Cetacean echolocation and outer space neutrinos

School of Ethology - Ettore Majorana Centre
Erice, Sicily – October 18-21 2013

Marine Mammal Bioacoustics: An overview of sound production and hearing in pinnipeds and cetaceans

Brandon L. Southall

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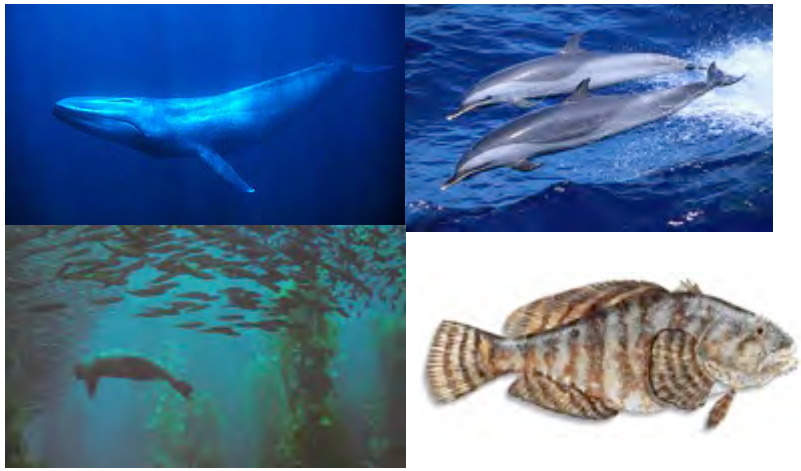
Long Marine Laboratory, Santa Cruz, CA

Duke University Marine Laboratory
Beaufort, NC

Marine Bioacoustics and Noise

The ocean is a naturally noisy place



Marine animals produce sound and listen for acoustic cues critical in their life history

Humans produce underwater sound either *intentionally* or *incidentally*

Lecture Objectives

1) **Overview of Marine Mammal Bioacoustics**

2) **Introduction to Human Noise Impacts**

3) **Scientific and Conservation Reasons to Listen with Ocean Observing Systems**

Who are the Marine Mammals?

Seals, Sea Lions, Walruses
"Pinnipeds"

Dolphins and Porporpoises
"Toothed Whales"

Great Whales
"Baleen Whales"

Manatees
Dugongs

Sea Otters
Polar Bears

Marine Mammal Species

Order CARNIVORA

Family Otariidae (sea lions, fur seals)
- Cape fur seal
- Antarctic fur seal
- Subantarctic fur seal
- Guadalupe fur seal
- New Zealand fur seal
- South American fur seal
- Galapagos fur seal
- Juan Fernandez fur seal
- Northern fur seal
- California/Galapagos sea lion
- Steller's sea lion
- Australian sea lion
- Hooker's sea lion
- South American sea lion

Family Odobenidae (walrus)
- Walrus

Family Phocidae (seals)
- Bearded seal
- Harbour seal
- Spotted seal
- Ringed seal
- Caspian seal
- Baikal seal
- Grey seal
- Ribbon seal
- Harp seal
- Hooded seal
- Mediterranean monk seal
- Hawaiian monk seal
- Southern elephant seal
- Northern elephant seal
- Weddell seal
- Ross seal
- Crabeater seal
- Leopard seal

Family Mustelidae (weasels and otters)
- Sea otter
- Marine otter

Family Ursidae (bears)
- Polar bear

Order CETECEA
Suborder ODONTOCETI

Family Physeteridae
- Sperm whale

Family Kogiidae
- Pygmy sperm whale
- Dwarf sperm whalle

Family Ziphiidae (beaked whales)
- Cuvier's beaked whale
- Arnoux's beaked whale
- Baird's beaked whale
- Shepard's beaked whale
- Longman's beaked whale
- Southern bottlenose whale
- Northern bottlenose whale
- Hector's beaked whale
- True's beaked whale
- Gervais' beaked whale
- Sowerby's beaked whale
- Gray's beaked whale
- Pygmy beaked whale
- Andrews' beaked whale
- Spade-toothed whale
- Hubbs' beaked whale
- Ginko-toothed whale
- Stejneger's beaked whale
- Strap-toothed whale
- Blainville's beaked whale

Family Plantistidae
- South Asian river dolphin

Family Iniidae
- Amazon river dolphin

Family Lipotidae
- Chinese river dolphin

Family Pontoporiidae
- La Plata dolphin

Family Monodontidae
- Beluga
- Narwhale

Family Delphinidae (dolphins)
- Commerson's dolphin
- Chilean dolphin
- Heaviside's dolphin
- Hector's dolphin
- Rough-toothed dolphin
- Atlantic humpbacked dolphin
- Indian humpbacked dolphin
- Pacific humpbacked dolphin
- Tucuxi
- Common bottlenose dolphin
- Indian Ocean bottlenose dolphin
- Pan-tropical spotted dolphin
- Atlantic spotted dolphin
- Spinner dolphin
- Clymene dolphin
- Striped dolphin
- Short-beaked common dolphin
- Long-beaked common dolphin
- Fraser's dolphin
- White-beaked dolphin
- Atlantic white-sided dolphin
- Pacific white-sided dolphin
- Dusky dolphin
- Peale's dolphin
- Hourglass dolphin
- Northern right whale dolphin
- Southern right whale dolphin
- Risso's dolphin
- Melon-headed whale
- Pygmy killer whale
- False killer whale
- Killer whale
- Long-finned pilot whale
- Short-finned pilot whale
- Irrawaddy dolphin

Family Phocoenidae (porpoises)
- Finless porpoise
- Harbour porpoise
- Vaquita
- Burmeister's porpoise
- Spectacled porpoise
- Dall's porpoise

Suborder MYSTICETI

Family Balaenidae (right whales)
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- Southern right whale
- Bowhead whale

Family Neobalaenidae
- Pygmy right whale

Family Balaenopteridae (roquals)
- Humpback whale
- Northern minke whale
- Antarctic minke whale
- Pygmy Bryde's whale
- Bryde's whale
- Sei Whales
- Fin whale
- Blue whale

Family Eschrichtiidae
- Grey whale

Order SIRENA

Family Trichechidae (manatees)
- West Indian manatee
- West African manatee
- Amazonian manatee

Family Dugongidae (dugongs)
- Dugong

Characterizing Marine Mammal Bioacoustics

Vocal Behavior

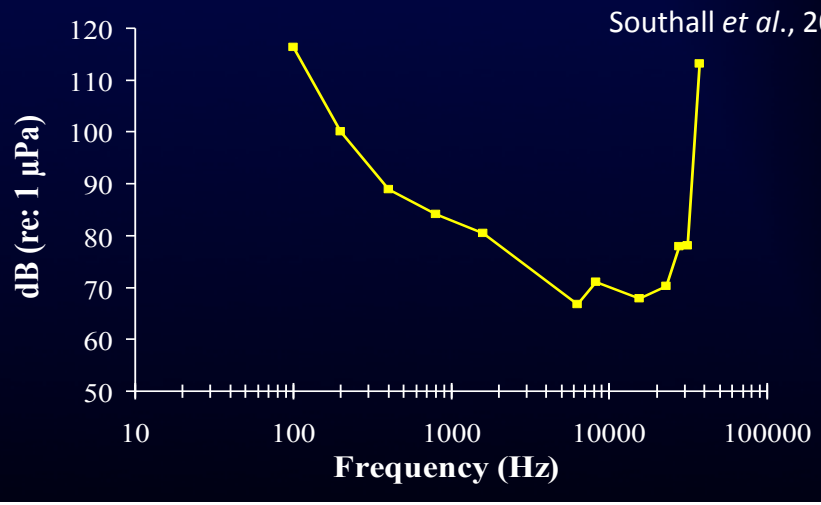
Behavioral Methods:
Trained animals

Hearing

Electrophysiological Methods:
(no training)

Biomechanical Modeling Methods:

Anatomical (see: Ketten poster)



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Pinniped Vocalizations

Northern Elephant Seal
Actual Speed

Walrus
Actual Speed

Harbor Seal
Actual Speed

Pinniped Bioacoustic Parameters

Call Types: Mainly **low frequency** growls, barks, moans, knocks, click-like calls

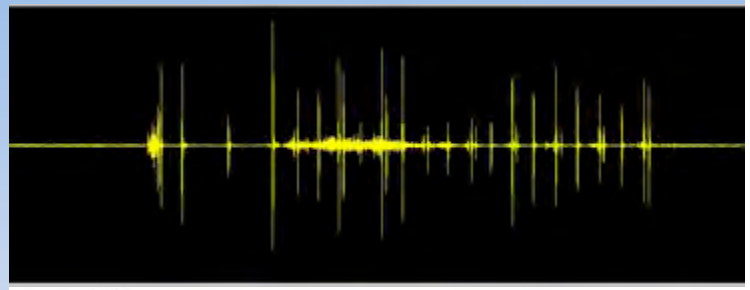
Functionality: Predominately in **social** interactions; navigation?

