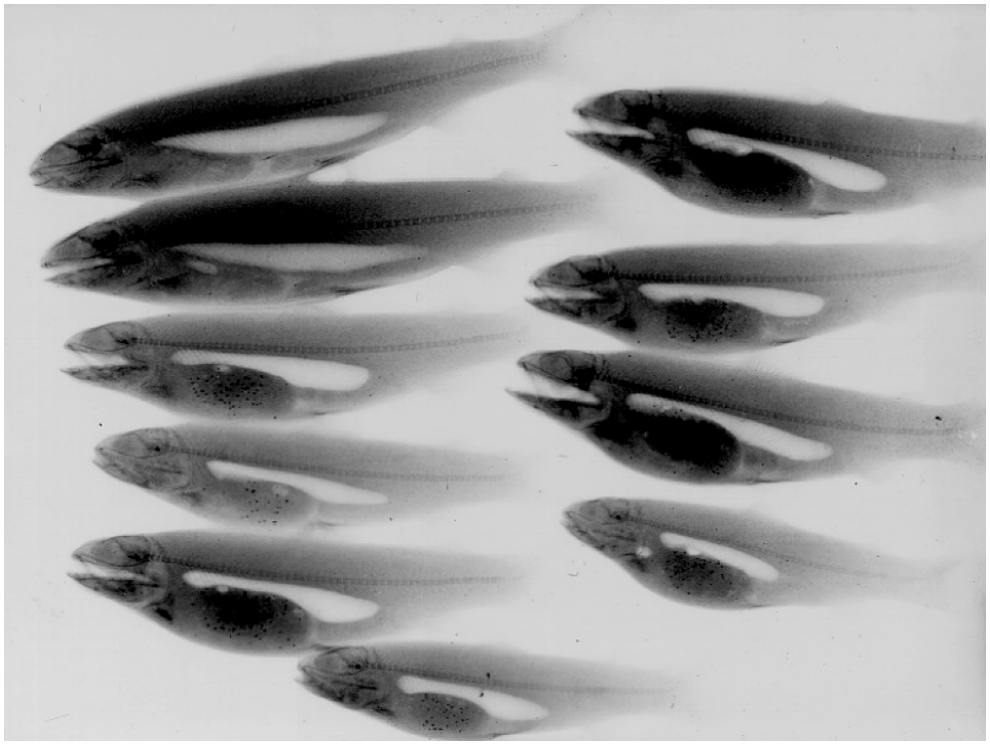
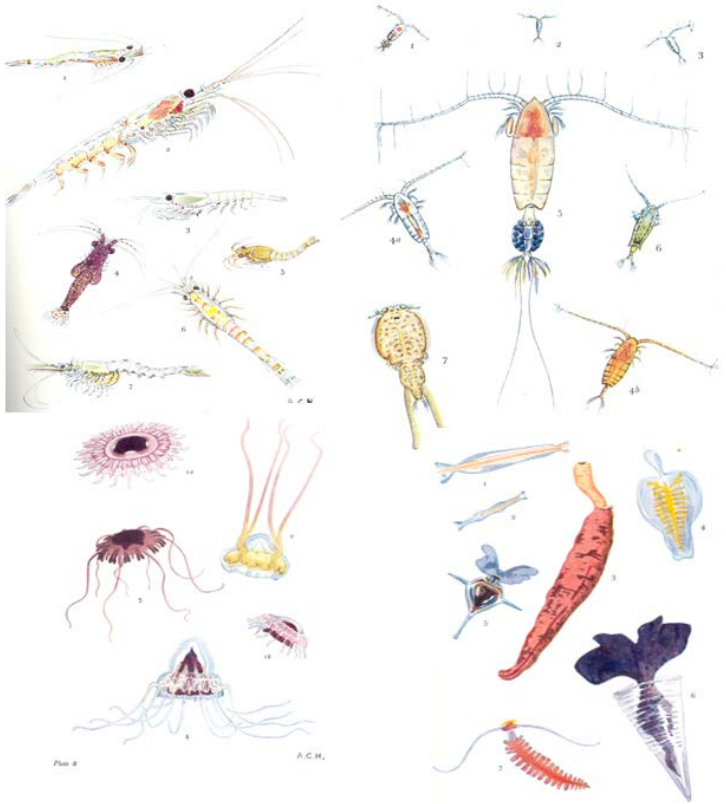
Fish and Zooplankton as Acoustic Targets





John K. Horne, University of Washington

Water as an Acoustic Medium

800x more dense than air

Minimal effects of gravity

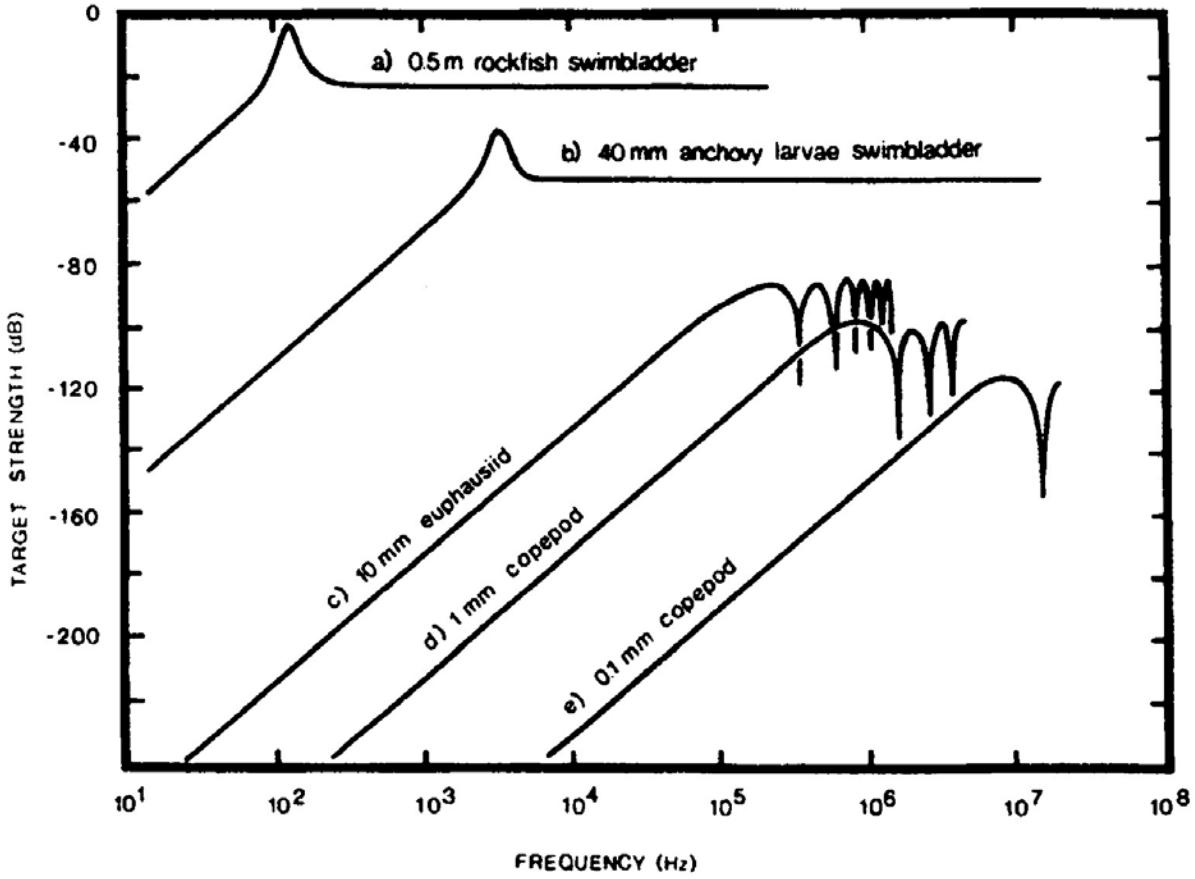
Friction – absorption α

Incompressible – vibrations propagate better in water than in air:

$c = 1500$ vs $333\ ms^{-1}$

Sound Scattering Regions

Rayleigh, Resonant, Geometric/Specular



Holliday and Pieper 1980

Zooplankton as Scatterers

Body Types

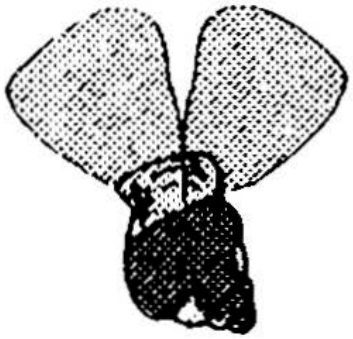
Gas-bearing

Agalma okeni

Fluid-like

Meganyctiphanes norvegica

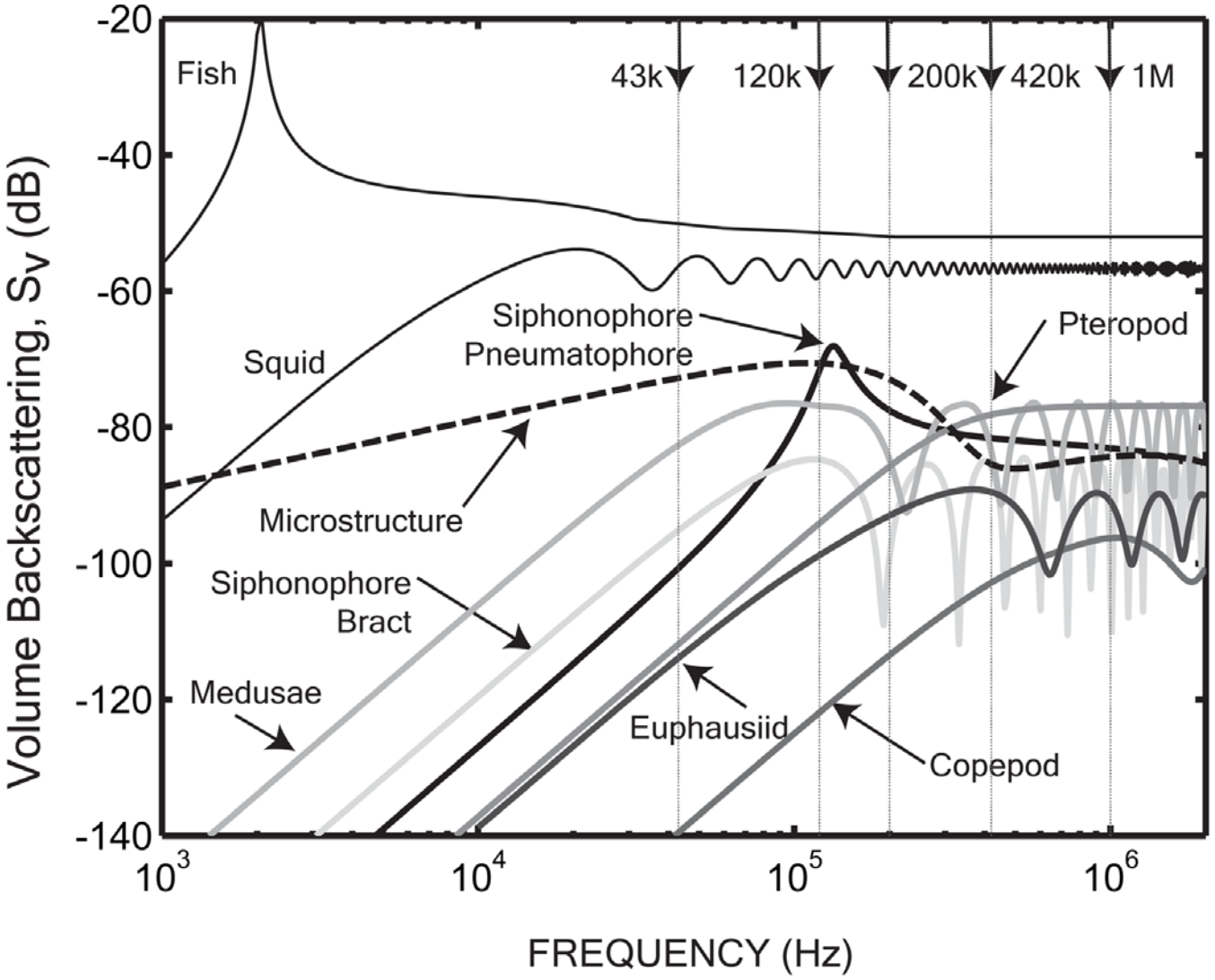
Elastic-shelled



Limacina retroversa

Martin *et al.* 1996

Zooplankton Backscatter Curves

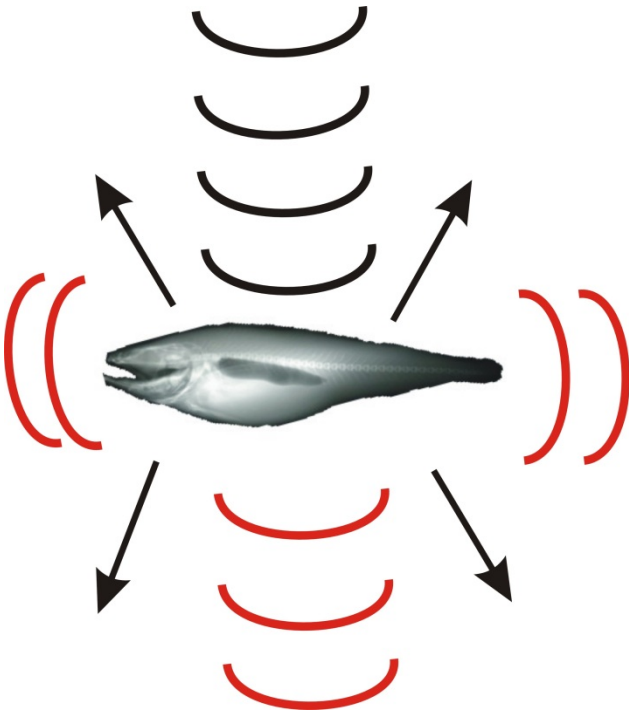


frequency

Lavery et al. 2007

Fish as Acoustic Scatterers

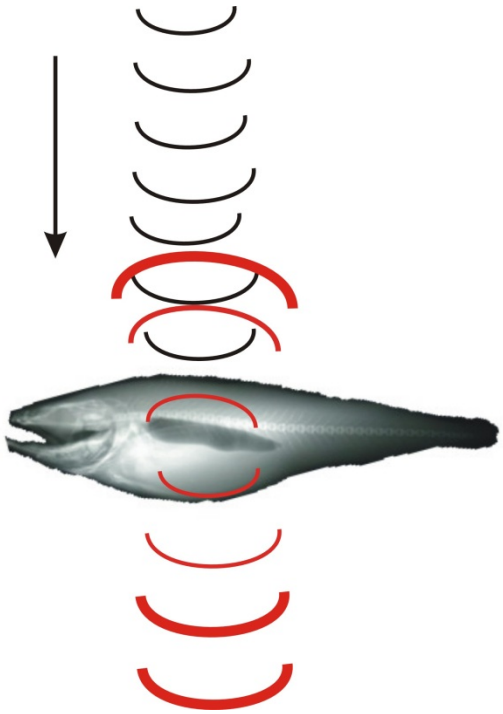
Rayleigh



$L/\lambda << 1$

point source

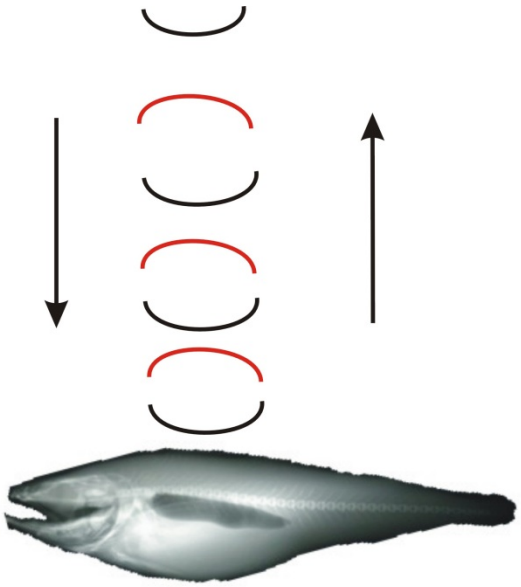
Resonant



$L/\lambda \approx 0.1$

organ pipe

Geometric



$L/\lambda >> 1$

wall

Acoustic Biological Perspective

Morphology	anatomy material properties
Ontogeny	growth (body, scattering organs) sexual maturity
Physiology	feeding gonad production
Behavior	group – shoaling and schooling, avoidance individual – orientation (tilt, roll, direction), avoidance

