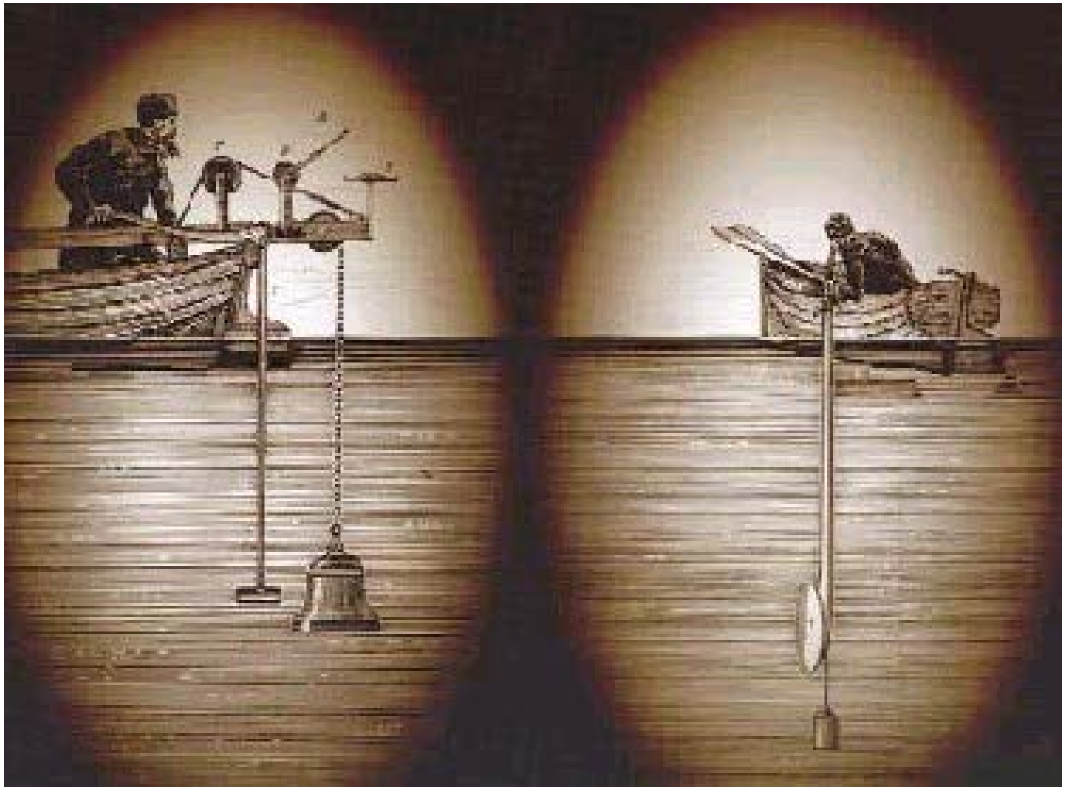
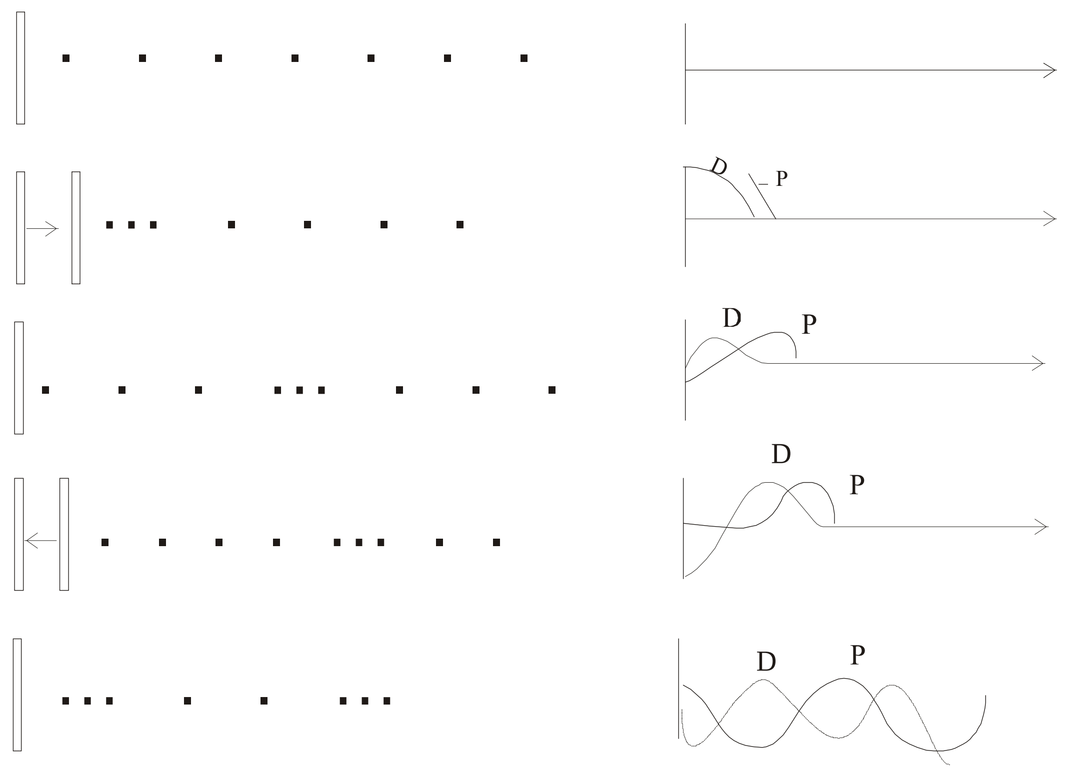
Principles of Underwater Sound



LO: Apply characteristics of sound in water to calculate sound levels.

What is Sound?

A disturbance propagated through an elastic medium causing a detectable alteration in pressure or a displacement of the particles.



Measuring Sound

Pressure (p): force/area

p = force/area, units Newton/m^2 (Pascal), $[MLT^{-2}/L^2] = [MT^{-2}L^{-1}]$

Imperial to SI conversion: 1 μBar = 10^5 μPa

Power (P): force * velocity

P = force * velocity, units watts, $[MLT^{-2}*LT^{-1}] = [ML^2T^{-3}]$

Intensity (I): power/area

I = power/area = $p^2/\rho c$

where ρ = density, mass/volume, units kg m^{-3} $[ML^{-3}]$

Quantity Relationships

Intensity is proportional to pressure squared

$$I \propto p^2$$

Pressure squared is proportional to power

$$p^2 \propto P$$

What is relationship between Intensity and Power?

What is a Decibel ?

A ratio in logarithmic form.

