PROVOKING PROPORTIONATE CONSIDERATION OF ANTHROPOGENIC NOISE ON TERRESTRIAL ANIMALS

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1 INTRODUCTION

Biodiversity in UK nature has generally been depleting since well before widespread data gathering began in 1970, and it continues to do so (1). It is in the interest of the UK (2) and of the planet as whole (3) to rectify this. However, if environmental pollutants such as noise, vibration, odour and light are not properly considered, then not only might humans be unknowingly causing harm to nature, but also, any actions to promote biodiversity may be critically uninformed and less effective as a result.

This paper focuses on noise, and specifically what measures could encourage the potential impacts of anthropogenic noise on terrestrial animals to be considered when any developments are at planning stage.

Assessing noise impacts on wildlife is complicated, as different animals have varying sensory organs and signal processing mechanisms, which make them perceive the world differently. Context, frequency, duration, timing, sound character, etc all expand how complicated the subject matter is. Moreover, previous DEFRA research (4) found that there was no strong evidence base for anthropogenic noise impacts on non-marine UK Priority Species and Species of Principal Importance. However, research of noise impacts on humans (5) shows that subtle widespread effects over time have substantial effects on overall population health. It stands to reason, therefore, that such adverse effects could be equally prevalent for terrestrial wildlife. While deriving definitive assessment criteria for noise impacts on wildlife is ambitious, particularly based on currently available research, this should not be a reason for not carrying out any assessments at all.

There are no objective measures for deciding if an assessment of anthropogenic noise on terrestrial animals should be carried out. It is therefore proposed that, if a simple process for scoping could be developed, then this process could be used to quickly determine if an assessment is worthwhile. This would not only provide enhanced protection to terrestrial wildlife but would also protect against redundant assessments being carried out. A method that enables quick determination of what animal species warrant assessment for potential noise impacts would also allow assessments to be proportionate, rather than carrying out assessments for all the species in an area. In adopting such a targeted approach, it is implicitly acknowledged that efforts should be made to streamline the planning process, rather than add to it.

Based on a review of the existing published literature, this paper discusses the feasibility of providing scoping criteria for determining which terrestrial animals on a site warrant an assessment of potential adverse noise impacts associated with any development works. It is proposed that a rational approach based on relative distances be taken, based on conservative assumptions, as summarised throughout the paper. Therefore, this study is not applicable to noise from airborne aircraft in flight, which warrants separate consideration as, for example, jet aircraft has been shown to potentially negatively affect nesting success for peregrine falcons (6).

Fundamentally, this paper intends to provide a positive step towards facilitating appropriate considerations of noise and terrestrial wildlife in the wider picture of holistic decision making for planning, without unduly burdening the process.

2 METHODOLOGY

2.1 Literature Review

This study focusses on terrestrial animals that are defined as protected species by the UK government [7]. Therefore, a combination of various platforms (predominantly Elsevier, Google Scholar, Pub-Med, and ResearchGate) have been used to search for papers related to anthropogenic noise impacts on the following types of animals:

- Badgers.
- Bats.
- Birds.
- Dormice.
- Great crested newts.
- Invertebrates.
- Natterjack toads.
- Otters.
- Reptiles.
- Water voles.

Where no, or little, research was found for a specific species, an attempt was made to find acoustic research for a similar species. For example, to provide an approximate representation of impact thresholds for natterjack toads, research available for different types of frogs was used. While frogs and toads have key biological and contextual differences, including different calls, they have relatively comparable ear structures and sensitivities to different frequencies (albeit with variance where species have a tympanum and are subsequently more sensitive at high frequencies) [8] [9] [10].
While different animals, which may seem comparable at first glance, can have quite different relationships to sound. It is proposed that where the differences in audibility thresholds are small, grouping animals together for the purpose of scoping is reasonable. For example, small birds generally have relatively comparable audiograms [11].

3 KEY DATA FOR SCOPING

3.1 Bats

Road traffic noise in isolation (i.e. audio playback of road traffic noise) is shown to be capable of reducing activity for various species of bats [12]. Sound masking can influence hunting [13]. Even where echolocation and traffic noise frequencies do not overlap, road traffic noise can provoke an avoidance response [14]. The influence of road traffic noise on foraging success is likely to be profound close to a road (within 7.5m) but is potentially negligible further away (50m+), although search time is still likely to be influenced [15].
Audio playback of compressor station noise has been shown to increase search times for bats in a comparable manner to road traffic noise [16]. This study shows that road traffic noise could result in meaningful increases in search times at much greater distances (up to 640m away). However, as this study also found meaningful increases in search time from low level low frequency electrical noise, this work is considered an overly onerous basis for scoping at this stage – until further research indicates otherwise.
As with road traffic noise, broadband noise has been shown to negatively affect foraging, regardless of whether the noise spectrum coincides with frequencies emitted by prey, or the bat for echolocation (17). Therefore, continuous noise is generally observed to have comparable effects. A scoping distance of 200m is considered reasonable for continuous noise based on the above.
While bats are observed to take temporary evasive action during and/or shortly after a passing train, there is no evidence that this is due to noise exclusively, and approaching trains are observed to have little influence on bat activity [18]. For trains, construction noise, and other intermittent sources of noise, conservative estimates for likely onsets of sound masking could be a basis for deriving scoping thresholds, as noise that results in sound masking is likely to provoke reflexive behavioural change

