Chapter 16. Ecological impacts of road noise and options for mitigation

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Summary

Roads and traffic alter the physical environment of species and ecological communities. They also change their acoustic environment through the introduction of noise, both during construction and when a road is open to traffic. Road-construction noise, such as that produced during earth works, pile driving and road surfacing, can be of high intensity but usually of limited duration. In contrast, road-traffic noise is often persistent over time – busy highways can carry substantial traffic for many hours per day, day after day and year after year. Road noise has a number of ecological impacts on wildlife living in nearby habitats.

1. Road noise may be stressful for animals.

2. Road noise makes it harder for animals to hear each other, their predators and their prey.

3. Road noise may cause temporary or permanent hearing loss in animals.

4. High levels of road-construction noise may injure animals, especially fish, in nearby habitats.

5. Animals and their acoustic environment may need protection from road noise.

6. Mitigation of road noise to protect animals and their acoustic environment should be considered prior to road construction.

7. There is an urgent need for more research into the various effects of road noise on animals and their ecological communities.

Road noise has a variety of ecological impacts, including effects on the physiology, behaviour, communication, reproduction and survival of animals that live in or move through the noise-affected areas. While further research is required to better understand the ecological consequences of introducing road-construction and road-traffic noise to a given habitat, measures to mitigate the known impacts of road noise on wildlife should be implemented as part of new road projects. Further research will also help to improve the effectiveness of measures to protect animals and their acoustic environment from road noise.

Key Words: acoustic interference, barotrauma, hearing loss, mitigation, road-construction noise, road-traffic noise, stress

Introduction

Sound is a radiant energy, transmitted as waves of pressure through a material medium such as air, water or soil. The pressure of a simple sound cycles up and down in a regular pattern over space and time. The frequency (or pitch) of a sound, measured in Hertz (Hz), is the number of cycles it completes per second. The amplitude (also known as volume or loudness) of a sound can be measured in pressure or intensity, and both are expressed in decibels (dB). The decibel level of a sound is expressed relative to a reference pressure, commonly 20 µPa in air and 1 µPa in water. As the decibel scale is a logarithmic scale, an increase of 10 dB corresponds to a 10-fold increase in amplitude. A-weighted decibels, abbreviated to dB(A) or dBA, describe the relative loudness of sounds in air as perceived by humans.

Noise can be defined as unwanted sound, or as the background sound found in any environment. Road noise – including the noise generated during road construction (road-construction noise) and the noise caused by vehicles travelling on existing roads (road-traffic noise) – differs from natural noise in a number of ways. During road construction, heavy machinery is used to clear vegetation, move rocks and soil, and prepare the road surface. In addition, blasting and/or pile driving may be used during construction of tunnels and bridges. Road-construction noise can be of high intensity but usually of limited duration, ranging from weeks to months at a given location. In contrast, road-traffic noise is usually of a lower intensity than road-construction noise but more persistent over time. Road-traffic noise is generally louder and lower-pitched than natural noise, with much of its energy occurring in the lower-frequency bands below 2,000 Hz (Patricelli & Blickley 2006). Depending on the volume and speed of traffic, local topography, road surface and prevailing weather conditions, the noise of vehicles travelling on a road can extend more than 2 km across the landscape on either side (also known as the road effect zone, REFER CH 1). Road noise has a range of ecological impacts, and it is important to consider these when planning new roads, and/or when attempting to reduce the impact of noise from existing roads on wildlife.

The aim of this chapter is to summarise the important effects of road noise (including road-construction noise and road-traffic noise) on ecological communities, and to discuss noise-mitigation options that may help to protect animals and their acoustic environment. Just as an animal lives in, and may be adapted to, a particular physical environment (e.g., a forest, a desert or a seagrass meadow), it also lives in, and may be adapted to, a particular acoustic (sound) environment (Morton 1975). Road noise can disrupt the acoustic environment of animals, with a number of important ecological consequences (Barber et al. 2010; Slabbekoorn et al. 2010).