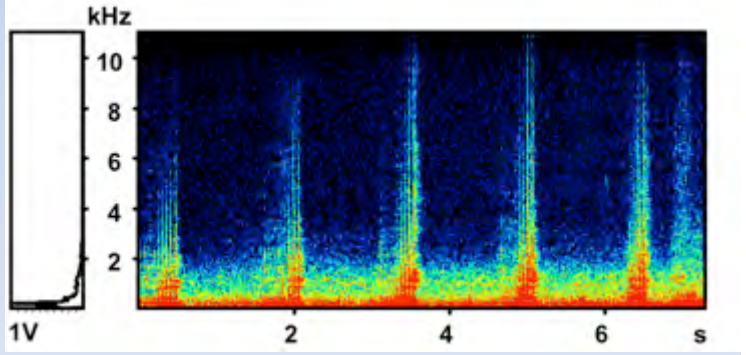
Frequency Range of Sounds:

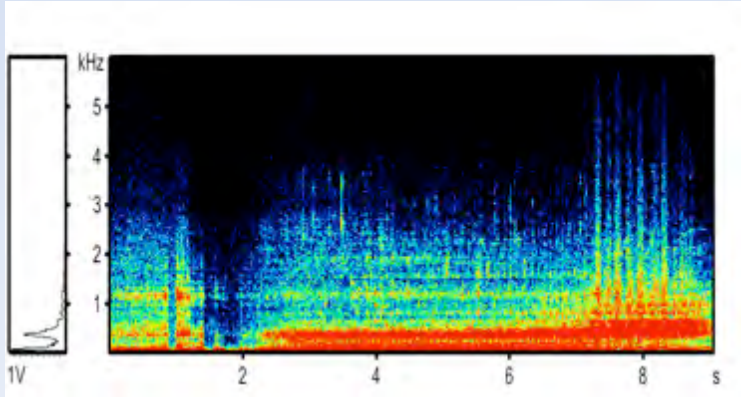
True seals: 0.1-120 kHz
Sea lions/fur seals: 0.1-8 kHz
Walrus: 0.1-10 kHz

Frequency Range of Hearing (best):

True seals: 0.1-50 kHz (1-40)
Sea lions/fur seals: 0.1-32 kHz (1-12)
Walrus: 0.1-15 kHz (1-12)







Sound Production in Baleen Whales

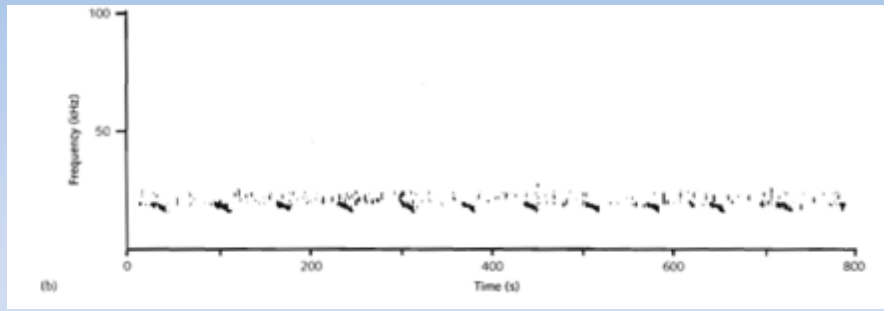
Blue Whale:
Actual Speed

Blue Whale:
10x Speed

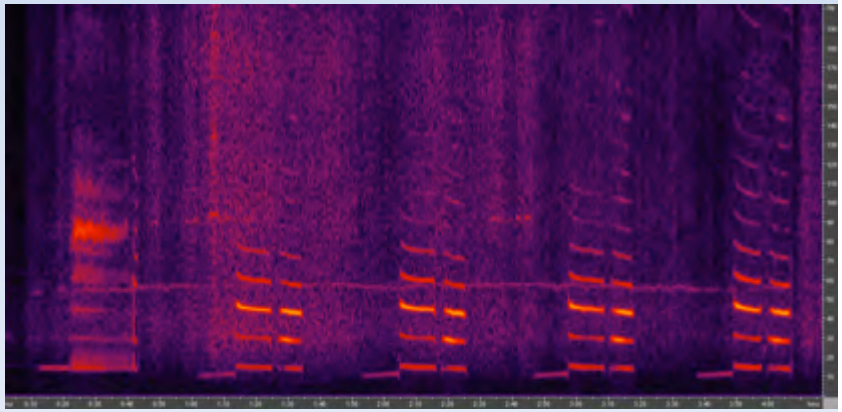
Humpback Whales:
Actual Speed

Baleen Whale Bioacoustic Parameters

Call Types: Mainly **low frequency (some infrasonic)** pulsed calls, more complex song in some (humpback)



Functionality: Predominately in **social** interactions; navigation?



Frequency Range of Sounds:

0.01-10 kHz (most low end)

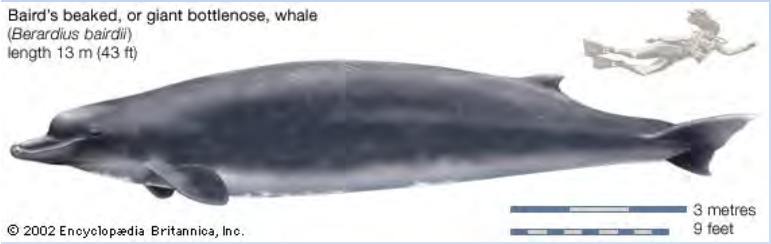
Frequency Range of Hearing (best):

??? (likely very low to mid-freq)

*** please see Ketten poster**

Sound Production in Toothed Whales

Social Calls of Killer Whales: Actual Speed



Baird's Beaked Whale Echolocation Signals: Actual Speed

Harbor Porpoise Echolocation Signals: 1/40x Speed

Toothed Whale Bioacoustic Parameters

Call Types: **Mod-frequency** whistles & burst pulses, **high-frequency echolocation** clicks

Functionality: Whistles in **social** interactions; Echolocation for **foraging and navigation**

Frequency Range of Sounds:

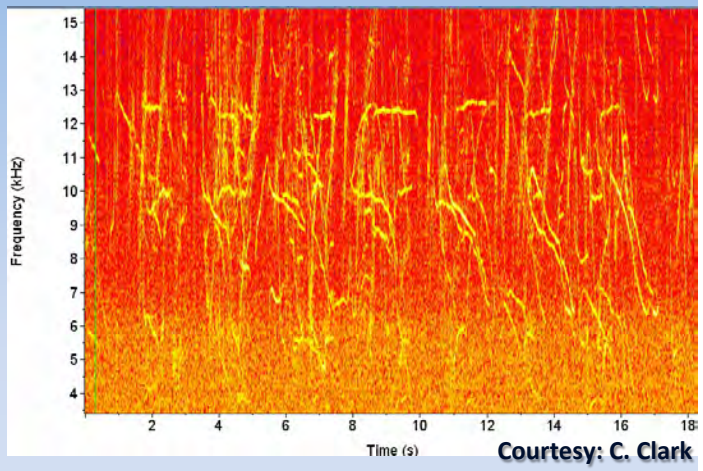
Most Odontocetes: 1-120 kHz

HF specialists: 20-150 kHz

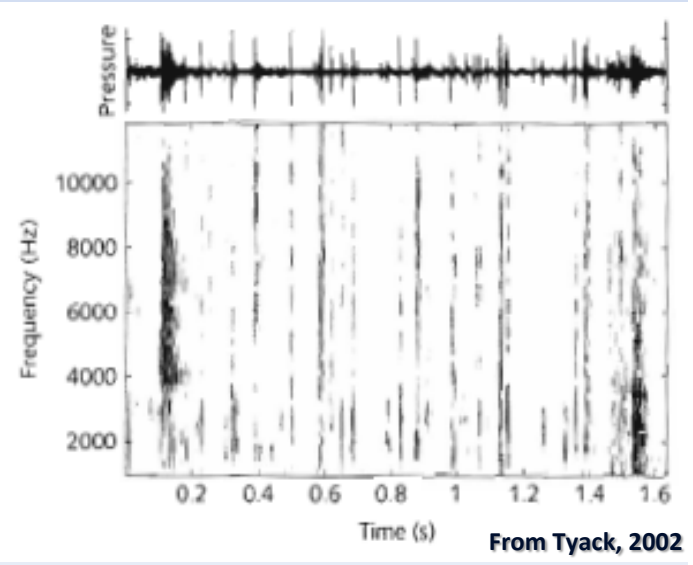
Frequency Range of Hearing (best):

Most Odontocetes: <0.1-120 kHz (10-75)

HF Specialists: 0.1-200 kHz (20-100)

