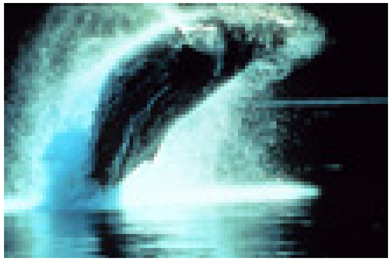
Anthropogenic Noise and Marine Mammals

Blue Whale

Fin Whale

Gray Whale



Humpback Whale

John K. Horne

Relevant Web Sites/Reports

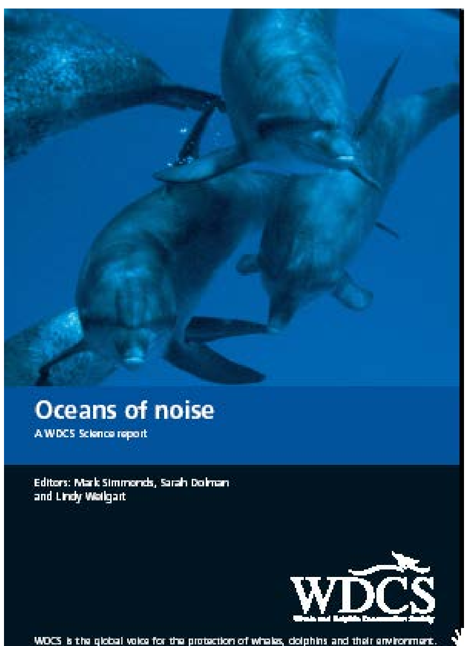
Oceans of Noise: www.wdcs.org.au

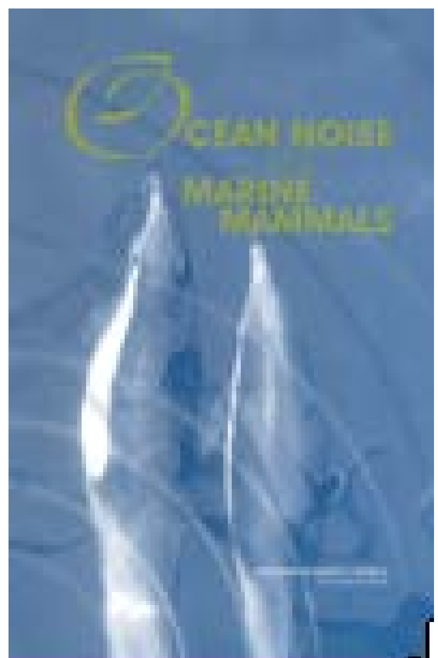
Ocean noise and Marine mammals: www.nap.edu

Southall *et al*. 2007. Marine mammal noise exposure criteria: Initial scientific recommendations. Aquatic Mammals 33(4).

Southall et al. 2009. Addressing the Effects of Human-Generated Sound on Marine Life

NMFS 2018. Revisions to: Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing (Version 2.0): Underwater Thresholds for Onset of Permanent and Temporary Threshold Shifts.





2018 Revision to:

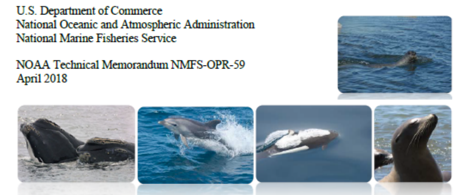
Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing (Version 2.0)

Underwater Thresholds for Onset of Permanent and Temporary Threshold Shifts

Office of Protected Resources
National Marine Fisheries Service
Silver Spring, MD 20910

U.S. Department of Commerce
National Oceanic and Atmospheric Administration
National Marine Fisheries Service

NOAA Technical Memorandum NMFS-OPR-59
April 2018



Sources of Noise

Natural

1. Geophysical sources: wind-generated waves, earthquakes, precipitation, ice

2. Biological sources: marine mammal vocalizations, fish & invertebrate sounds

Anthropogenic

Intentional: high intensity,acute; Unintentional: lower level,chronic

1. Ships: propeller, propulsion machinery, hydraulic flow over hull

2. Airguns & seismic exploration

3. Sonars: military, civilian, research

4. Offshore drilling, pile driving

Ocean ‘Background’ Noise

- 50 dB re 1 $\mu Pa^2/Hz$ (no vessels), 80 to 90 dB (vessels)
- 1950 to 1975 sound levels increased by ≥10 dB (vessel traffic)
- doubling # of ships +3 to +5 dB, increased vessel speed +6 dB
- vessel increase (1972 to 1999): 57,000 to 87,000

Overall 16 dB from 1950 to 2000 (Mazzuca 2001)

i.e. doubling every 5 decades, 7% annual increase

Marine Mammal Hearing

Odontocetes:

- 200 Hz to 100 kHz, some to 200 kHz
- peak sensitivity 20 kHz to 80 kHz
- moderate sensitivity 1 kHz to 20 kHz

Mysticetes:

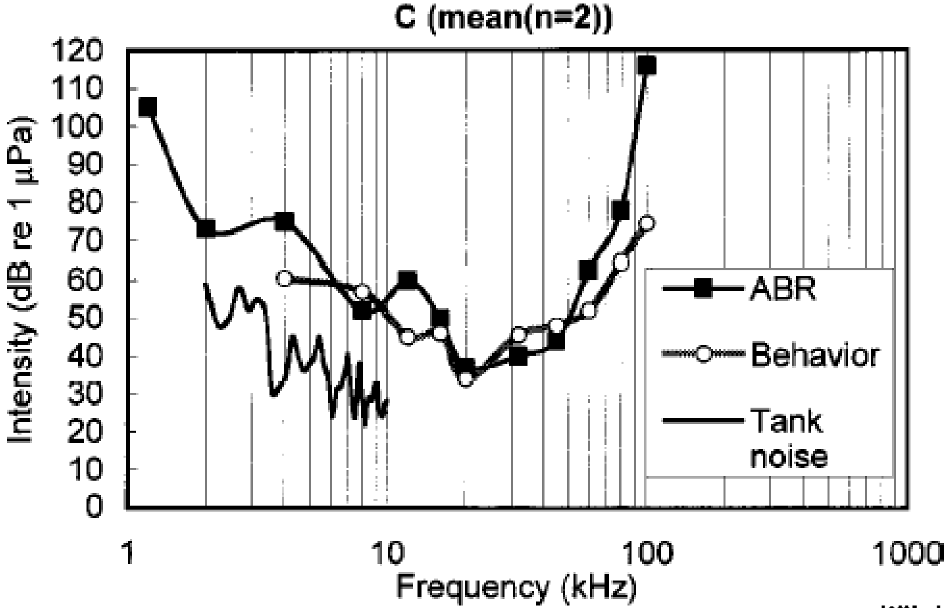
- 20 Hz to 20-30 kHz
- larger species (blue, fin) 10 Hz (?)

