Are Sharks Even Bothered by a Noisy Environment?

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1 Introduction

There is growing concern that sounds produced by anthropogenic sources have the potential to impact bony fishes. However, there are no data as to whether elasmobranch fishes (sharks, rays, and skates) could be affected by exposure to anthropogenic sources.

According to the International Union for the Conservation of Nature (IUCN), ~60% of elasmobranch species are considered threatened with extinction due to overfishing and habitat degradation (Godin and Worm 2010). Elasmobranchs are important from an evolutionary perspective because they have evolved little over hundreds of millions of years and represent a unique opportunity to examine one of the more basal stages within the evolution of vertebrates. This paper considers the possibility that anthropogenic noise may have an effect on elasmobranch fishes. The analysis is based on the results from noise-exposure studies in teleosts as well as knowledge of elasmobranch anatomy and physiology. A review of how elasmobranchs detect sound and their hearing abilities is addressed, with the goal of touching on areas in need of further exploration.

2 Elasmobranch Sound Detection

Elasmobranchs detect sound using inner ear end organs (see Myrberg 2001 for review). It is likely that the saccule, a portion of the utricle, and the macula neglecta are the acoustically sensitive organs, whereas the lagena and the other portion of the utricle are utilized for detection of gravity and rotational stimuli. Unlike the hardened otoliths in teleosts, the sensory epithelia (maculae) of the saccule, utricle, and lagena in elasmobranchs are covered by otoconia, a gelatinous matrix of calcium carbonate granules (a pattern also found in primitive teleost fish and all terrestrial vertebrates). In contrast, the fourth end organ, the macula neglecta, is covered by a gelatinous cupula that is similar to the cupula found in the lateral line organs and ampullae of the semicircular canals. The macula neglecta is not unique to elasmobranchs, but these are the only vertebrates in which there is evidence that it serves a role in acoustic detection. The elasmobranch auditory system is also unique

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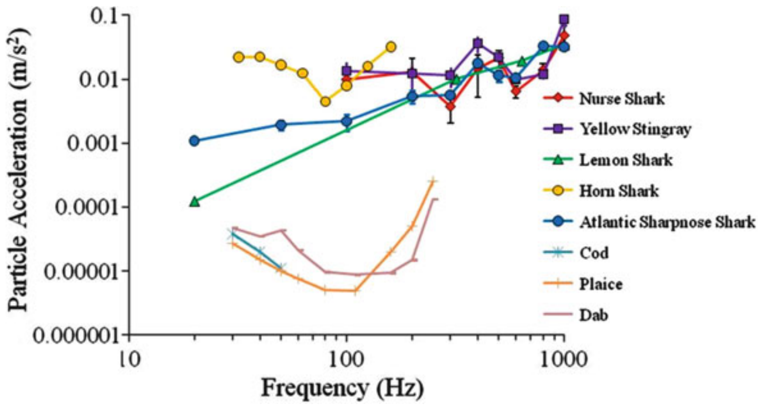

Fig. 1 Particle motion audiogram describing hearing thresholds of elasmobranch and teleost fishes. Modified from Casper and Mann (2009) and Fay (1988)

in having a direct connection from the saccular chamber to the surface of the head and the outside environment through the endolymphatic duct. However, no direct evidence has linked the duct to any specific role in the detection of sound.

There are two proposed pathways for sound to travel to the inner ear of elasmbranchs (Corwin 1981). First, the otoconial pathway involves the saccule and utricle end organs. The elasmobranch body is approximately equal in density to the surrounding water and is therefore acoustically transparent. As a consequence, sound waves travel through the fish until they come into contact with a structure of greater density such as the otoconia. These otoconia lag in movement relative to the surrounding tissues. This results in bending of the cilia of the sensory hair cells that underlie the otoconia, and this, in turn, generates a physiological response that results in sound detection.

The second, nonotoconial sound pathway involves the macula neglecta. This sensory structure is located in the dorsal portion of the ear in the posterior canal duct. Sounds travel from above the elasmobranch head and through an area of tissue located above the ear called the parietal fossa. In the ventral end of the parietal fossa is a small membrane, the fenestra ovalis, that leads to the posterior canal duct. Sound waves depressing this membrane produce a flow of fluid through the posterior canal duct, shifting the position of the cupula of the macula neglecta and stimulating the sensory hair cells.

Measures of hearing bandwidth and frequency (the audiogram) for particle motion have been obtained in five species of elasmobranch fishes using classical conditioning or auditory evoked potential methods (Fig. 1; see Casper and Mann 2009 for a review). Because elasmobranchs do not have a swim bladder or any other air-filled cavity, they are incapable of detecting sound pressure. Thus particle motion is presumably the only sound stimulus that can be detected. The hearing bandwidth for elasmobranchs is from ~20 Hz up to 1 kHz, with similar thresholds in all species above 100 Hz (Casper and Mann 2009). Below 100 Hz, however, the two more active swimming piscivorous species, *Rhizoprionodon terraenovae* (Atlantic sharpnose shark) and *Negaprion brevirostris* (lemon shark), have more sensitive hearing, suggesting that hearing could be more important for the detection of prey. The other three species, *Ginglymostoma cirratum* (nurse shark), *Heterodontus francisci* (horn shark), and *Urobatis jamaicensis* (yellow stingray), are demersal species and likely use other senses including the lateral line and electroreception to find buried prey. Thus, although it is clear that elasmobranchs can detect particle motion, they do not appear to be as sensitive as teleosts measured in comparable ways (Fig. 1). One explanation for this difference in hearing sensitivity could be due to the composition of the denser otoliths in teleosts compared with the otoconia in elasmobranchs. A denser otolith might be more sensitive to particle motion and therefore yield more sensitivity to the auditory system. However, knowledge of the hearing of elasmobranch fishes is based on data from only a few of the hundreds of species, and so one must be cautious in making generalizations about an entire subclass of fishes based on these data.

