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Impacts of Anthropogenic Noise on Fishes

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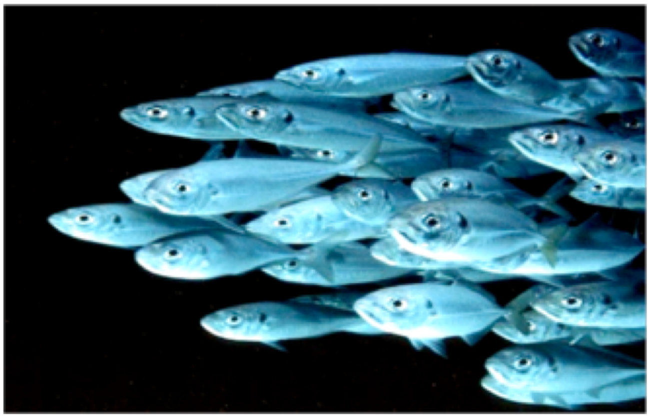

There is growing international concern about the potential effects of anthropogenic (human-made) noise on fishes in our seas, lakes and rivers. Human noise-generating activities are increasing. These activities include shipping, sonars, offshore oil and gas exploration and production, dredging, trawling, and other industrial activities, including the construction of renewable energy systems. Continuous sounds from activities like shipping increase overall background noise levels, whereas others, including construction work, produce shorter but more intense sounds. Many of these sounds have the potential to affect fish behaviour, whereas the most intense sounds may cause physical harm to animals near the source. In order to regulate sound-producing activities, there is an urgent need to establish sound exposure criteria. Future research must focus on providing information that will lead to improvement of the quality and validity of regulatory guidelines and criteria.

Background

Of all of their senses, hearing provides fishes with information from over the widest area around the animal, at various light levels, and with limited interference from objects in the water. Sound travels considerable distances through water and propagates through the substrate, especially from sources like pile drivers. Various limitations of other senses, such as vision, touch, taste and smell in the aquatic environment, make sound an exceptionally important cue for fishes and many invertebrates. Sound (Box 1) is used for communication between fishes, mating and other behaviours, the detection of prey and predators, orientation and navigation, habitat selection, and learning about the overall soundscape (the "acoustic scene") to locate natural underwater features. Because the ability to detect sounds is very important to fishes, anything that interferes with this ability can decrease the fitness and survival of individuals and populations.

Indeed, a great concern is that anthropogenic sound may be detectable by fishes over great distances, and such sounds can affect fishes in many ways. However, fishes, like humans, may also ignore sounds that are not too loud, some sounds may have no impact upon fishes.

Anthropogenic noise may have a wide range of effects on fishes (Box 2). Very intense impulsive sounds from explosions, pile driving, and seismic oil and gas surveys may result in death, mortal injuries, adverse effects on hearing abilities and detrimental physiological effects. Continuous sounds, such as those generated by shipping, dredging, trawling, and drilling can change the soundscape dramatically and can interfere with (mask) the detection of natural sounds and cause behavioural changes.

Because of the continued increase in anthropogenic underwater noise from a wide range of sources, there is an urgent need to examine the effects of different types of anthropogenic sounds on fishes under varying conditions of exposure. However, currently there are so many fundamental knowledge gaps on the potential effects of anthropogenic sound on fishes that it is almost impossible to reach clear conclusions on the nature and levels of sound that have potential to cause changes in behaviour or even physical harm. Further research is required to examine the immediate to long term impacts of sound exposure with respect to fitness of individuals as well as to populations and ecosystems. In addition, sound exposure criteria need to be developed that define those sound levels that potentially have adverse effects.

Box 1: Underwater Sound

Seas, lakes and rivers are not silent. Natural underwater sounds are generated by rain, surface waves, lightning strikes, and turbulence; natural seismic energy; and mammals, fishes, and invertebrates.

Although the basic physics of sound in water are similar to those in air, the density of water is greater, and as a result sound travels over four times faster than in air (about 1,500 m/s vs. 343 m/s). See dosits.org for an excellent primer on underwater acoustics.

As sound propagates from a source, it can be detected as pressure fluctuations in the medium, above and below the local hydrostatic pressure: the "sound pressure." Sound pressure is a scalar quantity that acts in all directions. It can be described in terms of its magnitude as well as its temporal and frequency characteristics.

Sound is also accompanied by a back-and-forth motion of the medium, referred to as "particle motion." This particle motion is a vector quantity. Accordingly, particle motion is described not only by specifying its magnitude, temporal and frequency characteristics but also the overall direction of motion of the energy.

All bony fishes (as well as sharks and invertebrates), detect and use information from particle motion, particularly at frequencies below several hundred Hz. Particle motion is used to locate the direction of the sound sources, even in those fishes that are also sensitive to sound pressure. When investigating the effects of sounds on fishes, it is important to describe the sounds in terms of particle motion as well as sound pressure, although this is often not done.