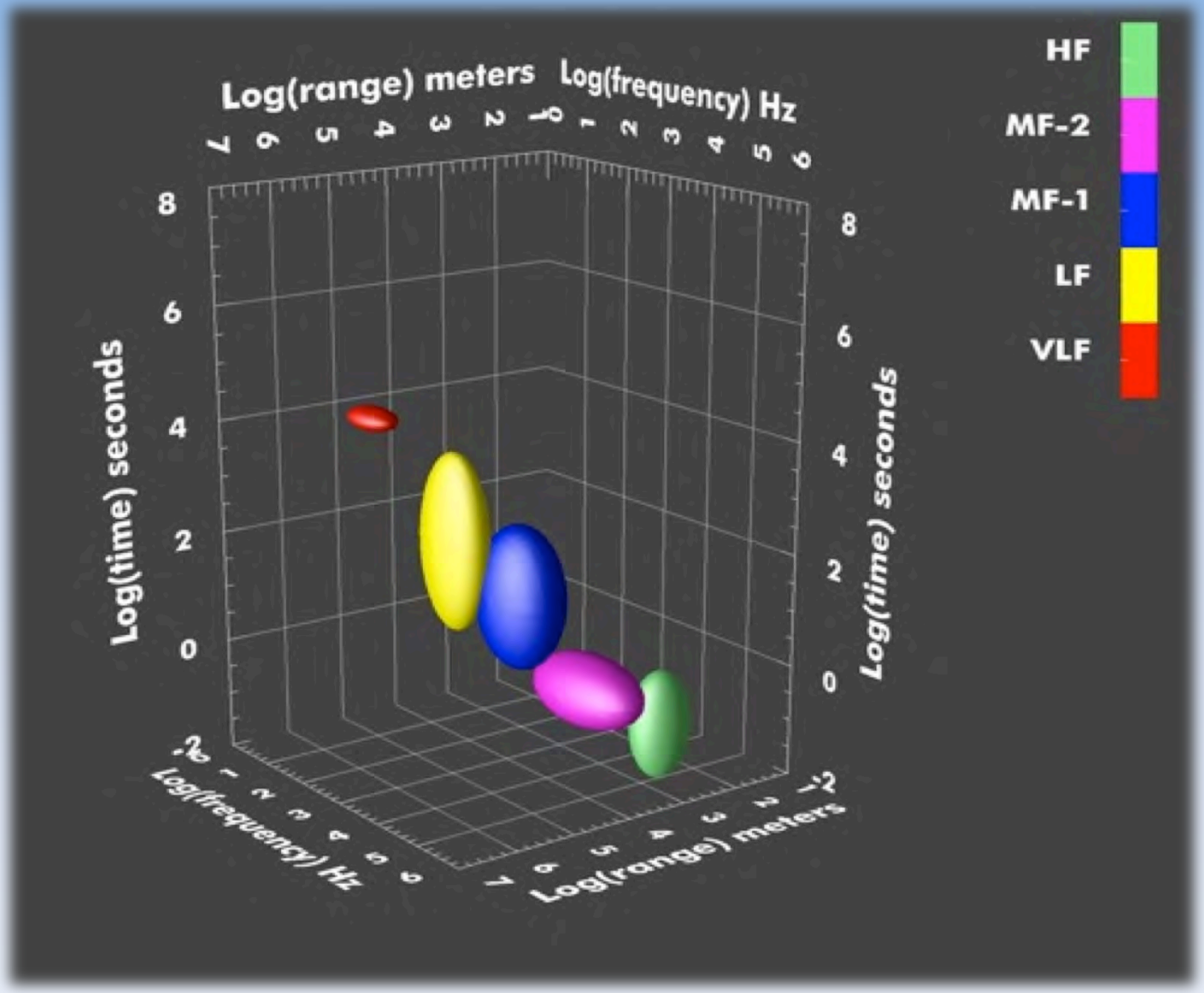


Courtesy: C. Clark



From Tyack, 2002

Marine Mammal Bioacoustics: Time-space-frequency spaces



Courtesy C. Clark

Natural sources of ocean noise

Wind-generated waves

Earthquakes

Precipitation

Ice

Space Neutrinos!

Invertebrates

Fish

Mammals

Human sources of ocean noise

Transportation

Dredging and construction

Oil drilling and production

Geophysical surveys

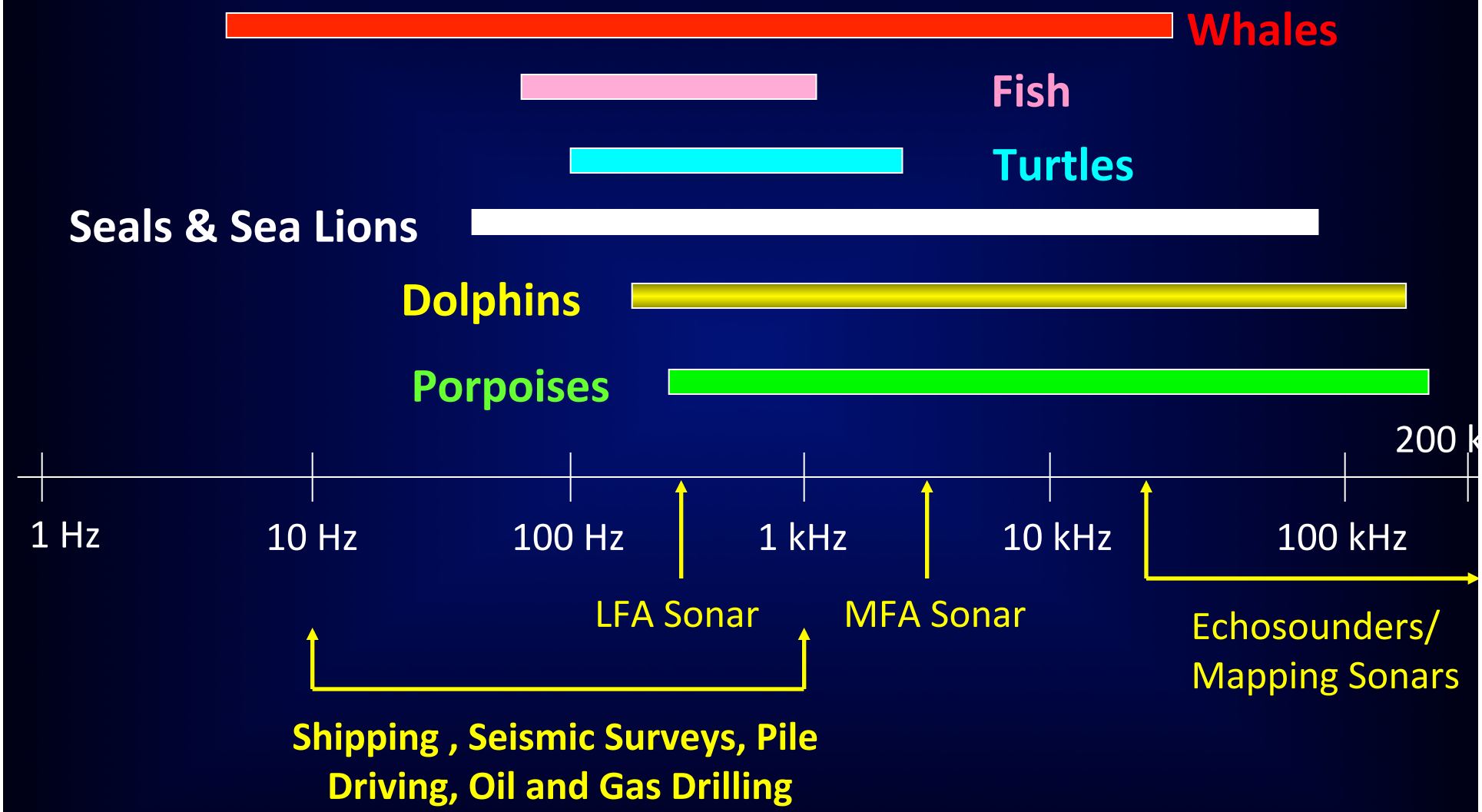
Active Sonars

Explosions

Communication systems

Ocean science studies

Frequency Bands of Hearing in Marine Animals and Typical Human Sounds



Functional Categories of Ocean Sounds: *Impulses*

Low-frequency (main energy <1 kHz)

- Natural:
  - Lightning
  - Fish
  - Some pinnipeds (walrus) in air and water
- Anthropogenic:
  - Seismic Airguns
  - Pile Driving
  - Explosions

Functional Categories of Ocean Sounds: *Impulses*

Main energy: Mid (1-10 kHz) & High-freq (>10 kHz)

- Natural:
  - Some pinnipeds (MF) in air and water
  - Toothed whales!
- Anthropogenic:
  - Seismic Airguns
  - Pile Driving
  - Chirp Sonars

Functional Categories of Ocean Sounds: *Continuous Signals*

Low-frequency (<1 kHz)

- Natural:
  - Waves
  - Precipitation
  - Earthquakes
  - Fish
  - Invertebrates
  - Most pinnipeds
  - Most baleen whales
  - Few toothed whales
- Anthropogenic:
  - Shipping!
  - Drilling
  - Dredging – marine construction
  - LFA sonar

Functional Categories of Ocean Sounds: *Continuous Signals*

Mid (1-10 kHz) & High-frequency (>10 kHz)

- Natural:
  - Some pinnipeds (mainly MF)
  - Baleen whales (MF)
  - Toothed whales
  - Some precipitation
- Anthropogenic:
  - Military sonar systems (MFA)
  - Navigational and mapping sonars
  - Underwater modems/communication systems

Effects of Noise on Marine Life

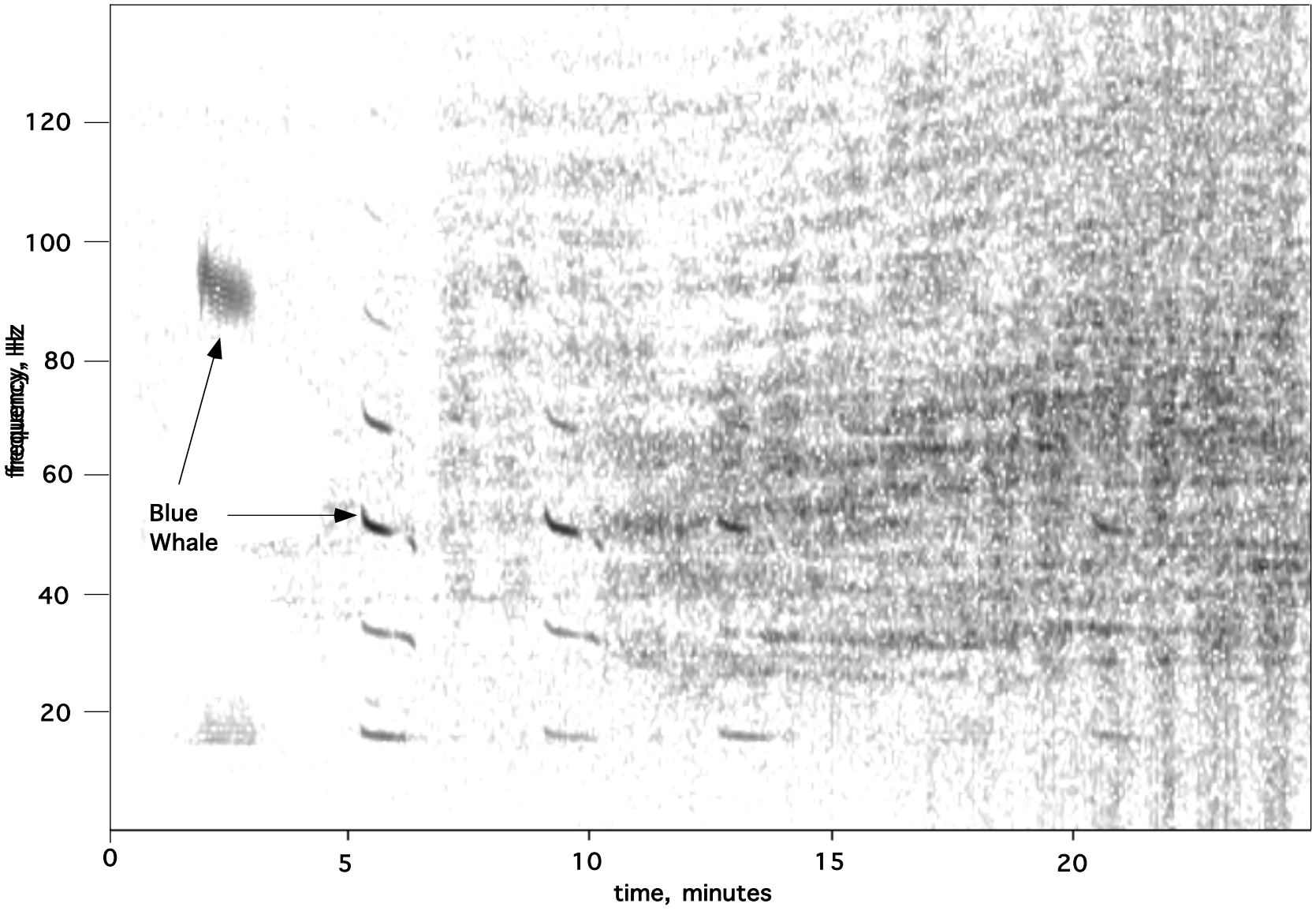
- None observable
- Interference with Communication
  - Auditory masking
  - *Temporary or permanent hearing damage*
- Behavioral Responses
  - Orientation, increased alertness, vocal changes
  - Effects on feeding, social activity, risk of predation
  - Habitat abandonment: temporary or *permanent*
- Physiological Effects (stress, DCS)
- *Stranding causing injury or death*