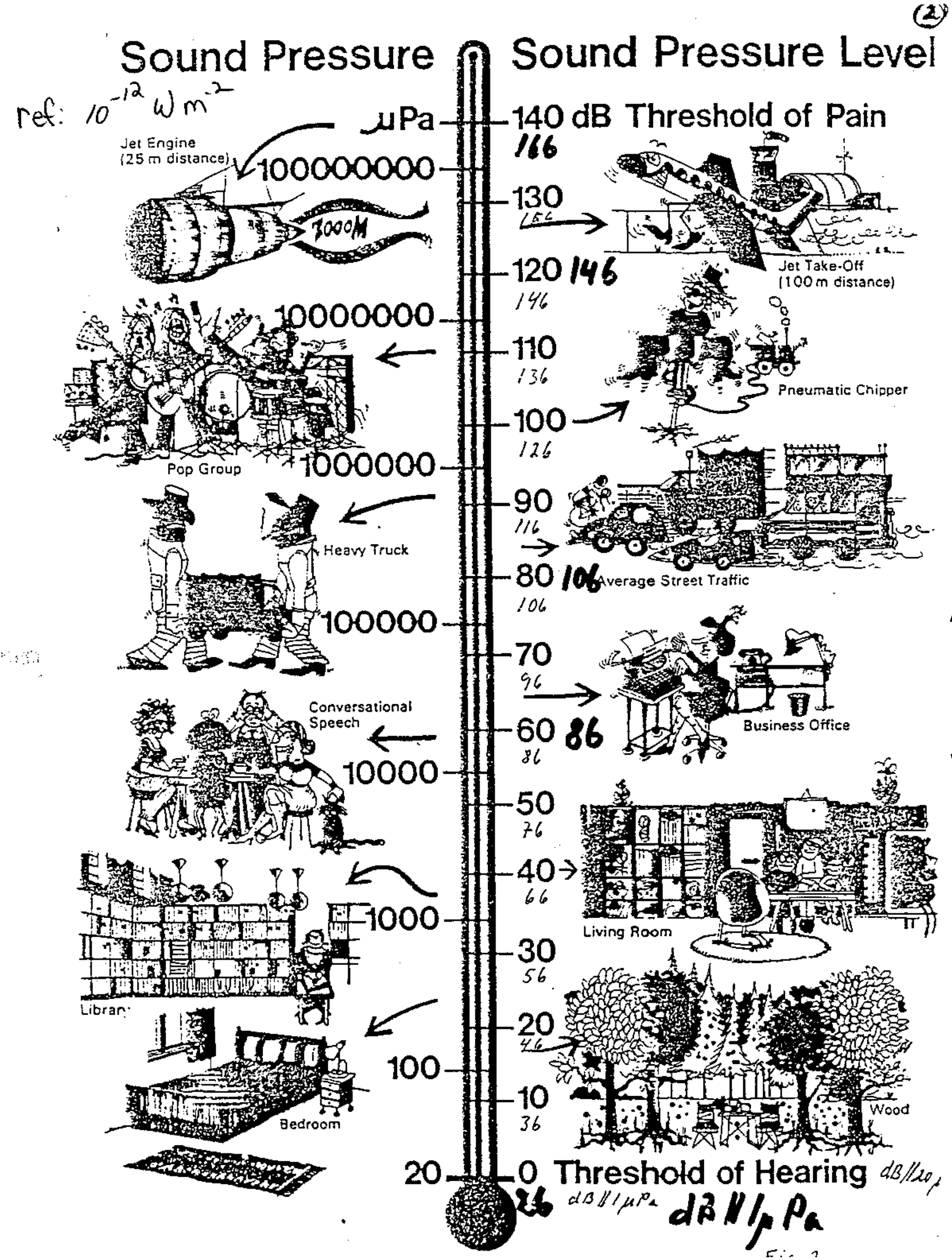
Intensity ratio: 10 log (I/I_o) where I_o is the reference intensity at 1 m

Pressure ratio: 10 log $(p^2/\rho c/\ p_o^2/\rho c)$ = 20 log (p/p_o) where p_o is a reference pressure (1 μPa) at 1 m

Example:

If $I_o = 1\ Wm^{-2}$
Then I = 100 Wm^{-2} becomes 10 log(100/1) = 20 dB || 1 Wm^{-2}

If $p_o = 1\ \mu Pa$
Then p = 100,000 μPa becomes 20 log(100,000/1) = 100 dB || 1 μPa

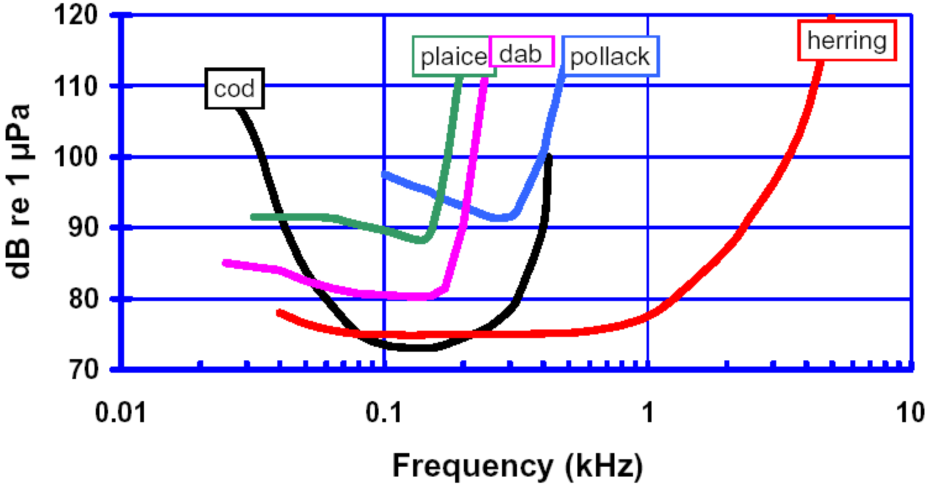


Air ref. = 0 dB

(threshold of human hearing)

