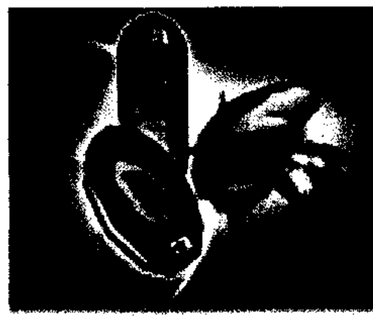


SHARK SENSORY CAPABILITIES

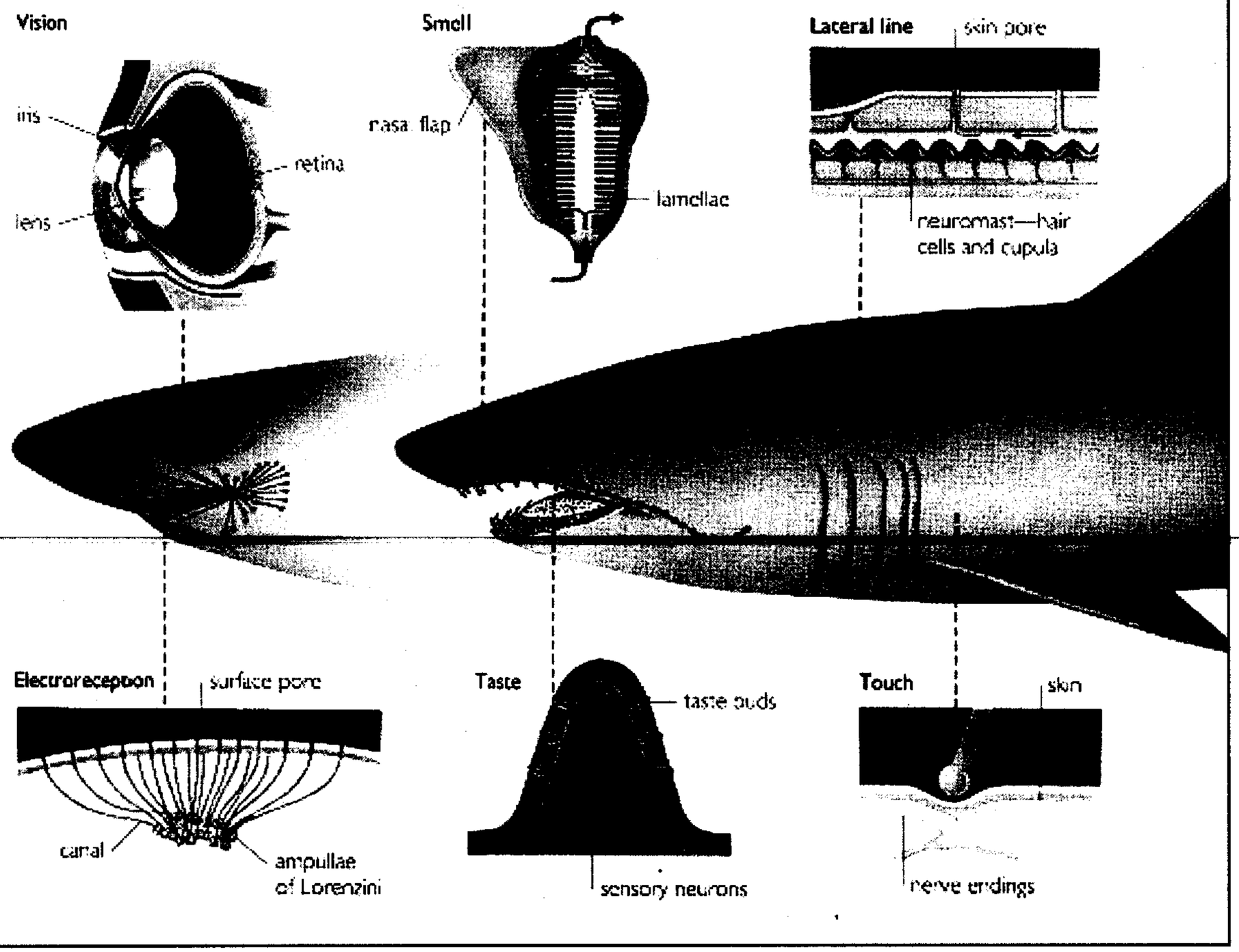
Sensory Systems

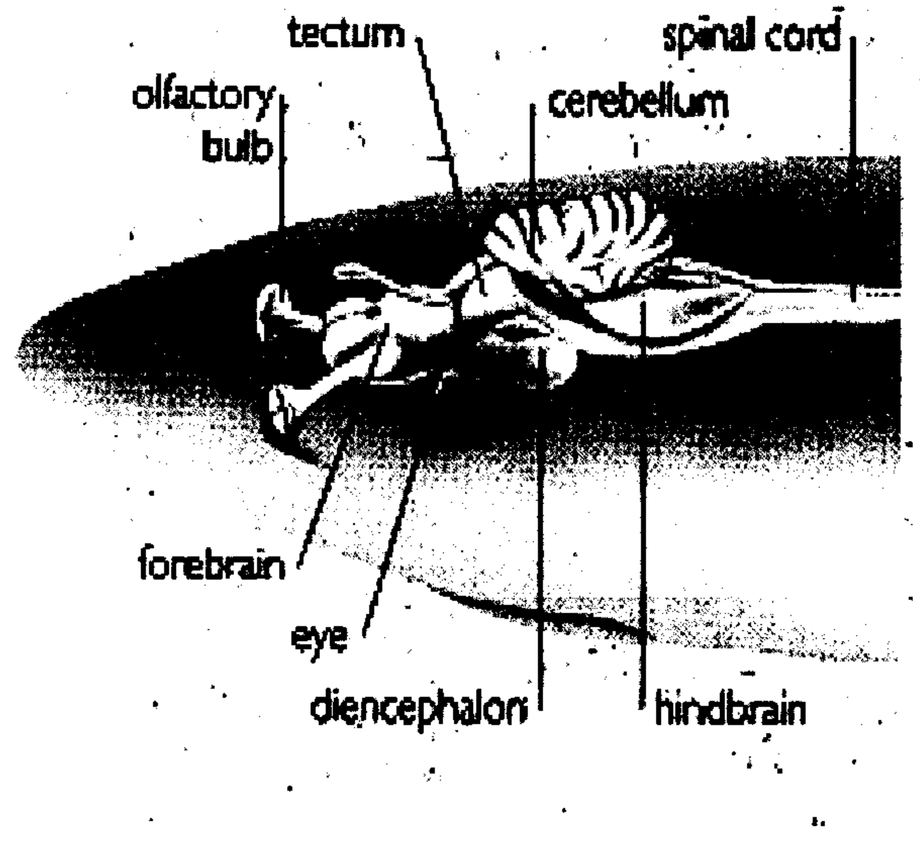