Morphological Categories

With Gas Inclusions

- physonectid siphonophores: gas-filled pneumataphore
- physostomous and physoclistous fish: swimbladder

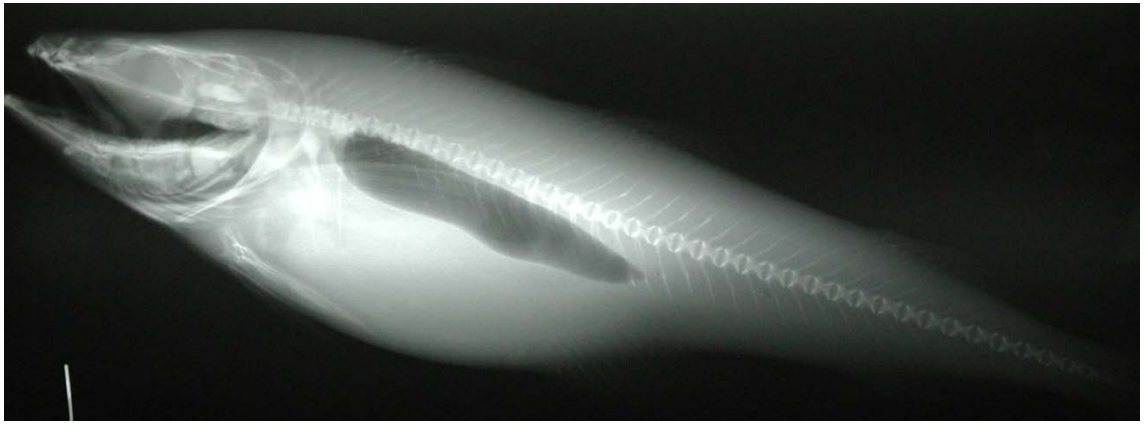
(open) (closed)

Without Gas Inclusions

- phytoplankton
- zooplankton
- fish without swimbladders or wax/ester swimbladders

Anatomy

- shape, scales, skin, fins, skeleton, muscles, swimbladder



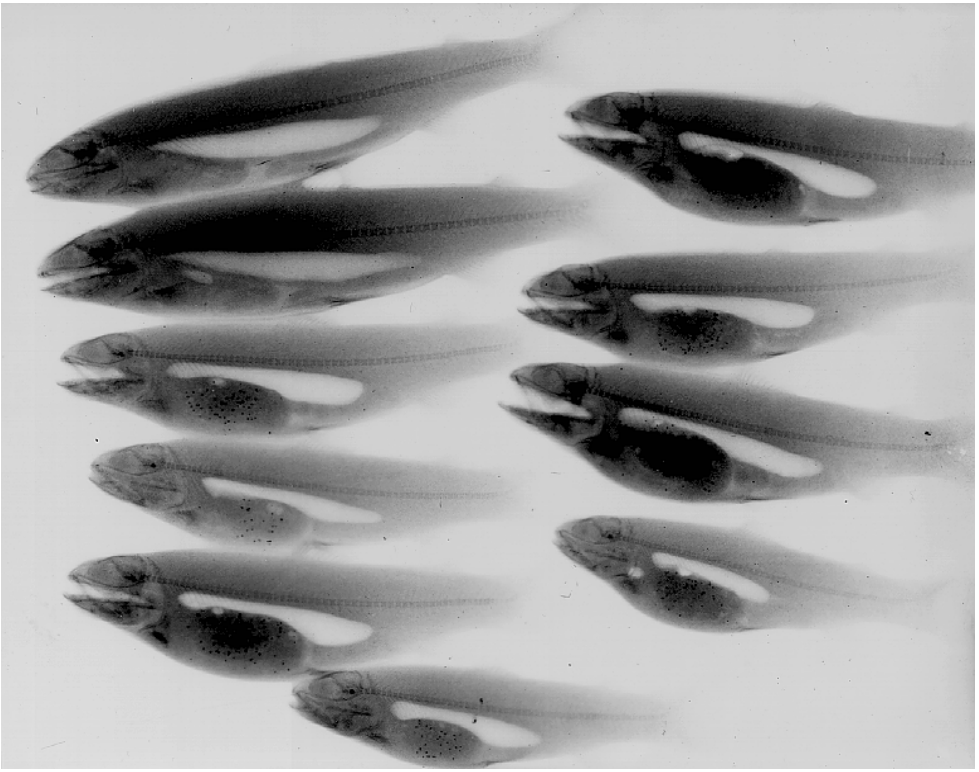
Walleye pollock (*Gadus chalcogrammus*)

Swimbladder Factoids

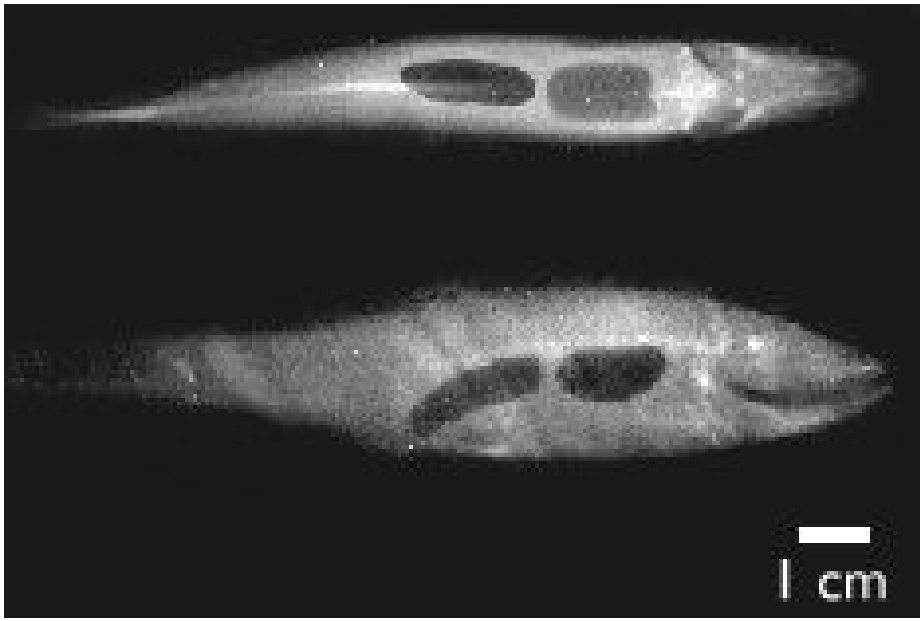
- 4-5% of fish volume (Sand and Hawkins 1973; Harden Jones and Scholes 1985)
- physostomes obey Boyle's law up to 10 atmospheres (Ona 1990; Mukai and Iida 1999)
- swimbladder wall can reversibly expand within 50% pressure reduction but bursts between 60-70% pressure reduction (Tytler and Blaxter 1973)
- > 90% of backscatter from swimbladder (Foote 1980)

Morphological Variability

Intraspecific: Brook Trout



Interspecific: Lavnun



Material Properties

Material Properties

- sound reflection influenced by density (g) and sound speed (h) contrasts

g: density ratio relative to water (unitless)

$$g_{fb} = \frac{\rho_{fb}}{\rho_w}$$

ρ: density (units kg m^{-3})

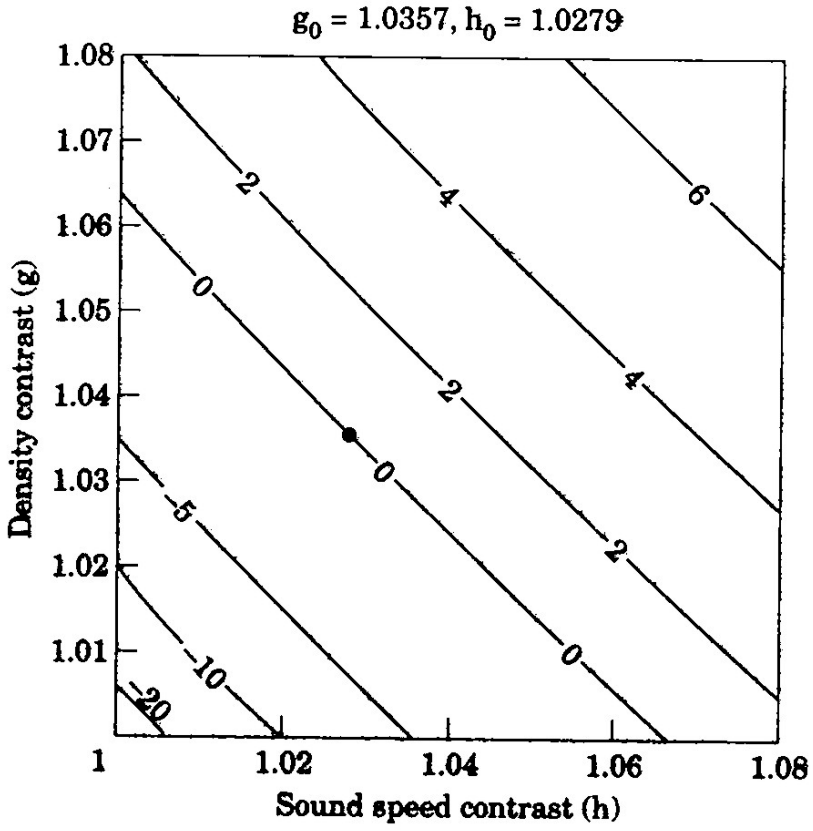
h: sound speed ratio relative to water (unitless)

$$h_{fb} = \frac{c_{fb}}{c_w}$$

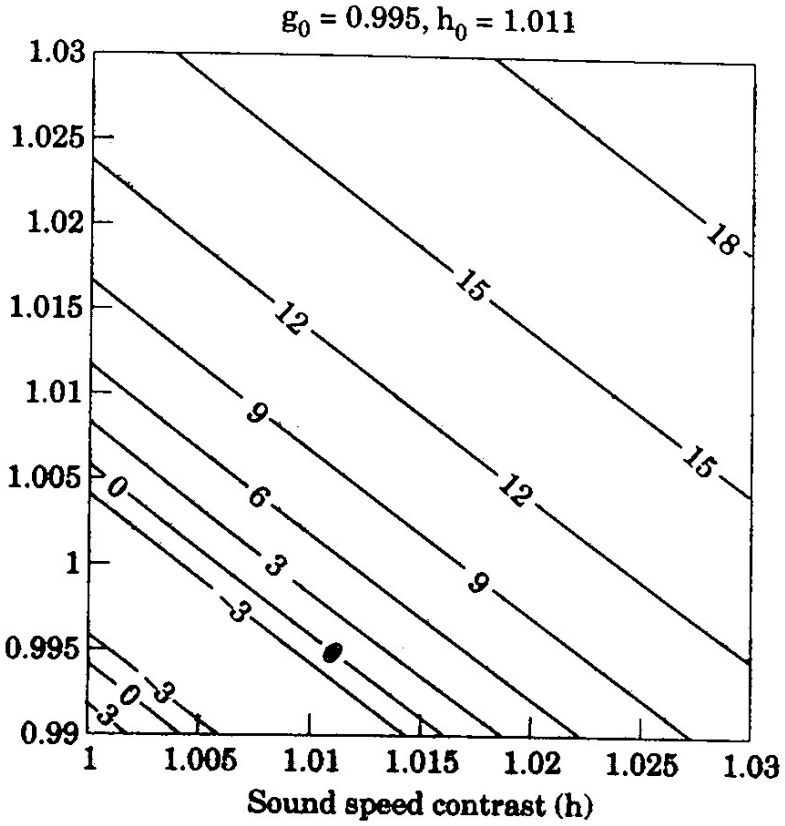
c: speed of sound (units ms^{-1})

