Methodology for Evaluating Potential Effects of Proposed Seismic Exploration on the Coastal Plain of the Arctic National Wildlife Refuge on Marine and Freshwater Fishes

Arthur N. Popper[1]
Environmental BioAcoustics, LLC
Silver Spring, MD

Potential Effects of Anthropogenic Sound on Fishes

Sound is used in a variety of ways by fishes. For all species, sound provides an "acoustic scene" (or soundscape) that serves as an acoustic overview of the world around the animals (e.g., Slabbekoorn 2018). This view is in three dimensions and extends for substantial distances. And, since, sounds are not limited by light levels, currents, or objects in the water, this information is available day and night, and even when there are obstacles in the environment (Bass and Clark 2003). The acoustic scene may include information about predators and prey, food sources, the location of objects in the environment, natural sounds (e.g., earthquakes, rain), etc. In addition, many species produce sounds and communicate with conspecifics (members of the same species) using species-specific sounds.

As a consequence, anything that interferes with the ability of fishes to detect the sounds in the acoustic scene could impact many behaviors including (but not limited to) the finding of mates, protecting territories, hearing acoustic warnings about predators, finding other members of the same species, or migration (e.g., Slabbekoorn et al. 2010). For this reason, anthropogenic (or man-made) sounds are of particular concern since they have the potential to impact fishes in a variety of ways including behaviorally and/or physiologically (see Table 1). Whether such effects occur will depend on many factors such as the sound level (at the fish), the frequency of the sound, its duration, and other characteristics. Of the potential effects, death and physical injury may occur as a result of loud sounds, whereas hearing threshold shifts, masking, and changes in behavioral may occur under moderate to low sounds levels (i.e., less serious effects occur from lower sound levels).

Underwater Sound[2]

For the context of this document, the most important issue regarding underwater sound is that sound in air and in water consists of both pressure and particle motion components. While particle

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[1] Dr. Popper is professor emeritus and research professor in the Department of Biology at the University of Maryland. He has been investigating fish hearing for over 50 years, and for the past 20 years he has been in the forefront of research on the effects of anthropogenic (man-made) sound on fishes and other animals. He is a Fellow of the Acoustical Society of America and of the American Association for the Advancement of Science (AAAS). He has published over 250 scientific papers, edited over 70 books on hearing, and is the editor of the magazine *Acoustics Today* (www.acousticstoday.org). His research is shared at his lab website – www.popperlab.umd.edu and a recent CV is at https://nacs.umd.edu/facultyprofile/Popper/Arthur.

[2] A general, lay-level, discussion of underwater acoustics, including about particle motion, can be found at www.dosits.org Popper and Hawkins (2018).

motion (the actual back and forth motion of the particles making up the medium) is minimal and not a component of hearing in air, it is a major component of the sound field in water.

Table 1: **Potential effects of anthropogenic sound on fishes**	
Effect	**Description**
Death	Instantaneous or delayed mortality.
Physical injury & physiological changes	Physical injury results in temporary or permanent impairment of the structure and functioning of some parts of the body. Physiological changes result in increased stress or other effects that can lead to reduced fitness.
Hearing Threshold Shift	Temporary loss of hearing results in decreased ability to respond to biologically relevant sounds.
Masking	The presence of noise results in a decrease in detectability of biologically relevant sounds (e.g., sounds of predators and prey, sounds of conspecifics, acoustic cues used for orientation).
Behavioral Responses	May include any change in behavior from small and short-duration movements to changes in migration routes and leaving a feeding or breeding site. Responses likely vary between species, depending on many factors such as the animals normal behavioral repertoire, motivational state, time of day or year, age of the animal, etc. Some changes in behavior, such as startle reactions, may only be transient and have little consequence for the animal or population.
No obvious behavioral responses	Animals may show transient or no responses, even if they detect the sound (e.g., to a very low-level sound). And/or habituation may take place. However, even if there is no response, there is always the possibility that physical injury and physiological changes may take place without the animal showing overt changes in behavior.