Lessons

1. Road noise may be stressful for animals

The noise of road construction and road traffic can startle nearby animals, causing a physiological stress response (Kight & Swaddle 2011). As a consequence, animals may move away from the noise-affected area, either temporarily or permanently. Permanent avoidance of areas affected by road noise will lead to a permanent decrease in the amount of habitat available for noise-sensitive species. In places with a high density of roads, such as parts of Europe and North America, this decrease can be quite dramatic (Forman & Deblinger 2000; Barber et al. 2010). On the other hand, noise-sensitive animals that do not or cannot move away from areas close to busy roads will experience chronic exposure to road-traffic noise, which may lead to chronic physiological stress

(McEwan & Wingfield 2003; Blickley et al. 2012a). This, in turn, can lead to secondary effects such as weakened immune function and reduced breeding success (Wikelski & Cooke 2006; Kight & Swaddle 2011; Blickley et al. 2012a).

An experimental study of greater sage-grouse in North America found that male birds avoided lekking sites (places they call from to attract females for mating) where speakers played recorded traffic noise (Blickley et al 2012b). Over three breeding seasons, the abundance of males was 73% lower at lekking sites with road noise than at quiet control sites. In addition, male birds that did use the noisy lekking sites had higher levels of stress hormones (glucocorticoids) than males at quiet sites (Blickley et al. 2012a). These results show that chronic road noise can cause sage-grouse to avoid otherwise suitable habitat, and can increase stress levels in the male grouse who remain in noisy areas. In marine habitats, some species of seals, porpoises and dolphins have been observed to move away from areas affected by pile-driving noise for the duration of construction works, although in at least one case, Indo-Pacific humpback dolphins returned when construction had finished (reviewed in Jefferson et al. 2009).

A recent study of great tits in The Netherlands found that breeding success was lower in noisy areas close to a busy motorway, with female birds laying smaller clutches of eggs and fewer chicks fledging than in quieter areas nearby (Halfwerk et al. 2011). Earlier research in The Netherlands found reduced bird densities next to noisy roads (Reijnen et al. 1995, 1996), and that territories near busy roads were more likely to be occupied by inexperienced male birds who then struggled to attract a mate (Reijnen & Foppen 1994). Similarly, a range of large mammals are known to be less abundant in habitats near roads, including caribou, African elephant, zebra and blue wildebeest (Newmark et al. 1996; Benítez-López et al. 2010). In many of these examples, it is unclear whether the observed effects of roads are due to physiological stress caused by road noise, difficulty communicating in noise (see Lesson 3, below), or the nearness of vehicles travelling on the road. The design of these studies means that different effects of roads such as noise, visual disturbance, or mortality caused by collision with vehicles cannot easily be separated.

2. Road noise makes it harder for animals to hear each other, their predators and their prey

Many animal groups – including insects, fish, frogs, birds and mammals – communicate using sound. For example, birds use songs and calls to attract mates, defend territories from rivals, keep in contact with their mate, parent or chicks, beg for food, and warn other birds of danger from potential predators. In addition, many animals rely on hearing to detect the sound of approaching predators, or the location of potential prey. Acoustic interference or masking occurs when background noise reduces the distance over which a sound can be detected. While animals have a number of strategies to make themselves heard in a background of natural noise (e.g. see Brumm & Slabbekoorn 2005), those that live in habitats near roads must also contend with noise from road construction and road traffic.

Acoustic interference from road noise can disrupt important social interactions between animals, and may have significant consequences for both individuals and populations. These include difficulty attracting and maintaining a mate, reduced breeding success, population declines, and changes in the composition of ecological communities in areas affected by road noise (Patricelli & Blickley 2006; Kight et al. 2012; Proppe et al. 2013). While some animals are known to sing or call differently in road-traffic noise to increase the distance over which they can be heard (e.g., singing or calling more loudly, at a higher pitch, or at quieter times of the day to avoid peak periods of road-traffic noise; Barber et al. 2010; also see Box 1), these changes are not large enough to regain all the communication distance that is lost (Parris et al. 2009; Parris & McCarthy, 2013).

Acoustic interference from road noise may also increase the vulnerability of animals to predators and/or decrease foraging success by animals that rely on sound to detect their prey (Barber et al. 2010). High levels of background noise increases watchfulness (also known as vigilance behaviour) in animals; because they cannot hear predators approaching, animals spend more time watching out for them and less time foraging for food (Barber et al. 2010). There is also evidence that animals such as bats avoid foraging near noisy highways where it would be difficult to hear their prey (Schaub et al. 2008). A recent behavioural experiment using simulated highway noise found that the foraging efficiency of the greater mouse-eared bat declined dramatically as it moved closer to the simulated road (Siemers & Schaub 2011; REFER CH 28). These kinds of noise effects may have further consequences for predator-prey interactions and food webs in ecological communities (Siemers & Schaub 2011).