Six senses of humans

Hearing, Balance, Vision, Smell, Taste & Touch

AND

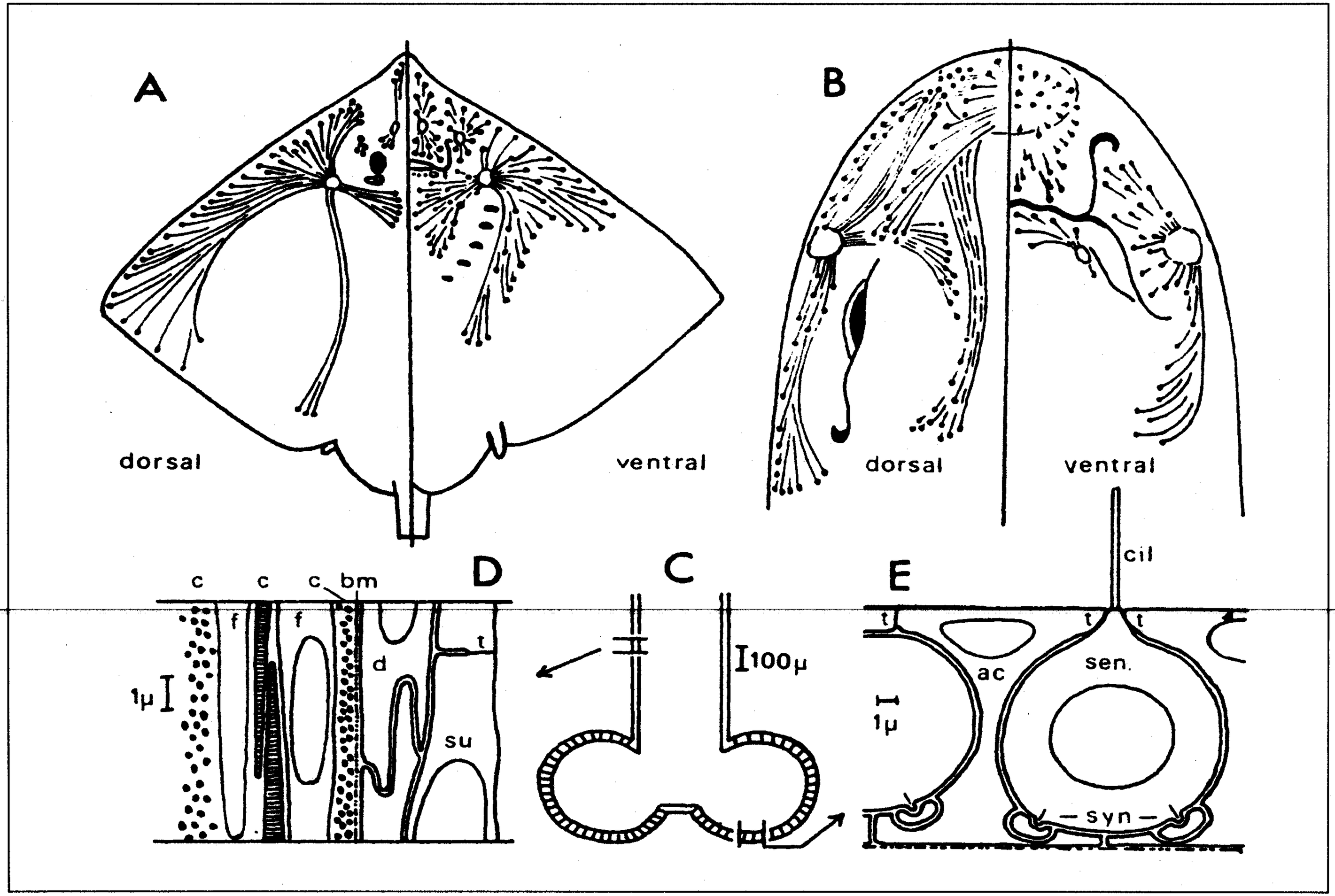
Mechanosensory lateral line and Electroreceptors