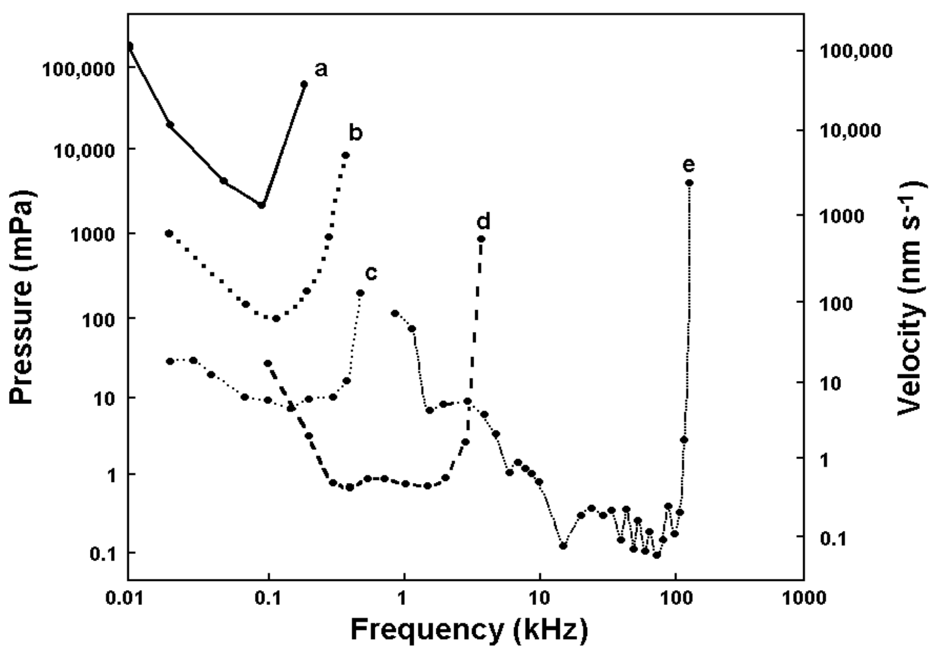
Water ref. = 26 dB

Animal Hearing Thresholds & Ranges



Human Hearing: 20 Hz to 20 kHz

courtesy of R. Mitson



a) lobster

b) Atlantic salmon

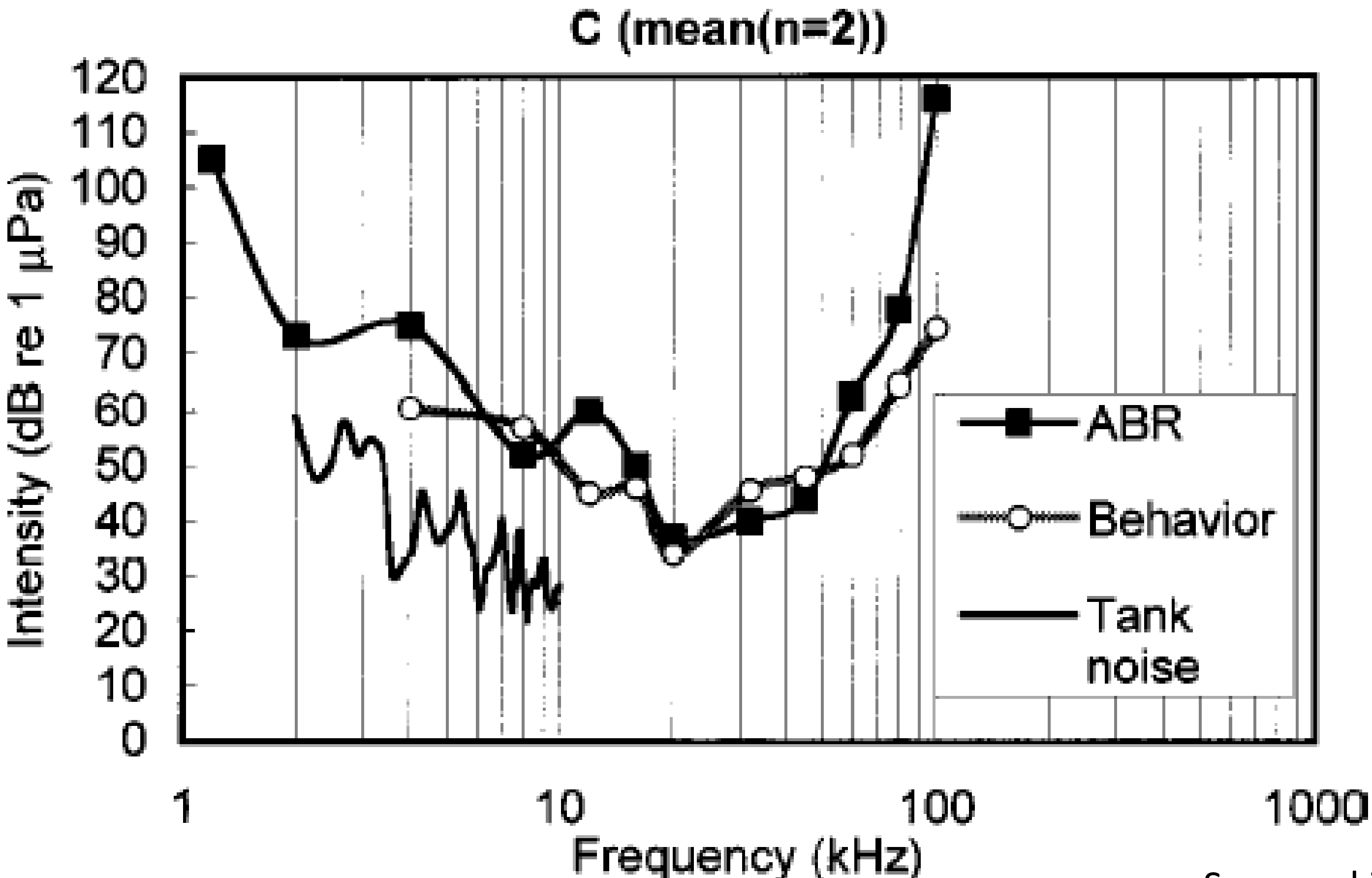
c) Atlantic cod

d) soldier fish

e) bottle-nose dolphin

MacLennan & Simmonds 1992

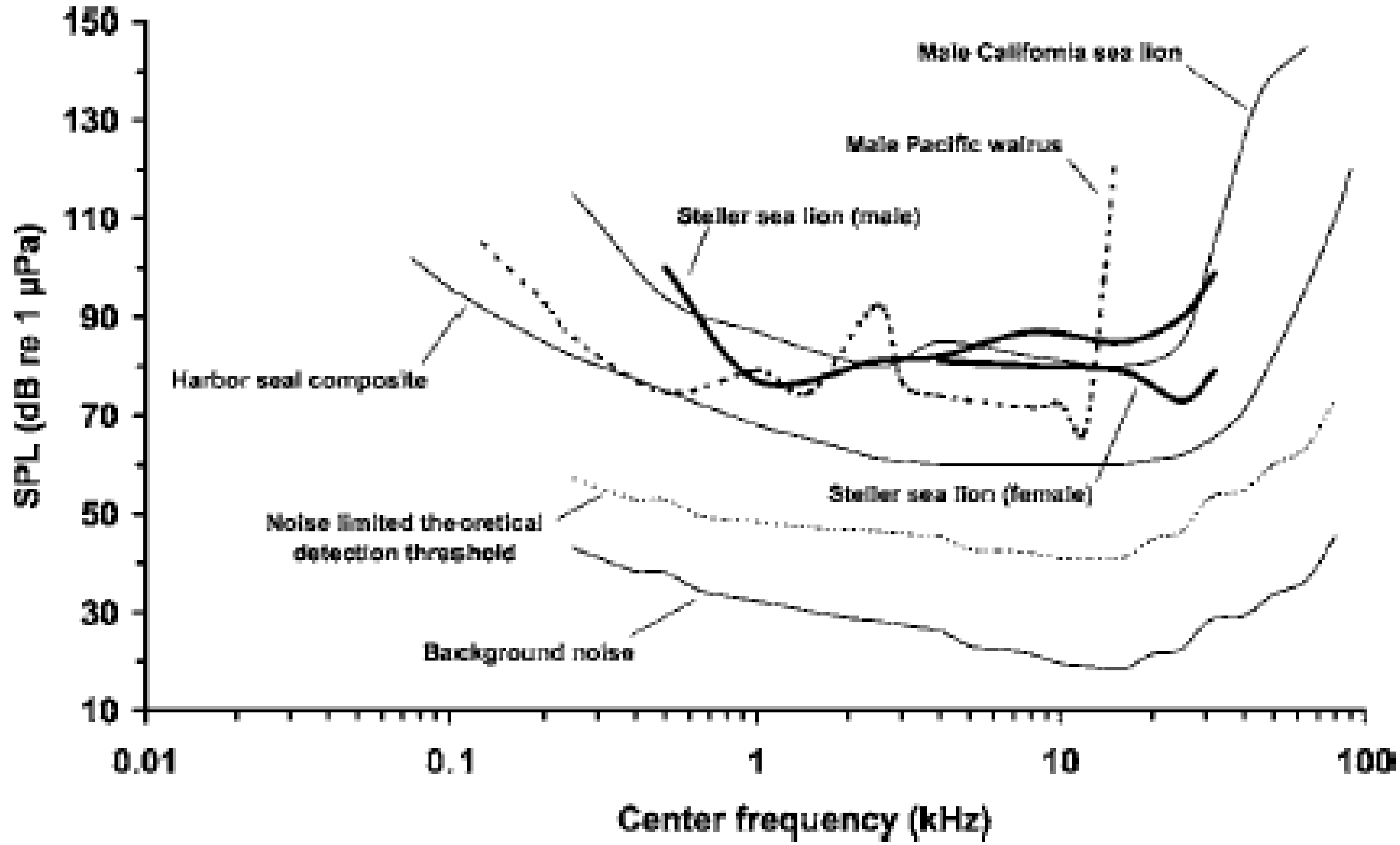