Pinnipeds

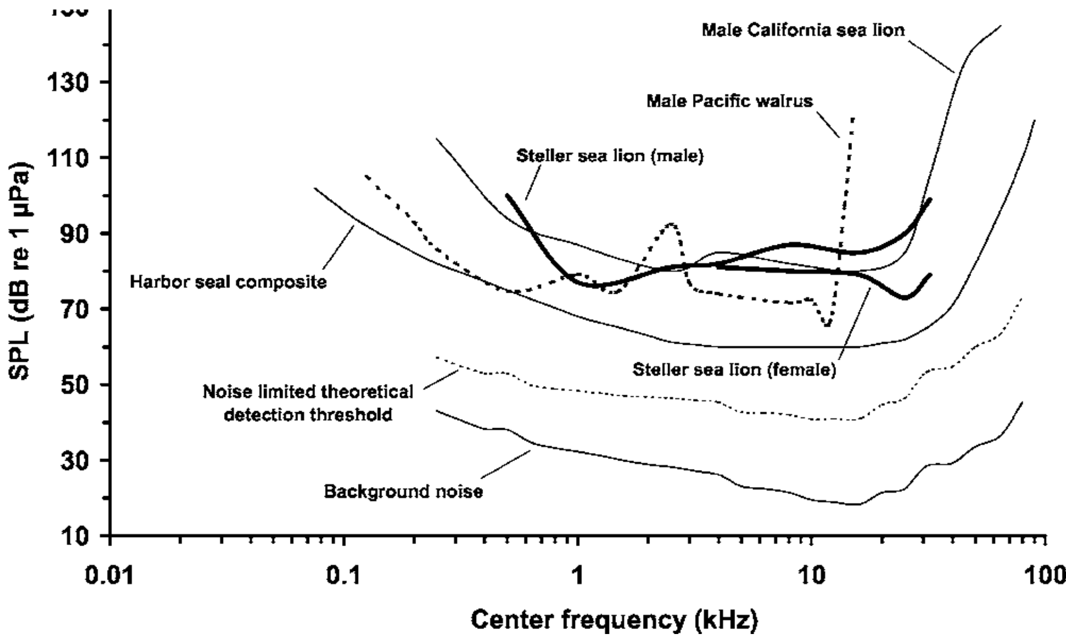
- 1 kHz to 20 kHz
- northern elepahant seal < 1 kHz

Marine Mammal Hearing

Killer Whale

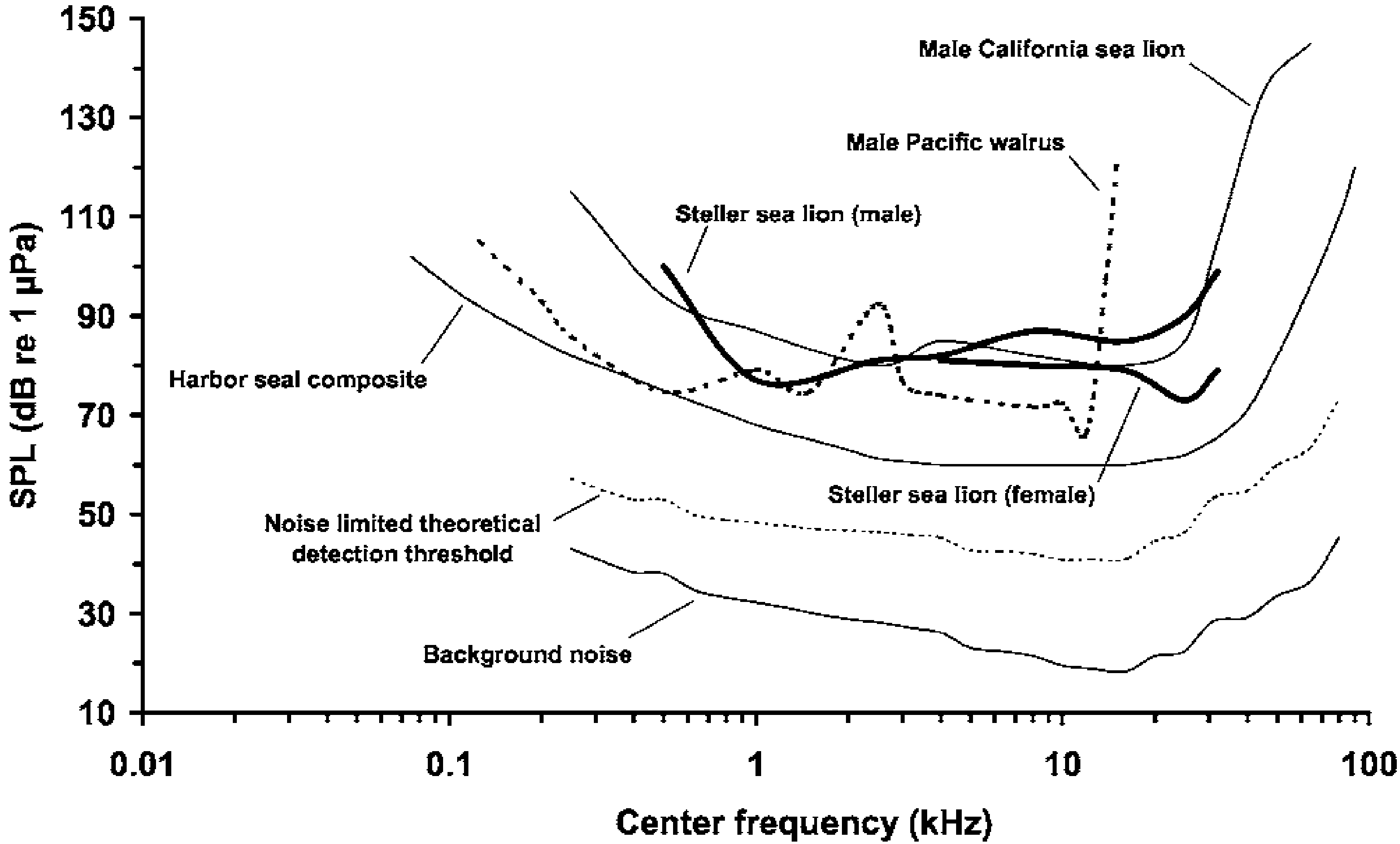


Pinnipeds



Kastelein et al. 2005

Pinniped Hearing



Kastelein et al. 2005

Mammal Hearing Groups

Hearing Group	Generalized Hearing Range*
Low-frequency (LF) cetaceans (baleen whales)	7 Hz to 35 kHz
Mid-frequency (MF) cetaceans (dolphins, toothed whales, beaked whales, bottlenose whales)	150 Hz to 160 kHz
High-frequency (HF) cetaceans (true porpoises, *Kogia*, river dolphins, cephalorhynchid, *Lagenorhynchus cruciger* & *L. australis*)	275 Hz to 160 kHz
Phocid pinnipeds (PW) (underwater) (true seals)	50 Hz to 86 kHz
Otariid pinnipeds (OW) (underwater) (sea lions and fur seals)	60 Hz to 39 kHz

* Represents the generalized hearing range for the entire group as a composite (i.e., all species within the group), where individual species' hearing ranges are typically not as broad. Generalized hearing range chosen based on ~65 dB threshold from normalized composite audiogram, with the exception for lower limits for LF cetaceans (Southall et al. 2007) and PW pinniped (approximation).