Sound Detection Capabilities of Fishes

All fishes are able to detect sound using the inner ear, including those species that do not produce sounds. Moreover, all fishes hear the particle motion component of the sound field, while only some species also are able to detect sound pressure (Popper and Hawkins 2018). The species that only detect particle motion, such as salmonids (e.g., Broad Whitefish), have their most sensitive hearing (hear lower sound intensities) from below (approximately) 30 Hz up to about 300 to 500 Hz (Figure 1). Fishes that also detect sound pressure generally have their best hearing to about 800 to 1,000 Hz. A smaller number of species, such as Lake Chub and Longnose Sucker shown in Figure 1, have specializations in their auditory systems that improve their hearing range (to perhaps 3,000 Hz). Species that can detect pressure often can detect lower level sounds than fishes that do not detect pressure (Ladich and Fay 2013).

Almost all fishes also have a second series of receptors along the body, the lateral line which detects water movements, including particle motion, from as low as 1 Hz to over 100 Hz (reviewed in paper in Coombs et al. 2014). Fishes use the lateral line to detect near-by motion of water and other objects. How the lateral line responds to anthropogenic sound has never been studied, but it is likely capable of detecting some portion of the sounds produced during a seismic study if the sounds are of sufficient intensity.

Bioacoustics of Arctic Fishes in Alaska

A summary of major Arctic Refuge Coastal Plain fish species is given in Table 2. Limited data are available on hearing for the Broad Whitefish, Burbot, and Nine-Spined Stickleback from a study done on Arctic fishes in the Mackenzie River Delta in Northern Canada (Figure 1) (Mann et al. 2007). Since many Northern Alaska species listed in Table 2 are salmonids, it is reasonable to suggest that their hearing capabilities are similar to that of the Broad Whitefish and other salmonid species. Such species can detect sounds up to about 300 to 500 Hz, and primarily (and likely only) particle motion (Hawkins and Johnstone 1978).

It is noted that the hearing range of the Arctic fishes for which there are data (Figure 1) include the sounds produced by vibroseis (sweeps from 1.5 to 96 Hz, according to the summary of the proposed action for seismic exploration, p. 4). Moreover, many of the sounds produced during a seismic study, such as from the associated machinery and other human activities used to support the seismic survey, may also be within the hearing range of fish species.