Killer Whale Hearing Thresholds



Szymanski et al. 1999

ABR = Auditory Brainstem Response

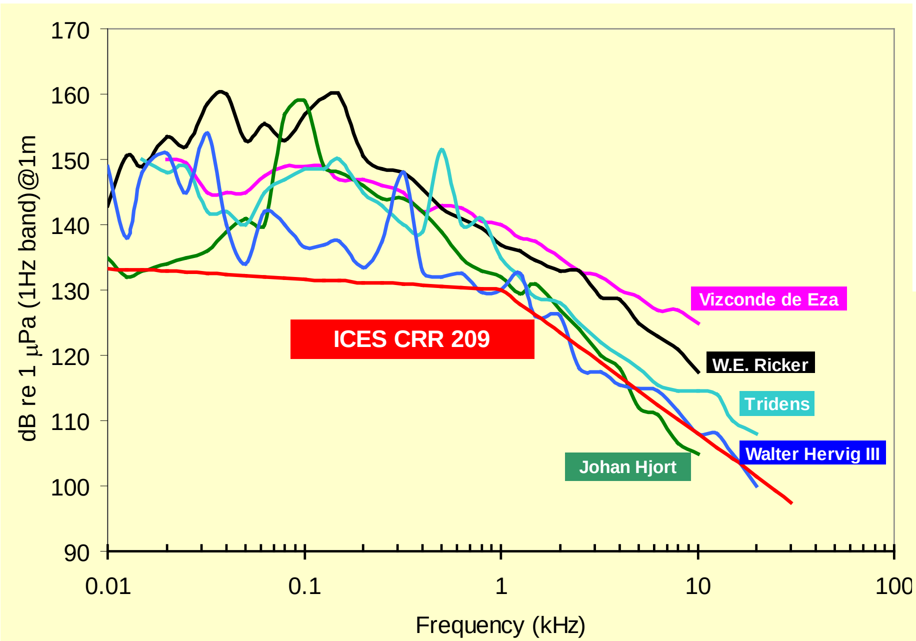
Steller Sea Lion Hearing



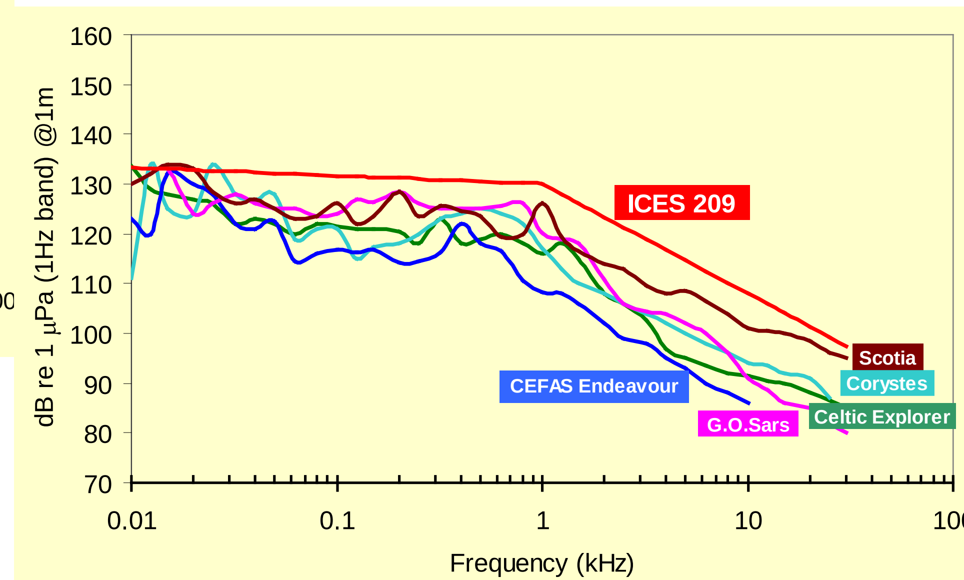
Kastelein et al. 2005

Vessel Noise: ICES 209

‘Noisy’ Research Vessels

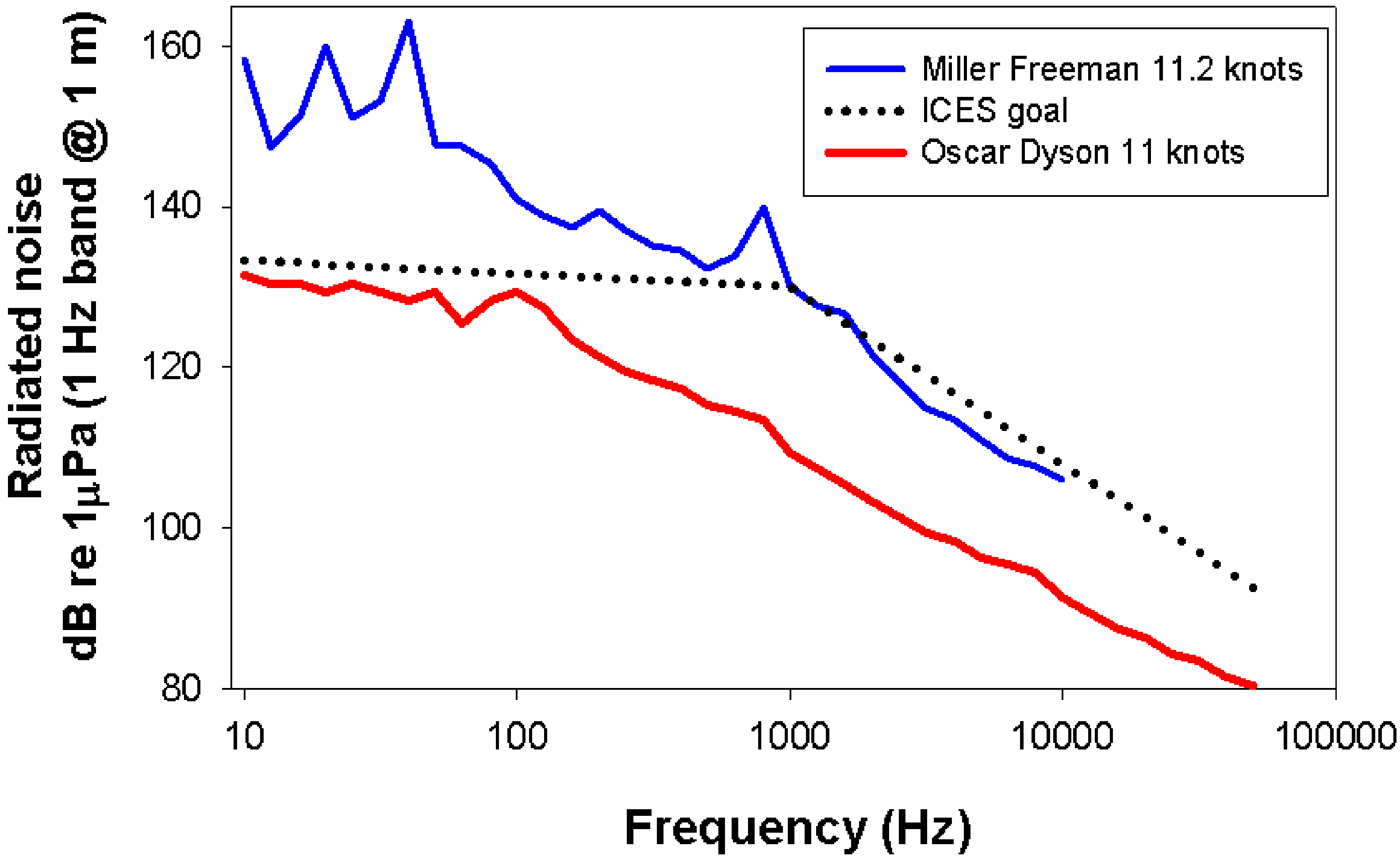


