Underwater Acoustics: Webinar Series for the International Regulatory Community

Webinar Summary: Potential Effects of Sound on Marine Mammals
Wednesday, March 16, 2016 at 12:00pm (US East Coast Time)

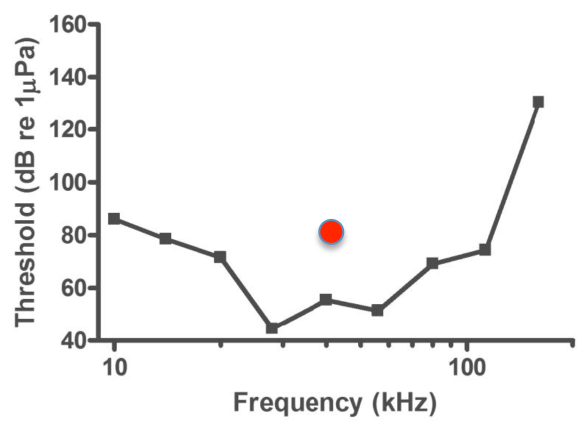
Temporary Threshold Shift (TTS): Causes, Effects and its Role in Acoustic Impact Assessments
Dr. Dorian Houser, National Marine Mammal Foundation

Review temporary threshold shift (TTS), a hearing phenomenon, the causes of TTS, and how it is used to assess the impact of sound on marine mammals.

- Give an overview of what TTS is and summarize what is known in marine mammals

What is Temporary Threshold Shift (TTS)?

- A hearing threshold is the lowest level of sound that can be detected at a given frequency.
  - An audiogram, a graph that describes the sensitivity of an organism to sound as a function of frequency, was shown (threshold on the y axis, frequency on the x axis)
    - The lower you go on this graph, the more sensitive an animal is to sound at that frequency
- A noise-induced threshold shift can occur if, after an animal has been exposed to sound, there is an elevation in the threshold (e.g. red dot on graph at 40 kHz)
- If the threshold returns to normal after the sound exposure, it is a temporary shift (a temporary threshold shift)
  - If it never returns to normal, then it is a permanent threshold shift (PTS)- this is a larger problem. Not discussing PTS during this presentation.



The impact of frequency, duration, and sound amplitude (on TTS)

- TTS is not an “all or nothing” phenomenon. There are other important factors that contribute to if an animal experiences TTS (or not). These are the duration, frequency, and amplitude of the sound [to which the animal is exposed].
    - ***Duration:*** for a given level of sound that an animal is exposed to, the longer duration of the sound, the more likely it is to cause a TTS. And if it does cause a TTS, greater durations, will then cause a greater amount of TTS.
        - The sound pressure level (SPL) of a sound is typically the average level of a sound (does not include duration)
        - When the duration of the sound and SPL are taken together, a pseudo-energy metric, the sound exposure level (SEL), can be calculated
            - This is what scientists are generally interested in - what is the combination of the duration and the amplitude of a sound that can lead to a TTS?
        - Hirsh et al (1955)- work done in the 1950’s in humans. The purpose of the graphs shown is that for a given SPL, the duration of exposure matters. The graphs show changes in the threshold of hearing (going left to right), after exposure to the same sound at different durations. After 4s of exposure to this particular sound, a shift occurs.
        - These types of studies are important, as they help predict what type of sounds may cause an impact (to marine mammals or humans)

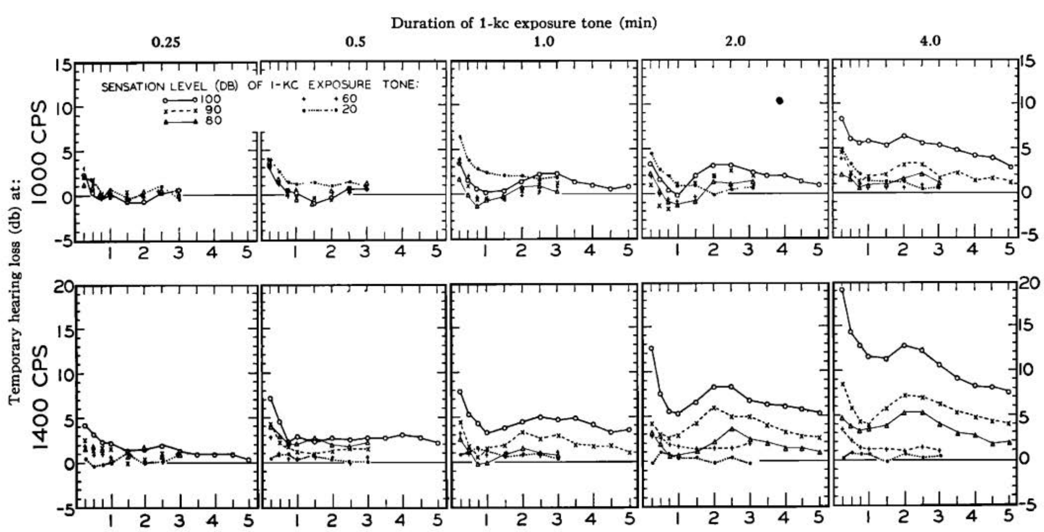


FIG. 3. Recovery curves (THL as a function of time after exposure) for 1000 (top) and 1400 (bottom) cps following exposures at 1000 cps. The five columns of curves represent five exposure durations. Within each family of curves, the parameter is the SL of the exposure.

