BioAcoustic Predation

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Approach to Problem

Predator: Southern Resident Killer whale

Prey: Salmon, preferred Chinook Salmon

Interaction: detection
discrimination
classification
identification

Noise: Environment
Other potential prey

Vocalization Types

Echolocation clicks: find food and navigate

Calls and Whistles: communicate among group members

Echolocation   Call

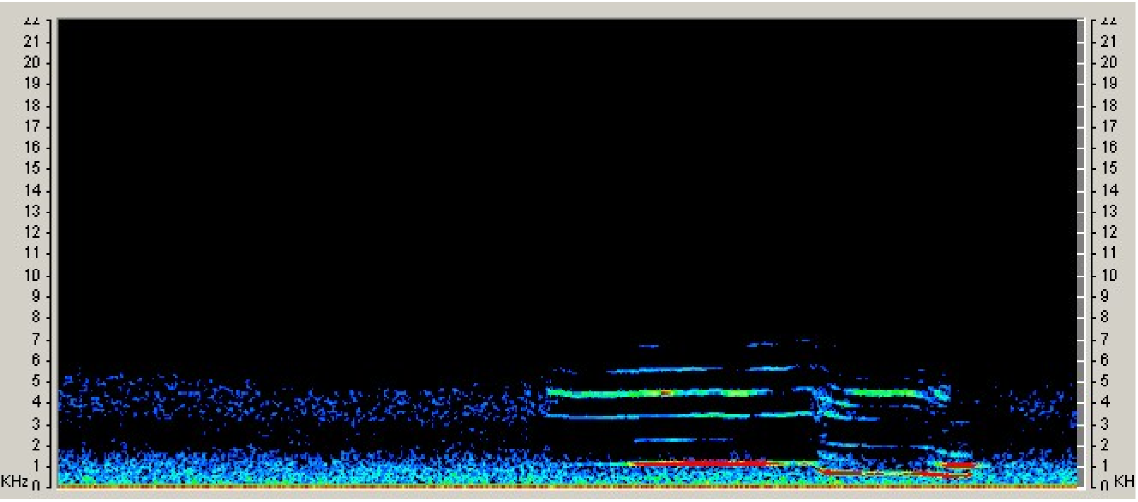
Echolocation Clicks:

- brief 80 to 120 ms
- bimodal spectra
- SL ~ 195 – 210 dB re 1 μPa
- maximum peak-to-peak SL 224 dB re 1 μPa

