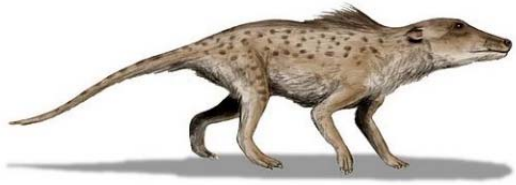
UW Hearing and Sound: Structure, Function, and Noise

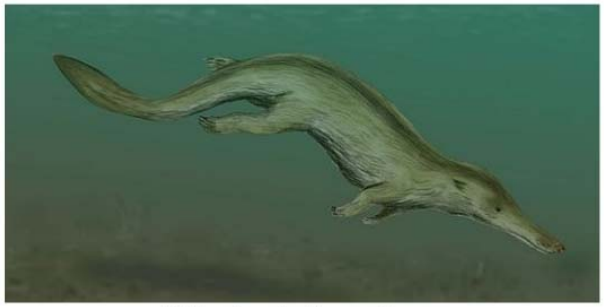
D.R. Ketten
WHOI/Harvard Medical School



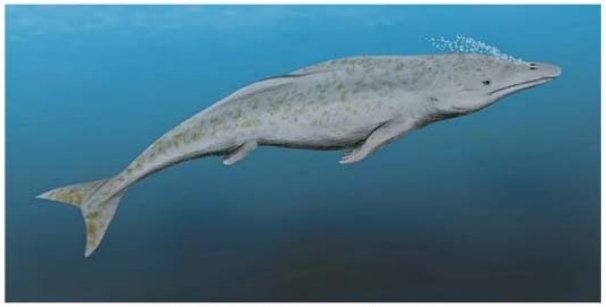
(http://spinops.blogspot.com)

Pakicetus
(cca 49-48 Ma)

Ambulocetus
(cca 50-48 Ma)



Kutchicetus
(cca 48 Ma)



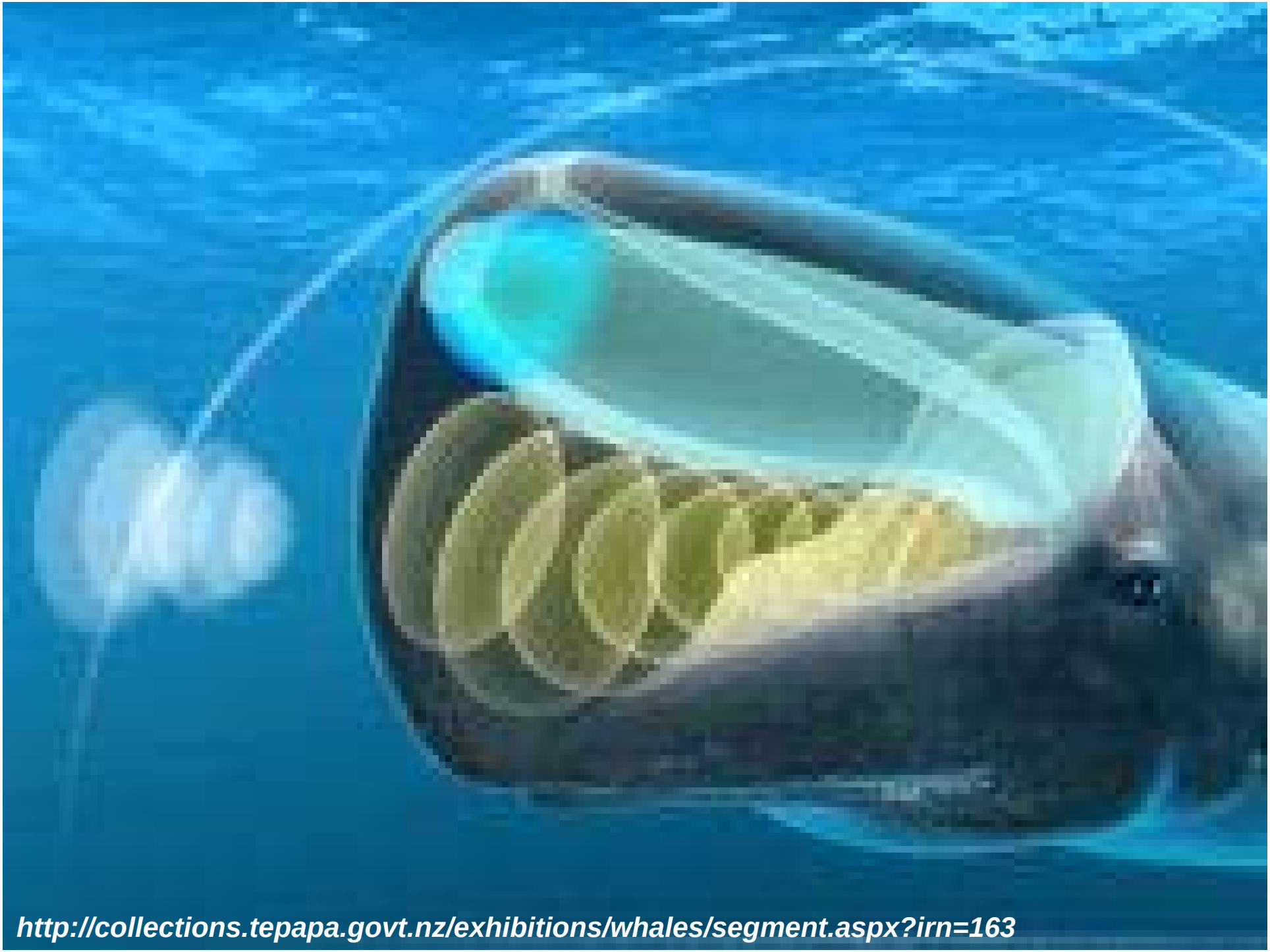
Protocetus
(cca 45 Ma)

Cetacea

Suborders:
Odontoceti
Mysticeti

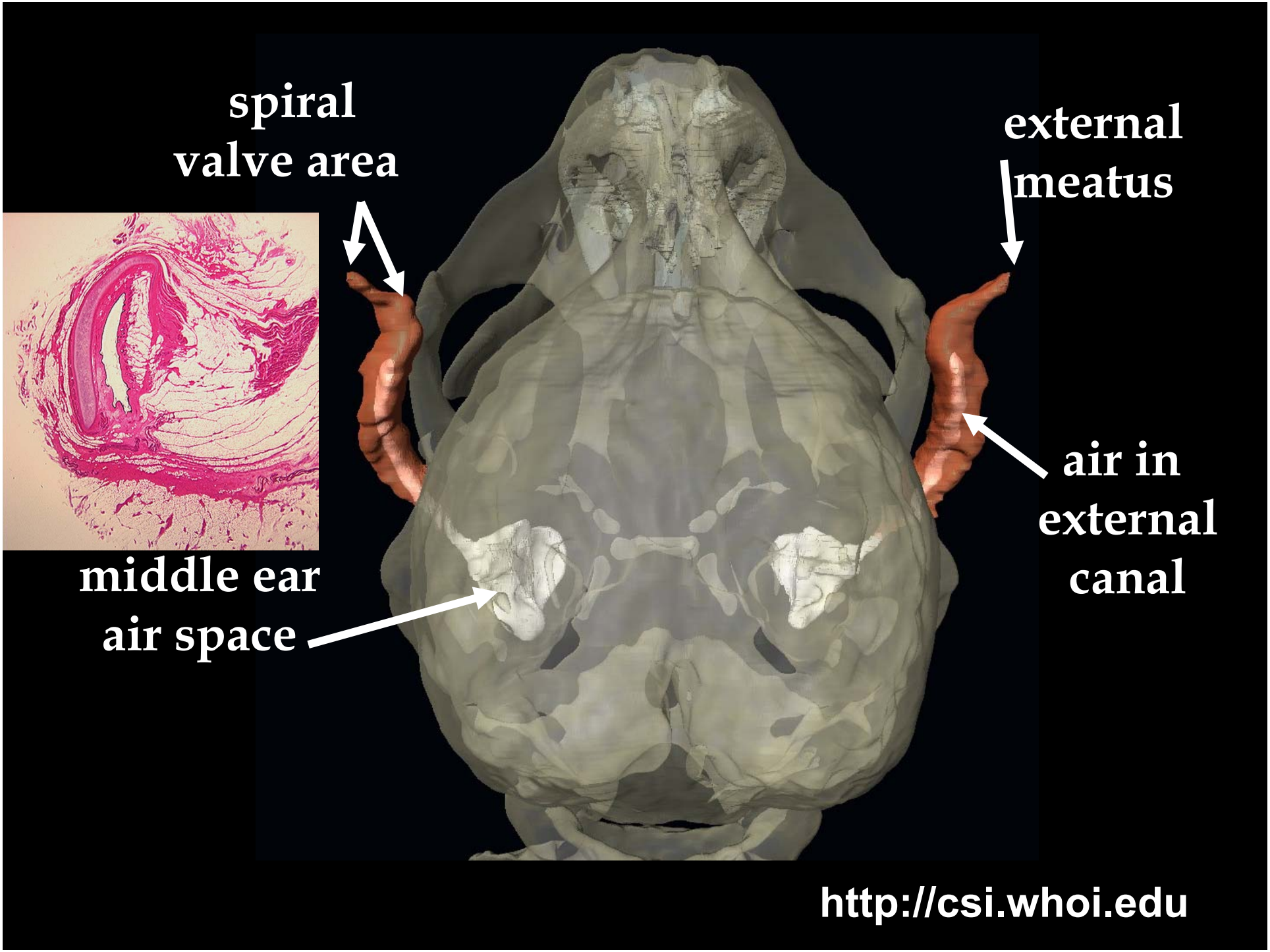
89 Species

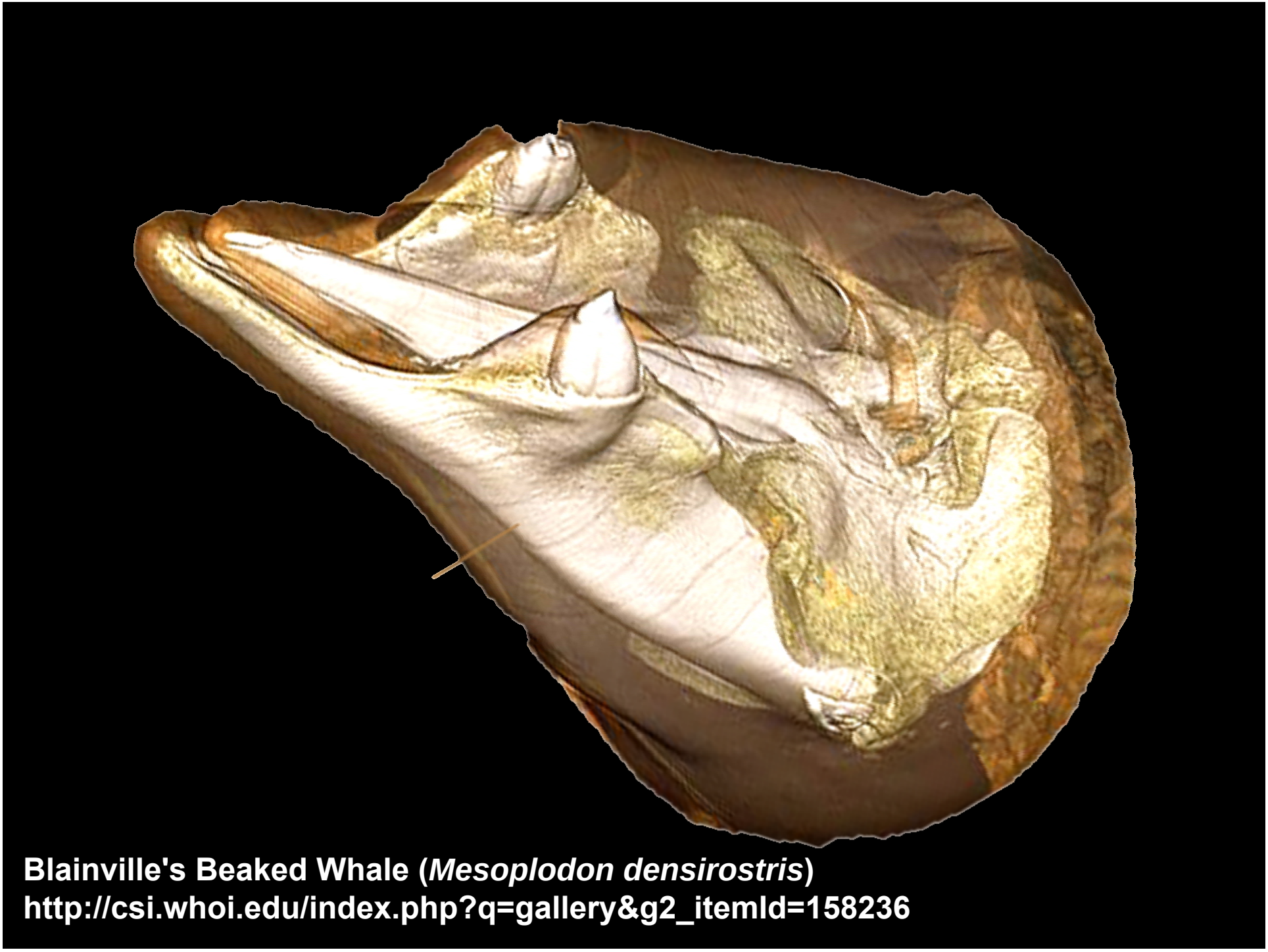
Courtesy Kathleen Vigness Raposa www.DOSITS.org



