Underwater Acoustics: Webinar Series for the International Regulatory Community

Webinar Outline: Marine Animal Sound Production and Reception
Tuesday, April 24, 2018
12:00 pm U.S. (Eastern, Daylight Time); 5:00pm UK (London); 12:00am China (4/25, Beijing)

Marine Mammals Underwater Hearing: Sound Reception and Sound Impacts (Dr. Darlene Ketten, Woods Hole Oceanographic Institution; The Hearing Research Center of Biomedical Engineering, Boston University; International Helmholtz Fellow, Germany)

Please note: This outline provides background information on all topics that may be discussed in the webinar. However, because of time constraints, some items may not be included in the presentation but may be addressed in the question period.

What is a Marine Mammal?

- Marine mammals belong to five vertebrate groups: cetaceans (dolphins and whales), pinnipeds (seals, sea lions, and walruses), sirenians (manatees and dugongs), mustelids (sea otters) and ursids (polar bears). For details see: https://www.marinemammalscience.org/species-information/list-marine-mammal-species-subspecies/
- Cetaceans are divided into the Odontoceti or odontocetes (toothed whales and dolphins) and the Mysticeti or mysticetes (baleen whales). Pinnipeds are divided into the phocids (true seals), the otariids (eared seals and sea lions), and the odobenids (walrus).
- Cetaceans and sirenians are "obligate aquatics", which means completely water adapted and unable to live on land; the other groups are amphibious, which is adapted in varying degrees to both air vs. water.

Marine Mammal Sound Production

- Like many land mammals, marine mammals, according to the species can produce sounds ranging from infra to ultrasonic frequencies.
- Odontocetes also produce ultrasonic (>20 kHz) frequency clicks and buzzes used in echolocation by manipulating air in specialized sacs in their nasal passages that channel sounds through the fatty melon at the top of the odontocete head rather than through the mouth. They also produce lower frequency sounds (typically 1-10 kHz) with their larynx that are related to communication. Peak spectra of echolocation signals are correlated with the type of prey and the habitat in which the species lives. Species that hunt small fish in complex environments use higher frequencies at lower intensities while off-shore species use lower frequencies, sometimes at high intensities.
- Mysticetes appear to use only their larynx to produce low to infrasonic signals. At present, we do not know if these signals are used only for communication or if they may have any other function, such as long-range navigation.
- All other marine mammals produce sounds only through the larynx and appear to be primarily for communication.

Marine Mammal Sound Reception

- Marine mammals, like land mammals, have a three-part auditory system: Outer Ear (sound collection); Middle Ear (amplification and mechanical transduction) and Inner Ear (neurotransduction). Images of ears of some marine mammals can be seen at http://csi.whoi.edu
- Most species of marine mammals have some level of adaptation for hearing underwater. Polar bears, some pinnipeds, and sea otters have pinnae (outer ear flaps) like land mammals but others lack obvious pinnae.
- Some pinnipeds have valves that control water entry into the outer ear canal.
- The middle ears in all marine mammals consist of a hollow bony walled chamber that houses a chain of three interconnected bones (middle ear ossicles): the malleus (hammer), incus (anvil), and stapes (stirrup). These act as levers to add approximately 30-40 dB (see decibel below) to the sound pressure of some frequencies. The malleus is connected to the tympanic membrane (eardrum), and the stapes connects to the oval window which is the entrance to the cochlea (inner ear). This system is common to all mammals but in marine mammals there are difference in the size, stiffness, and mass of these bones that relate to the ability to hear infra or ultrasonic sounds underwater.
- Cetaceans have no functional outer ear and have developed unique fats that act like pinnae to receive and channel underwater sound to the middle ear. They also have extremely dense middle and inner ear bones with no thin-walled air spaces (like our mastoids) that would be a liability when diving. Specialized soft tissues in their middle ear are thought to be related to controlling middle ear volume at different depths.
- The inner ear (cochlea) of all marine mammals is similar to cochleae of land mammals in that they are highly developed spirals with fluid-filled three chambers. The middle chamber contains specialized membranes (basilar and tectorial membrane) that resonate in response to sound energy. Nerve fibers connected to hair cells arrayed along the membrane send a signal to the auditory brain centers according to which cells respond to incoming sound. The membranes of some cetaceans are “tuned” to detect and encode frequencies as low as 10 Hz and as high as 190 kHz. Some species hear 10-12 octaves, compared to the human range of 8 octaves. Cetacean ears also have double to triple the neural density of other mammals. We refer to these as “hypertrophied” cochlea because they are so hyper developed compared to land mammal inner ears.
- In addition to the specializations of the ears per se, cetaceans also have differences from land mammals in ear spacing and in the size of auditory centers in the brain that help them detect signals in noise and to have exceptional sound localization abilities as well as the ability to decode underwater differences in sound speed and wavelength,

Marine Mammals and Sound Impacts

- Hearing is a very important sense for marine mammals but they have to evolved “Super Ears” that are impervious to hearing loss. Like all mammals, marine mammals are subject to hearing loss from noise exposure (NIHL or Noise Induced Hearing Loss) but also from disease, aging, and/or trauma. Captive odontocetes and pinnipeds tested over several years have been shown to gradually lose high frequency hearing as they age just as we see in humans. This is called presbycusis or “old ears”. Some of this is due to wear and tear of inner ear structures, like the loss of muscle, bone, etc. in other parts of the body from aging. In the inner ear, “wear and tear” comes mostly from sound processing over the years. High intensity sound exposure can exacerbate normal wear and tear, such as in an industrial environment. We do not have evidence at this time of increased hearing loss from high noise ocean regions, but there are captive studies that show some marine mammals can have temporary threshold shifts from high sound

exposures. This in combination with the studies showing marine mammal hearing loss with age suggest marine mammals, despite their adaptations, are subject to NIHL if exposed to sounds for long periods of time and at high intensities. However, the liability for NIHL differs by species according to whether a sound is in their hearing range and how sensitive they are to it.