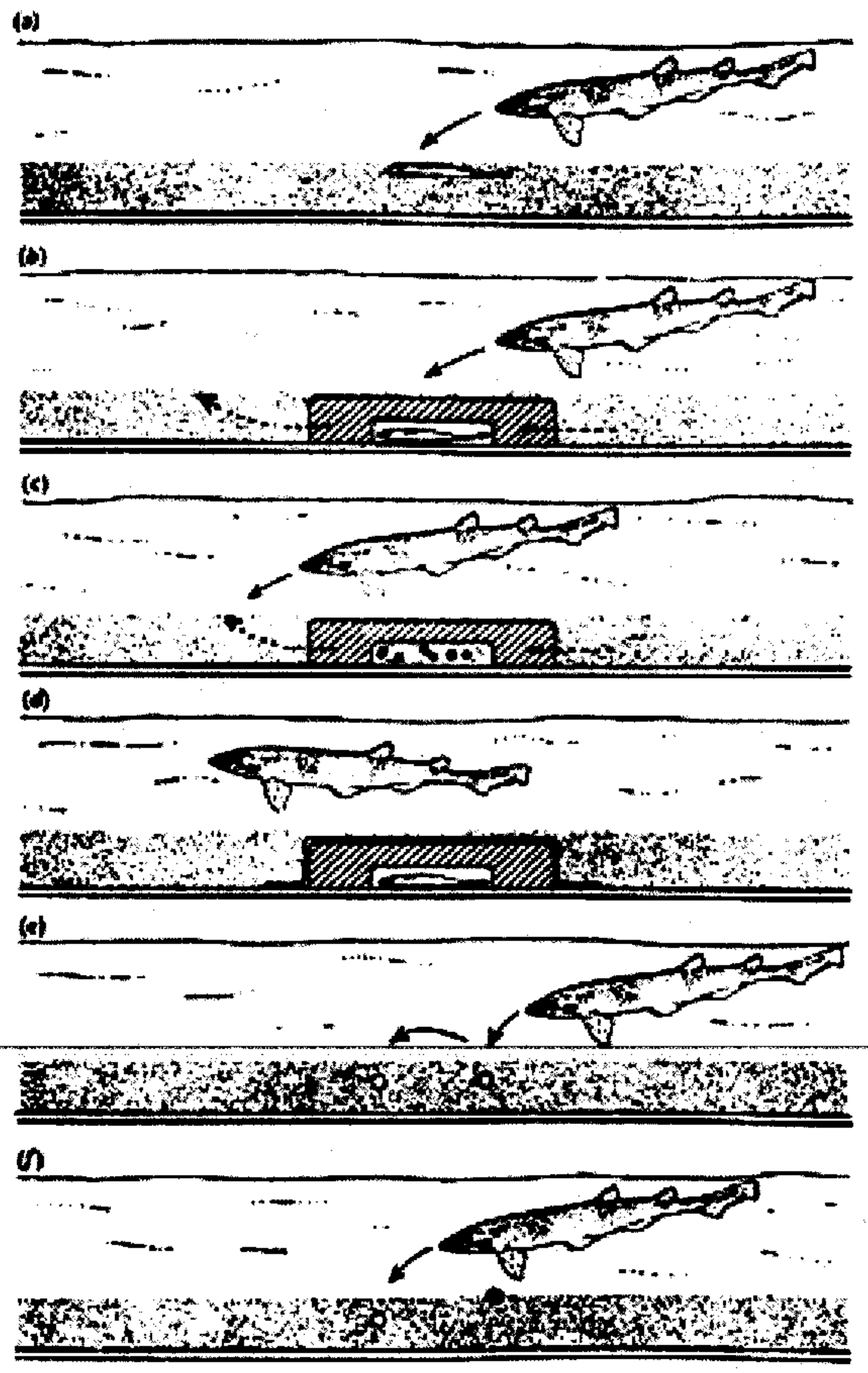
Many species have a brain that is larger in size than that of some birds and mammals.

Sharks and rays have exquisite sensory systems and a large brain for processing biologically relevant information.


A
dorsal
ventral
B
dorsal
ventral
D
c
c
c
bm
f
f
d
t
su
1μ
C
100μ
E
cil
t
t
t
ac
sen.
1μ
syn