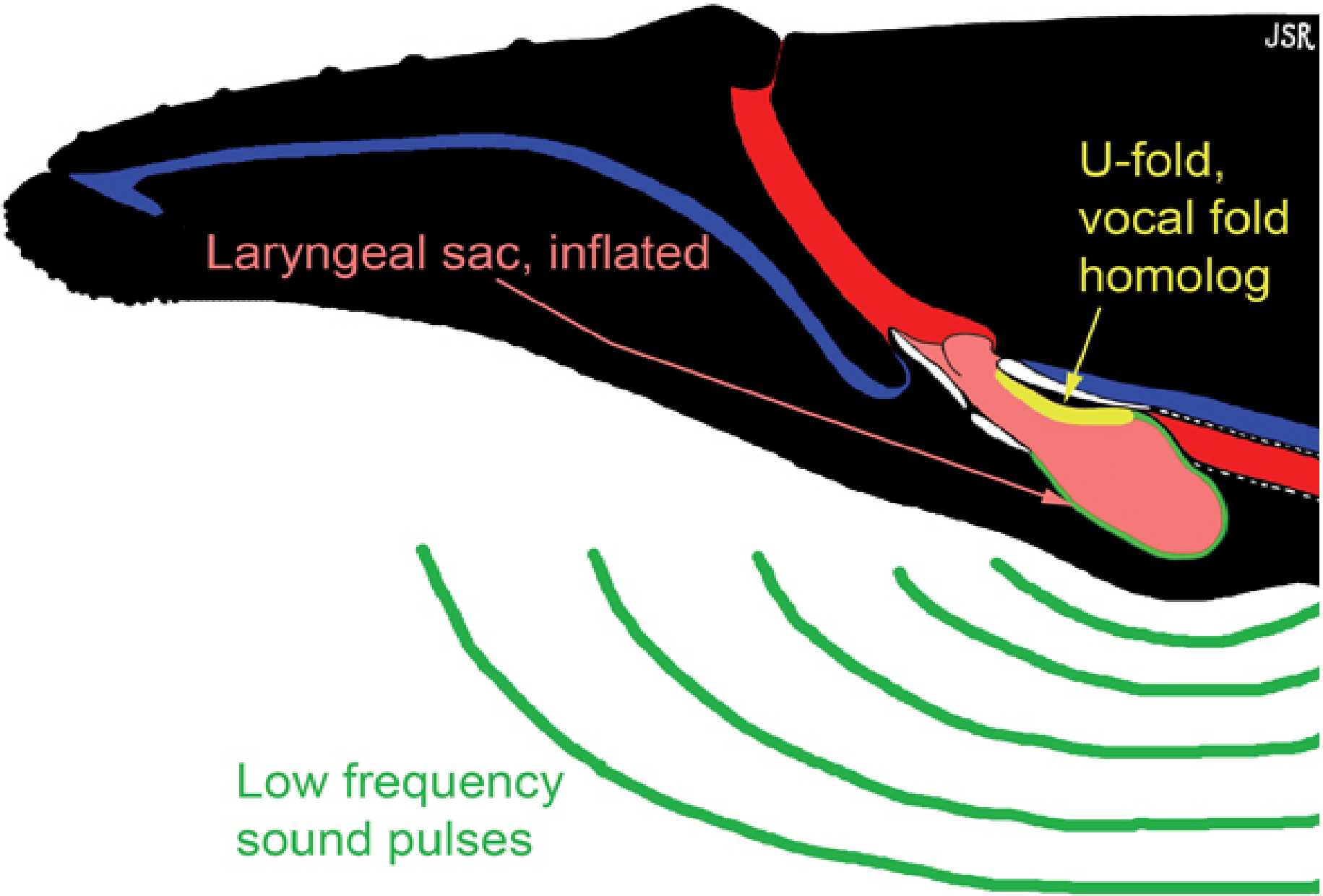
http://collections.tepapa.govt.nz/exhibitions/whales/segment.aspx?irn=163

IMAGING DATABASE
http://csi.whoi.edu
Supported by ONR/DURIP/CNO-EnvDiv

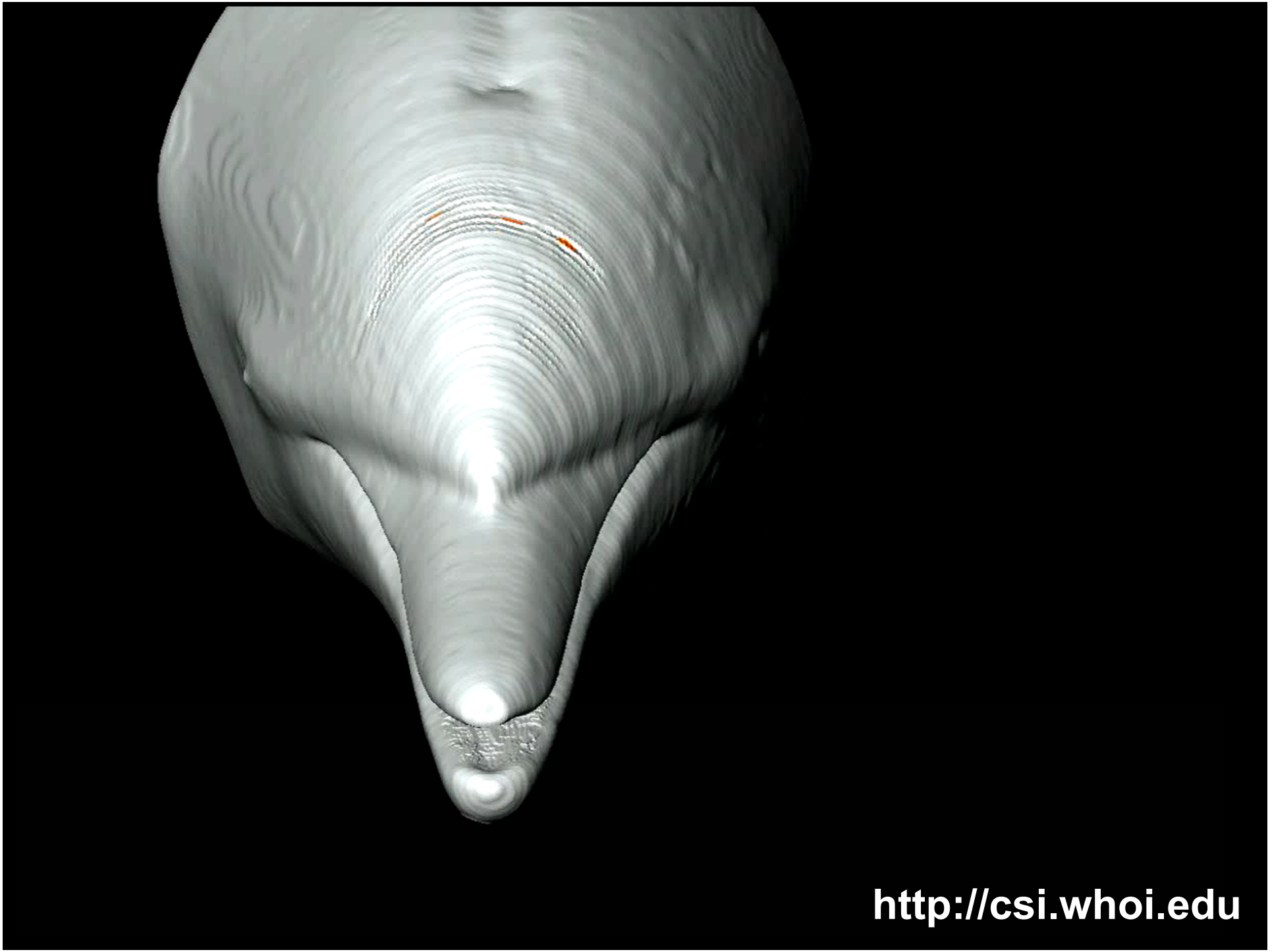

spiral
valve area
external
meatus
air in
external
canal
middle ear
air space
http://csi.whoi.edu



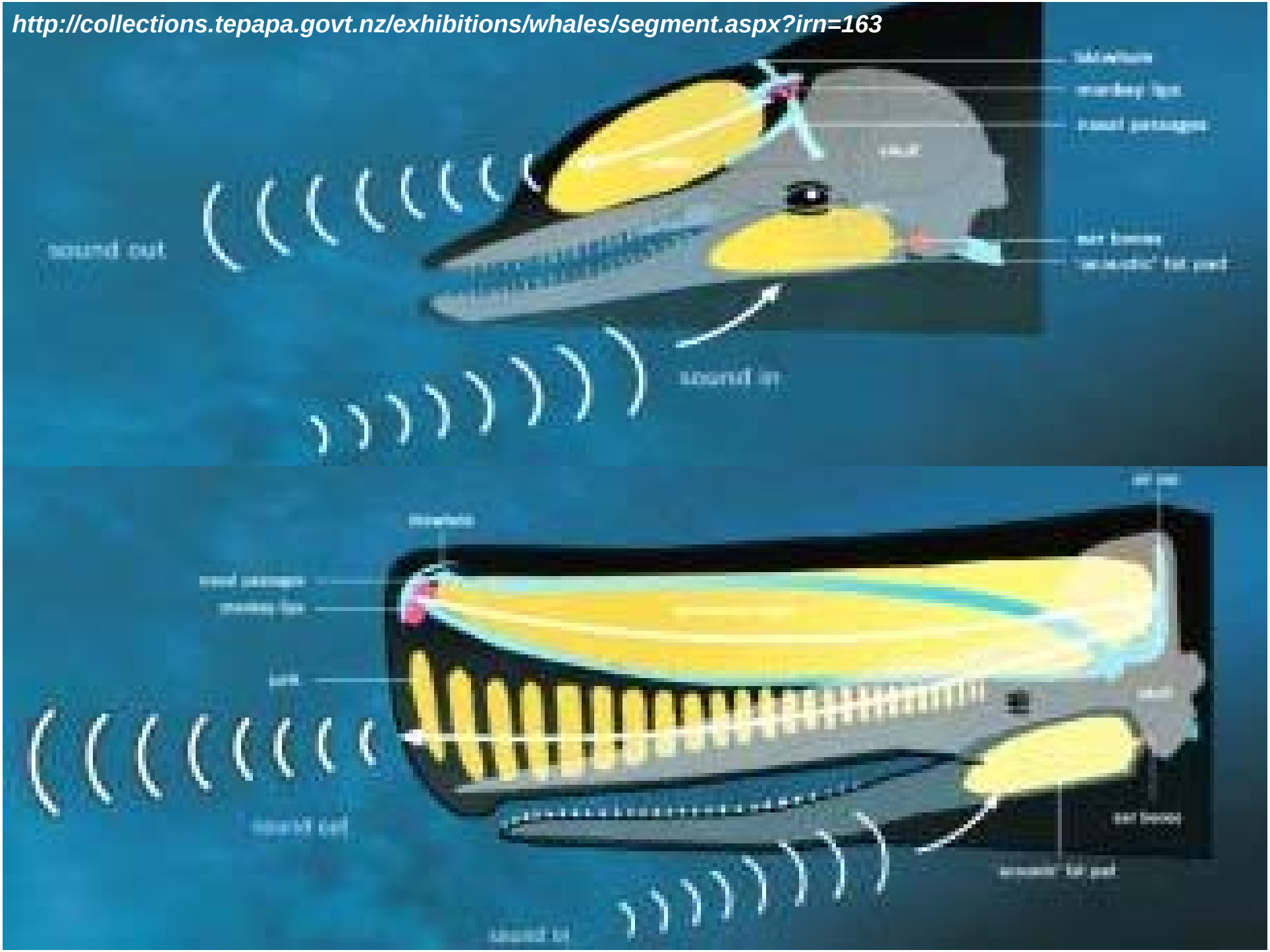
Blainville's Beaked Whale (*Mesoplodon densirostris*)
http://csi.whoi.edu/index.php?q=gallery&g2_itemId=158236



