caught songbirds. Iscience. 2023;26(5). https://doi.org/10.1016/j.isci.2023.106650.
98. Teixeira CP, De Azevedo CS, Mendl M, Cipreste CF, Young RJ. Revisiting translocation and reintroduction programmes: the importance of considering stress. Anim Behav. 2007;73(1):1–13. https://doi.org/10.1016/j.anbehav.2006.06.002.
99. Funabiki Y, Konishi M. Long memory in song learning by zebra finches J Neurosci 2003;23:6928–6935. https://doi.org/10.1523/JNEUROSCI.23-17-06928.2003.
100. Kleist NJ, Guralnick RP, Cruz A, Lowry CA, Francis CD. Chronic anthropogenic noise disrupts glucocorticoid signaling and has multiple effects on fitness in an avian community. Proc Natl Acad Sci. 2018;115(4):E648–57.
101. Schroeder J, Nakagawa S, Cleasby IR, Burke T. Passerine birds breeding under chronic noise experience reduced fitness. PLoS ONE. 2012;7(7):e39200. https://doi.org/10.1371/journal.pone.0039200.
102. LaManna JA, Martin TE. Costs of fear: Behavioural and life-history responses to risk and their demographic consequences vary across species. Ecol Lett. 2016;19:403–13. https://doi.org/10.1111/ele.12573.
103. Peacock J, Spellman GM, Tollin DJ, Greene NT. A comparative study of avian middle ear mechanics. Hearing Res. 2020;395:108043. https://doi.org/10.1016/j.heares.2020.108043
104. Peacock J, Spellman GM, Greene NT, Tollin DJ. Scaling of the avian middle ear. Hear Res. 2020;395:108017. https://doi.org/10.1016/j.heares.2020.108017.
105. Proppe DS, Sturdy CB, St Clair CC. Anthropogenic noise decreases urban songbird diversity and may contribute to homogenization. GlobalChange Biology. 2013;19:1075–84. https://doi.org/10.1111/gcb.12098.
106. Engel MS, Young RJ, Davies WJ, Waddington D, Wood MD. Defining Mechanistic Pathways for Anthropogenic Noise Impact on Avian Species. Curr Pollut Reports. 2024;1–30. https://doi.org/10.1007/s40726-024-00303-z.
107. Moher D, Liberati A, Tetzlaff J, Altman DG. The PRISMA group. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. PLoS Med. 2009;6(7): e1000097. https://doi.org/10.1371/journal.pmed1000097.
108. Gunnarsson G, Elmberg J, Sjöberg K, Pöysä H, Nummi P. Experimental evidence for density-dependent survival in mallard (Anas platyrhynchos) ducklings. Oecologia. 2006;149:203–13. https://doi.org/10.1007/s00442-006-0446-8.
109. Dorado‐Correa AM, Zollinger SA, Brumm H. Vocal plasticity in mallards: multiple signal changes in noise and the evolution of the Lombard effect in birds. J Avian Biol. 2018;49(1): jav-01564. https://doi.org/10.1111/jav.01564.
110. Conomy JT, Dubovsky JA, Collazo JA, Fleming WJ. Do black ducks and wood ducks habituate to aircraft disturbance? The Journal of wildlife management. 1998;1135–1142. https://doi.org/10.2307/3802568.
111. Goudie RI, Jones IL. Dose-response relationships of harlequin duck behaviour to noise from low-level military jet over-flights in central Labrador. Environ Conserv. 2004;31(4):289–98. https://doi.org/10.1017/S0376892904001651.
112. Freeman AR, Hare JF. Infrasound in mating displays: a peacock's tale. Anim Behav. 2015;102:241–50. https://doi.org/10.1016/j.anbehav.2015.01.029.
113. Rathoure AK. Baseline status of flora and fauna at Thesil Neem Ka Thana District Sikar, Rajasthan and Impact due to Sand / Bajini mining at Kantali river. Oct Jour Env Res. 2016;4(2):122–45.
114. Luque-Fernández CR, Caballero K, Pauca GA, Villegas L, Alcelay I, Machaca J. Unmanned aerial vehicle, and GIS tools, to monitor the reproduction of the flamingo Phoenicopterus chilensis (Aves: Phoenicopteridae). Revista de Biología Tropical. 2021;69(2), 733–742. https://doi.org/10.15517/RBT.V69I2.45794.
115. Rose P, Badman-King A, Hurn S, Rice T. Visitor presence and a changing soundscape, alongside environmental parameters, can predict enclosure usage in captive flamingos. Zoo Biol. 2021;40(5):363–75. https://doi.org/10.1002/zoo.21615.
