Presentation prepared for:

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Overview of Potential Impacts of Human-made Sound on Marine Mammals

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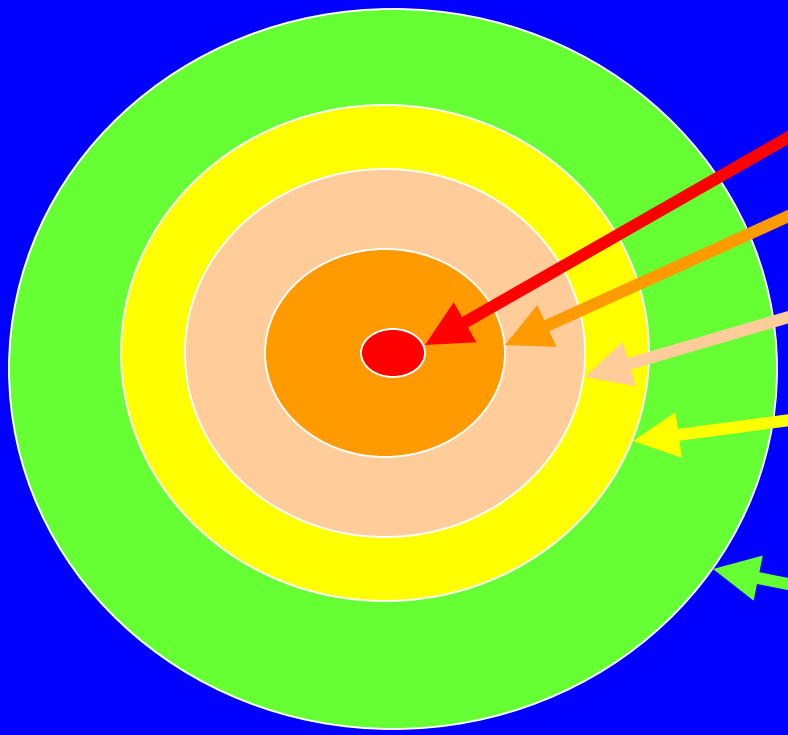
Policy on Sound and Marine Mammals: an International Workshop
28 September 2004
London

Zones of Noise Influence



- Injury
- Hearing Loss
- Avoidance
- Behavioral disturbance
- Masking (could occur whenever sound level above ambient noise)

Adapted from Richardson and Malme 1995

Non-auditory Injury

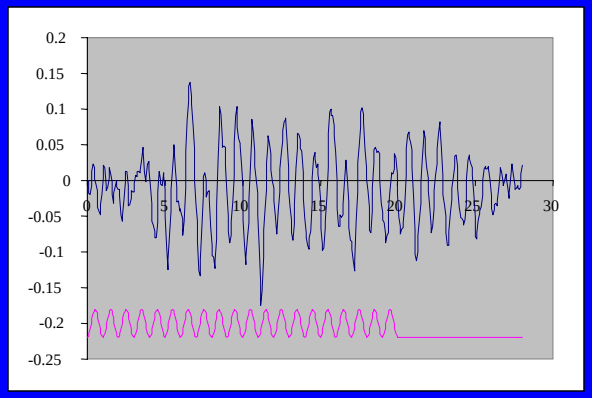
- Underwater explosions produce a gas bubble with pressures of 50000 atm and 3000°C.
- Bubble expands to create peak pressure in a few msec.
- Volume of bubble oscillates creating damped series of pressure waves
- At some range from explosion, velocity of pressure wave slows to speed of sound, and then propagate like sound waves

Blast Injury

- Greatest Effects at boundaries of tissues with different densities, especially gas-liquid interface
- Gas-containing organs such as lungs, GI tract, and gas-filled cavities especially susceptible
- Pinnipeds and odontocetes have been reported killed and baleen whales seriously injured from underwater explosions in the wild

Acoustically Enhanced Bubble Growth

- Most relevant for prolonged tonal signals
- Crum and Mao JASA 1996 report on models of acoustically enhanced diffusion leading to growth of bubbles in tissue
- “sonars and other high intensity acoustic projectors pose little risk [of bubble growth] to divers and marine mammals unless they are in the immediate vicinity of the source”
- For exposure > 210 dB re 1µPa bubble growth can be expected within seconds and can grow to sizes that might block capillaries and other small blood vessels



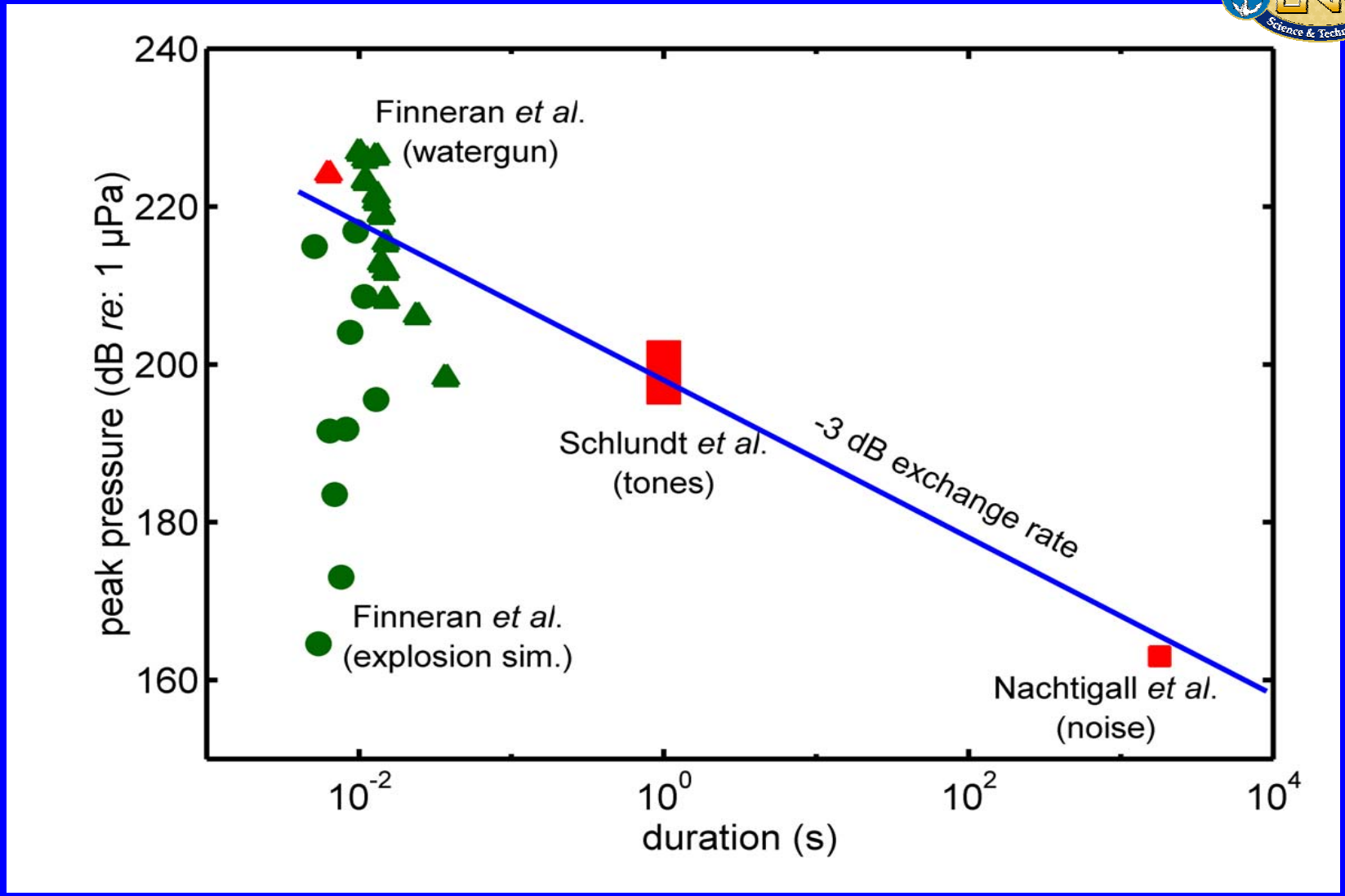
Envelope Following Response

Signpost for Auditory Injury: Measuring Temporary Threshold Shift in Marine Mammals