- How sounds are presented is also important. If there are breaks in a sound, then there is the potential for the ear to recover.

- ***Amplitude:*** another factor to take into consideration
  - Hirsh et al 1955, again.
    - In the graphs, subjects are exposed to sound for 15 s, 30 s, 1 min, 2 min and 4 min (different lines). The number at the top of the graphs is how many seconds after exposure that threshold is measured. Numbers below the graphs (x-axis) are the SPLs individuals were exposed to, from 20-100 dB SPL. As SPLs increase, greater shifts occur (especially for 80-100 dB SPL exposures).
    - Sound that was used for this exposure was at 1 kHz (1,000 cycles per second (cps), which is an old way to refer to frequency). Threshold shifts were measured at 1 kHz (top graph) and 1.4 kHz (bottom graphs).
      - When an animal is exposed to a given sound, the TTS will occur at a higher frequency than that of the exposure. This is what the bottom graphs show: not much shift from 20-80 dB SPL exposures, but large shifts at 100 dB SPL exposure with shifts being larger at 1.4 kHz (above the frequency of the exposure).

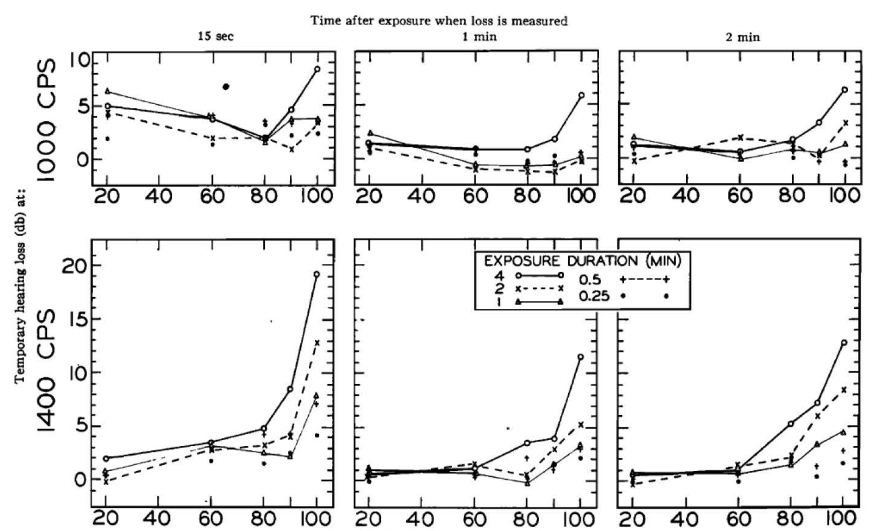
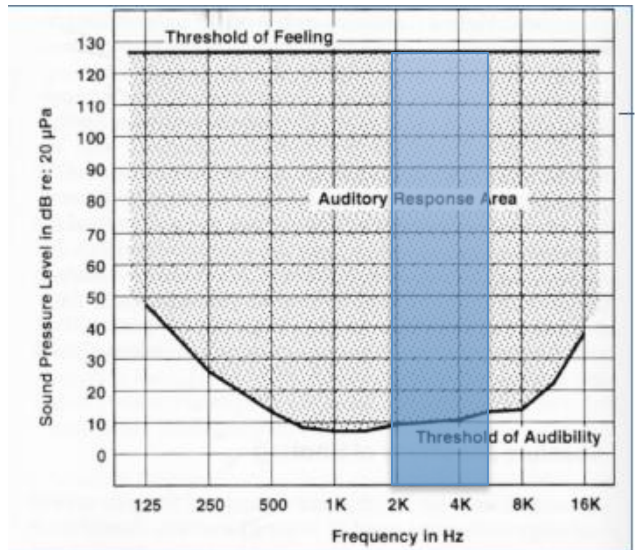


FIG. 4. Dependence of temporary hearing loss (measured 15 sec, 1 min, and 2 min after a 1-kc exposure) on the SL of exposure. The more regular dependence is seen for 1400 (bottom) than for 1000 (top) cps. In all cases the relation between THL and exposure level becomes greater as the duration (parameter) is increased. Only the THL measured 15 sec after exposure shows the greater value after 20 than after 60, 80, or 90 db exposures, and even then only clearly for durations greater than 30 sec.

- This is an important concept to consider when trying to interpret how the sound [we] put into the ocean might affect marine mammals. It's not necessarily the frequency of the sound exposure that is most impacted, but those frequencies a ½ octave to an octave above the exposure frequency.

- ***Frequency:*** not all frequencies at which we hear have the same potential for TTS.
    - Work with humans show the greatest potential for TTS is between 2-6 kHz. This is the region closest to where humans are most sensitive to sound (graph shows this).
    - Whether or not this is true for marine mammals is currently being researched.



