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Review

The acoustic playback technique in avian fieldwork contexts: a systematic review and recommendations for best practice

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Acoustic playback is commonly used to study wild birds, with applications as diverse as investigating behaviours, ascertaining the presence of rare and elusive species, and attracting individuals to a location. The number of studies employing playback is growing larger every year because it is easy to apply, increasingly affordable and very effective. However, the way that it is used and reported varies significantly across researchers and species. This lack of a protocol for reporting acoustic playbacks inevitably slows the progress of the field, as studies cannot be easily compared. In 1991, some of the most knowledgeable researchers in the field of animal communication met at a North Atlantic Treaty Organization (NATO) Advanced Research Workshop (ARW) at Thornbridge Hall in the UK to consider the design of playback experiments. The proceedings of the meeting were published in 1992 and contain crucial guidelines regarding this use of playback. In this paper we review the literature for papers published since that milestone that use acoustic playback in ornithological fieldwork contexts. We use the RepOrting standards for Systematic Evidence Syntheses (ROSES) to evaluate the description of the methods used. The main goal of this review paper is to identify a shared set of rules for employing and reporting the playback technique in such contexts to promote reproducibility and comparability. We found 625 peer-reviewed articles in three on-line databases, of which 419 reported field (rather than captive) studies employing avian playback. The biggest hindrance to reproducibility is the availability of the acoustic tracks used by authors; 4% (15 articles) of our sample made their tracks publicly available. We found that only one article provided enough details for their playback application to be fully reproducible. Further, only five articles (0.92%) provided enough information for reproducibility, even if we assume information about track preparation and recording details to be unnecessary when tracks are available. Based on our synthesis of the literature, we provide a set of recommendations for the reporting of playback uses to promote reproducibility, including sample paragraphs of description as supplementary material. We strongly recommend that tracks used for such experiments are deposited in dedicated on-line repositories for the use of other researchers. While our focus is avian

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fieldwork applications of the playback technique, we believe that our findings can be easily transferred to other animal systems subject to acoustic playback.

Keywords: bioacoustics, bird, method, ornithology, reproducibility.

While crucial experimental design aspects of studies involving acoustic playback have received extensive coverage over the years (e.g. pseudoreplication: Hurlbert 1984, Kroodsma 1989a, 1989b, 1990, 1992, 2017, Searcy 1989, McGregor *et al.* 1992, Weary & Krebs 1992), the comparability and reproducibility of the reported experiments to our knowledge have not been investigated. However, for scientific experiments it is important to use comparable methods (Barker 2008) and to report them clearly (McGregor 2000, Wiley 2003), enabling fellow researchers to critique the method, reproduce the experiment or perform their own experiments in comparable fashion.

The primary driver of this review was to ascertain whether it is possible to reproduce the application of the playback technique from avian field context studies relying solely on the published content. Many different animals respond to playback of pre-recorded sounds, for example by vocalizing in turn, or approaching the speakers and sometimes interacting with them by closely examining, and even attacking them.

Historically, a useful source of suggestions for the design of studies using acoustic playback is the book resulting from the Thornbridge Hall North Atlantic Treaty Organization (NATO) Advanced Research Workshop (ARW) Consensus, which includes a table listing features considered important in such experiments (McGregor *et al.* 1992). This publication arose from a meeting in August 1991, when experts in animal communication congregated to discuss experimental design and analyses of the rapidly growing number of acoustic playback experiments. The table provides a very useful list of aspects of experimental design using playback, specifically test sounds, environmental conditions, test animals, playback equipment and procedure. However, as more numerous and advanced recording, broadcasting and analytical tools have become widely available, increasingly detailed investigations are possible (Freeman *et al.* 2017).

Whenever playback is used to seek a behavioural response, as opposed to increasing detectability or testing tolerance to noises, the methods used should aim to make the target audience mistake the broadcast stimuli for real animals. Nevertheless, the equipment used for playback is of varying quality, and given that some species can discriminate altered sounds (e.g. Wong & Gall 2015, Luther *et al.* 2017), accounts of playback procedures should include sufficient detail to allow for reproducibility and assessment of playback quality. Reproducibility is one of the vital elements of scientific method (Baker 2016), delivered mainly via the ‘material and methods’ section within peer-reviewed publications, although it can also include on-line access to data or other material. However, information that allows reproducibility is also important because we do not really know what the birds are hearing and reacting to, and because carrying out the same experiment with different devices (e.g. broadcasting the same stimuli with speakers covering different frequency ranges) may produce different results. While accepting that not all variables are measurable, nor all experimental conditions (e.g. weather) potentially replicable, we should strive to report what is possible to enable readers to paint the most accurate picture of our applications of the technique as possible.

There are two main reasons for focusing on avian fieldwork contexts. First, the number of articles published annually on playback in avian field contexts is increasing (Fig. 1). Secondly, the use of playback in many other systems and contexts has been recently covered by extensive reviews. These cover marine mammals (Deecke 2006, Weilgart 2007, Tyack 2009, Ichikawa *et al.* 2011, Janik & Sayigh 2013), amphibians (Narins 2018), bats (Jones & Siemers 2011, Gager 2019), rodents (Wöhr 2018), primates (Fischer *et al.* 2013) and insects (Mankin *et al.* 2012), as well as considering several specific applications such as cognitive research (Gentry *et al.* 2020), interactive playback (King 2015), gender identification (Volodin *et al.* 2015), effectiveness of heterospecific vs. conspecific vocalizations in attracting animals (Putman & Blumstein 2019), duets (Douglas & Mennill 2010) and eavesdropping (Magrath *et al.* 2015). Compared with wild environments, studies involving

