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Potential uses of anthropogenic noise as a source of information in animal sensory and communication systems

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Abstract

While current research on the impact of anthropogenic noise has focussed on detrimental effects, there are a range of ways by which animals could benefit from increased noise levels. Here we discuss two potential uses of anthropogenic noise. Firstly, local variations in the ambient noise field could be used to perceive objects and navigate within an environment. Secondly, introduced sound cues could be used as a signal for prey detection or orientation and navigation. While the disadvantages of noise pollution will likely outweigh any positive effects, it is important to acknowledge that such changes may benefit some species.

1. Introduction

All sensory systems are affected by noise when acquiring information from the environment. Current research on the effects of noise has focussed on detrimental effects and how animals deal with interference from noise (Brumm & Slabbekoorn, 2005). Recent concerns about sound pollution have led to several studies on the effects of anthropogenic noise on animals (see reviews by Barber et al., 2009; Nowacek et al., 2007; Slabbekoorn et al., 2010). At its most extreme noise pollution can have pronounced population-level consequences, such as lethal beaked whale strandings in relation to Navy sonar exercises (Tyack, 2009). Other more common effects are temporary or permanent damage to the auditory system, avoidance responses leading to changes in local abundance and distribution, masking of communication or other sound cues used as information sources, distraction from relevant signals, increased stress levels, hypertension and decreased reproductive success (Barber et al., 2009; Chan et al., 2010; Nowacek et al., 2007). Thus, noise is now seen as a major environmental problem that requires mitigation strategies.

While most studies highlight the detrimental effects of noise, increased noise levels can also be beneficial to some species. There is now a much greater recognition of how animals use sounds outside of direct signal exchanges. Eavesdropping on conspecific and other species' communication signals or movement sounds are much more widely used as sources of information about predator or prey presence and habitat choice than previously assumed (Barber et al., 2009; Deecke et al., 2002).

Similarly, anthropogenic noise can be beneficial to some species depending on context and how others react to it. For example, prey of greater mouse-eared bats (*Myotis myotis*) (Schaub et al.,

2008) and western scrub jays (*Aphelocoma californica*) (Francis et al., 2009) experience a decrease in predation pressure due to predators avoiding increased local noise. Similarly, masking of movement sounds by anthropogenic activity may decrease foraging success in predators benefiting prey species (Barber et al., 2009). Conversely, this acoustic crypsis could also allow predators to avoid detection by prey and increase their foraging success (Chan et al., 2010).

While these examples are seen as the main possible benefits of noise in the recent literature, there are a range of mechanisms by which animals could potentially benefit from noise. Here we discuss two other potential uses of sound. Firstly, local variations in the ambient noise field could be used to perceive objects and navigate within an environment. Secondly, introduced sound cues could be used as a signal for prey detection or serve as acoustic landmarks for orientation and navigation.

2. The use of local variation in the ambient noise field to detect objects

One potential information stream provided by anthropogenic noise is from detectable differences within the ambient noise field. Variation in the ambient noise field can provide information on an object through the presence of an ‘acoustic shadow’. In the visual domain, one way to detect objects is using differences in illumination (i.e. shadows and reflections) created between an object and a directional point source such as the sun. In the acoustic domain there is often no dominating source of illumination and the noise field is typically made up of a myriad of different natural and anthropogenic sources. However, in some cases the ambient noise field will contain localized sound sources such as snapping shrimp on fringing reefs or breaking waves around isolated rocks. In such circumstances reflectors may cause ‘acoustic shadows’ which would manifest as local attenuations in the noise field. Directional hearing and sound source segregation could allow an organism to detect the change in the ambient noise field and detect the object.

Another way of gathering information using the acoustic ambient noise field is with ‘acoustic daylight’ or ‘ambient noise imaging (ANI)’. Objects can be detected using incoherencies within the ambient noise field as a main source of illumination (thus providing ‘acoustic daylight’) (Buckingham et al., 1992). In this case reflective objects will modify the ambient noise field, creating a source of information which can be extracted through different methods. In engineering applications, imaging of reflective objects has been achieved by focusing scattered sound onto a paraboloid reflector, essentially creating an 'acoustic lense' (Buckingham et al., 1992). More accurate pictorial images can be created by using a paraboloid reflector in conjunction with a hydrophone array which enables beam forming and mapping of relative intensities in each beam (Epifanio et al., 1999). Acoustic daylight imaging has led to the successful development of a computerized detection system, ADONIS, capable of using ambient noise to detect underwater objects (Epifanio et al., 1999). This system was able to detect various objects including 1-metre wide neoprene and corrugated steel targets, a swimming diver, and 113-litre polyethylene drums filled with air, wet sand, and sea water at distances of at least 40 m (Epifanio et al., 1999).