Box 1. Effects of road-traffic noise on the grey shrike-thrush

The grey shrike-thrush is a common, sedentary Australian songbird (Fig. 1) found in a variety of habitats including forests and woodlands. The song of the grey shrike-thrush is melodious and varied, containing pure tones, trills, and whistles. Males sing to attract a mate, while both males and females sing to defend territories from neighbouring birds (Higgins & Peter 2002). The frequency (pitch) of the grey shrike-thrush song overlaps the frequency of road-traffic noise, so we would expect these birds to have difficulty hearing each other in areas with high levels of road-traffic noise.

Fig. 1. The grey shrike-thrush (photo by ??).

Parris and Schneider (2009) studied the effects of road-traffic noise and traffic volume (the number of vehicles travelling on a road each day) on the grey shrike-thrush at 58 roadside sites on the Mornington Peninsula in south-eastern Australia. The roads ranged in size from narrow, unsealed roads with very little traffic to multi-lane freeways carrying 32,000 vehicles per day. However, each road had a narrow strip of native vegetation on each verge, providing habitat for birds and other animals (Fig. 2). This study design reduced other habitat differences between quiet and noisy sites that may have influenced the birds.

Fig. 2. A roadside study site on the Mornington Peninsula in south-eastern Australia, showing the narrow strip of *Eucalyptus* woodland on each side of the road (photo by Kirsten Parris).

As the level of traffic noise at a study site increased, the grey shrike-thrush sang at a higher frequency (Fig. 3). While this change would help it to be heard above the noise of the traffic, it is not large enough to overcome the masking effect of the noise entirely – the bird would only get back around 10% of the communication distance lost in noise (Parris & McCarthy 2013). In addition, the chance of finding one or more grey shrike-thrushes on a visit to a site decreased from around 85% at the quietest sites to 15% at the noisiest sites (Fig. 4), suggesting that the birds are less likely to be present at noisier sites. Acoustic interference from road-traffic noise may be making it more difficult for these birds to establish and maintain territories, attract mates and maintain pair bonds, possibly leading to reduced breeding success in noisy roadside habitats (Parris & Schneider 2009). Given the narrowness of the roadside verges and the active nature of these birds, we would expect to detect the birds if they were present, even in very noisy conditions.

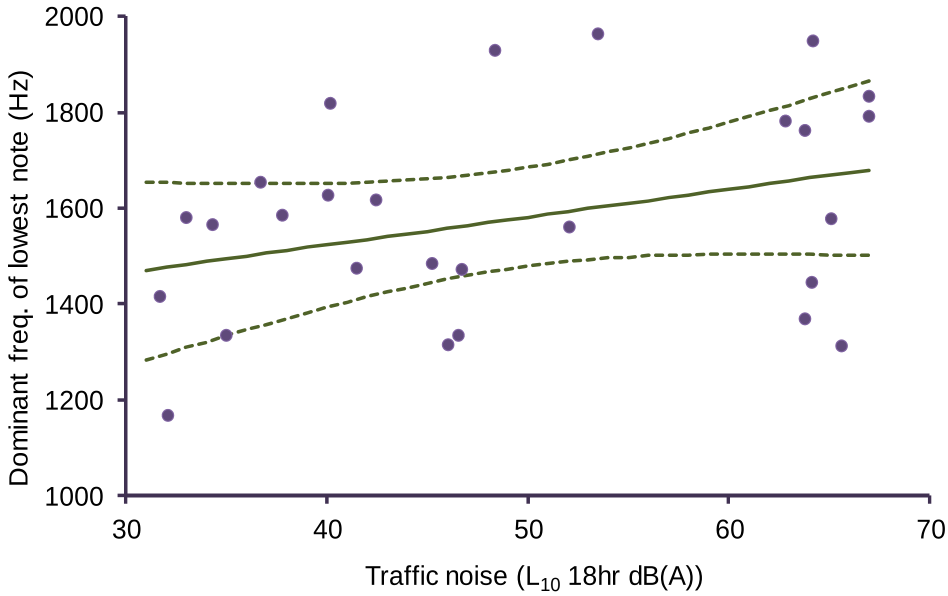

Fig. 3. The grey shrike-thrush increases the frequency of its song (as measured by the dominant frequency of the lowest note) as the level of traffic noise at a site increases. The sound-pressure level of the traffic noise is expressed as L_{10} 18hr dB (A), which is the 90th percentile of the distribution of traffic noise experienced in the 18 hours between 6am and midnight. The solid green line shows the predicted relationship, the dotted green lines the 95% credible intervals, and the purple circles the data points, with one point for each site where the species was recorded. (Adapted from Parris & Schneider (2009), copyright is held by the authors).