Hearing Group	*a*	*b*	f_1 (kHz)	f_2 (kHz)	*C* (dB)	*K* (dB)
Low-frequency (LF) cetaceans	1.0	2	0.2	19	0.13	179
Mid-frequency (MF) cetaceans	1.6	2	8.8	110	1.20	177
High-frequency (HF) cetaceans	1.8	2	12	140	1.36	152
Phocid pinnipeds (PW) (underwater)	1.0	2	1.9	30	0.75	180
Otariid pinnipeds (OW) (underwater)	2.0	2	0.94	25	0.64	198

$$W_{aud}(f) = C + 10\log_{10}\left\{\frac{(f/f_1)^{2a}}{[1+(f/f_1)^2]^a[1+(f/f_2)^2]^b}\right\} \text{ dB}$$

$$E_{aud}(f) = K - 10\log_{10}\left\{\frac{(f/f_1)^{2a}}{\left[1+(f/f_1)^2\right]^a\left[1+(f/f_2)^2\right]^b}\right\} \text{ dB}$$

* Equations associated with Technical Guidance's auditory weighting ($W_{aud}(f)$) and exposure functions ($E_{aud}(f)$):

Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing (Version 2.0)

Relative Anthropogenic Sources

TABLE 3. Comparison of anthropogenic underwater sound sources ordered by their potential for marine mammal high-intensity sound exposure.

Sound Source	SPL dBre 1μPa @1m	Ping Energy (dB re $1\mu Pa^2 * s$)	Ping Duration	Duty Cycle (%)	Peak Frequency (Hz)	Band Width (Hz)	Direct-ionality
Underwater Nuclear Device (30 kilo-ton)	328	?	1000 s	Inter-mittant	Low	Broad	Omni
Ship Shock Trial (10,000 lb TNT)	299	?	100 s	Inter-mittent	Low	Broad	Omni
Military Sonar (SURTASS/LFA)	235	243	6 – 100 s	10	250	30	Horizontal
Airgun Array 2000 psi and 8000 in^3	256	241	30 ms	0.3	50	150	Vertical
Military Sonar (53C)	235	232	0.5 – 2 s	6	2,600-3,300	Narrow	Horizontal
Super Tanker 270 m long	198		CW	100	23	5-100	Omni
Research Sonar (ATOC Source)	195		20 minutes	8	75	37.5	Omni
Acoustic Harrassment Device	185	185	0.5 - 2 s	50	10,000	600	Omni
Multibeam (Echosounder Hull-mounted)	235	218	20 ms	0.4	12,000	Narrow	Vertical
Research Sonar (RAFOS float)	195		120 s	small	250	100	Omni
Fishing Vessel 12 m long (7 knots)	150		CW	100	300	250-1000	Omni
Acoustic Deterrent Device (AquaMark300)	132	127	300 ms	8	10,000	2000	Omni

Affect of Noise on Marine Mammals

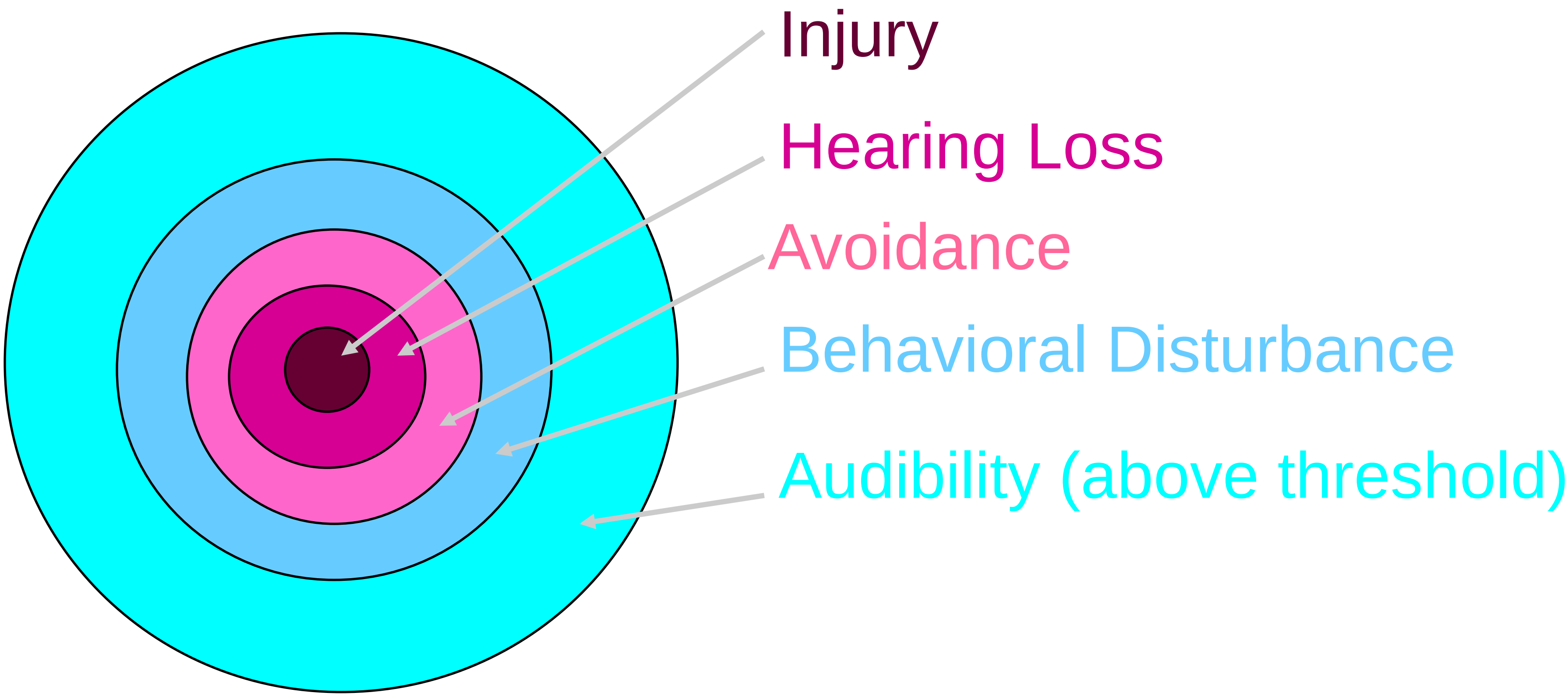
Factors:

1. Acoustic properties: sound pressure level
2. Animal behavior
3. Ambient acoustic features of environment

Richardson et al. 1995

Annoyance factors: loudness by frequency, fluctuation

Zones of Noise Influence & Responses



Adapted from Richardson & Malme 1995

Hearing Loss

- shift to higher threshold caused by exposure to high-intensity sound
- may be temporary (TTS) or permanent (PTS)
- extent of loss dependent on sound power spectrum, hearing sensitivity, duration of exposure

Examples:

bottlenose dolphin: temporary loss at 193 to 196 dB re 1 μPa at 20 kHz for 1 second tone

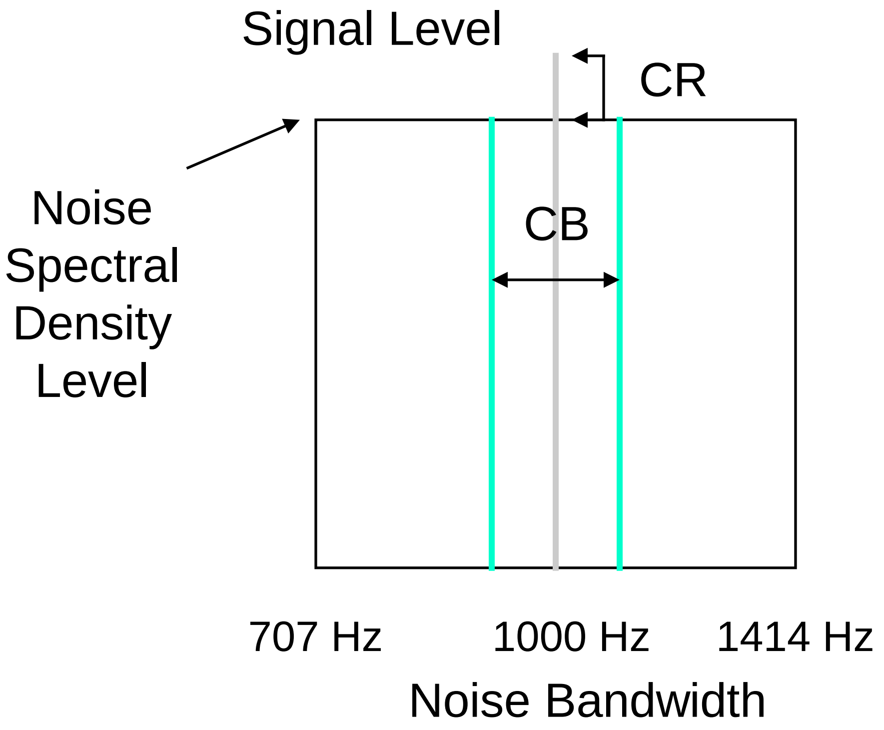
beluga whale: temporary loss at 217 dB re 1 μPa

Why is Hearing Loss Important?

- poor communication, reduced echolocation and foraging
- behavior modifications: migration, mating, stranding, vulnerability to predators

Noise Masking

- occurs when a frequency critical band (CB) occurs around a desired signal
- amount a pure tone must exceed noise spectral level to be heard is the critical ratio (CR)



Potential Result: signal may not be heard due to noise

SONAR and Mammal Strandings

- Canary Islands (2002) military exercise
- 4 hours later, 14 beaked whales stranded near site
- gas bubbles present in blood vessels and gas-filled cavities
- liver, kidney, fatty tissue

Cause (?):

- rapid ascent (decompression)
- sound pressure on gas nuclei

See Nature 425: 549-575, 2003

Mass Strandings

- only odontocetes are known to mass strand
- most involve Cuvier’s beaked whales (*Ziphius cavirostris*)
- 3 to 10 multi-animal strandings per decade (1960 to 2000)
- correlated with use of high-intensity sonar: first tested 1957, deployed 1960’s
- 11 of 32 documented strandings of beaked whales coincided with concurrent naval activities
- mid-frequency sound (1-6 kHz) implicated in strandings

Acoustic Thermometry of Ocean Climate (ATOC)

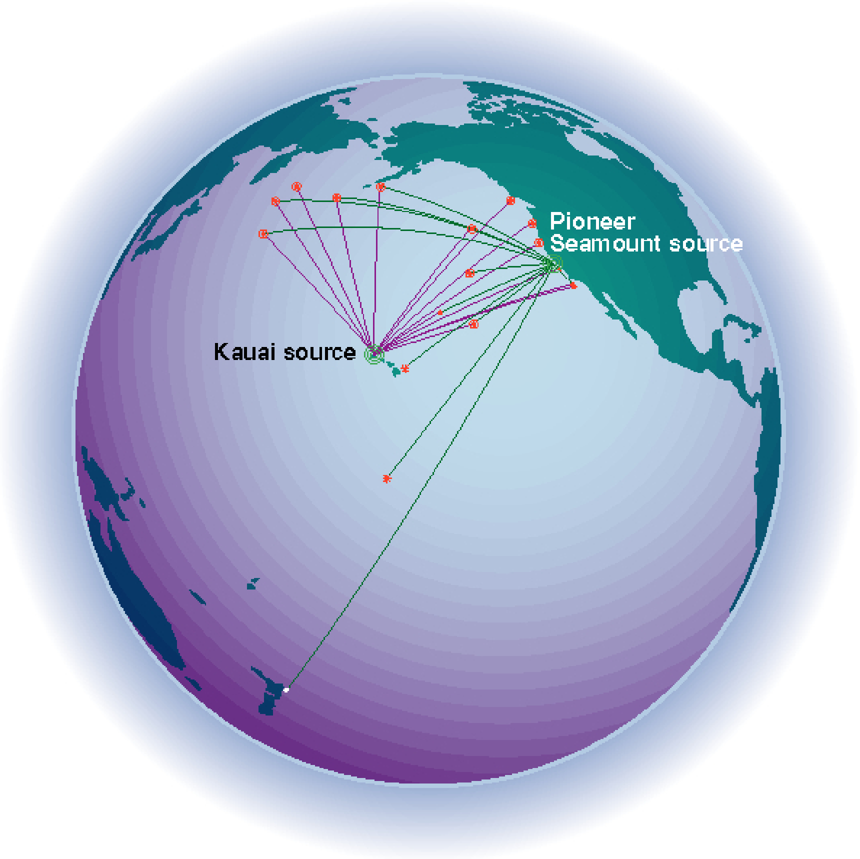
aka North Pacific Acoustic Laboratory

Source Level: 195 dB re 1μPa @1m

Signal: centered at 75 Hz with 37.5 Hz bandwidth

Duty Cycle: 5 min. ramp up, 20 minute duration, 4 hour interval

- goal to monitor average ocean temperature over long time to see if ocean warming



