Orca hearing weighted decibels:

Underwater sound measurement appropriate to studies of Orcinus (killer whales)

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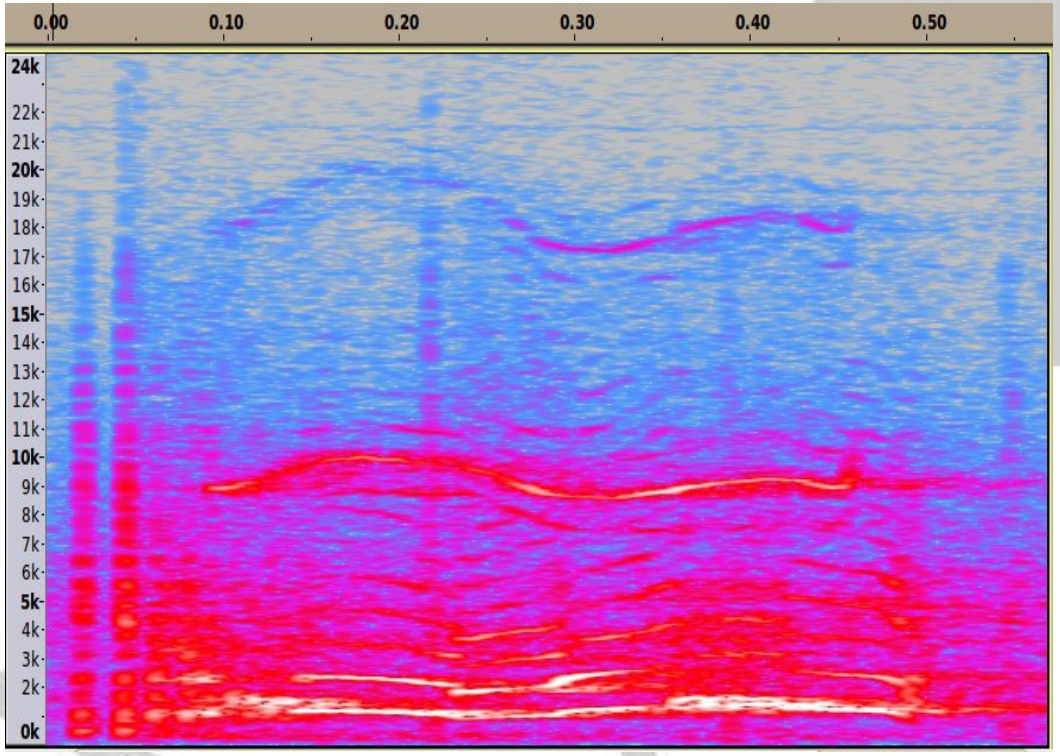
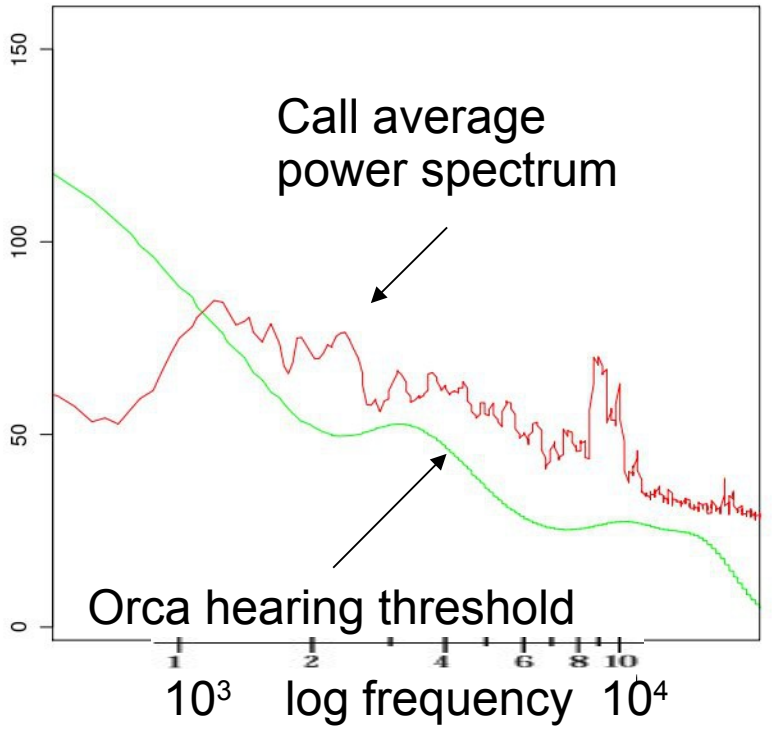
Orcas use sound for social communication