Generally Increasing Severity

but

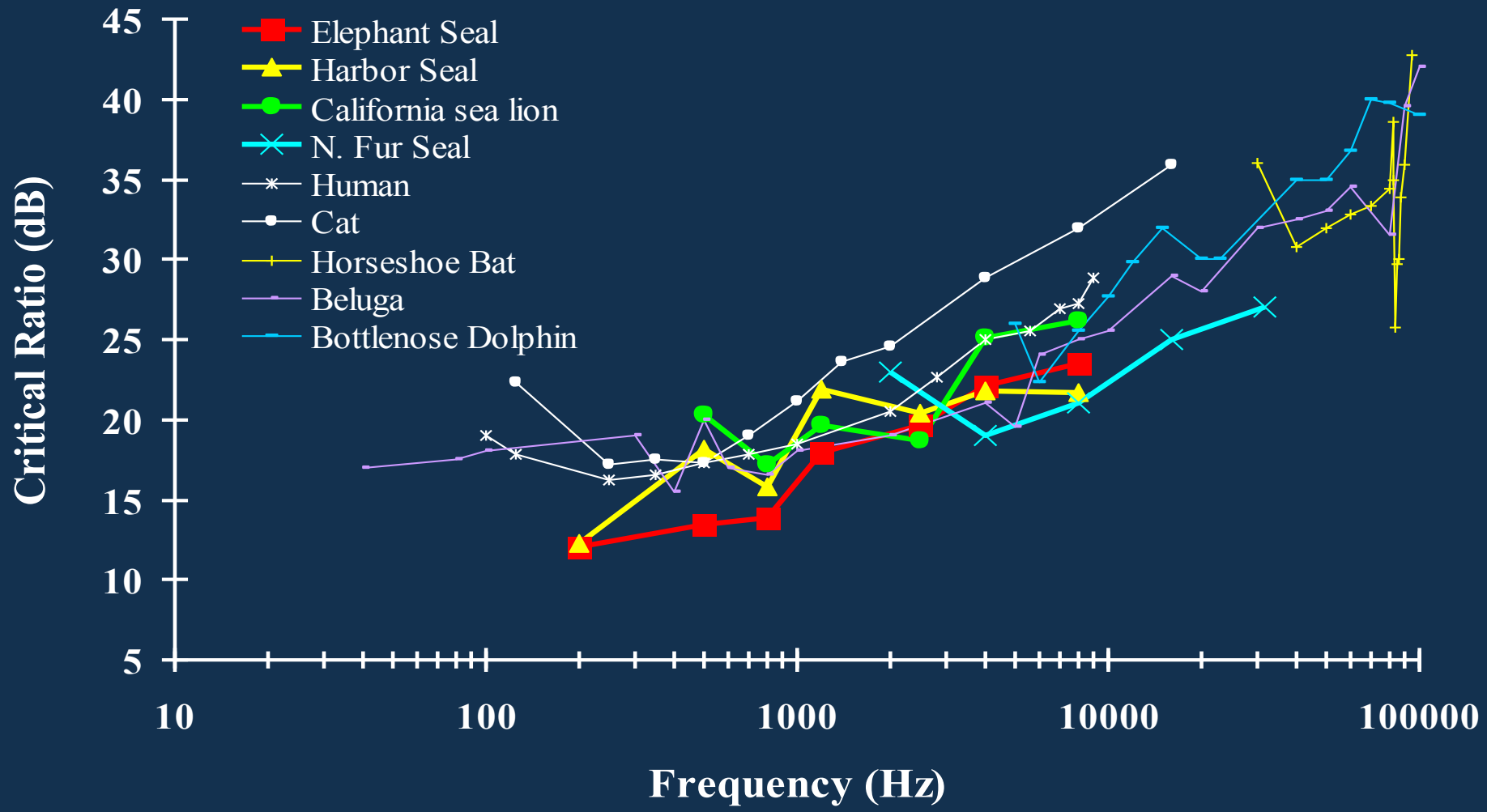
Generally Decreasing Occurrence

Masking of Vocal Communication

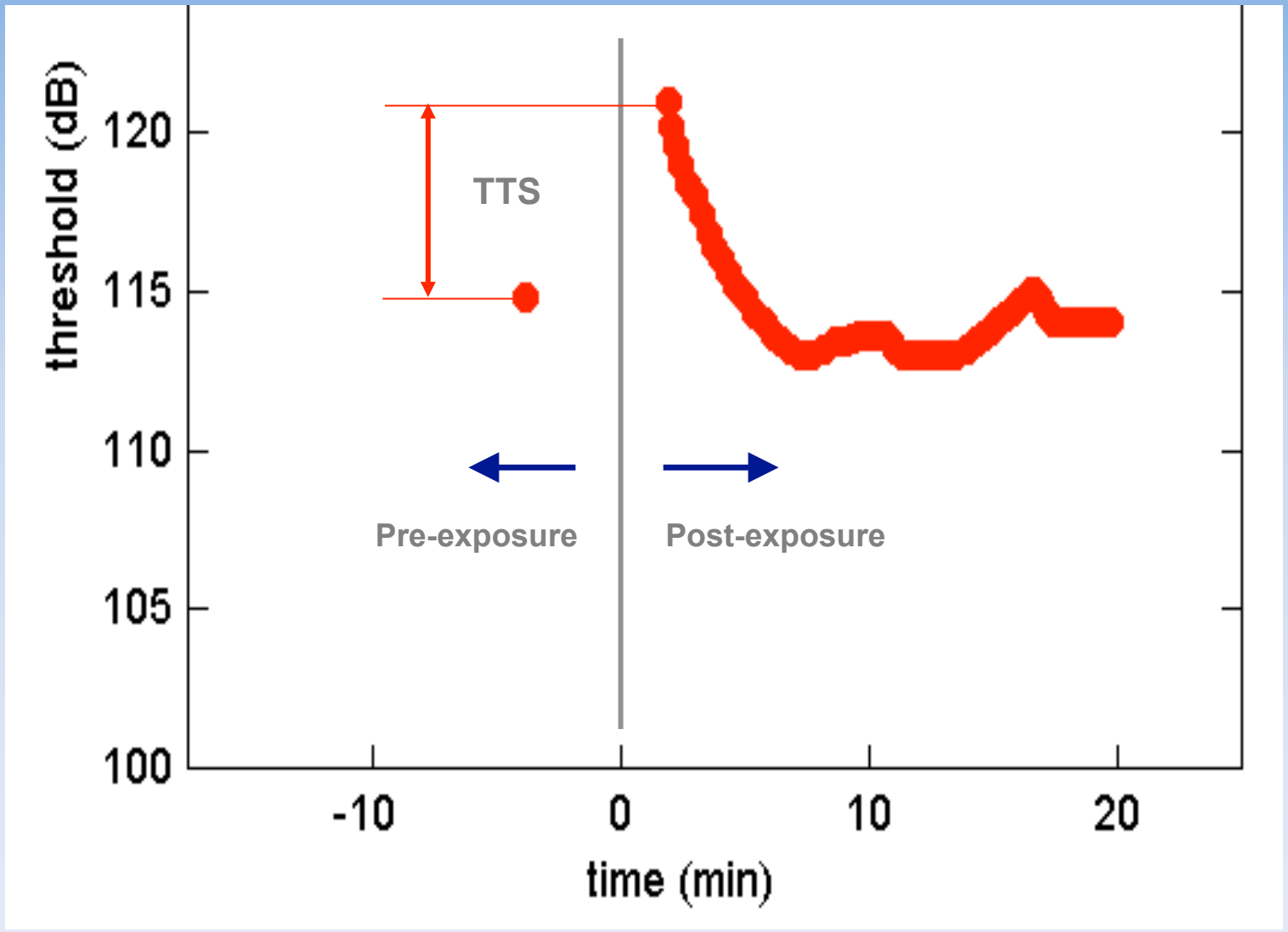


Courtesy: C. Clark

Critical Ratios of Selected Mammals



Temporary Threshold Shift (TTS)