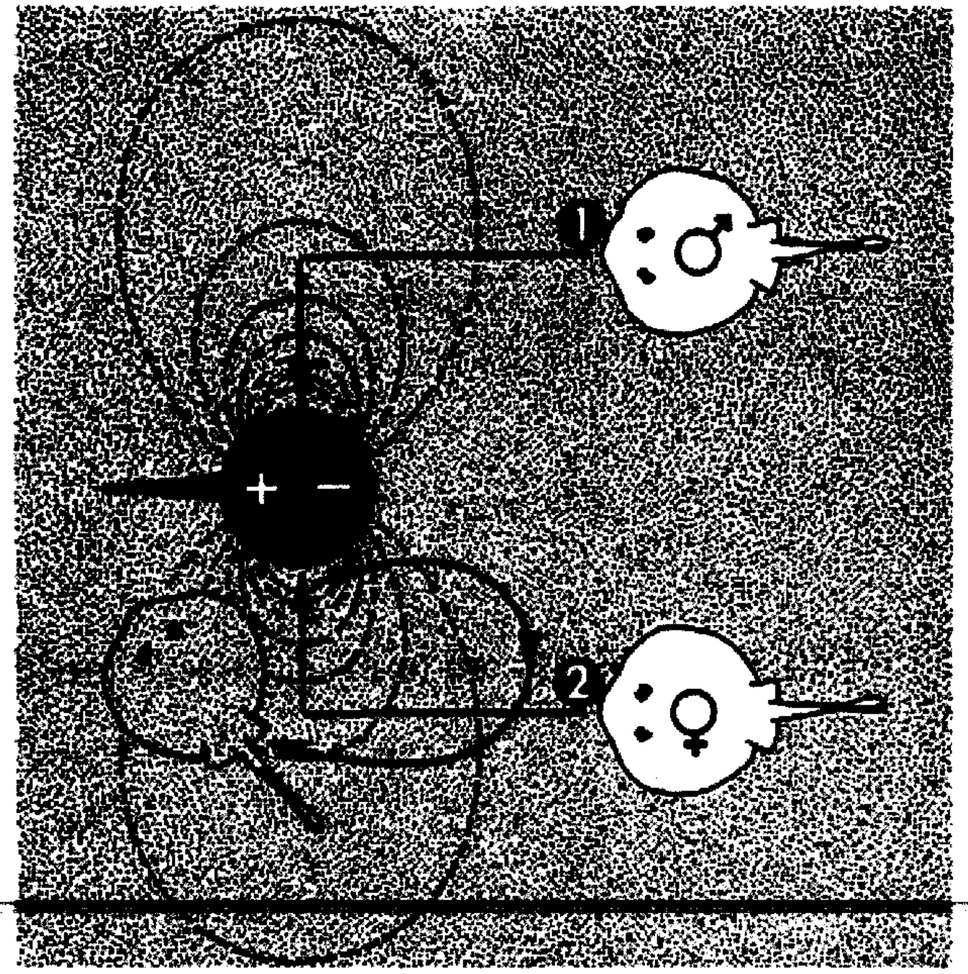
Shark and Rays use Electric Field Sensors ("Electroreception") to detect Prey, Mates and Predators