Vocalization Spectrogram

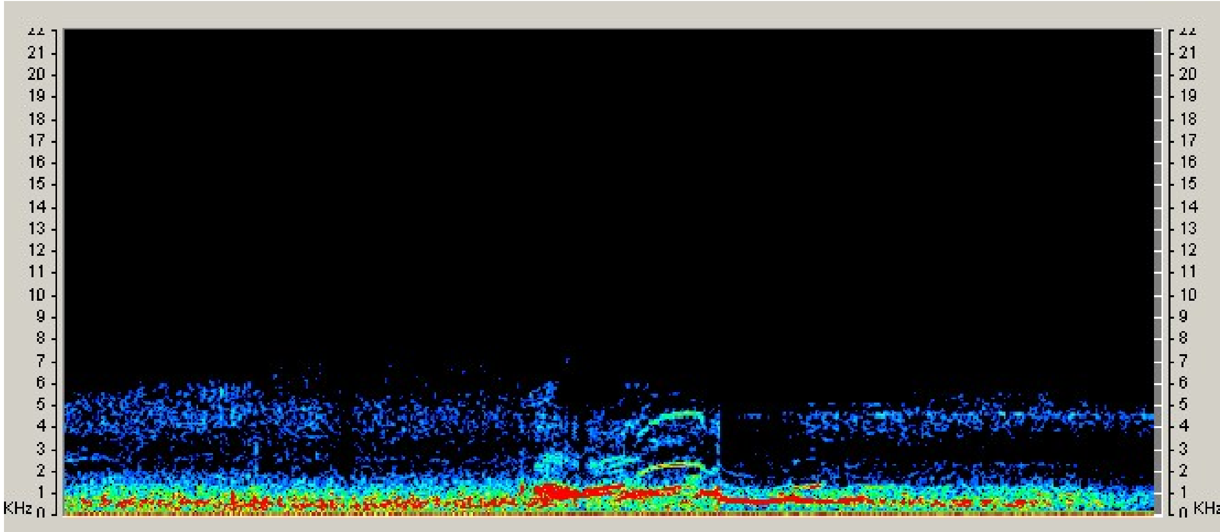
Frequency

22 kHz

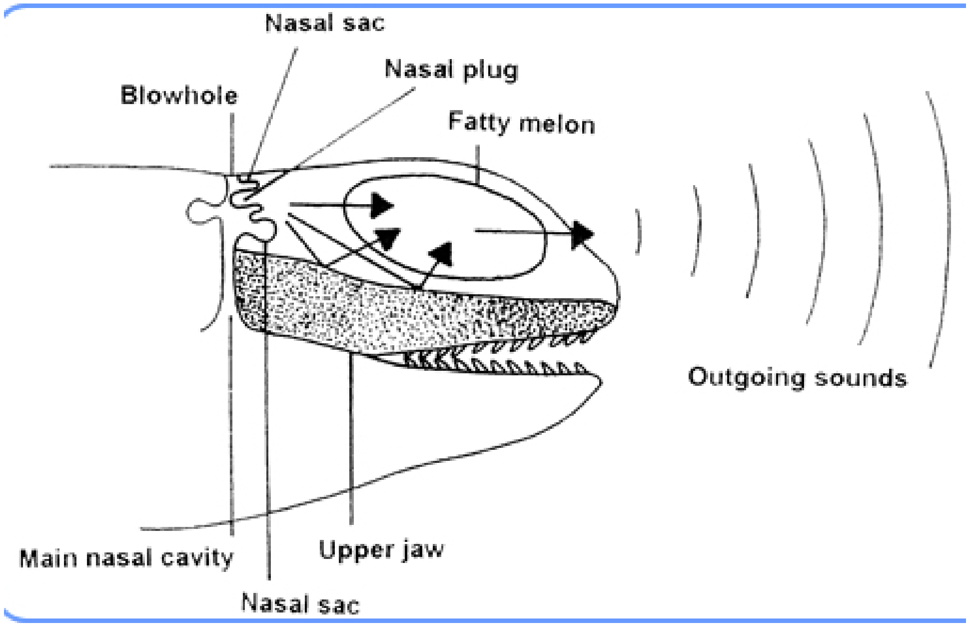


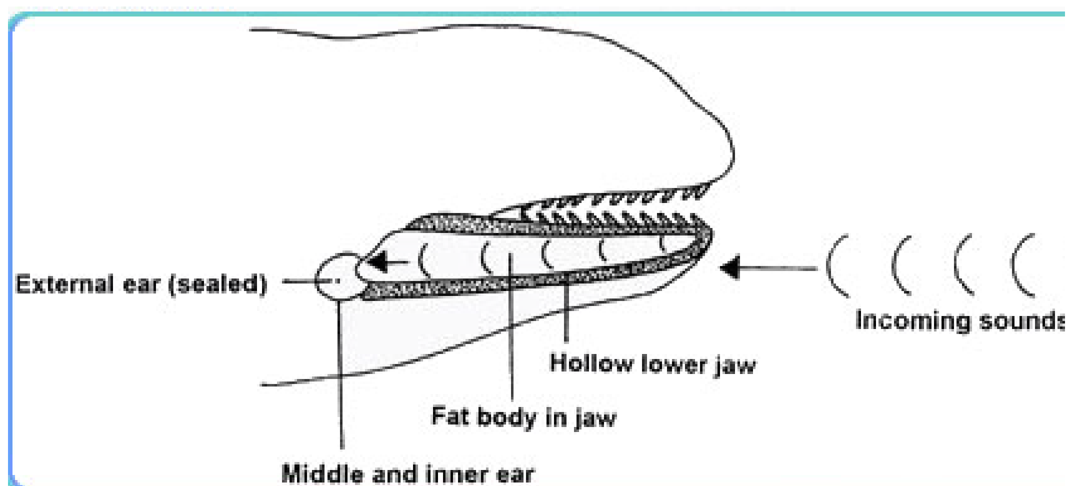
0 kHz

Time

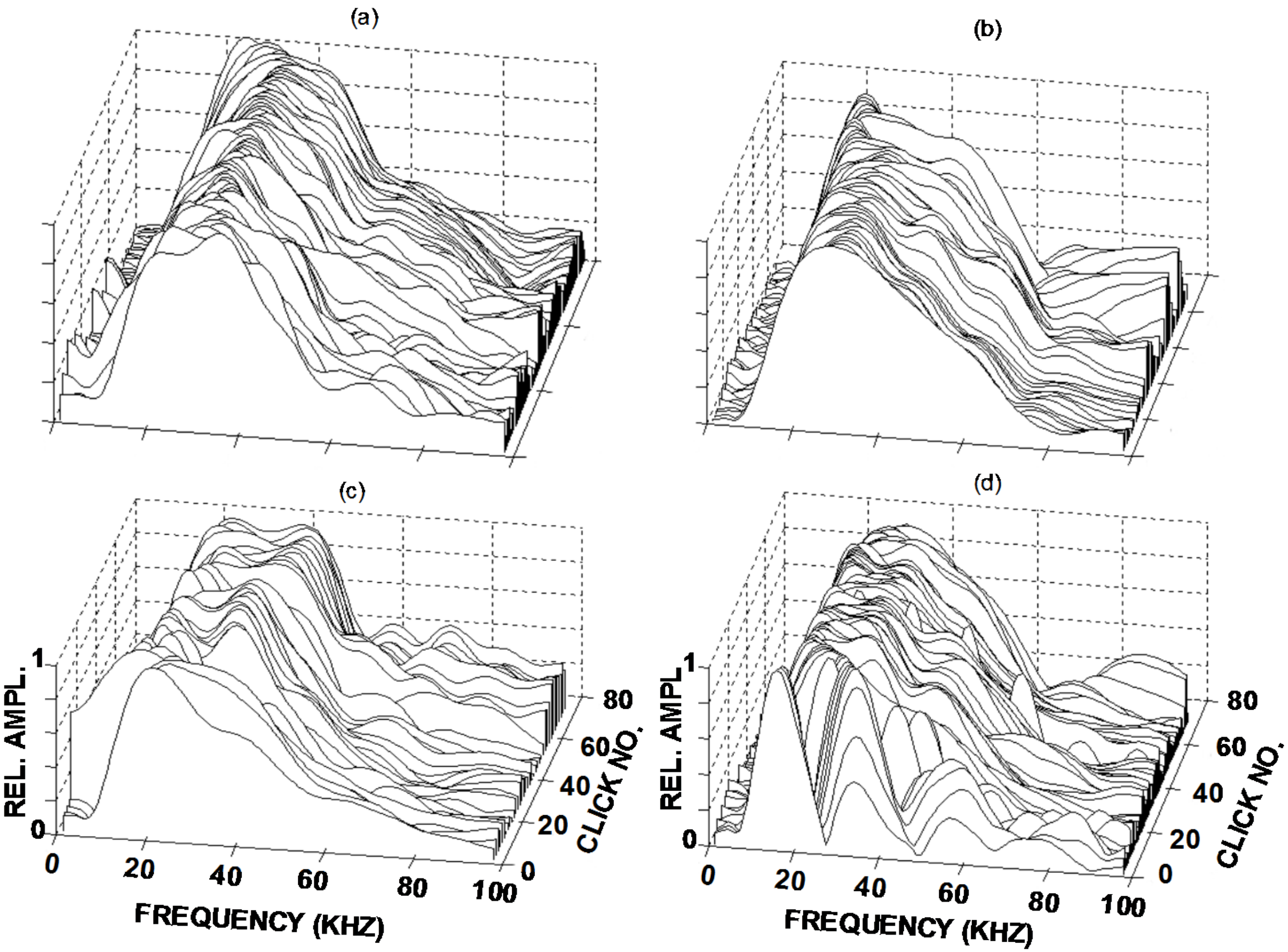


Sound Production and Reception





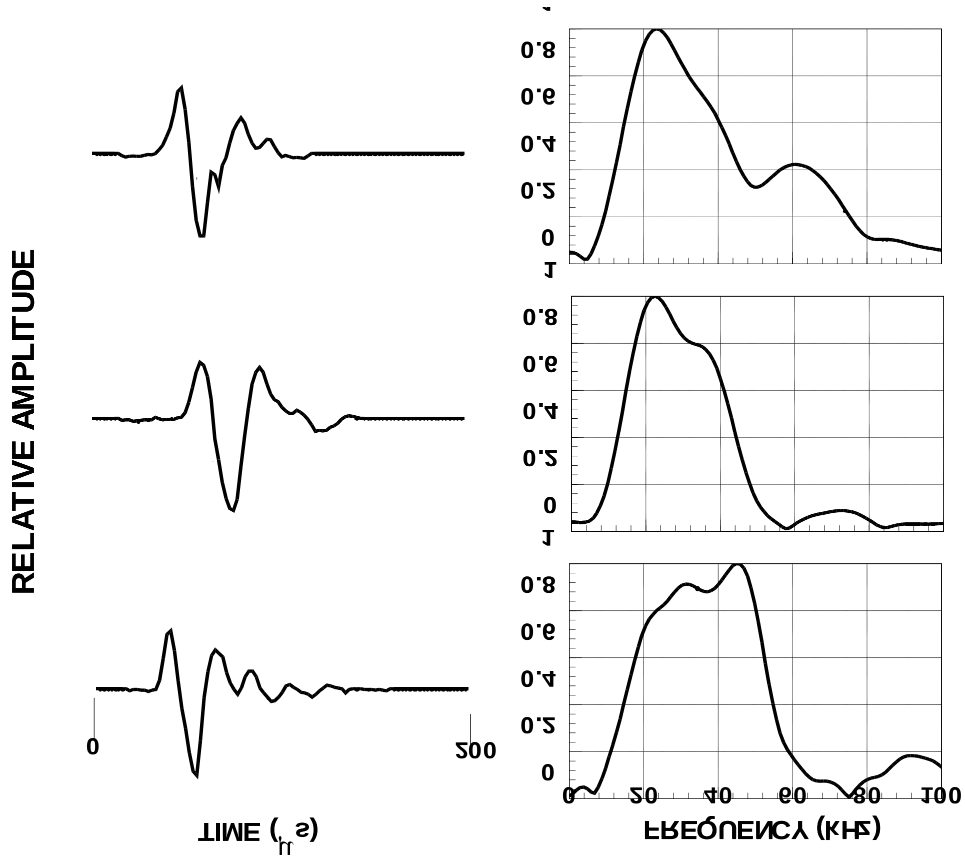
Spectra of Killer Whale Click Trains



some regions stable others variable

Waveforms & Frequency Spectra

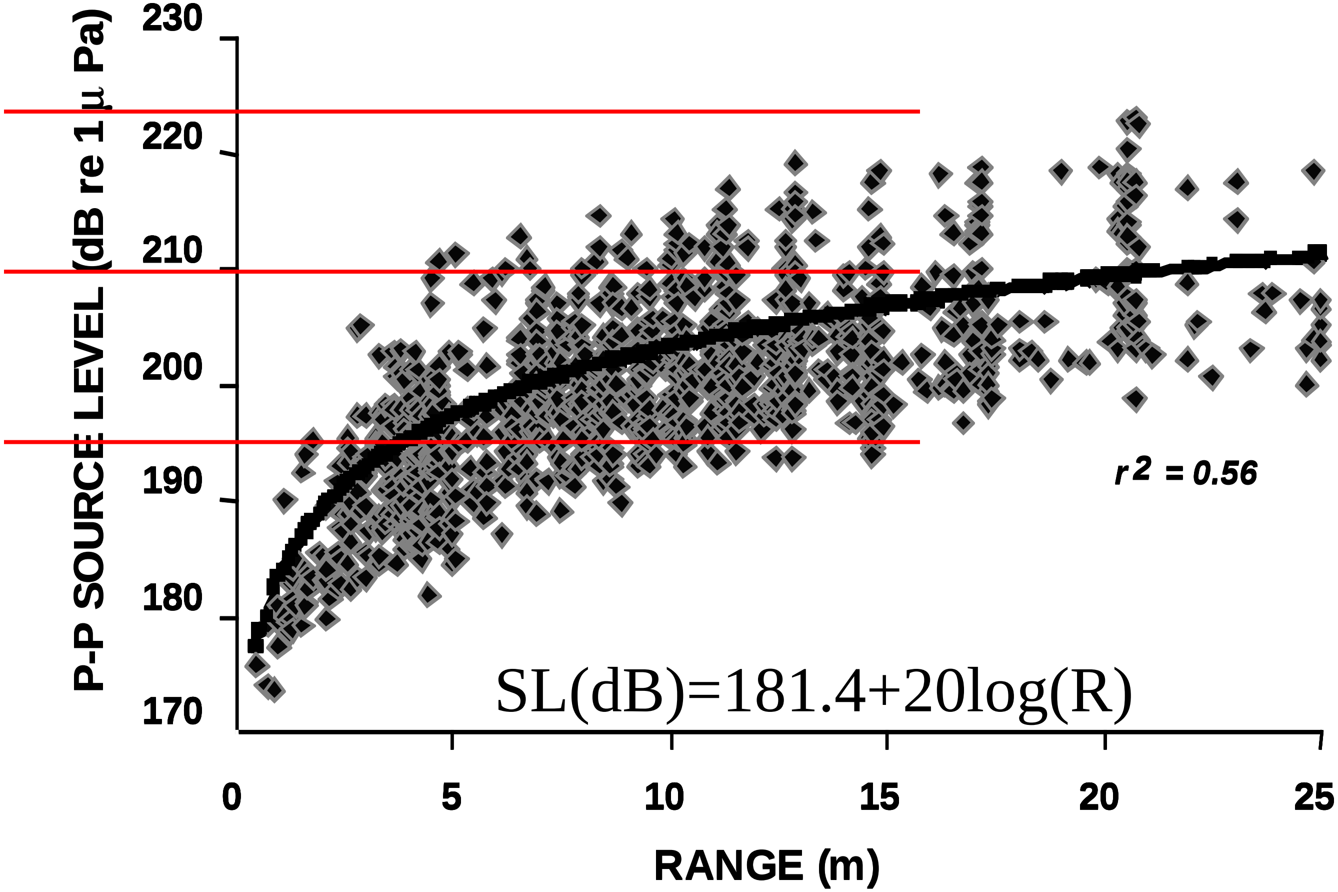
Waveform Frequency Spectra



Source Level and Range

max. p-p SL 224 dB re 1 μPa

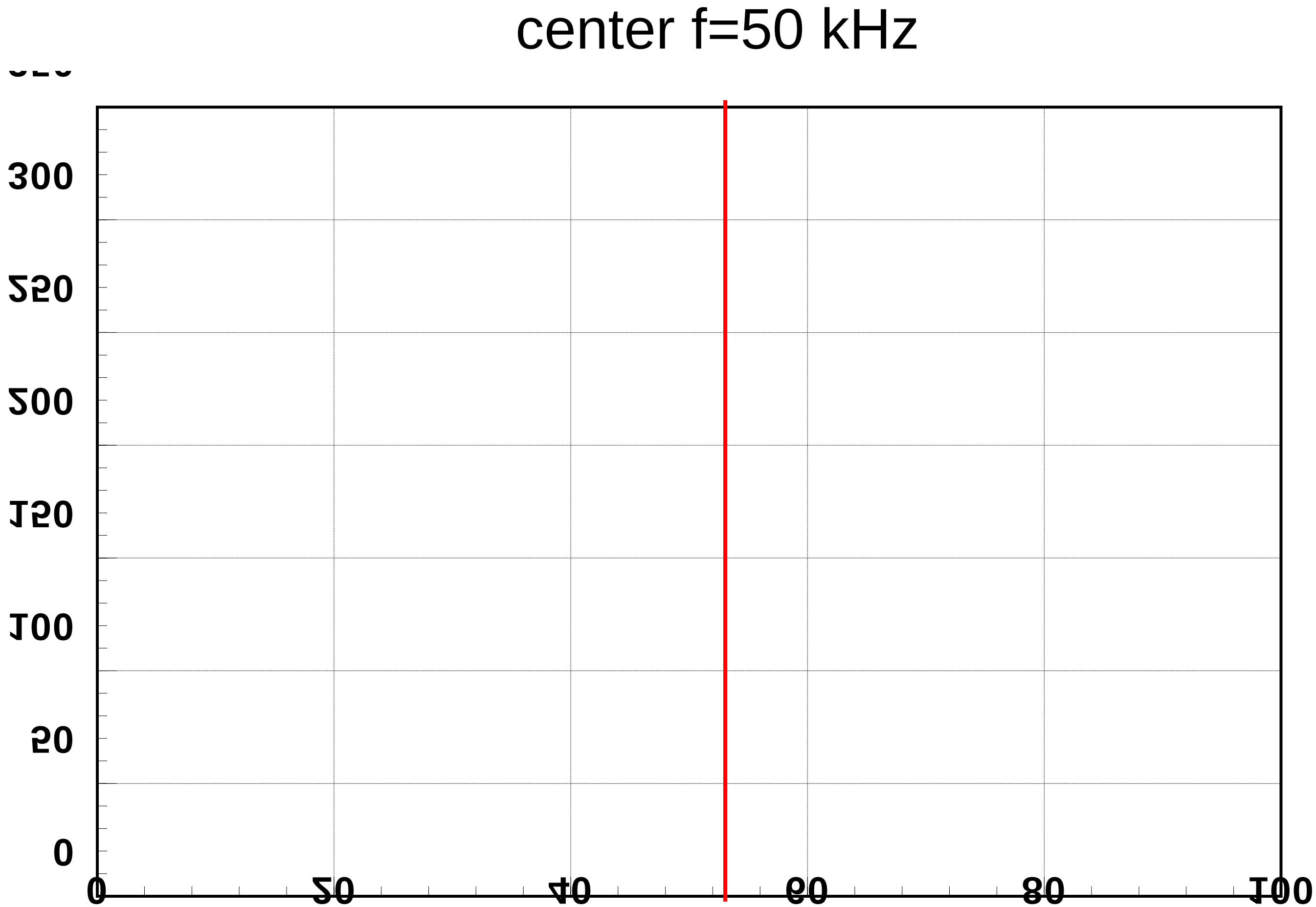
75% SL between 195 and 210 dB re 1 μPa



SL increased with range on a single target, compensate for spreading loss

Echolocation Center Frequencies

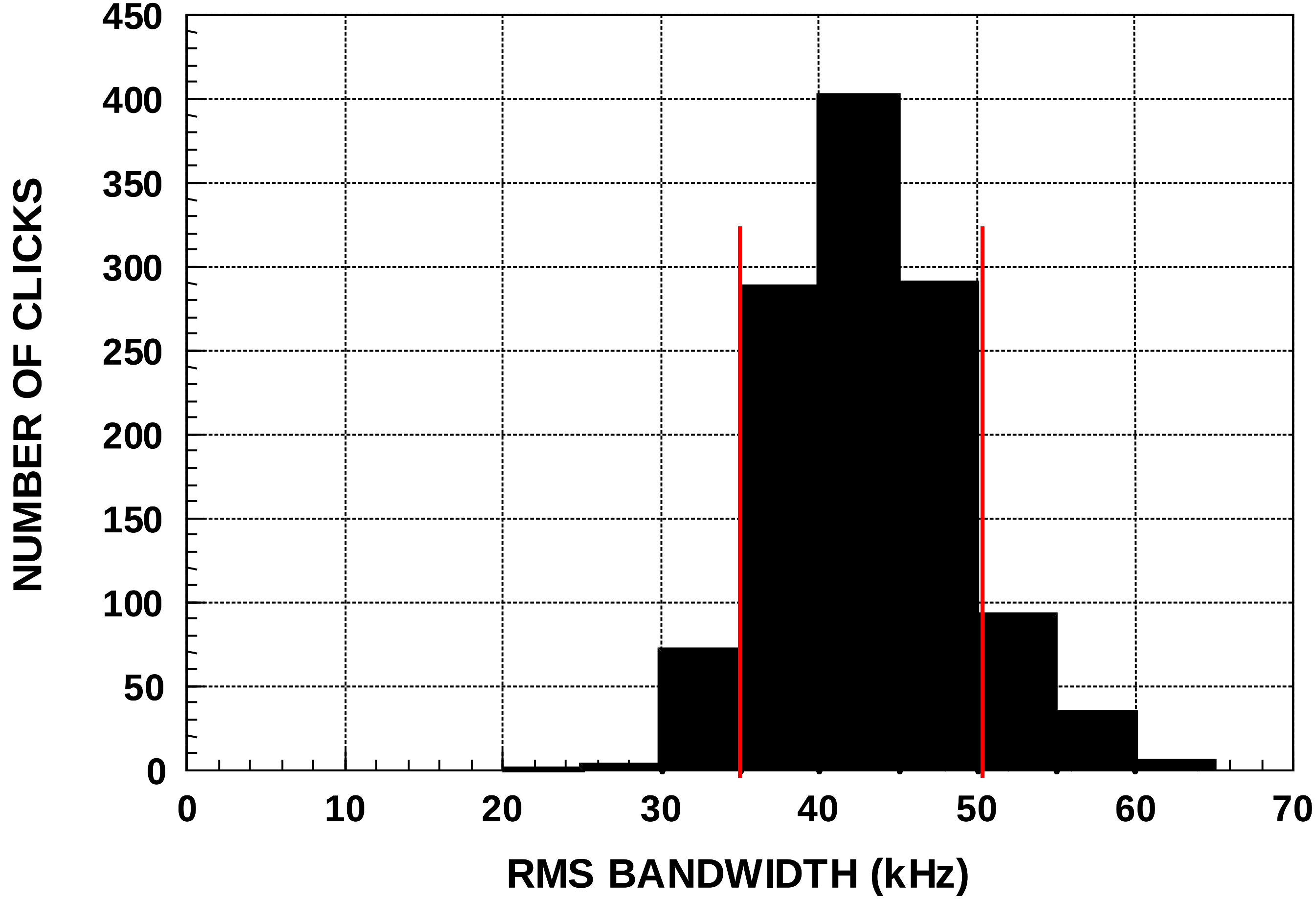
89% of clicks had bimodal spectra



Echolocation rms Bandwidth

width of spectrum around
center frequency

peak at 40 kHz



83% bandwidth
between 35 – 50 kHz

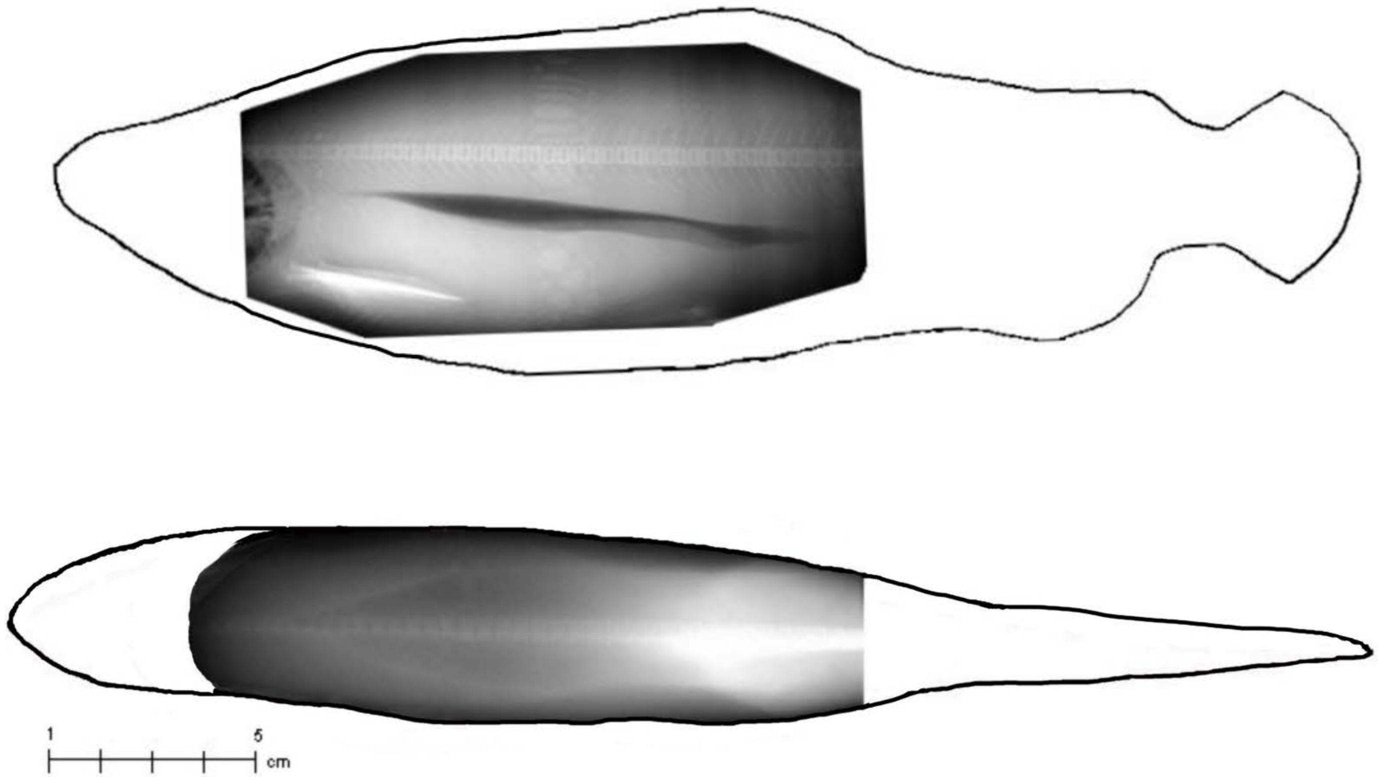
Dietary Specialists?

Evidence:

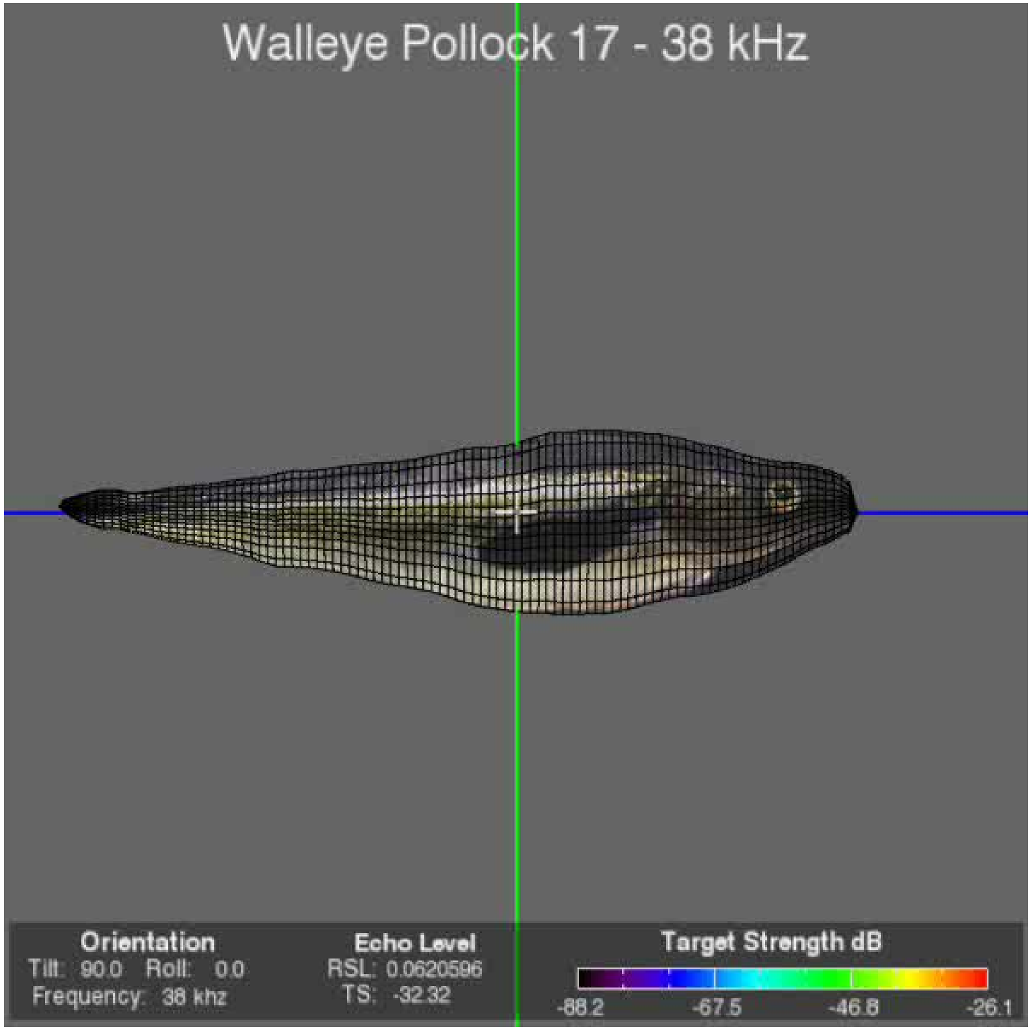
- Surface remnant and stomach necropsies
- 22 fish species, 1 squid species
- 96% of prey salmonids
- Chinook salmon (*Oncorhynchus tshawytscha*) most common

Ford et al. 1998 Can. J. Zool. 76: 1456-1471
2006 Mar. Ecol Prog. Ser. 316: 185-199