- Measure the threshold at which animal just detects a sound
- Expose animal to loud sound
- Measure hearing again to see if threshold shifted
- Determines exposure above which hearing may be affected

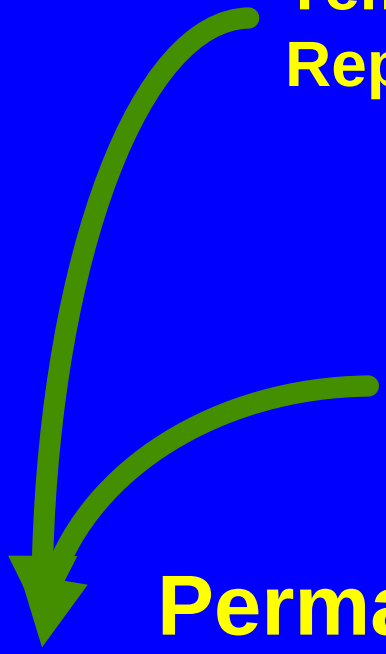
Summary of TTS for captive odontocetes

Courtesy J. Finneran



Mechanisms for Permanent Hearing Loss

Temporary Threshold Shift - TTS
Repeated many times over years

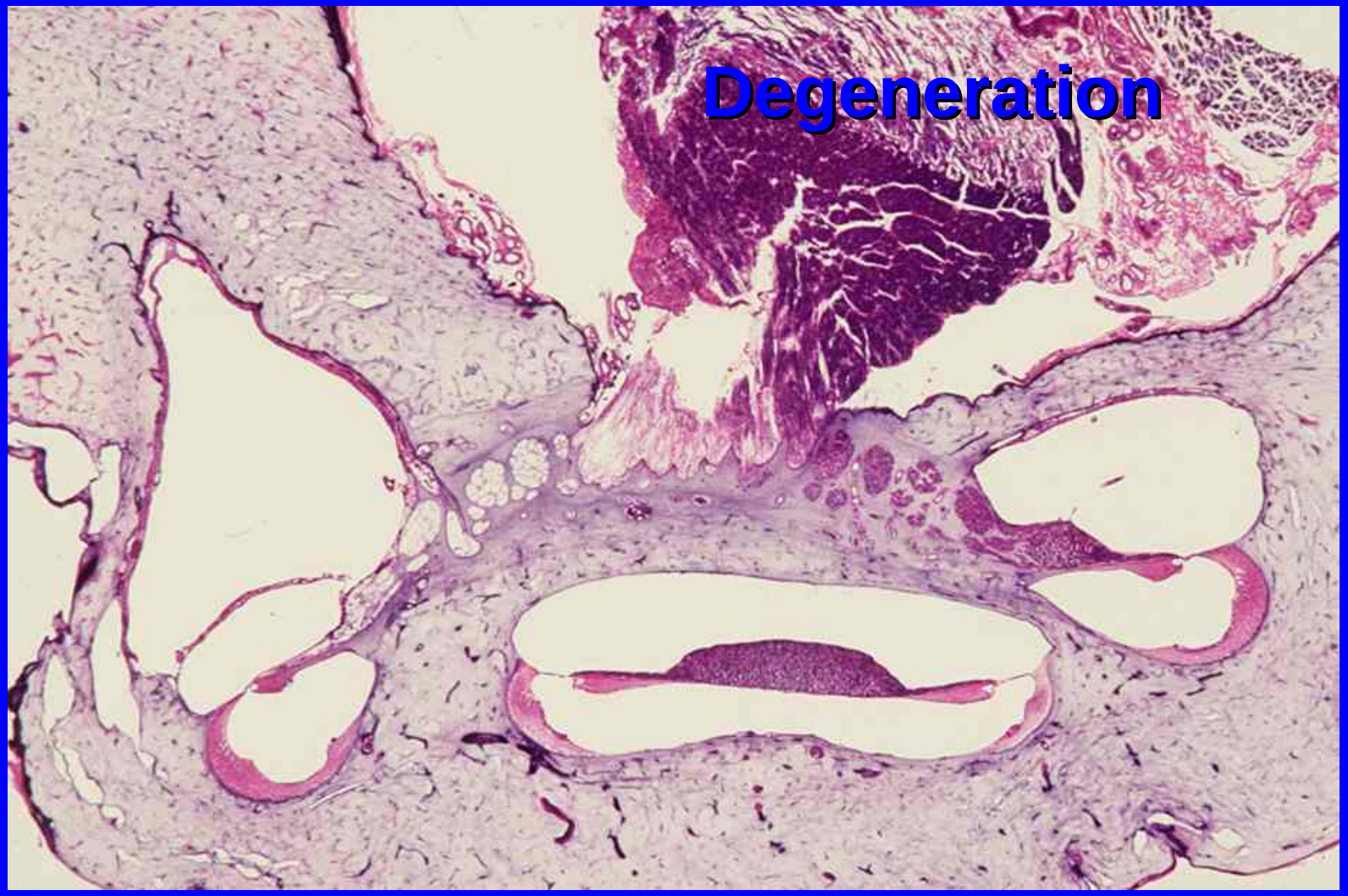


Exposure to Intense Sound

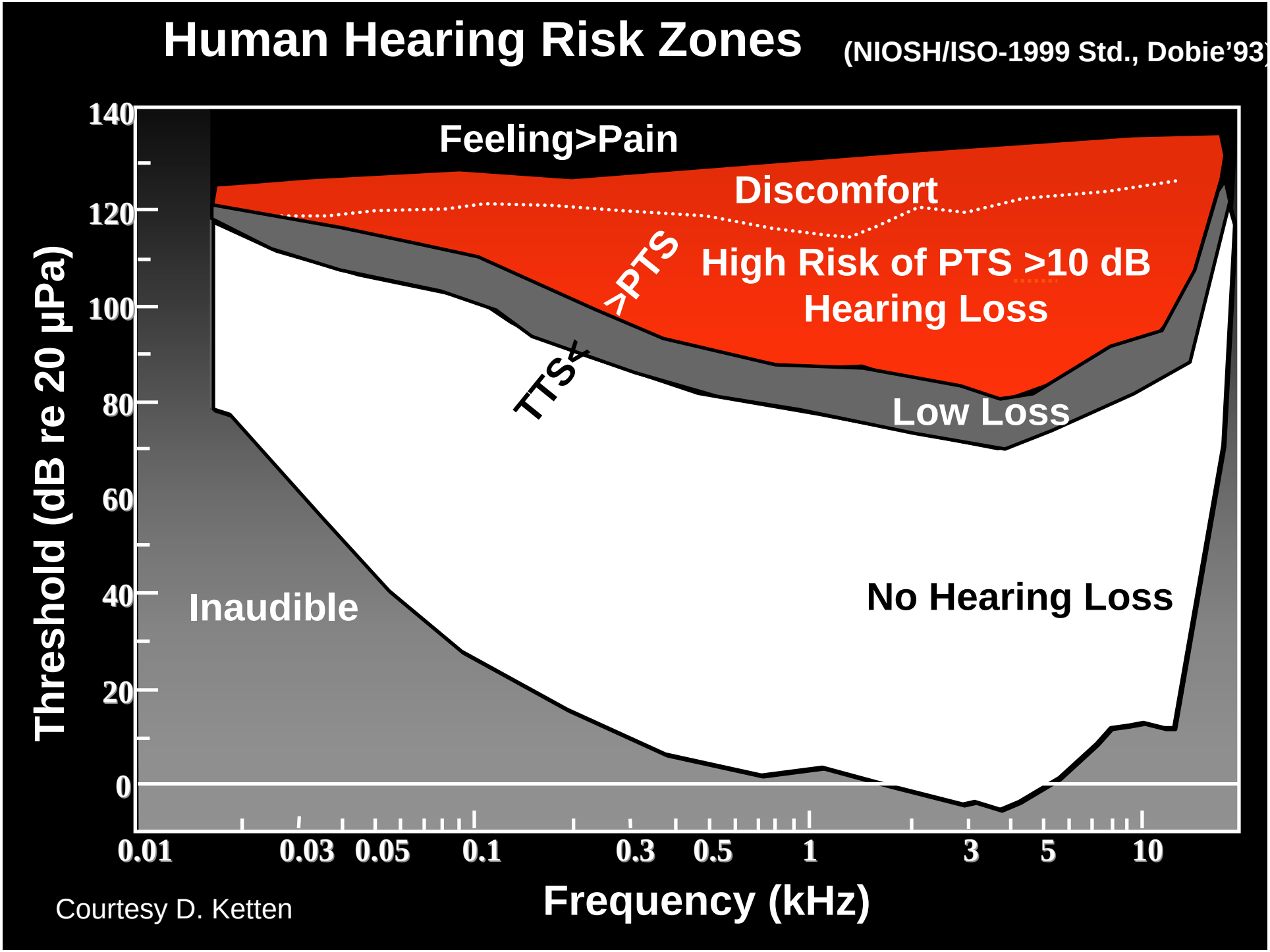
Permanent Threshold Shift - PTS

- **Neuronal Loss**
- **Hair Cell dysfunction**
- **Bony degeneration**

Degeneration of cochlea in old male Tursiops consistent with hearing loss



Courtesy D. Ketten