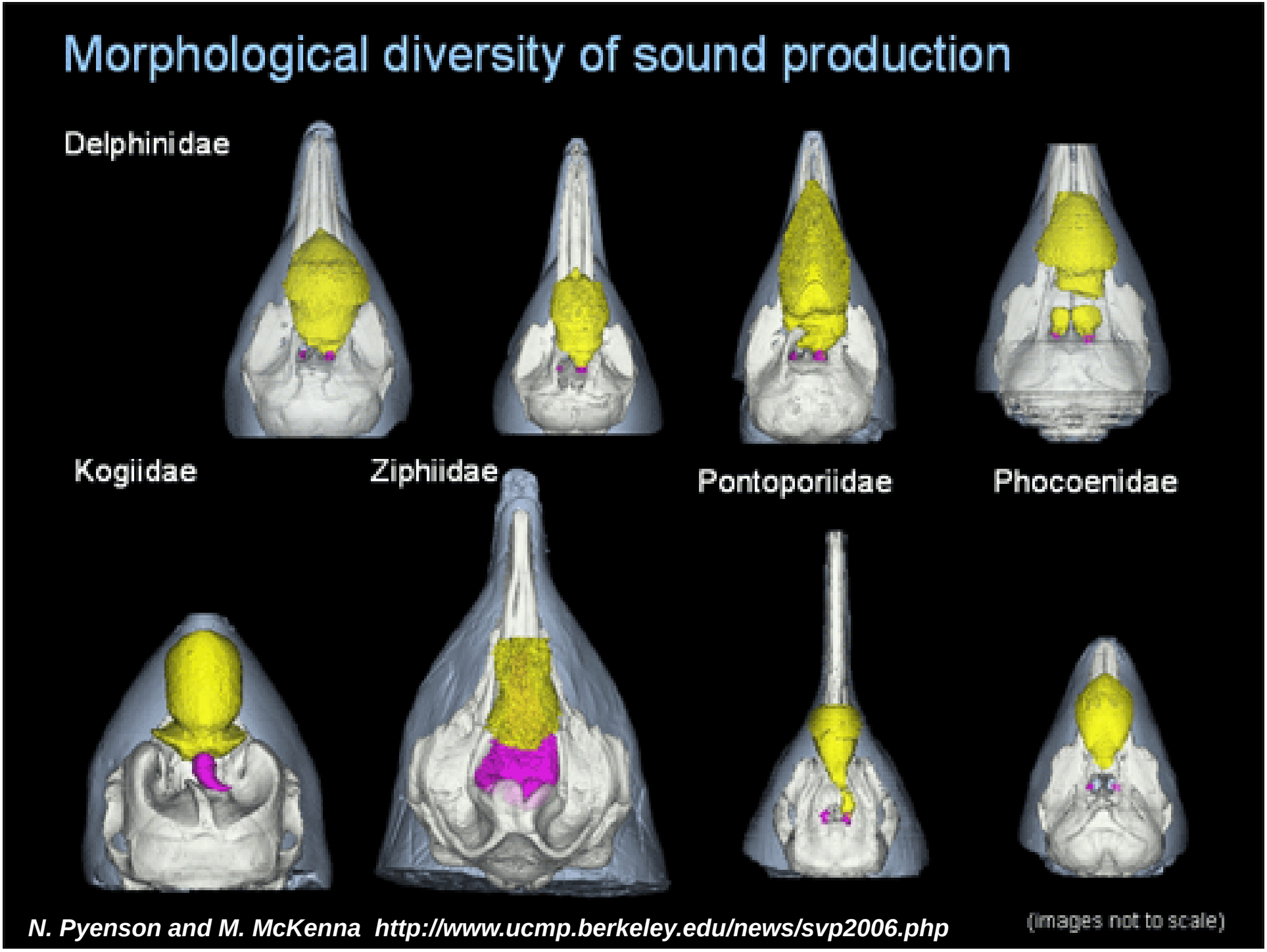
J. Reidenberg/www.DOSITS.org


http://csi.whoi.edu

http://collections.tepapa.govt.nz/exhibitions/whales/segment.aspx?irn=163

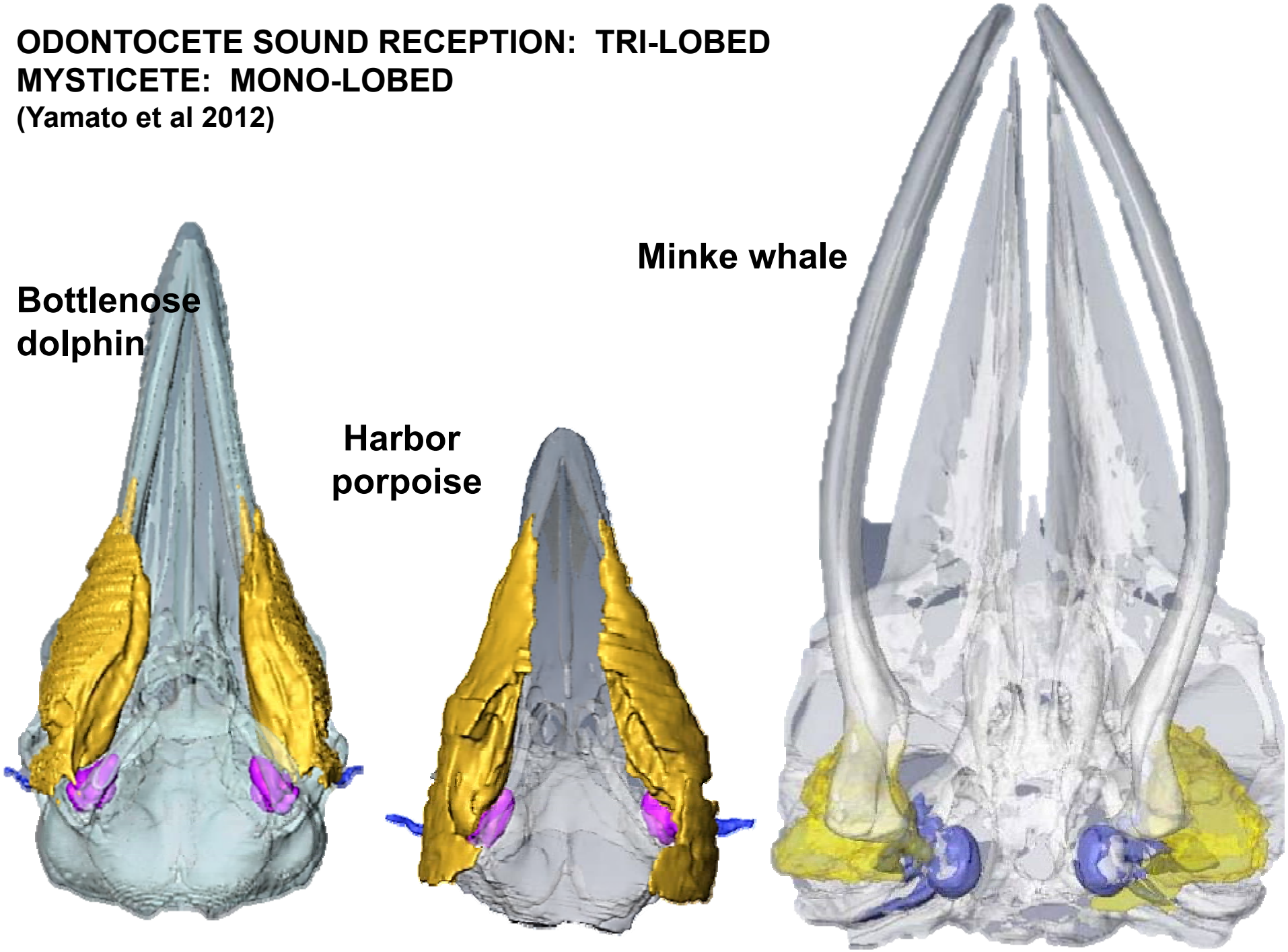


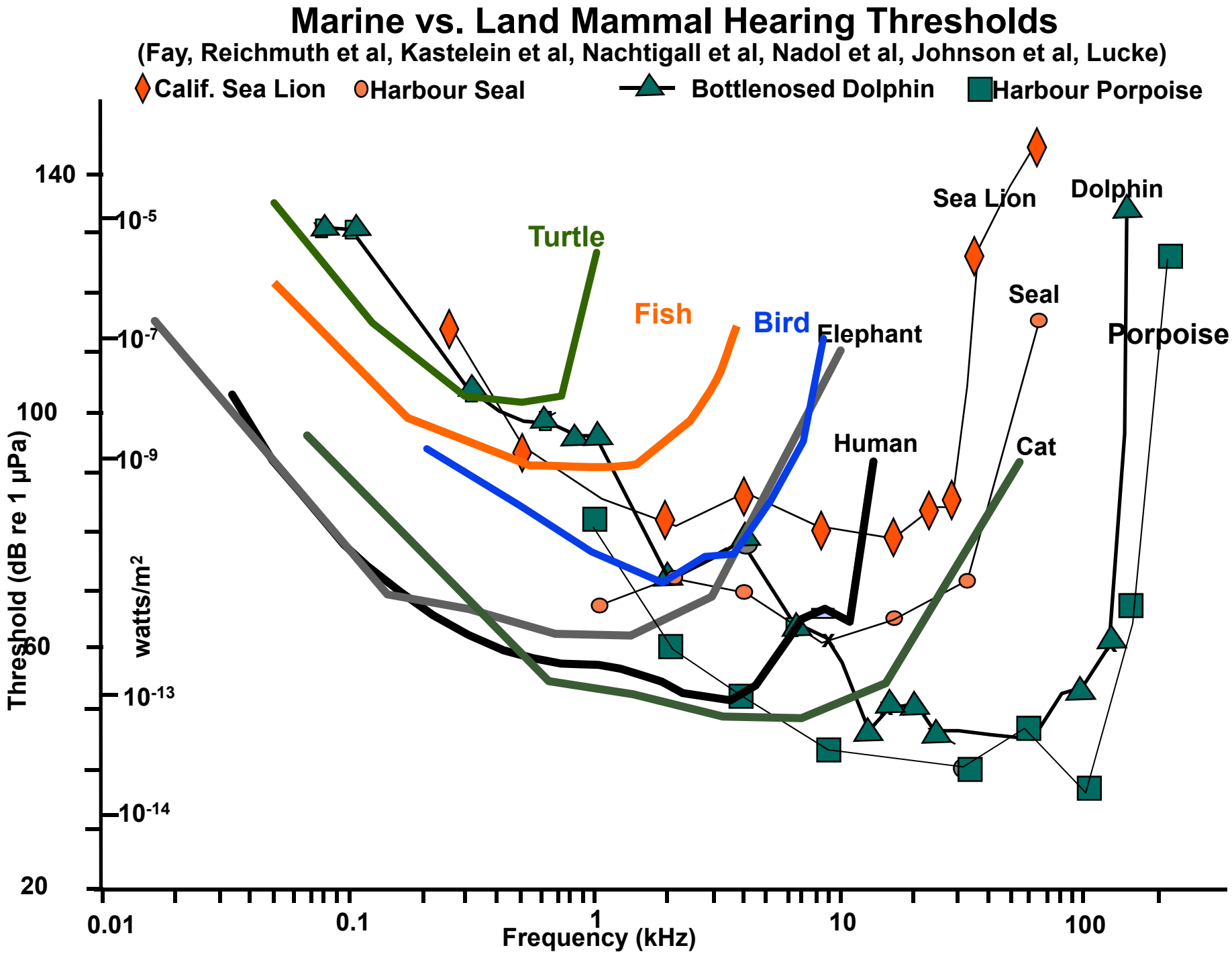
Morphological diversity of sound production