2.1 Shark Behavioral Responses to Sound

The US Navy became interested in sounds that might attract or repel sharks following repeated observations of the presence of sharks in areas where ships were sunk by torpedoes during World War II. Acoustic attraction studies revealed that coastal and oceanic sharks (18 species observed) would often approach underwater speakers broadcasting low-frequency, erratically pulsed sounds from as far away as several hundreds of meters (Myrberg 2001). A few studies also attempted to determine the features of sounds that might cause sharks to leave a location. They found that sudden onset, loud (20–30 dB above ambient noise levels) sounds played when a shark approached a location would result in startling the shark and it would turn away from the area. In most cases involving attraction and repelling, the sharks would habituate to the stimuli after a few trials. There have been no experiments exploring behavioral responses to sound in either skates or rays. There have also been no studies examining the effects of exposure to anthropogenic sound sources in any species of elasmobranch.

3 Sources of Anthropogenic Noise That Could Affect Elasmobranch Fishes

There are many human-based activities that produce anthropogenic noise, including sonar, aquatic construction, air guns, boat activity, and offshore wind farms, that could potentially threaten aquatic inhabitants. Based on the location of sources, rate of occurrence, frequency ranges, and damaging effects associated with exposure, several of these sounds could have negative effects on elasmobranch fishes.

3.1 Aquatic-Based Construction

Pile driving is used for construction, including installation and repair of bridges, docks, and other structures, in aquatic environments. There is documentation that elasmobranchs tend to aggregate around coastal and offshore man-made structures (Stanley and Wilson 1991). A major concern is that elasmobranchs congregating near such structures could be impacted by the intense sounds during pile driving. Sound levels can reach 237 dB re 1 μPa at frequencies within the range of hearing of elasmobranchs (100–1,000 Hz; Hildebrand 2009). Sounds at such high levels could yield hearing damage in the form of temporary threshold shift (TTS), resulting in a short-term decrease in auditory sensitivity. However, the more likely source of damage would be barotrauma as a result of the impulsive energy produced when the hammer hits the pile. Recent evidence (see Halvorsen et al., Chapter 52) suggests that some of the barotrauma damage found in teleosts when exposed to pile-driving stimuli is in the liver, kidneys, and intestines, all of which are very prominent in the elasmobranch body plan. Another consideration is for demersal elasmobranchs that are almost constantly in contact with the substrate. The intense vibrations within the sediment from pile driving could also be damaging, especially when considering the body shape of skates and rays. Many of the organs of these dorsoventrally flattened fishes are in close proximity to the ventral body surface, providing little protection from pile-driving vibrations.

3.2 Offshore Wind Farms

With the need for cost-effective forms of electricity, more countries are exploring the application of offshore wind farms. Wind farm installation generally involves pile-driving construction, with the associated noise issues as discussed in the previous section. Once completed and operating, the rotation of the turbines produces a constant low-frequency noise (~60–300 Hz) at sound levels of ~150 dB re 1 μPa (Hildebrand 2009). These levels are likely not loud enough to cause any hearing damage (TTS), but there could be the potential of masking of sounds that elasmobranchs might use to detect prey or avoid predators. Because the wind mills are anchored to the substrate, there is also the potential for vibrational stimuli traveling through the structure that could impact demersal elasmobranchs.

3.3 Boat Noise

The number of vessels in the worldwide shipping fleet has grown dramatically over the last 50–60 yr. Obviously, the size, speed, and other features of the ships can affect the type of noise produced as they travel through the water, but in general, the sounds produced can be quite dramatic. A typical shipping vessel can produce sounds of ~190 dB re 1 μPa at very low frequencies (40–100 Hz; Hildebrand 2009). At these sound levels, it is unlikely that hearing damage would occur in elasmobranchs, but the sounds would certainly be loud enough to mask detection of biologically relevant sounds. A few studies have examined the effects of shipping noise and other noise exposure on the production of stress hormones in teleost fishes. Extended exposure resulted in increased levels of cortisol, which can affect a variety of health parameters in fishes (Wysocki et al. 2006). No similar studies have yet been conducted on elasmobranch fishes, but there is the potential of similar effects to those encountered in teleosts.

4 Summary

Elasmobranch fishes have been around for hundreds of millions of years with very little evolutionary changes, yet our understanding of their hearing abilities is limited to only a few of the hundreds of extant species. Our general understanding suggests a relatively narrow hearing range with relatively poor sensitivity, particularly compared with many teleosts. This lack of knowledge makes it difficult to evaluate the potential effects that could be associated with exposure to anthropogenic noise. However, given the combination of the worldwide increase in anthropogenic aquatic noise as well as the drastic population decline in many species of elasmobranch fishes, it is imperative that noise-exposure studies be conducted to determine whether these fishes are being further threatened by our noise pollution.

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