Regulation Consideration of Ocean

MICHAEL SMITH

Mapping Multibeam Echo Sounders

A Square Peg in a Round Hole

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At a time when we know more about the moon's surface than our own planet's seafloor, innovation in acoustic ocean mapping technology holds the key to the future. The Shell Ocean Discovery XPrize launched in 2015 was designed to inspire innovation in ocean exploration and discovery of the deep sea, and all competing teams utilized some form of ocean mapping echo sounder (Figure 1).

Figure 1: XPRIZE entry SEA-KIT USV *Maxlimer* being deployed for sea trials in Horten, Norway. The sensor gondola below SEA-KIT USV *Maxlimer* contains a HiPAP acoustic navigation system and EM304 multibeam echo sounder system.

What are Multibeam Echo Sounders?

Echo sounders are commonly used for mapping the bathymetry and recording backscatter of the seafloor and water column for safeguarding navigational pathways, fisheries research, deriving benthic habitat information, as well as for geophysical exploration of natural resources. The development of multibeam echo sounders (MBES), capable of collecting multiple soundings with a single transmission, provided the opportunity to more quickly and efficiently map the seafloor and water column in comparison to conventional single beam echo sounders. MBES utilize advanced beamforming techniques to generate a narrow swath of sound in the along-track direction of the ship that propagates to the seafloor. The energy transmitted perpendicular to the vessel track is a broad swath designed to map the ocean bottom not only under the vessel but extending out to the sides. The focusing of the acoustic energy in the downward, vertical direction reduces the amount of energy being transmitted in the horizontal direction away from the survey vessel. Through advanced signal processing, a receive beam is formed which converts the reflected and backscattered echoes of the seafloor to a high resolution seafloor bottom detection. The multibeam geometry allows the receiver to discriminate discrete points on the seafloor across the swath from which the echoes are coming, while a single beam echo sounder only records one depth within a broad area of ensonification (typically with a diameter of half the water depth). Thus, multibeam sonars produce a much higher resolution map of the seafloor compared to more traditional single beam echo sounders.

One Size does not Fit All

Present day MBES systems come in a variety of shapes, sizes, and frequencies to meet a wide breadth of operational needs (Figure 2). Available multibeam echo sounders range in frequency from 12 kHz-700 kHz. The lowest frequencies are most appropriate for very deep water (<11,000 m) and provide the largest acoustic coverage, as low frequencies attenuate less rapidly than high frequencies. Higher frequency systems are limited in their propagation range and are predominantly used in shallow coastal (10-450 m) water, or on vehicles sampling very close to the seafloor, and provide the best resolution for imaging bathymetric features and small objects, such as pipeline installations.

Multibeam systems have undergone significant technological advancement in

Figure 2: A 30 kHz EM 302 Kongsberg MBES system hull-mounted to the NOAA ship *Okeanos Explorer* while it was in dry-dock.

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electronic and beamforming capabilities, resulting in the development of systems with multi-swath and multi-sector functionality (Figure 3). With the multi-sector feature, MBES systems generate a number of smaller swaths, or sectors, by generating short independent transmissions with non-overlapping, narrow bandwidths which facilitate motion compensation by allowing for the independent delay or steering of each sector. The multi-sector capabilities allow MBES systems to reliably operate in a wide range of sea states and water depths by compensating for vessel motion at each individual sector. The multi-swath feature allows a vessel to move faster while getting the same sounding density as a single swath. Most modern multibeam systems can be operated under various pulse length and angular geometries depending on the operational requirements of the survey. These include single/dual swath, auto-ping mode/ manually-selected mode, depth-specified modes, motion compensation on/off, varying angular swath widths, continuous wave (CW)/ frequency-modulated (FM) transmission signals, among others. In standard operation, the auto-ping mode updates the signal parameters in real-time based on the depth of the survey area, while manually-selected modes will lock the system into a given set of parameters per mode. The ping rate is typically limited by the depth in the area and the angular swath width, as the transducer typically waits