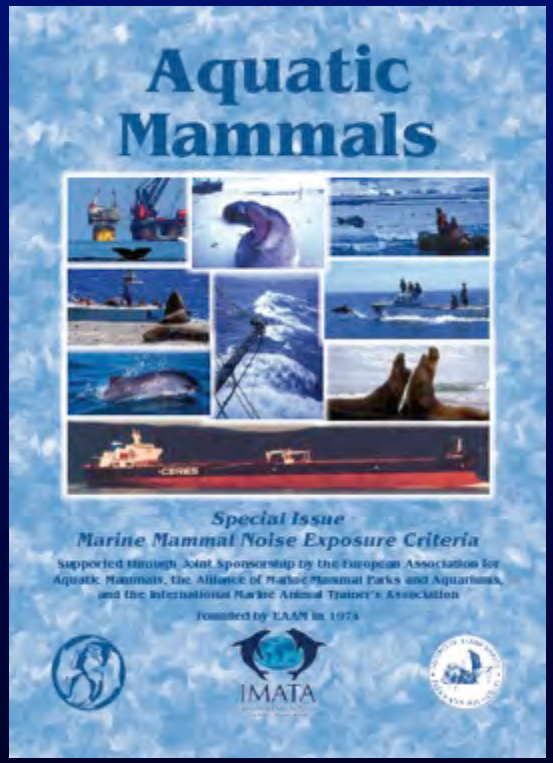
Courtesy: J. Finneran

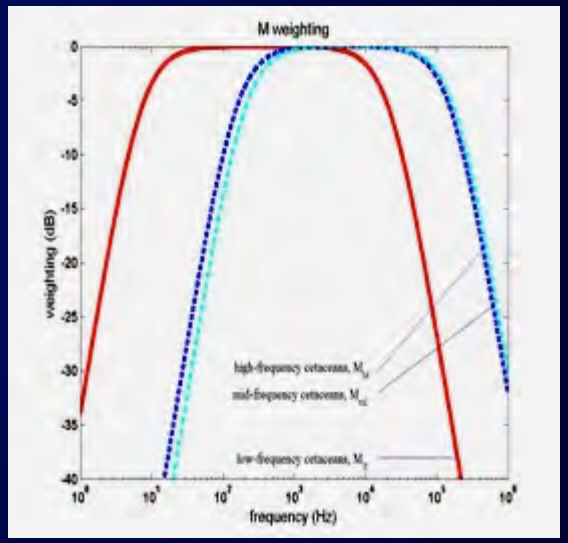
Conventional regulatory view of ocean sound

Single sound source

2-D sound “isopleths” uniform
for all species across frequency

MARINE MAMMAL NOISE EXPOSURE CRITERIA:
INITIAL SCIENTIFIC RECOMMENDATIONS
Southall et al. (2007)

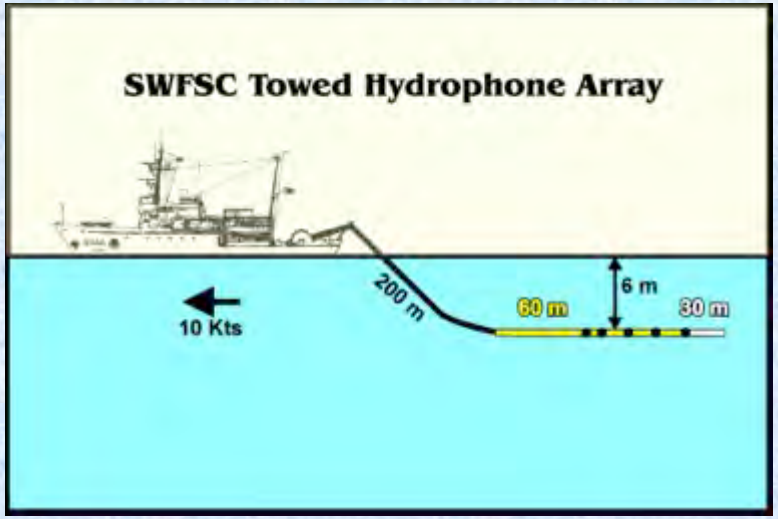


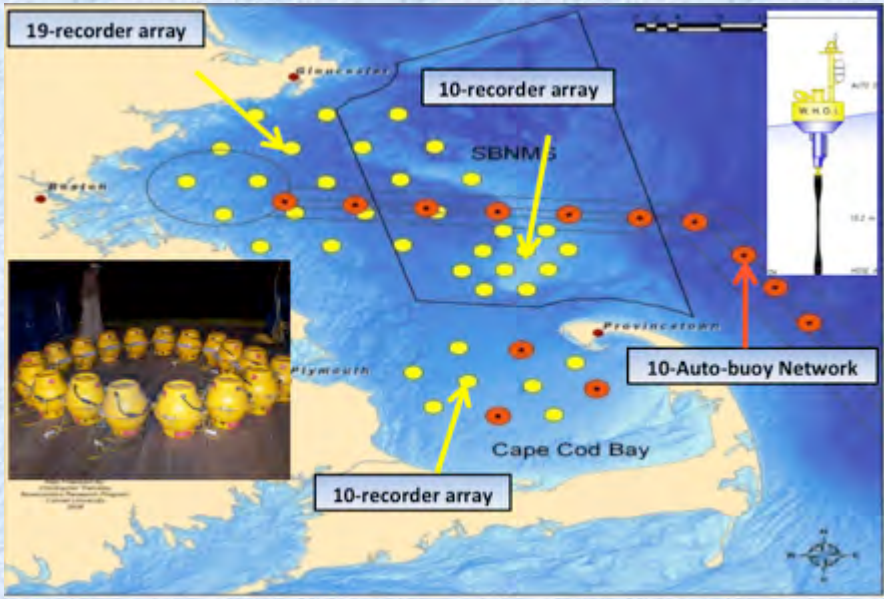


* Quantitative dual-criteria for direct auditory injury

* Severity scaling metric for behavior based on vital rates

Advancing Field Technologies and Methods to Address Behavioral Impacts





MORE DETAILS COMING HERE IN P. TYACK AND B. GISINER TALKS ON MONDAY

Biological and Behavioral Response Studies of Marine Mammals in Southern California (SOCAL-BRS - 2010-2015)

www.socal-brs.org

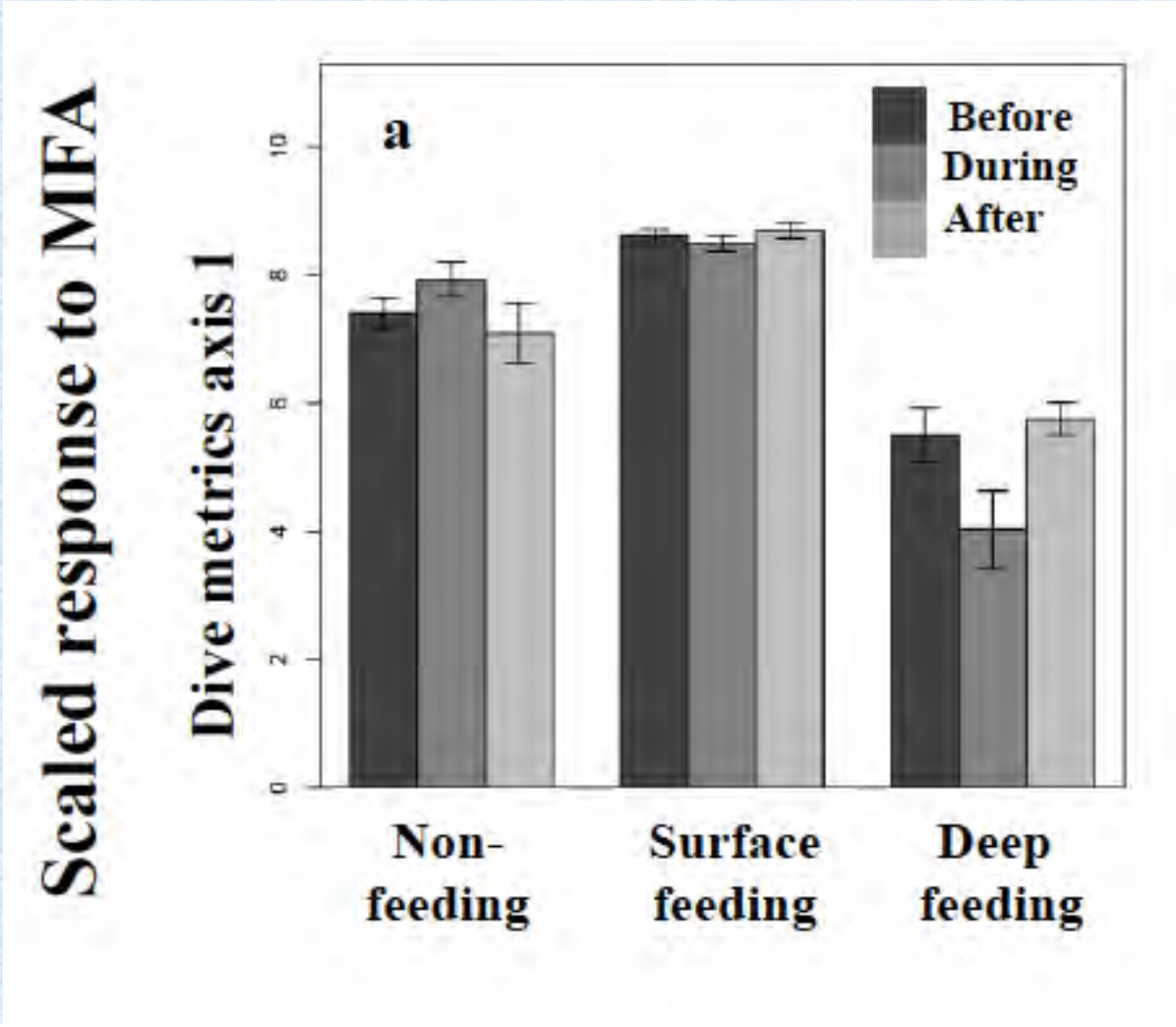
Photo taken under U.S. NMFS permit # 14534