Prey



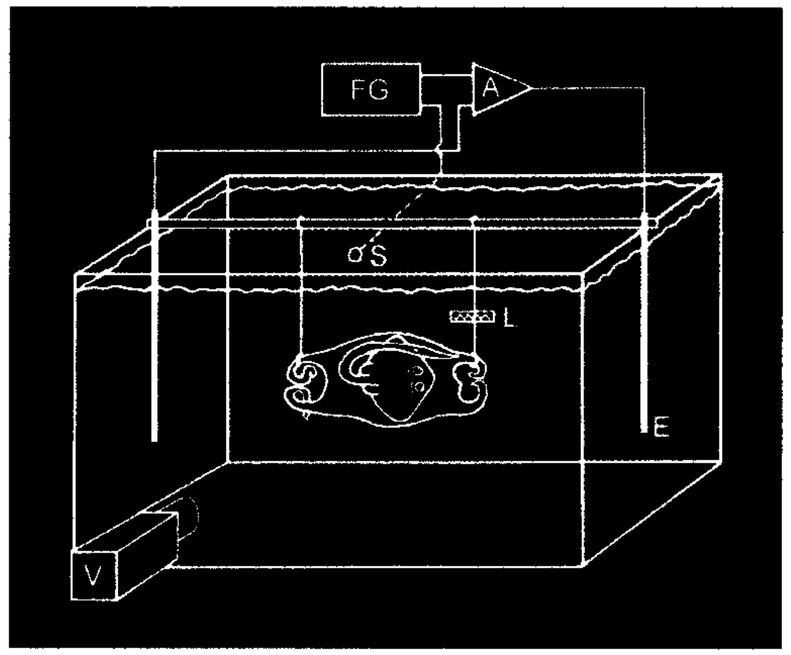
Kalmijn 1972

Mates



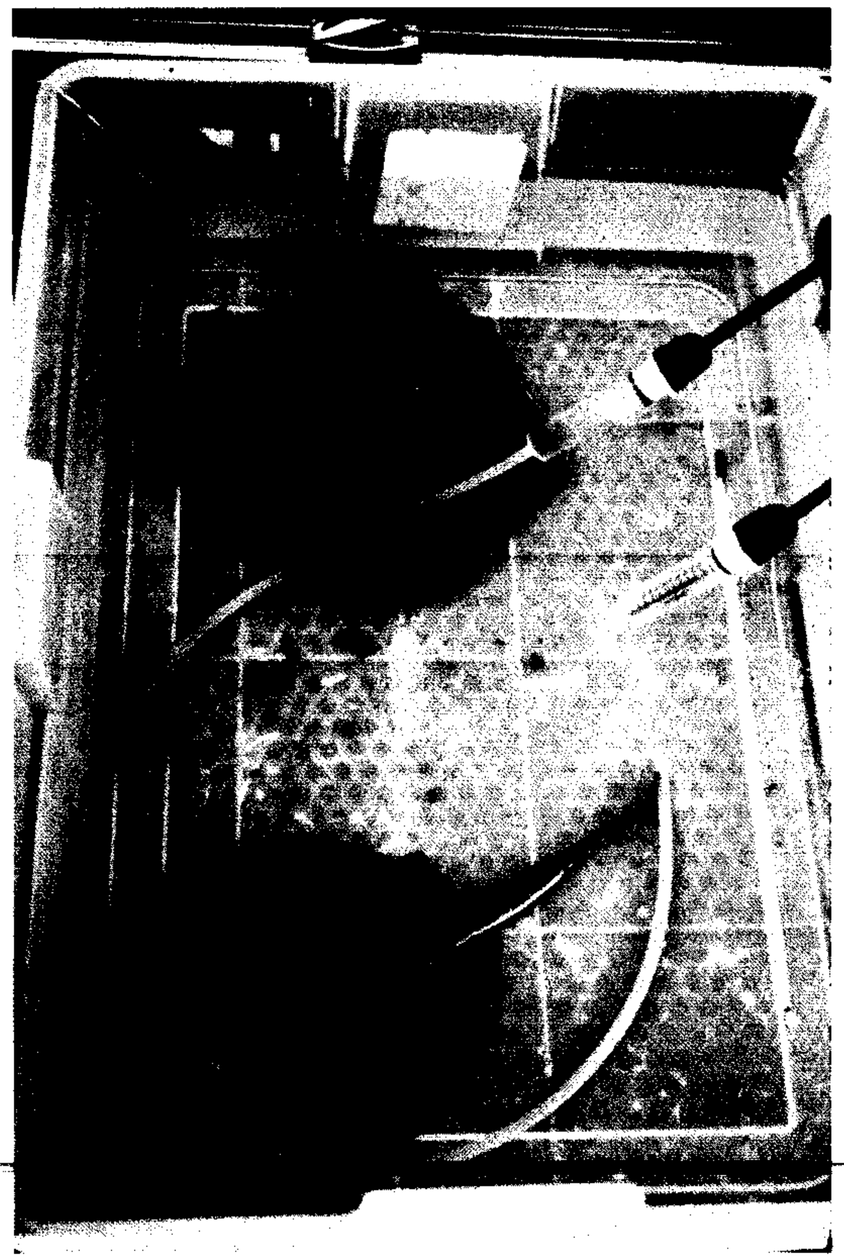
Tricas et al. 1995

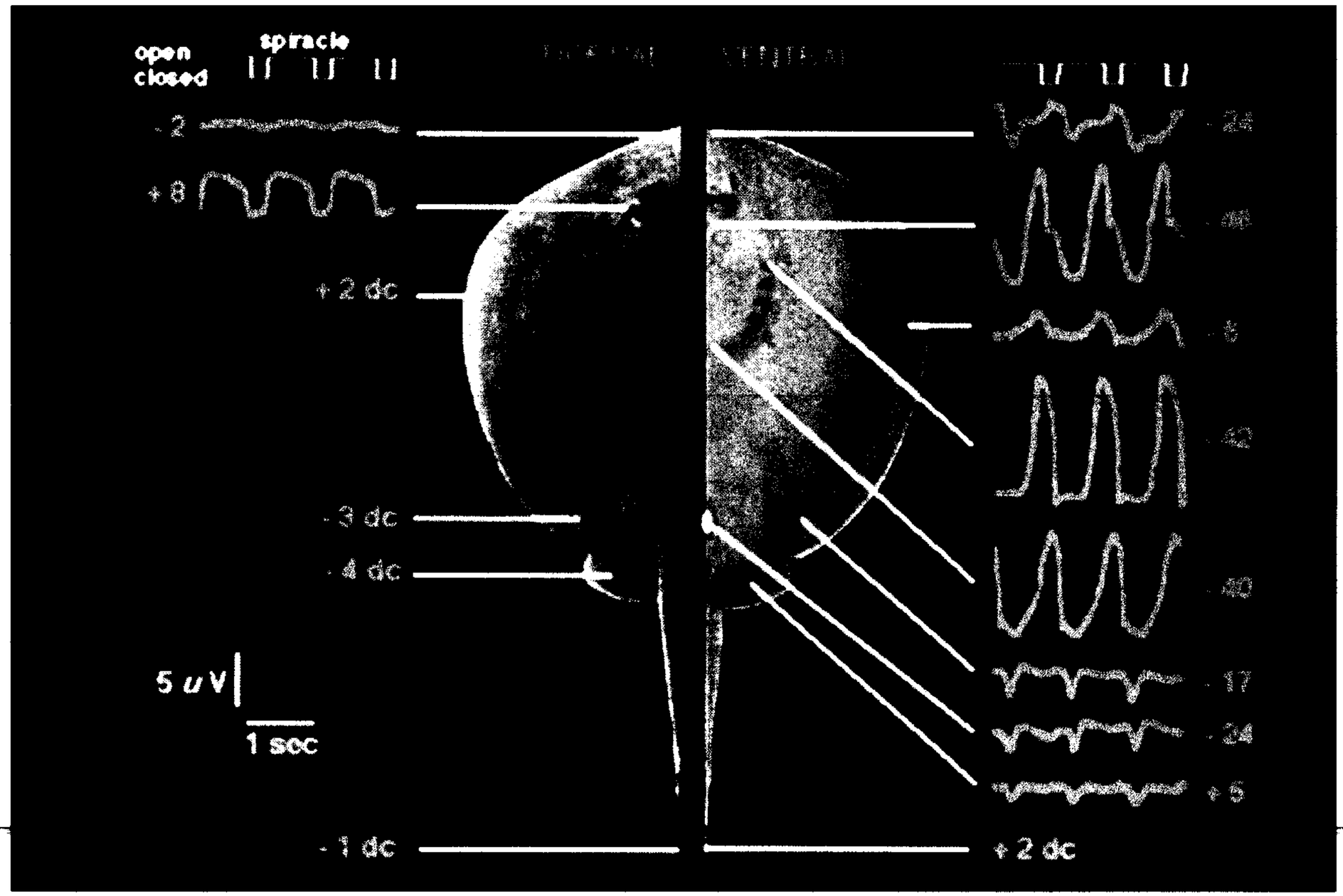
Predators



Sisneros et al. 1998

Bio Electric Sensing Present and Can be Exploited for all Elastobranch Marine Species (Sharks/Rays/Skates)