TS Variation: Zooplankton

Euphasid

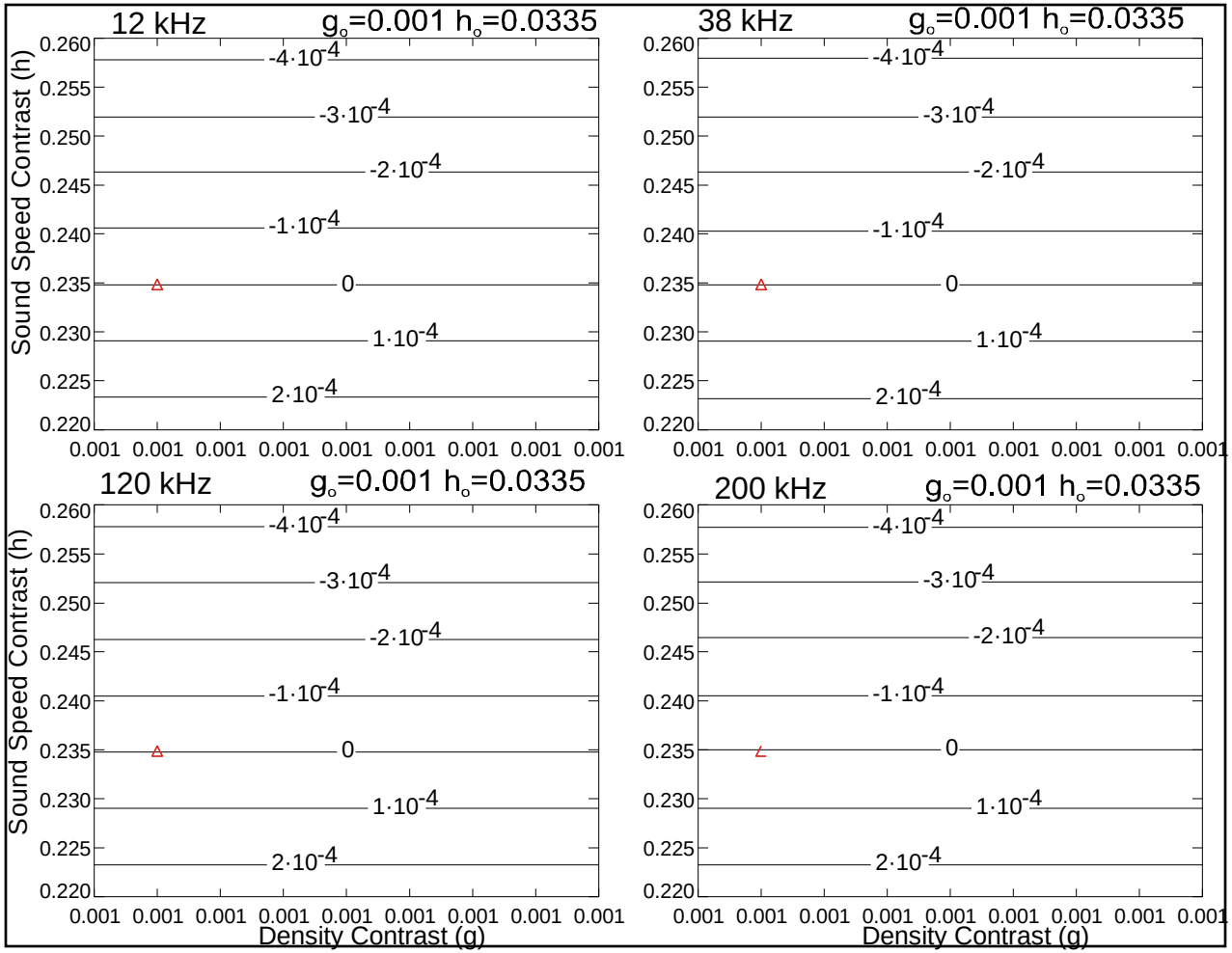


Copeopod

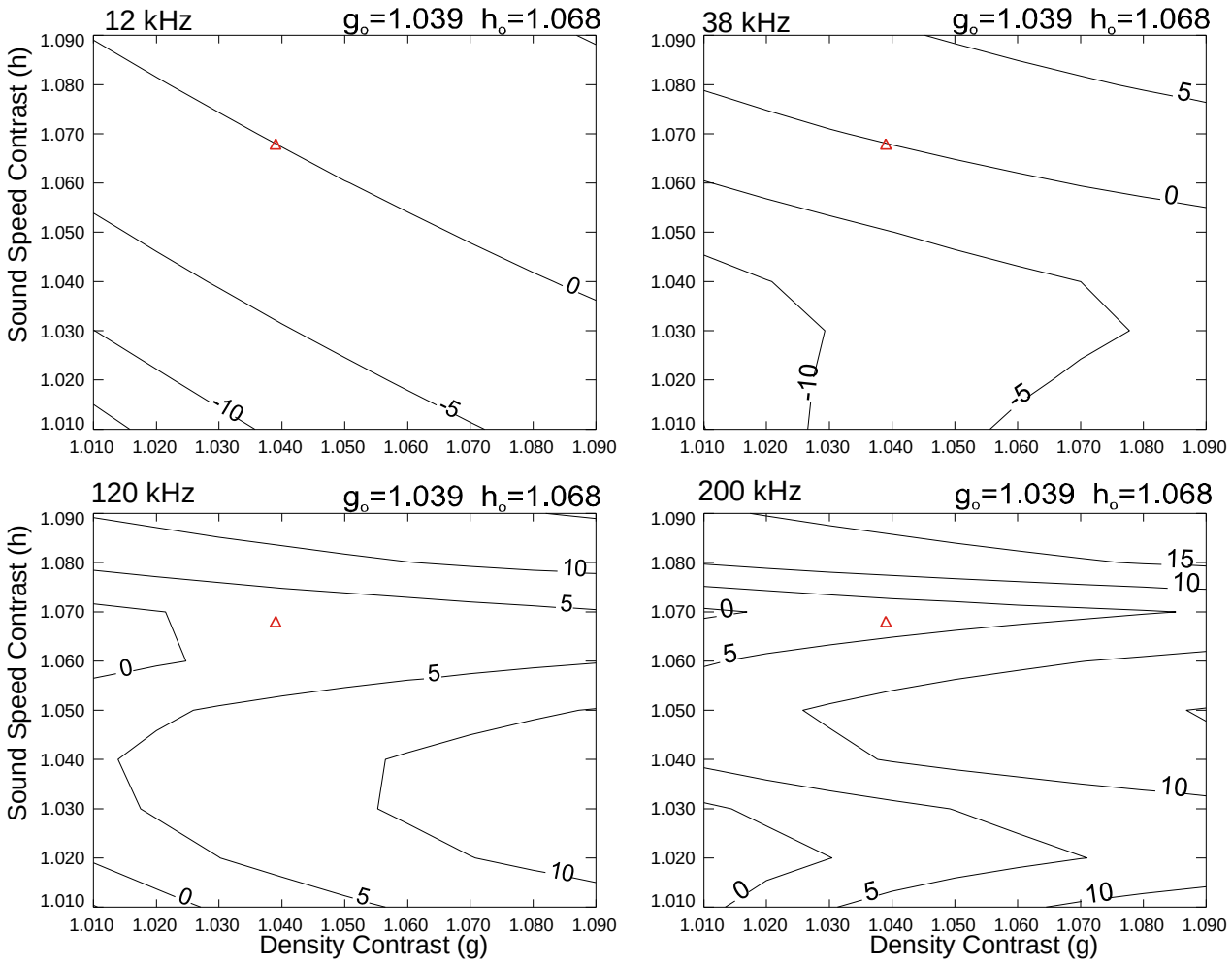


Chu *et al.* 2000

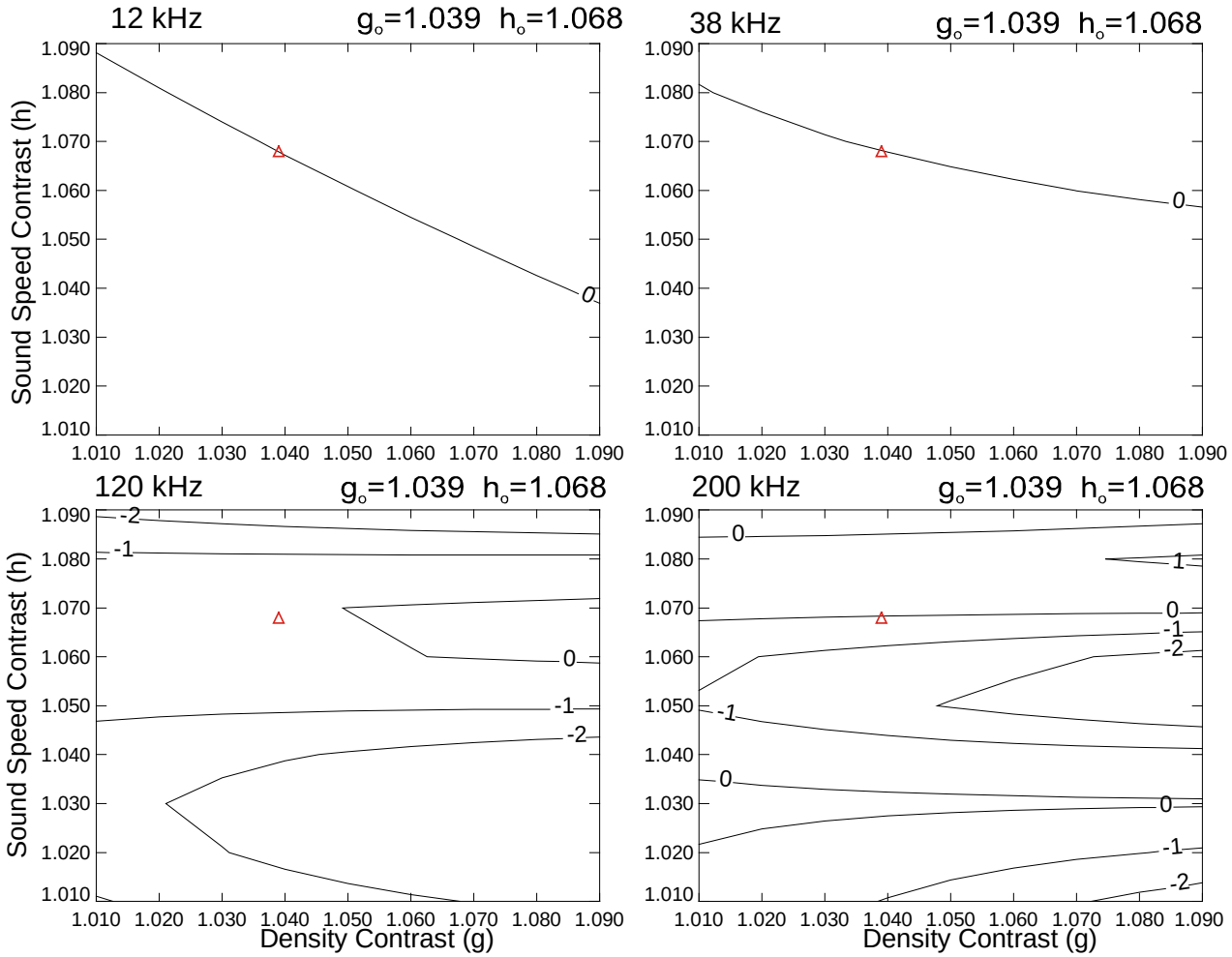
TS Variation: swimbladder



TS Variation: body

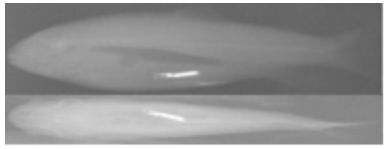


TS Variation: Fish



Ontogeny: Fish Swimbladder

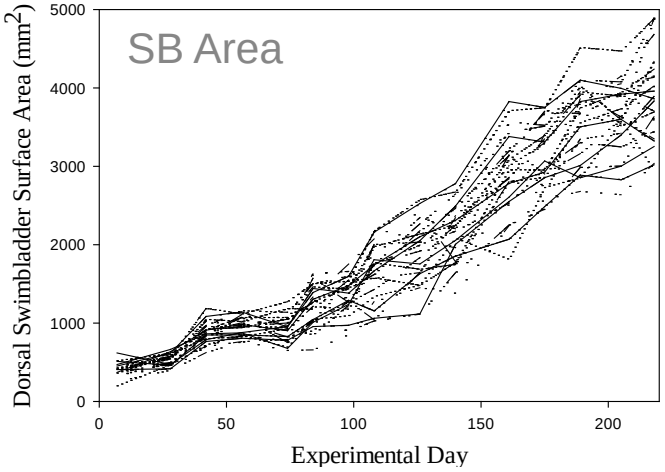
106.5 mm

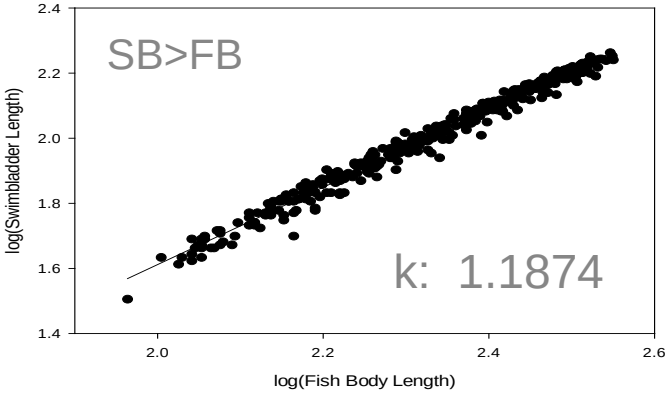


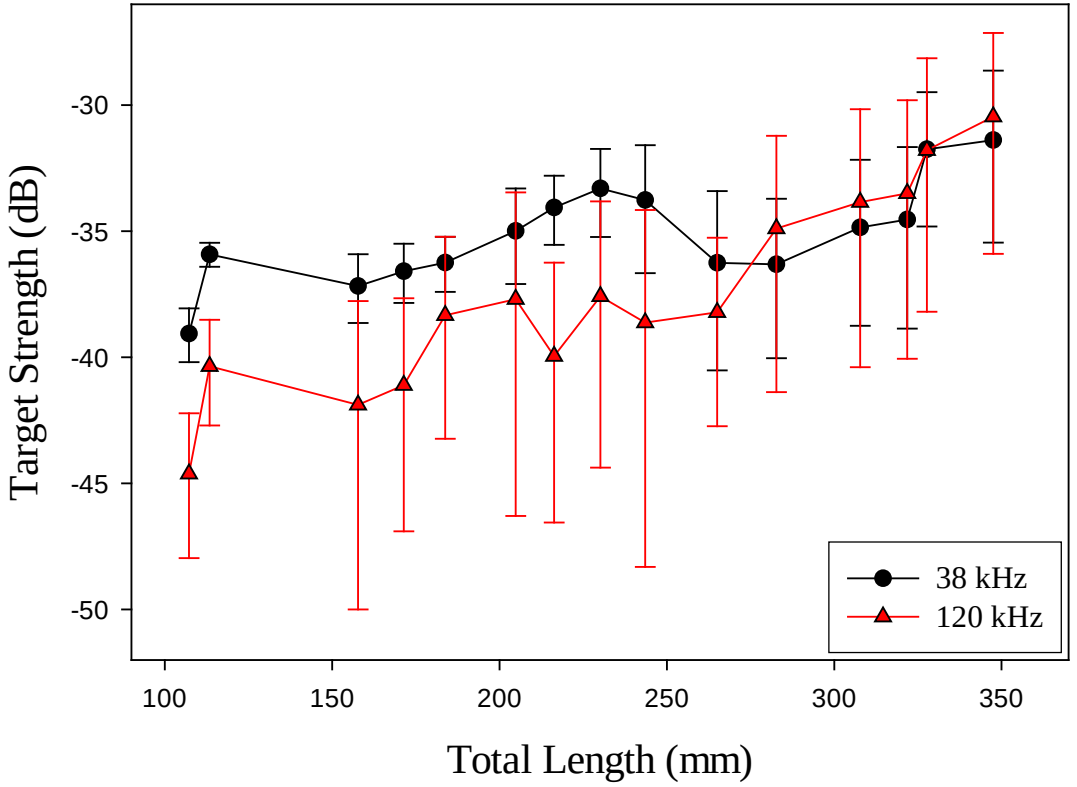
333 mm

Donaldson trout

Acoustic Ontogeny

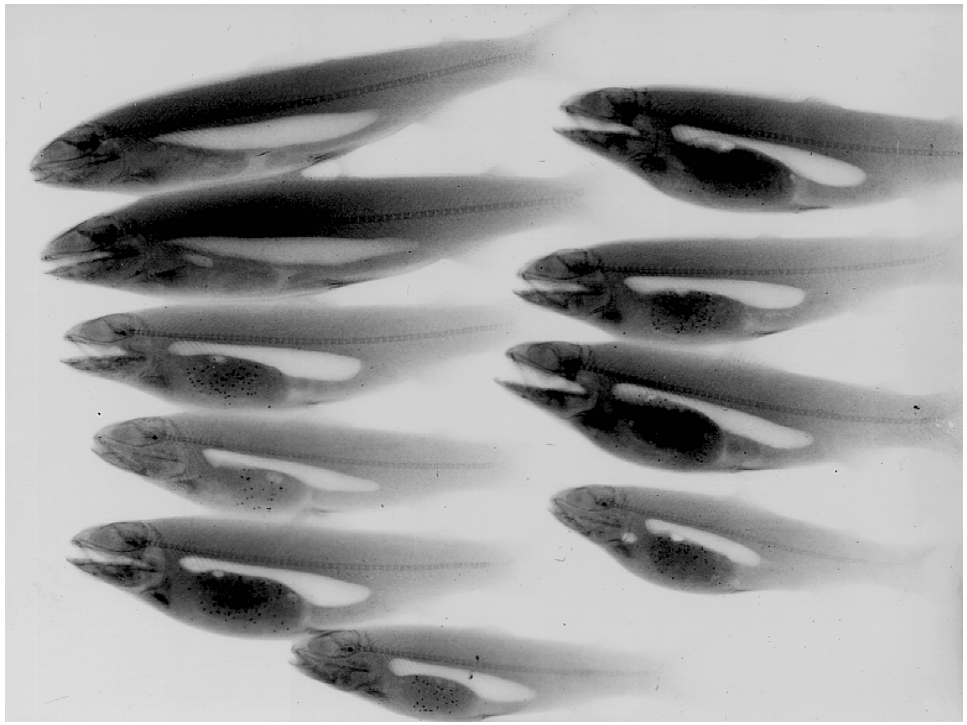