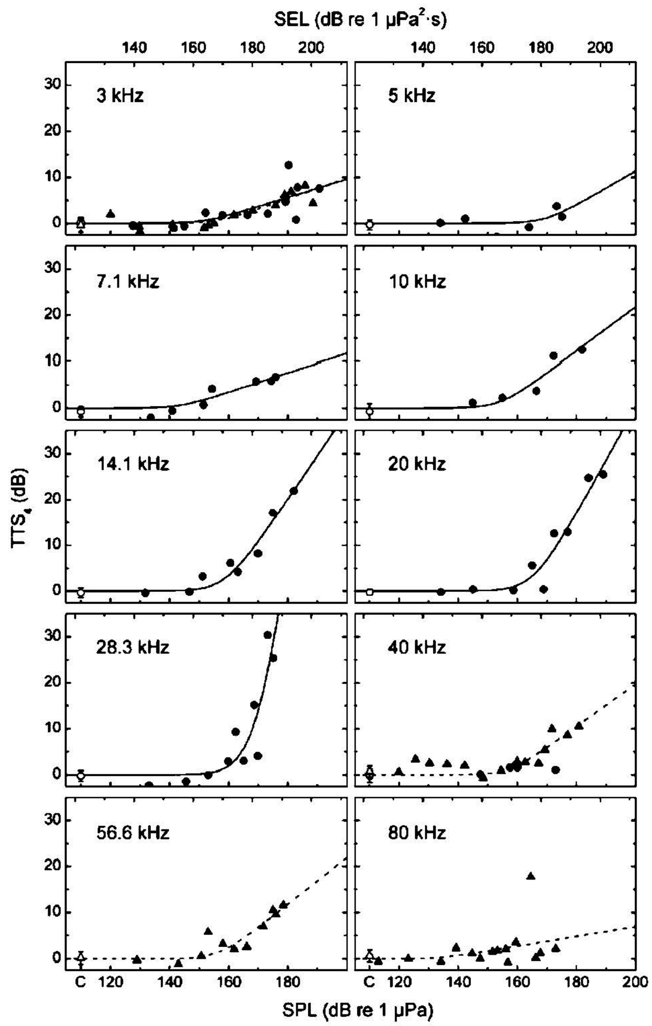
The role of TTS in assessing acoustic impacts to marine mammals

- National Marine Fisheries Service (NMFS) is responsible for regulating marine mammals under the Marine Mammal Protection Act (MMPA) [in US waters]
- There are two categories of harassment under the MMPA:
    - Level A- has the potential to injure a marine mammal or marine mammal stock in the wild
    - Level B- has the potential to disturb a marine mammal or marine mammal sock in the wild
    - These are not definitions for military purposes- those definitions are slightly different
- TTS is currently considered a Level B Harassment (under the MMPA)
    - Because it is a physiological phenomenon, it is odd that TTS is considered a Level B Harassment. The reason why is because TTS has historically been assumed to be something from which an animal can recover from without injury; and it has the potential to affect an animal's

ability to hear other biologically significant sounds in the environment. If you therefore impede an animal's ability to respond to a sound, then you have a potential affect on normal behaviours (e.g. the sound of a predator, and if animal can not detect it, then it may not respond in the same way [did not flee as it usually would] - normal behaviour disrupted).
  - Whether or not TTS occurs without injury has been debated in recent years (talk about briefly at end).

- Regulatory concerns:
  - What are the types of sounds being put into the ocean that are potentially impacting marine mammals?
    - Impulsive sound (e.g. explosions, echolocation clicks, snapping shrimp)
      - Have a rapid rise time in pressure; they generally have a broader spectrum (wider range of frequencies that are excited at once)
    - Non-impulsive sound (e.g. sonar signals, whale calls, boat engine noise; sometimes referred to as "continuous sound")
  - Usually interested in anthropogenic sounds and how they might impact marine mammals
    - TTS studies in marine mammals began in the 1990's
      - Finneran, J. J. 2015- "Noise-induced hearing loss in marine mammals: A review of TTS studies from 1996-2015". Journal of the Acoustical Society of America (JASA). Recommended resource.
      - Decent number of species have participated in TTS studies (bottlenose dolphins, beluga, Yangtze finless porpoise, harbour porpoise, harbour seal, seal lion, elephant seal)
      - Types of sounds animals have been exposed to have been quite varied, which complicates trying to determine patterns of TTS.
        - Look at frequency, duration, and temporal pattern and whether they affect marine mammals.
      - There are not many laboratories that do this type of work; over last 20 years, work has been product of 6 labs across Europe, U.S., and Russia (one lab just closed, so now down to 5 labs)
    - Affect of sound amplitude and duration on TTS in MM, seems to follow same pattern as observed in humans

- Focus on work done with bottlenose dolphins
- Graphic [below] shows change in TTS as function of change in SPL (and SEL). For a sound (for this example, one that is on for 100 s), as increase from 170 to 195 dB in SPL, see a fairly dramatic shift for the same frequency.
    - Same pattern happens across frequencies that have been tested



- In a similar manner, duration of sound also affects magnitude of TTS that occurs
    - For sounds at constant sound pressure level, but different durations (and resulting different sound exposure levels), as duration increases, greater shifts occur. (graph also shows recovery of hearing sensitivity after cessation of the exposure)

- Take home is that, as in humans, we see the same patterns in marine mammals (to date) with regards to amplitude and duration of sound exposure
- Potential for TTS is also affected by frequency of the sound to which MM are exposed; similar to humans, but there are differences, at least as seen thus far in the limited species tested. Work shown again focuses on bottlenose dolphins (which have had a broader range of frequencies tested for the onset and growth of TTS than other MM to date)
  - Graphics shown- measure of TTS at different exposure frequencies (3 kHz, 5 kHz, up to 80 kHz for bottlenose dolphin). At different frequencies of exposure we do have different thresholds at which we start to see the occurrence of TTS.
    - See greatest onset and growth occur between 14, 20, and 28 kHz for the bottlenose dolphin.
    - What we don't see, necessarily, is the same pattern that we see in humans, where greatest TTS occurs at frequencies of best hearing. Bottlenose dolphins are most sensitive at 40-80kHz- onset of TTS not as dramatic at these frequencies as it is between 14 and 28 kHz. So there are some differences when we start to do cross-species comparison.
    - Species differences in susceptibility- one of the issues [we] face when thinking about potential impacts to animals in the environment. For humans there are thousands and thousands of data points that have been collected for a single species, but for marine mammals, there are only a few data points and lots of species.
  - These differences are starting to come out.
  - For two animals exposed to the same 4 kHz signal, the harbor porpoise, has a much lower threshold for the onset of TTS, than the harbour seal.
    - Similar comparisons to bottlenose dolphins
      - Harbor porpoise seems to be more susceptible to onset of TTS than other cetaceans.