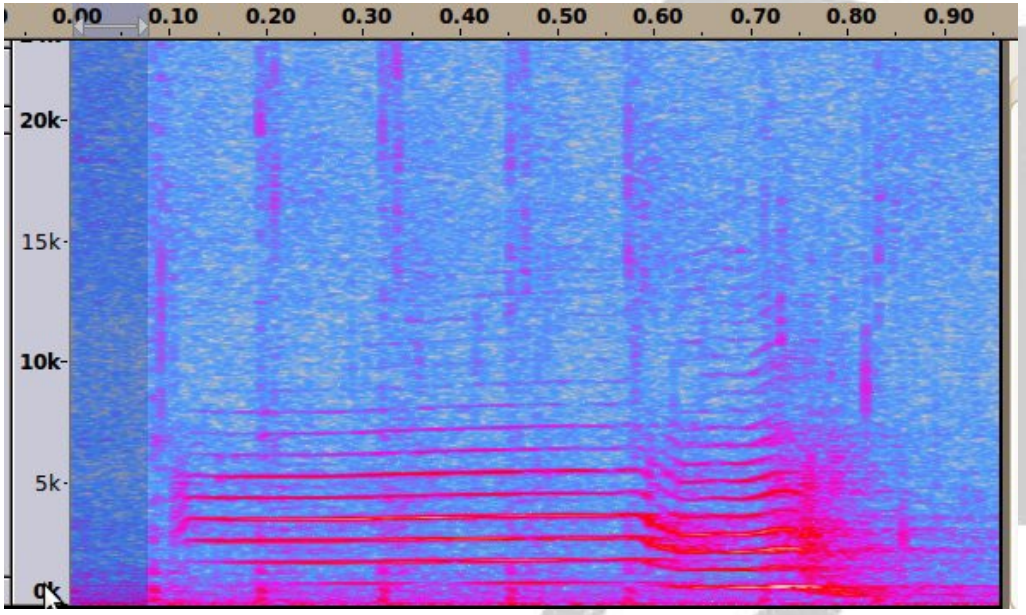


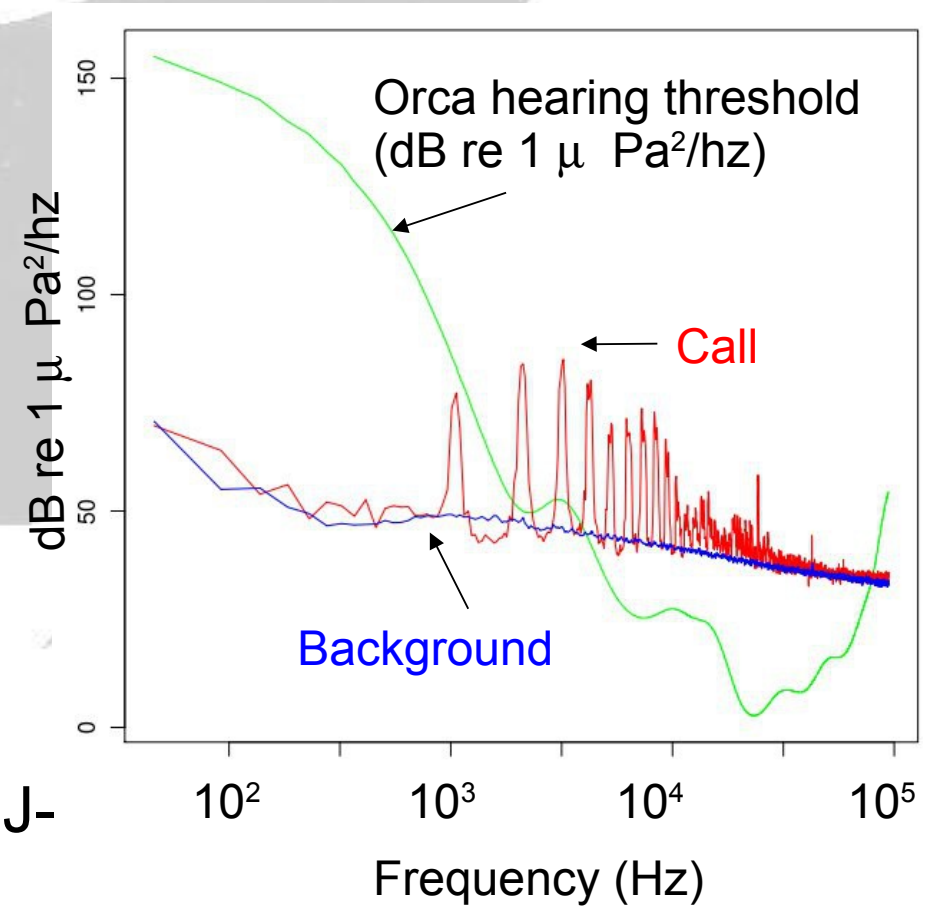


Social call power spectrum mapped on the orca hearing threshold

The power spectrum of the call has the same slope as that of the orca hearing sensitivity curve (1 kHz – 10 kHz).