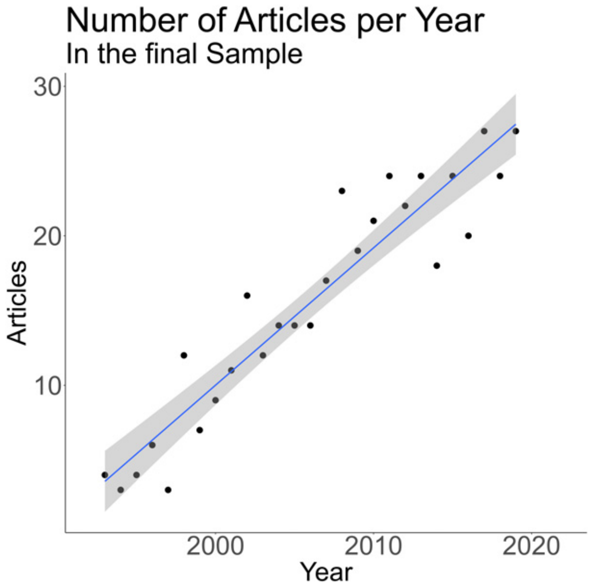

Figure 1. Number of articles in our sample by year of publication.

acoustic playback with captive birds have appropriately been reviewed using different criteria (e.g. Beecher *et al.* 1986, Derégnaucourt 2011, Derégnaucourt & Bovet 2016), accounting for the diverse conditions under which it is possible to perform acoustic playback in captive conditions.

Some examples of the applications of acoustic playback in ornithological field contexts include the detection of elusive species (Marion *et al.* 1981, Okahisa *et al.* 2016), attraction of birds (Podolsky & Kress 1989, Martin *et al.* 1995), study of predator–prey interactions (Mougeot & Bretagnolle 2000, Abbey-Lee *et al.* 2018), study of territoriality (Akçay *et al.* 2011, Leedale *et al.* 2015), effects of changes in vocalization syntax (Hedley *et al.* 2017, Taylor *et al.* 2017), eavesdropping (Vargas-Castro *et al.* 2017, Niederhauser *et al.* 2018), genetic/acoustic discrimination (Lipshutz *et al.* 2017, Provost *et al.* 2018) and neighbour/stranger recognition (Dadwal & Bhatt 2017, Moskát *et al.* 2017).

AVIAN PERCEPTION OF SOUND, AND RELEVANCE TO PLAYBACK

Objective parameters to increase the reproducibility of playback are needed because human perception of sound differs from that of birds, and this has implications for the recording and broadcasting of avian vocalizations. Sounds emitted from vocalizing animals are often directional (Patricelli *et al.* 2008) and are affected by attenuation, reverberations, amplitude fluctuations and atmospheric effects (Catchpole & Slater 2003). The combination of these various degradations means that sound changes over distance in a non-linear way. The ability of birds to identify the direction from which a signal arrives can be directly linked to physiological cues (Dent & Dooling 2003, Larsen *et al.* 2006, Bradbury & Vehrencamp 2011, Schnyder *et al.* 2014). Additionally, birds' ability to estimate the distance from a signaller through degradational cues, or to 'range' a sound, has been extensively reported.

Hence, to avoid misinterpreting the responses observed when performing playback, it is important to consider how birds localize sound sources and whether they may identify degradation cues, and potentially behave differently because of these.

Ranging

Richards (1981) reported recording two different vocalizations, respectively 10 and 50 m away from a singing Carolina Wren *Thryothorus ludovicianus*. These two vocalizations were then played back to conspecifics at a standardized amplitude. The Wrens exposed to this playback responded by counter-singing to the 'far' song and by attacking the 'near' song. This was, to our knowledge, the first experiment leading to what Morton (1983) formalized as the 'Ranging Hypothesis'. The hypothesis states that birds assess distances from one another using sound degradation, by comparing newly heard sounds to an internal representation of the undistorted sound. The use of degradation cues to estimate signaller distance has been tested and reported multiple times (McGregor 1994, Naguib 1996, 1998, Fotheringham *et al.* 1997). However, some results were thought to be unreliable, as a bird could potentially move position and triangulate to estimate distance to a loudspeaker if tracks were played for a sufficiently long time (Wiley 1998, Naguib *et al.* 2000). Further studies have shown that birds are able to range vocalizations by relying only on degradation cues (Holland *et al.* 2001, Naguib & Wiley 2001, Zahorik 2002), emphasizing the importance of considering ranging during experimental design.

The detection of sound alteration

Birds can sense differences in amplitude and frequency modulated sounds (Stebbins 1983, Bradbury & Vehrencamp 2011). Avian amplitude (Dooling & Searcy 1981, Cynx *et al.* 1990) and frequency discrimination thresholds (Saunders *et al.* 1978, Dooling *et al.* 2000) have been found to be similar to those of humans. Beason (2004) suggests that birds generally hear best between 1000 and 5000 Hz, with upper and lower auditory limits of 25 000 Hz (25 kHz) and 5 Hz respectively. However, some studies report upper limits closer to those typical of humans (20 kHz, after conditioning), and theoretical ones up to 30 kHz (Schwartzkopff 1955, Dooling 2004, Li *et al.* 2011a, Martin 2017). Some bird vocalizations include high-frequency harmonic components extending into the ultrasonic range (Brand 1938, Thorpe & Griffin, 1962, Narins *et al.* 2004, Tanimoto *et al.* 2017) and, in some species, the energy carried by these high-frequency components is like that of the vocalizations' audible components (Li *et al.* 2011a). Although high-frequency components could be by-products of vocalization, they may instead have a specific role in signalling to conspecifics (Thorpe & Griffin 1962, Wilson & Hare 2004, Li *et al.* 2011a). It has therefore been suggested that assumed avian auditory system limits may need to be re-evaluated (Narins *et al.* 2004, Li *et al.* 2011a). Experiments concerning noise (Scharf 1970, Lohr *et al.* 2003) and frequency alterations over time (Ratcliffe & Weisman 1985, 1986) suggest that the way that birds perceive differences in sounds may be quite different from ours. Of course, such perceptions could be specific to genus or species. Lohr *et al.* (1998), and Dooling and Prior (2017) showed how the ability to discriminate sound alterations in the fine structure of the sound (local timing, accounting for spectral and temporal cues within individual harmonic syllables), rather than just in the *temporal envelope* (accounting for the global features of a sound) in some birds is significantly better than in humans.