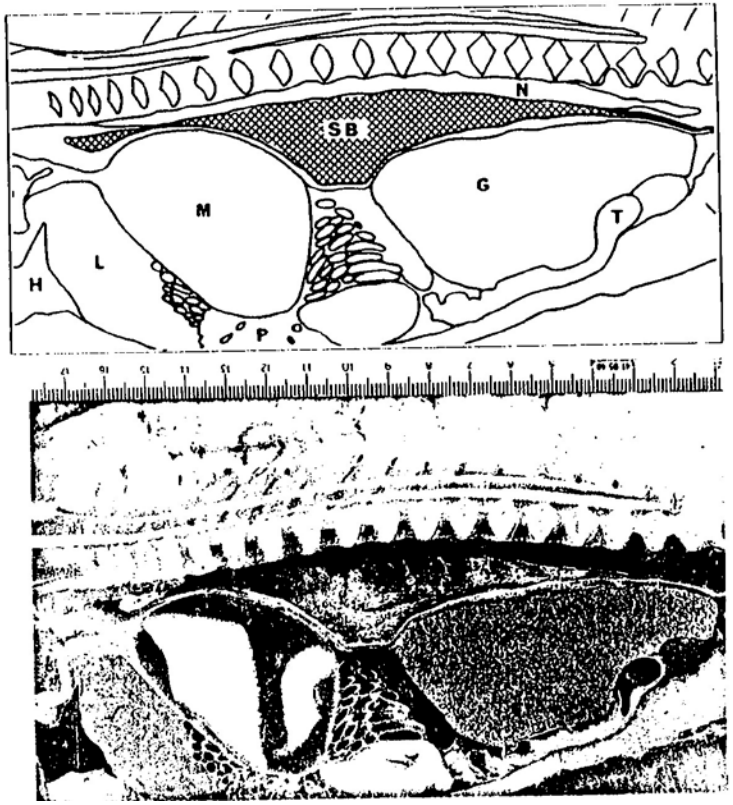


Physiology

Feeding

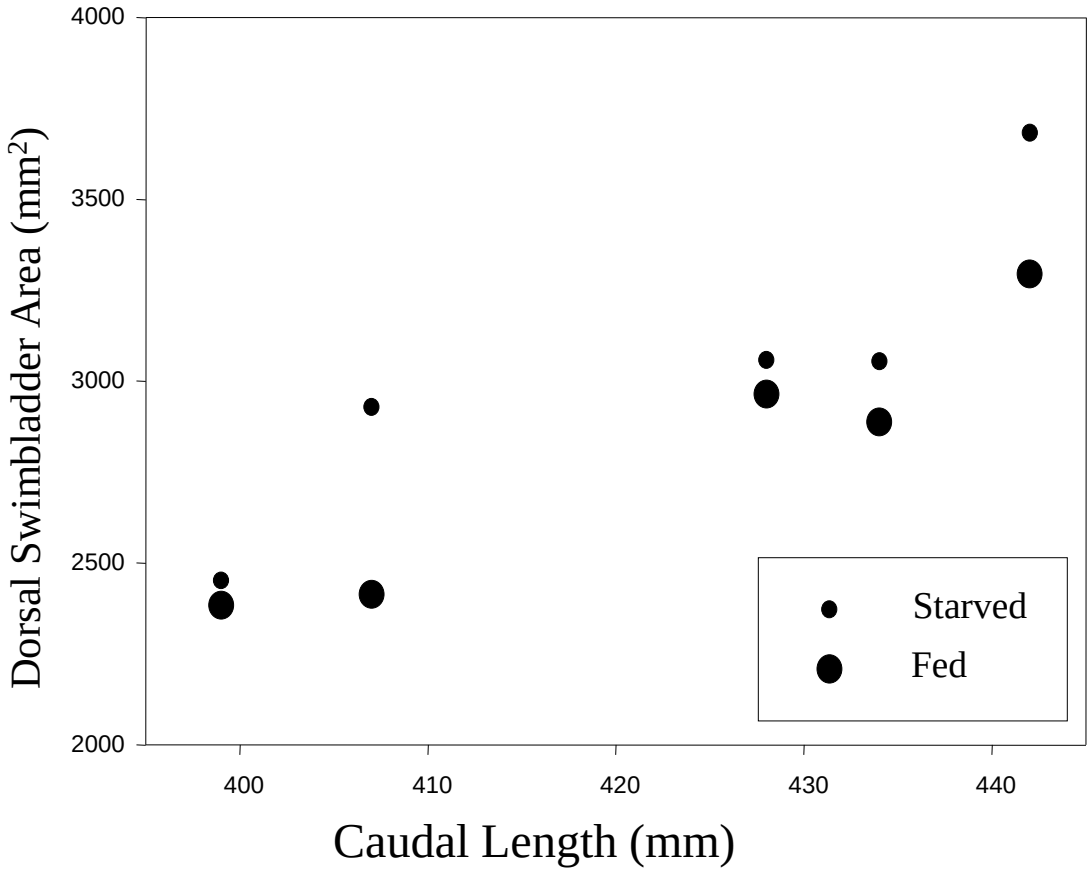


Gonad & Feeding



Ona 1990

Physiology: Fish Feeding



Horne 2003

Swimbladder Pressure Experimental Setup

3 fish, pressurized to 9.0 kg m^{-3}

dorsal and lateral

tissue sound speed

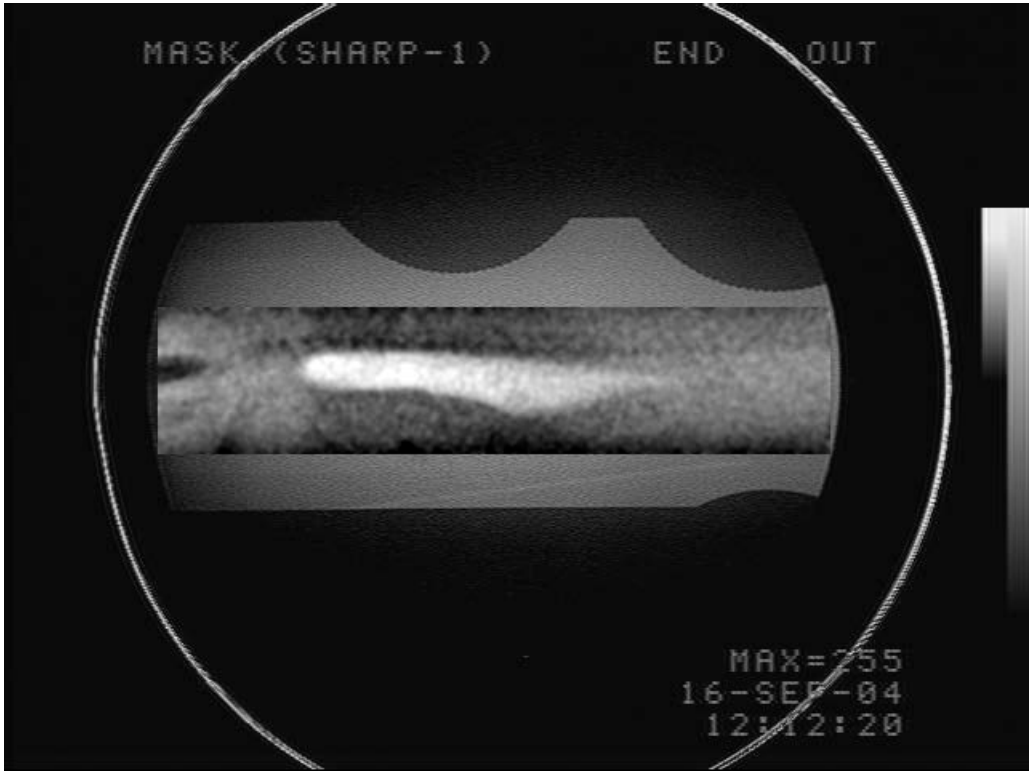
body and swimbladder digitized

KRM modeled backscatter

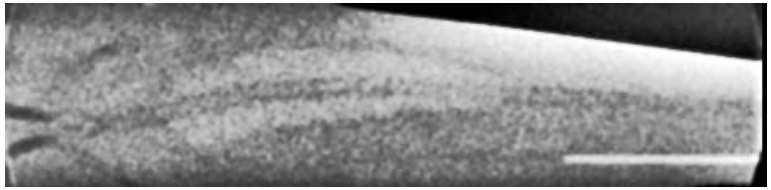
20 L pressure chamber

Swimbladder and Pressure

Lateral

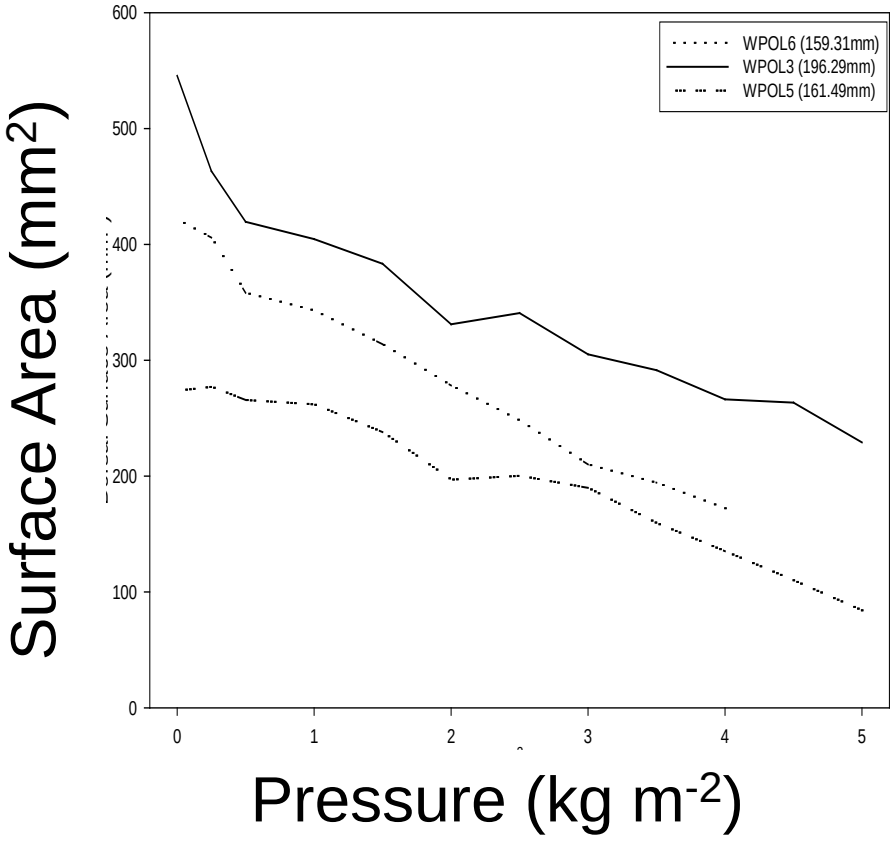


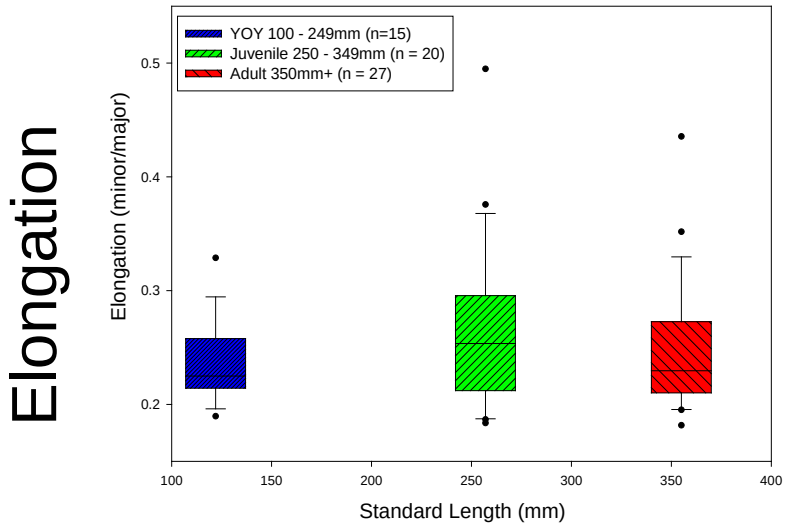