The most common Southern Resident orca call



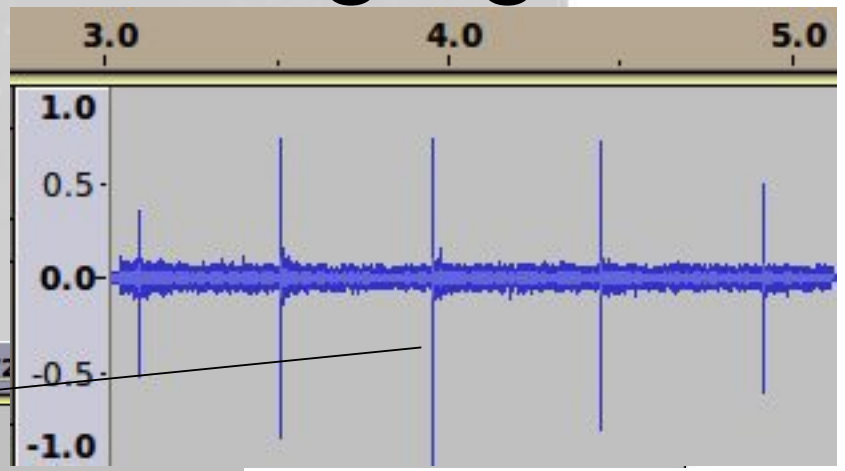


This signature call is thought to be J-pod's contact call. Note that the fundamental falls below the orca hearing threshold but many high frequency peaks are very audible to the orca.

The received level of this call is 110 dB re 1 μ Pa across the 10Hz – 100 kHz bandwidth of our detector.

Orcas use echolocation clicks for navigation and foraging

Studies (Au et. al. 2003) have shown that orcas can likely detect echos from their principal prey, chinook salmon, at distances up to 100 m or more.



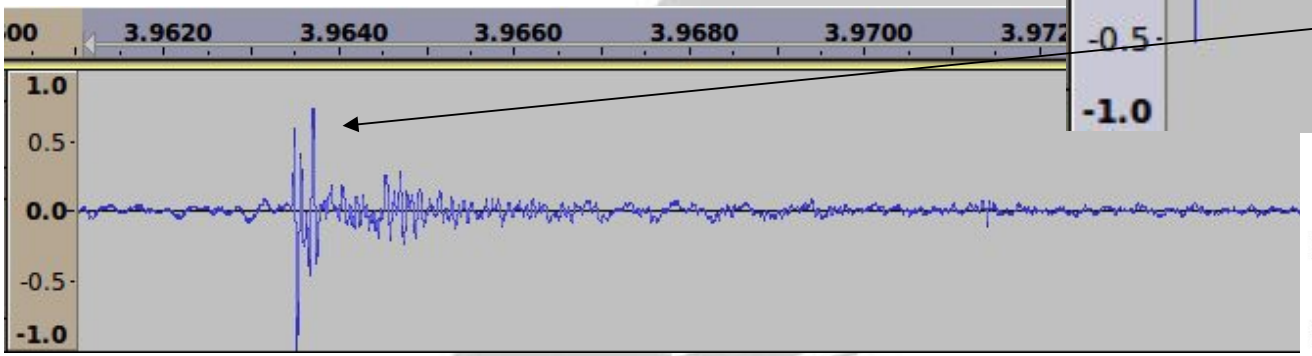
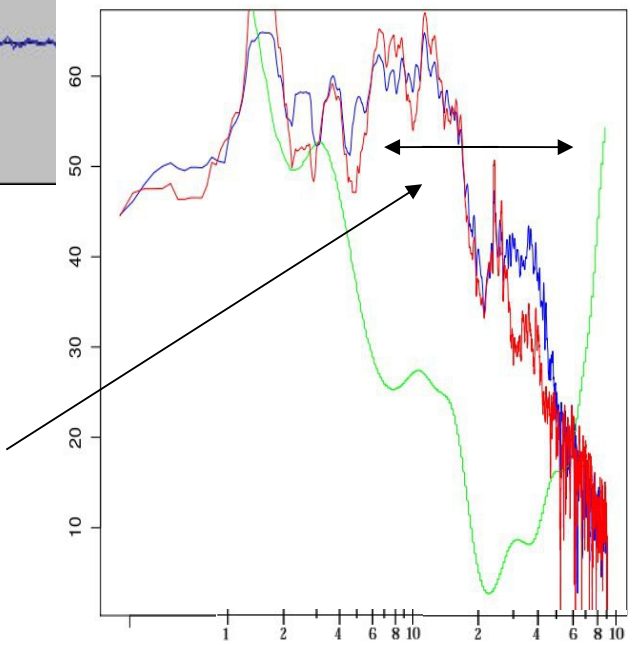