to compensate [19]. However, there is limited information on critical ratios for bats, such as the research carried out on the greater horseshoe bat [20]. In the presence of limited information, continuing with a 200m scoping distance for intermittent sources seems reasonable, but warrants specific research.

3.2 Birds

3.2.1 Owls (Strigiformes)

Owls are considered in isolation to other birds due to their notable reliance on sound.
Road traffic noise has been shown to impede owl hunting and the masking and/or distraction effects of traffic noise are expected to potentially occur beyond 120m from a road [21]. Emulation of compressor noise 50m away (73 dBA) has been shown to half the probabilities of a northern saw-whet owl detecting and accurately striking a mouse, reducing the overall chance of chance to almost zero; Emulations of compressor noise up to 800m away (46 dBA) are still observed to negatively impact on hunting success [22]. Therefore, a scoping distance in the order of 1000m could be considered a reasonable basis for scoping for constant sources of noise. Noise levels from plant/machinery and road traffic can be quite variable. Nevertheless, the noise levels from the compressor referenced are high for plant/machinery noise. Therefore, this is considered a conservative basis.
Noise from helicopters and chain saws has been shown to be capable of greatly increasing owl flush frequency; however, this effect is found to cease at distances over 105m away [23]. Impulsive or short-lived noise in isolation may therefore warrant closer distances for scoping. However, there is no study of how this noise may distract from hunting. Moreover, the regularities and durations of intermittent or impulsive noise will influence the effect. Furthermore, the onset of alert behaviours is still observed by Delaney et al up to around 660m from a helicopter. Noise levels from this study is observed to be comparable to the order of noise produced by construction activities [24] and railway traffic [25]. Therefore, retaining the 1000m scoping distances is considered reasonable, albeit conservative.
Research based on dBA values is informative. However, it is worth noting that an 'O-weighting' to account for owl hearing frequency bias has been derived [23] and could be used for further research and assessments.

3.2.2 Other Birds

There is generally more research for noise on birds than for other animals. An American compilation of the effects of highway noise on birds [11] notes both that:

- noise levels in the region of 50 to 60 dBA are a reasonable guideline for the onset sound masking and of short-term behavioural adaptation strategies (in a quiet suburban area); and
- around 800 feet (~244m) from a 2-lane American highway the noise level is < 50 dBA and the noise from a 4-lane highway is around 55 dBA.

Therefore, 250m is considered a reasonable scoping distance on this basis. This is reinforced by a study, which shows noise levels below 49 dBA to not significantly affect birds [26].
A report on construction noise and waterfowl [27] notes construction noise below 50 dBA to have minimal effects. Above 50 dBA, behavioural changes such as increased scanning behaviour and reduced feeding are observed. Based on typical noise levels from construction activities [24], and propagation losses outdoors [28], noise levels from construction works would likely be in the order of $L_{Aeq,T}$ 50 dB 250m away.

3.3 Great Crested Newts

Urodele orientational choices are shown to be dictated by multiple sources such as smell, magnetism, and celestial cues [29] [30] [31] [32] [33] [34]. The influence of acoustic cues on orientation will be context dependent.
There is little acoustic research to draw from for great crested newts. Nevertheless, there is evidence of great crested newts orientating themselves in relation to sound [35]. This has also been demonstrated for the palmate newt [36]. Therefore, sound masking would potentially reduce the extent to which great crested newts could rely on sound for orientation.

Comparing the audiograms of the median bird [11], aquatic salamander [37], grass frog and fire-bellied toad [38], it is considered unlikely that newts are particularly sensitive to sound, in comparison to birds for example. However, there is not enough information to derive approximate scoping thresholds, and certainly not enough information to carry out a subsequent assessment, should an assessment of potential anthropogenic noise impacts on great crested newts be scope in.

3.4 Medium-Sized Mammals

Badgers have been shown to be capable of chronic stress; however, noise is not isolated in this study [39].

The fundamental frequencies of badger vocalisations are approximately between 27 and 1191 Hz [40], which, though slightly lower, are relatively comparable in range to human vocalisations [41]. However, badgers are shown to have meaningful differences in hearing anatomy to humans [42] [43]. Little additional information is available on how badgers interact with sound. Therefore, estimating suitable scoping thresholds for badges is impractical.