Human Hearing Risk Zones
(NIOSH/ISO-1999 Std., Dobie'93)
Feeling>Pain
Discomfort
>PTS
High Risk of PTS >10 dB
Hearing Loss
TTS<
Low Loss
Inaudible
No Hearing Loss
Threshold (dB re 20 µPa)
140
120
100
80
60
40
20
0
0.01
0.03
0.05
0.1
0.3
0.5
1
3
5
10
Frequency (kHz)
Courtesy D. Ketten

Effects of Manmade Noise

Injury

- Usually analyzed at the level of the individual
- Add to other “takes” from other causes to evaluate cumulative impact on population

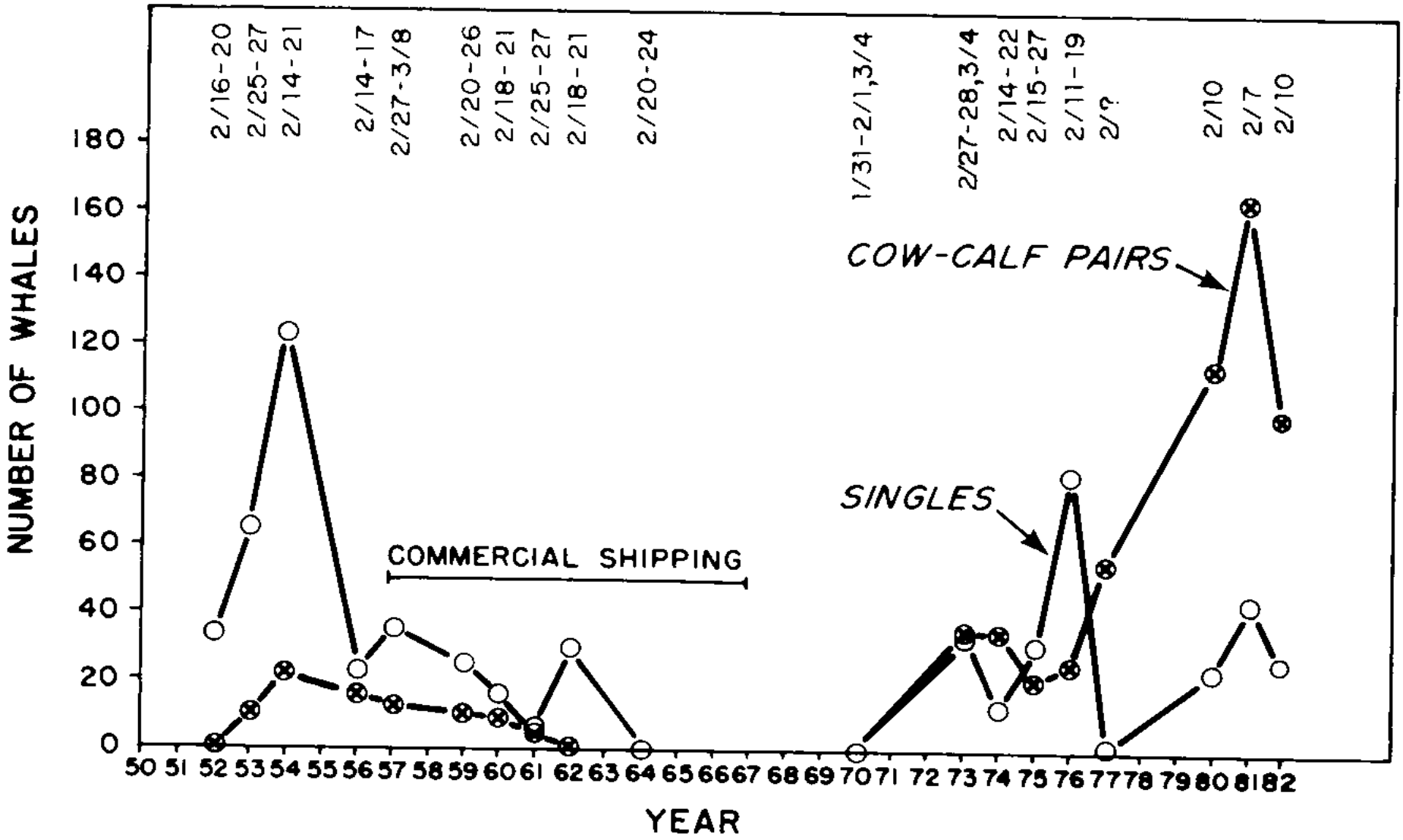
Disruption of Behavior

- Conservation policy relies upon protecting populations, but by the time one has detected a decline due to noise etc., it is often too late
- Use behavior as a proxy to estimate possible demographic impact