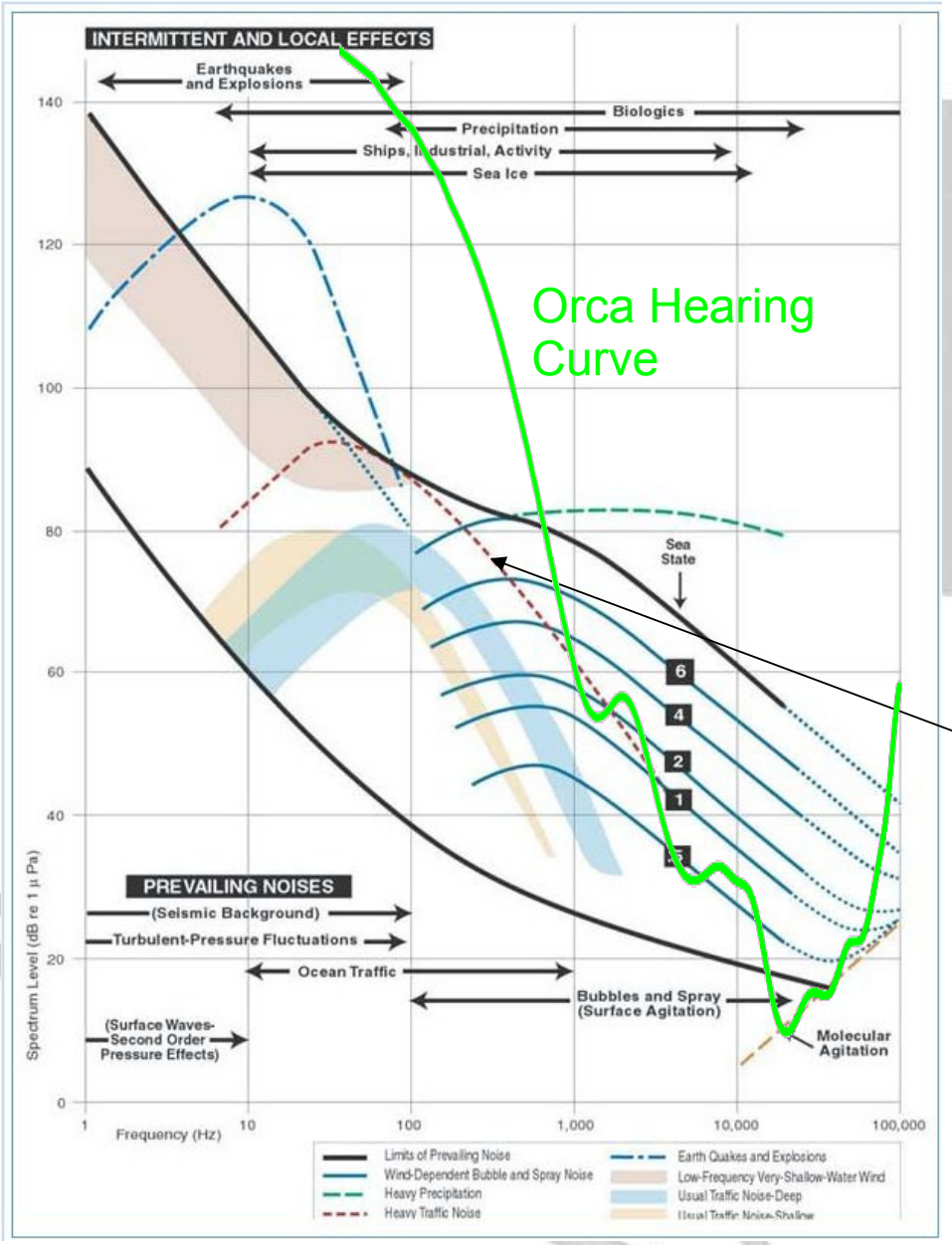
Photo: Beam Reach - 2011

These clicks have significant power in the 5 – 50 kHz band where orca hearing is best.