        - Differences in species susceptibility have been used to estimate the types of sound exposure level MM need to receive for a TTS to occur.
            - Finneran and Jenkins 2012.
                - These thresholds that are presented are constantly in flux as we gather more info to calculate auditory weighted functions (weighted thresholds across different groups of animals- low frequency cetaceans, high frequency cetaceans, phocids, special considerations for harbour porpoise and beaked whales).
                - Reflect that within these species, they have differences in susceptibility for TTS by frequency. But for most species we do not have information, so we have to group them to how we best think they are related in their hearing

Cautions

- TTS data collected thus far shows a fair bit of individual variability
    - Graphic, two animals (top seals, lower belugas) exposed to same conditions, showed different magnitudes of TTS.
        - This condition is not unheard of- happens in humans as well. Difference is that with human, when we apply measures of TTS to the same set of standards for damage risk criteria, those assessments are based on thousands of measurements over decades, where with MM, its a few measurements made over the last two decades.
- All TTS is not the same. We are rapidly using evoked potential (electrophysiological) measures much more often than behavioural measures for some of these studies.
    - Behavioural measures are the gold standard. When we think of animals in the wild, it's the behavioural ability of the animal that is important, the behavioural threshold, that we look at for detection capability
    - Auditory evoked potential (AEP) measures measure activity of the brain. They often show that there is an effect to the nervous system that can be

recorded by looking at the physiology, but somehow the animals can compensate for this (i.e. behavioural threshold returns to normal).

        - Showed a recovery in hearing threshold following TTS, that behaviourally come back to normal, but through AEP methods, there was still an impact to the auditory system (although still don't quite understand exactly what that impact means at this time).
    - When talking TTS, it is important to know if it was AEP measurements or behavioural measurements of TTS

"Is TTS injury?" – impact of TTS work with laboratory animals

- Work by Kujawa and Liberman 2009- work with laboratory animals.
    - Animals with a TTS of 40 dB 24 hours after noise exposure ceased: over a period of time, these animals showed nerve degeneration, without hair cell loss, along the basilar membrane
        - Evidence of damage or injury to auditory apparatus not observed through traditional means of looking for it
    - Absence of hair cells occur weeks to months after pronounced TTS
- Could something like this happen with MM?
    - Work done with marine mammals usually doesn't produce a TTS of 40 dB 24 hours after exposure- this is a very robust TTS
    - In real world, would any MM receive an exposure that would cause such a shift to be around for such a period of time?

Conclusion

- Have questions, have made progress…
- TTS has become one of the foundations for assessing auditory impact. But we still have a lot of holes to fill in to better understand the potential for this physiological impact to occur in marine mammals.

Additional information on the DOSITS website:

Science of Sound > What sounds can animals hear?
http://www.dosits.org/science/soundmeasurement/soundsanimalshear/

Science of Sound > How is hearing measured?
(http://www.dosits.org/science/soundmeasurement/hearingmeasured/)

Science of Sound > Why do sounds have different properties?
(http://www.dosits.org/science/soundsinthesea/properties/)

Science of Sound > How do people and animals use sound in the sea?
(http://www.dosits.org/science/soundsinthesea/peopleanimalsuse/)

Science of Sound > Advanced Topics > What is intensity?
http://www.dosits.org/science/advancedtopics/whatsintensity/

Animals and Sound > How do marine mammals hear?
(http://www.dosits.org/animals/soundreception/mammalshear/)

Hearing in Land Mammals
(http://www.dosits.org/animals/soundreception/mammalshear/landmammals/)

Hearing in Pinnipeds, the Amphibious Ear
(http://www.dosits.org/animals/soundreception/mammalshear/hearinginpinnipeds/)

Hearing in Cetaceans and Sirenians, the Fully Aquatic Ear
(http://www.dosits.org/animals/soundreception/mammalshear/hearingincetaceans)

Animals and Sound > Potential Effects (Marine Mammals) > Hearing Loss
http://www.dosits.org/animals/effectsofsound/marinemammals/hearingloss/

Animals and Sound > Advanced Topics > Temporary Threshold Shift (TTS) Studies
http://www.dosits.org/animals/advancedtopics/temporarythresholdshift/