In animals, the use of ambient noise for object imaging would be limited by having only two ears functioning as receivers. While spatio-temporal integration and directional hearing could solve some of these issues, real imaging such as seen in engineering applications is unlikely to be possible. Nevertheless basic forms of ambient noise imaging, such as for the detection of large obstacles, have been successfully shown in humans (Ashmead & Wall, 1999). Some additional evidence suggests human subjects were capable of detecting an object's size (Gordon & Rosenblum, 2004) and shape (Rosenblum & Robart, 2007) in a continuous broadband noise field.

To date no study has directly investigated whether animals use this information. However, based on theoretical models it has been suggested that animals are capable of using acoustic daylight imaging for navigation and object detection (Potter, 1997). Some empirical studies may also point towards such abilities even though alternative explanations cannot be ruled out. Blinded rats (Riley & Rosenzweig, 1956) and seals in darkened environments (Oliver, 1978) have been shown to perform well in navigation and obstacle avoidance experiments. It is possible changes in the ambient noise field were used for navigation. However, it is also possible that the seal detected hydrodynamic disturbances caused by the wires using its vibrissae (as shown in Dehnhardt et al., 2001).

The ability to utilize ambient noise may also explain the presence of advanced auditory capabilities in fish species that do not produce sounds themselves (Fay, 2009). For example, the goldfish (*Carassius auratus)* does not use any known form of sound communication, but it has a very acute sense of hearing (Fay, 1998). Rather than being used for communication, it is possible that the fish use their sensitive hearing to exploit ambient noise information. Although this possibility has not been well investigated, Lewis and Rogers (1992) demonstrated fish have the potential to use ambient noise to detect other fish. They successfully conditioned fish to discriminate between artificial Gaussian noise fields; either without any scattering or with scattering similar to that which would occur from resonance in swim bladders (Lewis & Rogers, 1992).

Anthropogenic noise could enhance or impede ambient noise imaging. In situations where anthropogenic noise sources are highly localised they may increase incoherencies in the noise field and therefore provide additional acoustic 'illumination', resulting in improved object detection capabilities for animals. However, it is also possible that anthropogenic noise sources can reduce inhomogeneity in a noise field by interfering with natural point sources or could mask localised ambient noise cues and prevent the perception of certain types of reflection patterns.

Currently, few studies have addressed the use of acoustic daylight imaging by animals. It is therefore difficult to predict how specific anthropogenic noise sources would affect an animal's perception. Further research investigating the abilities and detection sensitivities of animal species of interest would be valuable.

3. The use of noise as a signal for prey detection

Many species use passive listening to movement sounds to detect and capture prey (e.g. bats: Schaub et al., 2008; dolphins: Gannon et al., 2005). Through learning, animals can associate specific sound stimuli with food availability. This would be most obvious where anthropogenic noise indicates prey patches. In the marine environment, anthropogenic noise from fishing boat engines, pingers, sonar and acoustic deterrent devices used on fish farms could be used by predators to locate prey resulting in a 'dinner bell' effect. Marine mammals have been found to be attracted by such sounds (Chilvers & Corkeron, 2001; Thode et al., 2007), occasionally even to sounds introduced with the intention of deterring them (Bordino et al., 2002). In wild populations, higher incidences of predation at fisheries with acoustic deterrent devices (ADDs) may be attributed to learned associations between sound and prey (Jefferson & Curry, 1996). ADDs produce loud sounds that are believed to cause avoidance responses in species, such as seals, that predate upon fish farms. While seals who have not previously been exposed to these avoid them, seals that have experience finding fish at that location quickly habituate to ADD sounds (Götz & Janik, 2010, in press). Through operant conditioning, ADDs can be associated with the presence of fish and then act as a ‘dinner bell’, potentially attracting seals to the area.