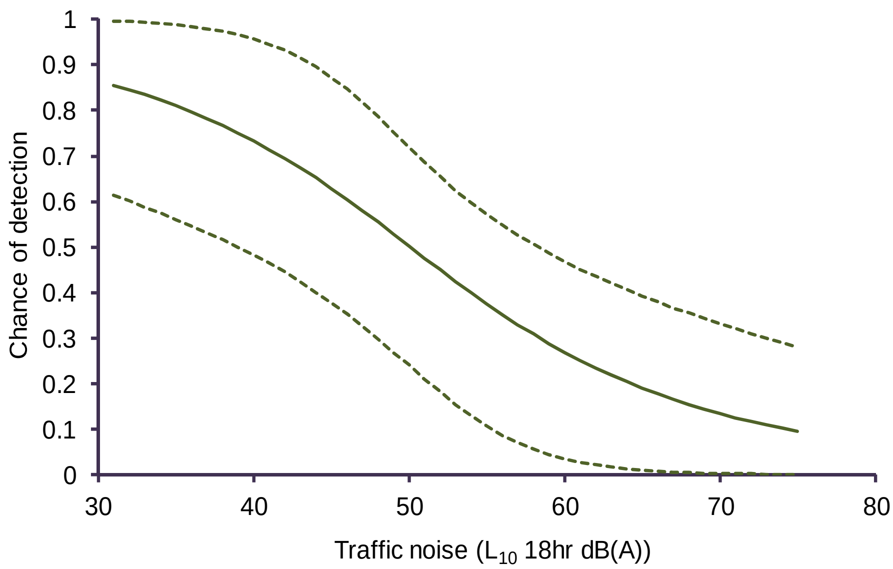

Fig. 4. The grey shrike-thrush was less likely to be found at sites with high levels of traffic noise, with the chance of detection decreasing as the level of traffic noise increased. The sound-pressure level of the traffic noise is expressed as L_{10} 18hr dB (A), which is the 90th percentile of the

distribution of traffic noise experienced in the 18 hours between 6am and midnight. The solid green line shows the predicted relationship and the dotted green lines the 95% credible intervals. (Adapted from Parris & Schneider (2009), copyright is held by the authors).

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3. Road noise may cause temporary or permanent hearing loss in animals

The noise of road construction or road traffic may cause temporary or permanent hearing loss in animals in nearby habitats. The hearing threshold of an animal refers to the point at which a sound is just loud enough to be heard – the higher the threshold, the louder the sound must be to be detected. High levels of noise can damage the cochlea in the inner ear, leading to a temporary or permanent increase in the hearing threshold of affected animals (Kight & Swaddle 2011). These kinds of auditory injuries can result from a single, extreme noise event or from chronic exposure to high levels of noise. In general, the higher the noise level and/or the longer it continues, the greater the change in hearing threshold, the longer it will take until normal hearing is recovered, and the greater the chance of permanent hearing loss (Kight & Swaddle 2011).

An early laboratory study of the effects of vehicle noise on species accustomed to a quiet, desert environment exposed the Mojave fringe-toed lizard and the desert kangaroo rat to 10 minutes of intermittent dune-buggy noise (Brattstrom & Bondello, 1983). Both species suffered hearing loss for a number of weeks, and during this time were unable to detect and respond to recorded calls of their predators. More recent research has focussed on acoustic injury in fish caused by road-construction noise in aquatic habitats, such as impulsive noise from pile driving (reviewed in Popper & Hastings 2009; Slabbekoorn et al. 2010). While more research is needed on the effects of road noise on hearing in birds, continuous noise above 93 dB(A) may cause a temporary increase in the hearing threshold of birds, while impulsive noise above 125 dB(A) may cause permanent hearing damage (Dooling & Popper 2007).