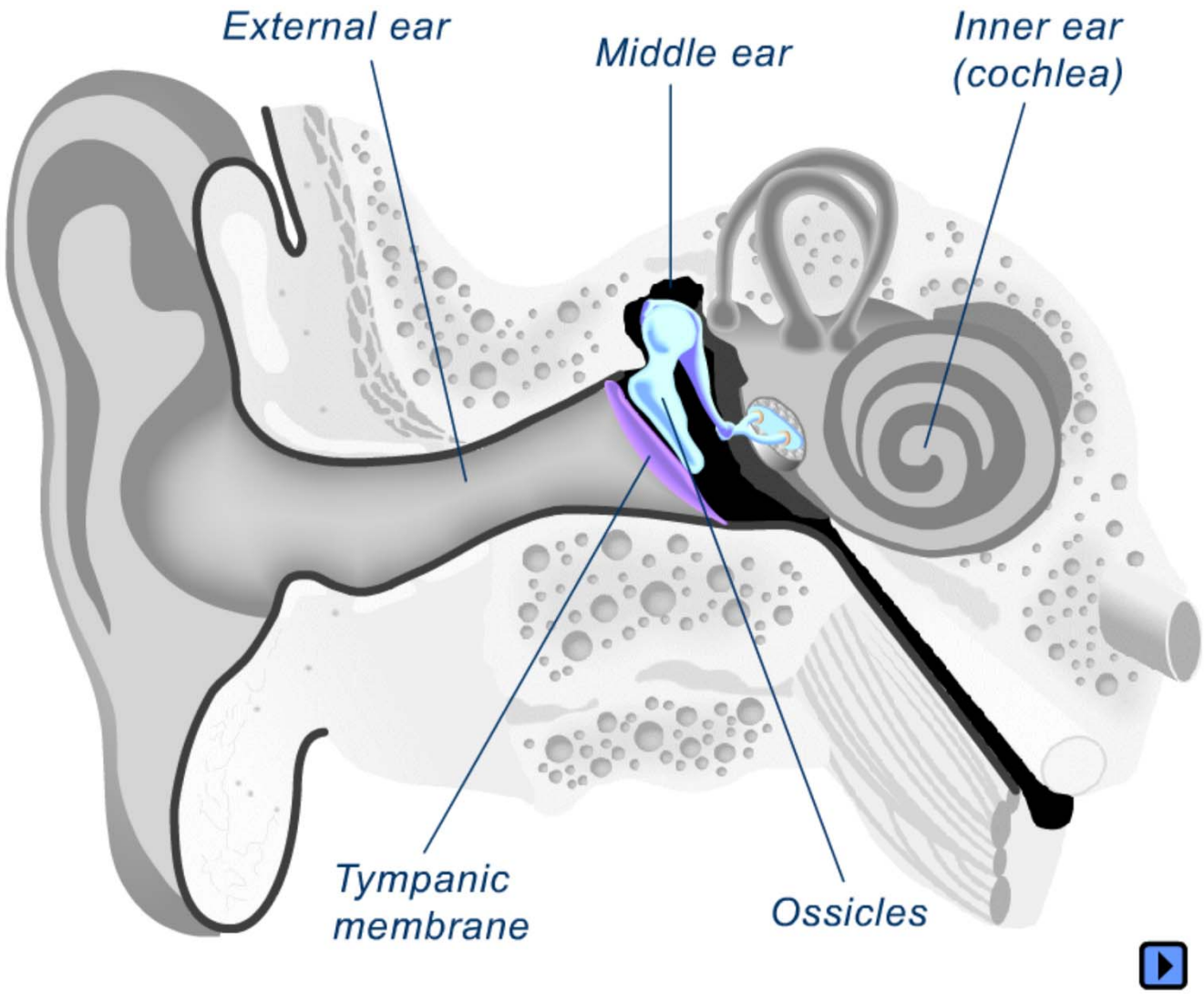


N. Pyenson and M. McKenna http://www.ucmp.berkeley.edu/news/svp2006.php

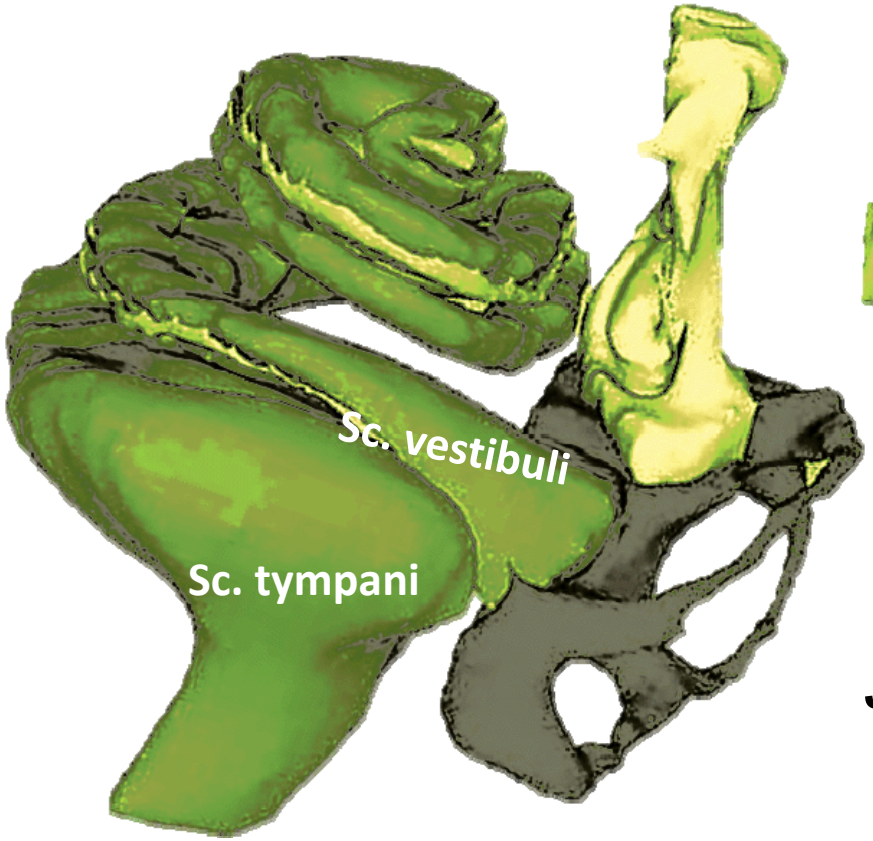
ODONTOCETE SOUND RECEPTION: TRI-LOBED
MYSTICETE: MONO-LOBED
(Yamato et al 2012)



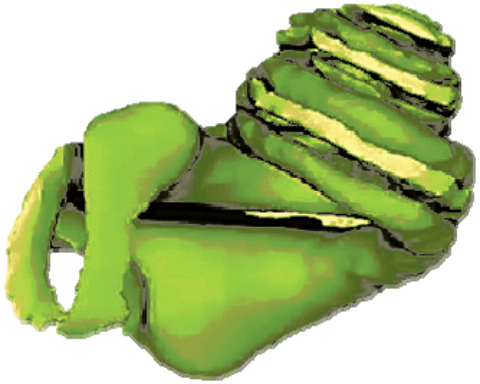

Marine vs. Land Mammal Hearing Thresholds
(Fay, Reichmuth et al, Kastelein et al, Nachtigall et al, Nadol et al, Johnson et al, Lucke)
Calif. Sea Lion
Harbour Seal
Bottlenosed Dolphin
Harbour Porpoise
Turtle
Fish
Bird
Elephant
Human
Cat
Sea Lion
Dolphin
Seal
Porpoise
Threshold (dB re 1 µPa)
watts/m2
140
100
60
20
10-5
10-7
10-9
10-13
10-14
0.01
0.1
1
10
100
Frequency (kHz)