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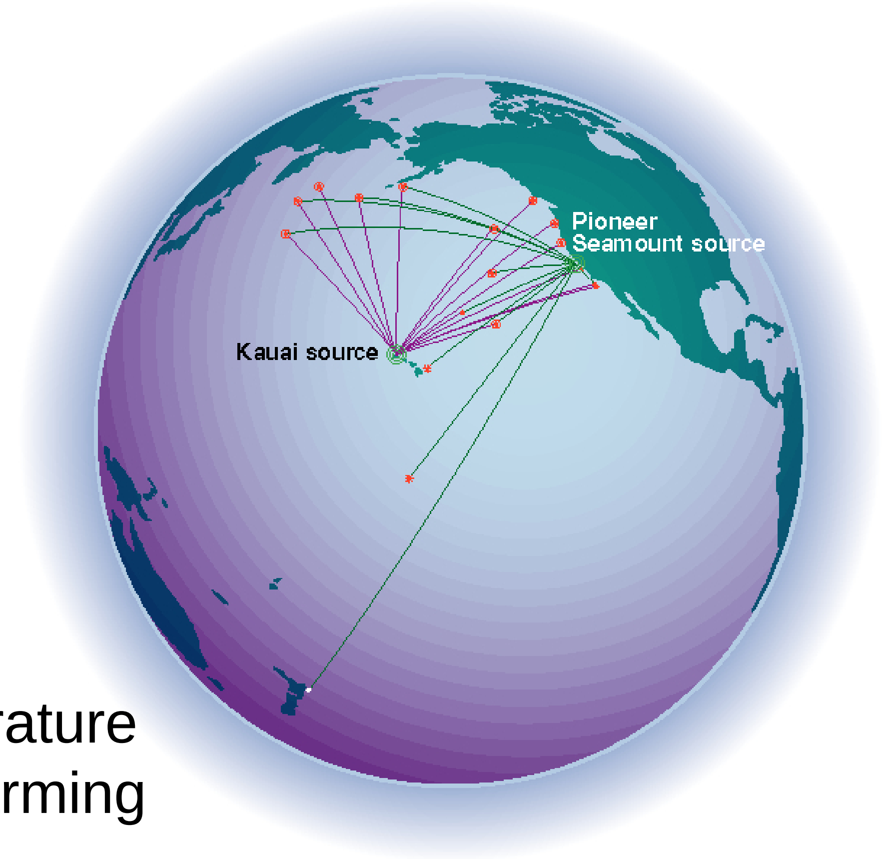

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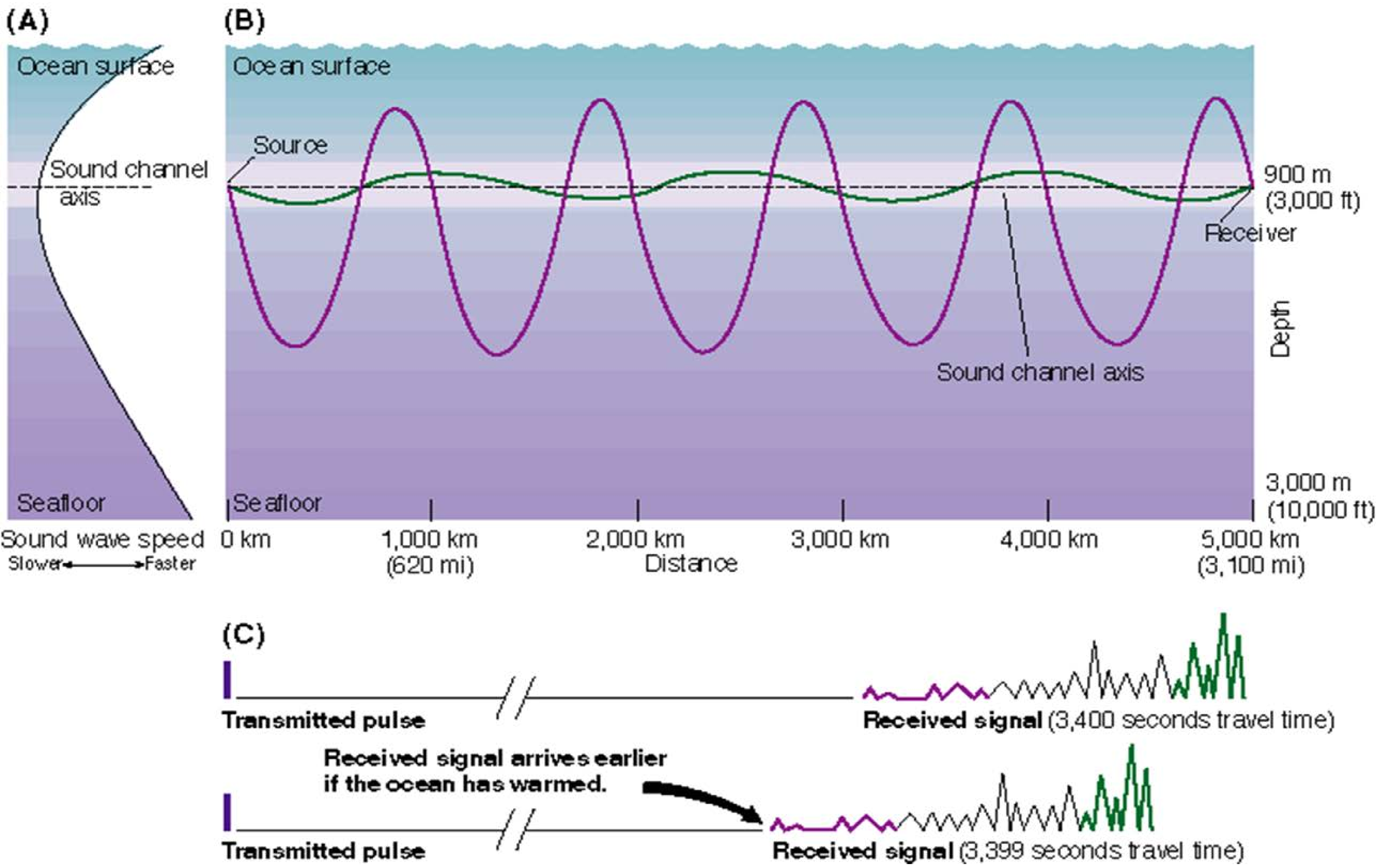
ATOC: Acoustic Thermometry of Ocean Climate



ATOC and Humpbacks

- no change in abundance, some change in pod distribution (but difficult to interpret)
- increases in duration and distance between successive surfacings with increase in ATOC sound level (5-15% variation)
- similar behavioral responses found at similar receive levels. RL is good predictor of response
- aggregate intensity level of song does not change with transmission condition