Dorsal

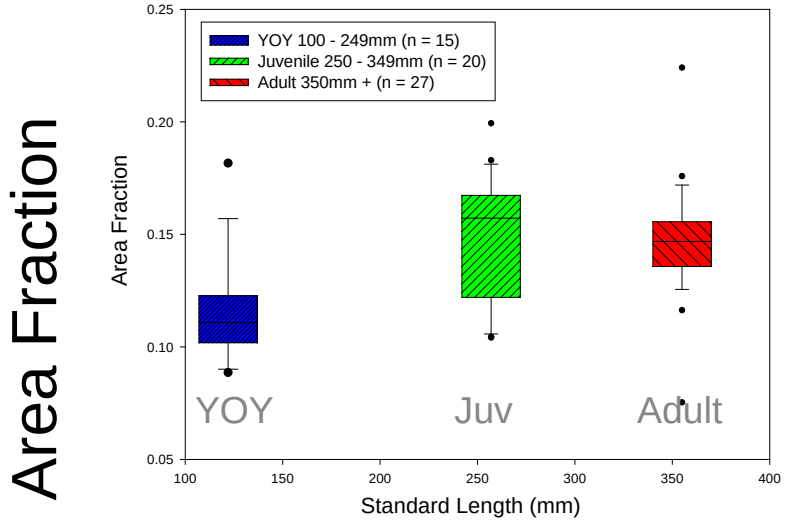


juvenile walleye pollock

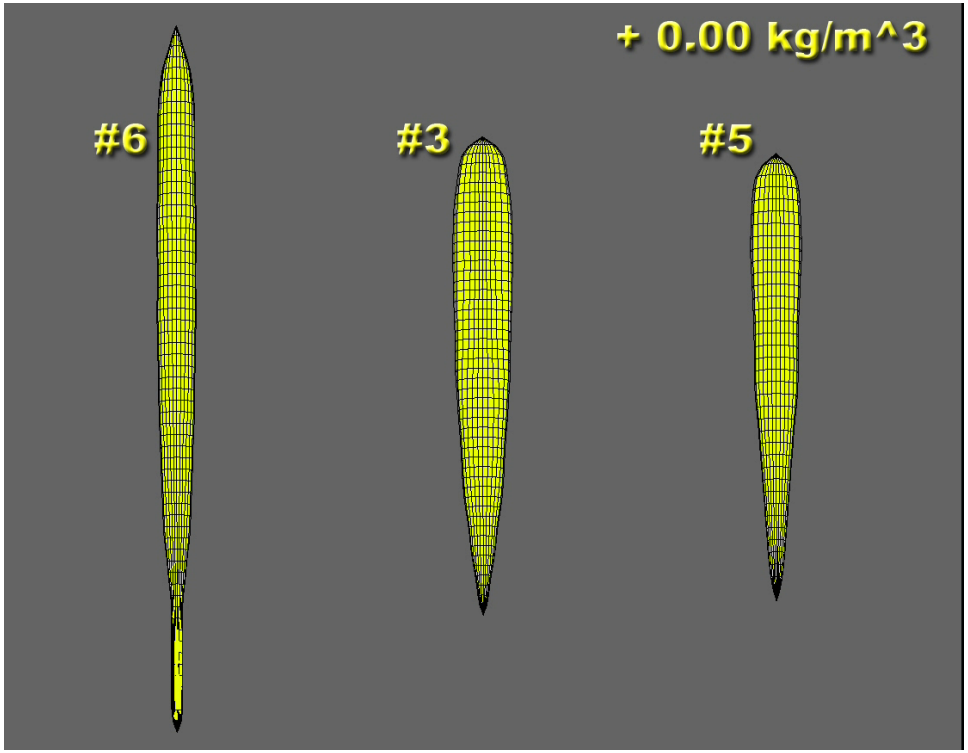
Swimbladder Dorsal Surface Area

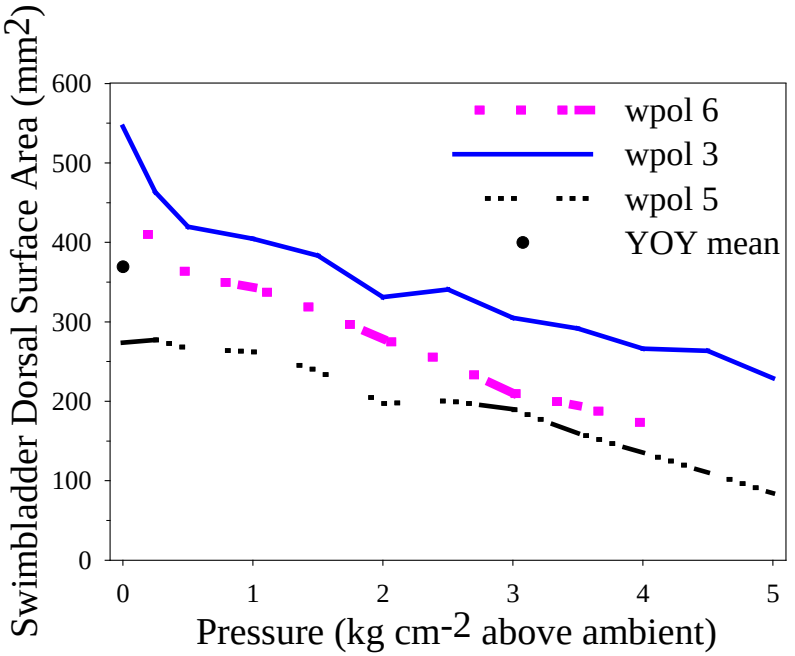






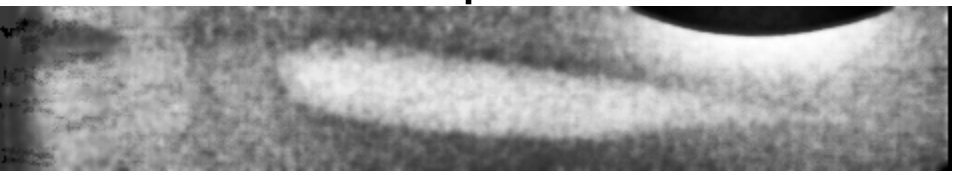
Dorsal Surface Area Changes

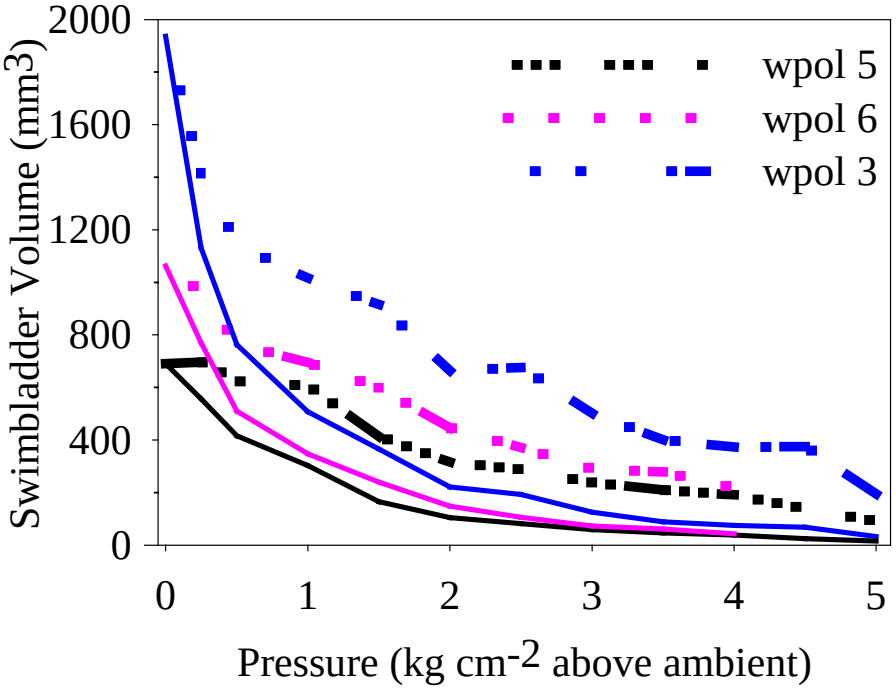




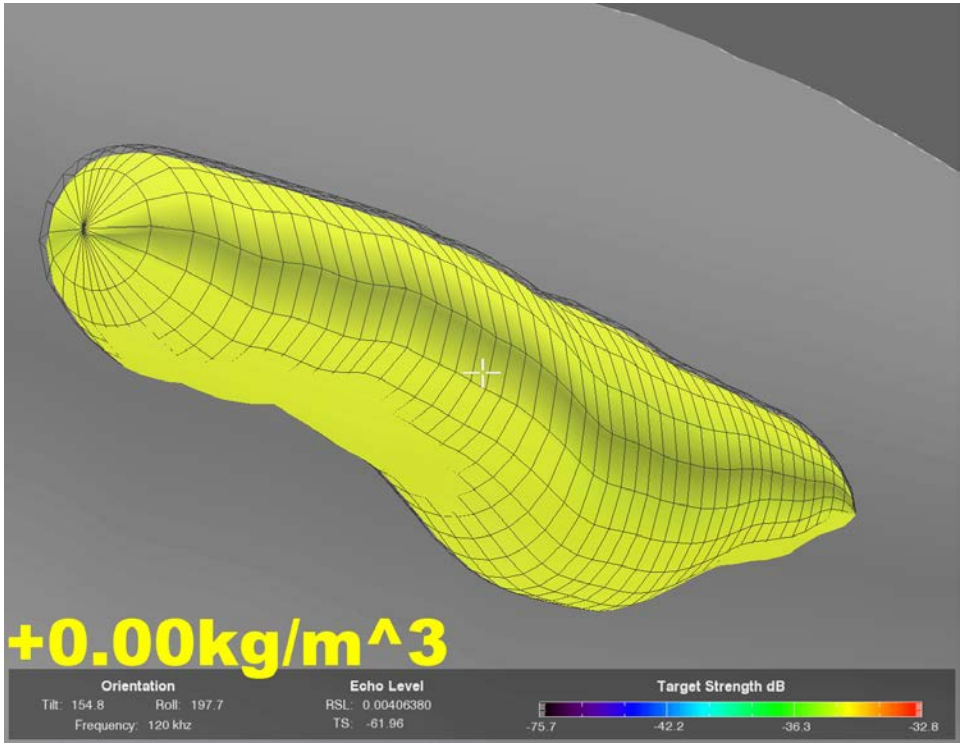
Swimbladder Volume Changes

wpol 6





wpol 3



Behavior

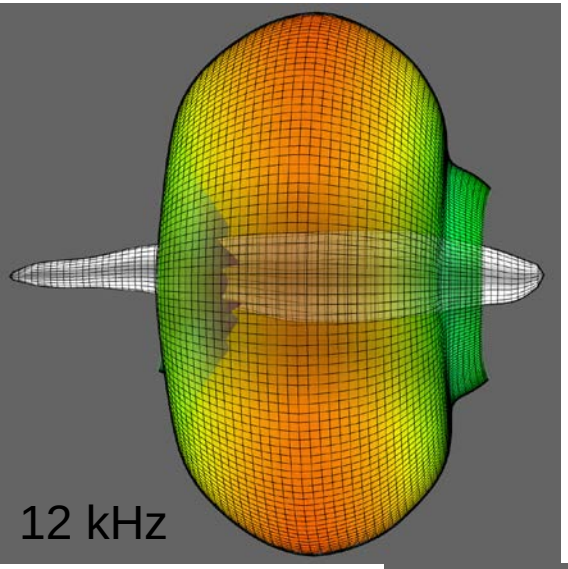
Individual

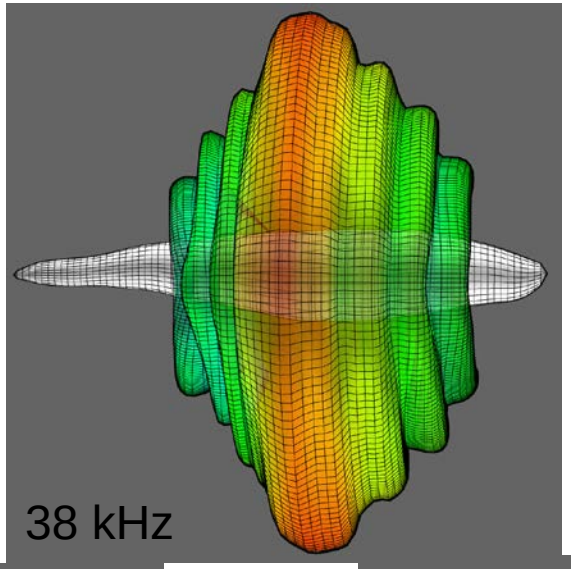
orientation (tilt, roll, direction), activity, avoidance