Reaction to sound alterations

Several studies have addressed the matter of differential responses to altered stimuli. Some species such as Field Sparrows *Spizella pusilla* and White-crowned Sparrows *Zonotrichia leucophrys* show stronger responses at lower frequencies (Nelson 1989, Luther *et al.* 2017), whereas other species such as Northern Cardinals *Cardinalis cardinalis* and Black-capped Chickadees *Poecile atricapillus* respond more vigorously than average to shifted frequency vocalizations (providing that background noise is not too high) or when presented with note-specific alterations (Luther & Magnotti 2014, Wong & Gall 2015). Average amplitudes of natural vocalizations at source are not known for most birds, and there is huge individual variation and modulation potential (Naguib 1995, Tanimoto *et al.* 2017). Higher broadcasting amplitudes usually elicit altered (often stronger) responses from wild birds (Dabelsteen 1981, Nelson 2000, Ritschard *et al.* 2010). Amplitude differences are thus double-edged swords, as the species' differential response to them could be advantageous when using playback to detect rare or elusive species (Marion *et al.* 1981, Okahisa *et al.* 2016), but be a source of bias in behavioural contexts. Finally, changes in the quality of a broadcast vocalization can have significant impact on the birds' response. Several species respond more aggressively to playbacks of clear vs. degraded vocalizations broadcast at the same amplitude (Richards 1981, McGregor *et al.* 1983, McGregor & Krebs 1984, Slabbekoorn 2004).

In this review we examine a sample set of papers that use the playback technique in avian field studies to investigate how reproducible the studies are. We synthesize our findings to provide a set of features that we deem important to report in published articles involving the playback technique in order to improve reproducibility; these come from both a review of the literature and experience. A consistent approach to performing and reporting experiments employing the playback technique would make it easier to understand, reproduce and compare the results of studies, thus enhancing advancement of this field. We also provide a series of practical recommendations, including suggestions on how to measure amplitudes more easily in the field.

METHODS

Literature search

We performed a systematic literature review following the RepOrting standards for Systematic Evidence Syntheses (ROSES) protocol (Haddaway *et al.* 2018) and searched three different on-line literature databases: Scopus (https://scopus.com), PubMed Central (https://www.ncbi.nlm.nih.gov/pmc/) and Web of Science (https://webofknowledge.com) on 18 December 2019. Our search was limited to original research articles (i.e. not reviews) from 1993 onwards (i.e. published after the 1992 Thornbridge Hall NATO ARW consensus). We searched using the following logical combination of keywords: `(*bird* OR avian) AND playback AND (*acoustic* OR sound) AND (natur* OR field)` where asterisks represent the possibility of any prefix/appendix to be attached to the search word (e.g. *natur** would include *nature* and *natur*`al)`.

We only included articles written in English in our sample. We also excluded all the search engine results that did not involve birds (although broadcast of avian vocalizations to non-birds was accepted, as well as broadcast of non-avian sounds to birds), all non-peer-reviewed articles (e.g. grey literature, theses) and articles only involving captive birds. All the articles remaining after these exclusion criteria were applied are included in our sample; a listing of the whole sample is available as supplementary material.

Assessment of primary studies

Focusing exclusively on the technical aspects of employing the acoustic playback technique, we prepared a checklist to evaluate the extent to which the reporting in each study was sufficient to reproduce it (Table 1). This list included all the information we expected to see in the Methods section and included information that is important both to reproduce the research and to interpret the results. The first criterion on the checklist considered how comprehensively the authors described the context in which they employed the playback technique by including relevant geographical, climatic and habitat information. Although not as objective as the other criteria, we first considered the amount of information regarding the playback context reported by articles in our sample. We used a point-based system according to which each article could potentially receive up to eight points, whereas all the remaining criteria assigned each article to a category. The remaining criteria ascribed articles to different categories according to the origin of their audio tracks (and details of the recording devices if not acquired from a third party), the availability of such tracks, details about their properties (frequency range and bit depth), whether and how these were processed, the actual playback procedure, observers' behaviour, and broadcasting details (including sound pressure level, see details in Table 1).

The standard screening strategy was first to assess eligibility as follows: read title and abstract, if not conclusive read methods section, if not conclusive read entire article and supplementary material. Subsequently, we read each eligible article and relative supplementary material to assign it to the different categories, according to the checklist.

For consistency, one author (A.D.R.) performed the bulk of the evaluation. A.D.R. also performed a second evaluation 1 year after the first, blind to the first result: the second evaluation matched 96.7% of the scores (see Supporting Information). We further verified the evaluation by asking five additional people (see Acknowledgements), blind to the main reviewer's scoring, to score three randomly selected unique articles already scored by A.D.R., plus two shared among all, for a total of 17 (4% of the sample) unique articles.