In the presence of limited specific research for Eurasian otters, reference is made to research for similar sized mammals. Passing road traffic, with peak sound pressure levels around 65 dBA, is shown to increase vigilance in dwarf mongooses [44]. Similar levels of road traffic noise could also potentially alter responses to olfactory cues (signals received through the nose) resulting in not only increased vigilance, but also disruption to anti-predator behaviour [45].

Eurasian otters (*Lutra lutra*) [46], as well as neotropical otters (*Lontra longicaudis*) [47] are observed to vocalise and rely on sound.

Consequently, the onset of meaningful sound masking for Eurasian otters is considered a reasonable basis for scoping. In-air auditory thresholds of the Eurasian otter [48] show otters to not be particularly sensitive to sound in comparison to other animals. Therefore based on typical noise levels from a highway [11] typical noise levels from construction activities [24], and propagation losses outdoors [28], 100m is considered a conservative scoping distance for otters, in relation to the potential onset of sound masking.

It may be that badgers have better hearing, more in-line with a mink [49]. However, there is not enough information available to challenge this.

3.5 Small Mammals

Mice are notably well researched in a laboratory setting. The hearing sensitivities of rodents are observed to be relatively comparable at higher frequencies, but more varied at lower frequencies, as some rodents are observed to have extended low-frequency hearing [50]. However, it is considered unlikely that dormice and water voles fall into this category of extended lower frequency hearing, based on the audiograms of mice [51] and rats [52], and an analysis water vole vocalisations [53]. Mice are more sensitive to sound at higher frequencies than humans [54], meaning that dBA values, which most research references, need to be considered in the context of sound source frequency bias.

A sound level greater than 112 dB at 6 kHz is shown to be able to kill a mouse [55], which shows how serious noise impacts can be on rodents. Serous health impacts are observed for mice exposed to sound levels above 90 dBA [56] [57] [58]. Elevated stress and reduced feeding are observed in mice exposed to high frequency machinery noise above 80 dBA [59]. Anthropogonic noise at these levels is also found to reduce activity and call production in american deer mice and woodland jumping mice [60]. Exposure to anthropogenic noise above 70 dBA can increase the likelihood of stillborn pups [57] and increase stress hormone release for mice [61]. Machinery noise above 60 dBA is also shown to be able to produce a physiological stress response in wild mice [62].

It is therefore considered reasonable to treat 50 dBA (and subsequently 250m, as for birds) as an onset threshold for potential adverse impacts.

3.6 Natterjack Toads

Spadefoot toads have been observed to leave their burrows and move to the surface in the presence of 95 dBA motorcycle noise [63]. However, noise is not necessarily isolated in this study.

Continued exposure to noise levels above 76 dBC are shown to result in increased corticosterone levels in tree frogs (64). Nevertheless, traffic noise levels of 70 dBA have been observed to have little influence on locomotion and vocalisation activity in the Marsh Frog (65). Furthermore, species richness for anurans in Puerto Rico was found to be comparable close to (<100m) a noisy highway (noise levels approximately 70+ dBA) and father away (>300m) (noise levels <60 dBA) (66).
Road traffic noise levels of 73 dBA have been shown to alter the vocalisations of green frogs and leopard frogs, but not the gray tree frog or American toads (67).
Based on the above, it is considered reasonable to assume that noise sources more than 100m away are likely to result in minimal noise impacts on natterjack toads. However, research specific to the natterjack toad would be valuable.

3.7 Orthopterans

Whilst research on invertebrates is limited, there is evidence to suggest it is likely that many invertebrates are impacted by anthropogenic noise (68).
Many invertebrates can detect substrate-borne vibrations. Some insects even use substrate-borne mechanical waves for communication (69). Therefore, more research on the potential impacts of vibration on invertebrates would be valuable.
Many invertebrates perceive particle velocity via flagellar mechanosensory structures, e.g. hairs or antennae (70). As humans do not perceive this component of sound waves in this way, it is at risk of not being given due attention. The particle velocity component of sound waves attenuates very quickly with distance (71). Therefore, it could be assumed that anthropogenic sources would be unlikely to result in meaningful adverse impacts on invertebrates. Nevertheless, this should be tested appropriately.
This paper focuses on UK crickets and grasshoppers (based on research for similar insects), as both use acoustic communication to attract potential mates (72). The frequencies at which orthopterans are sensitive to sound are considerably higher than humans (73). However, research references either ‘unweighted’ (assumed to be Z-weighted), or A-weighted, values, which limit the extent to which the values can be leaned on.
Noise has been shown to influence chorusing and call frequency in the cicada (74). Noise has also been shown to influence the song of grasshoppers (75) (76). At noise levels above 70 dB (assumed to be Z-weighted), female field crickets are found to potentially be less attracted to signalling males (77). Exposure to road traffic noise around these levels prior to sexual maturity is also shown to influence adult mate location behaviour in field crickets - hindering the ability of females to locate mates (78). Road traffic noise levels as low as 36 dBZ are observed to potentially result in shorter durations of calls/singing, with higher noise levels causing an increased probability of pausing in tree crickets (79). Therefore, it is considered reasonable to have a large scoping distance for orthopterans. At this stage 1000m is considered reasonable based on the above, but more frequency specific analysis would be necessary to refine this value. In this regard, given that the high frequencies orthopterans are sensitive to diminish quickly with distance, it is likely that such evidence could justify a less onerous scoping threshold.