External ear
Middle ear
Inner ear
(cochlea)
Tympanic
membrane
Ossicles


10 mm

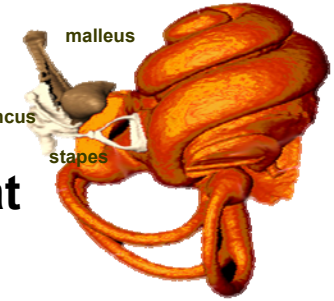


Grey Whale
60.2 mm

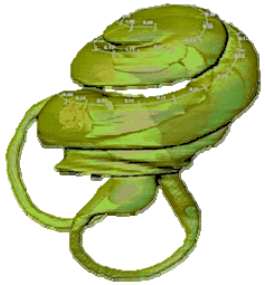


Cat
25.8 mm

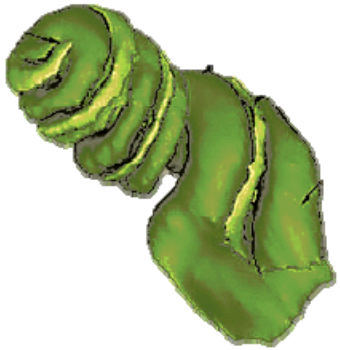
Harbour Porpoise
24.2 mm



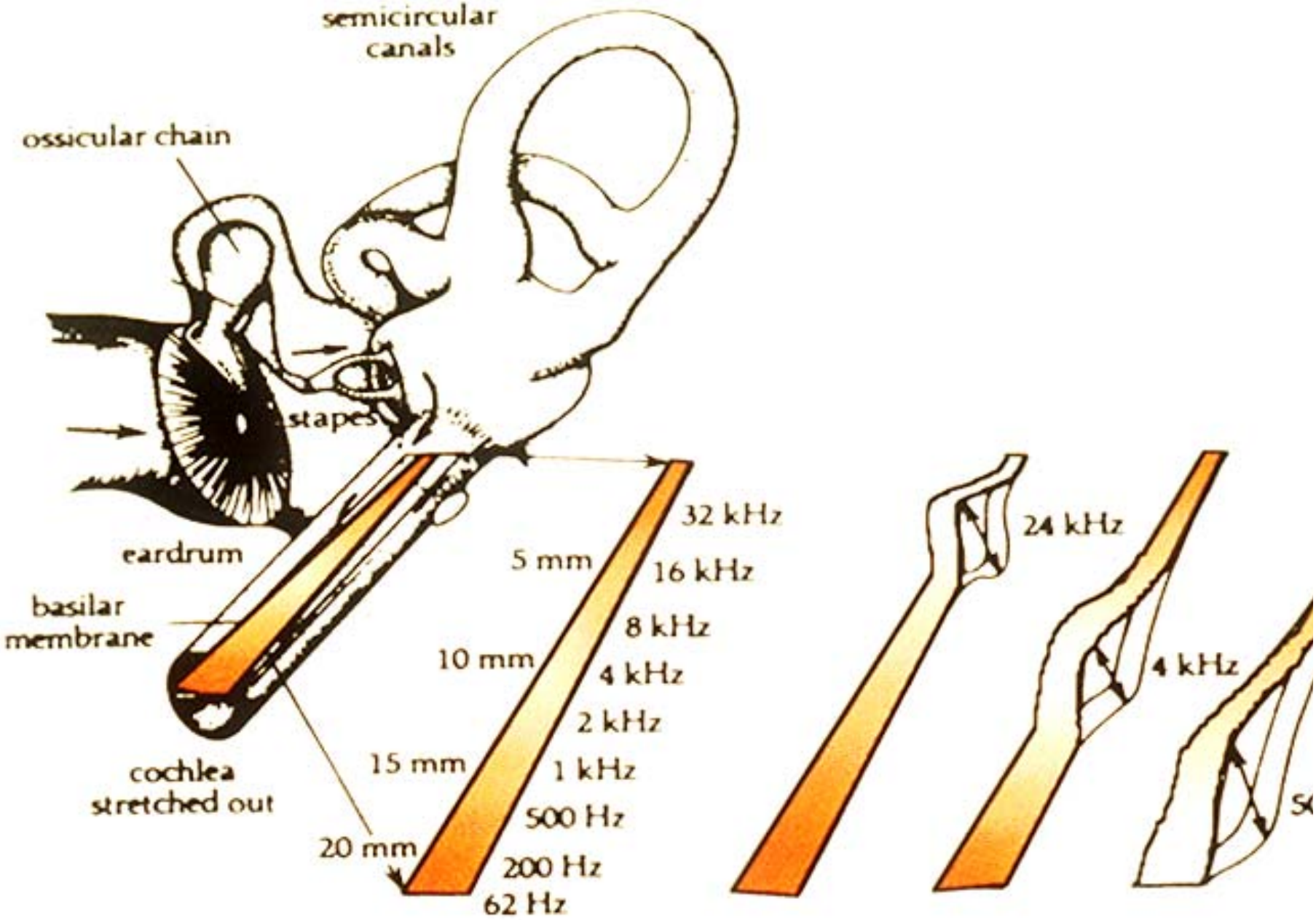
Big brown bat
8.7 mm

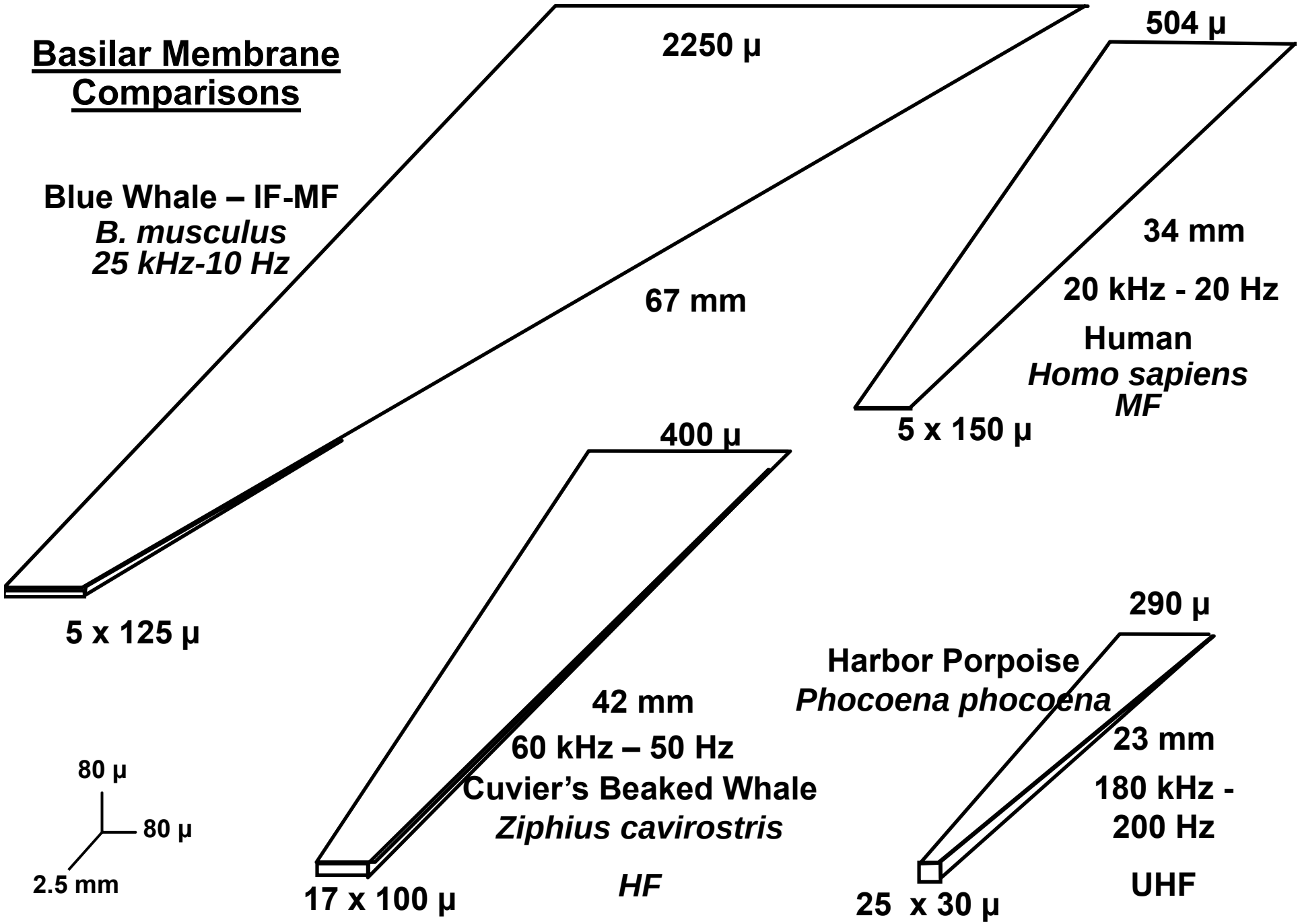


Japanese Pipistrelle bat
6.8 mm



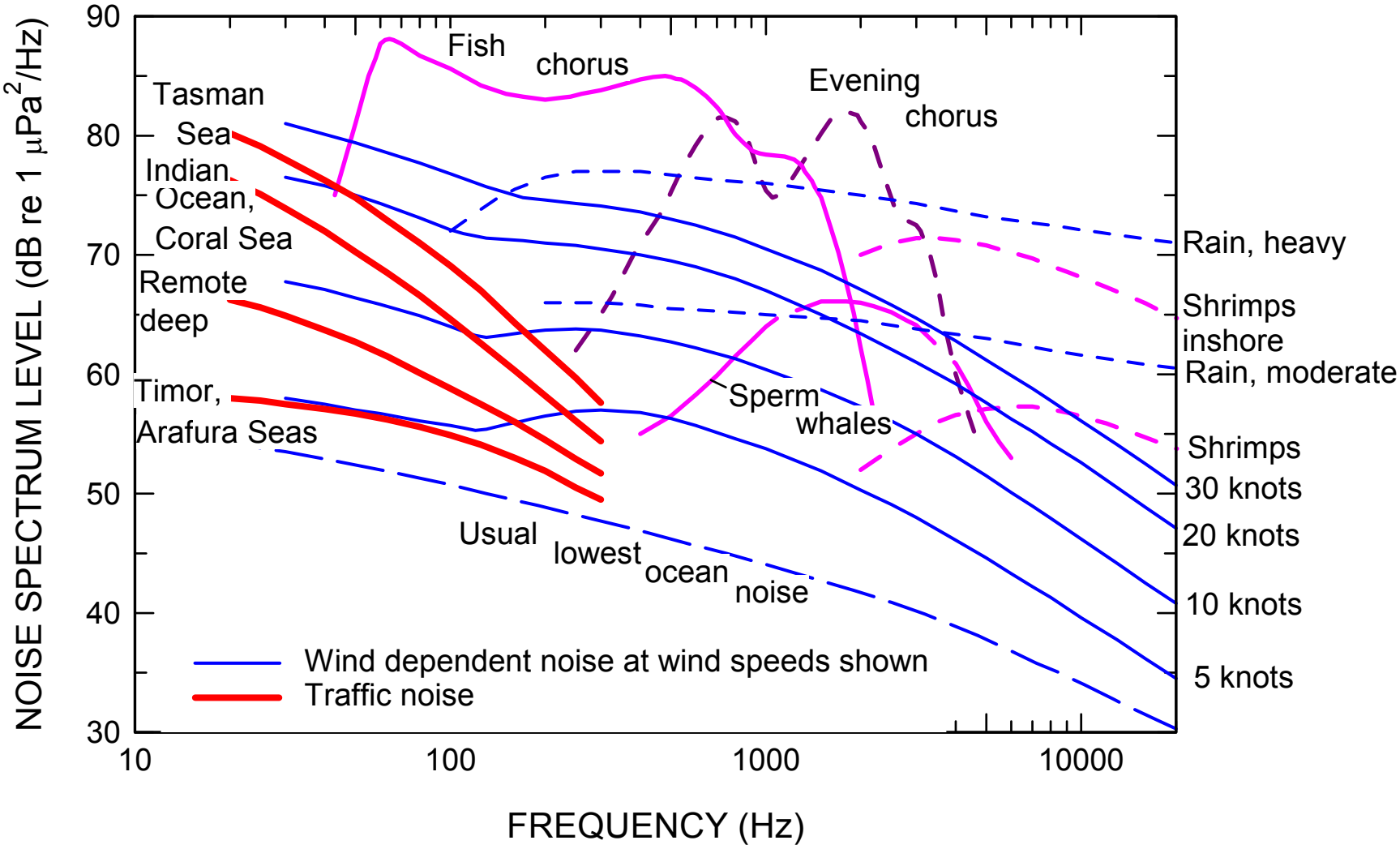
Chinchilla
18.5 mm

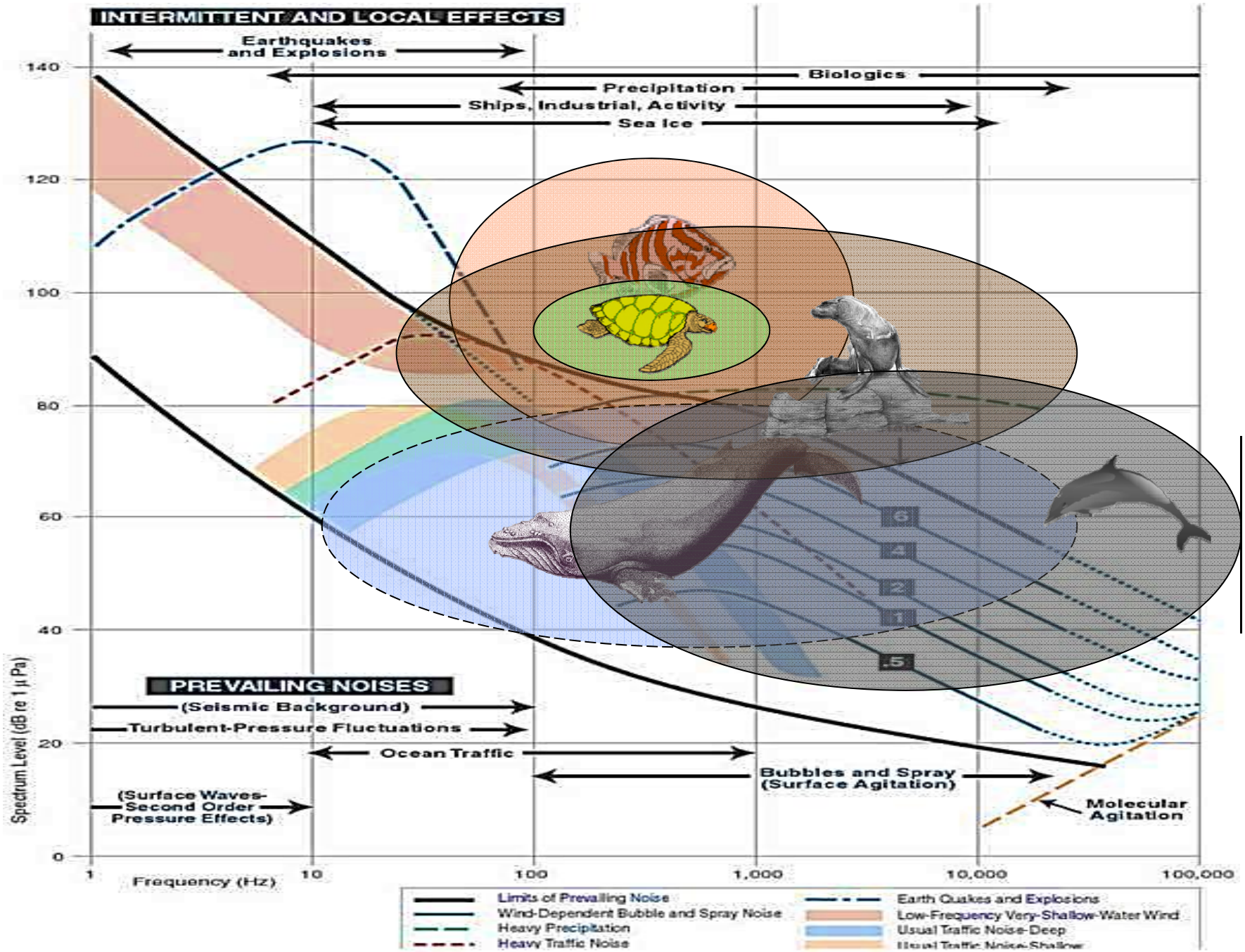

semicircular canals
ossicular chain
stapes
eardrum
basilar membrane
cochlea stretched out
5 mm
10 mm
15 mm
20 mm
32 kHz
16 kHz
8 kHz
4 kHz
2 kHz
1 kHz
500 Hz
200 Hz
62 Hz
24 kHz
4 kHz


Basilar Membrane Comparisons
Blue Whale – IF-MF
B. musculus
25 kHz-10 Hz
2250 µ
67 mm
5 x 125 µ
504 µ
34 mm
20 kHz - 20 Hz
Human
Homo sapiens
MF
5 x 150 µ
400 µ
42 mm
60 kHz – 50 Hz
Cuvier's Beaked Whale
Ziphius cavirostris
HF
17 x 100 µ
290 µ
Harbor Porpoise
Phocoena phocoena
23 mm
180 kHz - 200 Hz
UHF
25 x 30 µ
80 µ
80 µ
2.5 mm

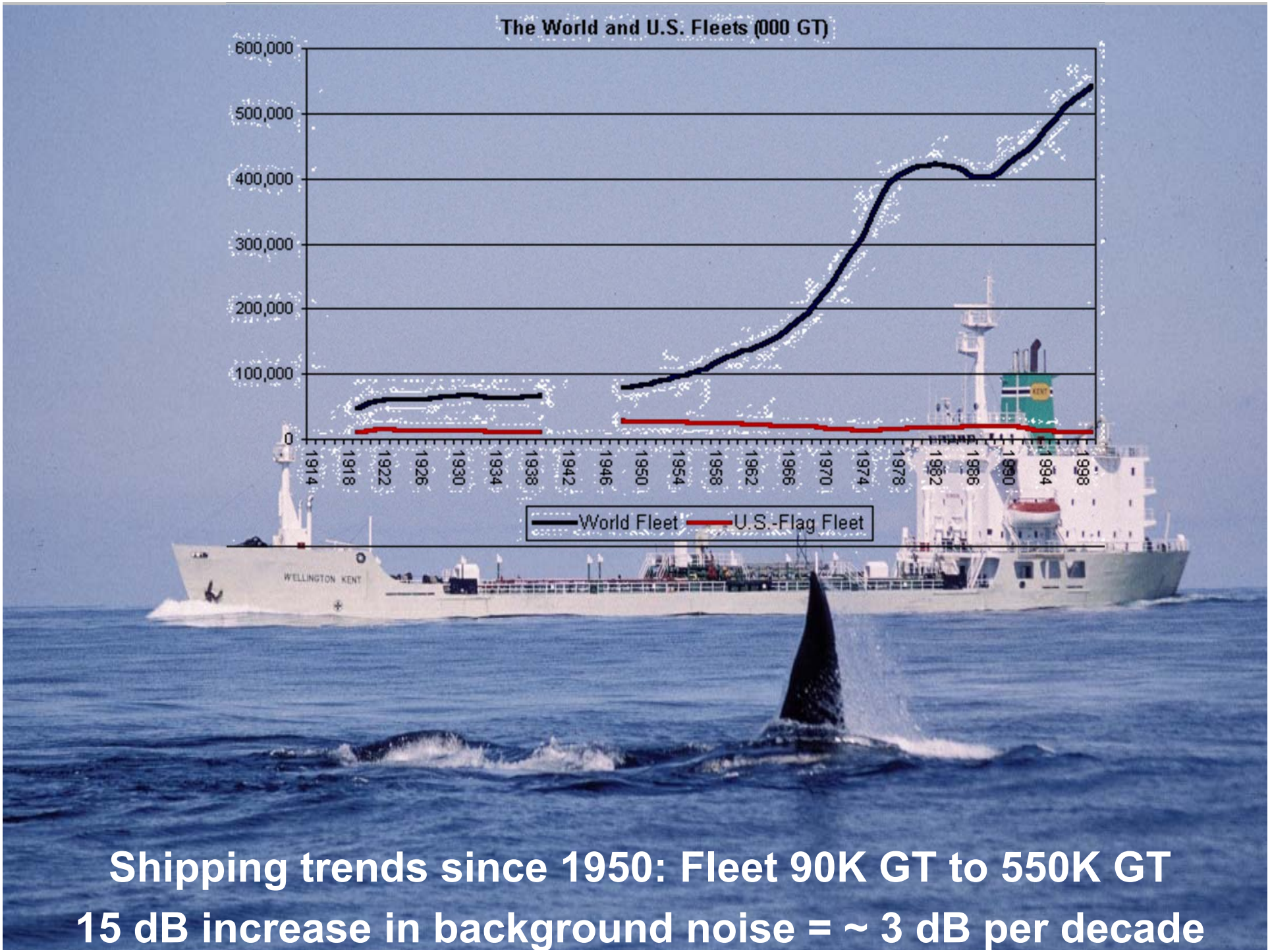

SOUND
in the
WATER!