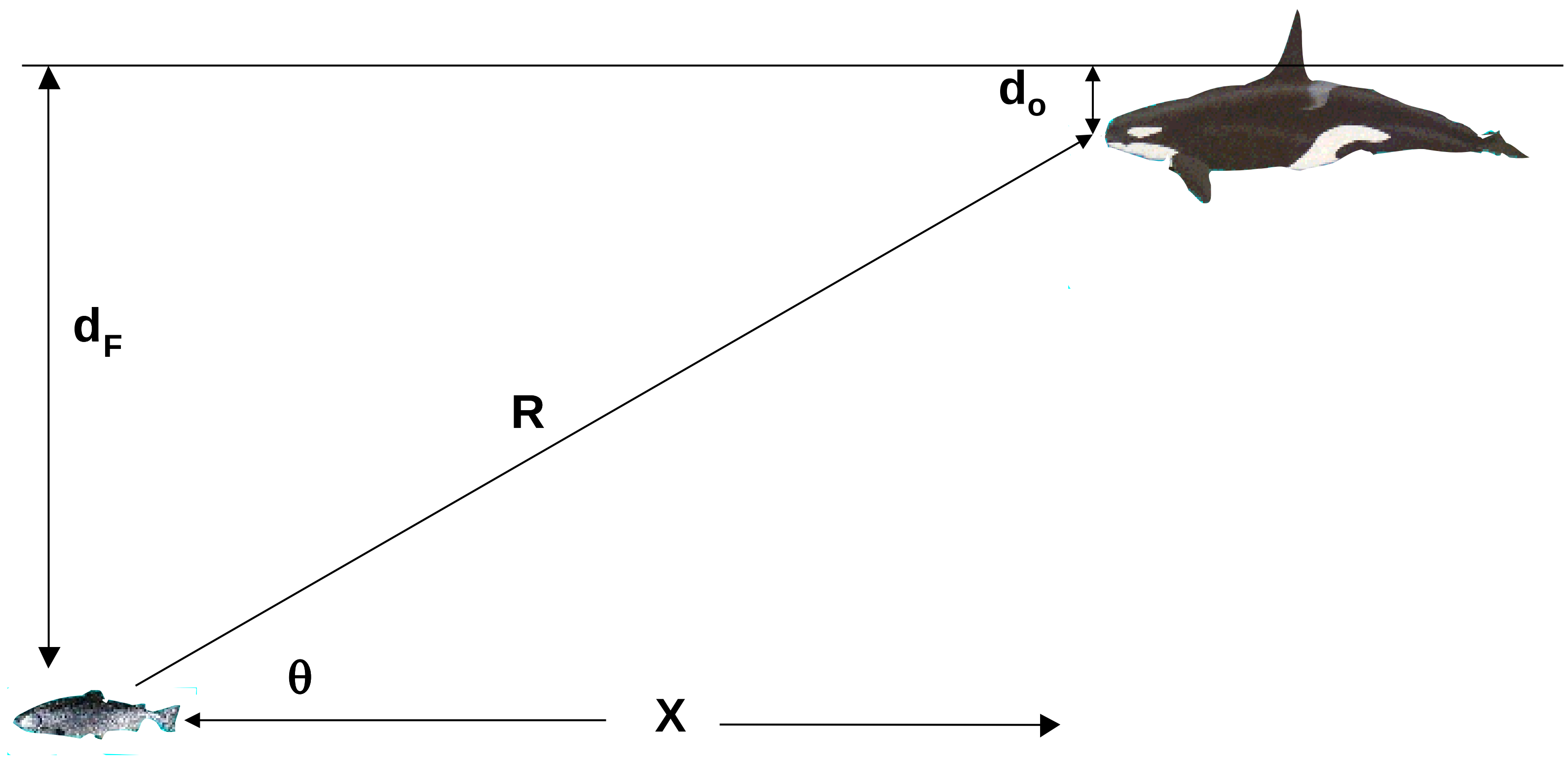
Preferred Prey: Chinook Salmon



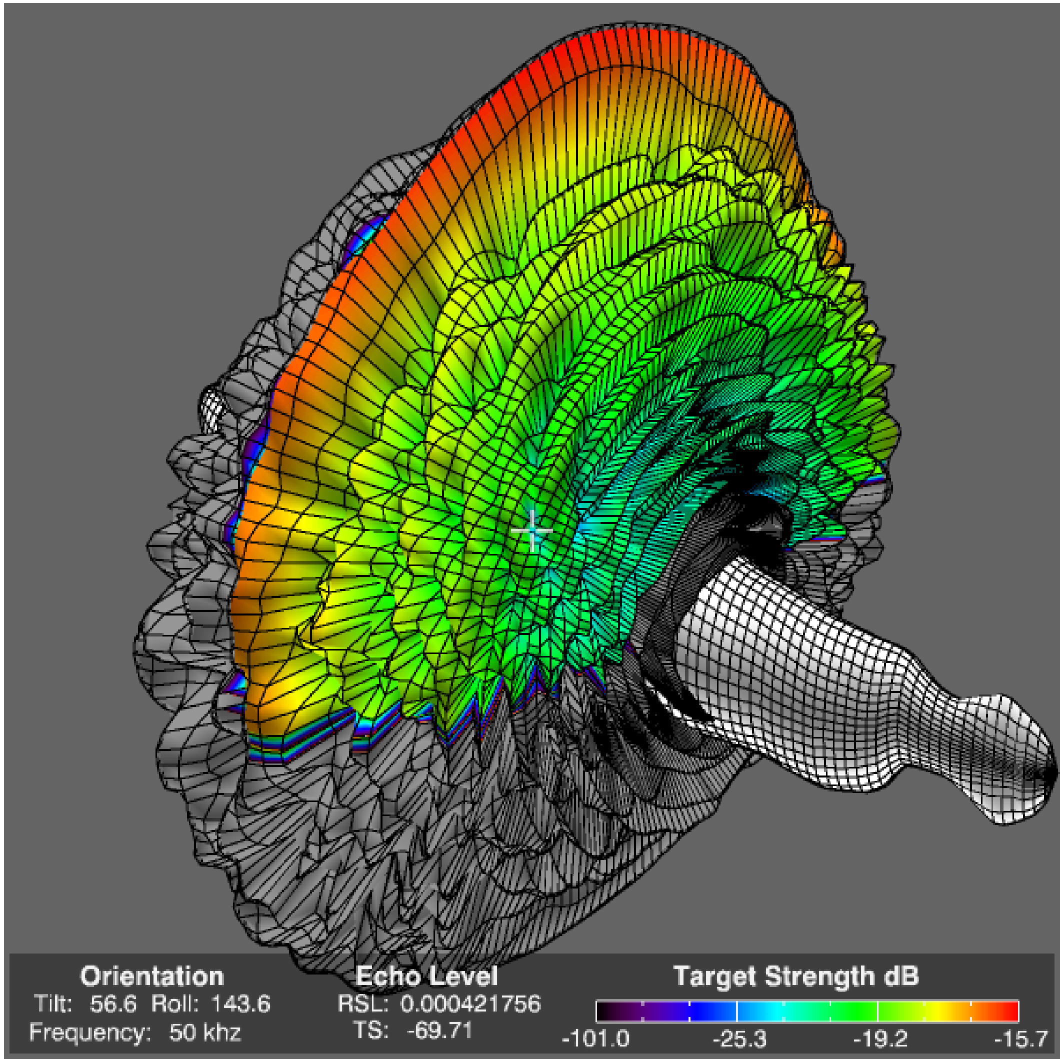
Acoustic Perception of Fish



Predator-Prey Assumed Geometry



Attack Quadrant Backscatter

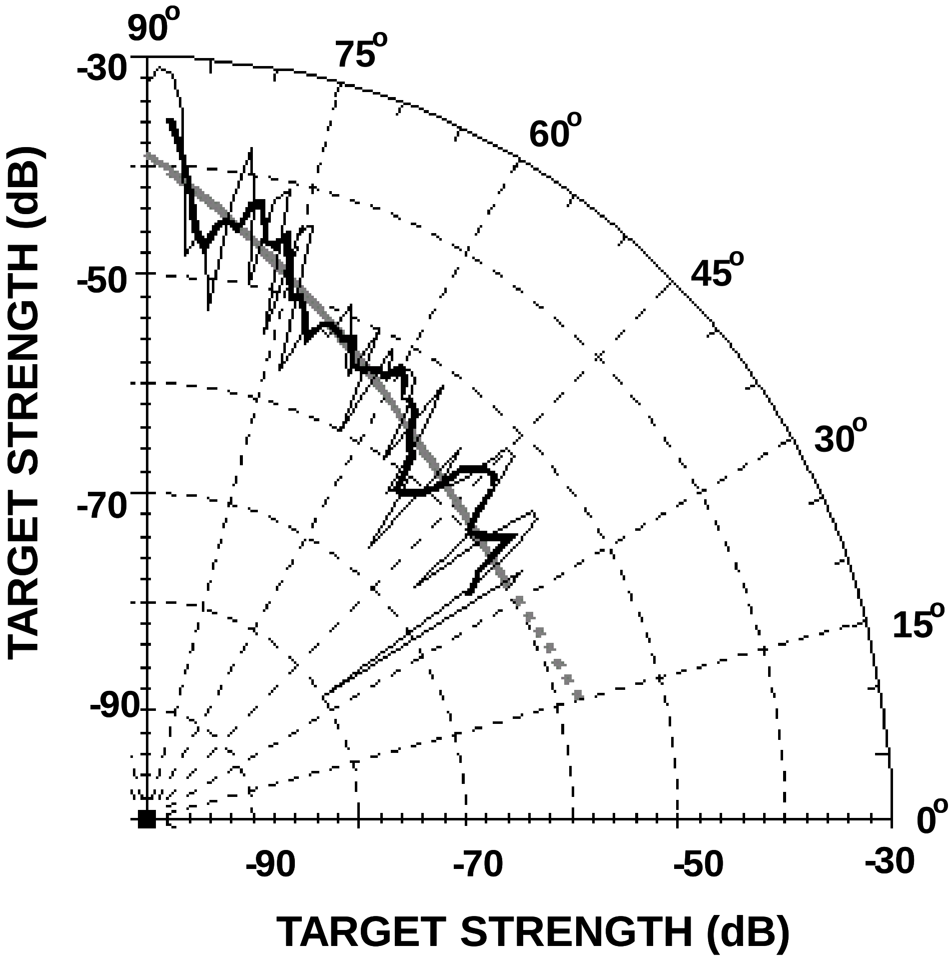


Chinook Salmon Backscatter

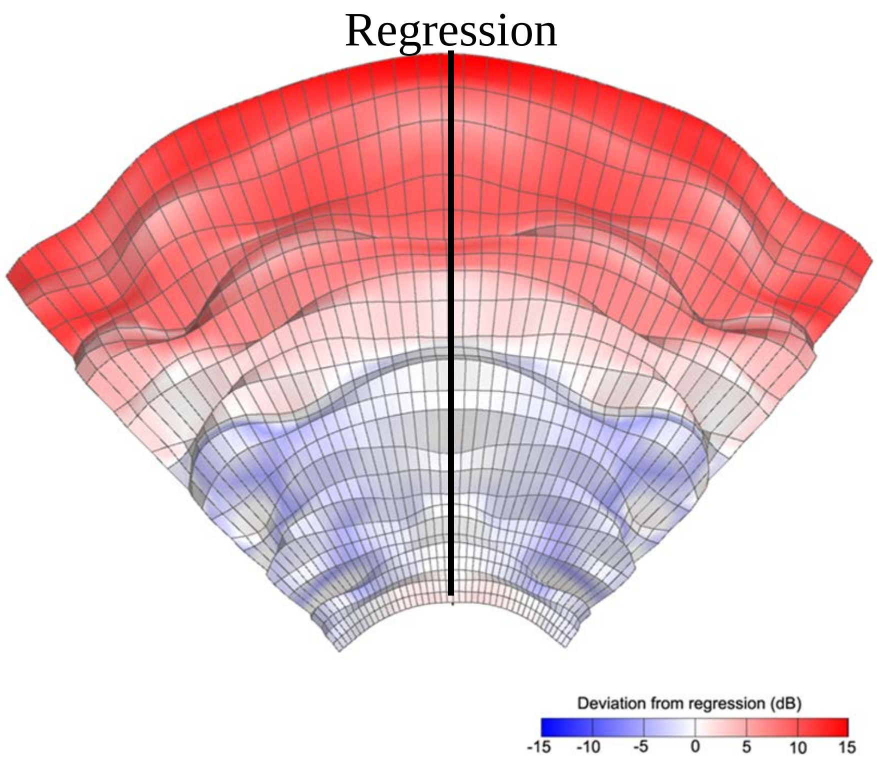
TS = 53.037- 0.410 θ + 0.006 θ^2

$r^2 = 0.88$

5-point moving average

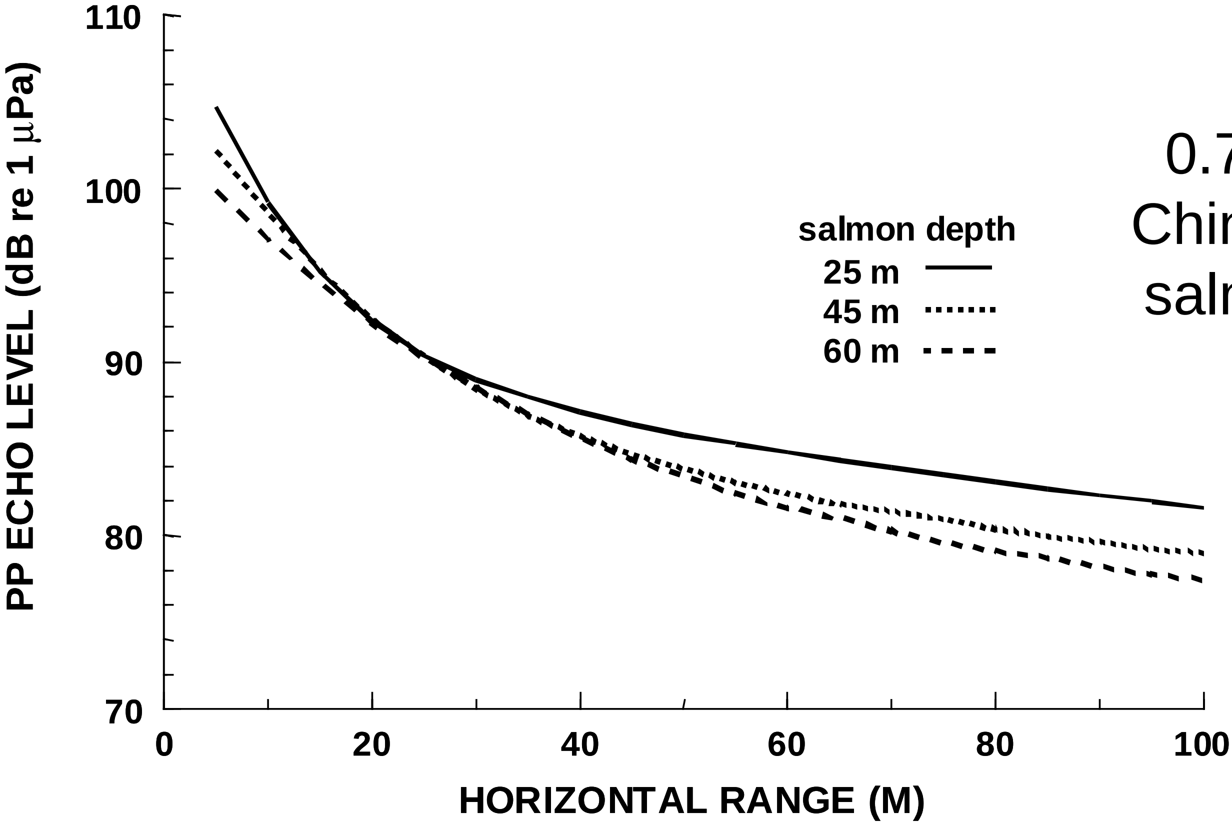


Deviation from Regression



Salmon Echo Level over Range

$$EL = 128.633 - 20 \log(R) - 2\alpha R - 0.410\,\theta + 0.006\,\theta^2$$



0.7 m Chinook salmon

80 dB

4 dB difference

Salmon Echo Level with Noise

$$NL = N_o + CR - DI$$

where NL = noise level, N_o= noise spectral density,
CR = critical ratio, DI = directivity index

CR = amount a pure tone must exceed noise spectral level

Sea state 4 @ 50 kHz: 35 dB re 1 $\mu Pa^2\ Hz^{-1}$ (Urick 1983)

CR of 12^{th} octave (Erbe 2002)

$$CR = 10 \log(2.9\ kHz) = 34.6\ dB$$

Killer Whale Directivity Index

Assume killer whale head analogous to a circular transducer:

$DI \propto$ radius

Estimate Killer whale DI_{oo} using Bottlenose dolphin (*Tursiops*)

DI_{tt} @ 50 kHz = 11 dB (Au and Moore 1984)

Then: $DI_{oo} = DI_{tt} + 20 \log (r_{oo}/r_{tt})$

Assume:

$r_{oo}/r_{tt} \sim 3 – 3.5$ If 3 then: $DI_{oo} = 11 + 9.5 = 20.5$ dB

Detectability at Sea State 4

$$NL = N_o + CR - DI$$

$$= 35 + 34.6 - 20.5$$

$$= 49.1\ dB_{rms}$$

$$= 58.1\ dB_{pp} \qquad x_{pp} = x_{rms} + 9$$

EL = ~ 80 dB – 58 dB = ~21 dB

@ 100 m range: salmon is still ~ 21dB above threshold

Detectability During Rain & Wind

Light rain (3 mm hr^{-1}) = 42 dB re 1μPa^2 Hz^{-1}

EL ~3 dB above threshold @ 100 m in rain and sea state 4

Moderate to heavy rain = 52 dB re 1μPa^2

EL above threshold @ ~40 m in rain and sea state 4

worst case as rain noise near surface and directivity assumed isotropic

rain noise & sea state: Scrimger et al. 1989, Urick 1983

Summary

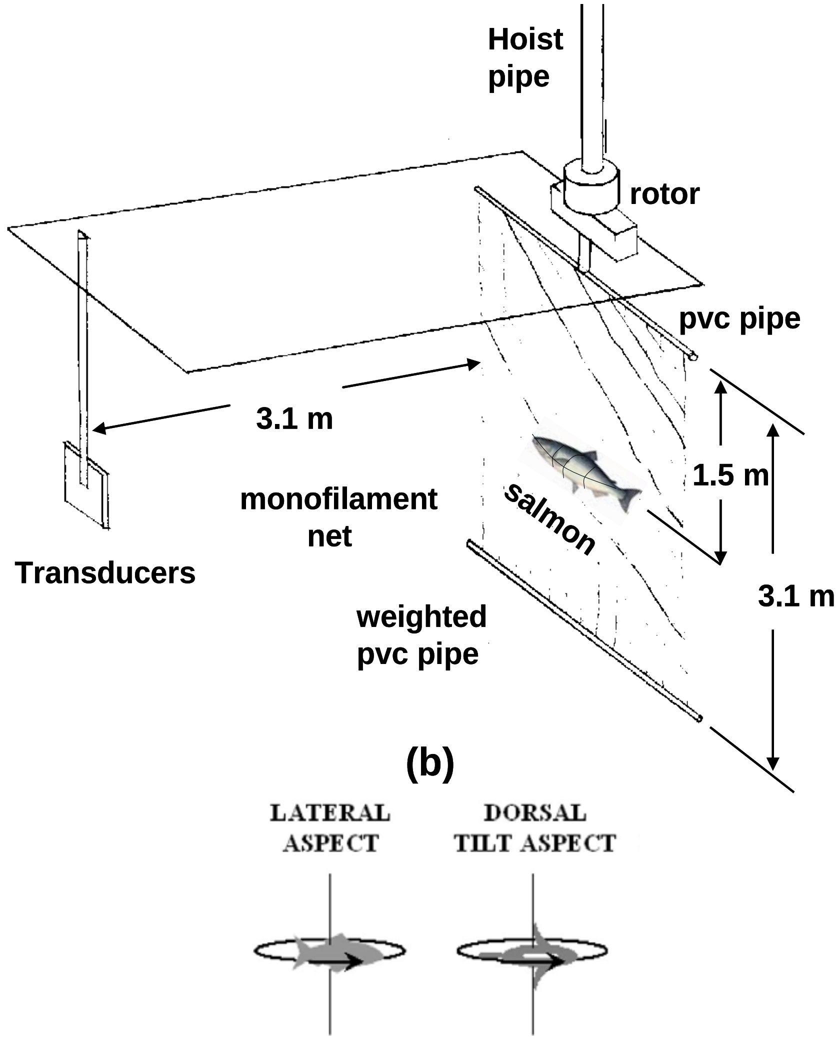
- killer whales can detect salmon over large ranges
- still detectable in noisy conditions

Next Steps:

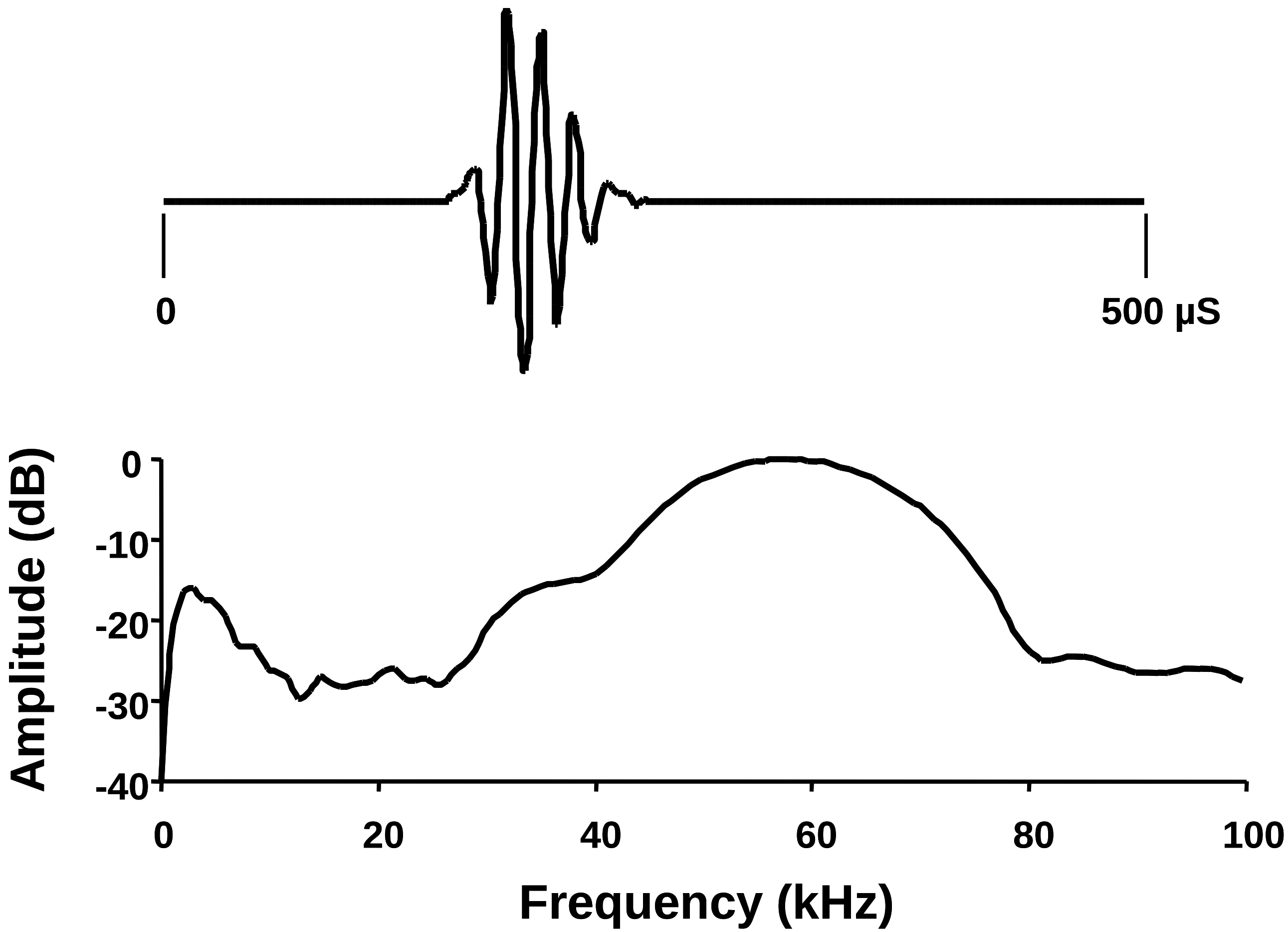
- need beampatterns, detection thresholds in quiet and noisy conditions, and critical ratio of killer whales
- need broadband models and measures of fish backscatter

Characterizing Salmon Backscatter

- mimic echolocation signal of killer whale
- known species and length of individual fish
- ensonify from different attack angles in dorsal and lateral plane
- 3 species: chinook, coho, sockeye