‘Quiet’ Research Vessels

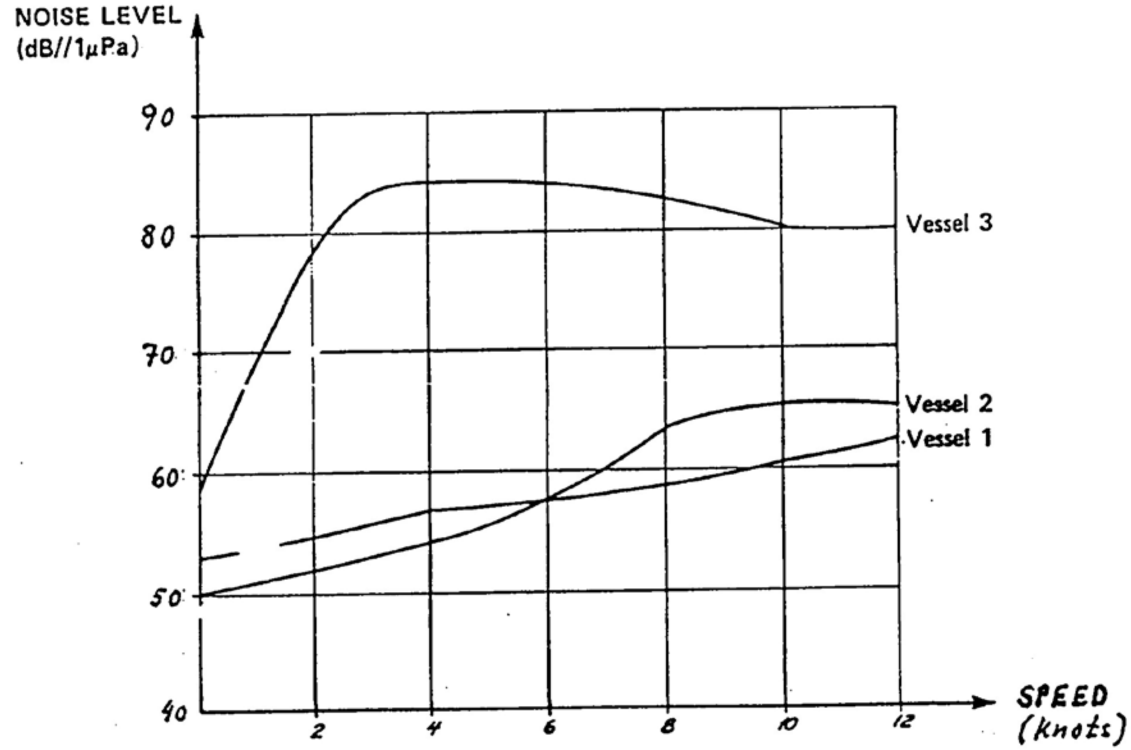


plots courtesy of R. Mitson

NOAA Vessels



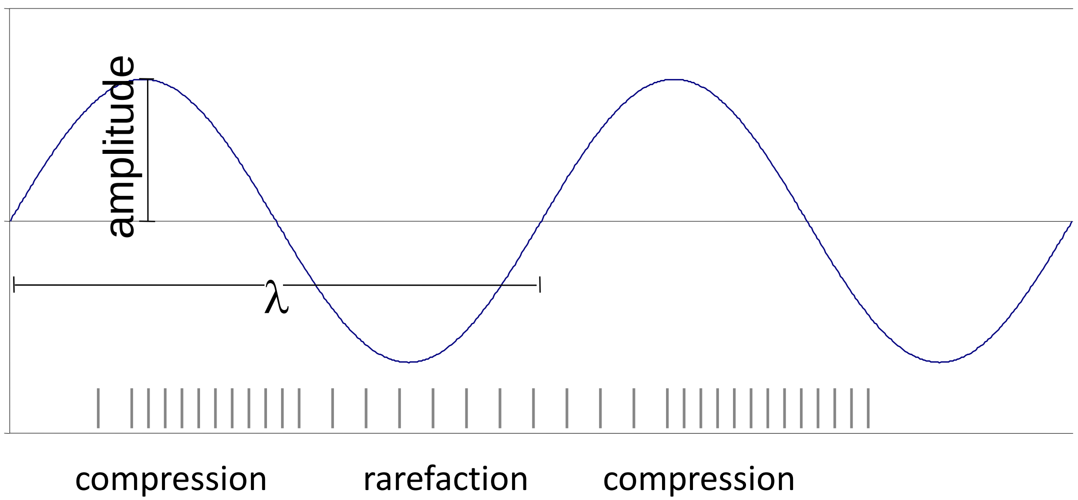
Vessel Noise α Vessel Speed



Vessel	Propeller	R.P.M.	Size
1. Trawler	Fixed pitch	30 - 113	223 feet
2. Purse seiner	Adj. pitch	100 - 300	245 feet
3. Trawler	Adj. pitch	375	299 tons