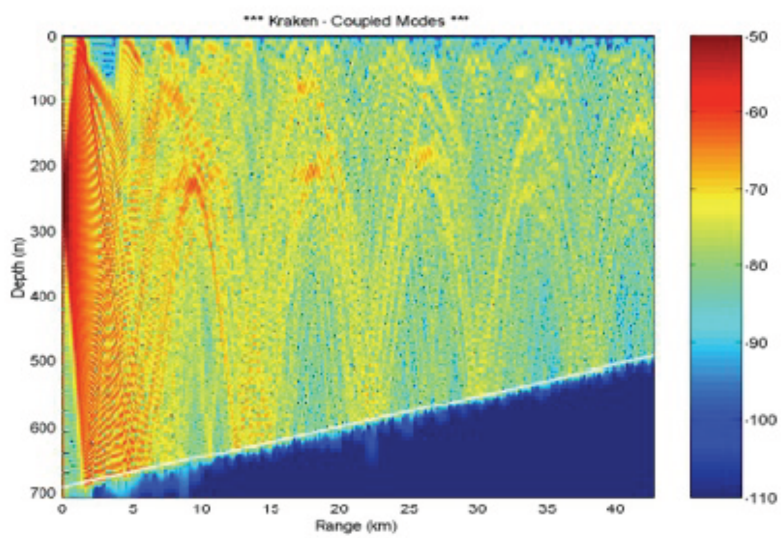
Animals and Sound > Advanced Topics > What components of sound are used for hearing?
http://www.dosits.org/animals/advancedtopics/componentsofsound/

The Golden Age of Marine Mammal Behavioral Response Studies: Recent Progress and Paradigm Shifts in Evaluation and Mitigation
Dr. Brandon Southall, Southall Environmental Associates, Inc.

In the last 10 years there has been a lot of work in this area in understand how animals respond behaviourally using various methods. There have been some paradigm shifts in how [researchers] think about these effects, as well as how regulators consider the increasing complexities surrounding these effects.

Conventionally, think of a single sound source (event)- a sound source is an activity that happened in isolation. Think of thresholds as 2-D sound "isopleths" or circles of sound levels in the ocean, with impacts based solely on exposure level "thresholds" (back then it was 160 dB and 180 dB that was used with behavioural contexts)

- In reality, there are multiple sounds sources (human, natural, biological activities). Animals are responding, then, to a complex acoustic environment.
- Sound propagation- in the below diagram, red represents loud sounds, blue represents quiet sounds. This shows the complicated pattern of sound propagation, and animals that may be closer to a source, may not be exposed to the highest level of sound, depending on where they are in the water column.



Measuring Marine Mammal Behavior

- Experimental Methods (what aspects of exposure, or different interactions of an exposure may be related to a response?)
    - Controlled Exposure Experiments (CEEs)- can be done in the field (most of what was covered in this presentation), also in the lab (not talked about here)

- Observational/Opportunistic Methods (watch an activity as it unfolds)
  - Monitoring behaviour using a variety of sensing methods during some activity that is uncontrolled
  - A lot of progress has been made on full-scale opportunistic efforts, but they are inherently limited in lacking an experimental design.
  - Observational studies are most effective and informative where specific hypotheses and observations are derived from experimental studies in the field or in the lab in order to test specific questions on broader scales with realistic acoustic events.

Historical Studies of Marine Mammal Behavioral Responses to Noise

- Richardson et al. (1991, 1995), work with bowhead whales in the Arctic. Put a speaker projecting the sounds recorded from a drilling rig, in a path in front of bowhead whales moving through ice (leads).
  - Dashed bars show controls where no sound presented.
  - Dotted lines show number of sighted animals when playback
    - See a shift where bowheads tended to be seen farther away from the playback speaker during the exposure sequences, than when there was a control
  - Took that distance, where greatest difference occurred, extrapolated that to be a received level, and from that concluded that 115 dB is where this avoidance response occurred.
    - What then typically would take place from that, take that received level, where get the received level from, and get it from an actual drill ship, and that is where you would get the actual response.
  - Early work was pioneering and laid the foundation for
    - That extrapolation from a simulation of something that was really small to something that is big and father away is something [researchers] have learned a lot about.
  - Other approaches (P. Tyack, work in CA, observing animals and tracks of animals relative to a sound source)
    - Migrating grey whales; dot in center is where put a speaker that projected a US version of LFA Sonar, couple hundred hertz to 500 hertz.
      - In control with no transmission (left), see straight tracks along coast; on right (exposure) see a hole open up in those tracks, around the speaker when it was active (animals go on one side or the other of the sound source).
    - Insight into some of the contextual issues- take that same sound source and move it just outside the path of where the animals are migrating, the effect essentially goes away. The animals are avoiding something in front of them that is active, but the same

received levels don't elicit the same avoidance response when it is *not* in the middle of the migratory path.

New Technologies - New Capabilities

Recent work involving experimental, high-resolution measurements has been enabled by some key technology innovations.

- One of the most important ones is **non-invasive, remote-deployed, archival tags** to obtain high-resolution, multivariate individual data
  - Depth (pressure sensors)
  - 3D movement (accelerometers, magnetometers)
  - Light (photo sensors)
  - High-sampling rate acoustics (up to 512 kHz; multiple hydrophones)
  - Lat/Long position
- Really given researchers the ability to ask fine, detailed questions about behavior and aspects of behavior under the sea surface that you can't see from initial measurements when looking at surface tracks of animals, etc.