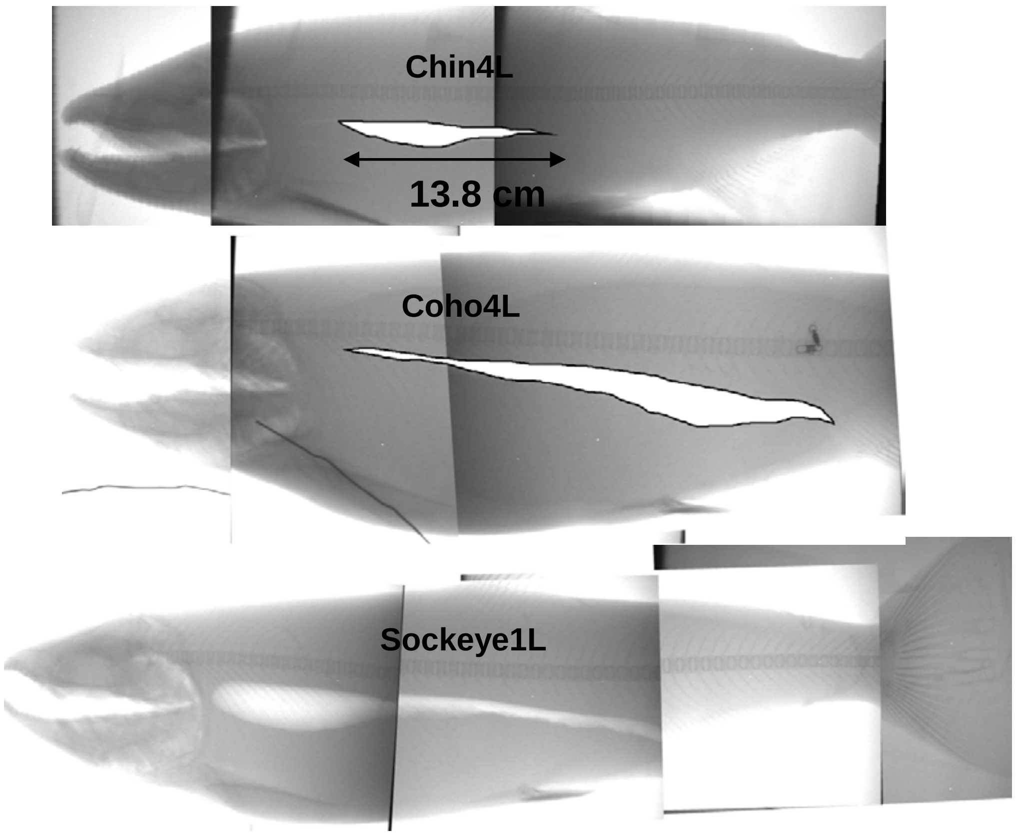


Sonar: waveform & frequency spectra

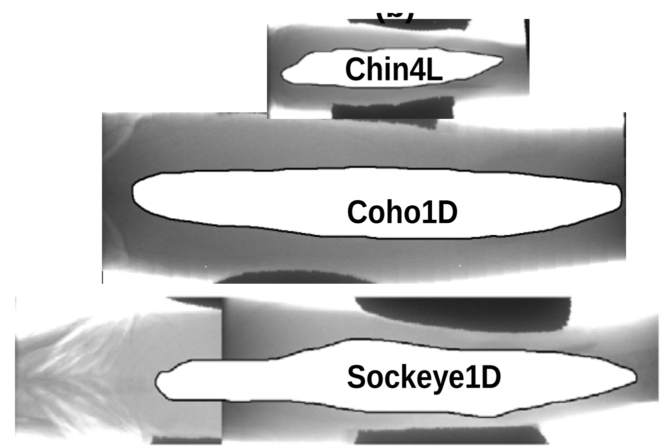


Salmon Swimbladders

Lateral



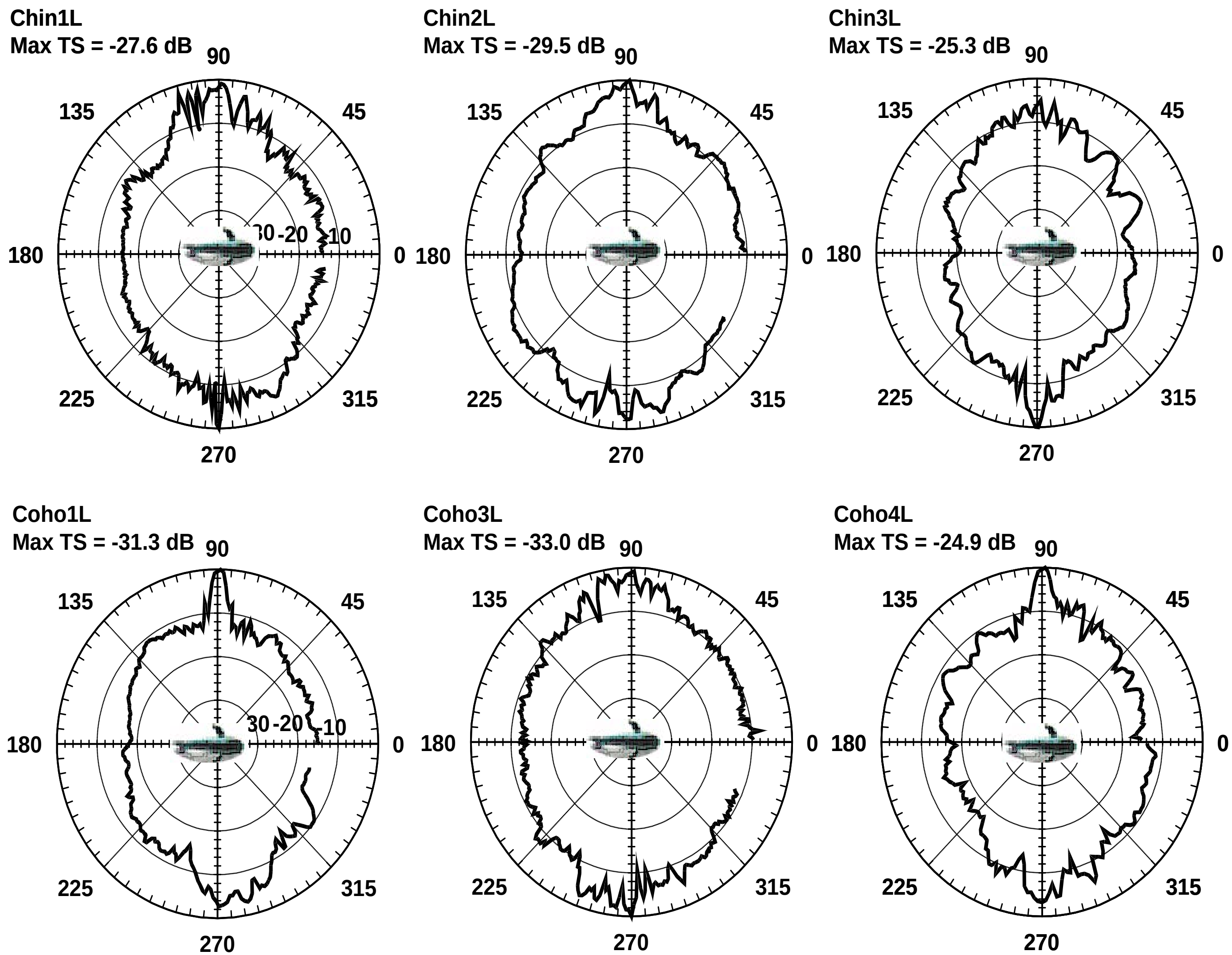
Dorsal



TS Lateral Plane

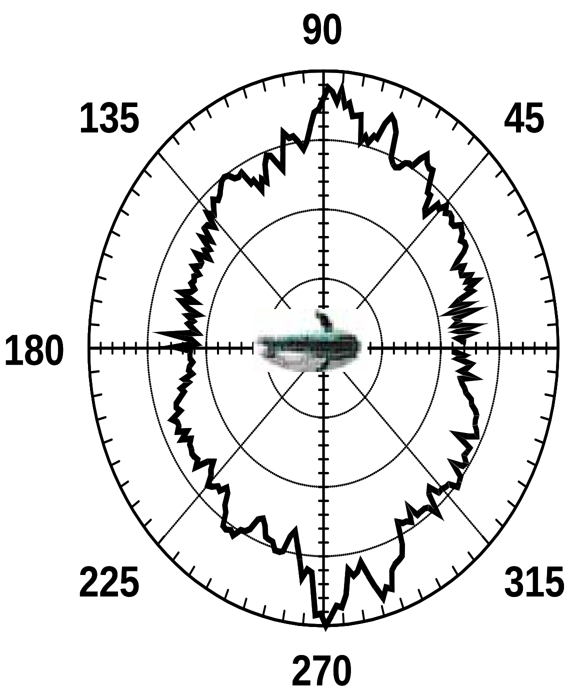
Chinook

Coho

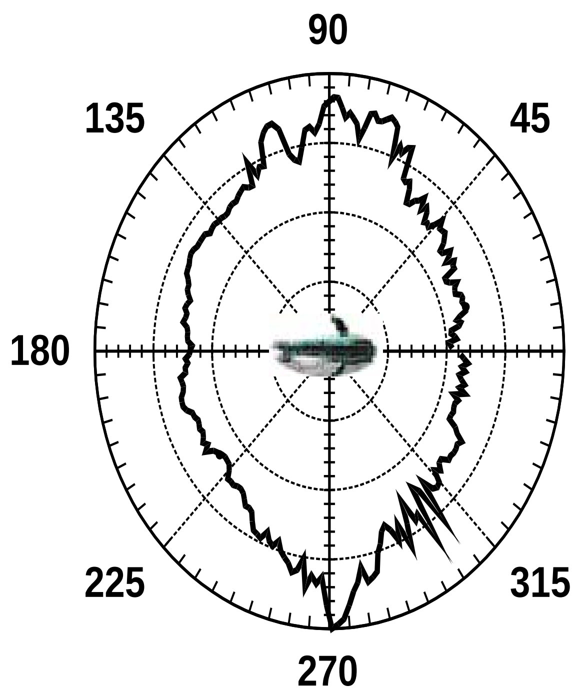


TS Lateral Plane 22.5°

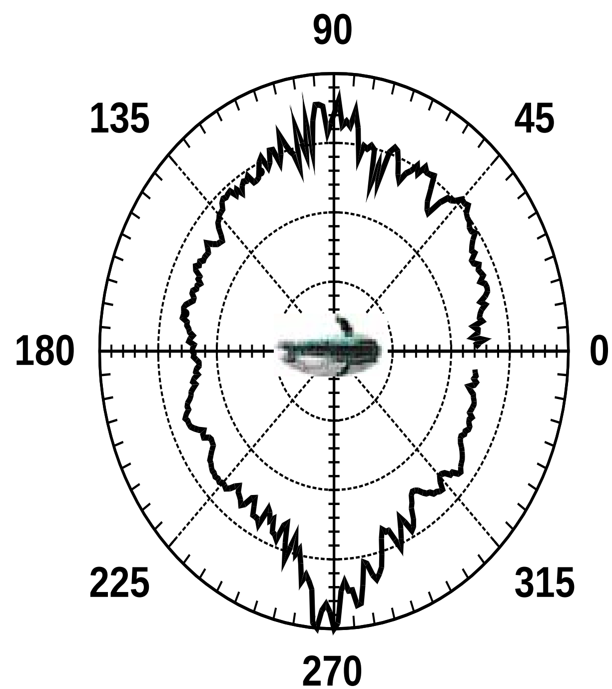
Chinook



Coho

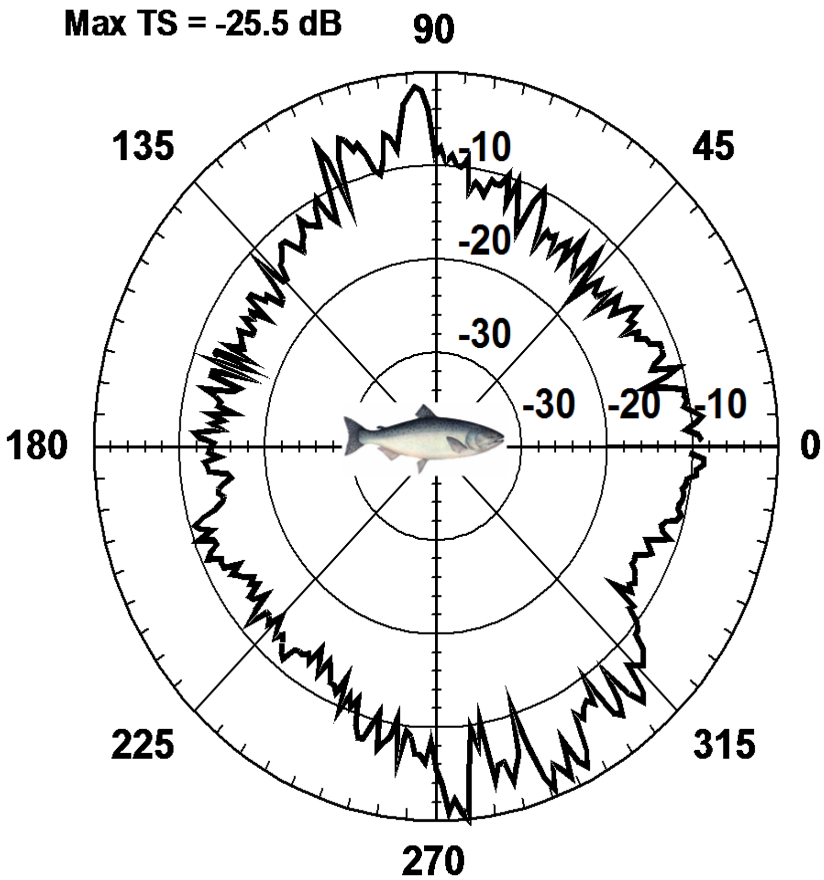


Sockeye

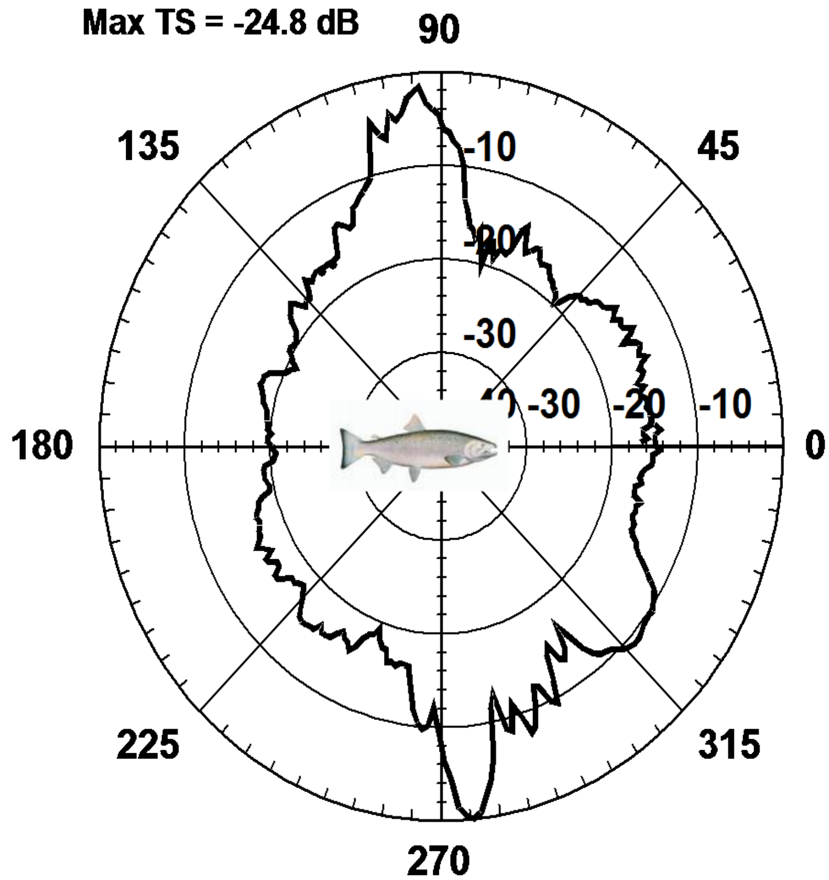


TS Dorsal Plane

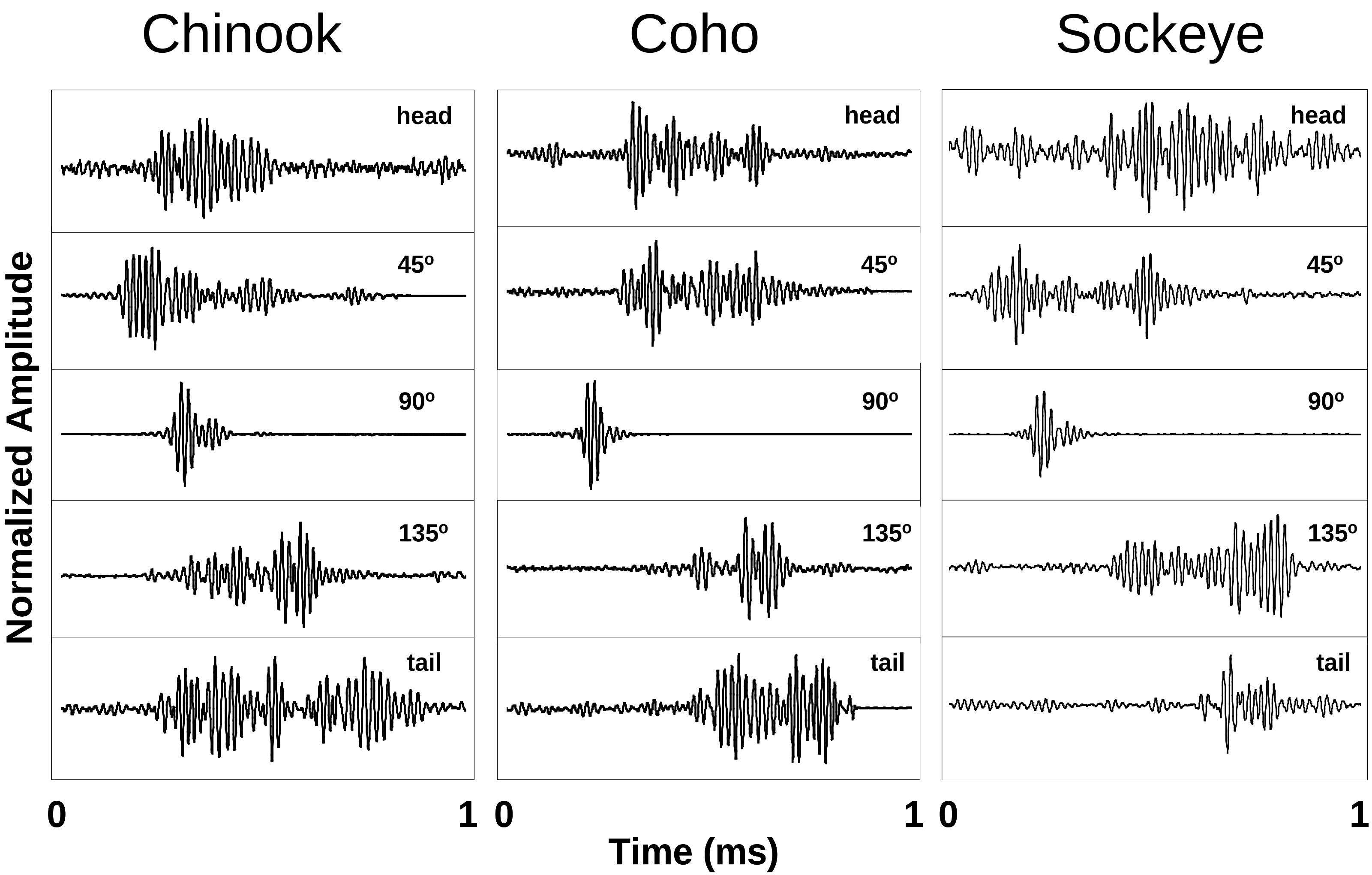
Chinook



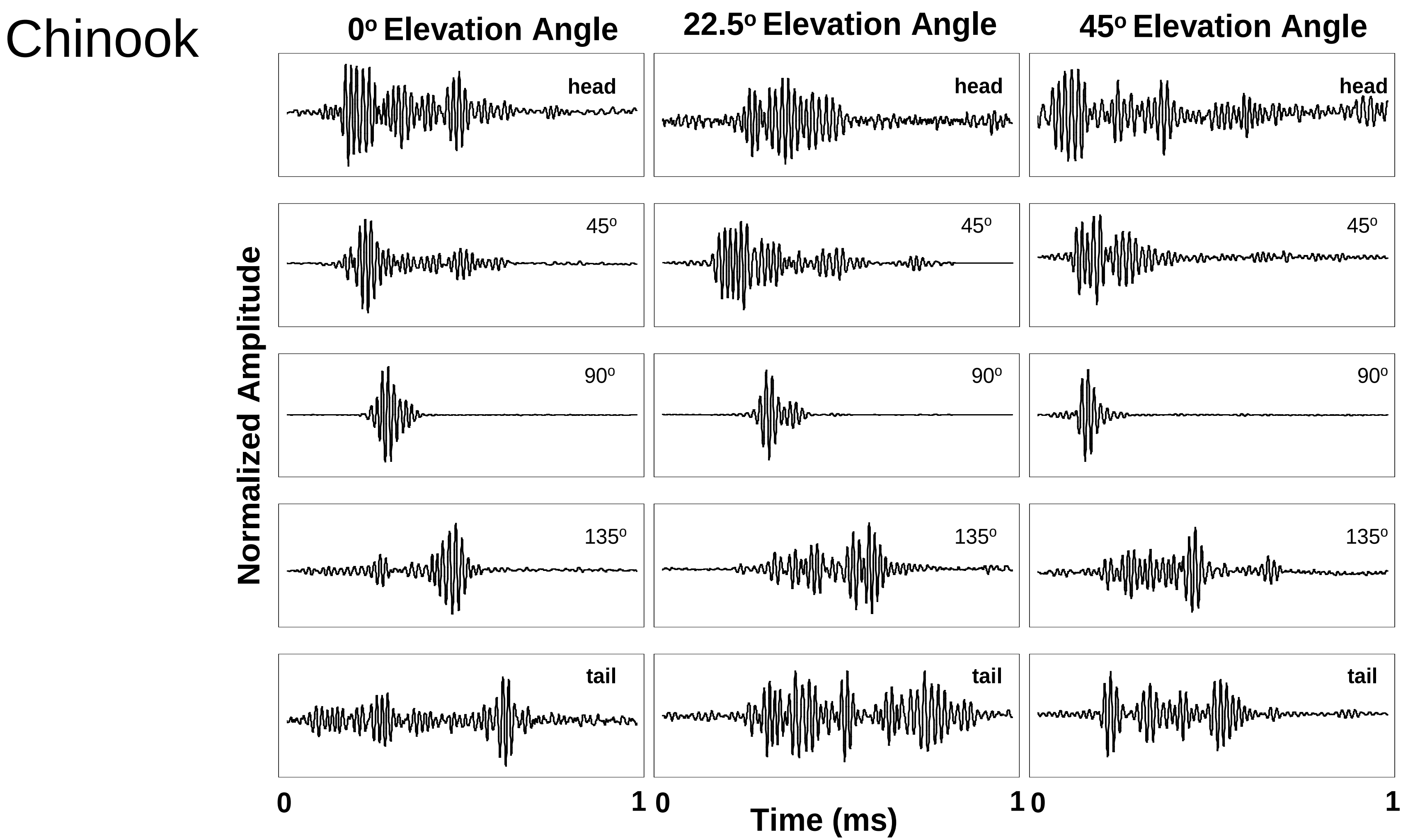
Coho



Normalized Echo Waveform



Normalized Echo Waveform

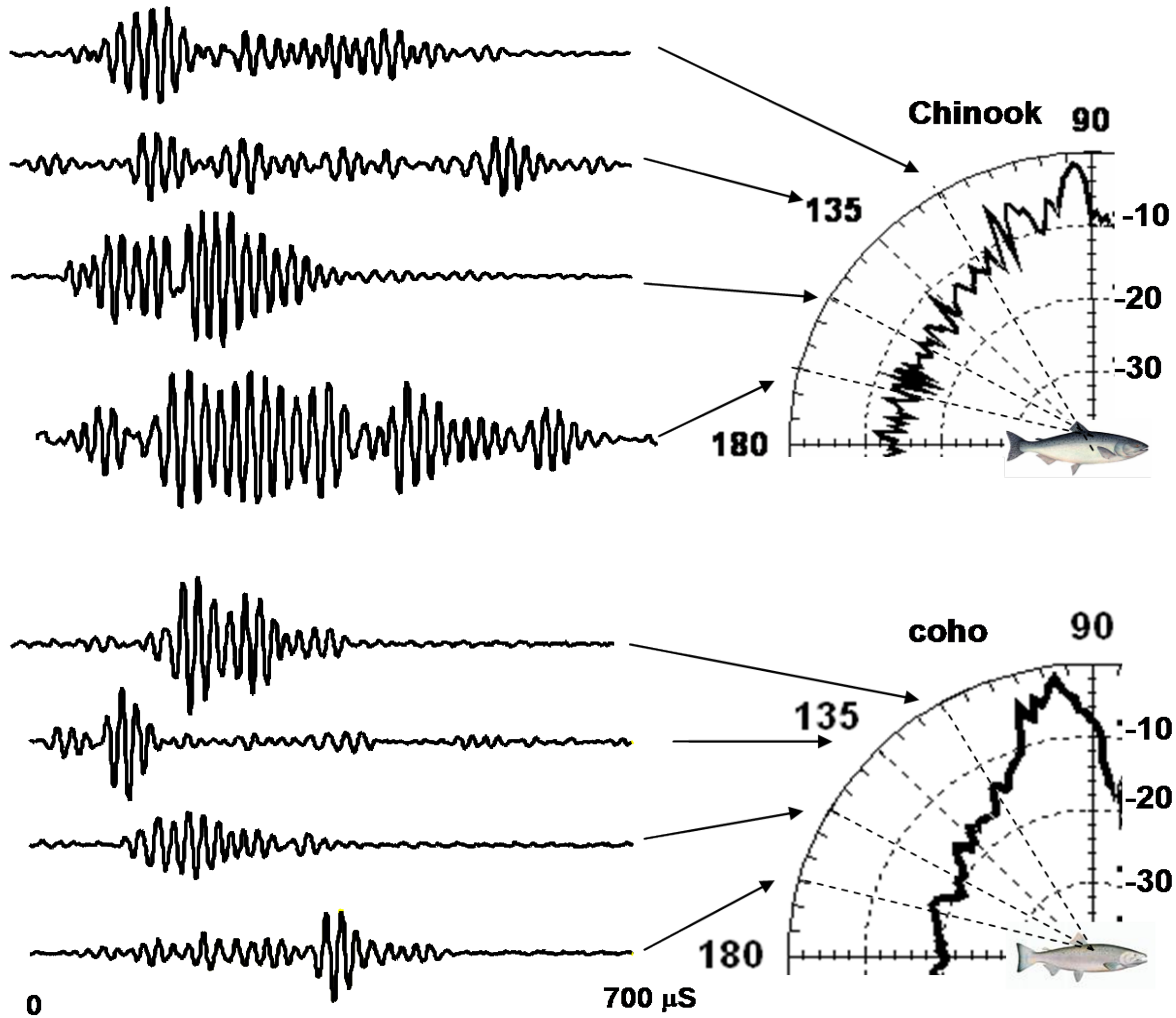


Can You See the Difference?