Sound Propagation

Longitudinal Compression Wave



λ = wavelength, units m

$\lambda = c/f$ where: c = speed of sound (ms^{-1})

f = frequency (cycles s^{-1}, Hz)

Speed of Sound

Speed of sound (c) = *f* (temperature (T), salinity (S), depth/pressure (z/ρ)), units ms^{-1}

UNESCO: Chen and Millero (1977)

$$c(S,t,P)=C_W(t,P)+A(t,P)S+B(t,P)S^{3/2}+D(t,P)S^2,$$

where

$$C_W(t,P)=(C_{00}+C_{01}t+C_{02}t^2+C_{03}t^3+C_{04}t^4+C_{05}t^5)+(C_{10}+C_{11}t+C_{12}t^2+C_{13}t^3+C_{14}t^4)P+(C_{20}+C_{21}t+C_{22}t^2+C_{23}t^3+C_{24}t^4)P^2+(C_{30}+C_{31}t+C_{32}t^2)P^3,$$

$$A(t,P)=(A_{00}+A_{01}t+A_{02}t^2+A_{03}t^3+A_{04}t^4)+(A_{10}+A_{11}t+A_{12}t^2+A_{13}t^3+A_{14}t^4)P+(A_{20}+A_{21}t+A_{22}t^2+A_{23}t^3)P^2+(A_{30}+A_{31}t+A_{32}t^2)P^3,$$

$$B(t,P)=B_{00}+B_{01}t+(B_{10}+B_{11}t)P,$$

$$D(t,P)=D_{00}+D_{10}P.$$

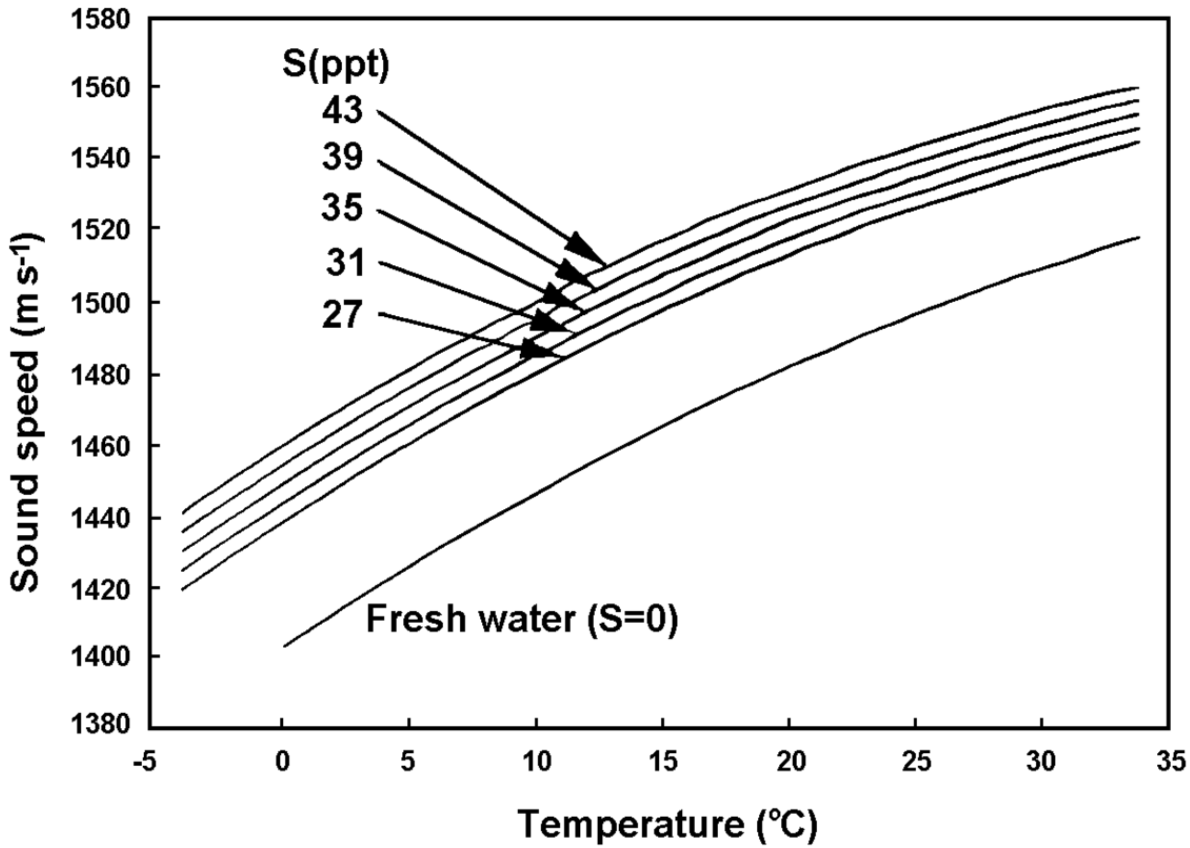
From Wong and Zhu 1995

TABLE I. Numerical values of the t_{90} coefficients for the UN equation.

Coefficients	Numerical values for Eq. (1)	Coefficients	Numerical values for Eq. (1)
C_{00}	1402.388	A_{02}	$7.166E-5$
C_{01}	5.03830	A_{03}	$2.008E-6$
C_{02}	$-5.81090E-2$	A_{04}	$-3.21E-8$
C_{03}	$3.3432E-4$	A_{10}	$9.4742E-5$
C_{04}	$-1.47797E-6$	A_{11}	$-1.2583E-5$
C_{05}	$3.1419E-9$	A_{12}	$-6.4928E-8$
C_{10}	0.153563	A_{13}	$1.0515E-8$
C_{11}	$6.8999E-4$	A_{14}	$-2.0142E-10$
C_{12}	$-8.1829E-6$	A_{20}	$-3.9064E-7$
C_{13}	$1.3632E-7$	A_{21}	$9.1061E-9$
C_{14}	$-6.1260E-10$	A_{22}	$-1.6009E-10$
C_{20}	$3.1260E-5$	A_{23}	$7.994E-12$
C_{21}	$-1.7111E-6$	A_{30}	$1.100E-10$
C_{22}	$2.5986E-8$	A_{31}	$6.651E-12$
C_{23}	$-2.5353E-10$	A_{32}	$-3.391E-13$
C_{24}	$1.0415E-12$	B_{00}	$-1.922E-2$
C_{30}	$-9.7729E-9$	B_{01}	$-4.42E-5$
C_{31}	$3.8513E-10$	B_{10}	$7.3637E-5$
C_{32}	$-2.3654E-12$	B_{11}	$1.7950E-7$
A_{00}	1.389	D_{00}	$1.727E-3$
A_{01}	$-1.262E-2$	D_{10}	$-7.9836E-6$