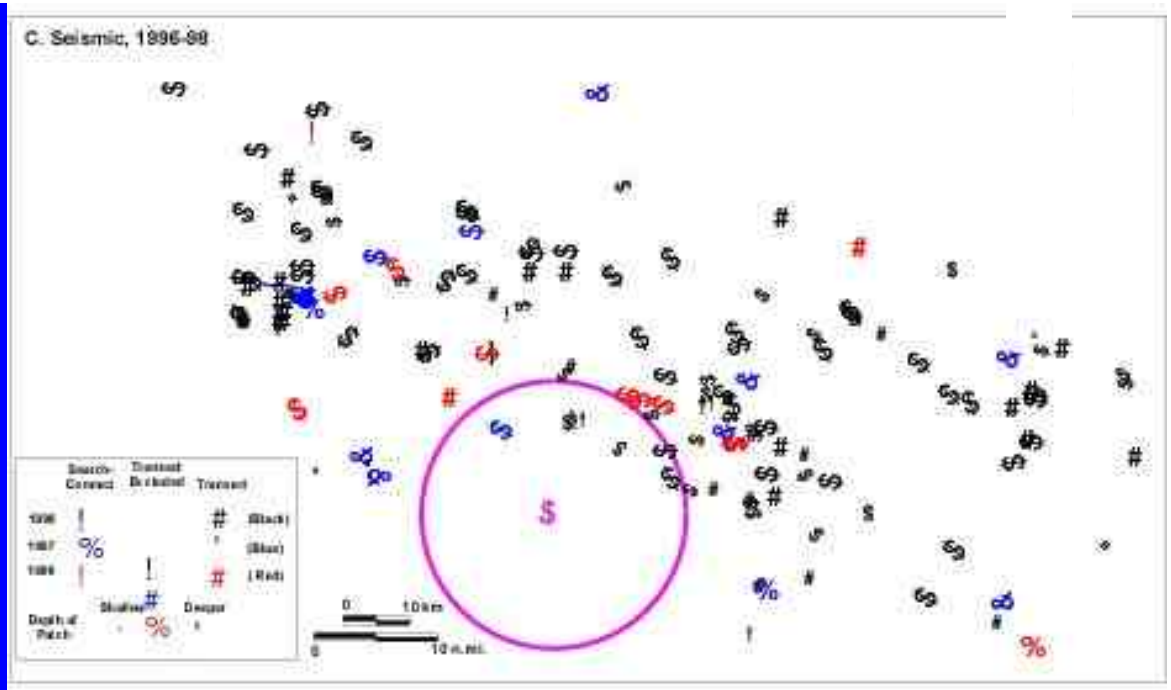
Avoidance responses can be viewed as an indicator of habitat degradation

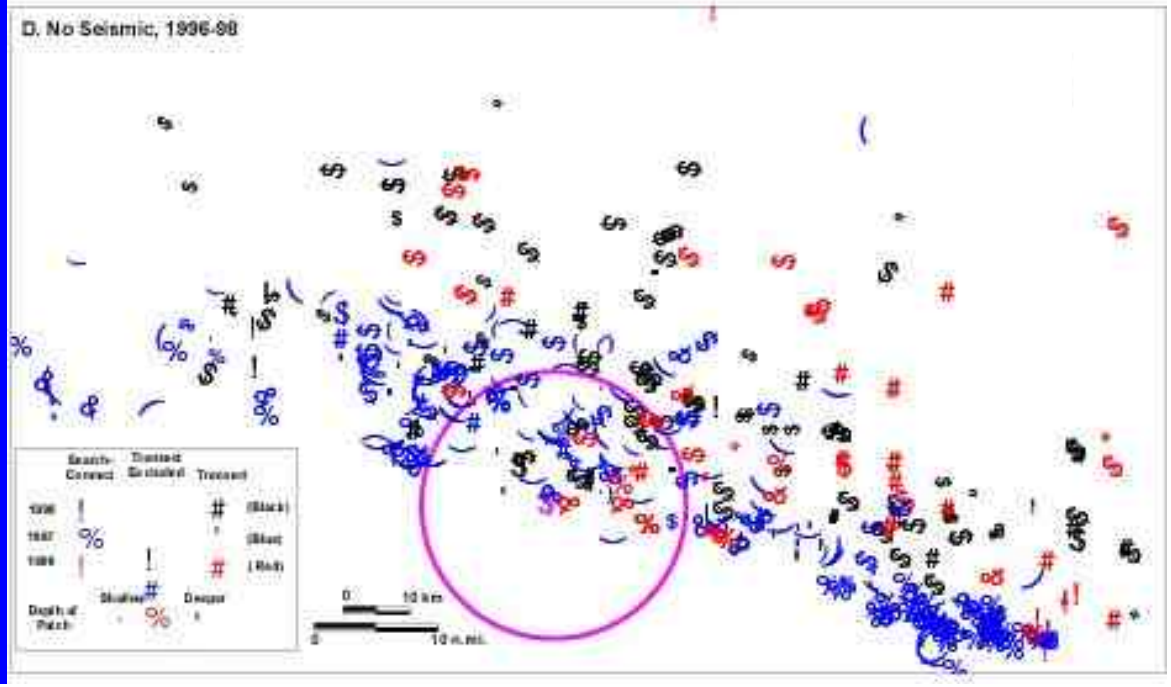
- How much of the habitat is impacted?
- What proportion of the population is impacted?
- Does avoidance interfere with use of resources that make habitat important?

Gray whales abandon breeding lagoon during shipping/dredging



Migrating bowhead whales avoid airgun sounds at 20 km or RL > 135 dB re 1 µPa





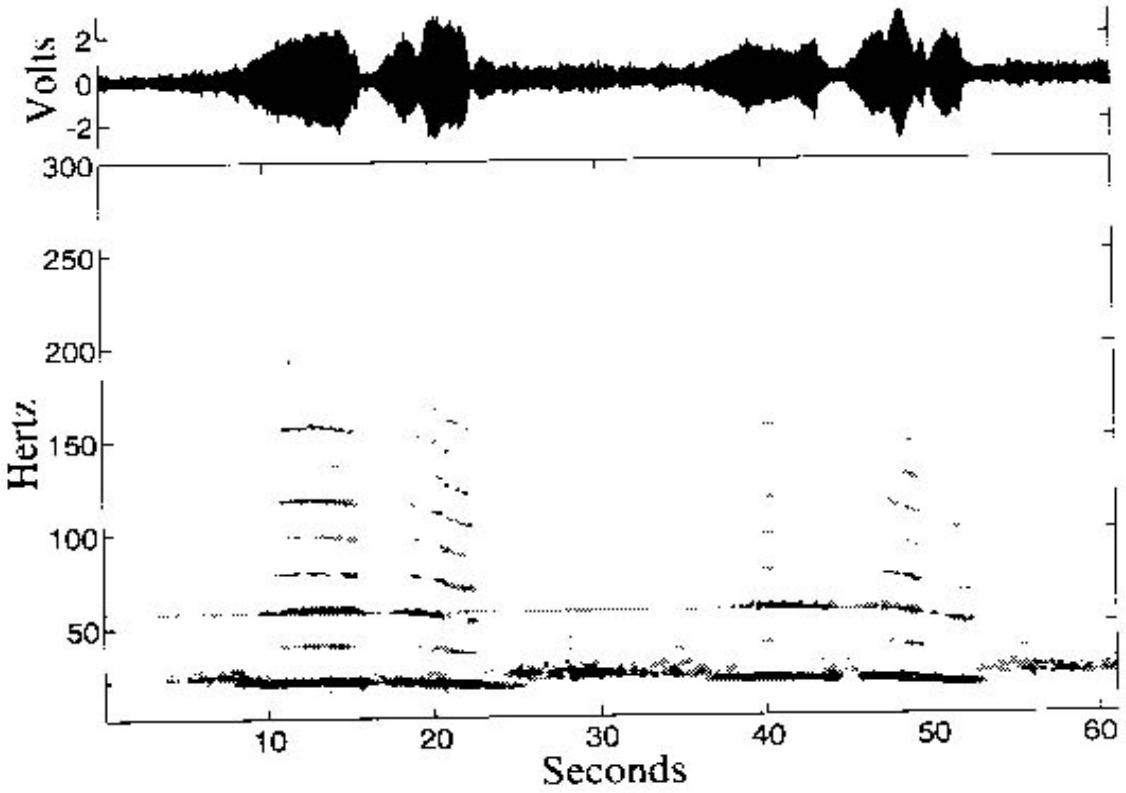
Courtesy W. J. Richardson; lgl

Behavioral Responses of Biologically Significant activities that can be related to adverse impact