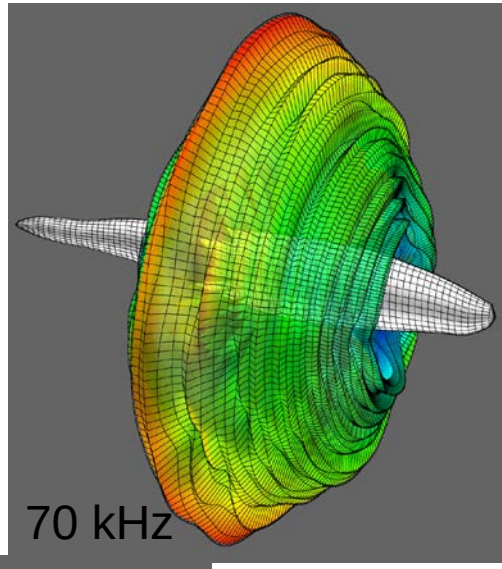
Group

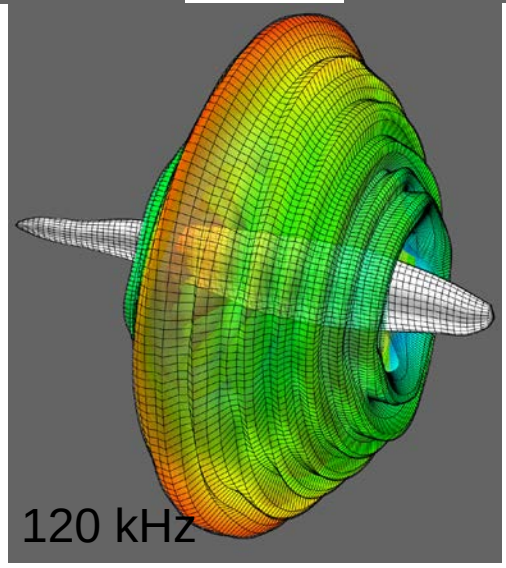
shoaling and schooling, avoidance

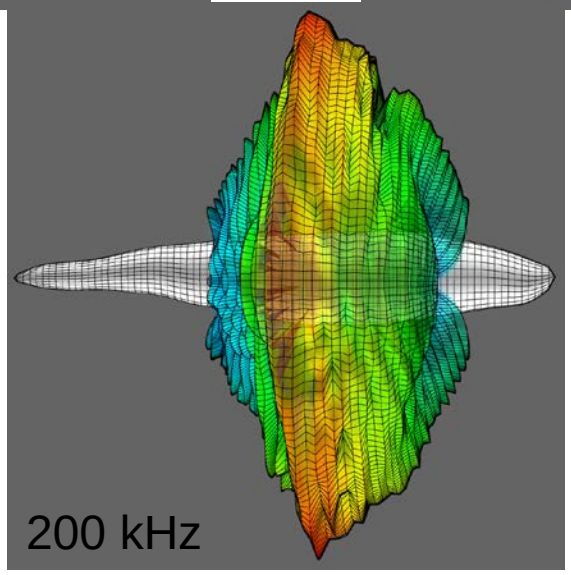
Tilt, Roll, and Frequency-Dependence



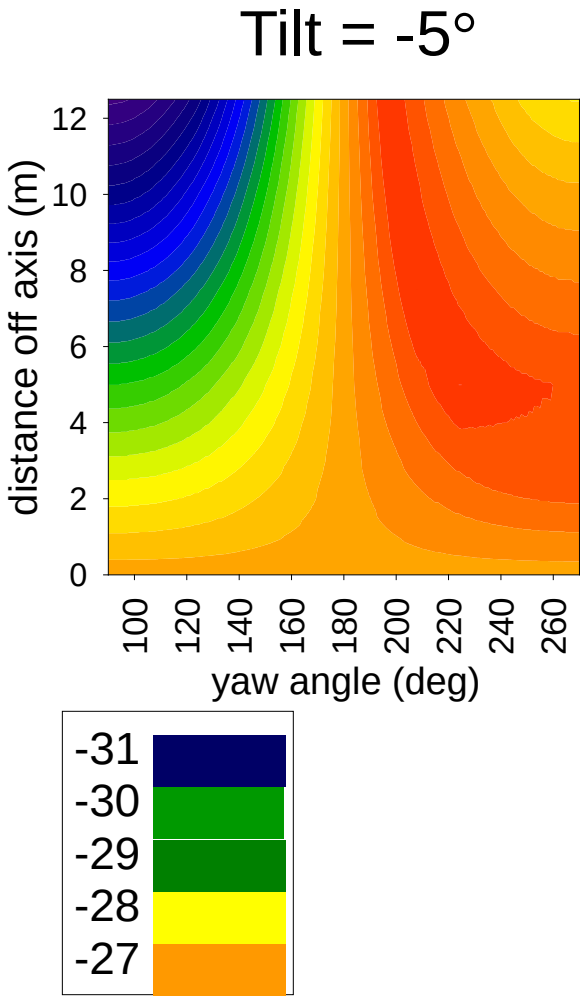


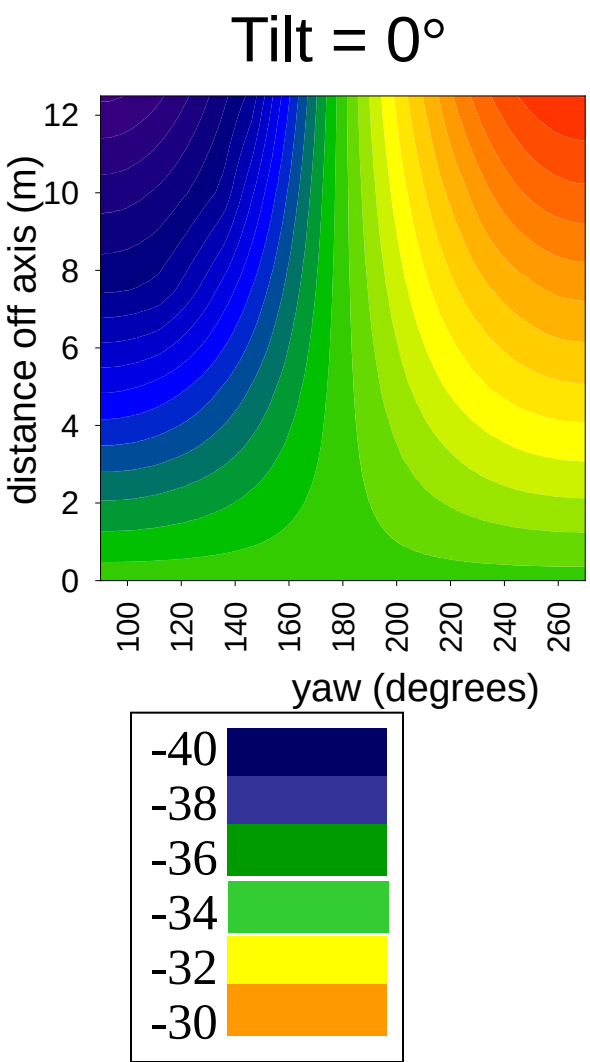


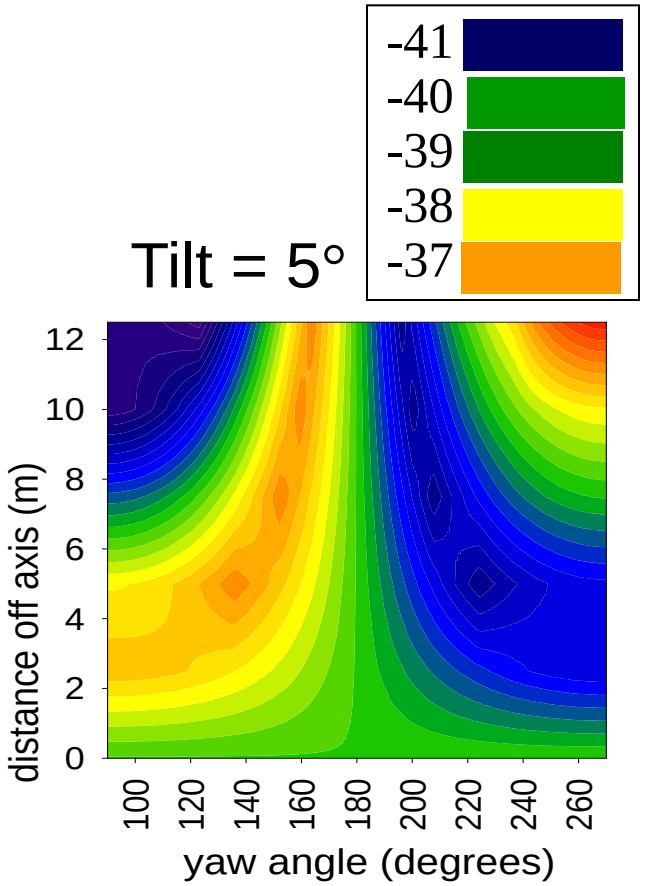




Tilt, yaw, and distance off axis

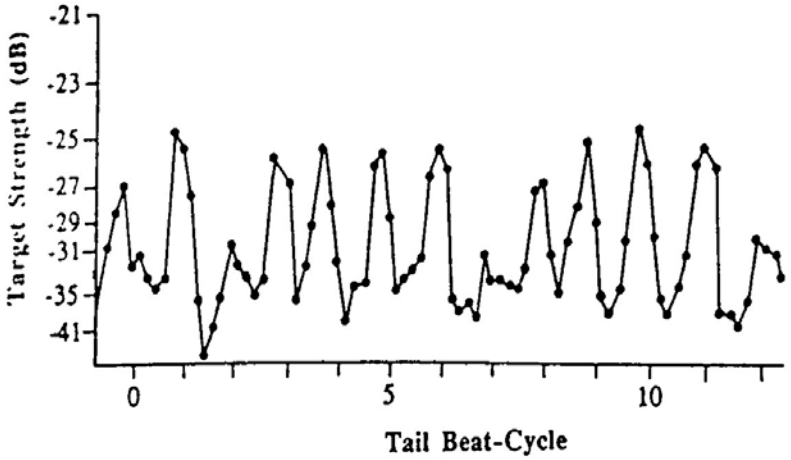






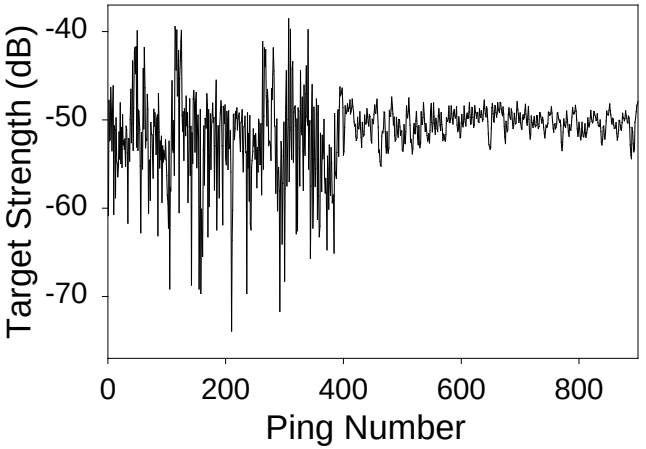
Behavior: Individual Activity

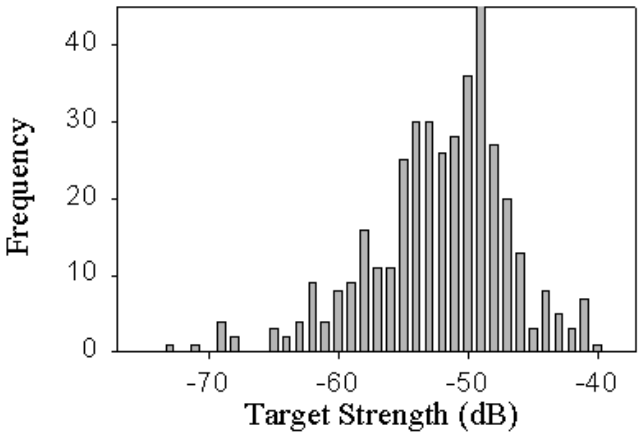
Atlantic cod (38 kHz)



Nakken and Olsen 1977

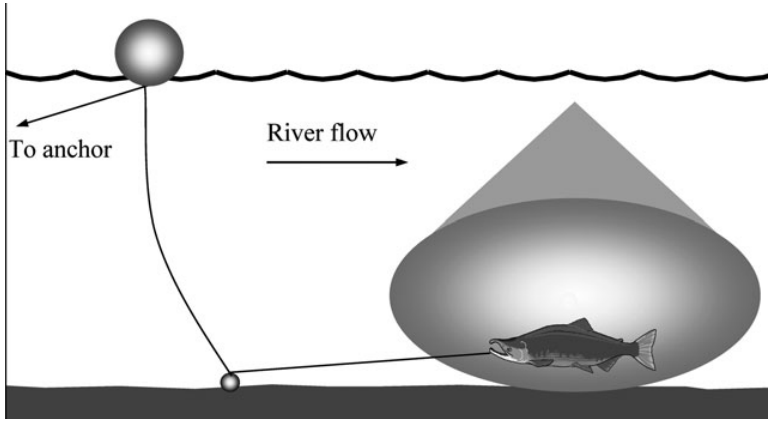
Lavnun (120 kHz)