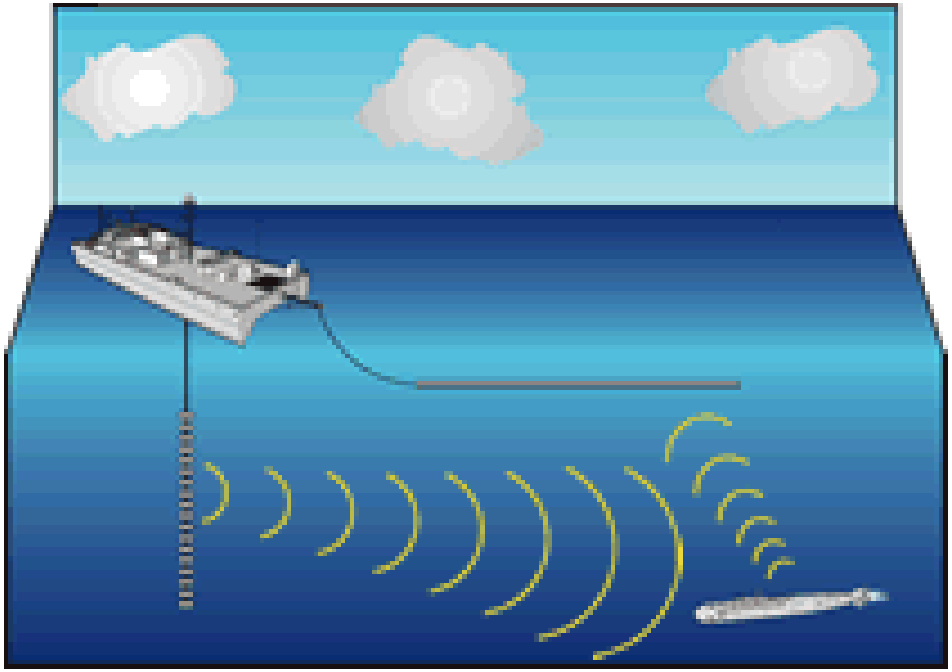
Conclusion: behavioral response barely detectable

A. Frankel

Low Frequency Acoustics (LFA)

Surveillance Towed Array Sensor System (SURTASS)

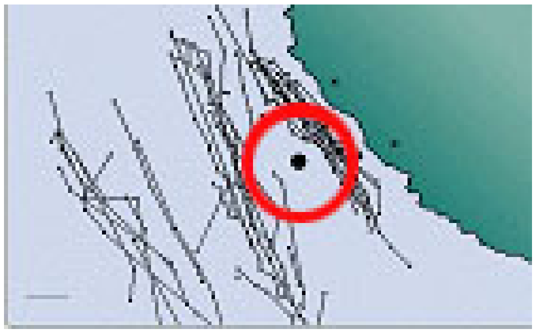
100-500 Hz



active sonar to enable long range (kms) detection of submarines

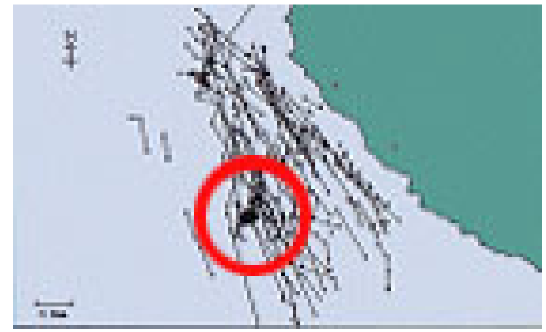
Humpback Migration &Breeding

Source in corridor

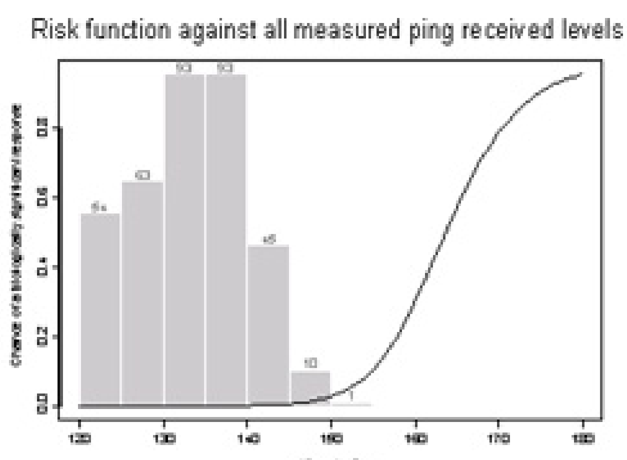


- whales changed course to avoid sound source

Source moved offshore (1 mile)