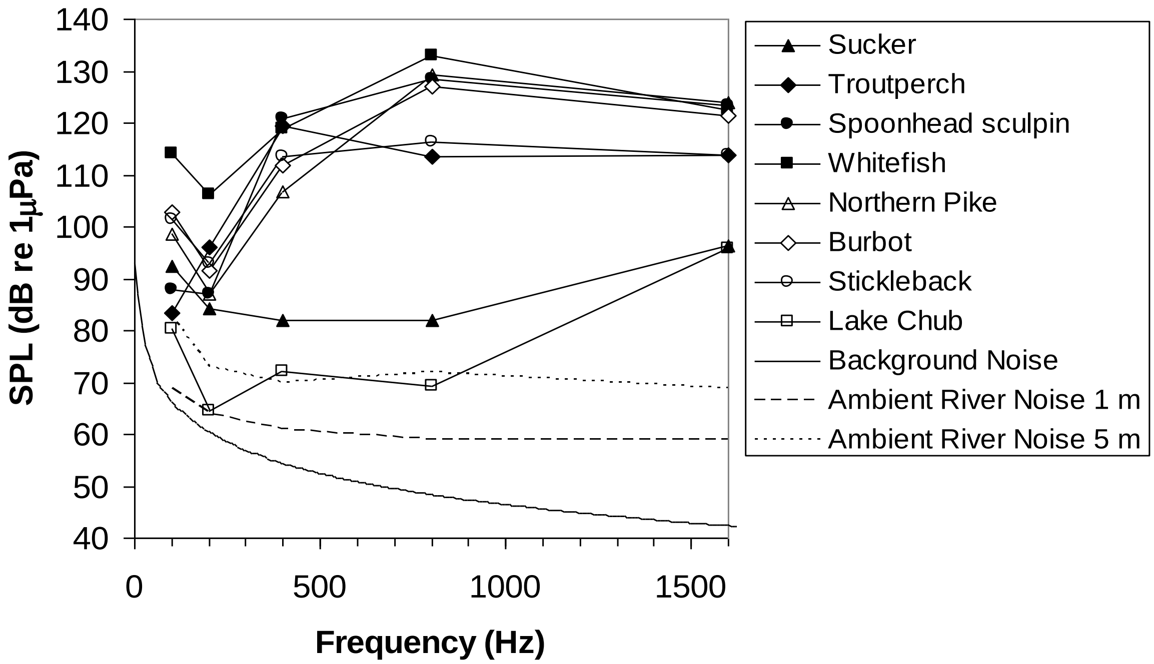

Figure 1. Hearing sensitivity (lowest sound detected) and frequency range of hearing (bandwidth) of eight northern Canadian freshwater species from the Mackenzie River Delta. (Figure from Mann et al. 2007). The data are presented as the lowest sound level that an animal can detect (threshold) at each of the tested frequencies. It is important to note that since these data were acquired using auditory evoked potentials (AEP's), they very likely do not represent the lowest sound levels that these species can hear and possibly not the full bandwidth of hearing. The data are plotted with background noise in the test tank and the background noise in the Mackenzie River measured at 1 m depth and 5 m depth in a channel (WesternGeco 2003)). Background noise measurements are spectrum level (dB re 1µPa/Hz$^{1/2}$). (Longnose Sucker - *Catastomus catastomus*; Troutperch - *Percopsis omiscomaycus*; Spoonhead Sculpin - *Cottus ricei*; Broad Whitefish - *Coregonus nasus*; Northern Pike - *Esox Lucius*; Burbot - *Lota lota*; Ninespine Sickleback - *Pungitius pungitius*; Lake Chub - *Couesius plumbeus*.)

Data Gaps Regarding Potential Seismic Effects on Northern Arctic Fishes

With the exception of one inconclusive report that was not subject to peer review (Morris and Winters 2005), nothing is known about potential effects of vibroseis on fishes. Moreover, since the acoustics of vibroseis and seismic signals from air guns are different acoustically[3] (e.g., Nyland 2002; Gisiner 2016), it is impossible to extrapolate from other seismic studies to understand potential impacts of vibroseis.

Table 2: Fish within the Arctic National Wildlife Refuge Coastal Plain (ANWR 1002 area) Freshwater and Near-shore Habitat. Data source USFWS (2015).

Species	Common Name	Family	Occurrence	Overwinter	Spawn Timing
Thymallus arcticus	Arctic Grayling	*Salmonidae*	Common	Yes	Spring
Prosopium cylindraceum	Round Whitefish	*Salmonidae*	Common	Yes	Fall
Salvelinus malma	Dolly Varden	*Salmonidae*	Common	Yes	Fall
Salvelinus alpinus	Arctic Char	*Salmonidae*	Common	Yes	Fall
Lota lota	Burbot	*Lotidae*	Common	Yes	Winter
Salvelinus namaycush	Lake Trout	*Salmonidae*	Common	Yes	Fall
Pungitius pungitius	Nine-Spined Stickleback	*Gasterosteidae*	Common	Yes	Spring
Cottus cognatus	Slimy Sculpin	*Cottidae*	Common	Yes	Spring
Coregonus nasus	Broad Whitefish	*Salmonidae*	Rare	No	Fall
Coregonus clupeaformis	Humpback Whitefish	*Salmonidae*	Rare	No	Fall
Coregonus autumnalis	Arctic Cisco	*Salmonidae*	Common	No	Fall
Coregonus sardinella	Least Cisco	*Salmonidae*	Common	No	Fall
Oncorhynchus keta	Chum Salmon	*Salmonidae*	Rare	No	Late Summer