- An important point is that sounds are not heard equally well by all animals and that sound and noise are not synonymous. Noise is an unwanted or disturbing sound, which means it depends upon how the animal (receiver) perceives it. Therefore, it is possible for one sound to be an important signal to one animal but to another animal or species it may be a disturbing noise or may be imperceptible. For this reason, we cannot accurately assess noise impacts with one metric; we must always assess sound and hearing impacts by species

Terminology

audiogram: A graph of hearing ability conventionally displayed as frequency vs. sensitivity measured as sound pressure

cochlea: the inner ear tissues contained in a set of spiral canals that transduce sound energy into neural impulses that convey multiple sound features, including frequency, timing, and intensity.

decibel (dB): a scale based on the log ratio of two quantities. It is commonly used to represent sound pressure level. The value of the decibel depends upon the reference pressure, which arbitrarily differs in air (reference pressure is 20 microPa) vs. water (reference pressure is 1 microPa). For this reason, the decibel level of sound is properly stated in the form of n dB re n microPa and in terms of sound energy the decibel number will be different in air vs. water. In terms of intensity, 100 dB re 20 microPa in air equals approximately 160 dB re 1 microPa in water.

infrasonic: below 20 Hz, the lower limit of human hearing

kHz: kilo Hertz. A Hertz (Hz) is a measure of sound frequency equal to 1 cycle/sec. A kHz is one thousand cycles per second

nares/narial: air passages that connect the throat area with the external opening of the nose.

octave: An octave is broadly defined as a doubling of frequency. Thus, a one octave shift from 500 Hz is 1,000 Hz; from 3,000 Hz, it is 6,000 Hz. Adult humans have on average an 8-octave functional hearing range of 32 Hz to 16 kHz

ossicles: the middle ear bones that act as levers to mechanically transform sound waves into pressure, frequency, and velocity components transduced by the inner ear.

pinna(e): external flaps made of folds of soft tissues and cartilage in mammals that extend from the sides of the head, with an opening that leads to the outer ear canal. These act as sound collectors and are usually shaped to enhance detection of some frequencies and the direction of incoming sound.

ultrasonic: above 20 kHz, the upper limit of human hearing.

Additional information on the DOSITS website:
Science of Sound > What sounds can people hear?
https://dosits.org/science/measurement/what-sounds-can-we-hear/

Science of Sound> What sounds can animals hear?
https://dosits.org/science/measurement/what-sounds-can-animals-hear/

Science of Sound > How is hearing measured?
https://dosits.org/science/measurement/how-is-hearing-measured/

Science of Sound > What are common underwater sounds?
https://dosits.org/science/sounds-in-the-sea/what-are-common-underwater-sounds/

Science of Sound > How do people and animals use sound in the sea?
https://dosits.org/science/sounds-in-the-sea/how-do-people-and-animals-use-sound-in-the-sea/

Science of Sound > Why do sounds have different properties?
https://dosits.org/science/sounds-in-the-sea/why-do-sounds-have-certain-properties/

Science of Sound > Advanced Topic > What is intensity?
https://dosits.org/science/advanced-topics/what-is-intensity/

Animals and sound > Why is sound important to marine animals?
https://dosits.org/animals/importance-of-sound/why-is-sound-important/

Animals and Sound > How do marine animals use sound?
https://dosits.org/animals/use-of-sound/how-do-marine-animals-use-sound/

Animals and Sound > How do marine mammals produce sound?
https://dosits.org/animals/sound-production/how-do-marine-mammals-produce-sounds/

Animals and Sound > How do marine mammals hear?
https://dosits.org/animals/sound-reception/marine-mammals-hear/

- Hearing in Land Mammals
  https://dosits.org/animals/sound-reception/marine-mammals-hear/land-mammals/
- Hearing in Pinnipeds, the Amphibious Ear
  https://dosits.org/animals/sound-reception/marine-mammals-hear/hearing-pinnipeds/
- Hearing in Cetaceans and Sirenians, the Fully Aquatic Ear
  https://dosits.org/animals/sound-reception/marine-mammals-hear/hearing-in-cetaceans/

Animals and Sound > Marine Mammal Communication

- Individual-specific vocalizations
  https://dosits.org/animals/use-of-sound/marine-mammal-communication/individual-specific-vocalizations/
- Group-specific vocalizations
  https://dosits.org/animals/use-of-sound/marine-mammal-communication/group-specific-vocalizations/
- Vocalizations associated with reproduction

https://dosits.org/animals/use-of-sound/marine-mammal-communication/vocalizations-associated-with-reproduction/
Sounds associated with aggression
https://dosits.org/animals/use-of-sound/marine-mammal-communication/sounds-associated-with-aggression/

Animals and Sound > How do marine mammals use or make sound when feeding?
https://dosits.org/animals/use-of-sound/marine-mammals-feeding/

Animals and Sound > How do marine mammals use sound to navigate?
https://dosits.org/animals/use-of-sound/marine-mammal-navigation/

Animals and Sound > What are the potential effects of sound on marine mammals?
https://dosits.org/animals/effects-of-sound/potential-effects-of-sound-on-marine-mammals/

Animals and Sound > Advanced Topic > What components of sound are used for hearing?
https://dosits.org/animals/advanced-topics-animals/components-of-sound/

Animals and Sound > Advanced Topic > Hearing Loss
https://dosits.org/animals/advanced-topics-animals/hearing-loss-advanced/