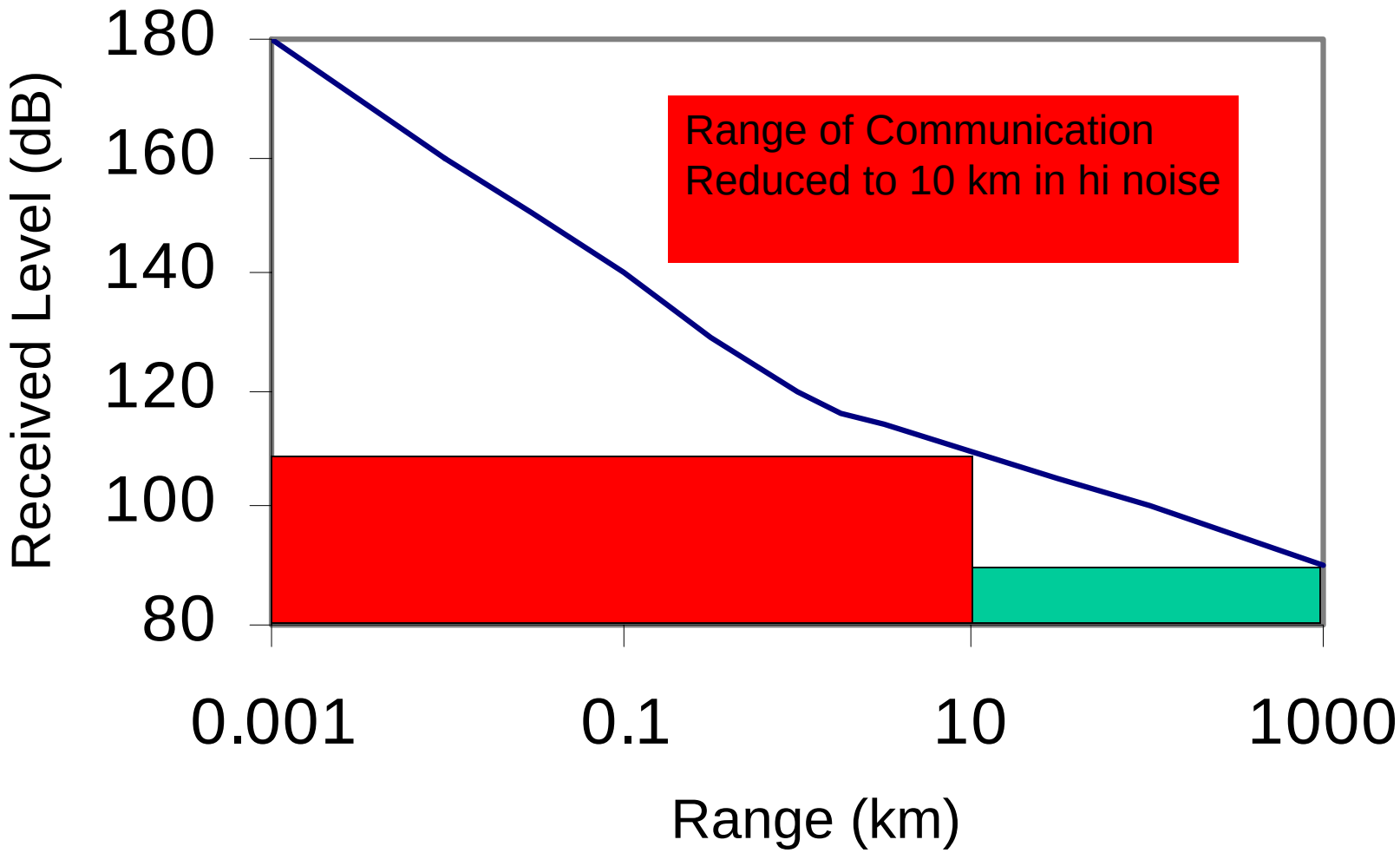
- Basic issues are demographic – effects on growth, survival, and reproduction
  - Reproduction: mating behavior
  - Survival: strandings, separation of calf
  - Growth: Feeding and energetics

Low frequency calls of blue whales

- Duration 10-20 sec
- Frequency 8-15 Hz strong harmonics
- Varies with geographical region
- Produced by males during breeding season