As a consequence, there are a number of critical data gaps that must be filled before it will be possible to properly assess the effects of vibroseis on Northern Arctic fishes. These are discussed below. However, it should be noted that there is a general dearth of data on effects of anthropogenic sound on fishes (Popper et al. 2014; Hawkins et al. 2015; Popper and Hawkins 2018) and until this broader set of questions are answered it is not possible to fully understand potential impacts of vibroseis or any other sound on fishes (Popper et al. 2014).

- *Acoustics of Vibroseis Sounds*: We have no knowledge of the signals from on-land or on-ice vibroseis that get to fishes (referred to as the received signal). Such sounds may be produced directly into the water (e.g., from the air or through ice) or by traveling through the substrate from someplace on land. In all cases, however, data are needed on signal levels, the spectrum of these signals (the component frequencies in the anthropogenic sound), and other signal characteristics in the water. This must be done for both sound pressure and particle motion over the whole region ensonified during a survey (both close to and far from the actual vibrator function) and over the full 24 hour day.

[3] For example, sounds from seismic studies using airguns are very high intensity, very short (less than 100 msec), and contain frequencies from below 10 Hz to up to 1,000 Hz. Sounds from vibroseis continue for many seconds, contain a much narrower range of frequencies, and are frequency sweeps rather than containing all of the frequencies at the same time.

- *Effects of Vibroseis Sounds on Fishes*: Other than for the incomplete and not-peer-reviewed study of Morris and Winters (2005), nothing is known as to how fishes respond to sounds from vibroseis, and even those data are for only a single species. These preliminary data suggests that Arctic char will move away from a vibroseis sound, but levels of sound were not reported, nor were the duration and specific characteristics of the sounds from a full survey. Studies are needed on behavioral responses of fishes for the duration of a survey, asking questions that include, but are not limited to, how the responses of fishes may change over the course of the survey and the behavior of fishes after the termination of the survey as compared to before the survey. Other data gaps include effects on acoustic communication, use of the soundscape, impact on reproduction, etc. Importantly, data must be obtained for a number of species since there are significant species-specific differences including in behavioral responses to sound, hearing capabilities, etc.

- *Sound Detection by Northern Arctic Fishes*: A fundamental question is whether fishes can detect the vibroseis sounds. In other words, do fishes hear well enough to detect the received vibroseis sounds (i.e., are the sounds below the lowest sound that the fishes can detect?). Information on both pressure and particle motion detection in a variety of Arctic aquatic habitat, used by fishes, is currently not available.

Analyses Needed to Fill the Most Critical Data Gaps in Order to Assess Potential Impacts

In order to properly assess potential impacts of a seismic survey, the following information, based on the aforementioned data gaps, are needed:

- Data on sound in the water for the duration of a seismic survey across the region for vibroseis as well as all other anthropogenic sounds associated with the survey activities. Research must focus on both sound pressure and particle motion, and includes important acoustic parameters such as sound level, bandwidth, signal duration, etc.

- Baseline data are needed on the aquatic soundscape in the same regions before and after survey operations to compare to the soundscape during a seismic survey.

- Behavioral observations on unrestrained wild fishes of select species in survey areas before, during, and after the survey. Data prior to operations are needed in order to provide a baseline for assessing if human activities impacted behavior. Post-survey data are needed to determine if any impacts on behavior continued after the survey and had long-term impacts on the fish.

- Filling in data gaps on potential effects of sounds of the same levels as found during a seismic survey using vibroseis including information on cumulative and aggregate effects of sound exposure and potential short and long term behavioral responses (as per selected gaps discussed in Hawkins et al. (2015) and Popper et al. (2014)).

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