10^3 frequency 10^4 hz 10^5

Ocean Noise and Orca Hearing

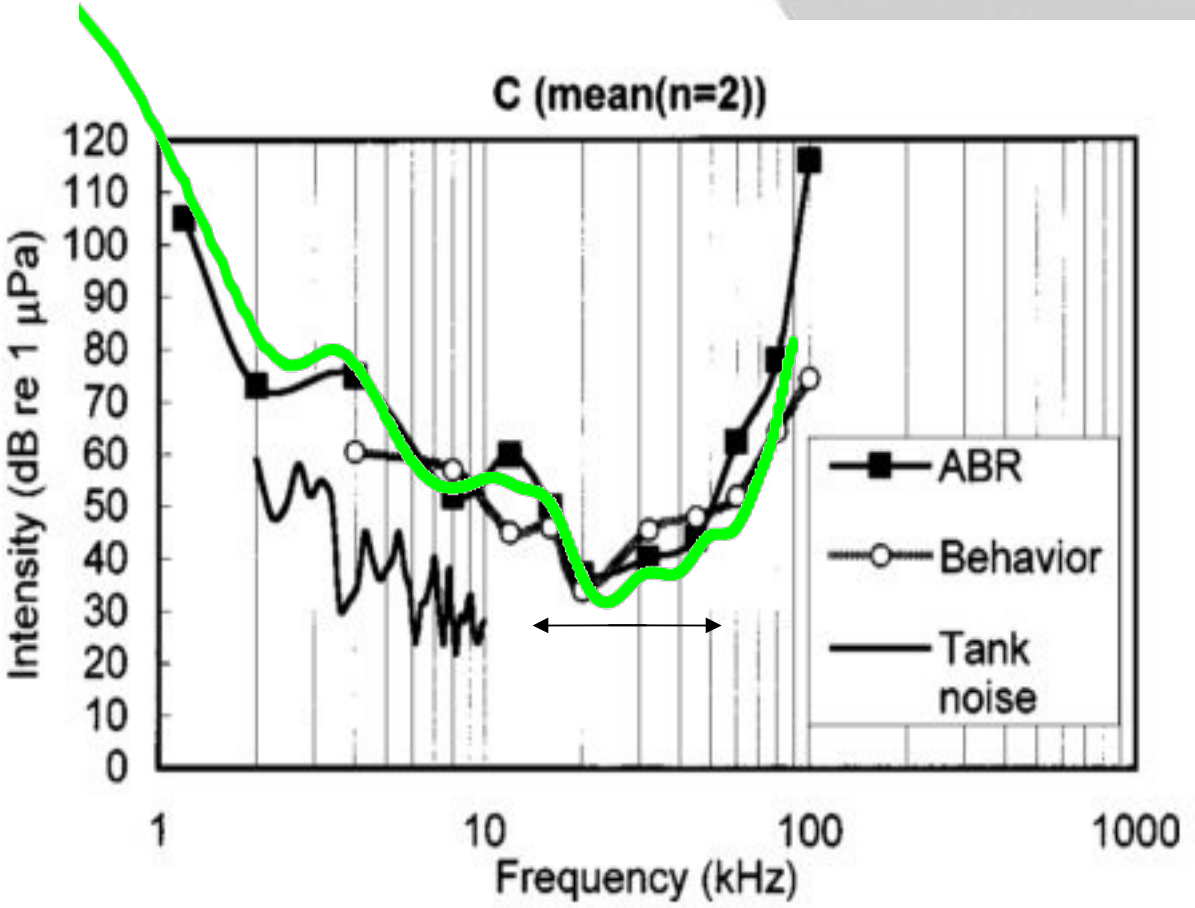


http://www.dosits.org/science/soundsinthesea/commonsounds/

- The purpose of this talk is to propose ways to evaluate underwater sounds, such as these on the famous Wenz curve, in terms of the hearing sensitivity of orca whales.

- For example, we are interested in the overlap between the hearing curve and the tail of the heavy traffic noise in the critical habitat of the Southern Resident orcas.

Orca hearing threshold



Audiograms of two orca determined by auditory brainstem response (ABR) and by behavioral experiment