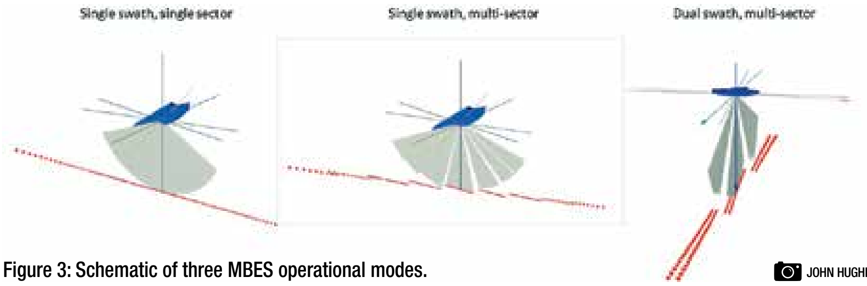

Figure 3: Schematic of three MBES operational modes.

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for the return of each sector's transmission before another signal is transmitted. Swath widths and angles may vary based on the geometry of the survey area (e.g., may be changed for canyons versus flat environments).

Most systems use a CW or gated single-frequency signal, but in some of the deeper operating modes, the sectors will automatically (or manually) switch from CW signal to a FM signal to increase the signal-to-noise ratio and ultimately the overall mapping resolution. In practice, only about 10% of the reported centre frequency is useable bandwidth for operating the system (e.g., a 12 kHz system can produce a useable signal between 10.8-13.2 kHz). This means the number of possible sectors is limited, since each requires its own non-overlapping operational frequency. The number of sectors used in a given mode and the operating frequency of each sector is a trade-off between staying within a reliable range of the physical capabilities of a system, while meeting the needs of the survey. For example, the large bandwidth needed to generate FM signals for better resolution in deep water environments means that modes that utilize FM signals may be limited to a single swath and/or a reduced number of sectors to operate properly.

Challenge Related to Marine Mammal Noise Exposure Regulation

With the development of innovative ocean mapping technology has come concern that sound produced by anthropogenic activities has the potential to harm marine life. This concern has largely been targeted at military sonars, pile driving, and seismic arrays used in the exploration of oil and gas, but regulatory attention has recently been extended to ocean mapping sound sources. One of the main reasons MBES have been less regulated is because of the assumption that only a narrow angular region below the ship would be ensonified by sound energy due to the directivity of these systems. However, current regulation of any anthropogenic sound source is directly related to both the sound exposure level and the exposure signal type, corresponding to not only injury but also behaviour. This is where the consideration for MBES becomes complex. Exposure levels for an animal not below the vessel will, therefore, always come from areas outside the main transmission of energy, which equates to significantly reduced sound levels compared to the main transmission. Additionally, the specific signals transmitted by MBES provide a unique challenge because there is often no single signal type used over the full duration of an ocean mapping survey. MBES signals are directly related to the system operational parameters that vary based on not only the operational needs of the survey but the location, weather, and oceanographic conditions. The dynamic capabilities of MBES systems optimize seafloor imaging by automatically shifting between CW and FM signals that have different physical structures, propagate through the environment differently, and have the potential to impact marine mammal behaviour differently.

When assessing impact of sound on marine mammals in terms of injury or behaviour, exposure threshold criteria have been developed that are linked to the signal type. Pulsed sounds are regulated differently and have separate exposure threshold criteria than