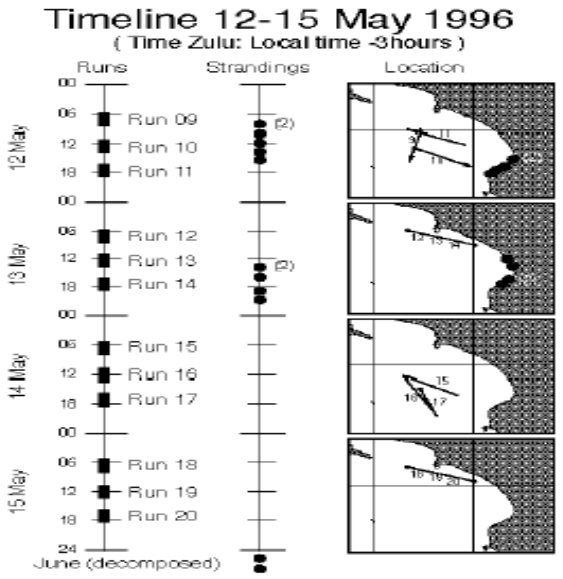


Increased Noise Can Reduce Effective Range of Communication



Concern over strandings of deep-diving beaked whales

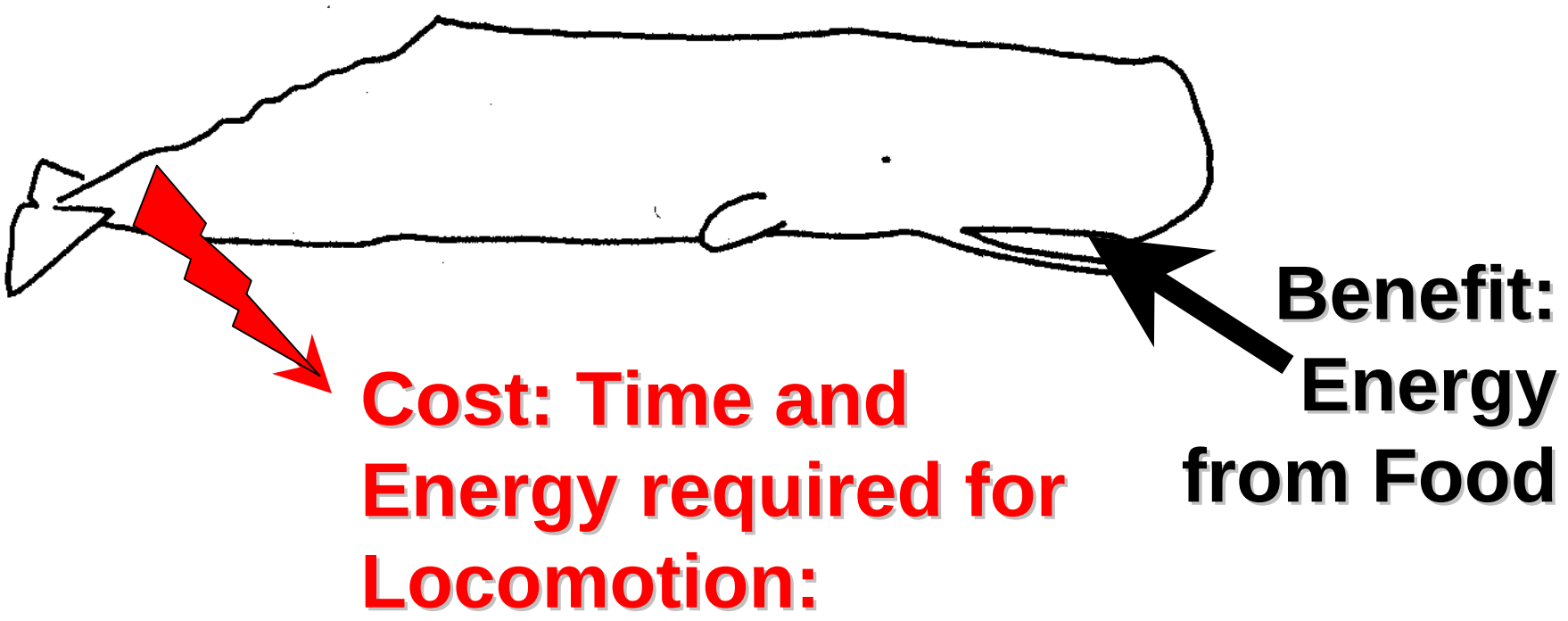
- Recent strandings in Bahamas, Greece, and Canary Islands
- >10 whales strand over tens of km within hours
- Associated with naval maneuvers
- What caused the strandings?
- If sound, what exposures are safe?



Disruption of feeding

Energetic Model: Feeding whale needs to stay in the black.

It must take in more energy than it expends in order to build reserves for growth and reproduction