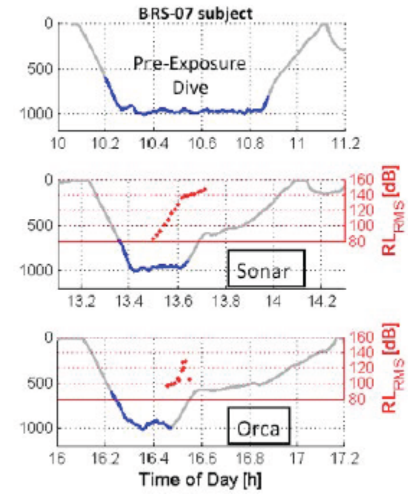
- These tools have been critical enablers of increasingly complex analyses and behavior, allowing scientists to ask really fine scale, detailed questions about things, such as changes in feeding patterns or individual calling behavior. It is understood that these are calling animals in an area, but being able to identify a vocalizing individual (with a tag on it) hasn't been able to be done till recently (with the incorporation of accelerometers into the tags). Allow scientists to address behavioral response, but to look at important things such as density estimates.

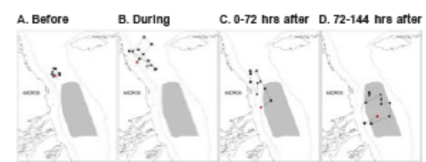
- One of the other interesting integrations of new technology is using active acoustics to measure the prey of feeding animals (Goldbogen et al, 2014; Friedlaender et al., 2016).
  - Show the track of an animal from a tag, and an image of output from a scientific fish finder, and the circles indicate the lunges of a feeding blue whale.
  - Integrate active acoustics in the tags, can look at the strategic kinematics of feeding behavior in these animals, but can use in behavioural response studies and has increased scientists abilities to describe the variability in behaviour and true aspect of response that may be due to sound, rather than changes in the environment (understand the prey context of sound response in feeding animals).

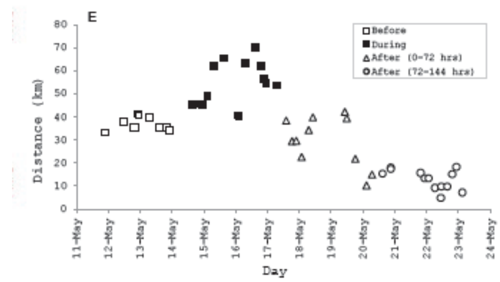
Recent Progress in Marine Mammal Behavioral Response Studies (high level findings from major projects happening around the world)

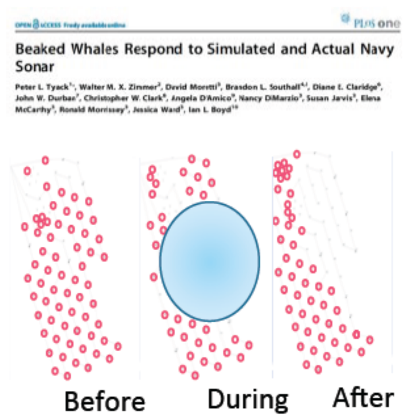
<u>2007-2008, Bahamas (AUTEC)</u>

- US Navy/NOAA coordinated BRS (behavioral response study; large international group) to obtain direct data on responses of cetaceans (including beaked whales) to the tactical mid-frequency sonar operational systems involved in previous stranding events
    - Satellite tags (longer duration) and acoustics tags (short term)
    - Panel on left, see dive for one animal pre-exposure, and then blue is when echolocating. During sonar exposure see different ascent pattern, echolocation stops. Subsequent dive with killer whale exposure, response more pronounced, also see movement of animal out of an area.
    - Middle panel, movement of a different animal with satellite tag. Gray hatch show sonar range. Animal off range before, then move further away during the operation, and then came back through the area. Similar avoidance over a broader scale with a longer time resolution.
    - Panel on right, show hydrophones on the range, circles indicate where animals (beaked whales) detected before and after.
    - Big picture- seeing movement and avoidance on 3 different time/space levels. Integration of these tell scientists animals stopped echolocating and moved away. Subsequent work has gotten into the dynamics of this, animals tend to return to the area, and the questions around what did this cost them (what were the feeding on before/after moved away, etc.)









2007-present, 3S Program (Norway)

- Dutch/Norwegian collaboration to measure responses to operational (European) Navy sonars
- Operational, mobile sources moving towards subject to increase dose. Have generated a number of results:
    - Taken the sensation level, how loud the sound seems to an animal, and generated some curves for the probability of response (with some variance in it)
    - Look at activity budgets- percent animals spend at surface, descending, feeding, drifting, silent active etc.
        - European LFAS exposure, more silence
        - Looking at changes in behavioral state (a lot of work has been done on this)

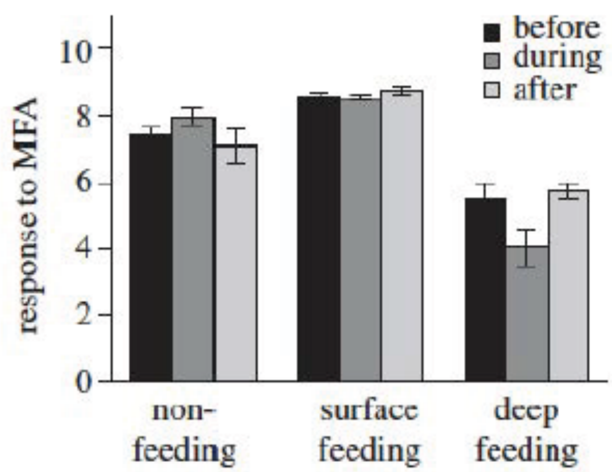
2010-present, BRAHHS Program (Australia)

- Australian (large scale) collaboration (supported by JIP and US Bureau of Energy Management) to measure potential behavioral responses and significance for migrating humpback whales to seismic airgun arrays.
- Strategically get high sample sizes (a lot of migrating animals come through the areas), careful controls, different exposure conditions (small airgun, ramp-up, full airgun array)
- Many papers starting to come out (Dunlop et al 2015, 2016)
- Single air gun studies, see changes in dive time and migration time in area (decreases in dive time and southbound migration during exposure)
    - Effect not correlated with source distance, RL, source direction, or exposure time
- One of the interesting things and are seeing some orientating responses to the source vessel itself; need to pay attention to effect of the experimental design itself
- Ramp up study findings (panel on right)- look at overall average of these values before and during exposure, really not seeing effect of a ramp-up procedure (described in 2015 paper).