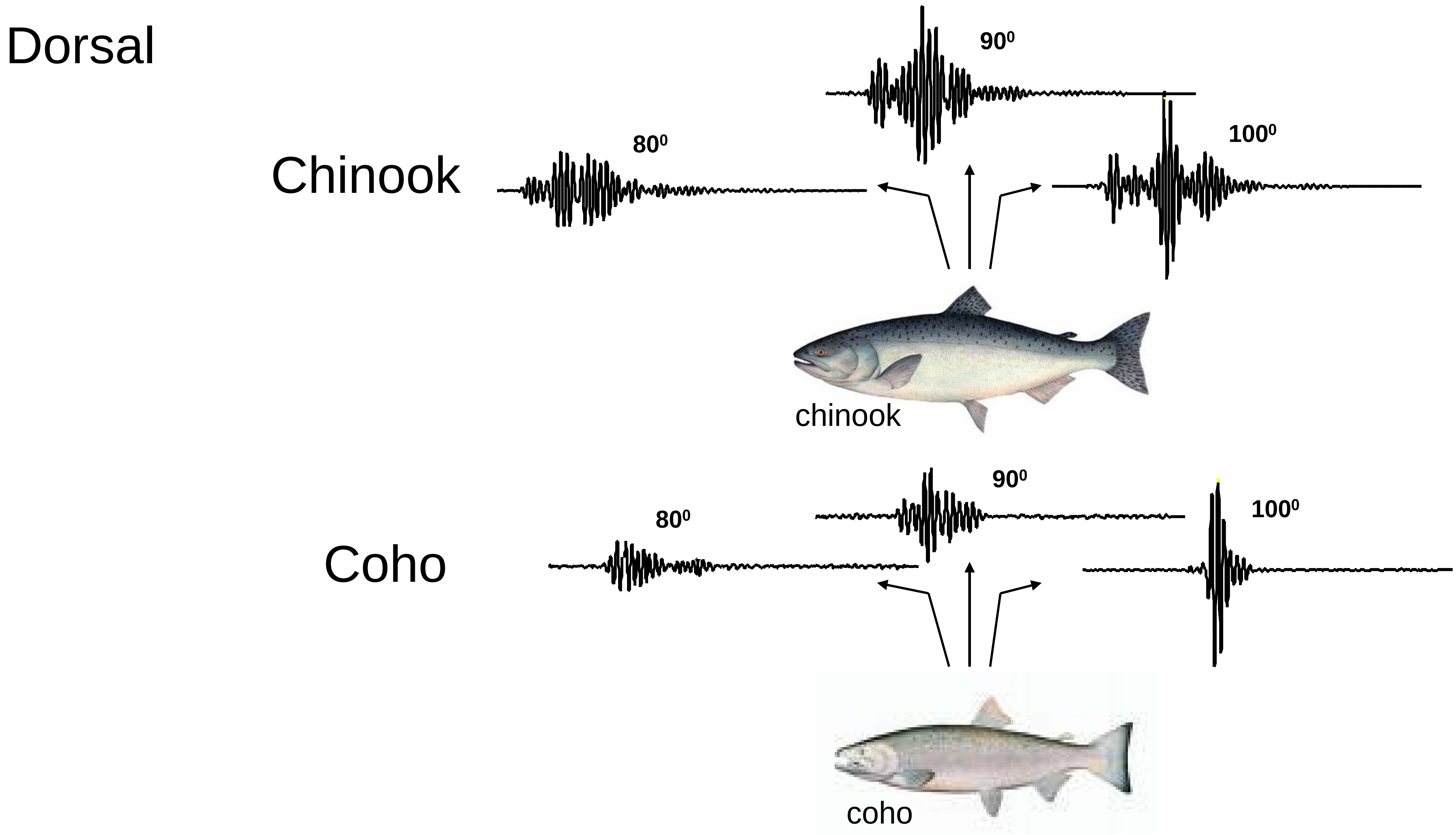
Oblique

Chinook

Coho



Can You See the Difference?



SR Killer whales & prey

Map distributions of potential prey

Map distributions of killer whales

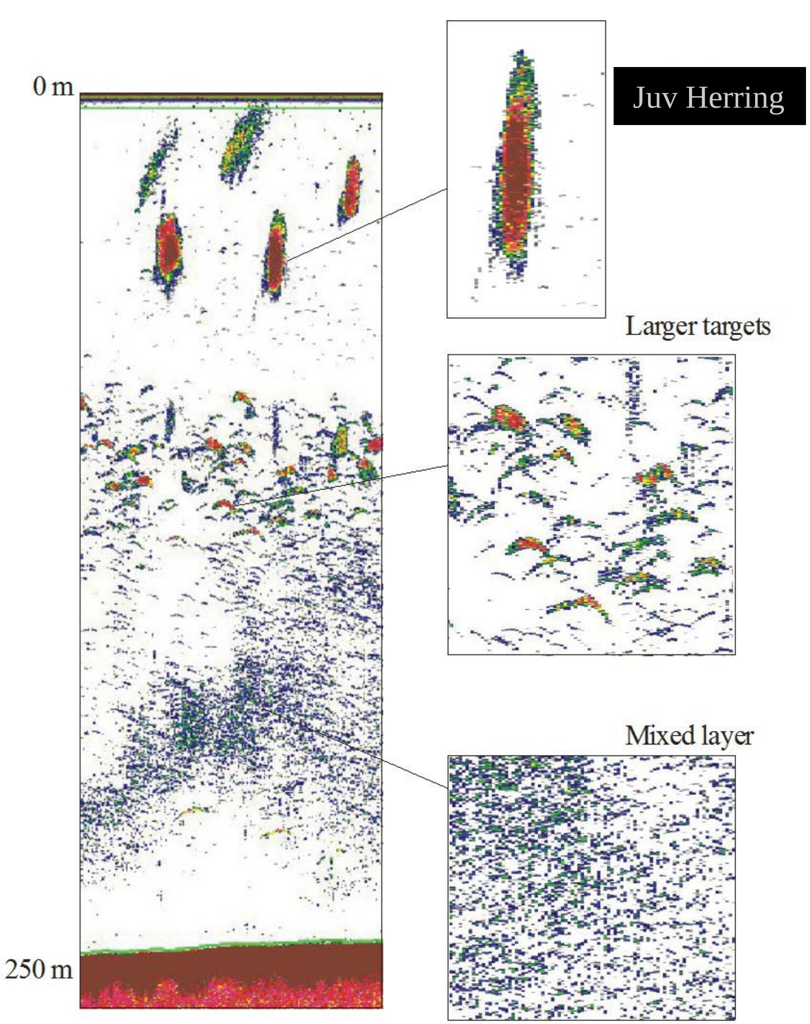
Observe and document feeding bouts by killer whales

Stéphane Gauthier, Rachel Latham,
Chris Jones, Mark Anderson
Adam U, Dave Ellifrit
Brad Hanson

Survey Effort

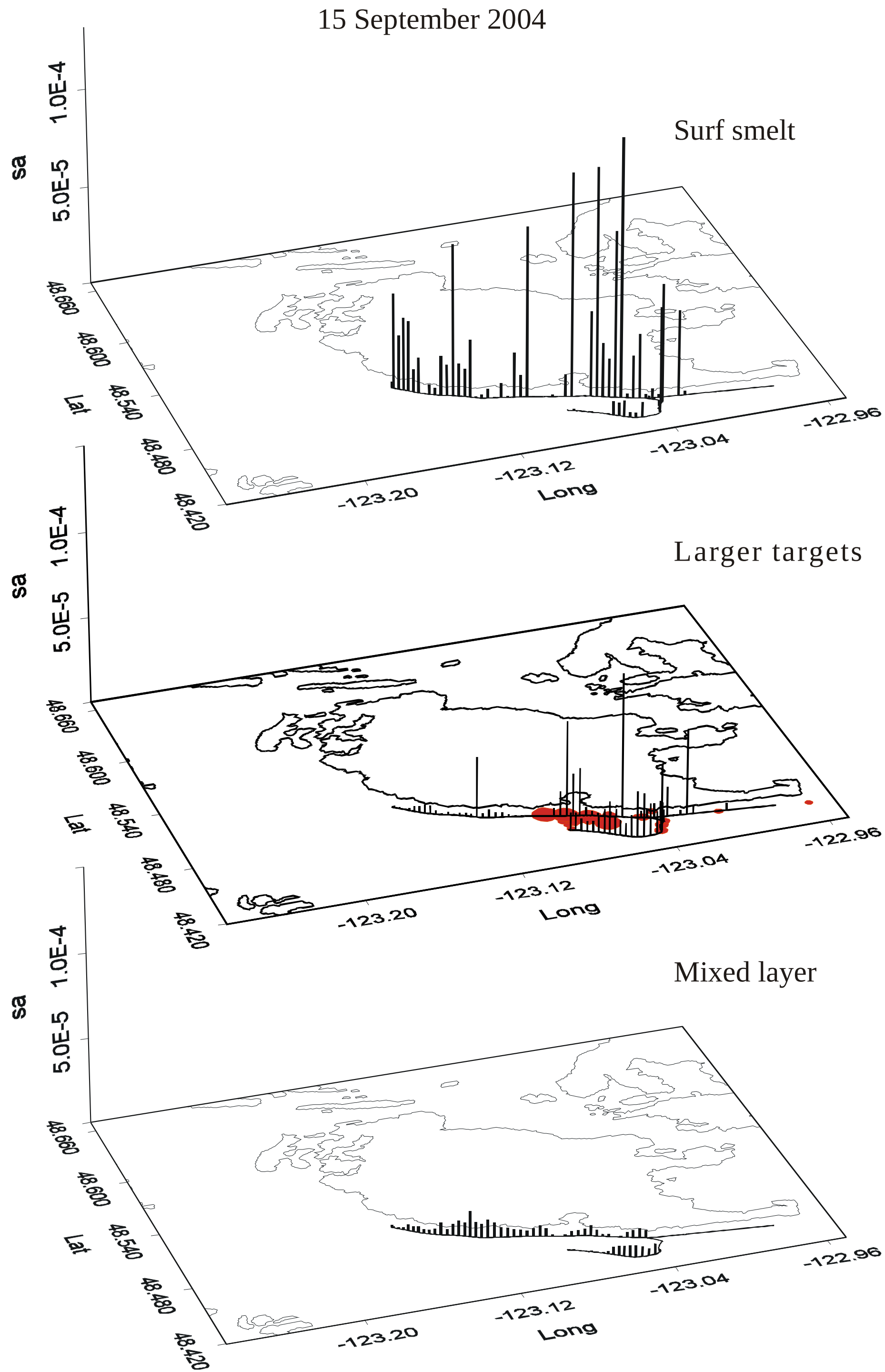
- 40 echosounder transects:
- 27 Eularian, 8 adaptive, 5 Lagrangian
- 14 multibeam deployments
- 11 midwater trawls; 14,312 animals
- 16 species (14 fish + 2 inverts)
- CPUE 0.26-296 f.p.m.
- 9 CTD profiles

Backscatter Categories



(only 6 caught)

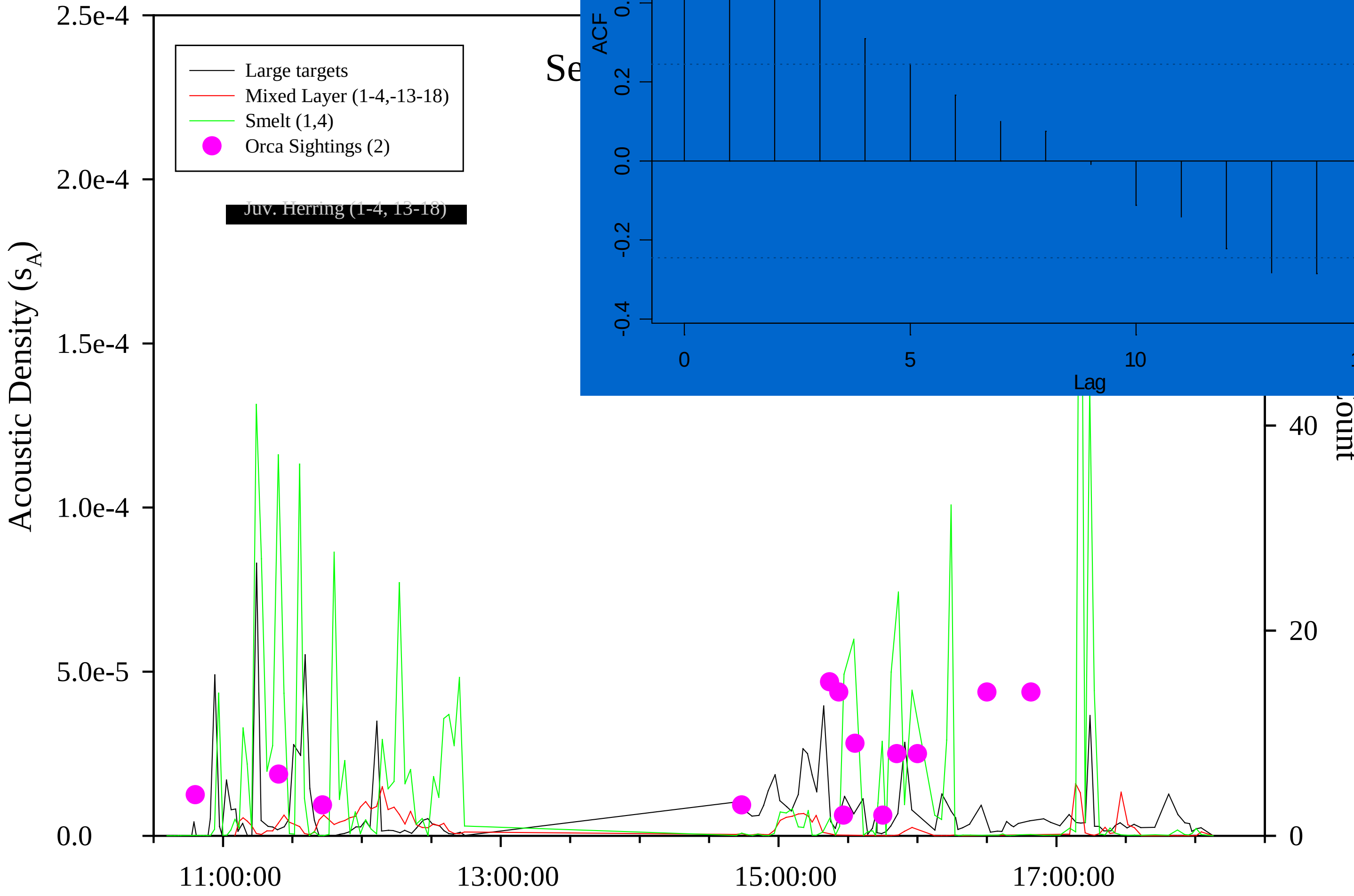
Haro Strait Fish & Whale Abundance



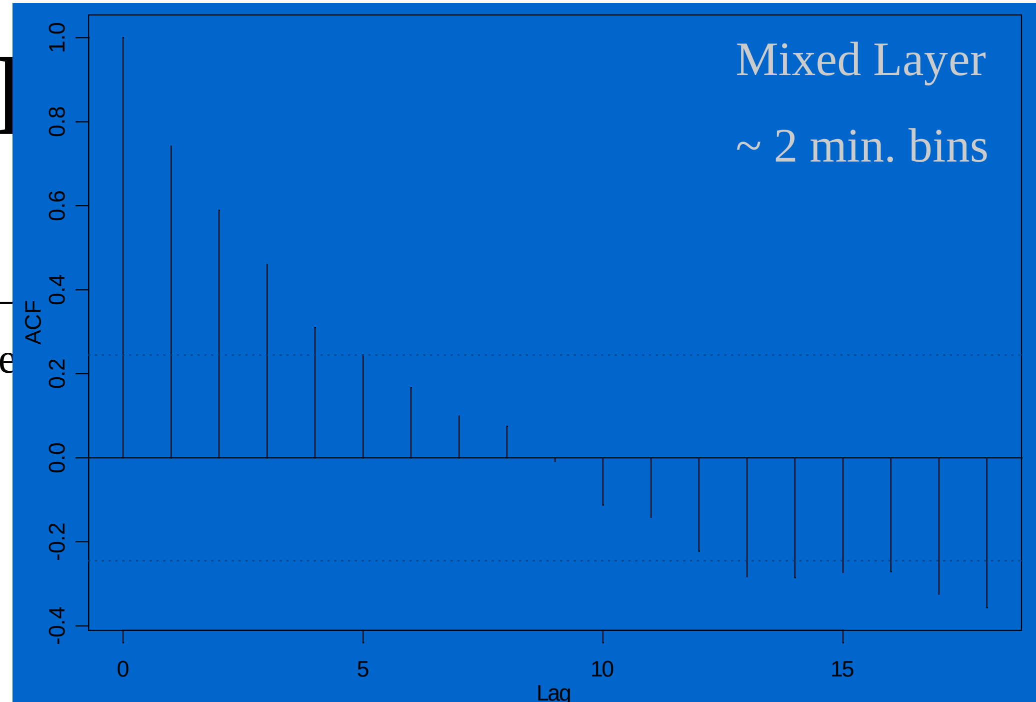
s_a area backscattering coefficient (integrated energy/unit volume, m^2m^{-2})