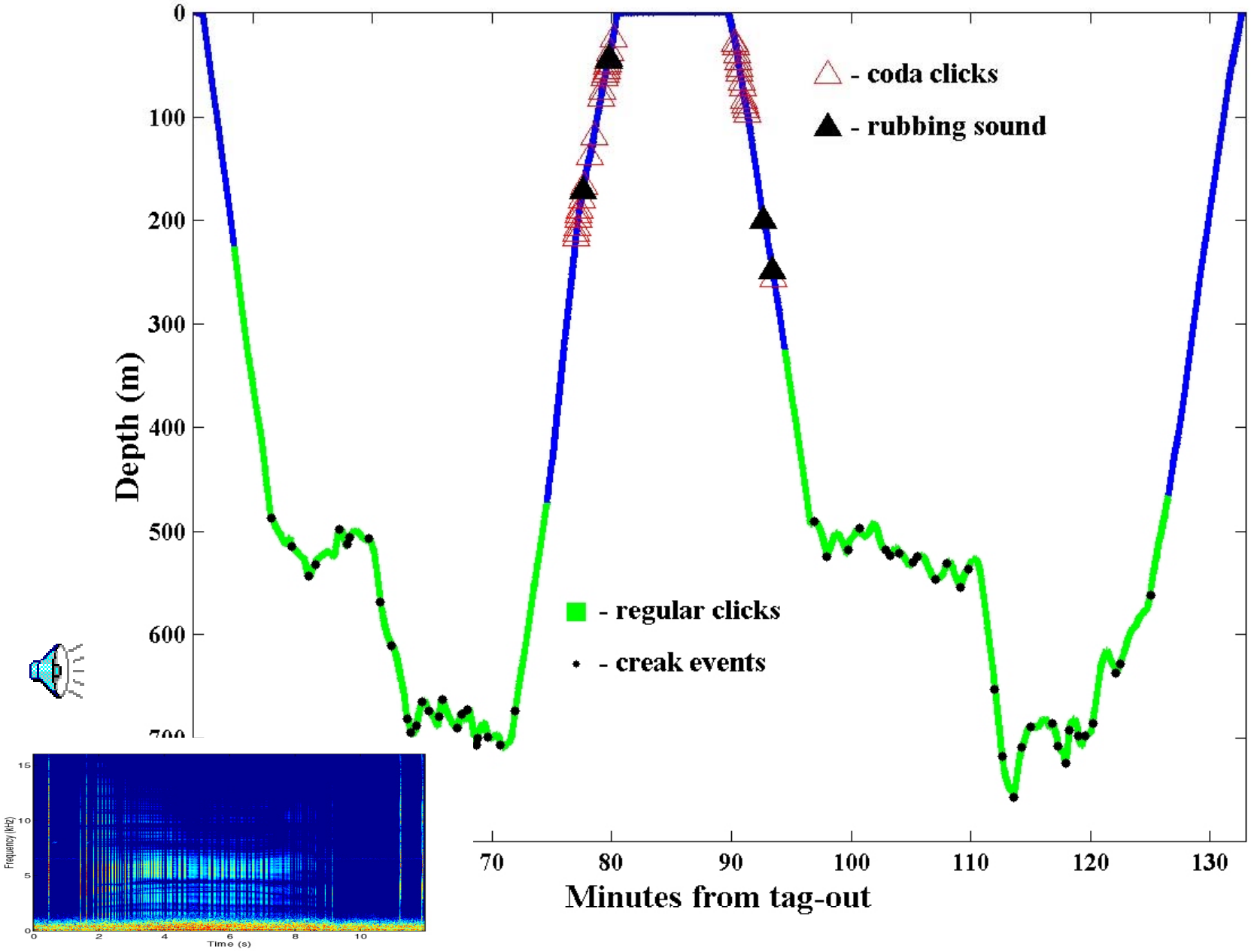


Digital Acoustic Recording Tag

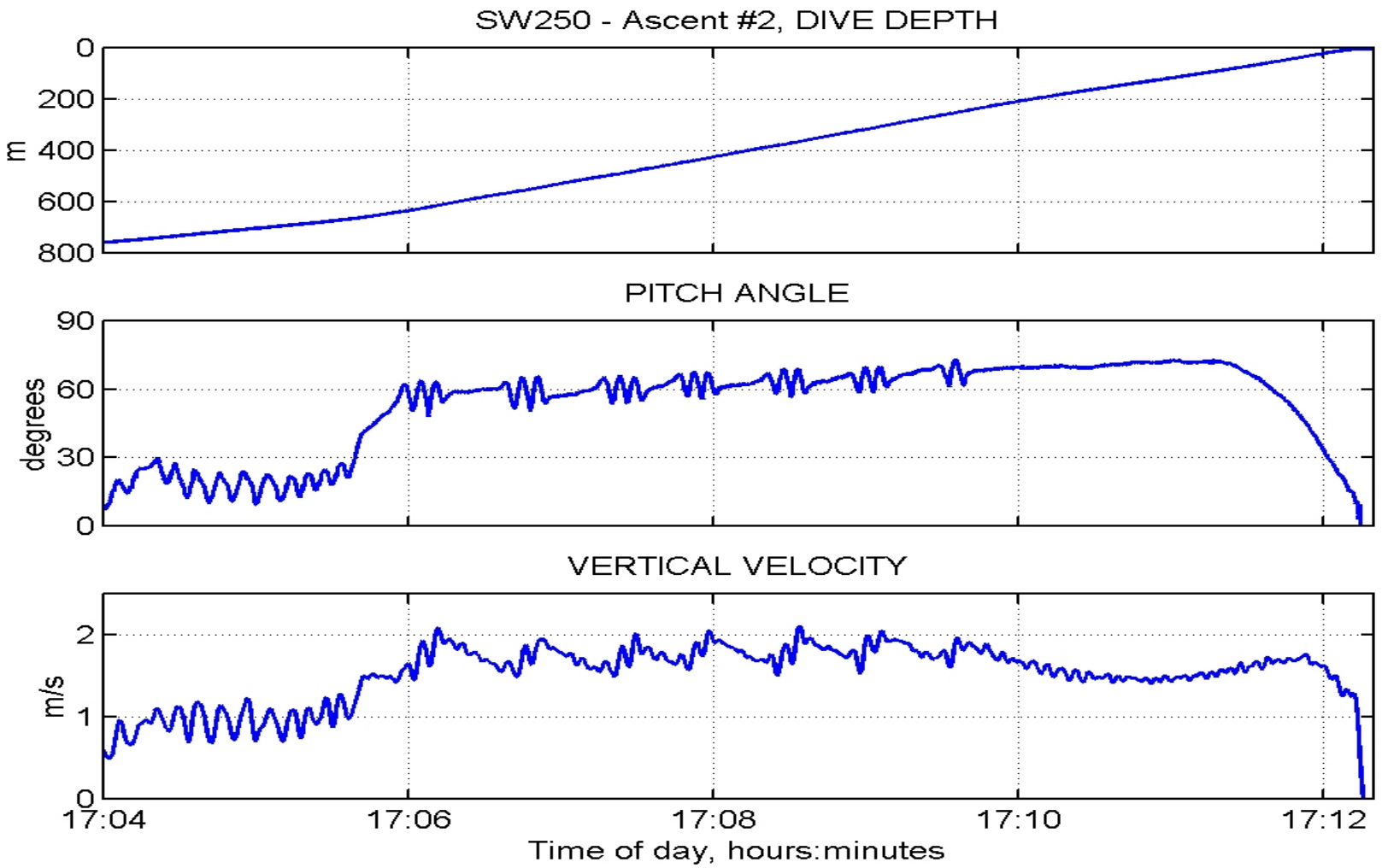
Developed by Mark Johnson, WHOI

- Measures received level of stimulus at whale while also measuring behavioral and physiological responses
- Tracks responses of marine mammals, especially deep divers, throughout their dives
- Improve understanding of functions and costs of behaviors in order to infer biological significance of behavioral disruption

Location of different vocalizations in dive



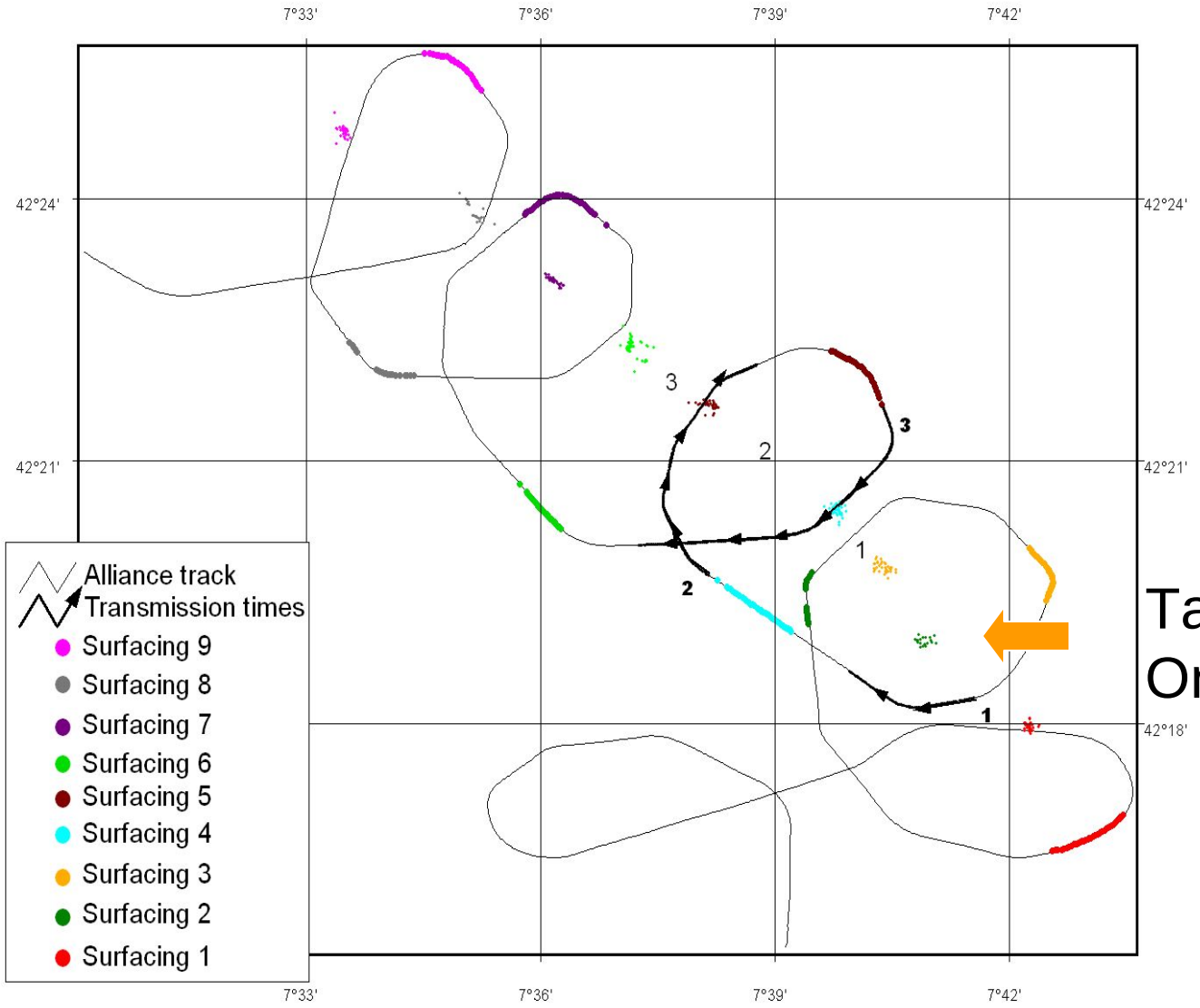
Flukebeat and pitch on ascent



Example of Controlled Exposure Studies of Sperm Whales

- Tag, visual observation, and acoustic monitoring of behavior
- Experiment with pre-exposure and exposure tag data from same individual
- Designed to evaluate effect of exposure on foraging

Sonar CEE on Tagged Sperm Whale



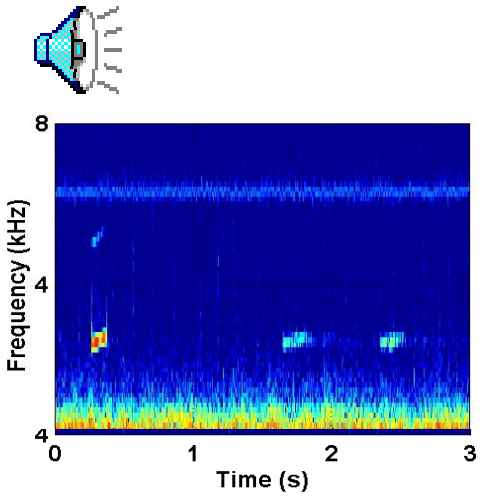
Requires diverse team:

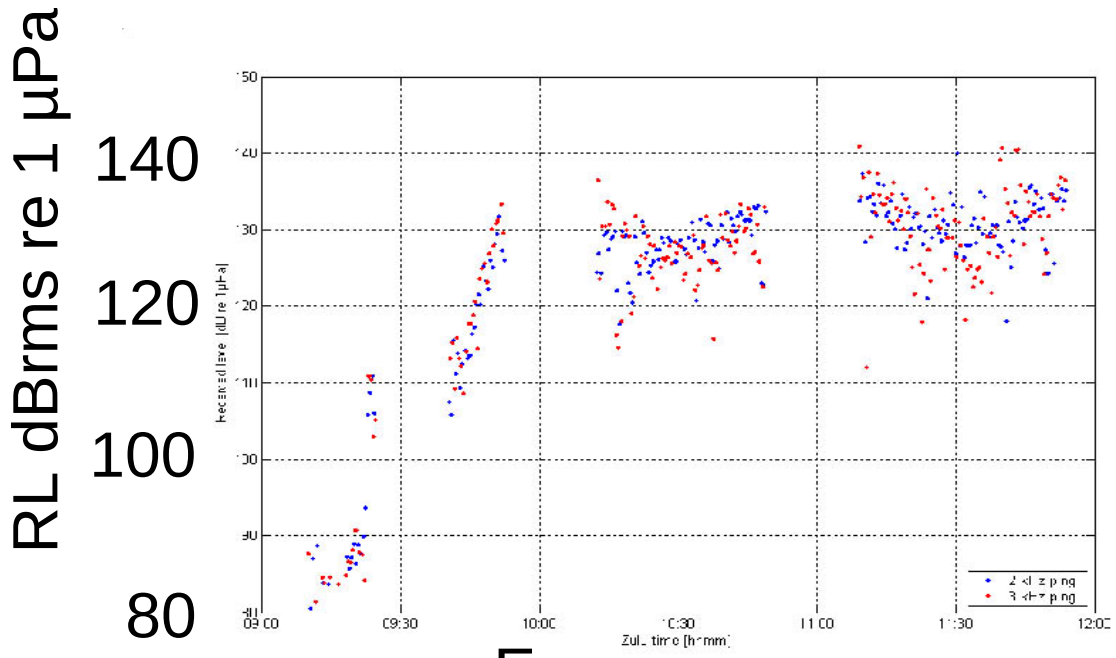
Silent ship

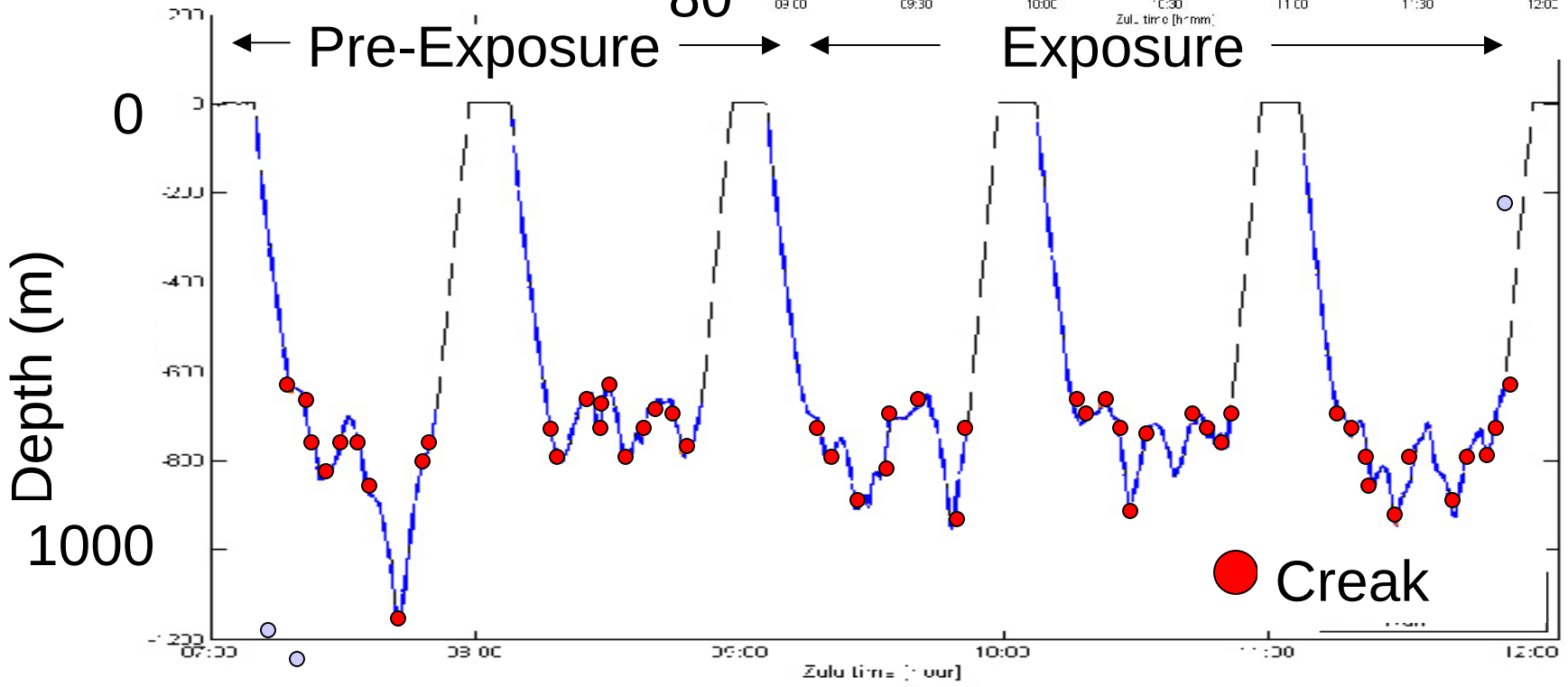
Acoustic monitoring

- Visual sighting
- Tagging

Acoustic modelling and source operation


Frequency (kHz)
8
4
0
1
2
3
Time (s)


RL dBrms re 1 µPa
140
120
100
80


Pre-Exposure
Exposure
Depth (m)
0
1000
Creak
Zulu time [hour]

Interpreting disruption of foraging behavior

- Cost:Benefit Modelling: Benefit is energy from food; Costs are time and energy of foraging
- Even for deep divers, we can measure
  - Proxies for foraging success
  - Movement parameters that enable calculation of cost of locomotion
- Need more theoretical modeling relating foraging cost:benefit to demography

Problem of cumulative impacts

Noise:

- Repeated exposure over time
- Multiple exposures at the same time
- Effects on >1 individual

Other sources of impact:

- Fisheries bycatch
- Fisheries reduce prey
- Chemical pollution
- Other human-induced changes to environment

Problem of Ecosystem Impacts

- Simple version: requires similar studies of effects of noise on other species, especially species ecologically coupled with marine mammals (predators and prey)
- Complex version: requires study of interactions between all ecosystem components, especially for synergistic effects
- Current state of science is not mature enough to answer all these questions


Questions?