Cascadia Research Collective
non-profit research and education since 1979

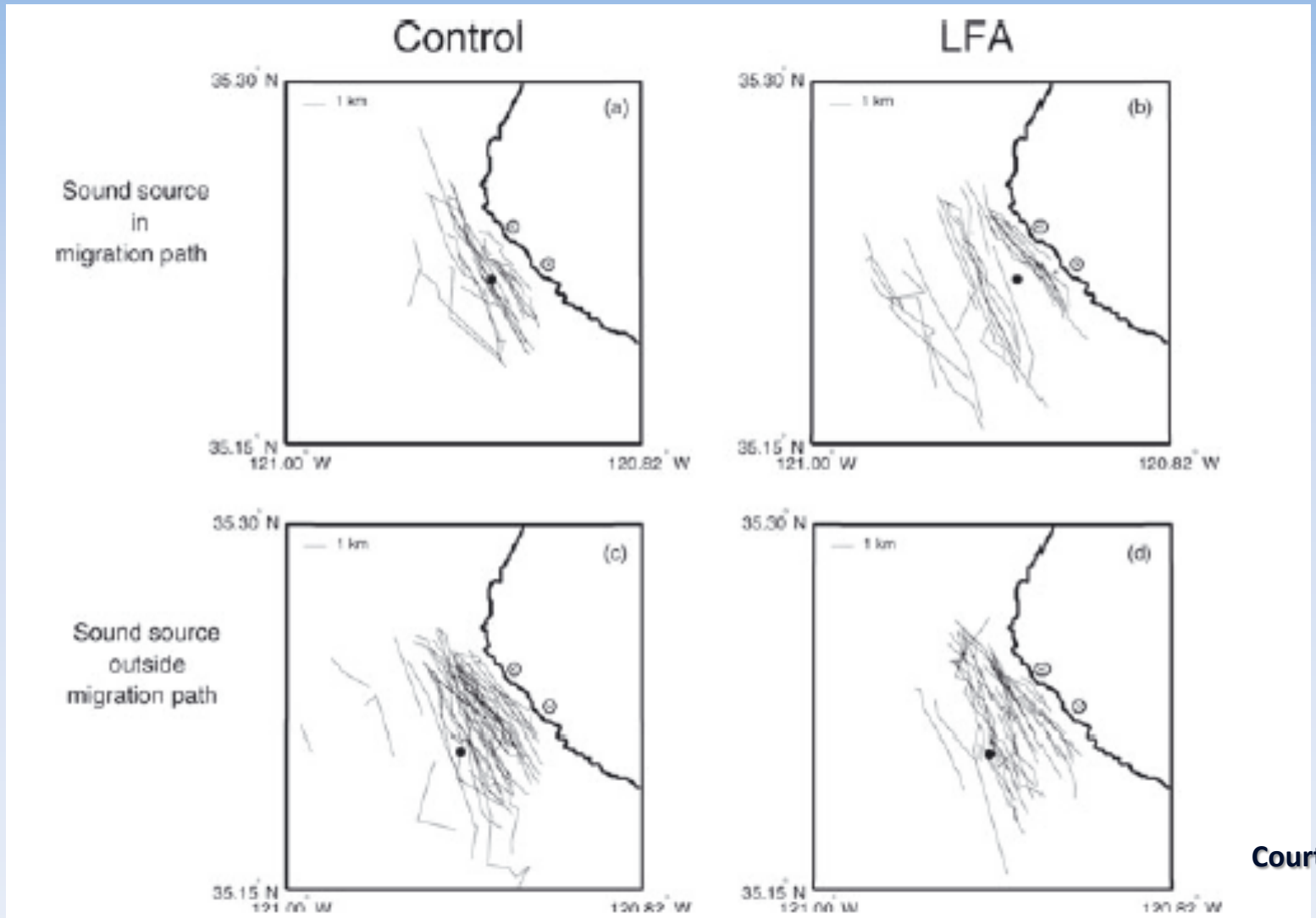
Applied Physical Sciences

Institute of Marine Sciences
an Organized Research Unit
at UC Santa Cruz

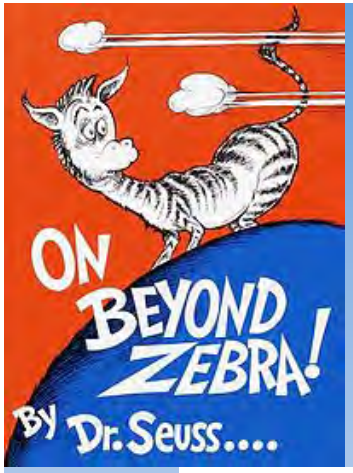
Controlled exposure experiments with blue whales and MFA: *behavioral state context*



Controlled exposure experiments (CEEs) with grey whales and LFA: *spatial context*



Courtesy: J. Buck, P. Tyack



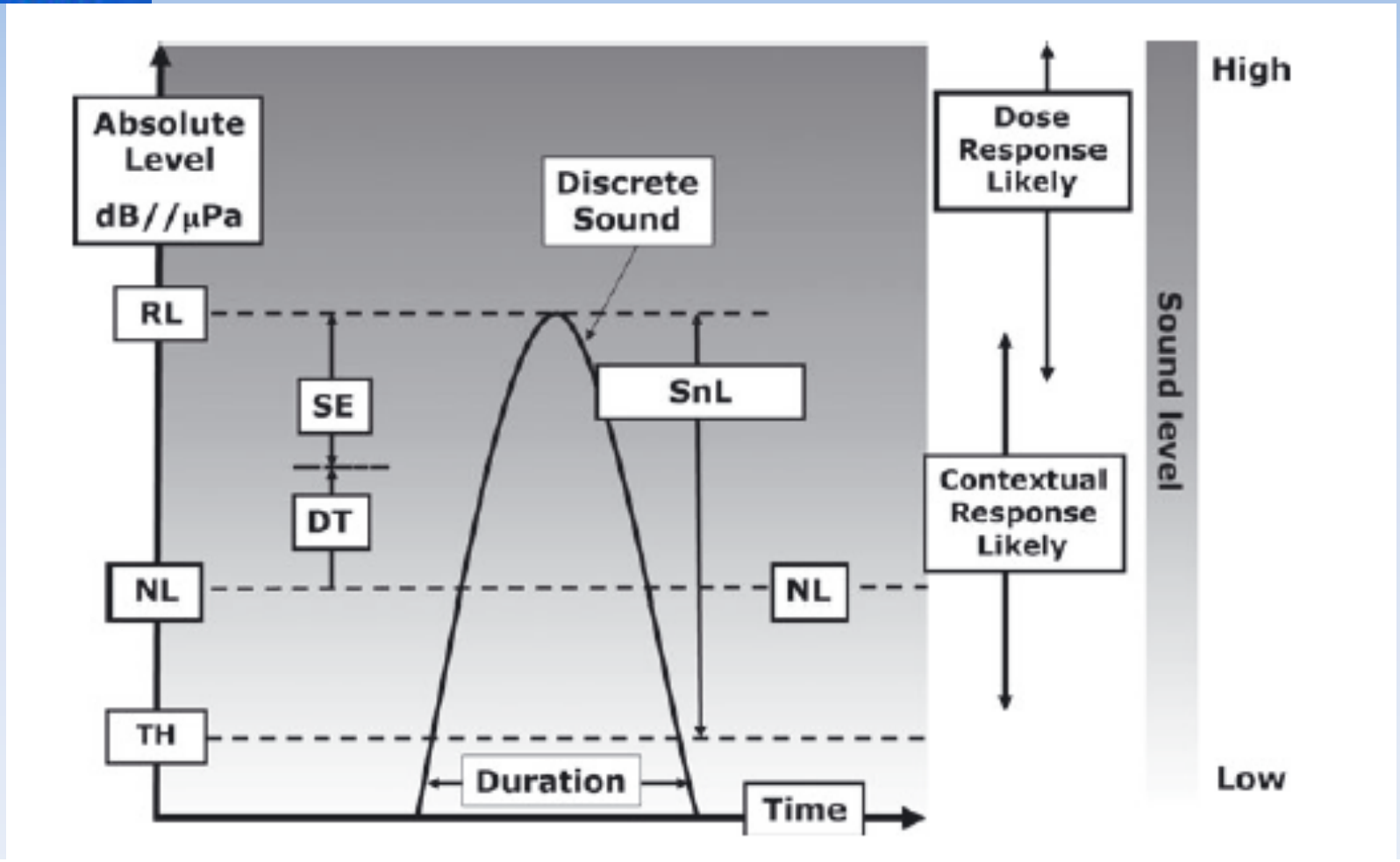
On beyond thresholds…

Conservation Biology

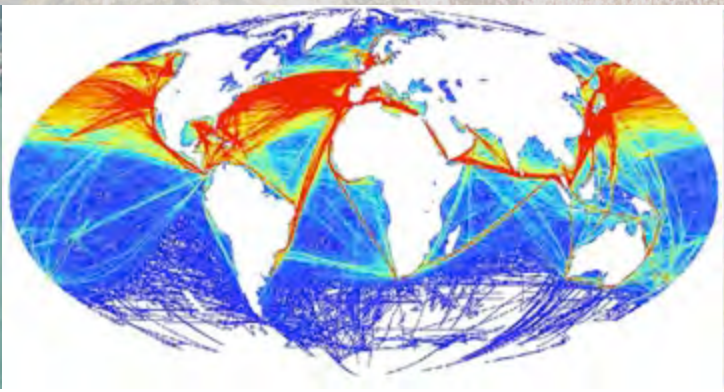
Conservation Practice and Policy

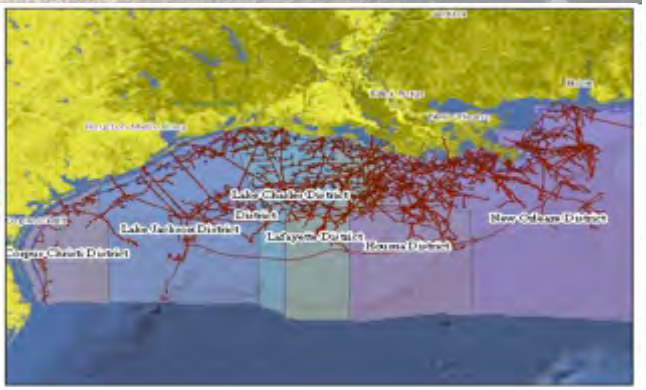
A New Context-Based Approach to Assess Marine Mammal Behavioral Responses to Anthropogenic Sounds