250 m horizontal bins

Predator – I

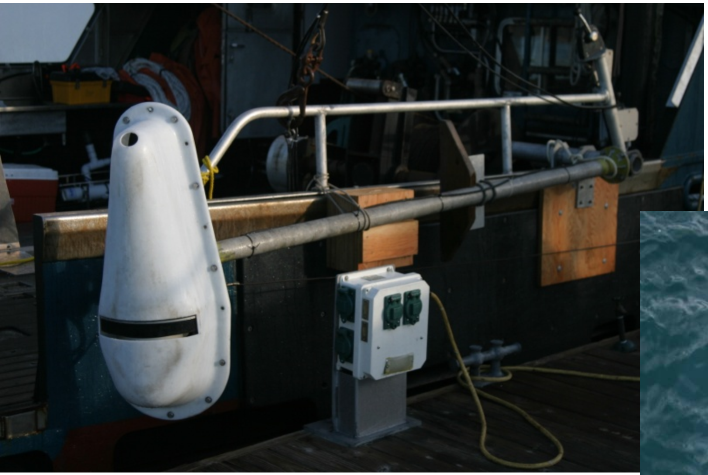


2.5e-4
2.0e-4
1.5e-4
1.0e-4
5.0e-5
0.0
Acoustic Density (s_A)
Large targets
Mixed Layer (1-4,-13-18)
Smelt (1,4)
Orca Sightings (2)
Juv. Herring (1-4, 13-18)
Se
40
20
0
ount
11:00:00
13:00:00
15:00:00
17:00:00

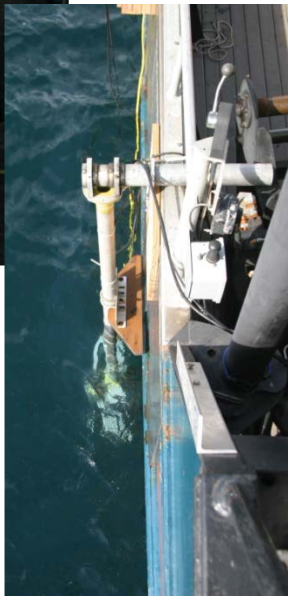


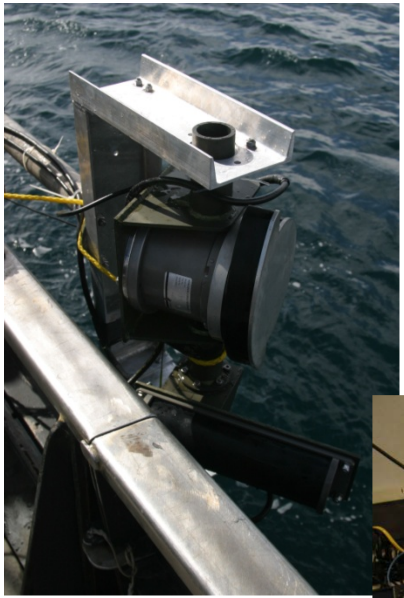
Mixed Layer
~ 2 min. bins
ACF
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
0
5
10
15
Lag