Ambient ocean noise in the Australian region
(courtesy Doug Cato, Univ. of Sydney)



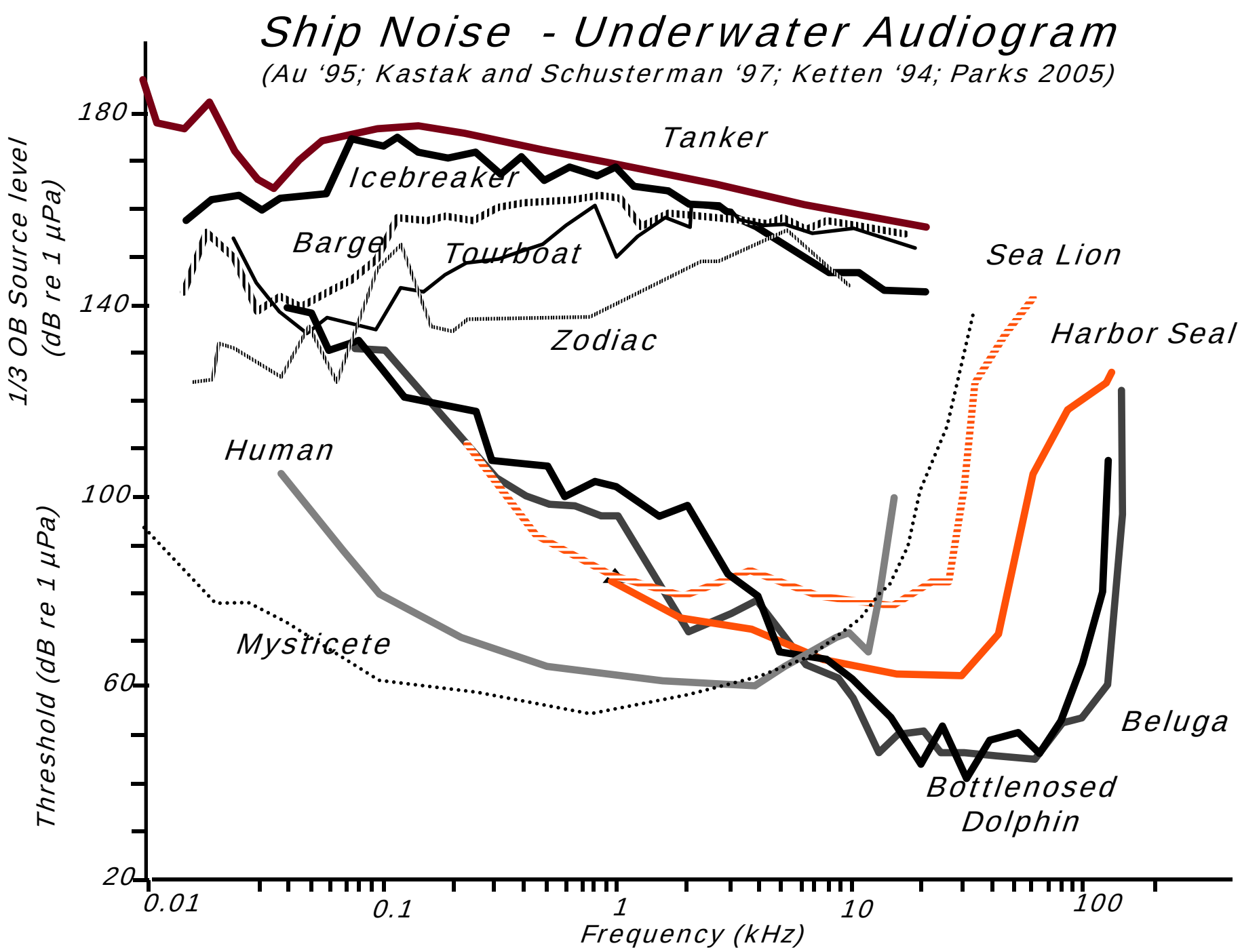


adapted from Wenz, 1962, Ocean Noise and Marine Mammals, NRC, 2003



Shipping trends since 1950: Fleet 90K GT to 550K GT

15 dB increase in background noise = ~ 3 dB per decade


Ship Noise - Underwater Audiogram
(Au '95; Kastak and Schusterman '97; Ketten '94; Parks 2005)
1/3 OB Source level (dB re 1 µPa)
Threshold (dB re 1 µPa)
180
140
100
60
20
0.01
0.1
1
10
100
Frequency (kHz)
Tanker
Icebreaker
Barge
Tourboat
Zodiac
Sea Lion
Harbor Seal
Human
Mysticete
Beluga
Bottlenosed Dolphin

Effect of Noise on Hearing in the Surface World

What do we mean by hearing?

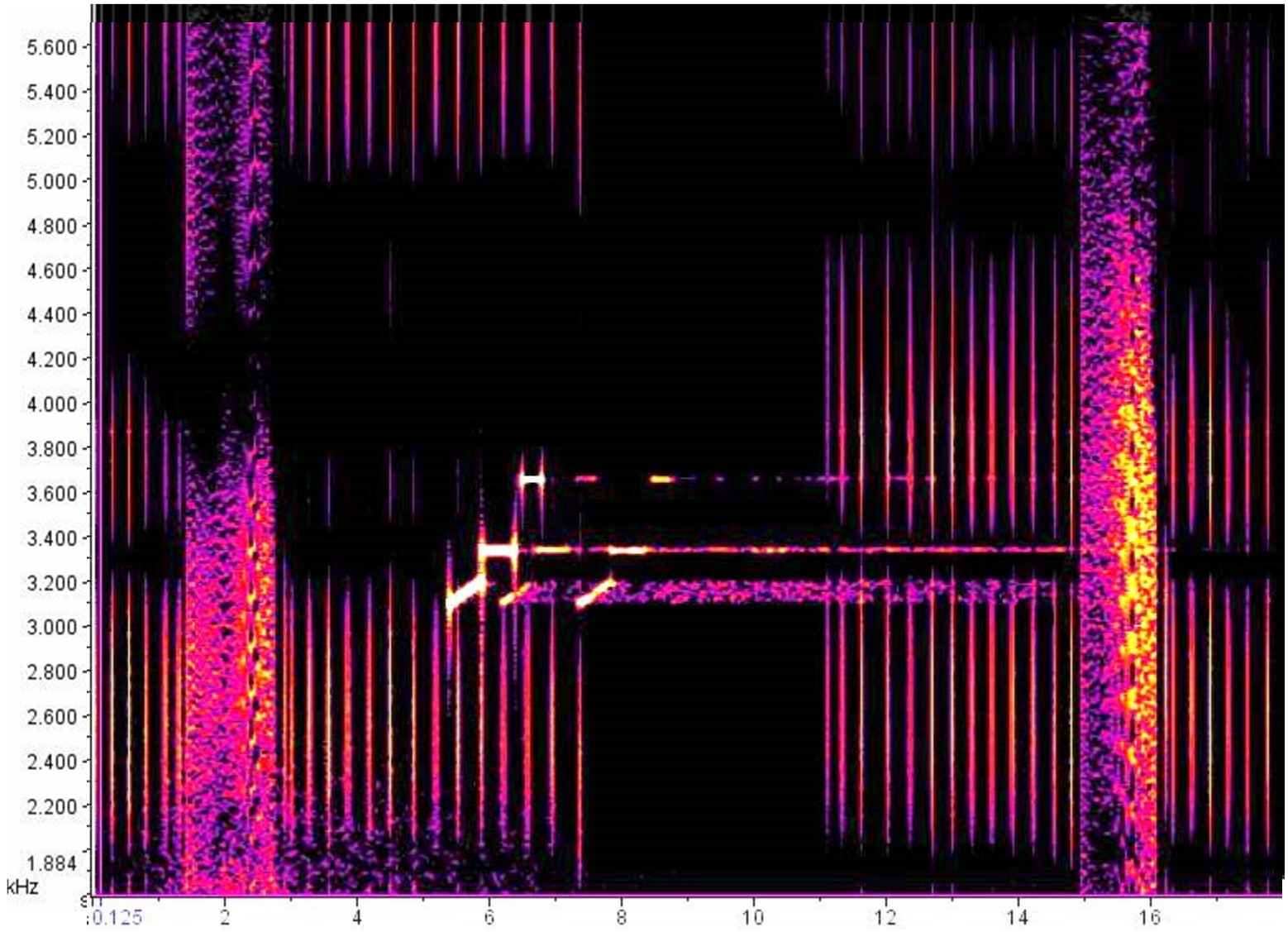
- Detection (smallest s/n ratio or CR)
- Discrimination (+ ~2-3 dB)
- Recognition (+ ~4-6 db)
- Comfortable Communication (+ ~15 dB)*

*Only measurable in humans

D-Tags:
Dive Profiles

Naval Sonar as recorded on Dtagged Whale

Courtesy Peter Tyack



Time in seconds

Public, Conservation, Legal Concerns

HARVARD MAGAZINE 19

Right Now

SPECT: SONAR

Whales Downed by Sound?

NAVY [illegible] may have caused a [illegible] stranding of whales this spring in the Bahamas. The National Marine Fisheries Service (NMFS) and the U.S. Navy are jointly investigating that possibility after 14 [illegible] whales [illegible] several different [illegible] in the northern Bahamian islands within several hours. The whales stranded in a south-to-north pattern as navy ships using tactical sonar passed over a deep underwater canyon beneath the [illegible] channel.

[illegible] marine biologist Darlene Ketten of the [illegible] graphic [illegible] Harvard Medical School, where she is assistant professor of otology and [illegible] investigation. Ketten is an expert on whale auditory systems and underwater acoustic trauma in particular, including impulse and blast effects. What she and other scientists found in studying the six whales that died from the stranding (the rest were successfully pushed back into the sea) was that all had hemorrhages in or around the ears. Says Ketten, "The traumas we found were to the auditory system and to some brain and throat regions that are commonly injured by intense pressures.

[illegible] of beaked whales in the northern Bahamas may have been caused by sonar from passing U.S. Navy vessels. Six of the beaked whales died, including this one born

Greece, 1996

Canarias, 1996

Italy, 1960

Madagascar 2009

Peru 2012

Bahamas, March 2000

Madeira, May 2000

Tasmania, Oct 2005

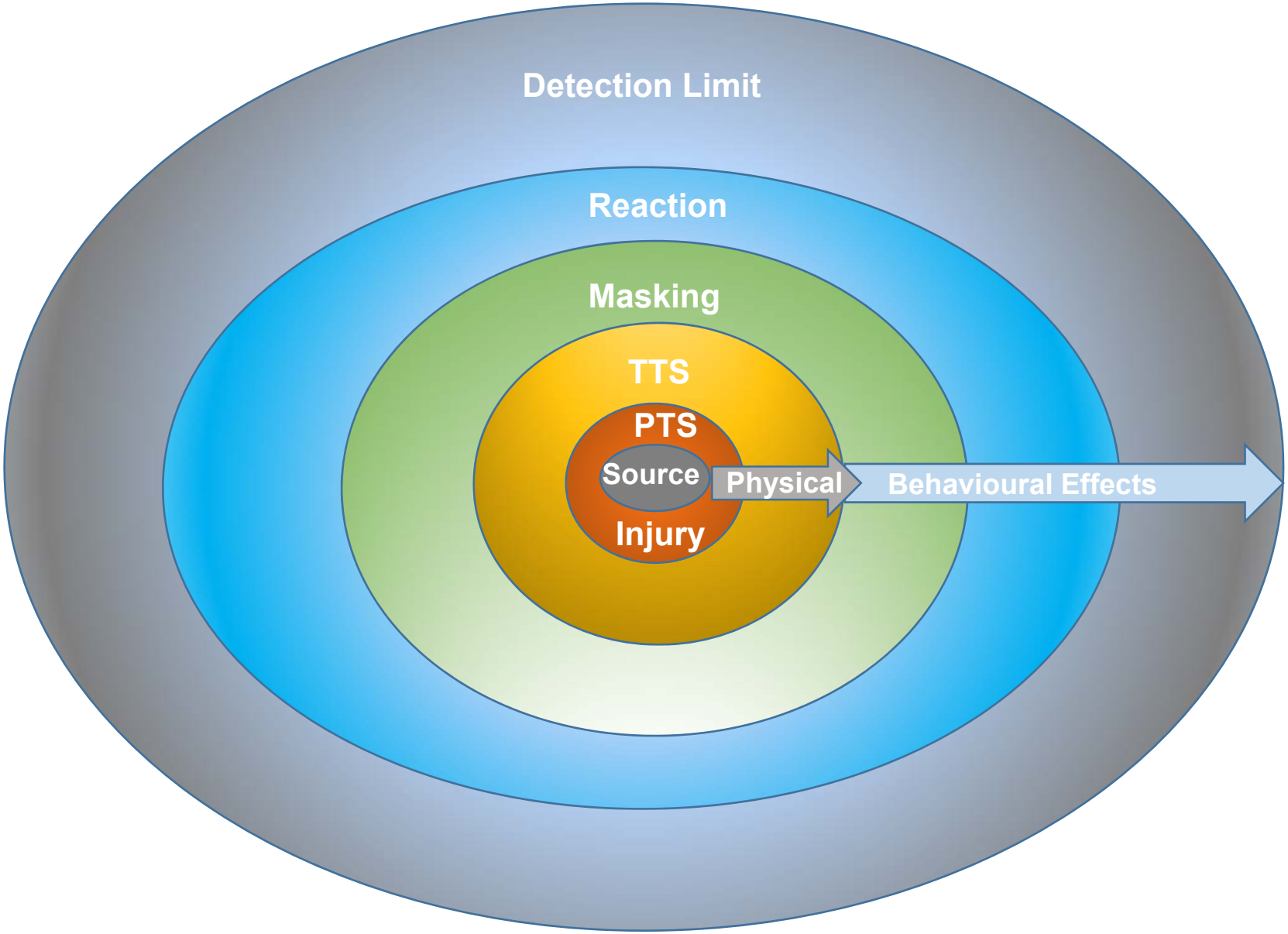
131 strandings
(1950 – 2014)

14 coincident with naval exercises
4 coincident with seismic vessels

Sound related stranding deaths: 322 (1950-2014)

(d'Amico et al, Aquatic Mammals, 2009; Ketten, Acoustics Today, 2014)