The ROSES protocol also includes procedures for obtaining missing data. However, we did not use these procedures because we consider them unnecessary; the main point of this review was to identify the degree to which we would be able to reproduce applications of the acoustic playback technique in avian field contexts wholly from the published material (including supplementary material).

RESULTS

Analysis of reporting in the literature

The online databases returned very different numbers of articles (Supporting Information Table S1). The total number of articles returned by the various searches was 1087, of which 625 were individual articles and the rest repetitions between the databases; we found 601 articles through Web of Science (of which we included 406 in this study, 294 were only found through Web of Science, see Supporting Information Fig. S1), 177 through Scopus (115 included, nine were only found through Scopus) and 73 through PubMed Central (38 included, four unique in PubMed Central, see Fig. S1). We included about two-thirds (419) of the total 625 unique articles resulting from the

Table 1. Scoring checklist. Whereas the first criterion is point-based (1–8, higher scores mean more detailed), all the others assign papers to categories (numeric values are not important). SPL, sound pressure level.

Feature	Points
Context	1–8
Location	
w/ coordinates	2
w/o coordinates	1
Vegetation	
Nothing	0
Description	1
References	2
Time	
of Year	1
of Day	1
Extra (Fauna/Geology/Weather)	
Nothing	0
Description	1
References	2
Feature	Category
Tracks origin	
Not specified	1
Recorded by the authors	2
Obtained from a third party	3
Some recorded by the authors and some obtained from a third party	4
Recording devices	
Not specified	1
Brand & model	2
Additional information	3
Frequency response charts	4
Not applicable	5
Tracks' availability	
Not available	1
Some available	2
Available	3
Recording parameters (Frequency range/bit depth)	
Not applicable	1
Not specified	2
Present	3
From tracks to stimuli	
No editing	1
Outlined but not reproducible	2
Reproducible	3
Not specified	4
Playback procedure	
Not specified	1
Outlined but not reproducible	2
Reproducible	3
Observers' behaviour	
Not specified	1
Outlined but not reproducible	2
Reproducible	3
Not applicable	4
Broadcasting SPL	
Not specified	1
Not shown, Explained	2
Shown, Not explained	3
Shown, Explained	4
Shown, Referenced	5
SPL measurement	
Not specified	1
Not measured	2
Measured, Not described	3
Described, Not reproducible	4
Reproducible	5
Broadcasting devices	
Not specified	1
Brand & model	2
Additional information	3
Frequency response charts	4

search in the sample. Of the 206 that we excluded, 62 were not about birds, 90 involved the use of captive birds in aviaries or laboratories, three were not classifiable as 'articles' (e.g. books, technical reports), 27 did not employ playback, 21 were not written in English and three were duplicates. The number of articles per year in the final sample of evaluated papers showed an increase from as few as three in the 1990s to high 20s from 2008 onwards (Fig. 1). We next discuss the distribution of articles according to each checklist criterion (Fig. 2).

Playback procedure, context and observers' behaviour

Half (52%) of the articles scored 4 or more on the context criterion (the maximum score was 8), which usually meant that coordinates for the study site, date and time of broadcast were provided (see Table 1 for detail). Overall, the most represented value (median) was 4, with a mean of 3.60 and a standard deviation of 1.18. Only 4% (17) did not specify any detail about the playback procedure (stimuli order and playback duration), whereas 45% and 50% provided some (190) or detailed (211) information. Nine per cent (38) of the sample did not specify the activities of the observer(s) during playback, whereas 26% (109) provided enough information to reproduce effectively what they were doing. Most (62%, n = 262)