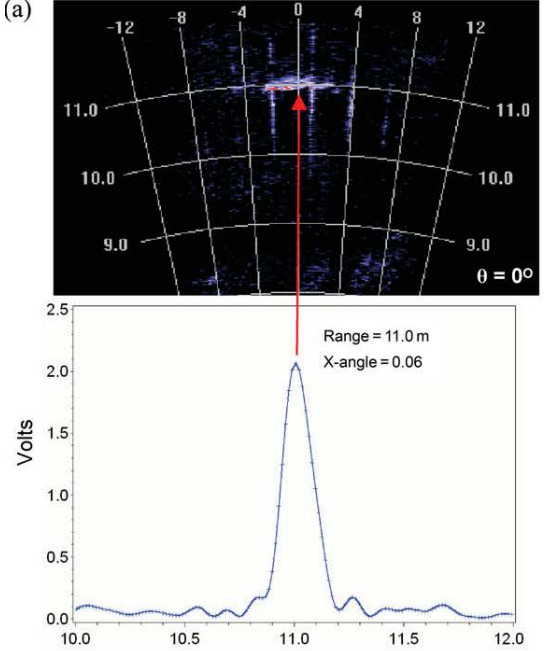
Horne *et al*. 2000

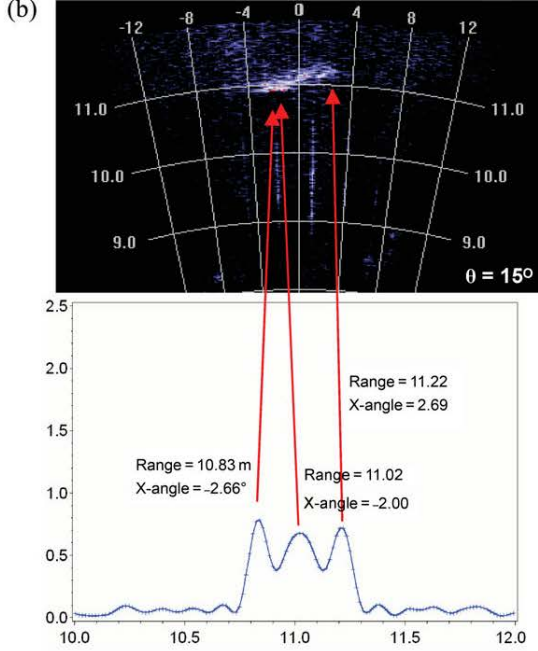
Orientation + Activity

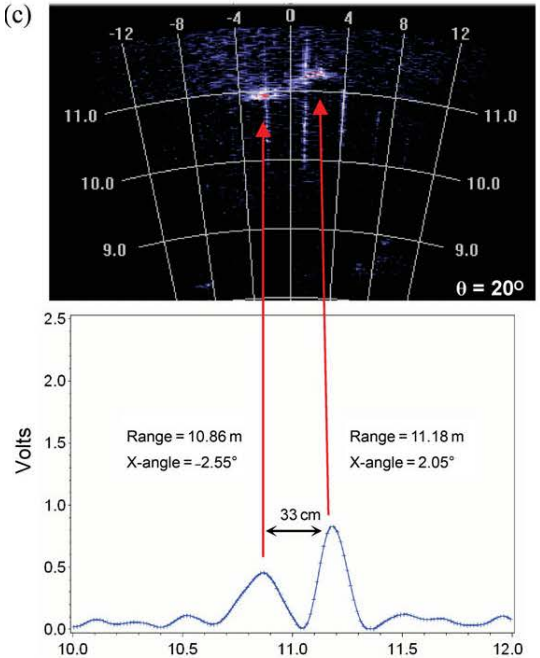


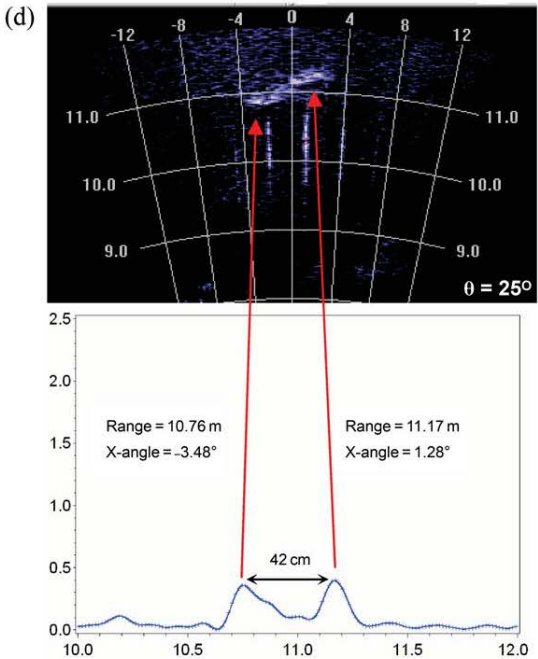
108 cm Chinnook

Burwen et al. 2007



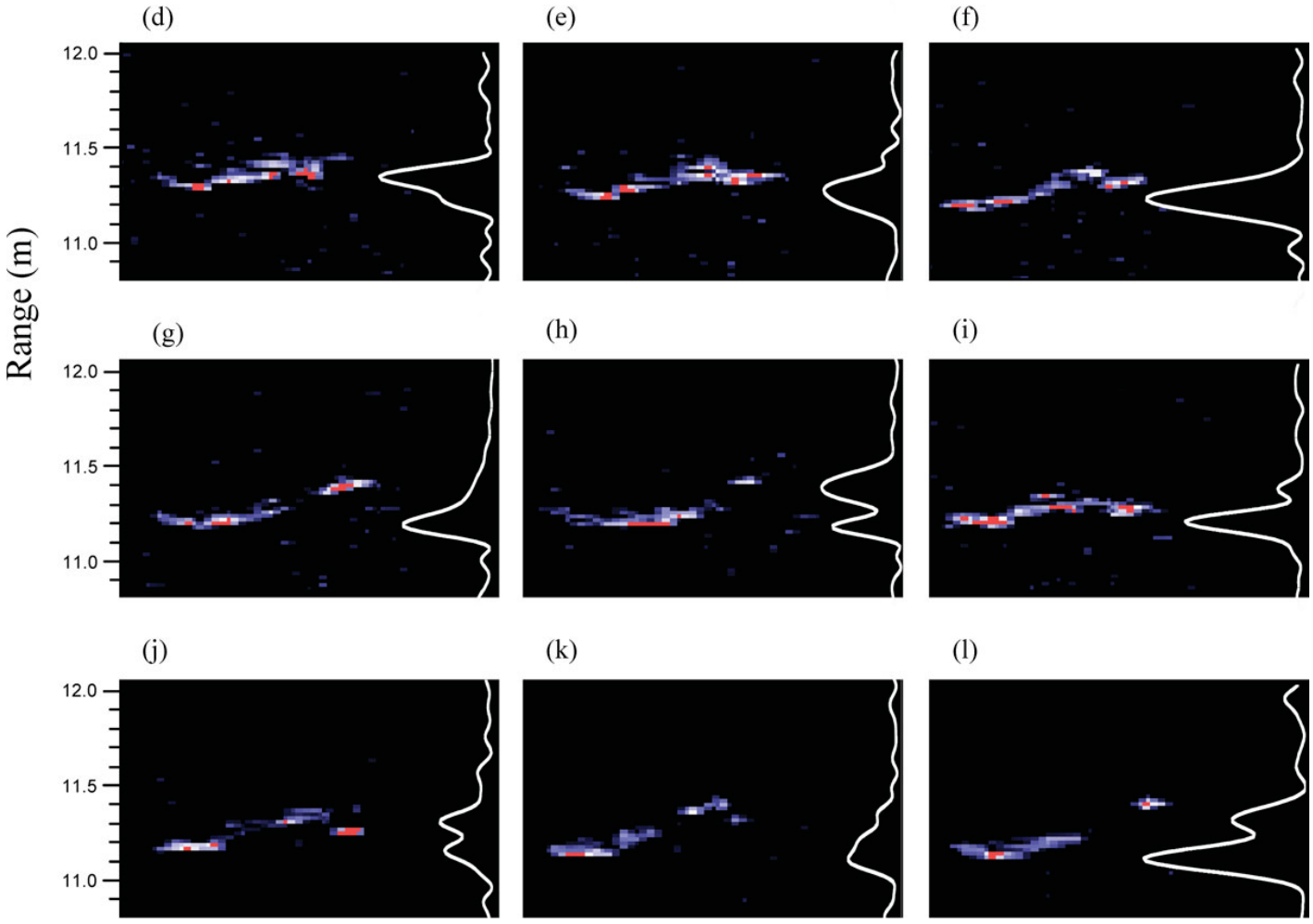






TS During Swimming Cycle

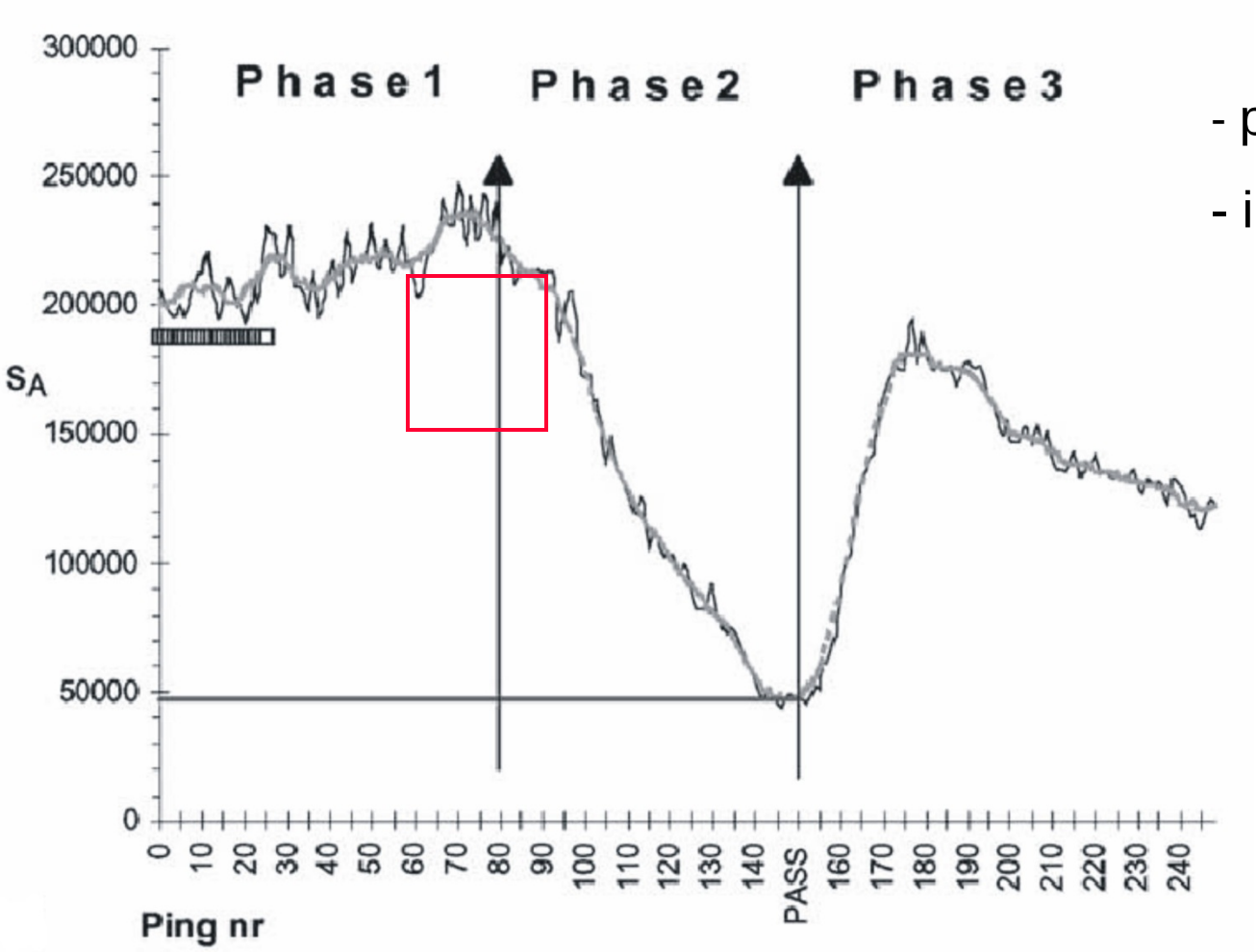
- free swimming Chinook
- echo envelope changes with yaw & curvature
- 2 tail beat cycles
- pulse length a factor



Tail beat pattern species specific (Meuller et al. 2010)