3.8 Reptiles

Whilst snakes are known to perceive airborne sound, their sensitivities to it are low (80). Snakes do not have an outer ear or tympanic middle ear (81). Furthermore, snakes generally produce sound at frequencies higher than those they are most sensitive to, implying a lack of dependence on communication via airborne sound, though this is more certain for some species than others (82). It is therefore considered unlikely that adverse impacts from airborne anthropogenic noise is a material concern for snakes. Nevertheless, anthropogenic vibration still warrants further research, as snakes perceive substrate vibration (83).
Various studies on lizards have found likely behavioural consequences of stress on lizards (84) (85) (86). Machinery noise has been shown to provoke signs of stress in lizards; noise levels above 70 dBA are likely to provoke head movement and freezing; noise levels above 60 dBA have the potential to influence head movement, cause freezing and reduce digging (62). Open cast mining in a forest, which

can be a loud source of noise, is noted to be below 64 dBA over 500m away [62]. Noise levels over 200m away from a 2-lane highway are noted to typically be below 60 dBA.
Therefore, 200m is considered a reasonably conservative scoping distance for the assessment of anthropogenic noise on lizards in the UK.

4 DISCUSSION

4.1 Proposed Approach for Scoping.

The below table summarises proposed scoping distances which, if the distance between a noise source and respective known animal location is less than, an assessment of potential anthropogenic noise impacts could be worthwhile. These distances are most relevant to road traffic noise and noise from machinery. More research would be warranted to understand how applicable these are to intermittent sources of noise such as passing trains and/or shooting ranges. Aircraft noise in particular is a source warranting separate scoping criteria.

Type of animal	Distance between source and receiver within which an assessment of anthropogenic noise impacts may warrant consideration
Bats	< 200m
Birds – owls	< 1000m
Birds (excluding owls)	< 250m
Great crested newts	Not enough information available
Badgers	Not enough information available
Otters	< 100m
Rodents (Dormice and Water Voles)	< 250m
Natterjack toads	< 100m
Orthopterans	< 1000m
Lizards	< 200m

Table 1: Potential scoping distances.

4.2 Limitations.

The idiosyncrasies of how different animals respond to sound makes the topic of potential anthropogenic noise impacts on terrestrial wildlife very complex. For the purposes of promoting proportionate action, a simplistic approach has been adopted with broad assumptions. The following are notable limitations to the adopted methodology:

- Animals are grouped together for the purposes of deriving scoping distances. In practice, even seemingly similar animals can interact with sound quite differently. For example, thresholds for birds are derived on the basis of sound masking; sound masking (and more severe impacts) will be very specific to the bird species(s) assessed [87].
- Scoping distances are limited by the robustness of existing literature. Findings are often observational and consequently limited by the potential for human bias. A review of the acoustic reliability of existing studies on anthropogenic noise impacts on birds concluded that more objective approaches are needed to advance research [88].
- Where research is based on laboratory experiments, there is no way of knowing the extent to which this would be replicated in the natural world. Also, no consideration has been made to the influence of sound levels being emitted indoors and how this would differ to external sound propagation (particularly in terms of frequency bias).
- Current research is predominantly based on broadband (single number) representations of sound levels (usually A-weighted). Therefore, precision in terms of sound source frequency bias is lacking.
- Scoping distances assume no screening, or valley effects, etc, and do not consider the influence of baseline sound climates.

- Research based on animals from around the world has been used to inform scoping distances/thresholds. In practice local adaptions will influence the observations of research.
- No consideration has been given to habituation. For example, anecdotal evidence of bats roosting close to noisy environments suggests they may habituate to noise [89], which could imply less severe impacts.
- It is assumed that any impact caused by anthropogenic noise is an imposition and therefore negative. However, for example, where the success of a predator is impeded, the respective prey may benefit [90] [91] [92] [93] [94]. However, this does call in to question the degree to which such beneficial impacts on one species at the expense of another may impact on the overall natural balance of biodiversity.
- Source noise levels vary greatly. Scoping distances are generally considered to be on the conservative side and are derived based on the upper end of typical noise levels for road traffic and machinery.

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