W.T. ELLISON,* B.L. SOUTHALL,†‡ C.W. CLARK,§ AND A.S. FRANKEL*



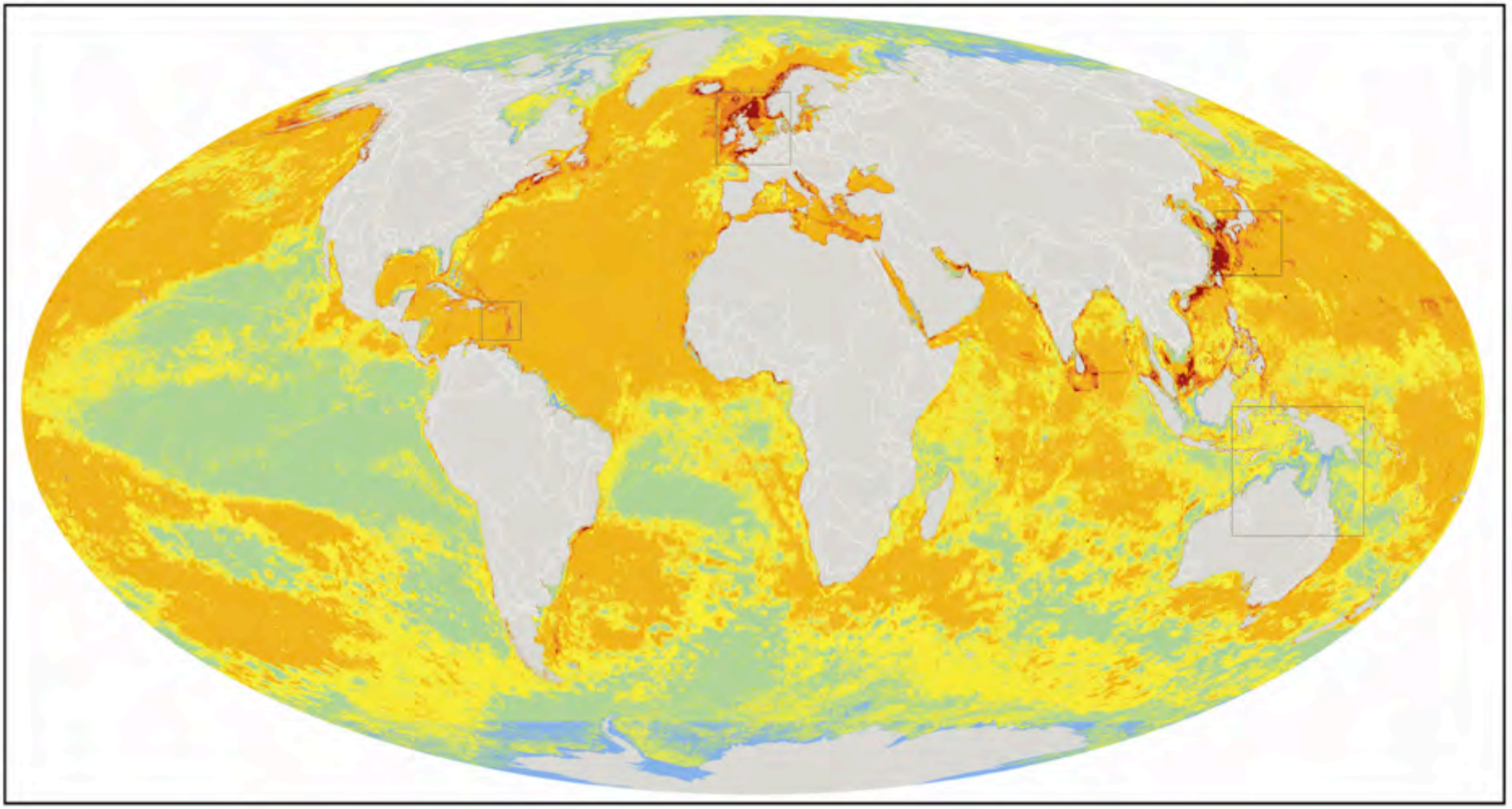
PARADIGM SHIFT: Concern, research, and management are broadening from severe, acute effects to non-lethal but chronic, interacting ones on realistic time/space scales





Collective impact of all uses:

Majority of surface oceans now experience high impact from mix of coastal & maritime activities



Scientific and Conservation Reasons to Listen with Ocean Observing Systems

Report of the
2006 NOAA National
Passive Acoustics Workshop

Developing a Strategic Program Plan
for NOAA's Passive Acoustics
Ocean Observing System (PAOOS)
Woods Hole, Massachusetts, 11–13 April 2006

March 2007

Sofie Van Parijs
Brandon Southall

Conveners and Workshop Co-chairs

2007-2009: Proposals for GoMex PAM Get Typical Government Response

2010

Efforts to Integrate PAM into the U.S. Integrated Ocean Observing System

"Addressing the Effects of Human-Generated Sound on Marine Life:
An Integrated Research Plan for U.S. Federal Agencies"

A Report of the Joint Subcommittee on Ocean Science & Technology (JSOST)

~ INTERAGENCY TASK FORCE ON ANTHROPOGENIC SOUND AND THE MARINE ENVIRONMENT ~

Contributing Federal Agencies (in alphabetical order):
Marine Mammal Commission (MMC)
Minerals Management Service (MMS)
National Oceanic and Atmospheric Administration (NOAA)
National Science Foundation (NSF)
U.S. Army Corps of Engineers (ACE)
U.S. Coast Guard (USCG)
U.S. Department of Defense, U.S. Navy (USN)
U.S. Department of Energy (DOE)
U.S. Department of State (DOS)
U.S. Fish and Wildlife Service (FWS)

OCEAN ACOUSTIC MONITORING IN IOOS:
TOOLS FOR MEASURING NATURAL SYSTEMS AND HUMAN IMPACTS

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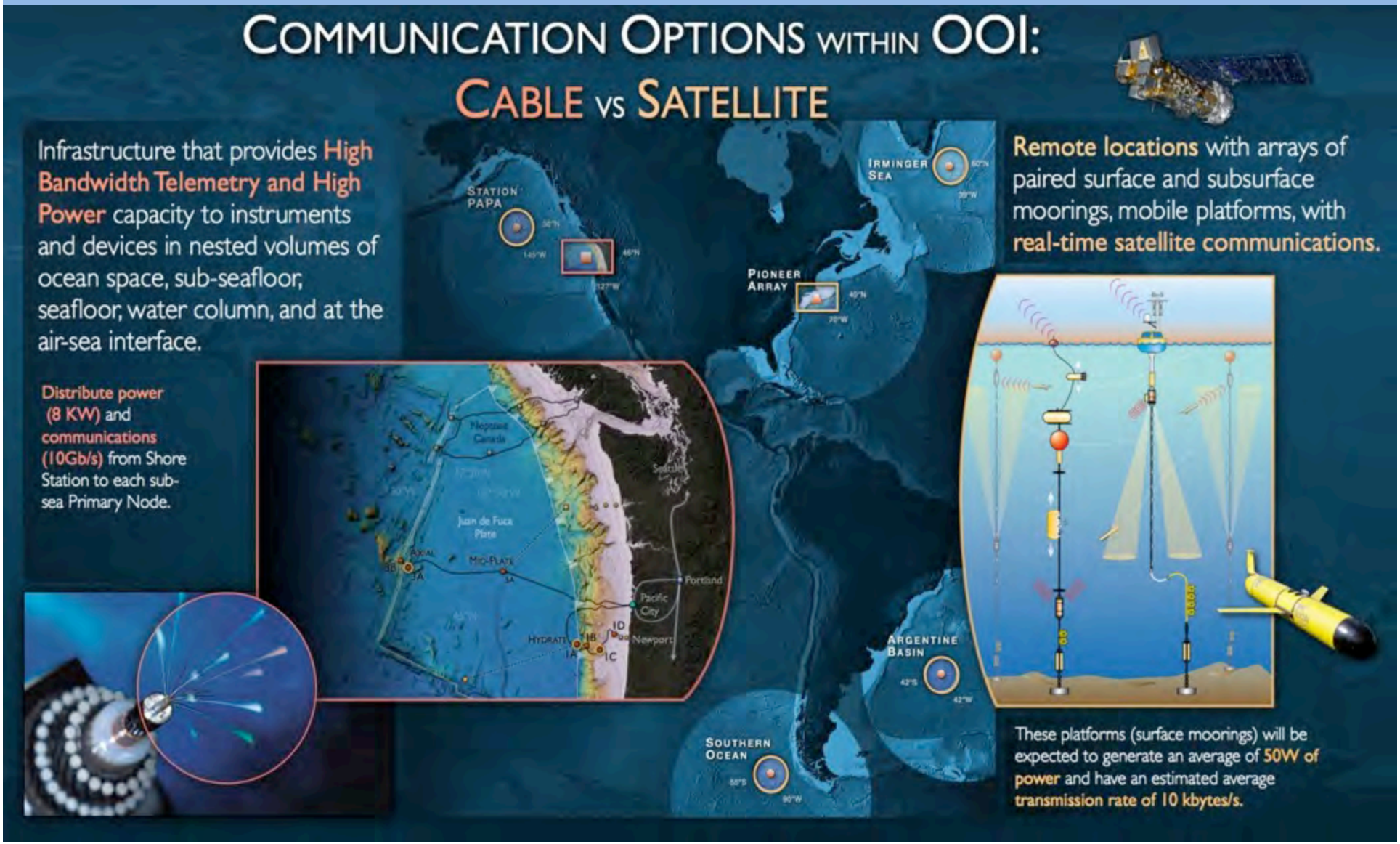
INTEGRATED OCEAN OBSERVING SYSTEM
U.S. IOOS SUMMIT REPORT
A New Decade for the Integrated Ocean Observing System