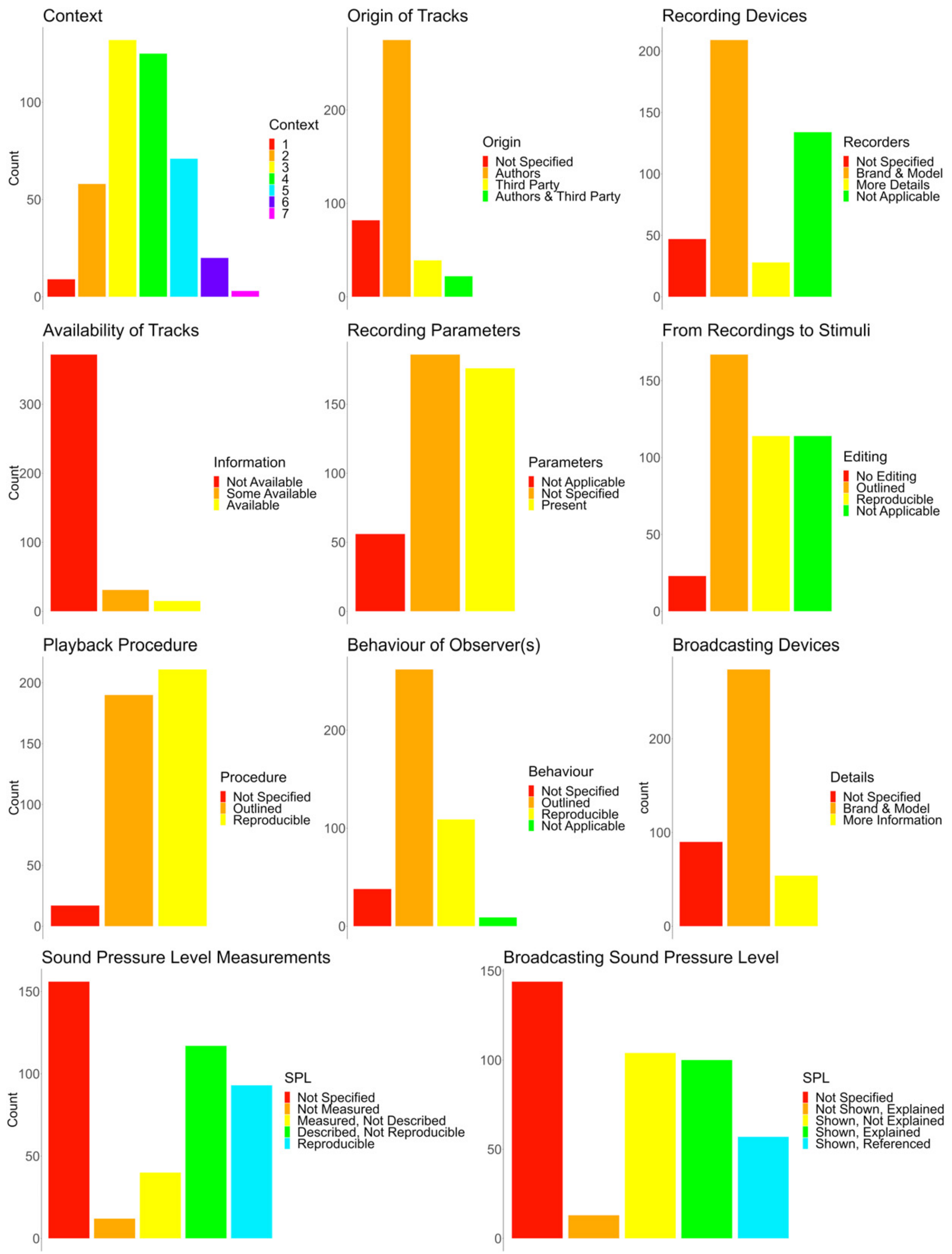

Figure 2. Numbers of the sample articles resulting from our literature search according to our review criteria in the checklist's order. The colours respectively represent the numbers of articles belonging to each category as per individual legends.

of the sample gave some information on what the observer(s) was doing, but not enough to faithfully reproduce it.

Recording devices and settings

Most of the articles in the sample (66%, *n* = 275) used custom tracks (either recorded or generated by the authors). Overall, tracks obtained from third parties were used in 9% (*n* = 39) of the articles, while 5% (*n* = 22) used a combination of custom and third-party tracks. The remaining 20% (*n* = 82) did not provide enough information to identify the origin of their tracks.

After excluding the 39 articles that obtained their recordings exclusively from third parties and the 104 for which we had no information about track origins, 297 articles that used recording devices remained. Of these, 70% (*n* = 209) provided the brand and model of their recording devices, and 9% (*n* = 28) included additional details (e.g. frequency response). Forty-seven articles (16%) did not provide information about the recording devices employed. None of the articles provided frequency response charts for their recording devices. Fifty-nine per cent (*n* = 176) of the articles in which the tracks were recorded by the authors provided both sampling rate and audio bit depth, whereas the remaining 121 articles did not.

Sound file preparation

Following recording, most tracks were post-processed to prepare them for playback. This can include various digital filters such as denoising, amplitude correction, segmentation and frequency range reduction. Most of the considered articles (73%, *n* = 305) reported something about their track preparation procedure. Of these, 7% (23) did not alter the tracks, 55% (*n* = 167) gave some information about their procedure and 37% (*n* = 114) provided enough information to reproduce their track editing.

Broadcast

Whenever possible, we acquired technical specifications for the loudspeakers used by the authors. Most articles (65%, *n* = 274) reported at least the brand and model of their devices; 13% (*n* = 54) also provided additional specifications occasionally including frequency response intervals (e.g. 'flat response ± 3 dB'), whereas 90 articles (21%) did not specify the broadcasting device employed. No article reported frequency response charts for their broadcasting devices.

Most of the articles in our sample (60%, *n* = 250) reported measuring their broadcasting sound pressure level (SPL). Twenty-two per cent (*n* = 93) provided a detailed report that included enough information to reproduce the same exact measurement, and 28% (*n* = 117) reported partial information about the measurement. Twenty-five per cent (*n* = 104) reported the SPL of broadcast without explaining how it was measured; 37% (*n* = 157) reported and explained their broadcasting SPL (57 of them also included references), and 34% (*n* = 144) did not report it at all; 3% (*n* = 13) explained their broadcasting SPL to the reader without reporting it.

For a playback experiment to be fully reproducible, the tracks used by the authors need to be publicly available. This is not yet common, with tracks from only 3.6% (*n* = 15) of our sample being easily available (without having to contact the authors); however, for some of the articles (7%, *n* = 31) a subset of the tracks was available. In all, 372 articles (89%) did not provide any means of retrieving any of the acoustic tracks employed.

Objectiveness of the review and reproducibility of the evaluation

Overall, we feel confident that we conducted an objective review in terms of both the selection and scoring of the articles. Of the two shared articles that we gave to five extra reviewers, one was always discarded as non-avian and the other was consistently scored by all, although some minor differences arose. Most differences both among external reviewers and between the main reviewer and the external reviewers related to SPL measurements.