Szmanski, Bain et. al.
J. Acoust. Soc. Am., Vol. 106, No. 2, August 1999

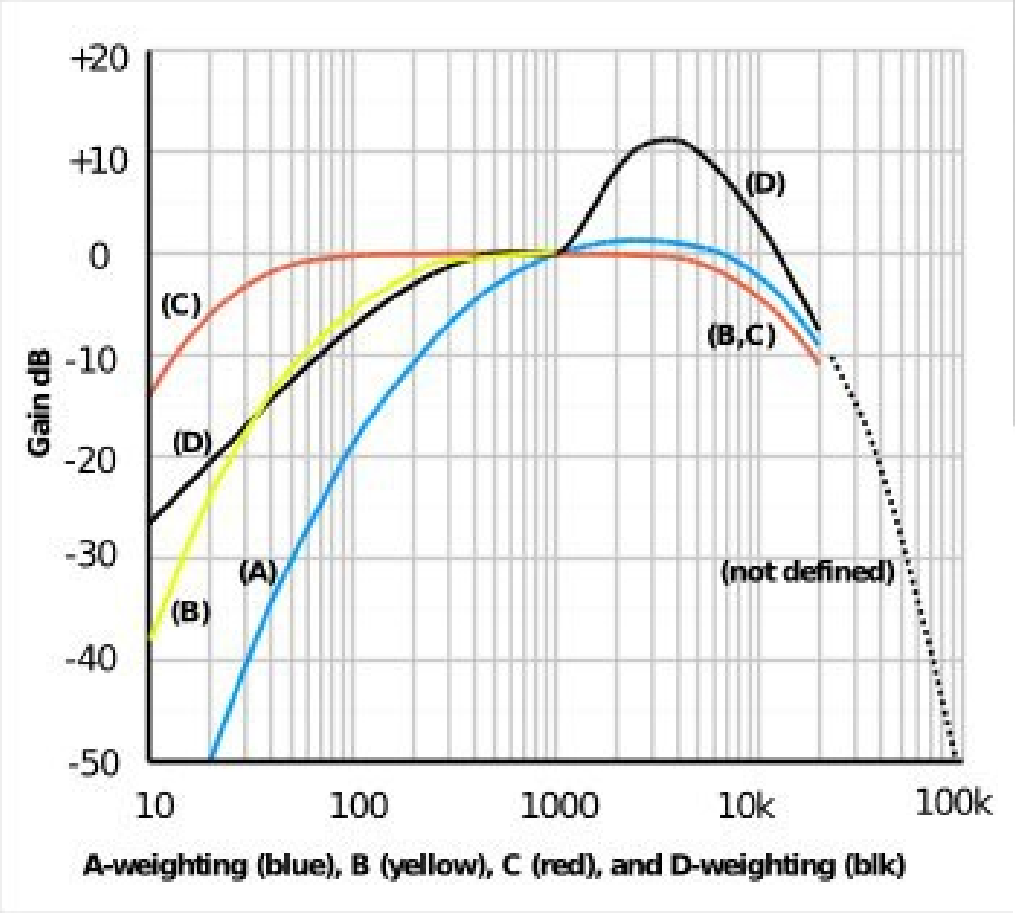
Szmanski, Bain et. al. played pure tones to two separate captive orca and used an up/down stair-step procedure to determine these average hearing curves.

Peak hearing sensitivity is in the 5-50 kHz range with highest sensitivity at 20 kHz.

The GREEN curve is the result of interpolating a cubic spline fit to these threshold hearing curves.

Equal Loudness Contours

Inverting the audio-gram! How peculiar.



http://www.lindos.co.uk

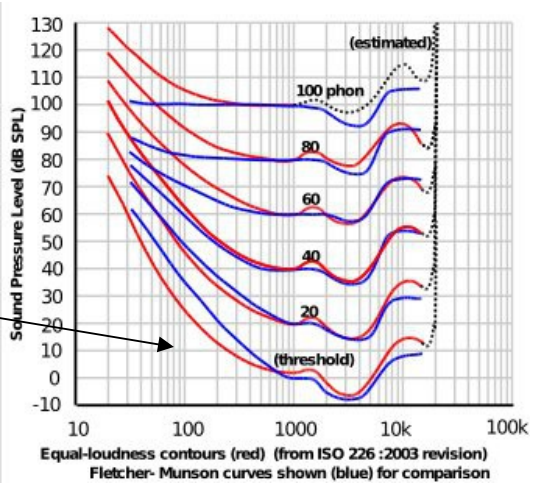
Weighting curves for human hearing:

A – auditory threshold equal loudness vs. frequency curve

B and C – for medium and loud sounds

D – equal loudness for airplane sounds

The A-weighting scheme was accomplished by inverting measured human equal loudness contours:



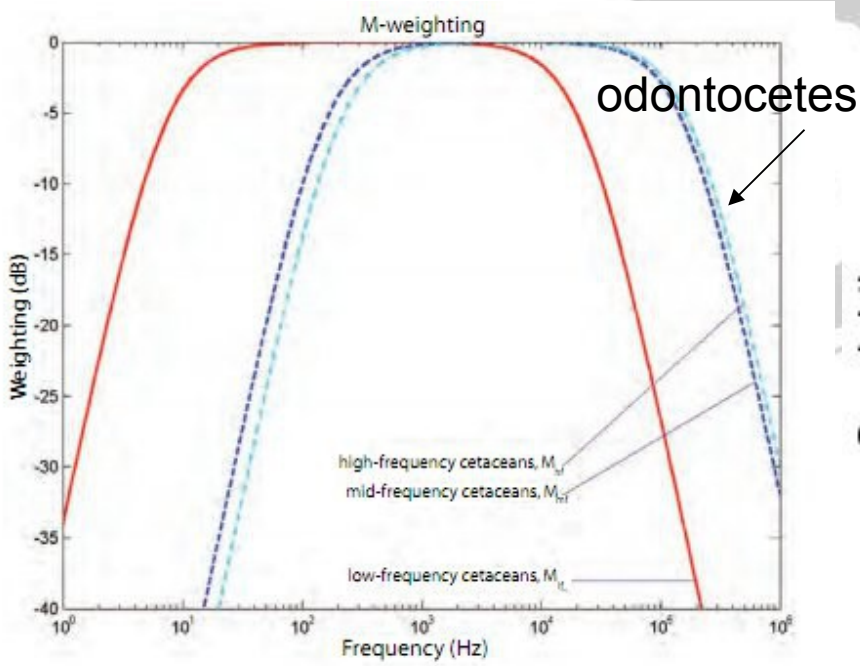
Marine mammal --

M-Weightings –

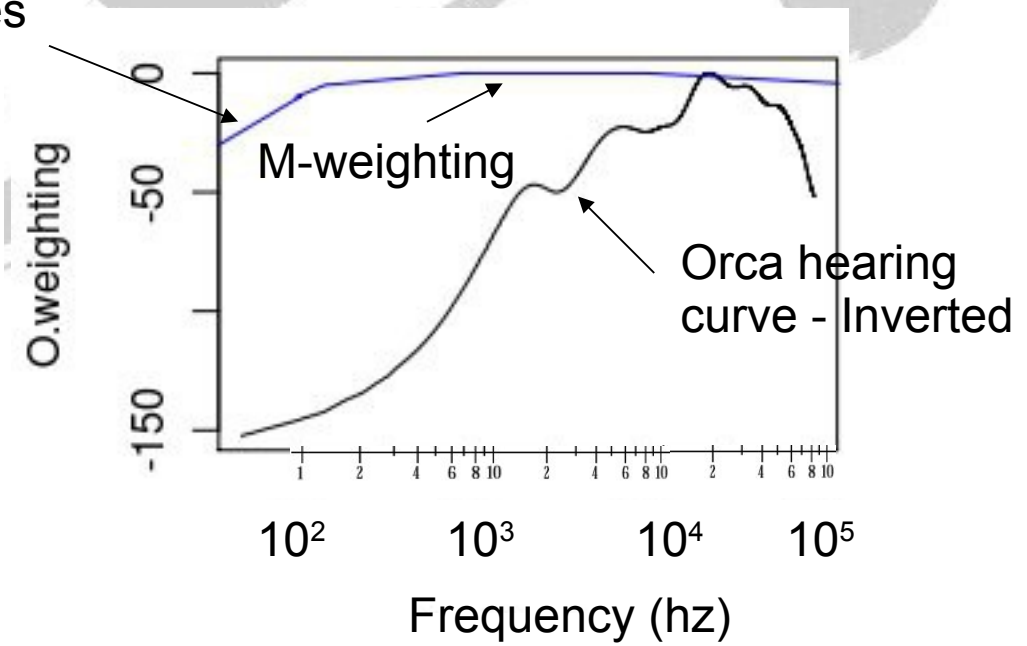
- a step in the right direction
- a solution to a different problem

M-weighting was introduced in 2007 as a generalized frequency weighting scheme and was applied to 5 groups of cetaceans.

"Their primary application is in predicting auditory damage rather than levels of detection or behavioral response."

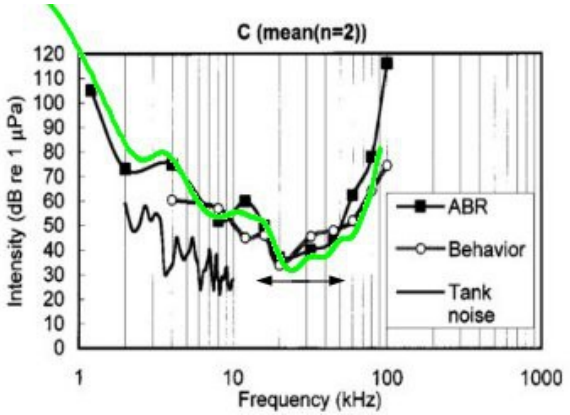


odontocetes



Ref: "Marine Mammal Noise Exposure Criteria", Southall et. al., Aquatic Mammals, 2007

Applying the dB-O weighting: I



The orca hearing threshold measurements were made by exposing trained orca to pure tones.

These pure tones are perceived through an auditory filter which has a bandwidth that Fletcher (1940) termed the critical band.

We follow Erbe (Marine Mammal Science, 2002) and take the critical band width to be 1/12 of an octave across the frequency spectrum.

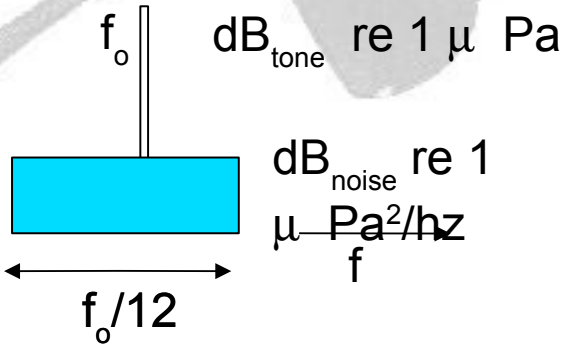
Orca noise hearing threshold in 1/12 octave bands = the values on the Szmanski curve above.