Current research utilizing artificial sound sources to mark fish such as the ocean tracking network (http://oceantrackingnetwork.org/) (Cooke et al., 2011) could also be influenced with such an effect. Many of these studies use acoustic coded radio transmitters (also known as pingers) which typically emit an ultrasonic acoustic signal that is inaudible to fish, but is audible to some marine mammal predators (Bowles et al., 2010). If the signal is detectable, the sound could be associated with the presence of prey and cause increased predation through a learned ‘dinner bell’ effect. Alternatively, marine mammal predators may initially avoid fish fitted with a pinger, thus reducing the predation of tagged fish. In either case, such tag effects cause significant differences in the mortality of tagged compared to untagged fish and therefore lead to erroneous conclusions when studying fish behaviour and survival rates.

Most of the studies illustrating the use of anthropogenic sound as a signal for prey detection are opportunistic. It is currently unclear to what extent acoustic cues affect prey detection or how long it would take for a predator to make an association between novel sound and an associated food source in its natural environment. However, first results show that some predators like bottlenose dolphins (*Tursiops truncatus*) use fish communication sounds to detect prey aggregations (Gannon et al. 2005). Thus, more controlled studies investigating the role of anthropogenic acoustic information in prey detection is needed.

4. The use of noise as a signal in orientation

While noise can be used to navigate within an environment, it could also be used as a signal to mark specific locations. Apart from the effects of habituation and sensitization, the role of learning in reactions to noise is often overlooked. However, changes in the acoustic environment of an animal may be used to inform the receiver about features relevant to its survival. Animals may use novel noise sources as an indicator of locations of interest, and therefore are vulnerable to changes in the noise field.

This is particularly a concern with the introduction of anthropogenic noise. Sounds of ocean structures such as reefs have been found to inform fish of their location (Simpson et al., 2005). For example, several species of reef fish have been shown to be attracted to the location of artificially simulated reef sounds, especially during larval stages (Leis et al., 2003; Simpson et al., 2004). Damselfish have been found to develop a preference for settling locations that have the same soundscape as what they experienced as larvae (Simpson et al. 2010). Additionally, ocean noise caused by waves or currents is suspected to be an important cue in the migration and orientation behaviour of marine mammals (Richardson et al., 1995). Introduced anthropogenic noise may mask other such signals and affect navigation.

Stationary anthropogenic noise sources could also be used as a navigational signal or acoustic beacon. This can be advantageous or of concern depending on when and for how long noise is introduced into the environment. Exposure to anthropogenic noise may lead an animal to use the novel sound source as a signal, functioning as an acoustic landmark for orientation. However, when the sound is removed or relocated this could confuse animals and create navigation errors. Currently very little is known about the role of acoustic landmarks in animals, but there are numerous examples of the use of visual landmarks in navigation (for example desert ants, *Cataglyphis fortis*, Collett 2010; honey bees, *Apis mellifera*, Cheng et al., 1987; and domestic dogs, *Canis familiaris*, Milgram et al., 1999). It is difficult to predict what role anthropogenic noise sources may play in animal navigation. Additionally, no information is available on the time it would take for an animal to associate locations with a novel sound source or how relocation of a sound source would affect its use as a beacon. Thus, future research investigating the role of anthropogenic sound in navigation would be valuable.

5. Conclusion

At present very little is known about how animals utilize sound information other than that from species-specific sounds. Our ability to evaluate the effects of anthropogenic noise on a population level is hampered by a lack of understanding of how animals deal with noise. It is often assumed that noise can only compromise the fitness of animals. While the disadvantages of noise pollution will likely outweigh any positive effects, it is important to understand how learning and perceptual mechanisms might be influenced by noise. Rarely, studies acknowledge that noise may have no effect or might even benefit some species.

We focussed here on the use of ambient noise for acoustic daylight imaging, in which ambient noise from anthropogenic sources could help to 'illuminate' the environment and aid sensory perception, and the use of anthropogenic sound as a signal marking locations for navigation or prey detection. Effects on species distribution and composition at locations of increased noise levels may allow for further advantages for selected species. To assess the role these effects might play, further work is needed on how animals use sound and react to it, especially concerning sensitivities for perception and learned associations with sound.

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