116. Smith AB, Fischer-McMorrow I, Kolbeinsson Y, Rasmussen M, Shero MR, McElwaine JN, ... & Mooney TA. Sensitive aerial hearing within a noisy nesting soundscape in a deep-diving seabird, the common murre Uria aalge. Marine Ecol Prog Ser. 2023;714, 87–104. https://doi.org/10.3354/meps14346.
117. Madders M, Whitfield DP. Upland raptors and the assessment of wind farm impacts. Ibis. 2006;148:43–56. https://doi.org/10.1111/j.1474-919X.2006.00506.x.
118. Villegas-Patraca R, Cabrera-Cruz SA, Herrera-Alsina L. Soaring migratory birds avoid wind farm in the Isthmus of Tehuantepec, southern Mexico. PLoS ONE. 2014;9(3):e92462. https://doi.org/10.1371/journal.pone.0092462.
119. Pontalti M, Barreto AS. Use of Unnamed Aerial Vehicles (UAVs) to monitor marine megafauna strandings in beach monitoring programs. J Coast Conserv. 2022;26(6):80. https://doi.org/10.1007/s11852-022-00924-w.
120. Pfeiffer MB, Blackwell BF, Seamans TW, Buckingham BN, Hoblet JL, Baumhardt PE, ... Fernández-Juricic E. Responses of turkey vultures to unmanned aircraft systems vary by platform. Sci Reports. 2021;11(1), 21655. https://doi.org/10.1038/s41598-021-01098-5.
121. McClure CJ, Schulwitz SE, Van Buskirk R, Pauli BP, Heath JA. Commentary: Research recommendations for understanding the decline of American Kestrels (Falco sparverius) across much of North America. J Raptor Res. 2017;51(4):455–64. https://doi.org/10.3356/JRR-16-73.1.
122. Lohr B, Wright TF, Dooling RJ. Detection and discrimination of natural calls in masking noise by birds: estimating the active space of a signal. Anim Behav. 2003;65(4):763–77. https://doi.org/10.1006/anbe.2003.2093.
123. Osbrink A, Meatte MA, Tran A, Herranen KK, Meek L, Murakami-Smith M, ... Templeton CN. Traffic noise inhibits cognitive performance in a songbird. Proc Royal Soc B. 2021;288(1944): 20202851. https://doi.org/10.1098/rspb.2020.2851.
124. Potvin DA, Curcio MT, Swaddle JP, MacDougall-Shackleton SA. Experimental exposure to urban and pink noise affects brain development and song learning in zebra finches (Taenopygia guttata). PeerJ. 2016;4:e2287. https://doi.org/10.7717/peerj.2287/supp-2.
125. Evans JC, Dall SR, Kight CR. Effects of ambient noise on zebra finch vigilance and foraging efficiency. PLoS ONE.

2018;13(12):e0209471. https://doi.org/10.1371/journal.pone.0209471.
126. Dharmasiri ME, Barber CA, Horn AG. Nestling European Starlings (Sturnus vulgaris) adjust their begging calls in noise. Bioacoustics. 2022;31(5):594–613. https://doi.org/10.1080/09524622.2021.2008495.
127. Brumm H. The impact of environmental noise on song amplitude in a territorial bird. J Animal Ecol. 2004;434–440. https://doi.org/10.1111/j.0021-8790.2004.00814.x.
128. Bodenchuk MJ, Bergman DL. Grackles. U.S. Department of Agriculture: Animal and Plant Health Inspection Service. Wildlife Damage Management Technical Series, 2020.
129. Bray A & Mengak MT. Managing Wildlife Damage: American Crow (Corvus brachyrhynchos). WSFNR-20–60A, August, 2020.
130. Zhao Y, Pagani-Núñez E, Liu Y, Xing X, Zhang Z, Pan G, ... Safran RJ. The effect of urbanization and exposure to multiple environmental factors on life-history traits and breeding success of Barn Swallows (Hirundo rustica) across China. Avian Res. 2022;13:100048. https://doi.org/10.1016/j.avrs.2022.100048.
131. McClure CJ, Ware HE, Carlisle J, Kaltenecker G, Barber JR. An experimental investigation into the effects of traffic noise on distributions of birds: avoiding the phantom road. Proc Royal Soc B: Biol Sci. 2013;280(1773):20132290. https://doi.org/10.1098/rspb.2013.2290.