Affects of Temperature and Salinity

Freshwater ~ 1500 ms^{-1} Salt water ~ 1460 – 1550 ms^{-1} Air ~ 330 ms^{-1}



Effect of T > S

Mackenzie 1981

Target Resolution and Travel

Target Resolution:

f (target distance (Δr), speed of sound (c), pulse duration (τ))

$$\Delta r = c\ \tau/2$$

* independent of frequency

Acoustic Pulse Travel Time:

time to echo = 2r/c

where r = range (m)

Frequency, Wavelength & Wavenumber

Frequency (f) = λ per unit time, units cycles s^{-1} (Hertz)

$$f = c/\lambda \ (ms^{-1}/m)$$

Wavelength (l)

$$\lambda = c/f \ (ms^{-1}/s^{-1})$$

Wave number (*k*)

$$k = 2\pi/\lambda \ (\text{rad } m^{-1})$$

Frequency and Period

Frequency (f) = λ per unit time, units cycles s^{-1} (Hertz)

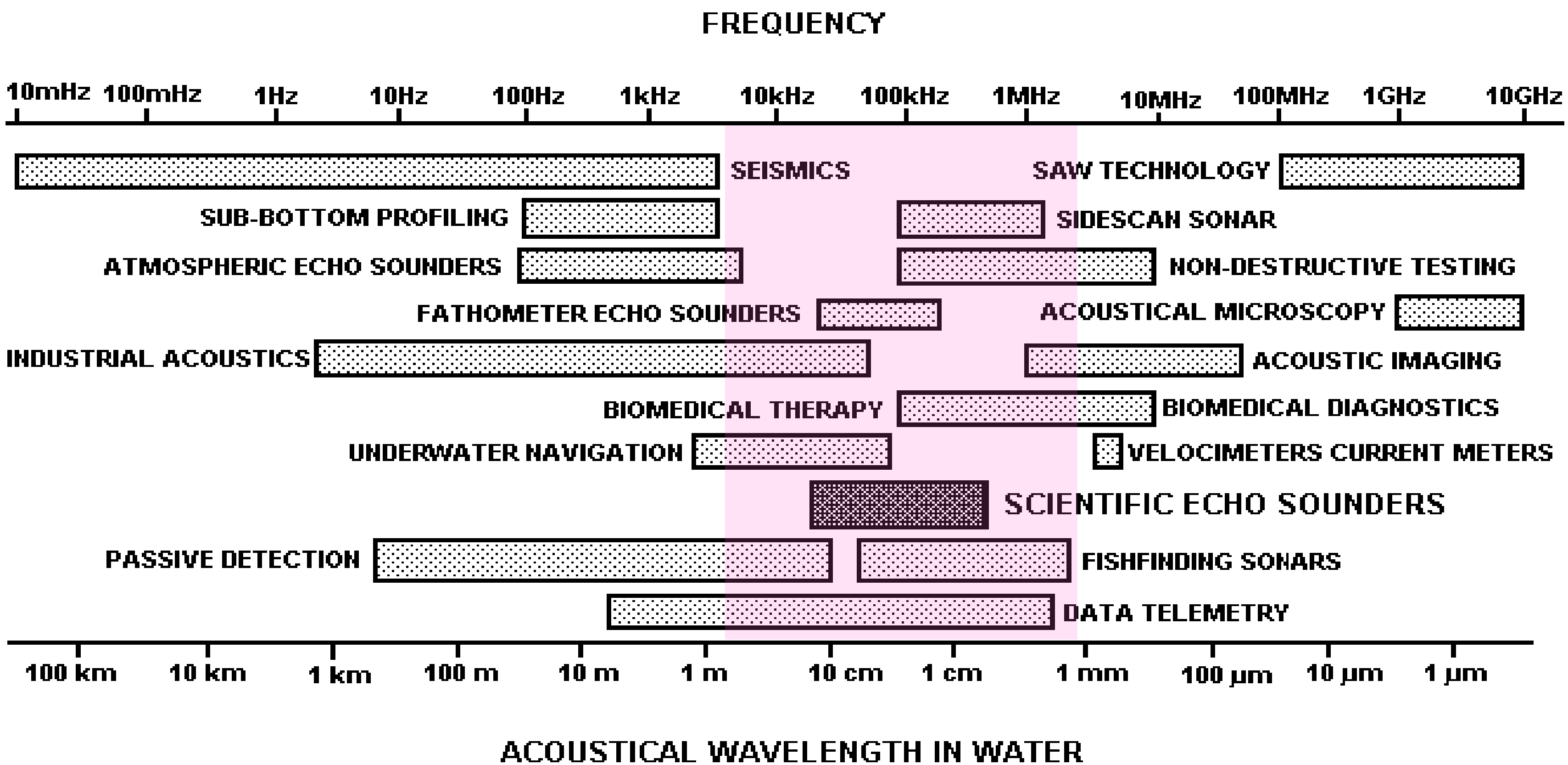
$$f = c/\lambda$$

Period (τ)= time for one cycle, units seconds

$$\tau = 1/f$$

in active acoustics this is the pulse duration, pulse length, or pulse width

Frequency Ranges of Acoustic Sensors



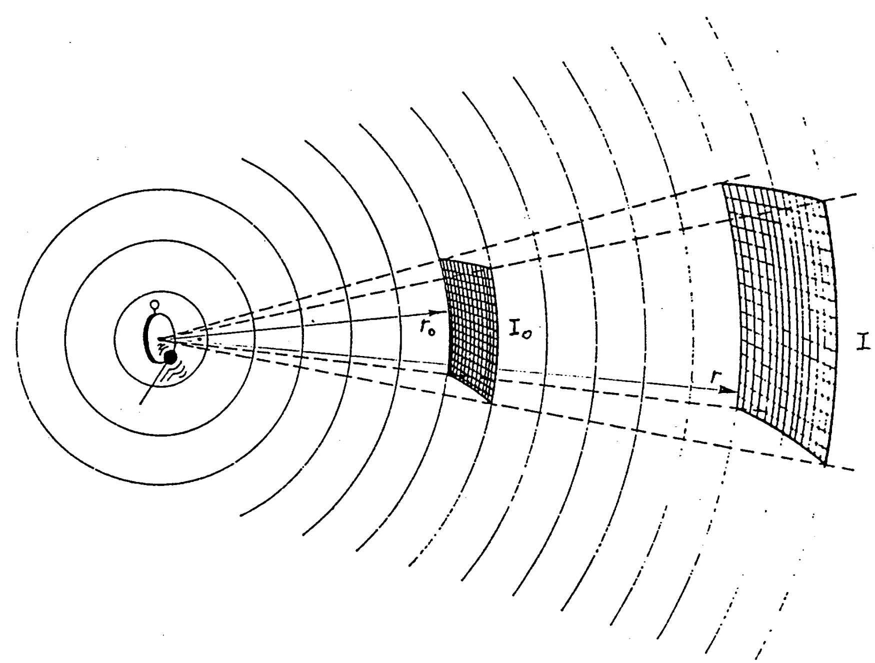
redrawn from Coates 1989

Transmission Losses

Geometric Spreading

- pressure decreases as the 1/distance from source
- spherical spreading from a point source (e.g. transducer)
- non-spherical or directed spreading (e.g. fish)
- 2-way spreading increases as range^2
- independent of frequency