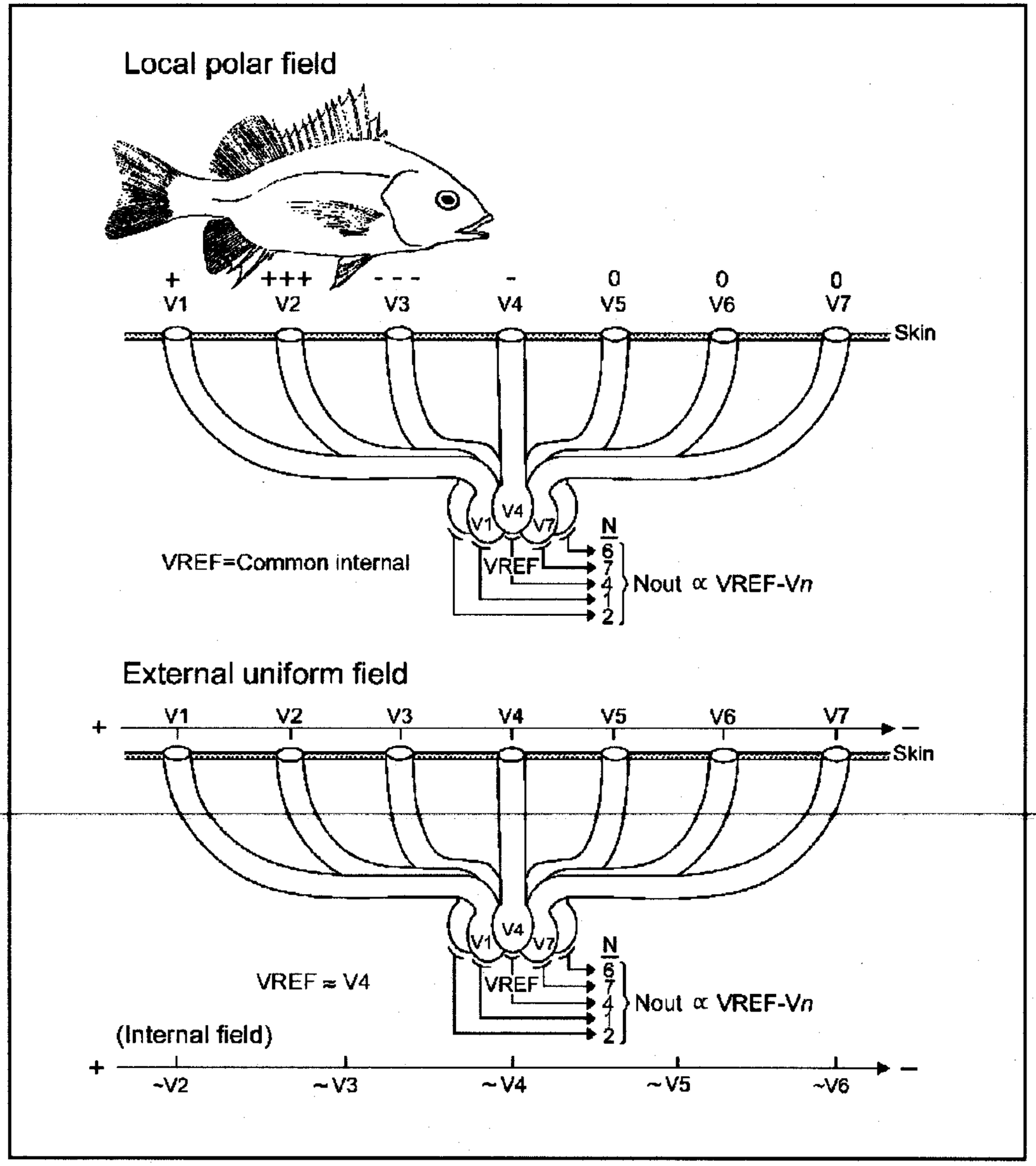




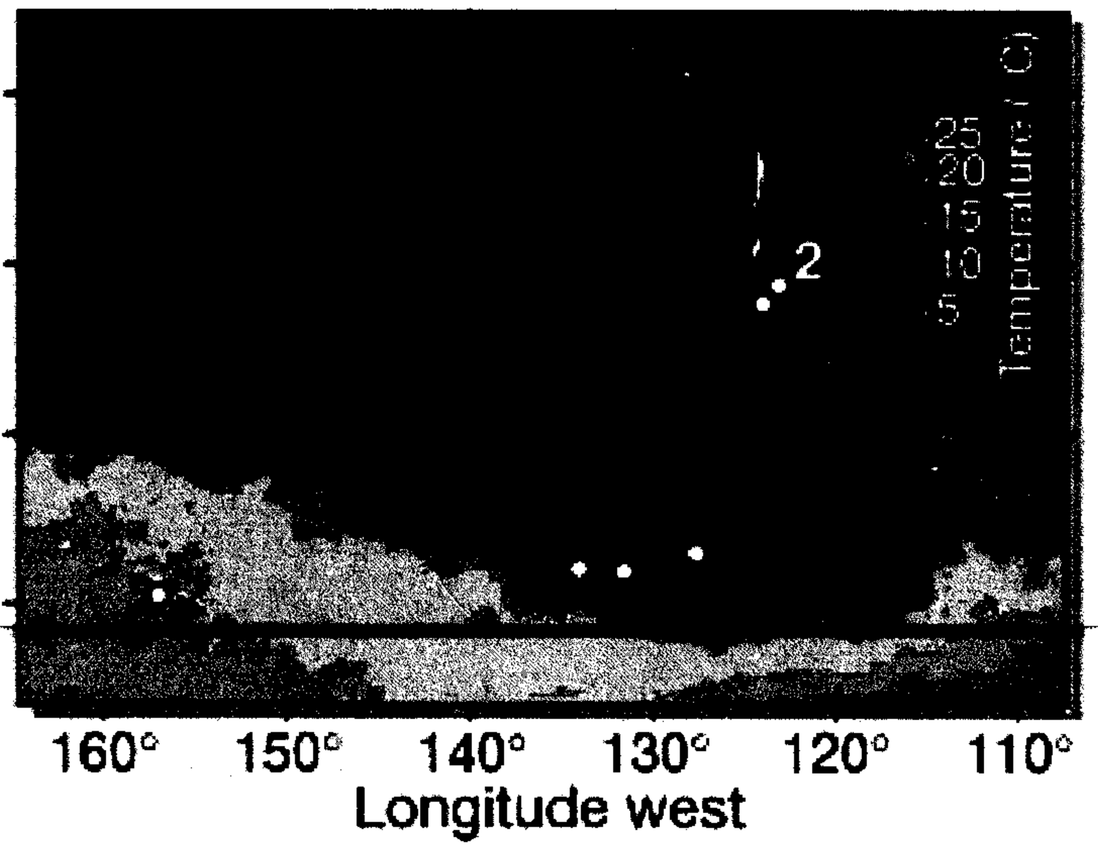
Bioelectric fields have been measured in related elastobranch species (Rays & Skates) and have been shown to have been used for sensory cueing and localization.

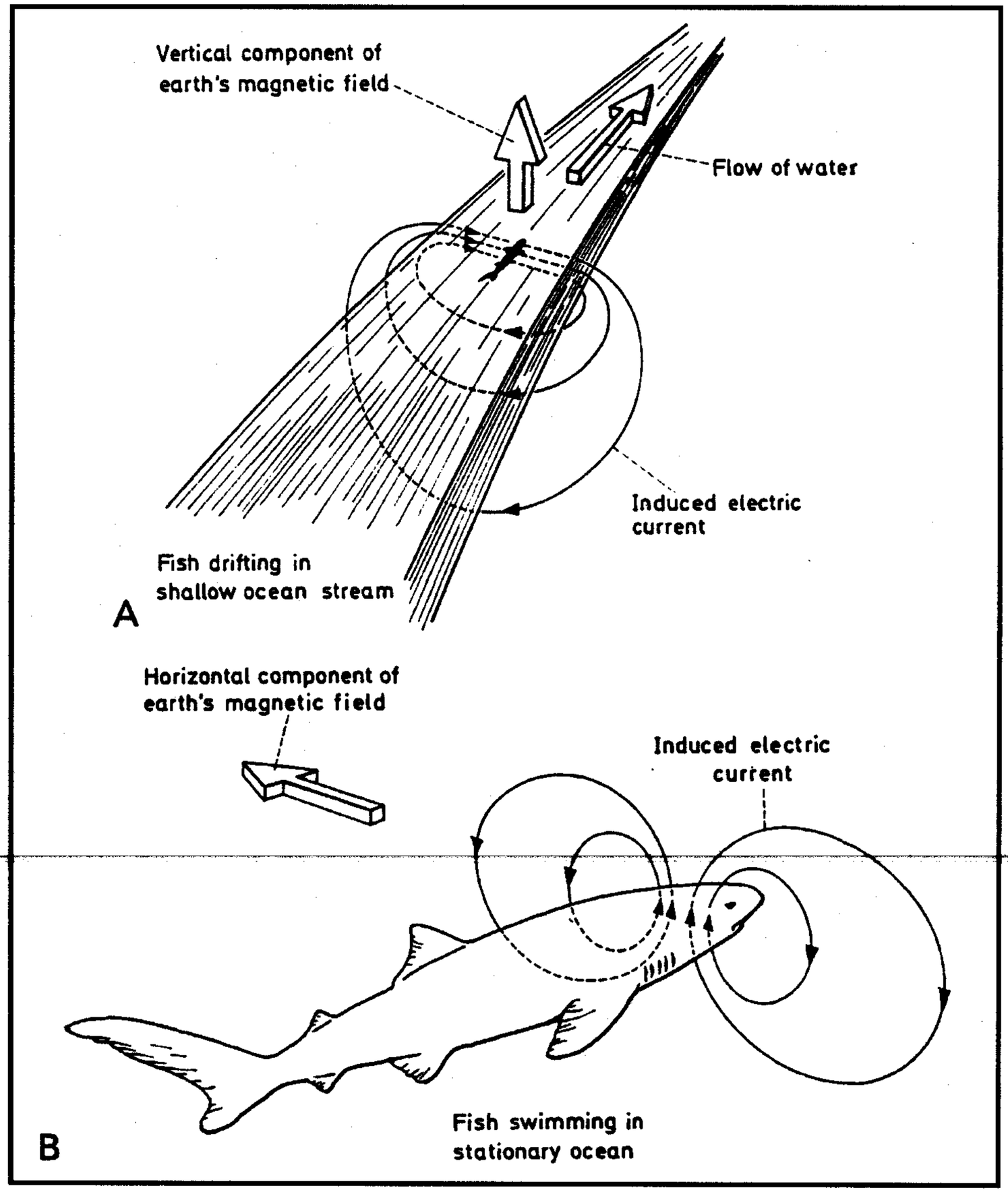
Elasmobranch & Bony Fish Electroreceptors