Orca noise hearing threshold in per hertz units:

$$db_{\substack{noise \\ threshold}} = dB_{tone} - \log10(f_o/12)$$

re 1 µ Pa^2/hz

re1 µ Pa



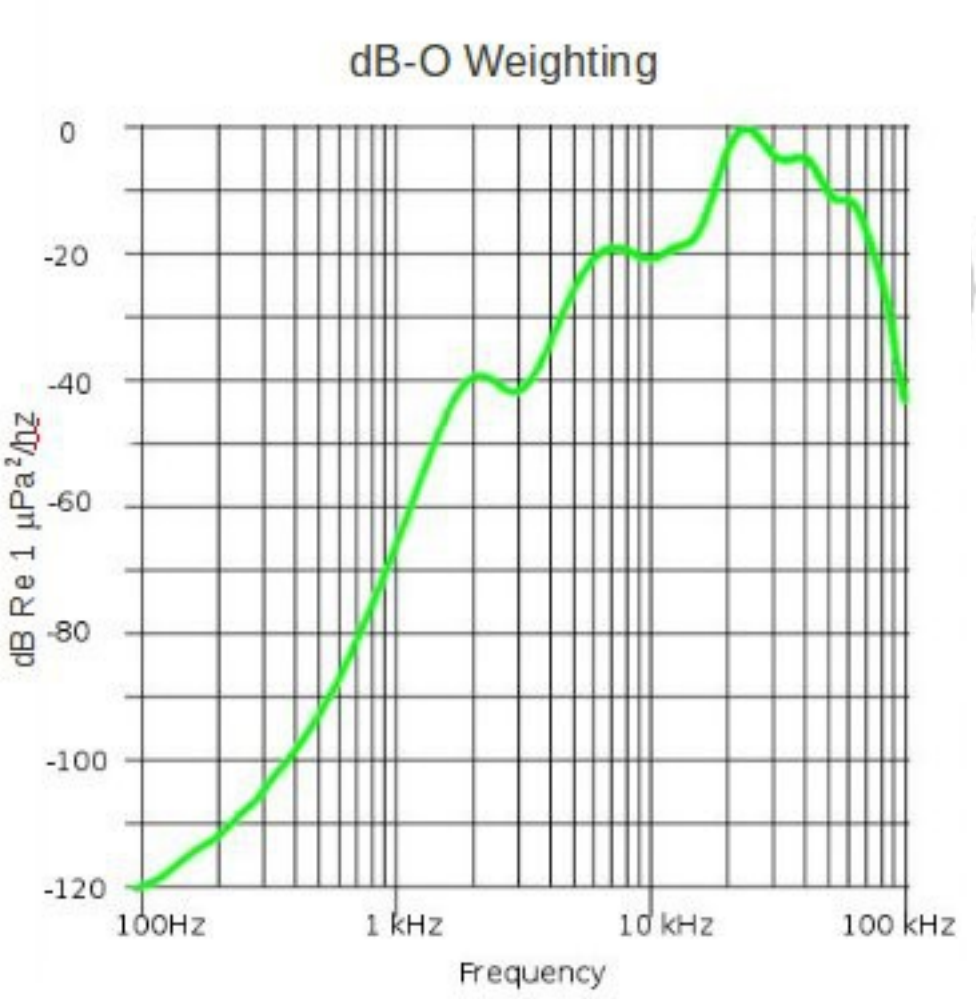
Equal intensity assumption:

Assume: The tone is just masked by the broadband noise when the spectral noise intensity summed over the critical band around the tone's frequency is equal to the intensity of the tone.

Applying the dB-O weighting: II

In the style of the A-weighting in atmospheric acoustics, the audiogram is now inverted and referenced to 0 dB at the frequency where the orca hearing is most sensitive (~20 kHz)

This O-weighting may now be applied to any observed spectrum level observations by weighting the spectrum level of a sound with this function.



Broadband db vs db-O (received levels)

Here are more than 9000 ship transits past Lime Kiln Lighthouse!

Conclusions

- Ships create noise well within the hearing range of the endangered Southern Resident orcas.
- These broadband noises persist for ½ to 2 hour periods as vessels pass while orcas are foraging and socializing in their critical habitat.
- The db-O defined here can identify ships with larger and smaller potential masking effects.
- db-O assessments coupled with behavioral observations of Southern Resident orca may open researchers to new insights on orca whales use of acoustics
- Ships with particularly high db-O factors should be modified either in their operations or drivetrain.

We express our thanks to The Whale Museum and Lime Kiln State Park for providing access to the wonderful underwater sounds at Lime Kiln.