4. High levels of road-construction noise may cause other injuries to animals in aquatic habitats

Construction of bridges or causeways across shallow bodies of water such as bays and estuaries often involves the driving of supporting piles into the marine substrate. Depending on the substrate, depth and the size of a project, pile driving can continue for many days or even months (Jefferson et al. 2009). Pile driving can produce such high levels of impulsive sound that the pressure waves of sound moving through the water cause internal injuries to fish. This type of injury is known as barotrauma, and results from rapid changes in the volume of gases within the body of the fish and in the solubility of gas in its blood and tissues (Halvorsen et al. 2012). Barotrauma injuries caused by underwater sound waves include emboli (gas bubbles that form in the blood and tissues when gas leaves solution), resulting tissue damage, and the rapid expansion of gas-filled organs such as the swim bladder. In more extreme cases, the swim bladder may rupture, or gas bubbles in the gills or heart may kill the fish instantly (Halvorsen et al. 2012).

A controlled laboratory study identified the threshold for the onset of injury to juvenile Chinook salmon as a cumulative sound-exposure level of 210 dB re 1 $\mu Pa^2.s$ (Halvorsen et al. 2012). This exposure level could be achieved, for example, from 960 pile-driving strikes at a sound-exposure level of 180 dB re 1 $\mu Pa^2.s$ each (the typical number of strikes needed to drive a single pile). If this threshold were to be exceeded, it would be likely to affect the survival of the exposed fish.

However, in a later study, this level of sound exposure caused substantial barotrauma in another species of fish, the hybrid striped bass (Casper et al. 2013). Impulsive sound from pile driving may occasionally be intense enough to cause barotrauma in small marine mammals such as dolphins and porpoises (Jefferson et al. 2009).

5. Animals and their acoustic environment may need protection from road noise

Given the variety and potential seriousness of its ecological impacts, animals and their acoustic environment may need protection from road noise. This will particularly apply in areas supporting populations of threatened species, and/or where levels of road-construction or road-traffic noise are expected to be high. Measures that can be used to mitigate road noise vary depending on the type of noise (road-construction or road-traffic noise), the size of the road and expected traffic volumes, and the type of habitats that may be affected by noise (terrestrial or marine). However, one widely applicable approach is to reduce or exclude the noise-generating activity at times when and places where animals of concern are known to be present, or are expected to be particularly vulnerable to the effects of noise. In terrestrial habitats, this could include ceasing road construction, closing roads or reducing traffic speeds (and thus traffic noise) during the breeding season of animals that communicate using sound, such as birds and frogs (Halfwerk et al. 2011; Parris et al. 2009). In marine habitats, pile driving could stop during the main calving season of mammals, as it does in Hong Kong to protect mothers and calves of the finless porpoise and Indo-Pacific humpback dolphin (Jefferson et al. 2009). However, this approach requires information on the distribution and/or breeding activities of the animals in question.

A number of other measures have been trialled to reduce the impact of pile-driving noise on fish and mammals in marine habitats, such as ramping up and the use of air-bubble curtains or jackets (Jefferson et al. 2009; Popper & Hastings 2009). Ramping up, in which the intensity of pile driving starts at a low level and then increases over time, is intended to warn fish and other marine animals and give them a chance to leave the area before sound-pressure levels are high enough to be dangerous. More research is needed on the best way to use this strategy for different groups of animals (Jefferson et al. 2009). Curtains of air bubbles can also be used to reduce the transmission of underwater sound. A small-scale experimental study in Denmark found that noise levels from pile driving were reduced substantially when such a curtain was in operation, and avoidance behaviour seen in nearby, captive harbour porpoises before the curtain was installed was no longer observed (Lucke et al. 2011).

Sound barriers have been used for decades to protect humans from high levels of road-traffic noise. However, they are rarely used specifically to protect non-human animals in this way. Sound barriers are usually constructed of solid materials such as earth, concrete, wood, steel or glass, and can reach from the ground up to 5 metres or more in height. While these kinds of structures are very effective at reducing levels of road-traffic noise in areas near busy roads, they also form a barrier to the movement of many animals that walk or hop along the ground, such as mammals, reptiles, amphibians and invertebrates. In addition, flying birds can collide with sound barriers made of glass unless they are patterned or coloured to make them more conspicuous. While it may be difficult for many ground-dwelling animals to cross a busy road safely, it becomes impossible where solid sound barriers are installed (REFER fencing CH ??). Alternatives to solid sound barriers include barriers made of dense vegetation, or barriers that have a small gap at the bottom to allow animals to pass underneath them. However, these kinds of barriers may be less effective at reducing road noise than solid barriers. The noise of vehicles travelling on a road can also be reduced through the use of quiet paving materials, and by improvements in engine, muffler and tyre design.