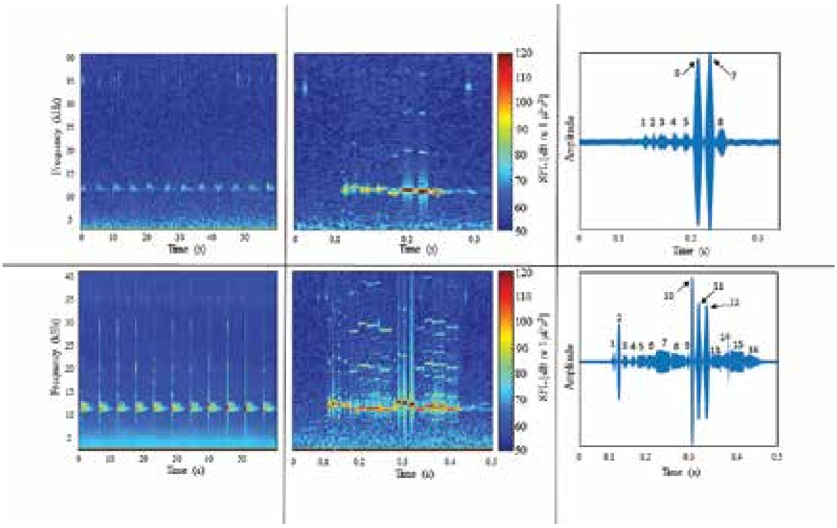

Figure 4: Top – 1-minute spectrogram (left), single transmission spectrogram (centre), and linear waveform (right) of a single transmission from the EM 122 during the deep, single swath, multi-sector mode with motion compensation enabled. Bottom – 1-minute spectrogram (left), single pulse spectrogram (centre), and linear waveform (right) from the EM 122 during the deep, dual swath, multi-sector mode with motion compensation and FM signals enabled.

continuous sounds. Pulsed, or impulsive, sounds are thought to be more damaging to the marine mammal auditory system and are regulated with more conservative thresholds of noise exposure than continuous sounds. Depth sounders, which include multibeam echo sounders, are classified as both types, not falling cleanly into either category. The variety of operational modes that can be utilized in MBES systems makes it particularly challenging to classify the MBES sound source for regulatory purposes with respect to anthropogenic noise exposure to marine mammals. Forcing MBES to be assessed in a single sound source category is like trying to fit a square peg in a round hole.

EM 122 Signals

As an exercise to highlight the range of signals within these systems, the contribution of a 12 kHz EM 122 multibeam echo sounder to a local soundscape was examined under two operational modes with motion compensation enabled: 1) deep, single swath, multi-sector CW only mode and 2) deep, dual-swath, multi-sector, FM-enabled mode. The EM 122 was selected because it has the lowest operational frequency of MBES systems; hence, the greatest sound exposure volume associated with marine mammal impact concerns. Assuming all source levels and operational parameters are uniform across systems operating at higher frequencies, the EM 122 represents the "worst case" scenario of MBES sound exposure due to its larger comparative ensonified volume. The Kongsberg EM 122, a deep water MBES, operates using either single or dual swath with four to eight sectors per swath and centre frequency of 12 kHz. The EM 122 is capable of automatically changing between its five operational modes as the depth of the water changes, which includes longer pulse lengths and frequency-modulated pulses in the outer sectors at the deepest depths.

Data from a hull-mounted EM 122 was collected along a line that transited over a bottom-mounted hydrophone mooring positioned at approximately 1,210 metres depth. A one minute and one signal transmission section of the hydrophone data during this time period was extracted and examined (Figure 4). The signal within the second operational mode is twice as long as the signal in the first operational mode. Even in the same water depth, this has repercussions on the pulse rate; in single swath, multi-sector mode a transmission is made 12 times in 60 seconds (Figure 4 – top), while in dual swath, multi-sector mode there are 11 transmissions in 60 seconds (Figure 4 – bottom). Note that where the transmission occurs relative to the hydrophone will determine its "apparent" waveform. So the relative amplitude of a given sector will depend on the location of the receiver.

In the ocean mapping community, the combination of all sector transmissions is commonly referred to as a pulse. However, the MBES signal transmission does not explicitly meet the physical definition of a rapid rise time, broadband pulse of sound (e.g., pile driving or seismic array signals) considered in existing sound exposure regulation. Where the MBES signals fall within the sound source categorization of current regulation is unclear due to the complexity of the signal. However, the potential consequence of these different signal structures on a listening marine mammal is the more important concern. This is especially relevant in the context of marine mammal behaviour, as certain anthropogenic sounds can be similar to biologically relevant cues produced by a predator or prey, and can have potentially variable effects on masking of communication signals when signal structure, length, and repetition rates are changing within a single survey. Understanding the breadth of MBES signals will be crucial to the future assessment of the impact of MBES on marine mammals as pulse length, repetition rate, and directivity of the sound energy may all likely play a role.

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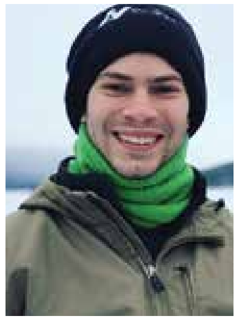

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