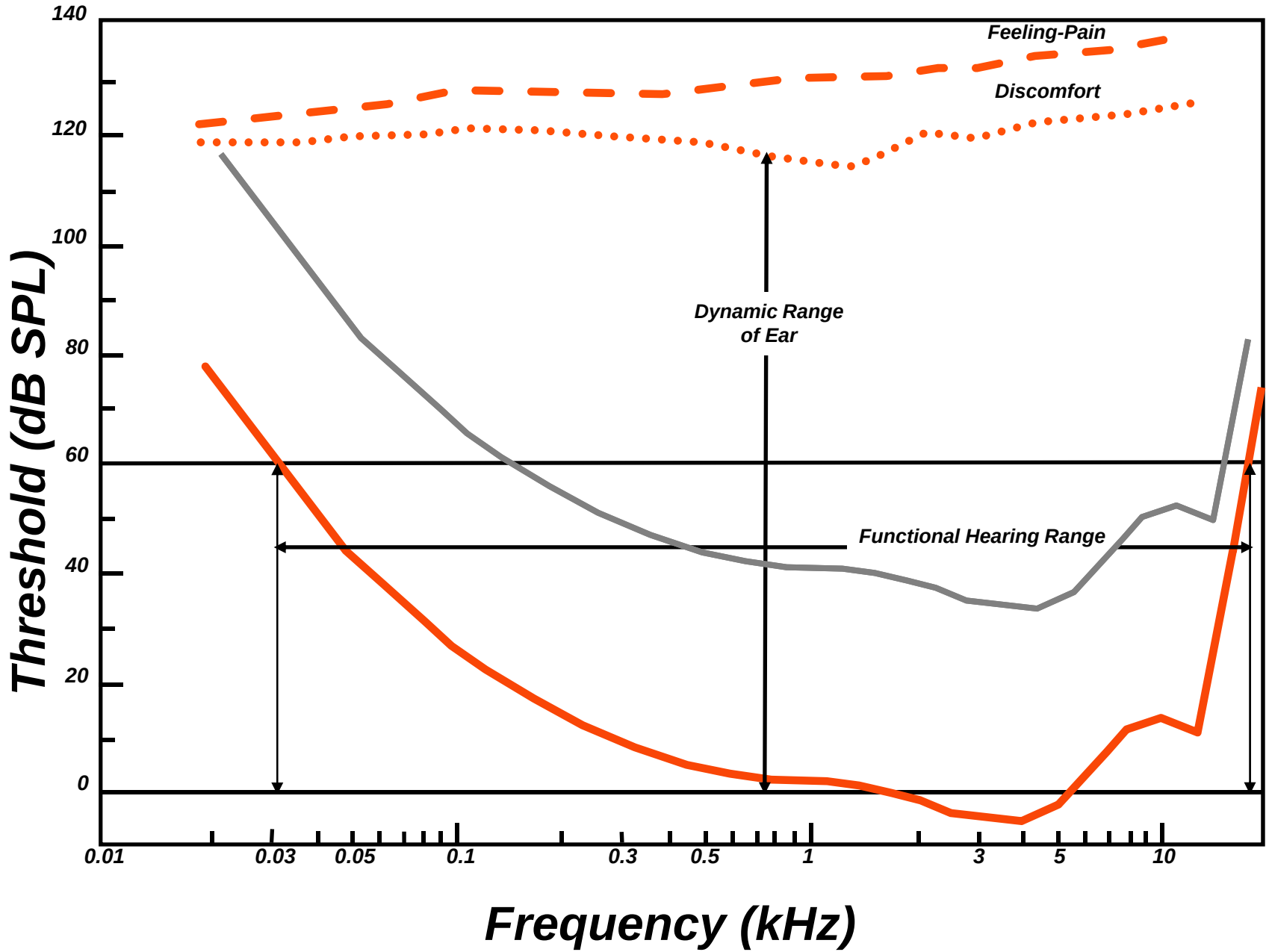

STRESS:
Herpes-like Virus Infection in
Yangtze Finless Porpoise
Pei et al. 2012, J. Wildlife Diseases


Detection Limit
Reaction
Masking
TTS
PTS
Source
Injury
Physical
Behavioural Effects

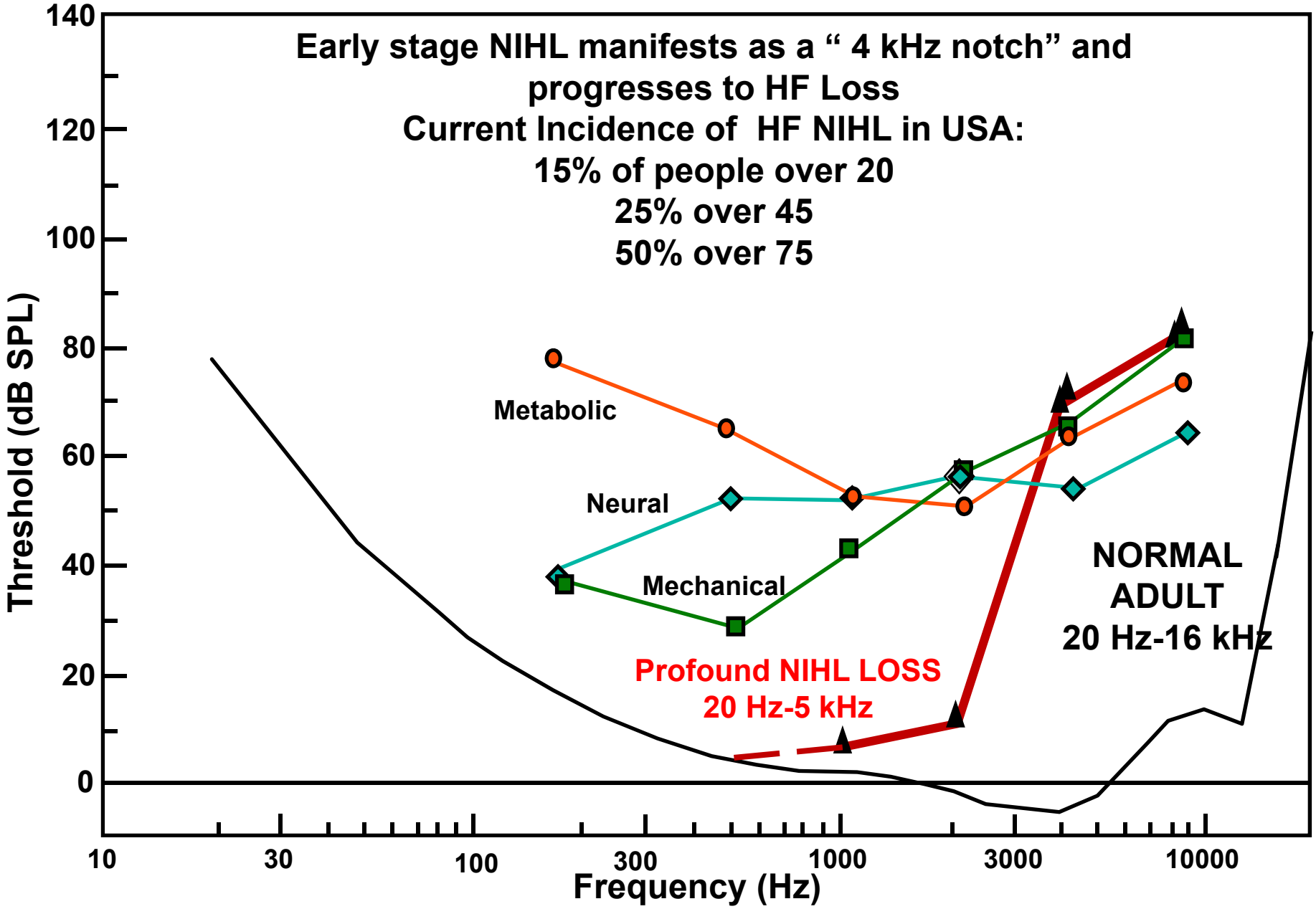
How “Tough” are Marine Mammals?

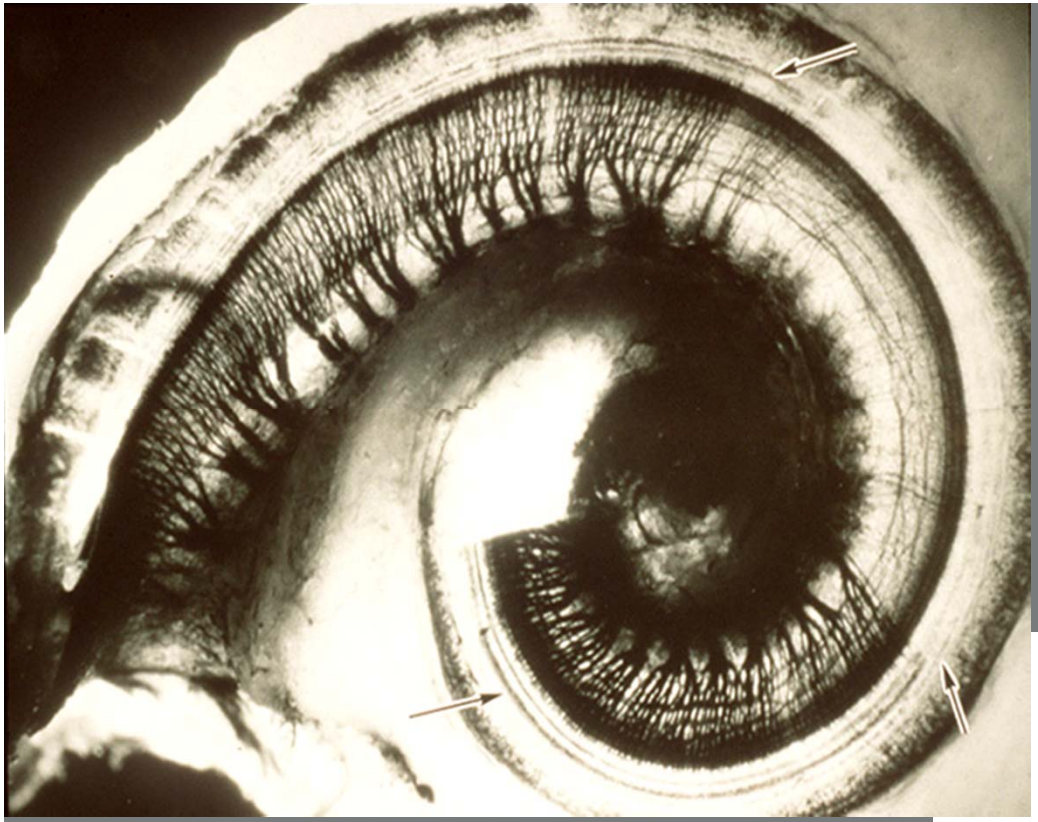
Is there evidence of hearing loss?

Human Hearing and Hearing Loss (TTS-PTS)*(NIOSH/ISO-1999 Standard)*



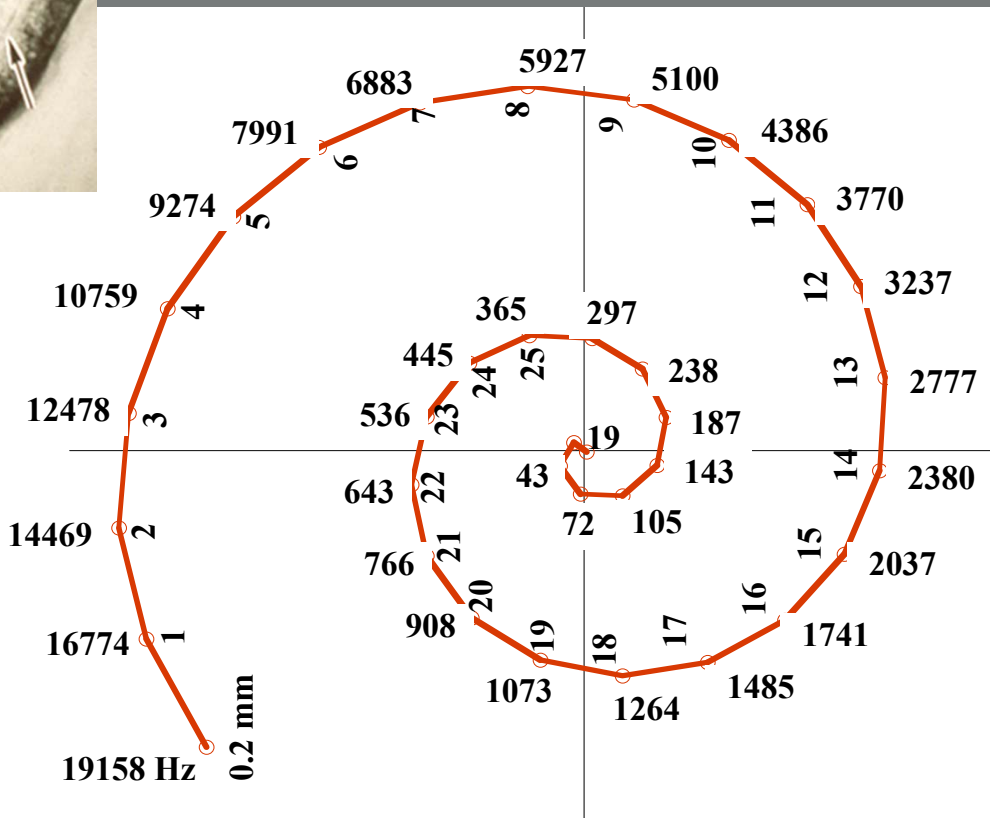
Davis et al. 2003, Kryter. 1996, Slepecky, 1986 ,Schuknecht, 1993; Yost, 2000, www.nidcd.nih.gov