6. Mitigation of road noise to protect animals and their acoustic environment should be considered prior to road construction

Given that mitigation of both road-construction noise and road-traffic noise may require substantial planning and investment, it should be considered in the early stages of a road project, well before construction begins (see also ch 2 and 9). Suitable preparation will include collection of ecological information such as the distribution and seasonal activities of different groups or particular species of animals in areas to be affected by the noise of the road. Planners will then need to consider the expected levels of noise during construction and when the road is opened to traffic, and choose suitable mitigation options. This issue currently receives very little attention, particularly in terrestrial habitats.

7. There is an urgent need for more research into the various effects of road noise on animals and their ecological communities

While a range of ecological impacts of road noise have been identified, many questions about these impacts remain unanswered. Key areas for future research include the short- and long-term consequences of road noise for social interactions, foraging behaviour, stress levels, survival, breeding success and abundance of animals such as frogs, fish, birds, bats, invertebrates and marine mammals. In addition, much more research is needed on the design and effectiveness of strategies to mitigate the expected ecological effects of road-construction noise and road-traffic noise. The best way to improve our understanding of the ecological impacts of road noise (and ways to mitigate them) will be to set up well-designed experiments (REFER TO EXPTS CHAPT) to address one or more of these questions while constructing and/or operating new roads.

Conclusions

Road-construction noise and road-traffic noise can have a multitude of effects on animals and their acoustic environment, in both terrestrial and aquatic habitats. At the level of an individual animal, these effects may include behavioural changes, increased physiological stress, injury or death. At the level of a population, they may include a lower probability of survival and reduced breeding success in habitats affected by road noise. As a consequence, animals and their acoustic environment may need protection from high levels of noise during road construction and/or operation, and suitable noise-mitigation strategies should be considered early in the road-planning process.

Further reading

Barber et al. (2010): Reviews the costs of chronic noise exposure for terrestrial animals

Kight and Swaddle (2011): Reviews the physiological effects of noise on animals

Slabbekoorn et al. (2010): Reviews the impacts of increasing underwater noise on fish

Warren et al. (2006): Reviews the effects of urban noise on animal communication and animal behaviour

References

Barber J. R., K. R. Crooks, and K. M. Fristrup. 2010. The costs of chronic noise exposure for terrestrial organisms. Trends in Ecology & Evolution **25:**180–189.

Benítez-López, A., R. Alkemade, and P. A. Verweij. 2010. The impacts of roads and other infrastructure on mammal and bird populations: A meta-analysis. Biological Conservation **143:**1307–1316.

Blickley, J. L., K. Word, A. H. Krakauer, J. L. Phillips, S. Sells, C. C. Taff, J. C. Wingfield, and G. L. Patricelli. 2012a. The effect of experimental exposure to chronic noise on fecal corticosteroid metabolites in lekking male greater sage-grouse (*Centrocercus urophasianus*). PLoS ONE **7:**e50462.

Blickley, J. L., D. L. Blackwood, and G. L. Patricelli. 2012b. Experimental evidence for the effects of chronic anthropogenic noise on abundance of greater sage-grouse at leks. Conservation Biology **26:**461–471.

Brattstrom, B. H., and M. C. Bondello. 1983. Effects of off-road vehicle noise on desert vertebrates. Pages 167–206 in R. H. Webb and H. H. Wilshire, editors. Environmental effects of off-road vehicles. Springer-Verlag, New York.

Brumm, H., and H. Slabbekoorn. 2005. Acoustic communication in noise. Advances in the Study of Behavior **35:**151–209.

Casper, B. M., M. E. Smith, M. B. Halvorsen, H. Sun, T. J. Carlson, and A. N. Popper. 2013. Effects of exposure to pile driving sounds on fish inner ear tissues. Comparative Biochemistry and Physiology Part A **166:**352–360.

Dooling, R. J., and A. N. Popper. 2007. The effect of highway noise on birds. California Department of Transportation.

Forman, R. T. T., and R. D. Deblinger. 2000. The ecological road-effect zone of a Massachusetts (U. S. A.) suburban highway. Conservation Biology **14**:36–46.

Halfwerk, W., L. J. M. Holleman, C. M. Lessells, and H. Slabbekoorn. 2011. Negative impact of traffic noise on avian reproductive success. Journal of Applied Ecology **48:**210–219.

Halvorsen, M. B., B. M. Casper, C. M. Woodley, T. J. Carlson, and A. N. Popper. 2012. Threshold for onset of injury in Chinook salmon from exposure to impulsive pile driving sounds. PLoS One **7**(6):e38968.