132. Dukas R, Kamil AC. The cost of limited attention in blue jays. Behav Ecol. 2000;11(5):502–6. https://doi.org/10.1093/beheco/11.5.502.
133. Chiu T, Fang D, Chen J, Wang Y, Jeris C. A robust and scalable clustering algorithm for mixed type attributes in a large database environment. Proceedings of the 7th ACM SIGKDD International Conference on Knowledge Discovery and Data Mining, San Francisco, CA, August 2001. 2001;263–268.
134. Field A. Discovering Statistics Using SPSS. 3rd ed. London: SAGE Publications Ltd; 2009.
135. Gill F, Donsker D. IOC World Bird List (v9.2). 2019. Accessed at https://www.worldbirdnames.org/https://doi.org/10.14344/IOC.ML.9.2
136. Kok ACM, Berkhout BW, Carlson NV, Evans NP, Khan N, Potvin DA, Radford AN, Sebire M, Shafiei Sabet S, Shannon G, Wascher CAF. How chronic anthropogenic noise can affect wildlife communities. Front Ecol Evol. 2023;11:1130075. https://doi.org/10.3389/fevo.2023.1130075.
137. Schäfer M. The soundscape is our sonic environment and the tuning of the world. Rochester, Vermont: Destiny Books; 1994.
138. Tomczak M, Tomczak E. The need to report effect size estimates revisited. An overview of some recommended measures of effect size. Trends in Sport Sciences, 1(21): 19–25, 2014. ISSN: 2299–9590
139. Rea LM, Parker RA. Designing and conducting survey research: a comprehensive guide. San Francisco: Jossey-Bass Publishers; 1992.
140. Power River Training Complex – EIS. Appendix I: Noise. 2014. Accessed at: https://www.ellsworth.af.mil/Portals/146/documents/AFD-141124-074.pdf
141. Tanaka T, Inaba R, Aoyama A. Noise and low-frequency sound levels due to aerial fireworks and prediction of the occupational exposure of pyrotechnicians to noise. J Occup Health. 2016;58(6):593–601. https://doi.org/10.1539/joh.16-0064-OA.
142. Yongwang L, Guojun L, Binbin D, Zhichuan G, Guoshan Z. Ground measurement of noise characteristics in drill string during drilling. Geoenergy Sci Eng. 2023;221:111210. https://doi.org/10.1016/j.petrol.2022.111210.
143. Dowling JL, Luther DA, Marra PP. Comparative effects of urban development and anthropogenic noise on bird songs. Behav Ecol. 2011;23(1):201–9. https://doi.org/10.1093/beheco/arr176.
144. Jokisch O, Fischer D. Drone Sounds and Environmental Signals - A First Review. 30th ESSV Conference, TU Dresden, March 2019.
145. Torija AJ, Clark C. A psychoacoustic approach to building knowledge about human response to noise of unmanned aerial vehicles. Int J Environ Res Public Health. 2021;18(2):682. https://doi.org/10.3390/ijerph18020682.
146. Pasanen T, Rytkönen E, Sorainen E. Leaf blower noise. In Joint Baltic-Nordic Acoustics Meeting 2004.
147. Cook JD. Tonal prominence in a leaf blower. 2016. Accessed at https://www.johndcook.com/blog/2016/05/12/tonal-prominence-in-a-leaf-blower/. Retrieved on 13/07/2023.
148. Villa A. Understanding The Frequency Of Riding Lawn Mowers: What You Need To Know. 2023. Accessed at https://aftonvilla.com/understanding-the-frequency-of-riding-lawn-mowers-what-you-need-to-know/. Retrieved on 13/07/2023.
149. Giardino DA, Marracini L. Noise in the Mining Industry: An overview. MSHA/IR 1129. U.S. Department of Labor and Mine Safety and Health Administration.1981. Accessed on https://www.osti.gov/servlets/purl/5773747. Retrieved on 03/10/2023.
150. Chiu CH, Lung SCC. Assessment of low-frequency noise from wind turbines under different weather conditions. J Environ Health Sci Engineer. 2020;18:505–14. https://doi.org/10.1007/s40201-020-00478-9.
151. Padois T, Berry A. Application of acoustic imaging techniques on snowmobile pass-by noise. J Acoust Soc Am. 2017;141(2), EL134-EL139. https://doi.org/10.1121/1.4976138.
152. Lee SC, Hong JY, Jeon JY. Effects of acoustic characteristics of combined construction noise on annoyance. Build Environ. 2015;92:657–67. https://doi.org/10.1016/j.buildenv.2015.05.037.