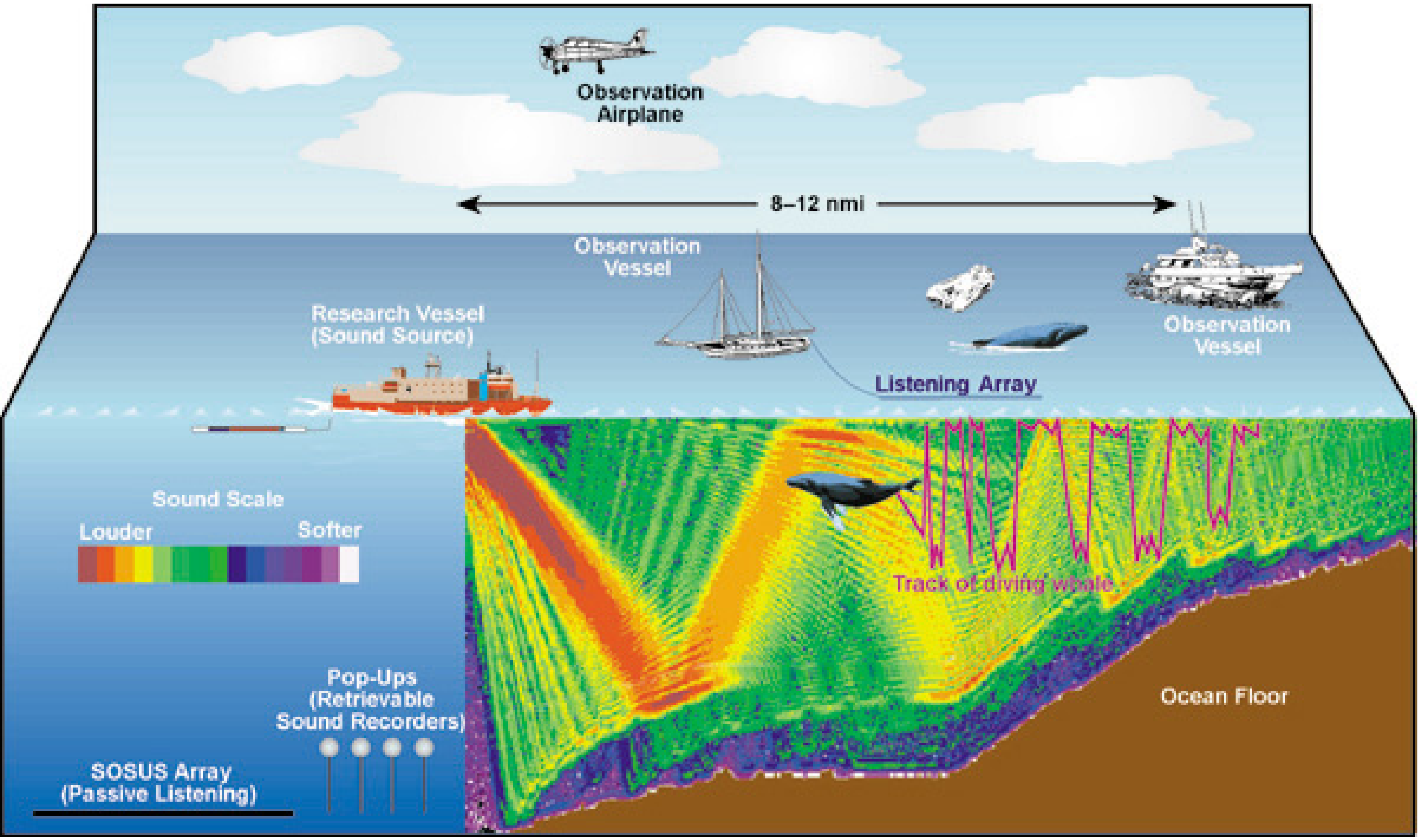
- whales did not change course



- low risk at RL

Examining Effects of LFA

Potential impacts on: whale feeding, migrating, breeding

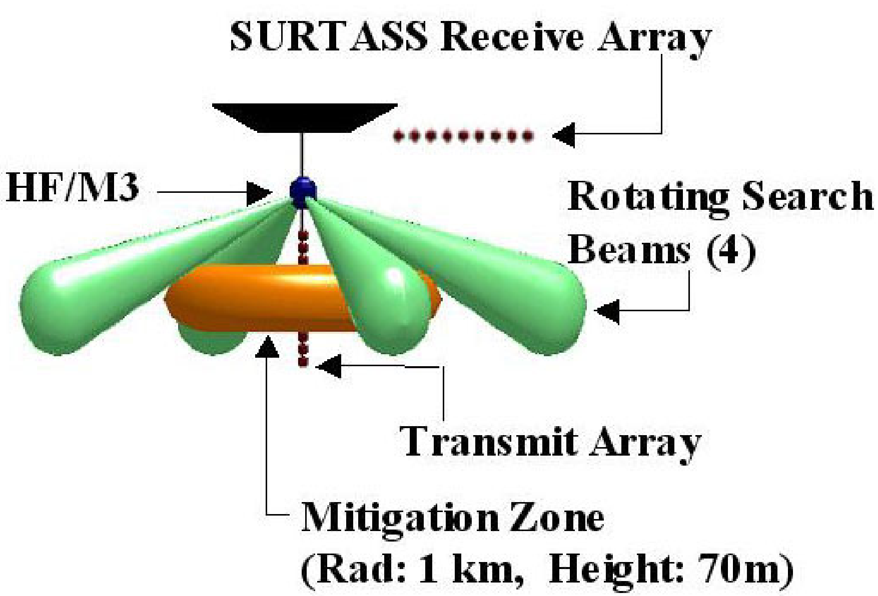


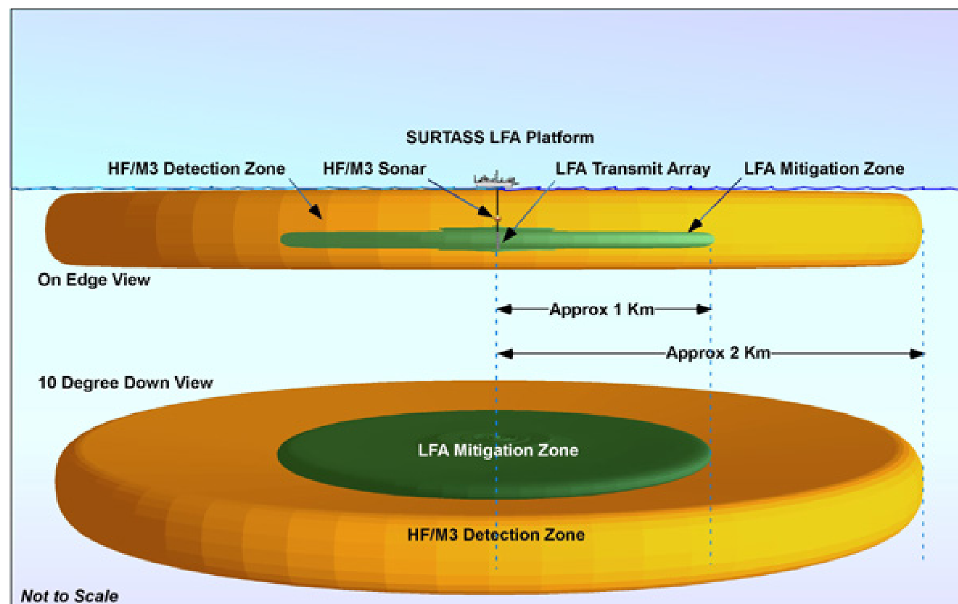
- 19 animal observations
- No overt behavioral responses
- No changes in whale distribution could be related to LFA operations

Marine Mammal Mitigation Sonar

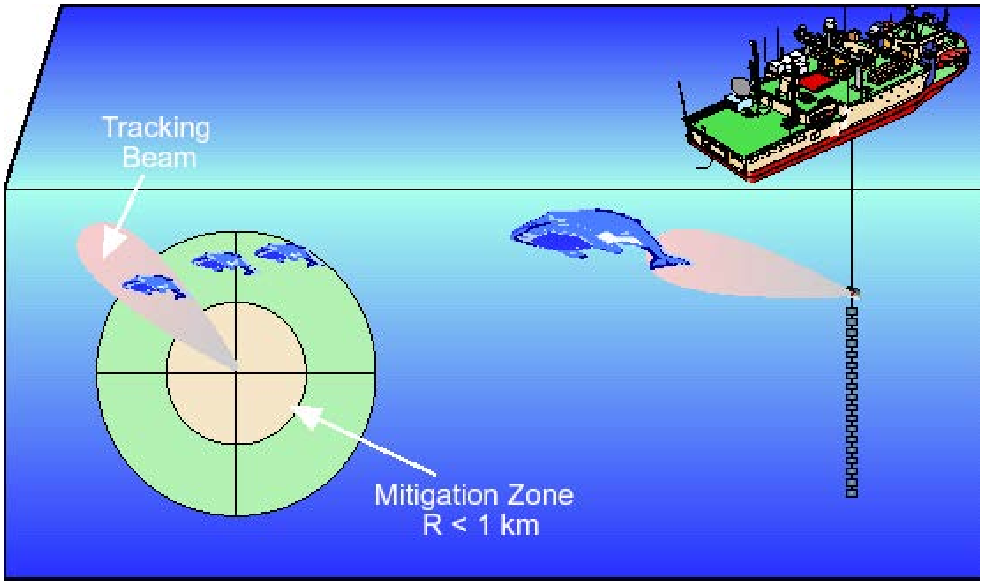
may be used in conjunction with other sonars