Figure 1.
Male haddock make repetitive knocking sounds when courting females. The knocks speed up to form a hum as courtship proceeds, with the male mounting the female. They then swim up through the water releasing eggs and sperm. Spawning grounds are dominated by haddock sounds. Listen to haddock sounds at: https://bit.ly/2WAyavU

The Importance of Sound Production and Reception to Fishes

Many fish species produce sounds. These include (but are not limited to) cod and haddock (Gadidae) (Fig. 1), catfish (Siluriformes), toadfish (Batrachoididae), drumfish & croakers (Sciaenidae) and sea robins (Triglidae). Sounds are produced in a wide range of contexts, such as feeding, mating or fighting. Sounds may be used by females to locate mature males and identify mates. Other commercially important species, such as tuna and salmonids, although not known sound producers, also rely on detection and analysis of the acoustic scene.

Fishes detect sound with paired inner ears, which are in the cranial cavity by the side of the brain. The ears closely resemble the inner ears found in other vertebrates. Because the fish's body is the same density as water, there is no need for external structures (external or middle ears) to carry sound to the sensory regions of the ear.

There are substantial differences in hearing sensitivity and frequency range among different fish species. For example, flatfish and the Atlantic salmon only hear particle motion (Box 1) and have a relatively narrow range of frequencies that they hear (20 to 500 Hz), whereas species like the Atlantic cod, where the gasfilled swim bladder is close to the ear, are also sensitive to sound pressure and hear a wider range of frequencies (20 to 1,000 Hz). Some fishes, and some Invertebrates, are also sensitive to infrasound (sound or substrate vibration at frequencies below 20 Hz).

For sensitive fishes, hearing is not limited by the lowest level they can hear in a quiet environment, but by their ability to detect and discriminate sounds against the ambient noise (background noise). Indeed, the level of ambient noise limits the lowest sound levels that some fishes can detect. This interference with detection of a biologically relevant sound by noise is called masking. If noise increases due to human activities, there may be additional masking and fishes may not be able to detect sounds of biological importance.

Box 2: Underwater Noise

There are many anthropogenic sound sources. These include container ships, ferries, pleasure craft and fishing vessels; trawling; pile driving (Fig. 2) and other forms of construction work; low-frequency naval sonar systems; seismic surveys for oil and gas; wind and water-driven turbines; and dredging and installing pipelines and cables.

Large modern ships are noisy, and due to worldwide increases in shipping, noise levels have doubled almost every decade.

There are two main "classes" of anthropogenic sounds. Some are transient or impulsive, while others are continuous.

Impulsive sounds, such as those produced during pile driving, airgun operation and explosions are often of short duration (generally well less than 1 sec) and show large changes in level over their time course. They may either be single or repetitive. Most often, such sounds are only present over the course of a particular project.

Continuous sounds are produced by shipping (both commercial and pleasure craft), operational wind and water turbines, and seabed drilling, and may continue for months or even years (e.g., in a harbour or close to a wind farm).

Offshore oil and gas activities include sounds from seismic surveys used in exploration and from drilling. Pile driving and dredging generate sounds in the water and in the substrate - "ground roll" - that may travel great distances. Environmental Impact Assessments often ignore the propagation of sound in the substrate.

Because overall noise levels in the sea, lakes, and rivers are changing dramatically as a result of human activities, it is important to determine what effects these changes are having upon aquatic animals.

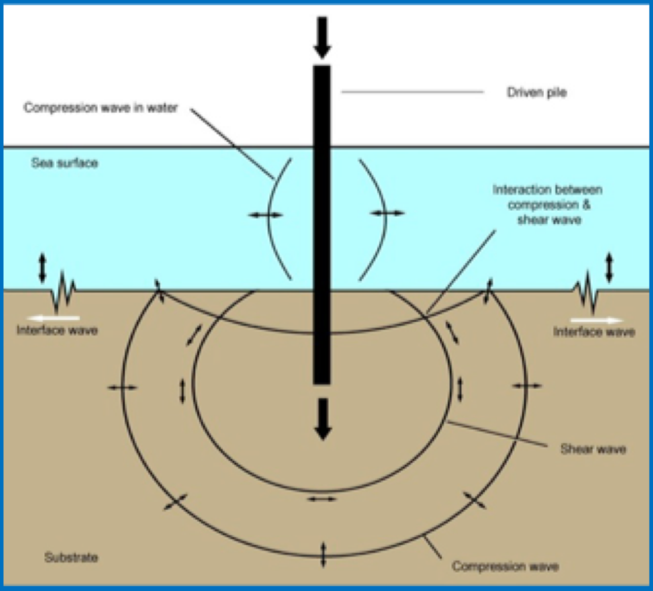

Figure 2.
Pile driving is one of the most intense sources of underwater sound. A metal or concrete stake or pile is hammered into the substrate, generating impulsive sounds within the water, and low frequency waves that travel within and along the surface of the substrate.