Multibeam Sonar



Simrad MS-20





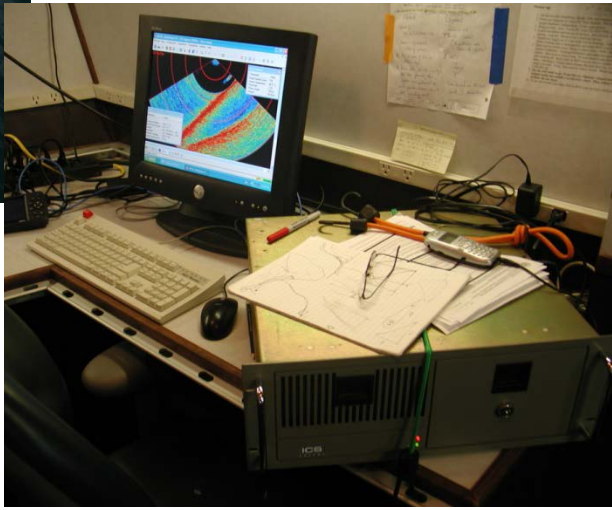
200 kHz

128 beams

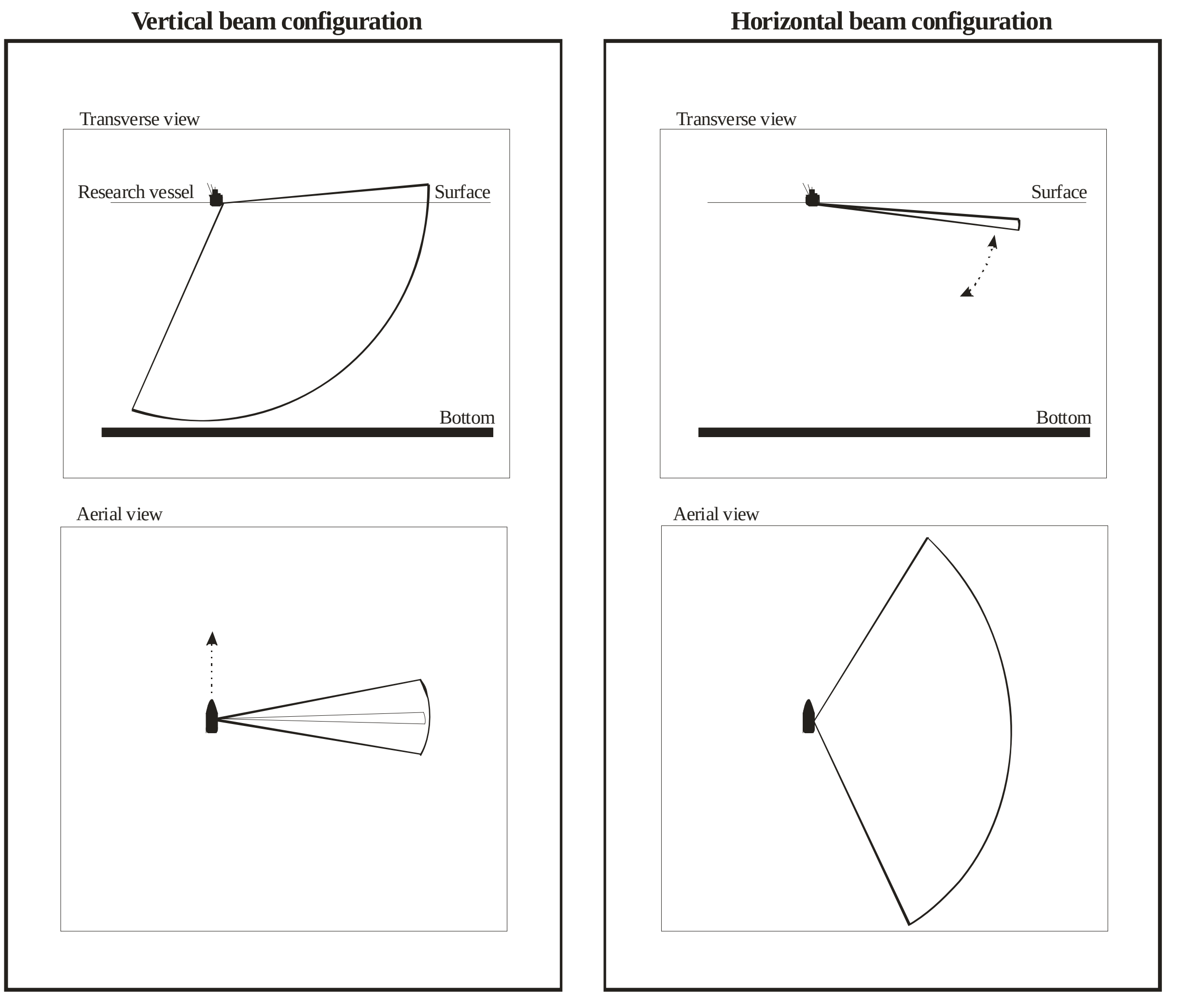
Transmit: 150^{o} x 1.6^{o}

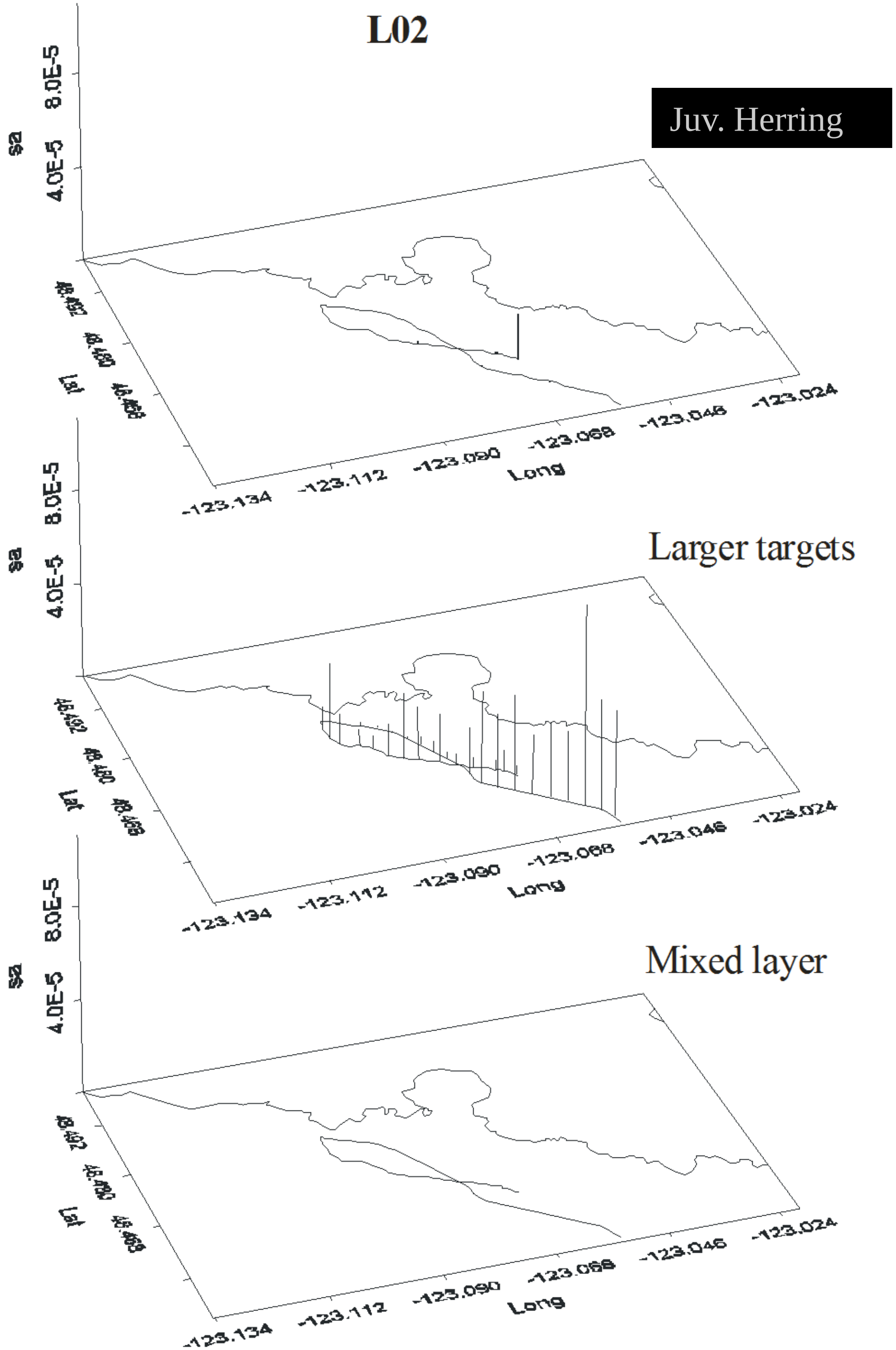
88^{o} x 17^{o}

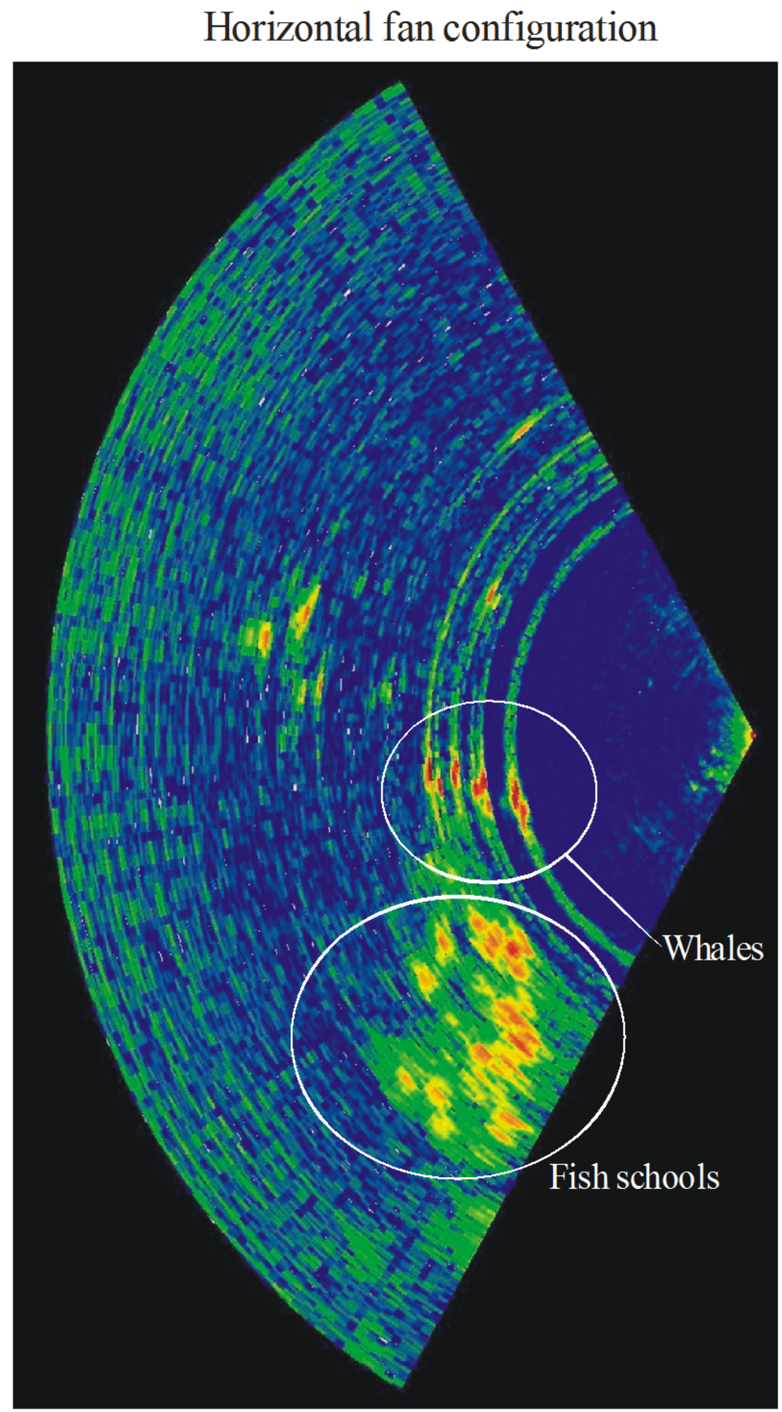
Receive: 1.5^{o} x 17^{o}

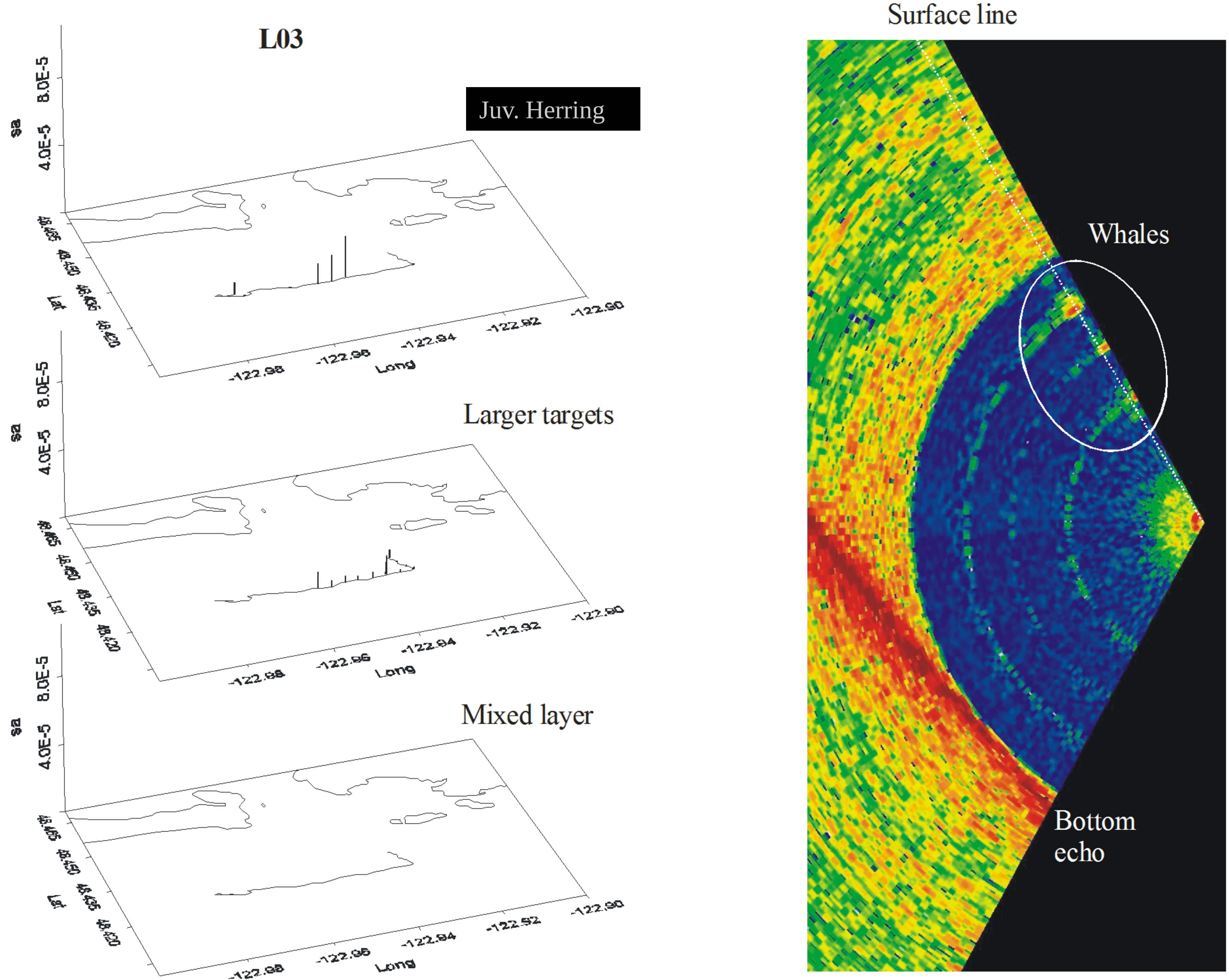


Multibeam Configuration

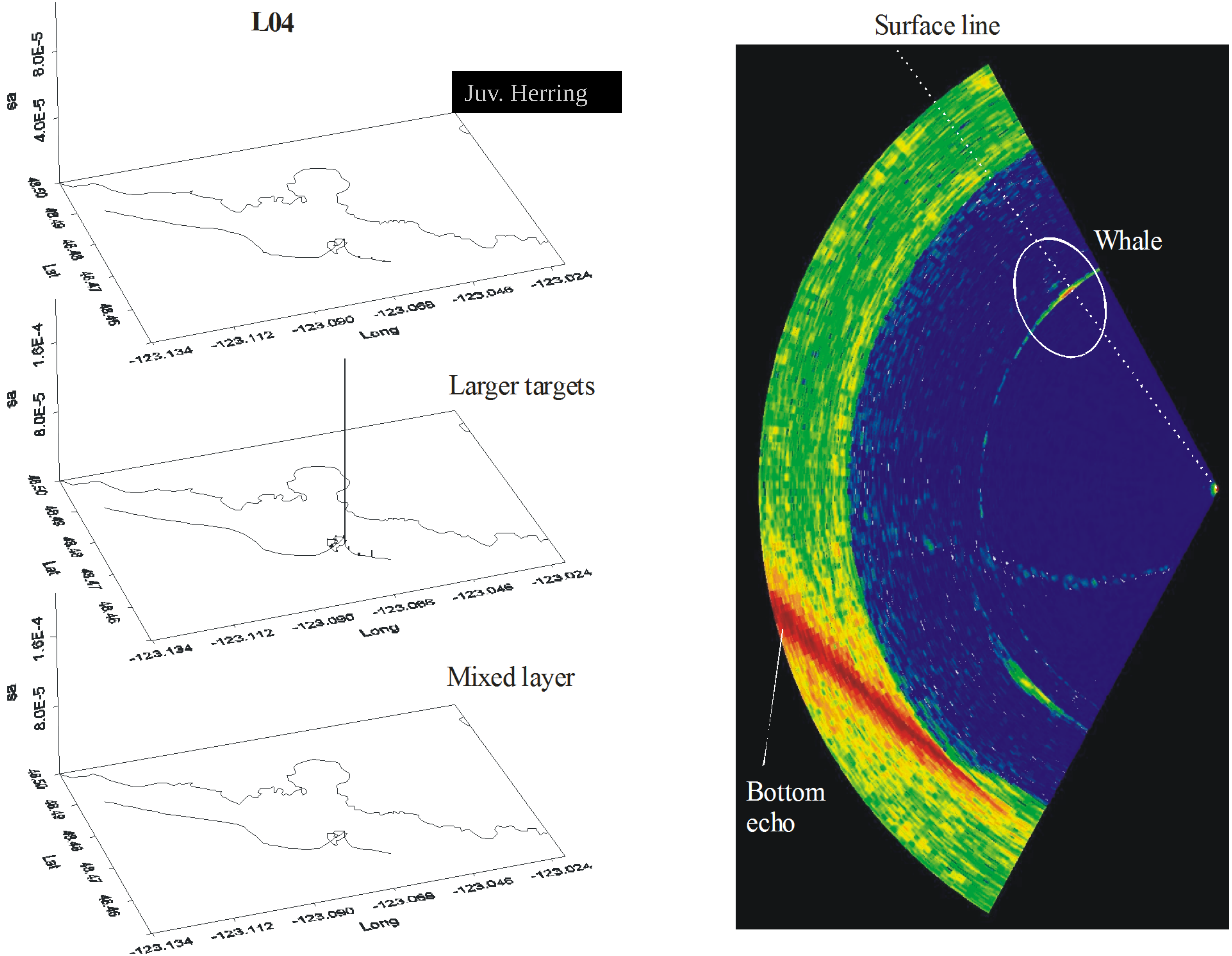


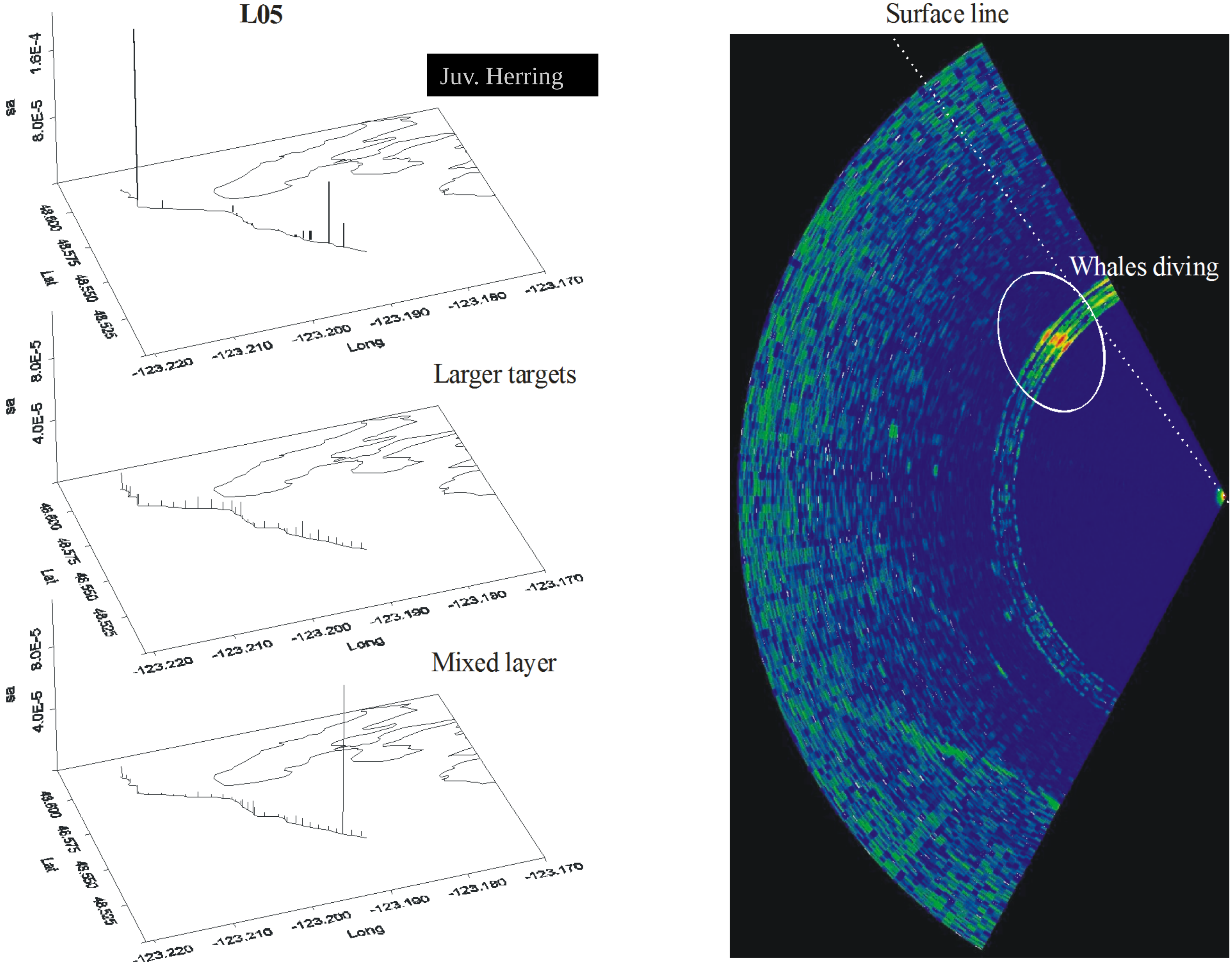

L02
Juv. Herring
Larger targets
Mixed layer
sa
8.0E-5
4.0E-5
Lat
Long
-123.134
-123.112
-123.090
-123.068
-123.046
-123.024


Horizontal fan configuration
Whales
Fish schools



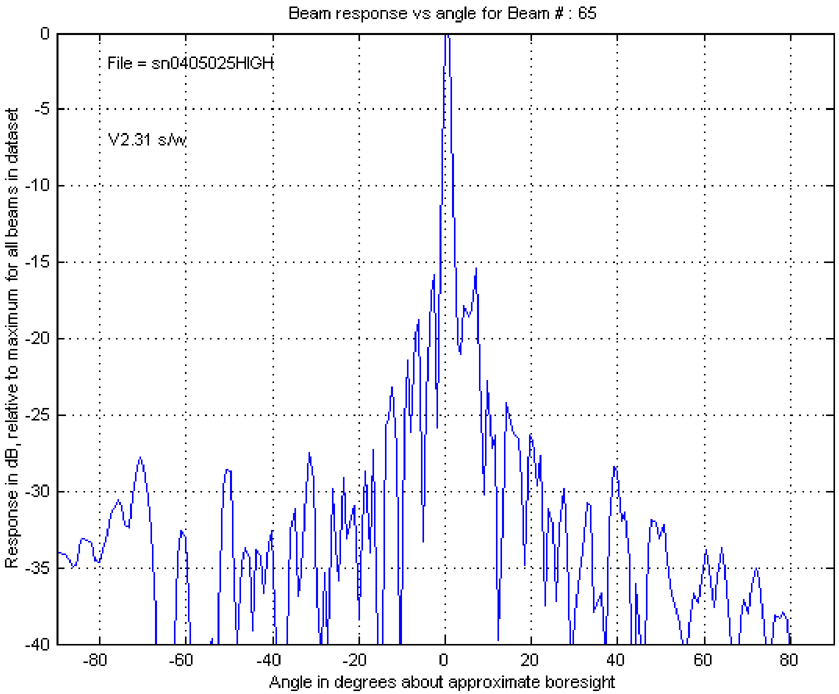
L03
Juv. Herring
Larger targets
Mixed layer
sa
8.0E-5
4.0E-5
Lat
48.450
48.435
48.420
Long
-122.98
-122.96
-122.94
-122.92
-122.90
Surface line
Whales
Bottom echo


L04
Juv. Herring
Larger targets
Mixed layer
sa
8.0E-5
4.0E-5
1.6E-4
Lat
Long
-123.134
-123.112
-123.090
-123.068
-123.046
-123.024
Surface line
Whale
Bottom
echo



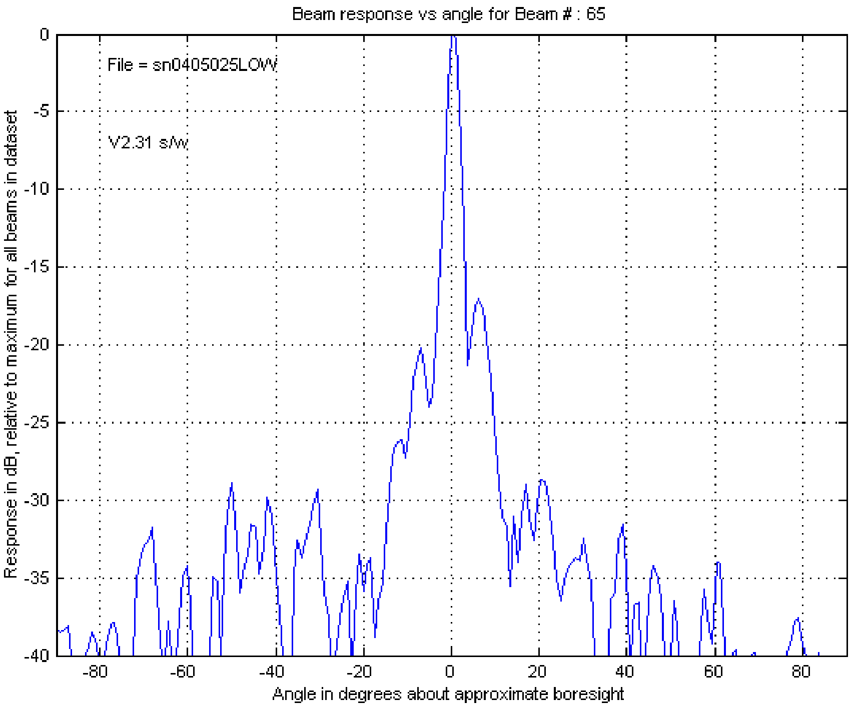
L05
Juv. Herring
Larger targets
Mixed layer
sa
1.6E-4
8.0E-5
4.0E-5
Lat
48.600
48.575
48.550
48.525
Long
-123.220
-123.210
-123.200
-123.190
-123.180
-123.170
Surface line
Whales diving

The Target 'Halo' Effect



Beamformed receive sidelobes

smaller beamwidth, higher sidelobes



wider beamwidth, lower sidelobes

Technique Assessments

Fish Distribution

- whole water column
- 3 scattering categories

Fish Identification

- trawl from same platform
- representative sample of middle layer? (7 chinook, 6 dogfish)

Killer whale counts

- standard surface counts
- qualitative multibeam observations

Killer whale foraging

- simultaneous predator and prey field
- can’t ‘see’ consumption of prey item

Increase Grad Student Effort