Reproducibility of methods

If we define a reproducible article as one that faithfully describes how playback is performed, how the stimuli are prepared, how the observers behave, at what SPL sounds are broadcast, and one that provides access to the employed tracks (although digital on-line archiving may not have been available for the entire sample, archives and institutions such as the Macaulay Library, established in 1929, have existed long before acoustic playback), we would only have one such article in our sample. This is a study of the low-frequency vocalizations of the North African Houbara Bustard *Chlamydotis undulata undulata* by Cornec *et al.* (2017). This definition of reproducibility specifically relates to criteria 4, 6, 7, 8 and 9 (Table 1), leaving the remaining criteria for comparison purposes. For example, criterion 1, which relates to context, might be essential for reproducing an experiment in similar conditions or conditions that differed in known degree from those of the initial study. If we assumed that we would not need to know how the stimuli were prepared, because they would be available, and not accounting for the SPL measurement parameter, we could drop criteria 6 and 9 and would have five reproducible articles in our sample of 419 articles (0.92%; Dufty & Crandall 2005, Li *et al.* 2011b, Krieg & Getty 2016, Cornec *et al.* 2017, Moskát *et al.* 2018).

DISCUSSION

Our literature review shows that as a community we are still not providing all the information that is needed to reproduce faithfully the research we carry out. In the next sections we provide some recommendations regarding the use of the playback technique and discuss aspects of avian physiology and behaviour that are likely to affect bird response to playback and hence highlight the need for reproducibility.

Recommendations (Table 2)

Report recording conditions

Ideally, high-quality, almost undegraded (e.g. recorded less than 1 m away from the subject) vocalizations should be used to make playback stimuli, to avoid conditioning responses with unwanted distance cues (Lambrechts & Dhondt 1995, Ríos–Chelén *et al.* 2017). As this is not always possible, the best compromise we can currently suggest is to account for at least the SPL and meteorological variables measured when the sounds were recorded, and the distance from the bird at which these were recorded. If this is not possible, we would recommend broadcasting or otherwise producing a reference sound (reproducible elsewhere) at a known distance from the speaker. This will help to determine, approximately, the SPL of the recorded vocalizing animal. By broadcasting vocalizations at the SPL measured at the time of recording, the possibility of broadcasting ambiguous signals, such as high-amplitude degraded songs, should be minimized (Table 2).

We suggest that all details of the mechanics of the recording are presented: recording device details (brand and model, settings), environmental conditions (vegetation structure, base noise SPL, temperature, humidity, wind speed and direction), SPL (including detailed measurements, see below), and bird orientation (relative to the recorder, e.g. 'facing the recorder') and distance while recording. All these are desirable variables to include in any report concerning the use of self-recorded stimuli. If tracks are obtained from third parties, the on-line repository identifiers are needed, together with the original source citation. We suggest including all the details as comments accompanying the tracks uploaded to on-line repositories.

Report post-processing methods

Post-processing for track creation also needs to be reported because performing the same experiment using tracks with different dynamic range (because of the bit depth), frequency response (because of the sampling rate), or altered using different filters, denoising algorithms and/or more advanced edits could all lead to different results. Understanding the degree to which a target species can discriminate amplitude and frequency modulations is a decisive step in conducting effective broadcasting experiments.

Make tracks publicly available

We strongly recommend that high-quality, 'losslessly'-encoded versions, such as Free Lossless Audio Codec (FLAC) and Waveform Audio File (WAV) files, of the final tracks are used and made publicly available on the internet. This enables readers to evaluate the quality of the sounds used, and other experimenters to use them directly, if applicable. This could be useful even when counterintuitive. For example, if we *broadcast* 'neighbour' and 'stranger' vocalizations to subjects, we may think them to be useful just to ourselves. However, our neighbour tracks could be employed by other researchers in need of a 'stranger' track and so on.

Table 2. Useful details to report to facilitate reproducibility of applications of ornithological playback techniques.

Feature	General information	Details
Context	Geography	Location description
		Altitude
		Slope
		Other geophysical information
		Vegetation community
		Coordinates
	Time	Time of year
		Time of day
	Environmental conditions	Temperature
		Humidity
		Wind speed
		Wind direction
		Further weather information
Tracks employed	Origin	Self-recorded/Third party
Recording device(s)	Brand & model	Specifications
		Microphone frequency response chart
		Accessories
Tracks availability	Whereabouts	On-line repository ID & reference
Recording details	Geography	Location description
		Coordinates
	Time	Time of year
		Time of day
	Environmental conditions	Temperature
		Humidity
		Wind speed
		Wind direction
		Further weather information
	Recordist(s)	Distance
		Orientation
		Δ height
		Measured SPL
		SPL meter brand & model
		SPL meter settings
	Noise	Base level
	Recording device settings	Sample rate
		Frequency response chart
		Bit depth
	Vocalization type	Description
		Number of different individuals
		Stimuli meaning
From tracks to stimuli	Post-processing	Software used
		Denoising algorithms
		Filters applied
		Additional edits
Playback	Procedure	Playback protocol
		Single/Multiple loudspeakers
		Interactivity or sequence
		Duration
	Presumed meaning to targets	Sound broadcast
		Relation to territory
Observers and target individuals	Prior/During/After playback	Presence/Absence
		(Eventual) Position
		(Eventual) Behaviour
		(Eventual) Additional target information

(continued)

Table 2. (continued)

Feature	General information	Details
		(e.g. stage in breeding cycle)
		(Eventual) Additional information about surroundings (e.g. last predator heard/seen)
Broadcasting	Sound pressure level	Measured SPL and distance (e.g. 75 dbA, 1 m away from the speaker)
		SPL explanation
		References
	Sound pressure level measurement	SPL meter brand & model
		SPL meter settings
		Context
	Device(s)	Brand & model
		Frequency response chart
		Signal-to-noise ratio
		Directionality
		Settings
		Positioning

There already are several online repositories that are, either partially or wholly, dedicated to avian vocalizations, such as Xeno-canto (https://www.xeno-canto.org/) and the Macaulay Library of the Cornell Laboratory of Ornithology (https://www.macaulaylibrary.org).