Higgins, P. J., and J. M. Peter (eds). 2002. Handbook of Australian, New Zealand and Antarctic birds. Volume 6: Pardalotes to Shrikethrushes. Oxford University Press, Melbourne, Victoria.

Jefferson, T. A., S. K. Hung, and B. Würsig. 2009. Protecting small cetaceans from coastal development: Impact assessment and mitigation experience in Hong Kong. Marine Policy **33:**305–311.

Kight, C. R., and J. P. Swaddle. 2011. How and why environmental noise impacts animals: an integrative, mechanistic review. Ecology Letters **14:**1052–1061.

Kight, C. R., M. S. Saha, and J. P. Swaddle. 2012. Anthropogenic noise is associated with reductions in the productivity of breeding Eastern Bluebirds (*Sialia sialis*). Ecological Applications **22:**1989–1996.

Lucke, K., P. A. Lepper, M. Blanchet, and U. Siebert. 2011. The use of an air bubble curtain to reduce the received sound levels for harbor porpoises (*Phocoena phocoena*). Journal of the Acoustical Society of America **130:**3406–3412.

McEwen, B. S., and J. C. Wingfield. 2003. The concept of allostasis in biology and biomedicine. Hormones and Behavior **43:**2–15.

Morton, E. S. 1975. Ecological sources of selection on avian sounds. The American Naturalist **109:**17–34.

Newmark, W. D., J. I. Boshe, H. I. Sariko, and G. K. Makumbule.1996. Effects of a highway on large mammals in Mikumi National Park, Tanzania. African Journal of Ecology **34:**15–31.

Parris, K. M., and M. A. McCarthy. 2013. Predicting the effect of urban noise on the active space of avian vocal signals. The American Naturalist **182:** in press.

Parris, K. M., and A. Schneider. 2009. Impacts of traffic noise and traffic volume on birds of roadside habitats. Ecology and Society **14:** http://www.ecologyandsociety.org/vol14/iss1/art29/

Parris, K. M., M. Velik-Lord, and J. M. A. North. 2009. Frogs call at a higher pitch in traffic noise. Ecology and Society **14:** http://www.ecologyandsociety.org/vol14/iss1/art25/

Patricelli, G. L., and J. L. Blickley. 2006. Avian communication in urban noise: causes and consequences of vocal adjustment. The Auk **123:**639–649.

Popper, A. N., and M. C. Hastings. 2009. The effects of anthropogenic sources of sound on fishes. Journal of Fish Biology **75:**455–489.

Proppe, D. S., C. B. Sturdy, and C. Cassady St Clair. 2013. Anthropogenic noise decreases urban songbird diversity and may contribute to homogenization. Global Change Biology **19:**1075–1084.

Reijnen, R., and R. Foppen. 1994. The effects of car traffic on breeding bird populations in Woodland. I. Evidence of reduced habitat quality for willow warblers (*Phylloscopus trochilus*) breeding close to a highway. Journal of Applied Ecology **31:**85–94.

Reijnen R., R. Foppen, and H. Meeuwsen. 1996. The effects of traffic on the density of breeding birds in Dutch agricultural grasslands. Biological Conservation **75:**255–260.

Reijnen, R., R. Foppen, C. ter Braak, and J. Thissen. 1995. The effects of car traffic on breeding bird populations in woodland. III. Reduction of density in relation to the proximity of main roads. Journal of Applied Ecology **32:**187–202.

Schaub, A., J. Ostwald, and B. M. Siemers. 2008. Foraging bats avoid noise. Journal of Experimental Biology **211:**3174–3180.

Siemers, B. M., and A. Schaub. 2011. Hunting at the highway: traffic noise reduces foraging efficiency in acoustic predators. Proceedings of the Royal Society B **278:**1646–1652.

Slabbekoorn, H., N. Bouton, I. van Opzeeland, A. Coers, C. ten Cate, and A. N. Popper. 2010. A noisy spring: the impact of globally rising underwater sound levels on fish. Trends in Ecology and Evolution **25:**419–427.

Warren, P. S., M. Katti, M. Ermann, and A. Brazel. 2006. Urban bioacoustics: It's not just noise. Animal Behaviour **71:**491–502.

Wikelski, M., and S. J. Cooke. 2006. Conservation physiology. Trends in Ecology and Evolution **21:**38–46.