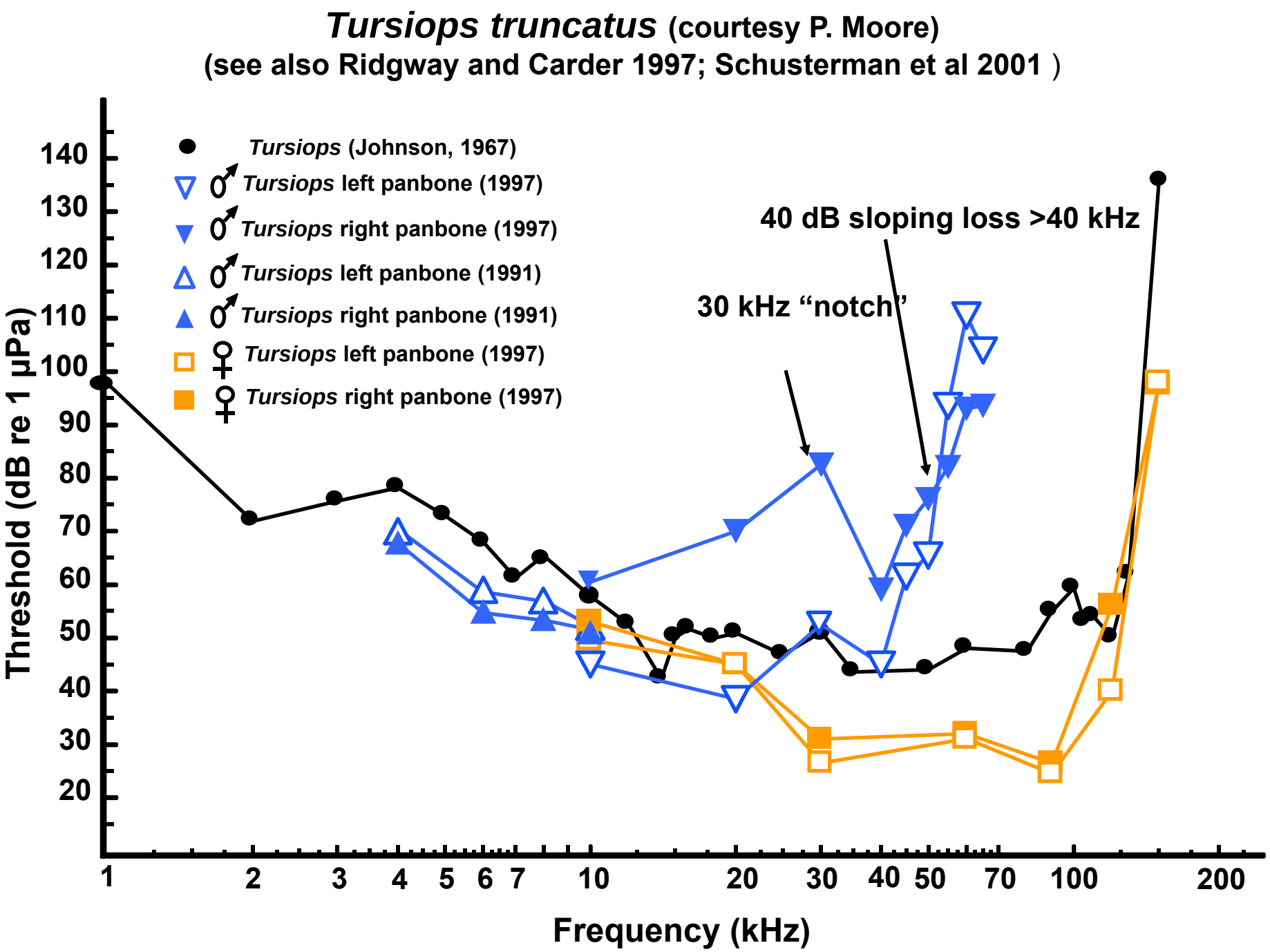


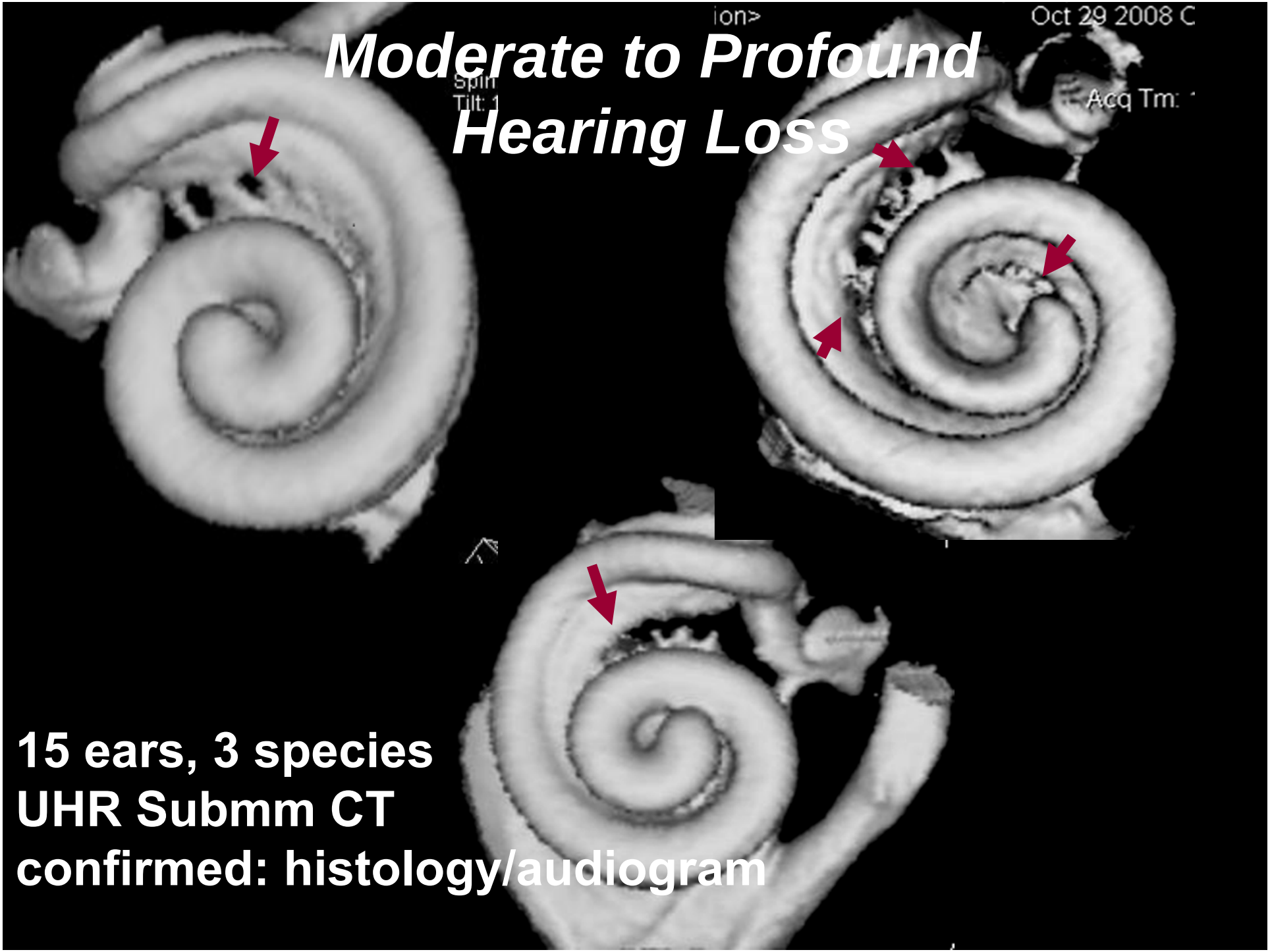


TTS to PTS: Recoverable dysfunction of cochlear structures

vs. permanent tissue loss




Tursiops truncatus (courtesy P. Moore)
(see also Ridgway and Carder 1997; Schusterman et al 2001)
Tursiops (Johnson, 1967)
Tursiops left panbone (1997)
Tursiops right panbone (1997)
Tursiops left panbone (1991)
Tursiops right panbone (1991)
Tursiops left panbone (1997)
Tursiops right panbone (1997)
40 dB sloping loss >40 kHz
30 kHz "notch"
Threshold (dB re 1 µPa)
140
130
120
110
100
90
80
70
60
50
40
30
20
1
2
3
4
5
6
7
10
20
30
40
50
70
100
200
Frequency (kHz)


Moderate to Profound
Hearing Loss
ion>
Oct 29 2008 C
Spin
Tilt: 1
Acq Tm:
15 ears, 3 species
UHR Submm CT
confirmed: histology/audiogram

High-Frequency Response of 8 *Tursiops* to a 100 ms Tone Stimulus of 111 dB re 1 micro Pa

Ridgway and Carder; JASA 101 (1), 1997

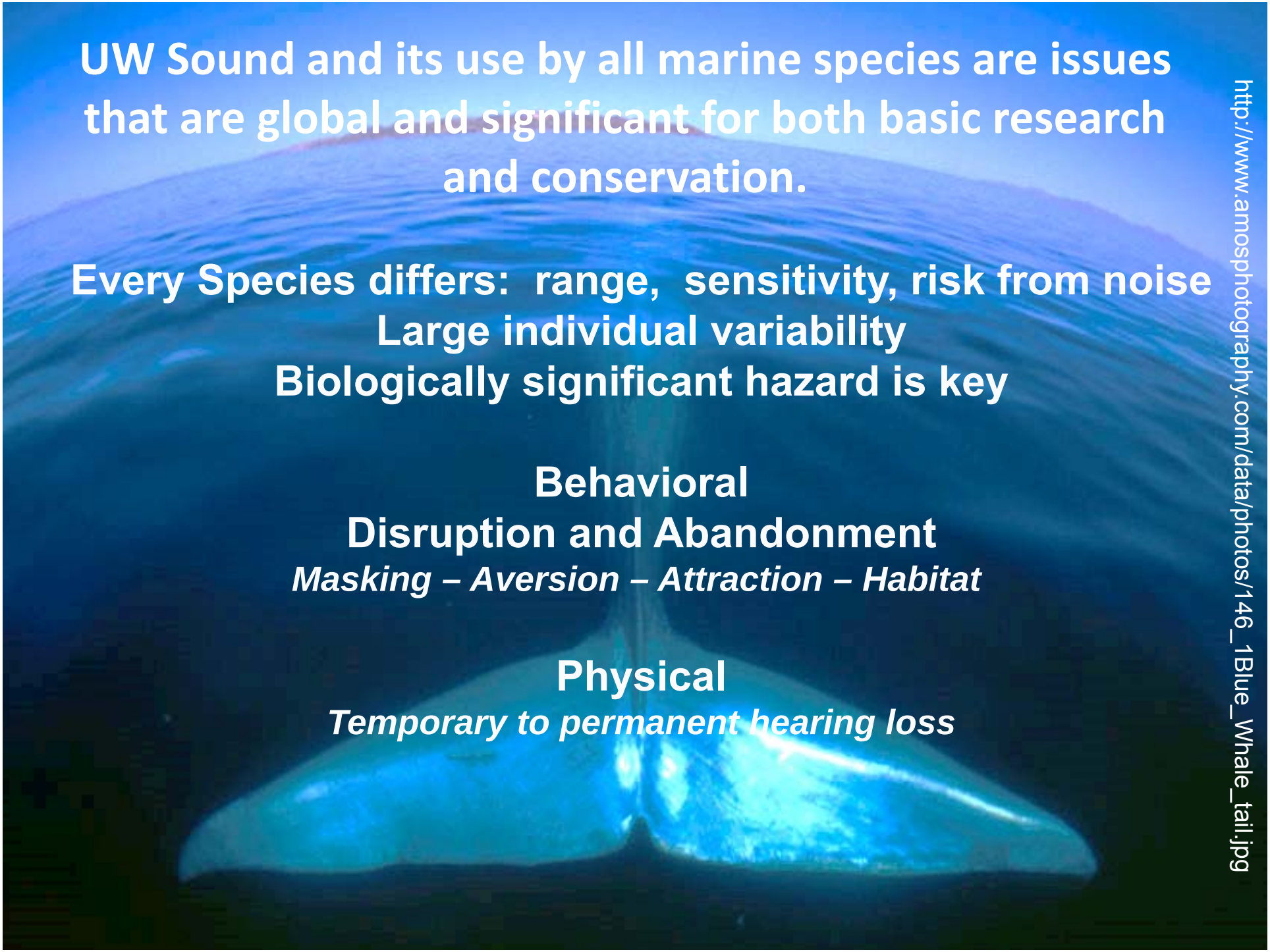
Animal	Sex	Age	Stimulus Frequency (kHz) 40	60	80	100	120
MAU	♂	34	▲	△	△	△	△
MKA	♂	23	▲	◭	△	△	△
IAY	♂	26	▲	◭	△	△	△
NAY	♂	7	▲	▲	▲	▲	▲
TOD	♀	35	▲	▲	▲	▲	▲
SLA	♀	33	▲	▲	◭	△	△
BRT	♀	32	▲	▲	▲	▲	▲
SAY	♀	11	▲	▲	▲	▲	▲

▲ > 95% Responses

◭ > 75% Responses

◭ < 50% Responses

△ > 50% Responses


UW Sound and its use by all marine species are issues that are global and significant for both basic research and conservation.
Every Species differs: range, sensitivity, risk from noise
Large individual variability
Biologically significant hazard is key
Behavioral
Disruption and Abandonment
Masking – Aversion – Attraction – Habitat
Physical
Temporary to permanent hearing loss
http://www.amosphotography.com/data/photos/146_1Blue_Whale_tail.jpg