Whenever sharing the final versions of the employed tracks is not possible, as in the cases of commercial recordings, the latter can be referenced, and the references accompanied by a detailed description of post-processing procedures.

Select playback technology appropriately

The most prominent aspect to consider regarding the use of a loudspeaker to broadcast bird vocalizations is probably how these will be perceived by the birds. It is advisable, when possible, to consider known hearing and vocal frequency bandwidth limits of target species, and to choose devices accordingly. Some articles in our sample mentioned the frequency response of their loudspeakers; we add that it always is desirable to include frequency response charts for all the employed equipment. Unfortunately, this information is not always included in the equipment's specification sheets. However, a reasonable approximation can be generated by broadcasting a frequency sweep at normalized amplitude (which can be generated using free or commercial acoustic software) in front of the SPL meter in logging mode; plotting the resulting amplitude will result in a rough, albeit informative, frequency response chart. The distance between loudspeaker and SPL meter, conditions (e.g. soundproof room) and method of generating the frequency sweep for completeness should also be reported.

Report playback parameters

The SPL (or SPL range) at broadcast should be measured and device specifications and settings for both loudspeaker(s) and SPL meter, including brand, model, signal to noise ratio, frequency response chart, positioning and eventual settings when applicable for loudspeakers should all be reported. As measuring the SPL of natural sounds in the field is often harder than anticipated, we suggest generating a long (e.g. 30 s) pure tone at the peak amplitude of the vocalization to broadcast, to normalize its amplitude with that of the natural sound at peak amplitude, and to measure more easily this instead of the more volatile natural sound. In addition, for the SPL meter, it is important to include distance at the time of measurement(s), brand, model, scale (dBA/dBC/dBZ/other), response (fast/slow), range (e.g. 30–130 dB) and frequency response (possibly including the chart). Returning to the playback itself, we recommend reporting coordinates and time of year and day, as well as environmental variables such as altitude, temperature, humidity, wind speed and direction, and a description of the area including surrounding vegetation community and geophysical information such as an indication of soil type and slope. The relevance of this contextual information is that although it may not directly influence the ability of other researchers to perform the experiment, it is helpful in interpreting results. Additional important features to report include procedural aspects, such the duration of playback, number of loudspeakers used, use of static/interactive playback, and observer(s) position and behaviour before and during playback.

CONCLUSIONS

The playback technique represents a very powerful tool in conservation contexts (e.g. eliciting vocalizations of rare or cryptic species), and can provide invaluable understanding of several aspects of a target taxon's behaviour. It is easy to use, relatively non-invasive and can provide directly interpretable outcomes. This makes it an excellent choice to pursue research questions in areas such as ecology, ethology and evolutionary biology.

While considering the development of our own studies involving acoustic playback, we were surprised to be unable to find a consistent set of guidelines for the design, execution and reporting of such experiments. To our knowledge, the table provided by McGregor *et al.* (1992), while not intended as an instruction list, represented the only available guideline authors could follow to better design their experiments until now. A recent paper by Gentry *et al.* (2020), while not specifically about ornithological field applications, also provides very useful guidelines that correspond well to those we have identified here.

Based on the literature and our own experience, we provide, in Table 2, a list of features to consider and report to allow any reader to reproduce future applications of the playback technique. Of course, as technology advances, and for specific environments and experimental aims, there may be other factors that need to be considered. We also provide two sample paragraphs (Appendix 1 and 2) that, in our opinion, would represent exhaustive reports regarding potential studies involving acoustic playback.

By consistently reporting methods in a community-wide fashion, and by making publicly available the acoustic stimuli we employ, the research community would allow fellow researchers not only to reproduce experiments but also to compare and evaluate the experiments reported, hence improving the reliability of future developments in bioacoustics more easily.

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AUTHOR CONTRIBUTION

Alberto De Rosa: Data curation (lead); Formal analysis (lead); Investigation (lead); Methodology (equal); Writing-original draft (equal); Writing-review & editing (equal). **Isabel Castro:** Conceptualization (equal); Methodology (equal); Supervision (equal); Writing-original draft (equal); Writing-review & editing (equal). **Stephen Marsland:** Conceptualization (equal); Methodology (equal); Supervision (equal); Writing-original draft (equal); Writing-review & editing (equal).

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Data Availability Statement

All the data are provided as supplementary material.

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APPENDIX 1

SAMPLE REPORT PARAGRAPH #1 (THIRD PARTY TRACKS)