2010-present, Southern California (SOCAL) (many references given: see www.socal-brs.org)

- > 175 tags deployed on 10 species (notably blue whales, beaked whales, and Risso's dolphins); > 80 CEEs using simulated and **actual Navy sonar** (in an experimental context- using some of the biggest systems used in previous strandings)
- Variables (beyond received level): behavorial state, prey distribution, **spatial orientation/movement**
- Responses: avoidance, changes in diving, feeding, social
- Certain species (beaked whales) appear particularly sensitive (e.g. beaked whales); other species are more tolerant but variable depending on exposure context

- Finding some clear differences based on the context of exposure
    - Blue whales (panel on left)- integrated metric of response- look at difference between non-feeding (no difference) surface feeding (no difference), and deep-feeding (big difference before, during, and after exposure)- animals that have overlapping sound exposure with regards to level
        - Probability of response depends on what the animals are doing at the time
        - Contextual aspects of exposure (e.g. behavioral state, prey distribution, relative proximity) can be as or more important than just the received level
        - May be a "duality in response". At relatively low received levels, have a context that is driving the probability or response that may depend on a bunch of things. As get close to animals, and higher received levels, there probably is a dose response. These may be overlapping, and may be different for different species.



New Paradigms - The Importance of Exposure Context in Response Probability

- Species differences in response probability exist, with some particularly sensitive species (e.g., beaked whales, harbour porpoise, melon-headed whales)
- Received level is an important aspect of the probability of response, but there are other contextual factors that are important (behavioral state, exposure level, animal proximity)
    - However, that doesn't mean you have to measure every possible contextual combination to understand broad patterns

- Quantitative exposure estimates can be improved using probabilistic movement models that incorporate broader aspects of exposure context, including behavioral states and physical range. While we are at the early stages of understanding some of these parameters, science in this field is moving rapidly and recent syntheses of needed research place understanding these parameters as high-priority needs.
- Ultimately the severity and consequences of response matter most, not just exposure or discrete response (PCOD)
    - Need to understand relationship between exposure and response, but the types of response, the extent to the way they persist, and extent affect things like feeding and reproduction are really important
        - Extending things from individual to population level scales
- Exposure ("take") estimates must be put into biologically meaningful, real-world context – risk assessment methods (that incorporate % of population and type of severity PCOD approaches point to)
- Exposure-response analyses in regulatory processes must incorporate new paradigms of response complexity and consequence; mitigation measures must remain simple
    - These were initially coupled (response equate mitigation); however the response is complex, and individuals need simple measures to implement/practice

Additional information on the DOSITS website:
Science of Sound > What sounds can animals hear?
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Science of Sound > What are common underwater sounds?
(http://www.dosits.org/science/soundsinthesea/commonsounds/)

Science of Sound > How do people and animals use sound in the sea?
(http://www.dosits.org/science/soundsinthesea/peopleanimalsuse/)

Animals and sound > Why is sound important to marine animals?
(http://www.dosits.org/animals/importanceofsound/whyissoundimportant/)

Animals and Sound > How do marine mammals hear?
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Hearing in Land Mammals
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Hearing in Pinnipeds, the Amphibious Ear
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Hearing in Cetaceans and Sirenians, the Fully Aquatic Ear
(http://www.dosits.org/animals/soundreception/mammalshear/hearingincetaceans)

Animals and Sound > How do marine animals use sound?
(http://www.dosits.org/animals/useofsound/animalsusesound/)

Animals and Sound > Marine Mammal Communication

Individual-specific vocalizations
(http://www.dosits.org/animals/useofsound/mammalscommunicate/individualspecific/)

Group-specific vocalizations
(http://www.dosits.org/animals/useofsound/mammalscommunicate/groupspecific/)

Vocalizations associated with reproduction
(http://www.dosits.org/animals/useofsound/mammalscommunicate/reproduction/)

Sounds associated with aggression
(http://www.dosits.org/animals/useofsound/mammalscommunicate/aggression/)

Animals and Sound > How do marine mammals use or make sound when feeding?
(http://www.dosits.org/animals/useofsound/howdomarineanimalsuseormakesoundwhenfeeding/)

Animals and Sound > How do marine mammals use sound to navigate?
(http://www.dosits.org/animals/useofsound/soundtonavigate/)

Animals and Sound > Potential Effects > Behavioral Changes
http://www.dosits.org/animals/effectsofsound/marinemammals/behavioralchanges/

Questions and Answers (asked during the webinar)- Transcript

2007 Exposure Criteria- is Brandon updating those exposure criteria?

As Dorian said, there has been a tremendous amount of work done in the last 2 decades. That [2007 criteria] was a good start. A lot has been done since then- improvements and advancements. Yes, they are working on updates to different parts of that [exposure criteria]. Much of the hearing work is benefiting from Jim Finneran's involvement and that group, and some of things that Dorian showed that they have been developing for the Navy criteria. There is a group that includes many of the same authors that are looking to update some of the weighting functions, TTS onset levels, and behavioral criteria. One of the key things they are looking at is incorporating difference aspects of sound propagation that take into account changes the environment imposes on things like impulsive sounds (that become non-impulsive). Probably 3 papers will come out as opposed to one big paper- published in 2017.