HF/M3

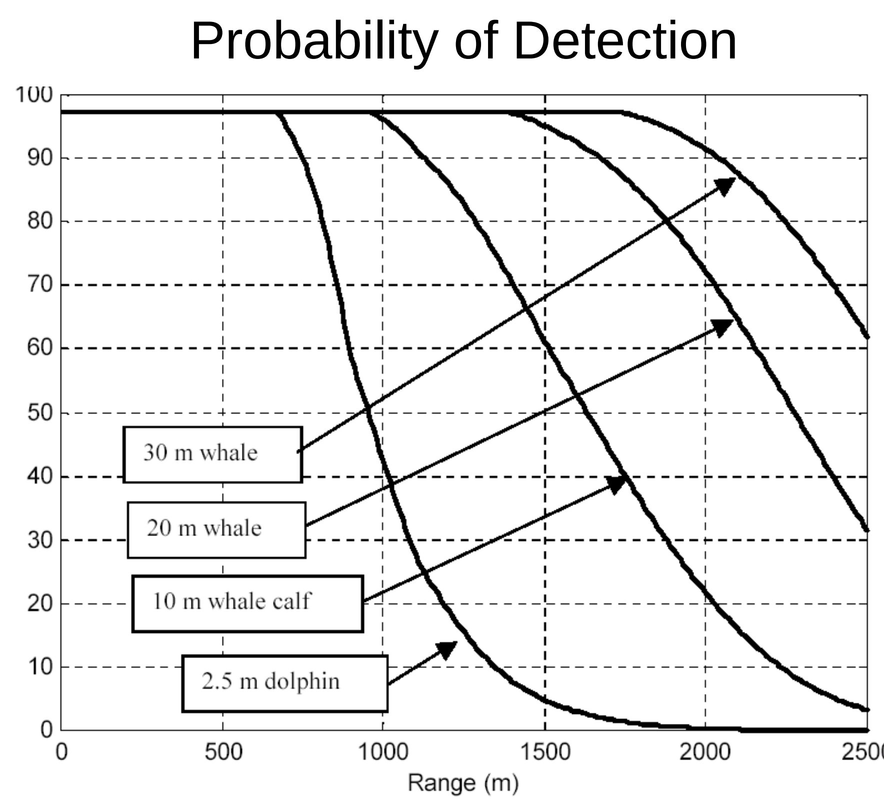




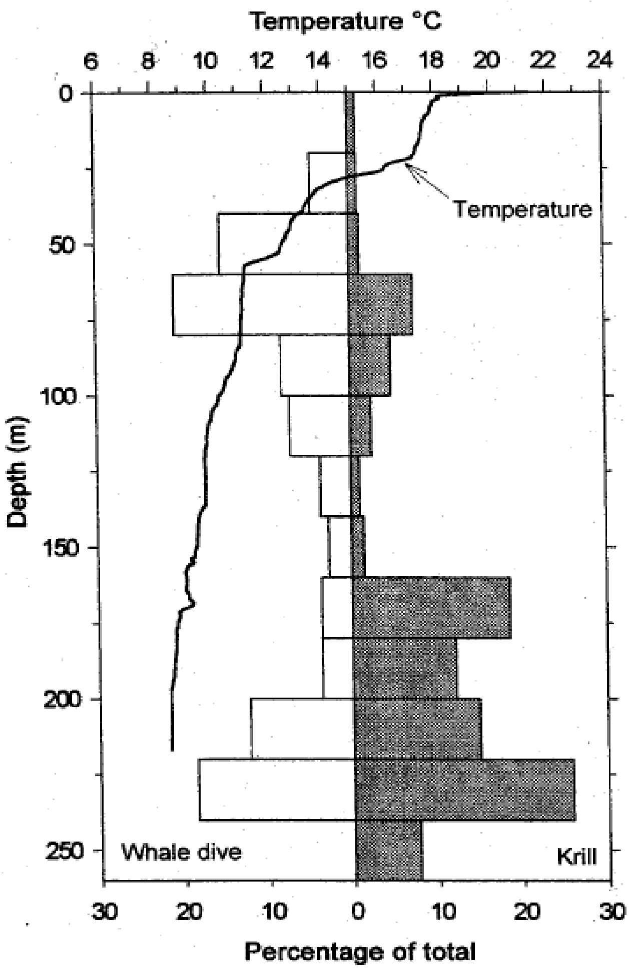
Monitoring Marine Mammals



- stop transmission of SURTASS if animal detected within 180 dB re 1 μPa
- range 0.75 to 1 km, depth 87 to 147 m



Whale Behavior & Sound



Croll et al. 2001

Observed: Miller et al. (2000) Humpbacks

- length of male song increased during LFA broadcast
- potential masking of communications

Not Observed: Croll et al. (2001) Blue and Fin

- foraging activity did not change during LFA broadcast (RL >140 dB re 1 μPa)
- encounter rates and dive behavior correlated with prey density and oceanography

Behavioral Response Review

- Response to single stimulus variable
- Response dependent on environment, source and receive characteristics
- Magnitude and period of signal/response may indicate biological importance

But not a linear response among animals to the same sound

U.S.S. Shoup

16 – 18 June, 2005 Haro Strait, WA

- 7.3 kHz sonar
- Source level 235 dB re 1 μPa @ 1 m
- 3 hour exposure
- Max RL estimated 180 dB rms
- Behavioral response
- Not loud enough to cause TTS

Challenges to Anthropogenic Studies

- behavioral changes (e.g. song length, migration) are short term (< 2 hrs); Can effects be measured on demographic scale (e.g. fitness - survival, calving rates)?

- how to decouple multiple effects of general increase in ambient noise from local sources? What about places where noise has decreased?

- if LFA effects are behavioral, shouldn't you be looking at 'shy' species? Dahl's porpoise vs harbor porpoise, Californian sea lions vs Steller sea lions

Research Priorities

Ocean Noise

1. Support long-term ocean noise monitoring programs
2. Collect, organize, and analyze historic marine anthropogenic noise data
3. Develop global models for ocean noise
4. Report signal characteristics for anthropogenic noise sources
5. Quantify the relationship between anthropogenic activity and noise level

Noise Effects

1. Understand causes of mass stranding events
2. Quantify behavioral responses to anthropogenic sound
3. Improve tools for marine mammal behavioral observation (e.g. tags, passive recorders)
4. Develop tools to study marine mammal physiology (stress, hearing)
5. Characterize marine mammal populations within high sound areas