$$\Delta I \;\alpha\; 1/r^2$$



Transmission Losses

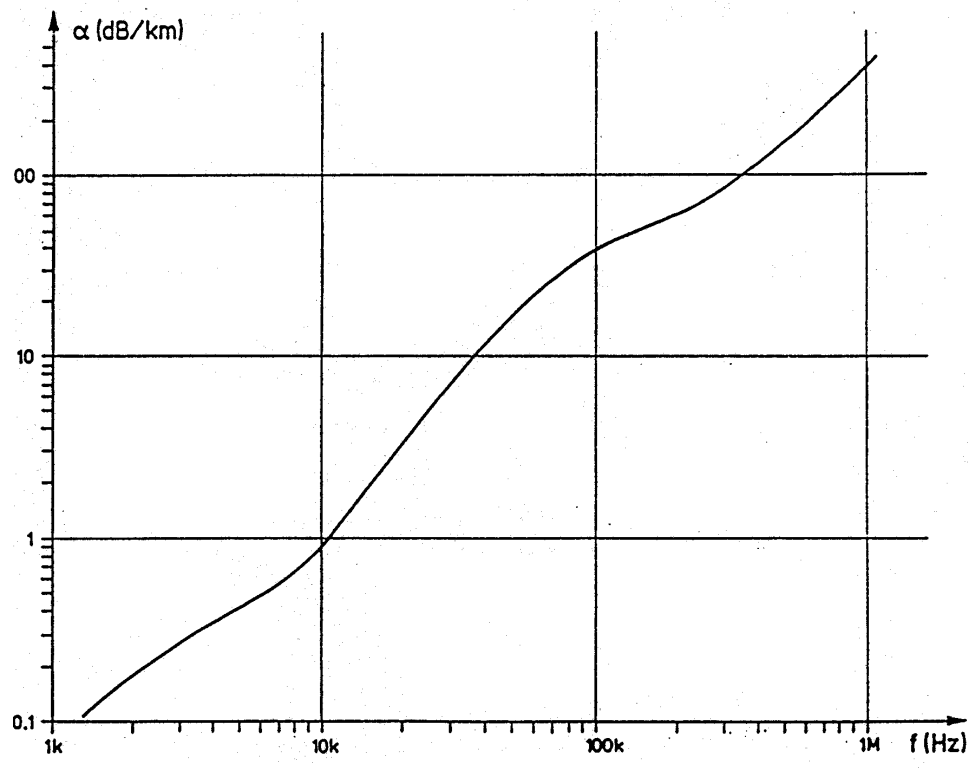
Absorption

- attenuation of pressure due to friction (α, units nepers/m or dB/m), temperature, salinity, and molecular relaxation

- proportional to range (r)
- dependent on frequency
- in FW below 200 kHz, relaxation does not occur

one way: α r

two way: 2 α r



What is a neper? natural log ratio

Which Loss is Greater?

Absorption

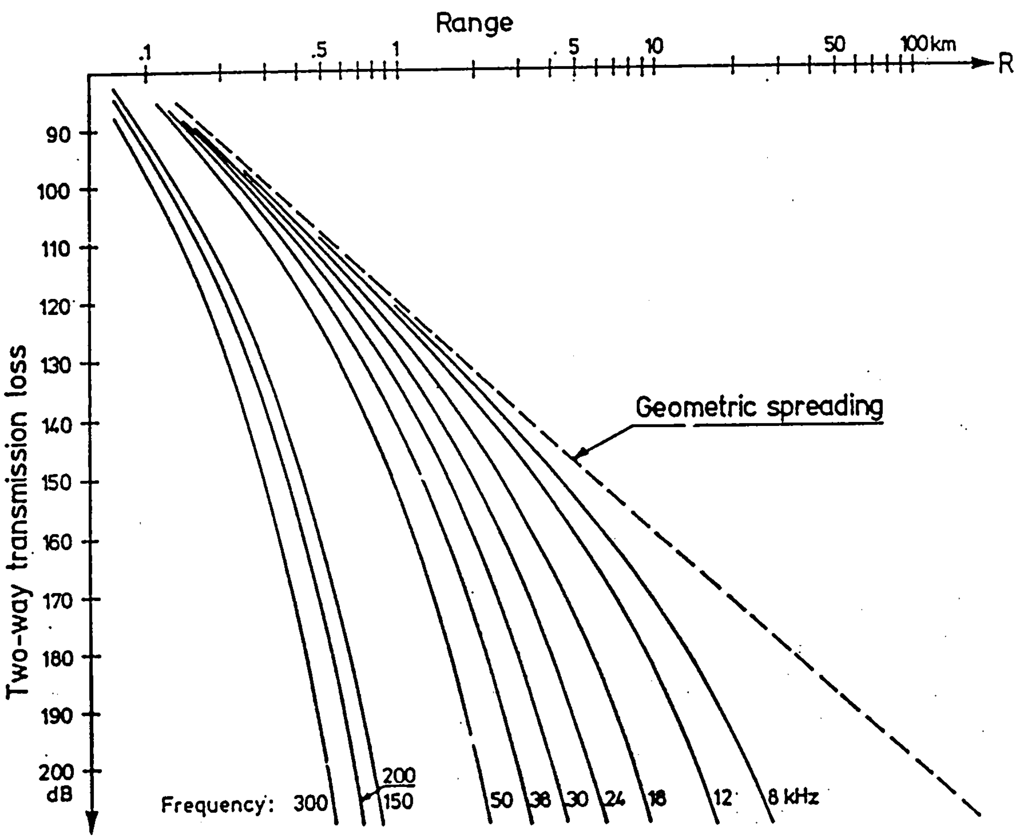
Frequency	Loss Rate
1 kHz	0.05 dB/km
10 kHz	0.5 dB/km
100 kHz	20 dB/km
1 MHz	300 dB/km

Spreading

~ 60 dB at 1 km

Spreading loss >Absorption loss at frequencies < 100’s kHz

Total Transmission Loss



1 way: $20 \log(r) + \alpha r$

2 way: $40 \log(r) + 2\alpha r$

TWO WAY TRANSMISSION LOSS VS. FREQUENCY.

Why Not Use Light?

Sound Level

Sound Level = Sound Pressure Level – Transmission Loss

Sound Pressure Level = initial intensity
(a.k.a. Source Level)