We obtained half of the original tracks from the Macaulay Library at the Cornell Lab of Ornithology and the rest from xeno-canto.org (ML1234, ML5678, ML9101, ML1121, ML3141, ML5161, XC7181, XC9202, XC1222, XC3242, XC5262, XC7282). All the original tracks were recorded in locations >800 km away from our experimental ones (see on-line repositories for details) and, given the sedentary behaviour reported for the target population (Otor 2009), we do not see any reason to think that any of them were of individuals known by our targets. In `GenericEditingSoftware, Version x.y.z`, we joined the original tracks two by two (in the given order, for a total of six tracks), separated by 1 s of generated silence. We then applied a High Pass Filter at 1000 Hz, added 5 s of white noise at the beginning of each track (amplitude 0.4) and normalized each track to 0 dB amplitude. We did not apply any further algorithm; the finalized tracks are available at our research group website (http://thisisour.url/research/media). Playback took place in three different locations within the plains of *Flat* natural reserve (#1: 12°34′56″N, 78.0°91′01″W; #2: 11°21′31″N, 41°51′61″W; #3: 71°81′92″N, 02°12′22″W), on the Xth, Yth and Zth of Month Year, respectively. All trials began at 21:00 h and lasted 30 min, consisting of 10 min of playback, 10 min of silence and repeat of the 10 min of playback. We broadcast a different pair of stimuli in each location to avoid pseudoreplication. The weather was generally stable throughout the three trials with $14°C < T < 17°C$, $65\% < H < 74\%$ and 3.4 km/h < Wsp < 5.7 km/h from 244° < Bearing < 275°. We recorded weather data using a `Brand` 1.23 portable weather station, which we set to log data every 15 s; the weather station logged data from 15 min before to 15 min after each trial and was placed on a tripod at a height of 1.5 m. Raw weather data are included as supplementary material to this paper and on our website. In all but one location (#2) we did not record any activity/presence of individuals prior to the beginning of the playback. In location #2, one male chased away a younger male *c*. 5 min prior to the beginning of the experiment; both males were colour-banded and we did not see them during the experiment. All three locations were sparsely vegetated, with only a few shrubs of a plant (*Genus speciensis*, L.) within a radius of ~ 40 m from the loudspeaker. The loudspeaker (`Sp. Ker MAX`, frequency response 140–14 000 Hz (chart included as Supporting Information Fig. S1), = 89 ± 4 dB) was set at 1.5 m height on a tripod, parallel to the ground. We used an `Sp. Lev M3734` Sound Pressure Level Meter (fast response, C setting – frequency response chart included as Supporting Information Fig. S2) to set broadcasting amplitude to 66 dB at 1 m distance, as this value has previously been reported to be the natural average for this species (Author *et al.* 2011). We video-recorded all trials using an `O/Brand` 4.56 Action Camera fixed on top of the loudspeaker. During the trials, two observers sat in a previously (1 week) assembled hide, approximately 30 m away but in sight of the remotely activable loudspeaker. All the videos are available at our research group website.

APPENDIX 2

SAMPLE REPORT PARAGRAPH #2 (SELF-RECORDED TRACKS)

We recorded the original tracks at a sampling rate of 48 kHz and audio bit depth of 16, using an `MIC #1234` microphone (frequency response 40 to 20 000 Hz, chart included as Fig. S1 –, sensitivity –50 dB) connected to an `Sr. EC X12345` digital recorder. The recording was carried out at the forest of *Trees* (12°34′56″N, 78°91′01″W), in the city of *Town*, *Country*, during the breeding season, on Month Xth Year morning from hh:mm to hh:mm h. At the time of recording, temperature averaged 9°C, humidity 67%, and the wind was blowing from 256° at an average speed of 12 km/h (`Brand` X12 portable weather station, logging every 30 s throughout the recording session – raw log available as supplementary material). We recorded four different males perching on ~ 2-m-high branches 5 ± 2 m away from our hide; no obstacles were between us and the recorders at any time. No individual was solicited to vocalize. The measured SPLs were 62.3, 63.1, 66.0 and 65.4 dB measured at 5 ± 2 m (`Sp. Lev M3734` Sound Pressure Level Meter, fast response, A setting – chart included as Fig. S2); details for individual vocalizations are provided as comments with the tracks uploaded on-line (identifiers: ML7181, ML9202, XC1222 and XC3242). At the time of recording, base background noise ranged from 48 to 53 dB as measured with the same device and settings as the birds' vocalizations. We selected only tracks recorded while the recordee was facing the recorder. We used AnotherEditingSoftware Verzion x.y to divide the 5-h recording into individual vocalization tracks (which we then uploaded on-line with the given identifiers above). We did not apply any filter or denoising algorithm. The playback experiment took place in the Forestpark Park, near the town of *City*, *Othercountry*, where we used an omni-directional (`Sp. Ker ∅`) loudspeaker, with frequency response between 40 and 18 000 Hz (Supporting Information Fig. S3) and signal to noise ratio of 91 ± 2 dB; we placed the loudspeaker on the provided support (`Sp.047 tripod`), 1 m high at the presumed centres of four different territories. The presumed owners of territories were sighted and recognized (by their unique colour band combinations) on-site prior to the beginning of the trials. Trials were initiated only if the territory owner had not been heard vocalizing for $t \geq 10$ min. Vegetation was dense, with 0.3376 ± 0.16 trees/m^2 in three of four locations (coordinates, pictures and point-centred quarter method tables in the Results section); location #3 was less dense, with 0.1875 trees/m^2. Dominant species were Onetree (*Primigenus specinæ*, L.) in locations 1 (73%) and 2 (54%), Anothertree (*Aliumgenus speciferus*, L.) in location 3 (80%) and Lastree (*Ultimugenus specii*, L.) in location 4 (64%). We used a different track for each location to avoid pseudoreplication, and we set the loudspeaker to broadcast each track at its originally measured amplitude to avoid unnatural broadcast (5 m away from the speaker using the previously mentioned settings on the `Sp. Lev M3734` Sound Pressure Level Meter).

SUPPORTING INFORMATION

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

Table S1. Number of articles found and included from the different on-line databases

Figure S1. Depiction of the on-line resources we found in the articles included in this study. Numbers within each section represents the number of articles found by each resource; i.e. we found 294 of the included articles only through Web of Science, whereas six articles were found by both PubMed Central and Web of Science.