Burwen et al. 2007

Ensemble Fish Avoidance

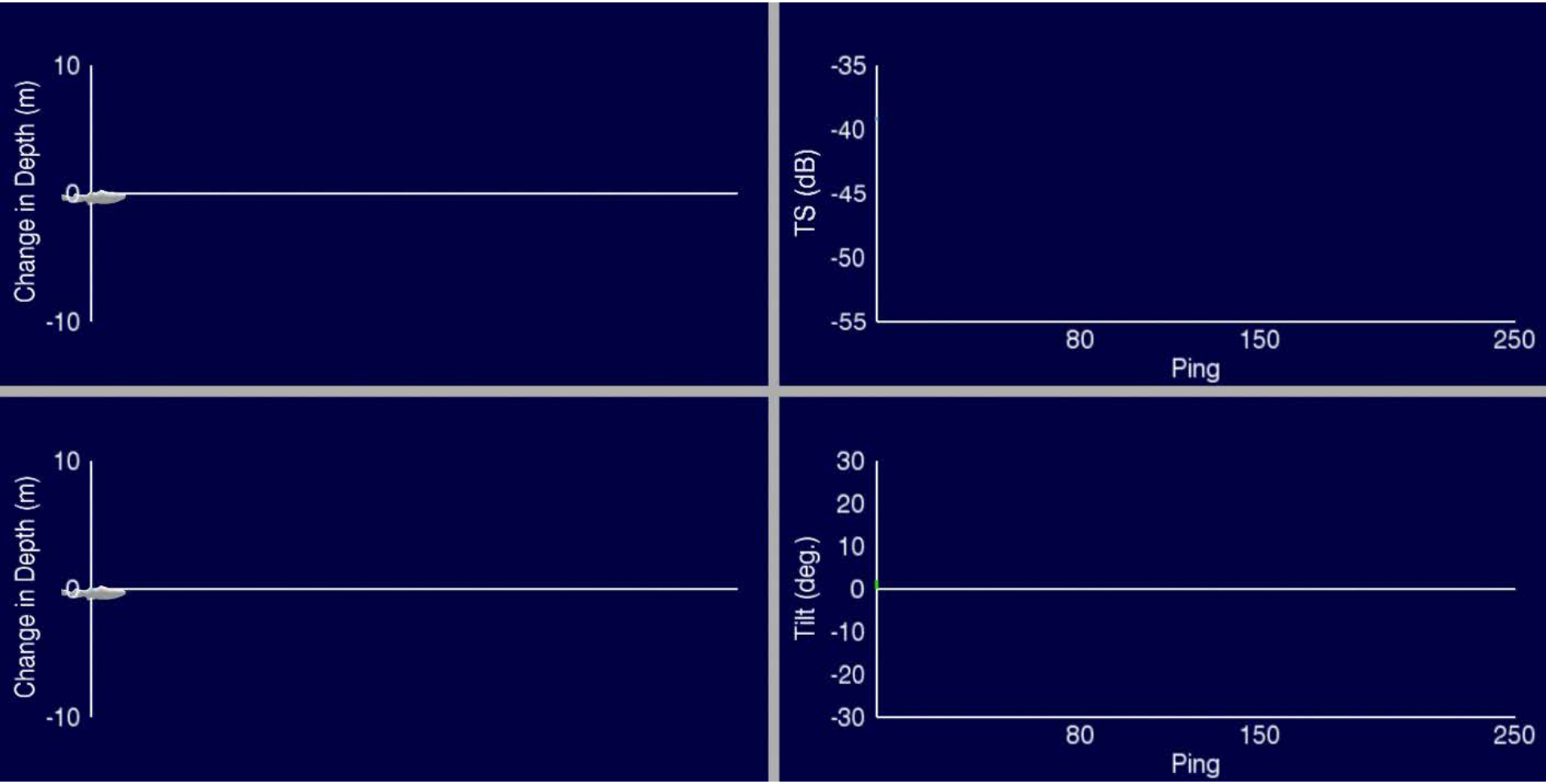


- population flux
- individual tilt angles

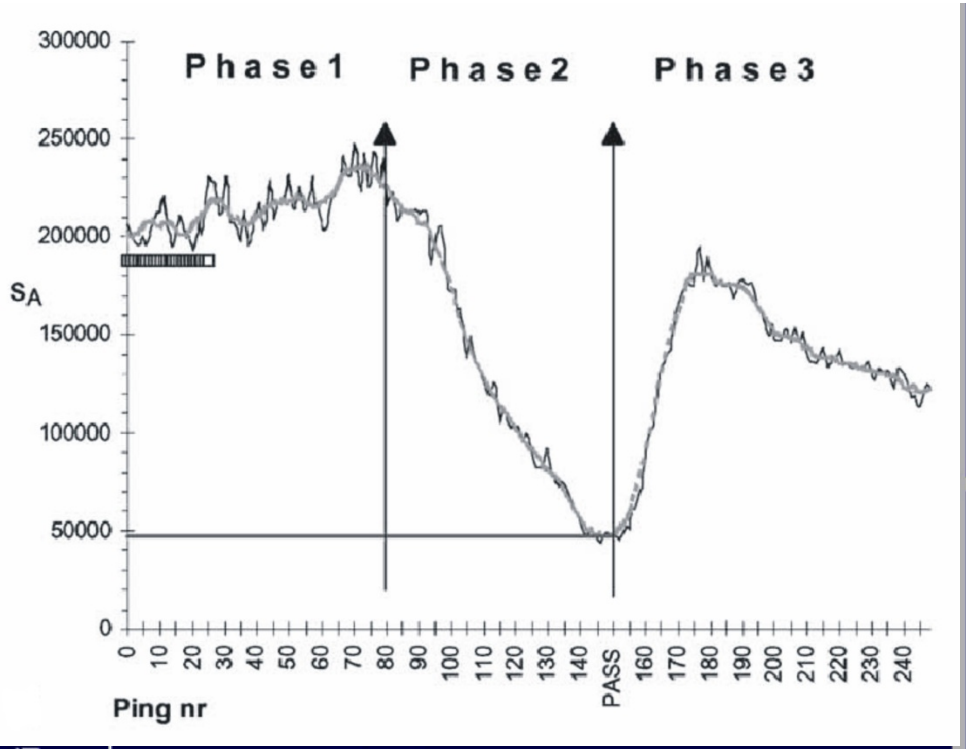
Figure 3a

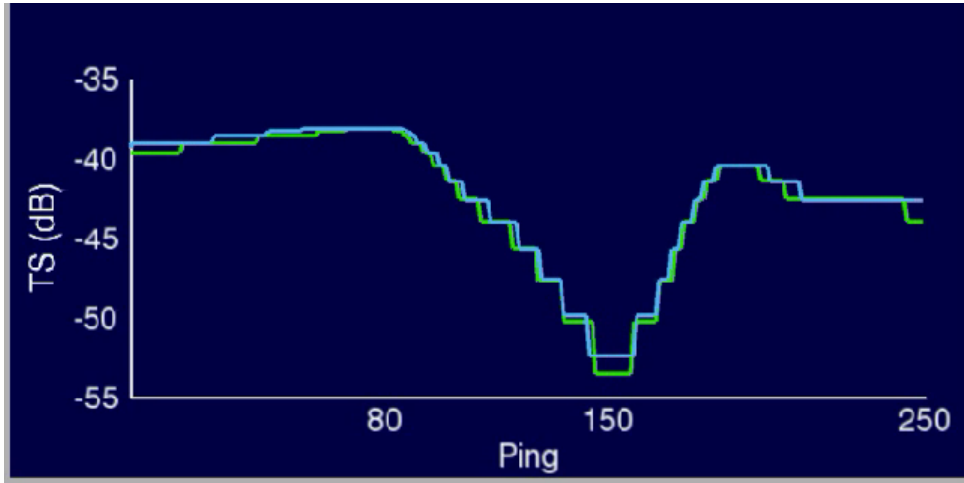
Vabo *et al.* 2002

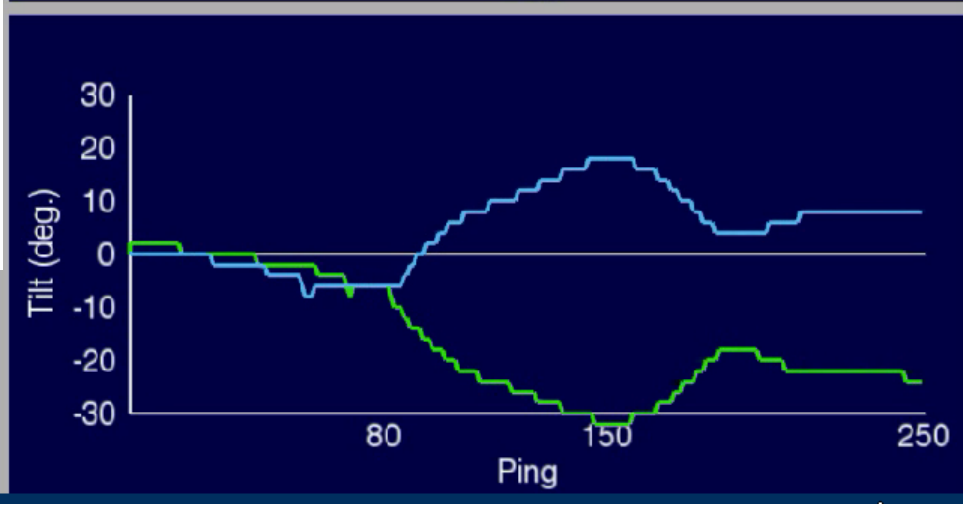
Fish Tilt Animation



Pattern Comparisons

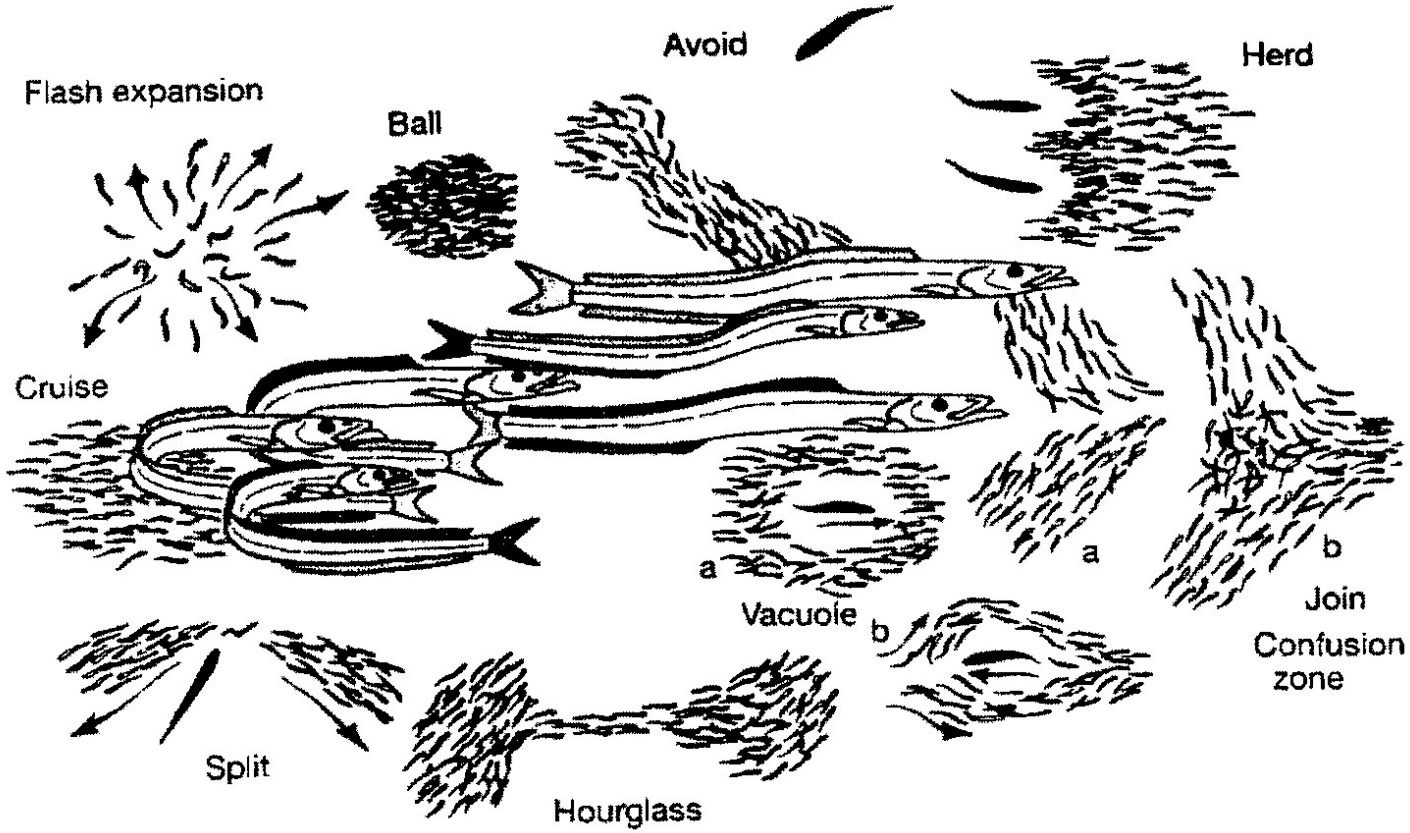






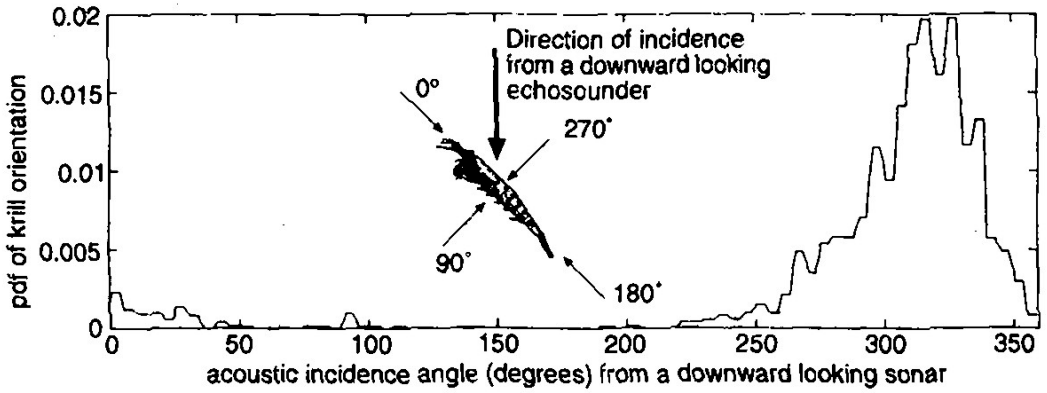
Behavior: Group Avoidance

Individual: avoidance

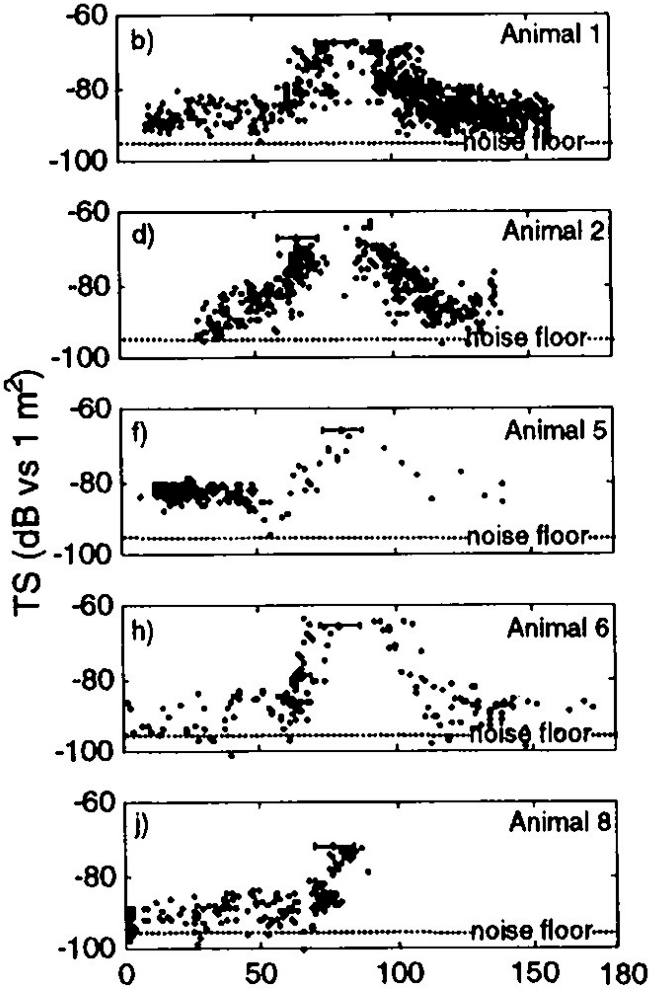


Pitcher and Wyche 1983

Behavior: Individual Zooplankton

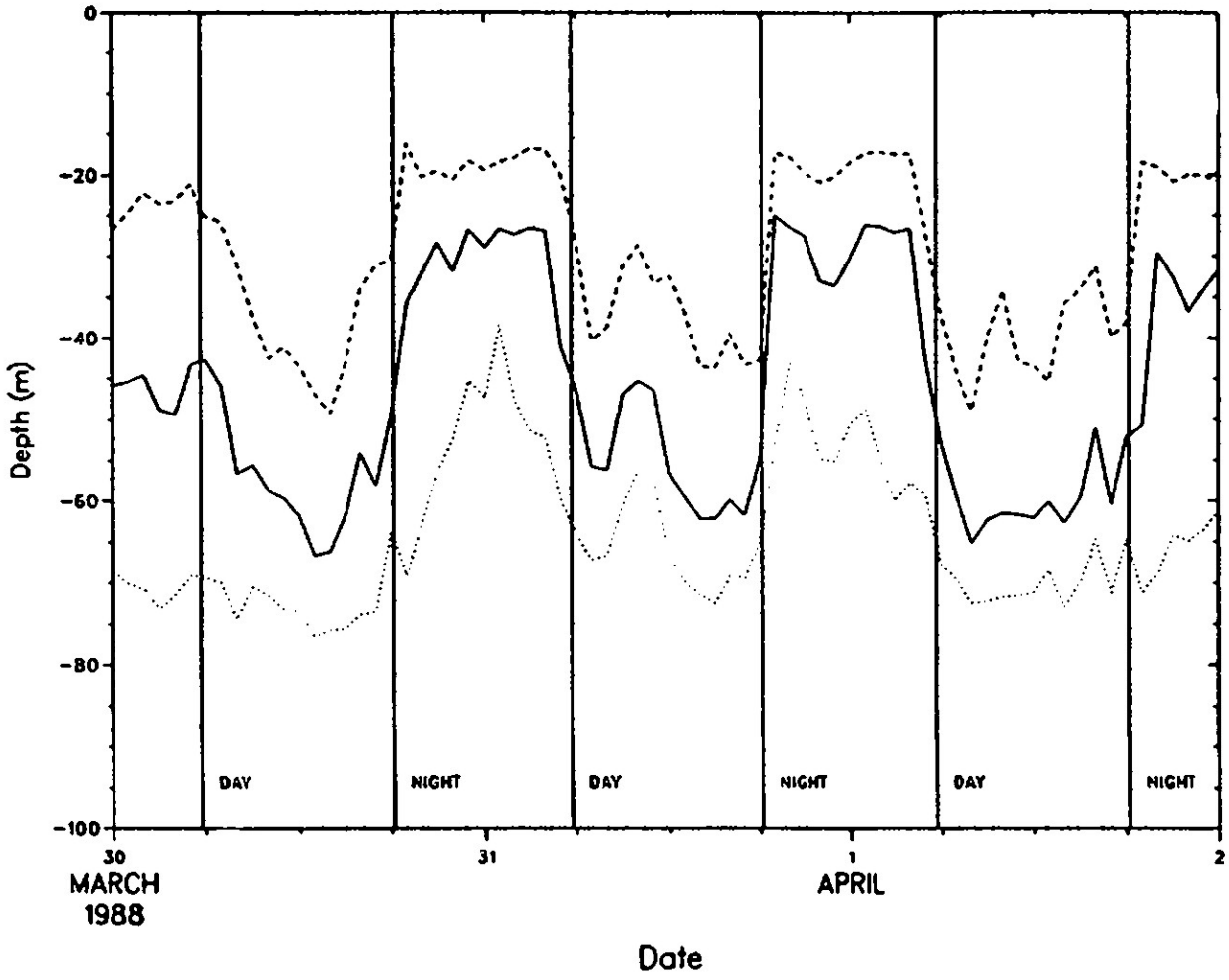


Kils 1981



McGhee *et al*. 1998

Behavior: Zooplankton Diel Migration



Smith *et al*. 1992

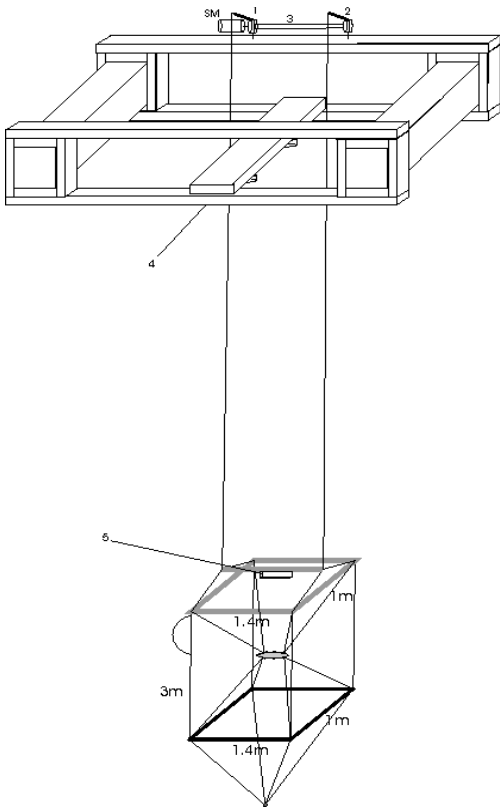
Acoustic Biological Perspective

Morphology	anatomy material properties
Ontogeny	growth (body, scattering organs) sexual maturity
Physiology	feeding gonad production
Behavior	individual – orientation (tilt, roll, direction), activity, avoidance group – shoaling and schooling, avoidance

Ranking Physical & Biological Factors

KRM model-based, non-dimensional ratios

Tilt > Frequency > Length > Depth



Empirically measured, non-dimensional ratios

Length > Tilt >> Freq > Depth

Hazen & Horne 2003