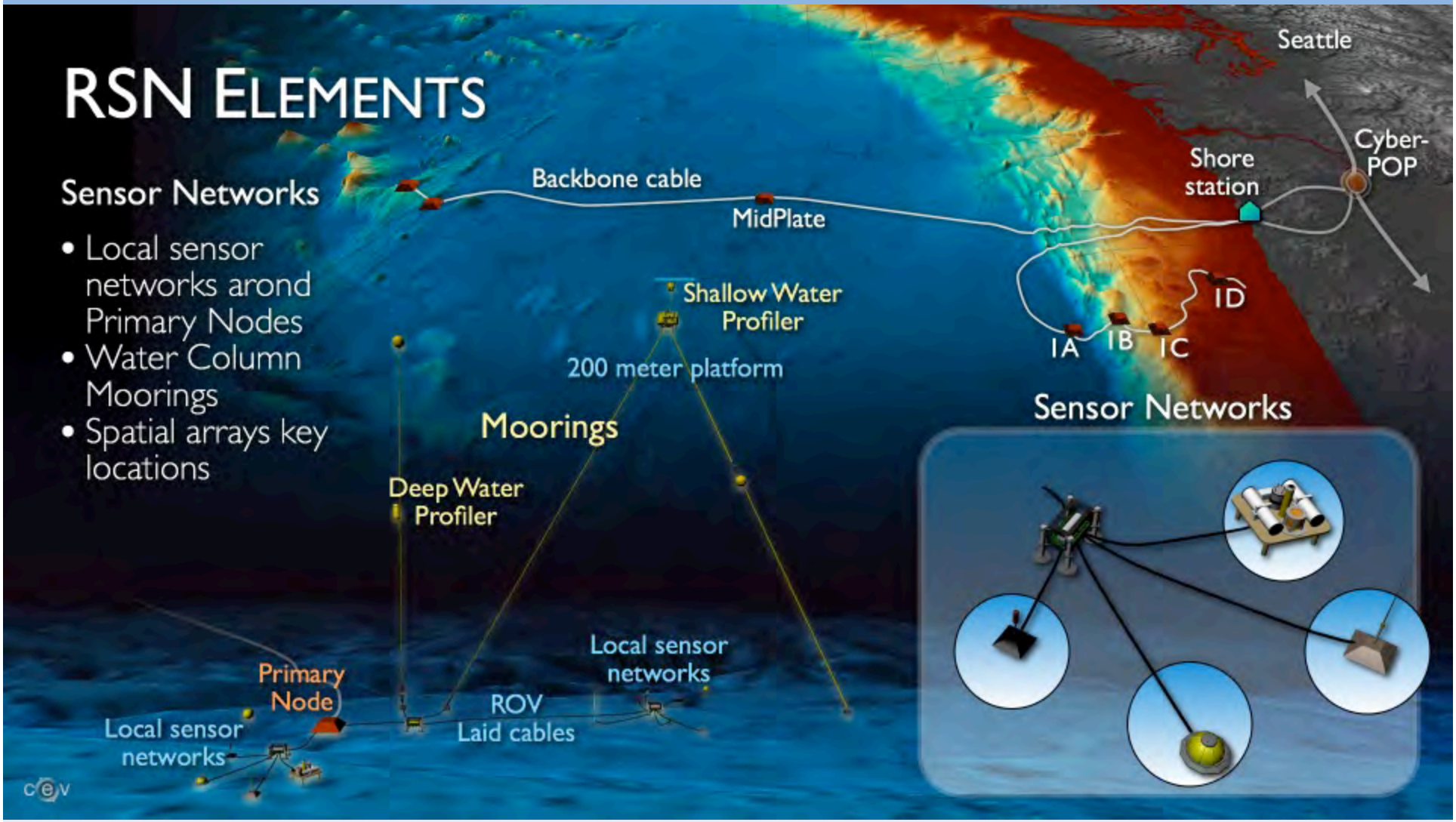
Cabled Observatory - Regional Scaled Nodes (RSN):

A Platform of Opportunity for Acoustic Observation



Networked RSN sensors-interdisciplinary studies

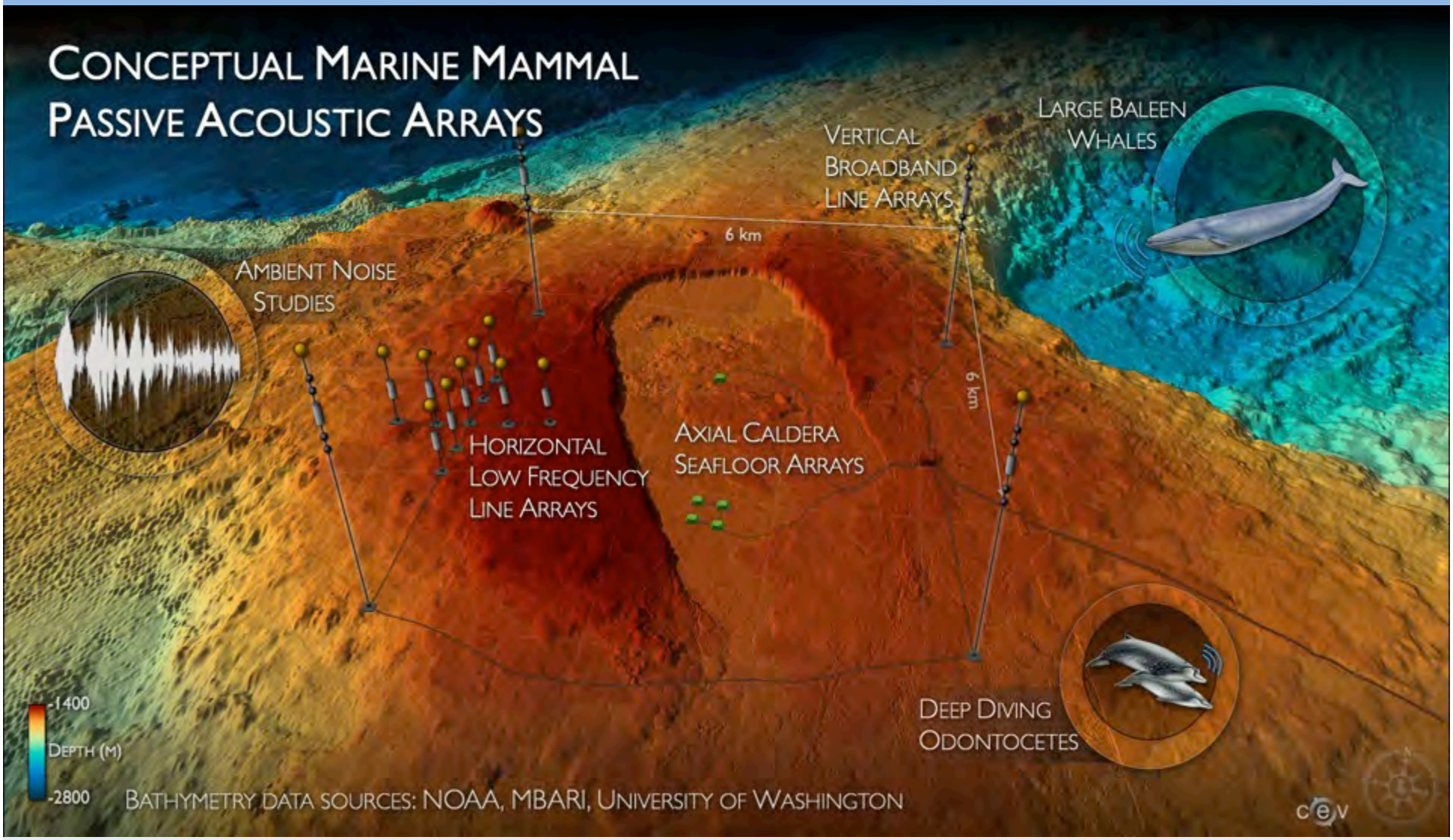
A Platform of Opportunity for Acoustic Observation

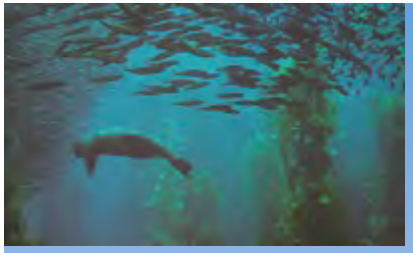


http://www.interactiveoceans.washington.edu/

NAIAD Conceptual Design:

Passive Acoustic Monitoring Systems





Closing Observations

1) The ocean is filled with natural and human sounds

2) But, there are frequency, time, and spatial distinctions among marine mammals and other sound sources

3) Effects of noise on marine life is an active area of interest and evolving technology

4) Cross-disciplinary partnerships integrating skills and technologies using observing systems critically needed






Sincere thanks to:
* Ettore Majorana Foundation and Centre for Science Conservation
* Conference organizers and Sponsors
* Gianni Pavan, Peter Tyack, Colleen Reichmuth
* Office of Naval Research and U.S. Navy Living Marine Resources Program