Adverse Effects of Underwater Noise

Fishes close to the sources of high-intensity sounds, and particularly impulsive sounds, can experience damage to body tissues (Fig. 3). This damage appears to result from rapid oscillation of the walls of the fish's swim bladder when stimulated by an impulsive source. Exposure to high-intensity sounds may also result in hearing loss from damage to various parts of the ear.

Anthropogenic sounds, even at lower levels, may result in temporary hearing impairment, physiological changes, changes in behaviour, and/or the masking of biologically important sounds, ultimately interfering with the detection of the overall soundscape and affecting sound communication by fishes.

Changes in behavioural responses to the presence of an anthropogenic sound can be especially significant and may range from small and short-duration movements to changes in migration routes, leaving a feeding or breeding site, or the inability to find places for settlement of juvenile fishes. Such responses are likely to vary from species to species depending on numerous factors, such as the animals' normal behavioural repertoire, motivational state, time of day or year, age of the animal, etc. At the same time, some behavioural responses, such as startle reactions, may only be transient and have little consequence for the individual or population.

Box 3: Assessing Effects and Impacts

Sound exposure criteria are required to define those levels of sound that are likely to affect aquatic animals adversely. These criteria would be used to regulate the generation of noise in aquatic environments and protect animals and enable regulators and others to make better decisions on the likely adverse effects of sound exposure.

Understanding critical sound levels is also important in the design of mitigation devices, e.g., air curtains around piles being driven, to lower sound levels from an anthropogenic source. At the same time, if a noise-producing scenario is not predicted to have any effect, then regulation may not be needed.

Interim sound exposure criteria for the onset of physiological effects on fishes were proposed in 2014 (discussed in detail in reference below). These interim criteria are now being used worldwide.

Studies on the physical effects of sounds on fishes are best expressed as dose-response relationships for different sound parameters such as signal intensity, number of pile strikes, inter-strike interval, etc. Currently, the only source for which we have a dose-response relationship is for pile driving.

Future research needs include investigations of how sound exposure might impair the ability of individual animals to survive, breed, reproduce, or rear young and to quantify how this impairment may affect the abundance of the species concerned as well as the extent to which sound affects the structure and functioning of fish populations and ecosystems, both marine and freshwater.

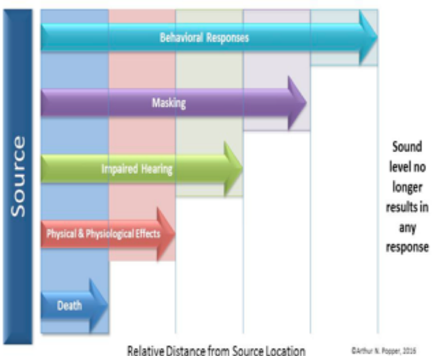

Figure 3.
The effects of sound vary with distance from any source. There are many potential effects close to the source while the potential types of effects decrease with distance from the source as the sound level declines.

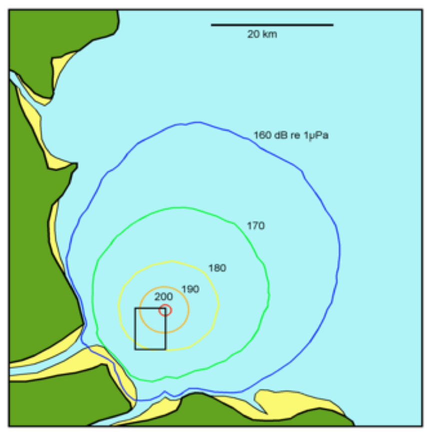

Figure 4.
It is possible to model the propagation of sounds from a source, here a pile driver, to assess the area affected. The blue line is the level above which behavioural effects may occur.

Summary

It is evident that there are major gaps in our understanding of the effects of anthropogenic sounds on individual fishes as well as the potential impacts of such sounds upon fish populations and aquatic ecosystems. Much of the research and literature has limited applicability, as many of the experiments to date were carried out on captive fishes under laboratory conditions where animals do not behave in the same way as they do in the wild. Additionally, there is a lack of information on fish responses to particle motion rather than to sound pressure. Thus, to develop better guidelines and criteria for fishes, it will be critical to fill many knowledge gaps on the potential impacts of sounds upon them. **The goal must be to increase knowledge so that sound exposure criteria can be revised and improved (see Box 3).** Such quantifiable indicators of impact or response need to **be integrated into environmental impact assessments** to ensure that fishes are protected. It is important to assess the sound levels at which fish are at risk of death or sustaining serious injury to internal organs, including damage to hearing. Further research is also needed on the behavioural responses of a range of fish species to different sound sources and under different conditions. As well as investigating responses to sounds of short duration, information is also required on responses to continuous or repeated exposure. What are the immediate effects of sound exposure, what are the longer-term effects in terms of fitness, and what are the likely impacts on populations?

This note is an abridged version of Popper A.N. & Hawkins A.D. (2019) Impact of anthropogenic noise on fishes. Full version available at www.fsbi.org.uk