Does the different physiology of sound reception in mysticetes, odontocetes, and pinnipeds change the way they react to sound, or is it all species specific and not similar within groups?

There are differences in the anatomy that relate to sound reception. Even with binned groups such as cetaceans, there is debate… such as with the mysticetes, its really anatomical modelling, and looking at the anatomy of the animals, that scientists are deriving their expectations as to how the animals are receiving sounds. With the odontocetes there is a discussion about whether or not the lower frequency sounds get to the ear differently than high frequency sounds. Pinnipeds have amphibious nature- terrestrial ear adapted to underwater hearing. Trying to get at whether that particular pathway has an effect or not…it is difficult…especially since don't know much about mysticetes. There are animals that have similar pathways of hearing, such as some dolphins and porpoises, but have distinctly different responses, eg. bottlenose dolphins may be very robust, tolerant, acclimate to sound exposure, where the harbour porpoises do not. Wouldn't' jump to the conclusion that just because the auditory apparatus is different that it dictates a different responsiveness of the animal.

Social structure and relative risk of predation in things like harbour porpoise…small group size and exposure, may affect their probability of response. May not necessarily hear different than animals that live in large groups, but may have a different response to a threat and perceive a sound exposure as threatening; their response may be different based upon social structure and risk of predation.

What are the differences of positive pressures and negative pressures on marine mammals (do the affect animals differently)? Can a negative pressure cause TTS or PTS? If so, with impulsive sound, is there a reason to consider dB peak to peak vs dB 0 to peak, especially for mitigation purposes?

The ear should work as a rectifier for the wave coming in, so as far as hearing apparatus concerned, the negative vs positive shouldn't have an effect on potential for TTS.

In 2007 criteria, use peak value. There has been a lot of work supporting peak to peak. Short answer is do not really know. There hasn't been enough comparative TTS work to compare the differences between peak pressure and peak to peak pressure. What we have come to in the field, those doing the work, is that we should report both of them. Current criteria is usually peak, but both are relevant. Difference based on if using full scale source or something generated in laboratory. But do not have enough right now to say which is a better indicator of potential effects. People report both.

Do seismic survey noises, which have lower frequency, 100-200 Hz, affect smaller marine mammals as well?

A recent study by Jim Finneran's group looked at airgun exposure to bottlenose dolphins, which is the best evidence of hearing effects for small marine mammals. They found that for animals that don't hear very well at low frequencies, when exposed to sounds that have a lot of energy at low frequencies, the auditory effects relative to sounds at frequencies at which they hear much better, are predictably much lower. Frequency weighting functions - which address frequency-specific hearing sensitivity - gets into this aspect of exposure. Sensation level is also really important. Overall, how loud a sound is, which is based on what an animal can hear, is important from an auditory perspective. That doesn't mean that in the field, those sounds are not audible to animals…they have some energy at the higher frequencies that animals can detect. There have been some documented changes in behavior for some smaller cetaceans. But scientists feel that relative effect, both auditory and behavioral, are more likely, and masking (interference of sound with communication) will be greater for low frequency sounds on low frequency animals, like whales and fish, and some phocids that use low frequency sounds, as opposed to some of the other cetaceans. Yes, they can be affected, but the relative probability is less than for more animals that are tuned to low frequencies.

DO we have any reason to believe that any of the LFSA sounds the US uses will lead to permanent hearing loss?

The probability of that is really quite low, determined from what they know about that kind of exposure levels and those sources, and work that has been done to look at low frequency hearing. There are some uncertainties…understanding of hearing in baleen whales is limited to auditory anatomy and modelling. The exposure levels needed to induce things like TTS and PTS are so high, that animals would probably need to be very close to the sound sources for an extended period of time for those kinds of effects to occur. This doesn't' mean there aren't the effects of masking and/or behavioral disturbance. One caveat, in baleen whales there are no direct measurements of TTS and we do not know what the probability of permanent threshold shift from LFAS, although it would probably be extremely low.

Even though a sound source is on for a long period of time, the profile of sound in the ocean is quite variable. It is unlikely any animals are exposed for any length of time in the same spot- they are continuously diving, exploiting the surface. The duration and amplitude of the exposure won't be constant for a diving marine mammal. That adds to the potential being relatively low.

Any studies or references on behavioral response to ship noise?

Most of the experimental work has focused on industrial sounds, seismic surveys, and sonars. A group in Australia just published a paper on the effects of ship noise on humpback whales. Some studies exist using modelling of sound fields to look at the potential for masking. There has been a lot of work on the effect of boat traffic on behaviour, e.g. whale watching and other contexts (Randy Wells' group). It is an important issue. Most of the concern relative to ship noise has to do with masking. Has been a few recent studies.

Also, there is a need to consider recreational boats…often associated with boats being in close proximity to the animals. It is not just the sound from the boats that is important, but also the presence of the boats in the area that contribute to the responses.