- **Detect weak external fields**
  - **Sharks < 1 to 5 nV/cm**
  - **Catfish 10 nV/cm**
- **Dipole or uniform fields**
- **Sensitivity ∝ canal length**
- **Somatotopically mapped**



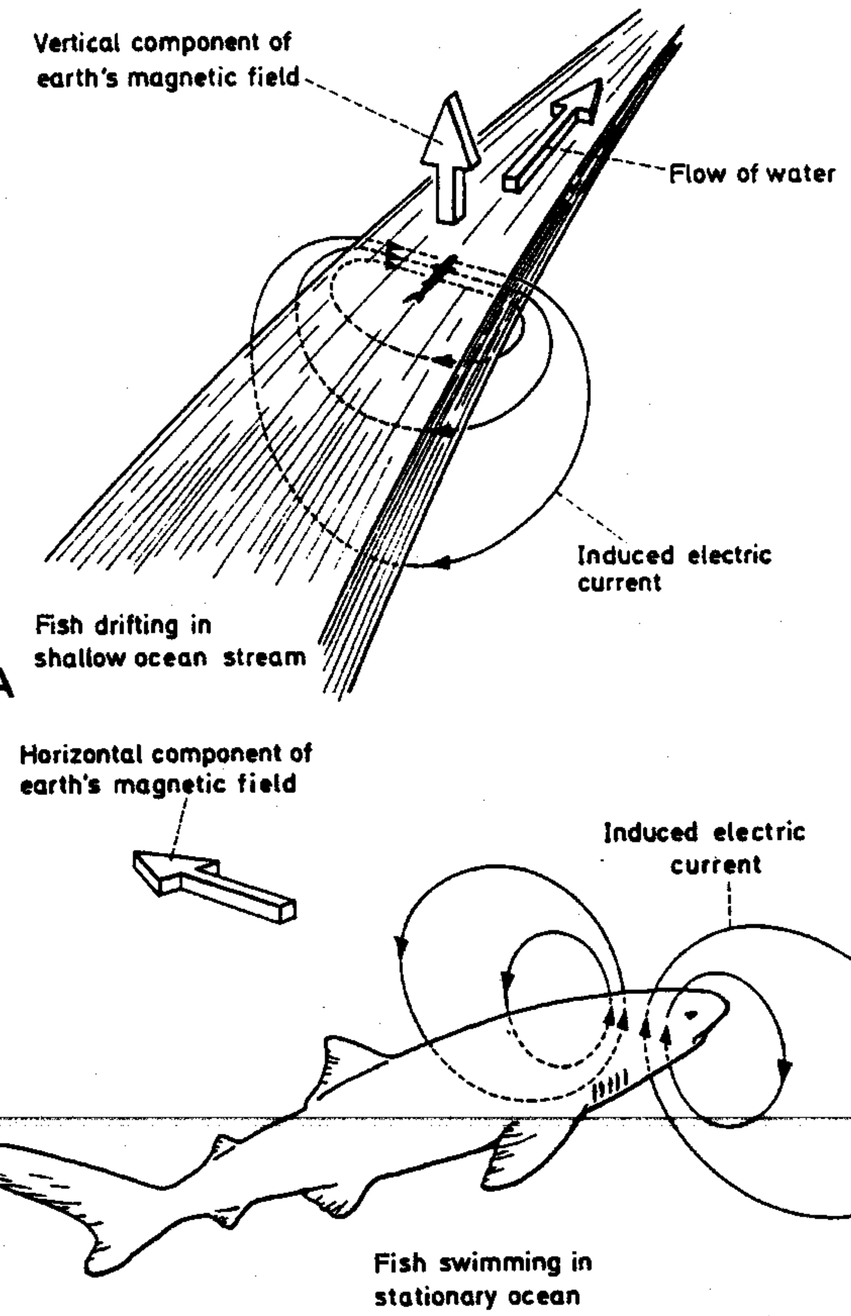
Theories of Geomagnetic Induction



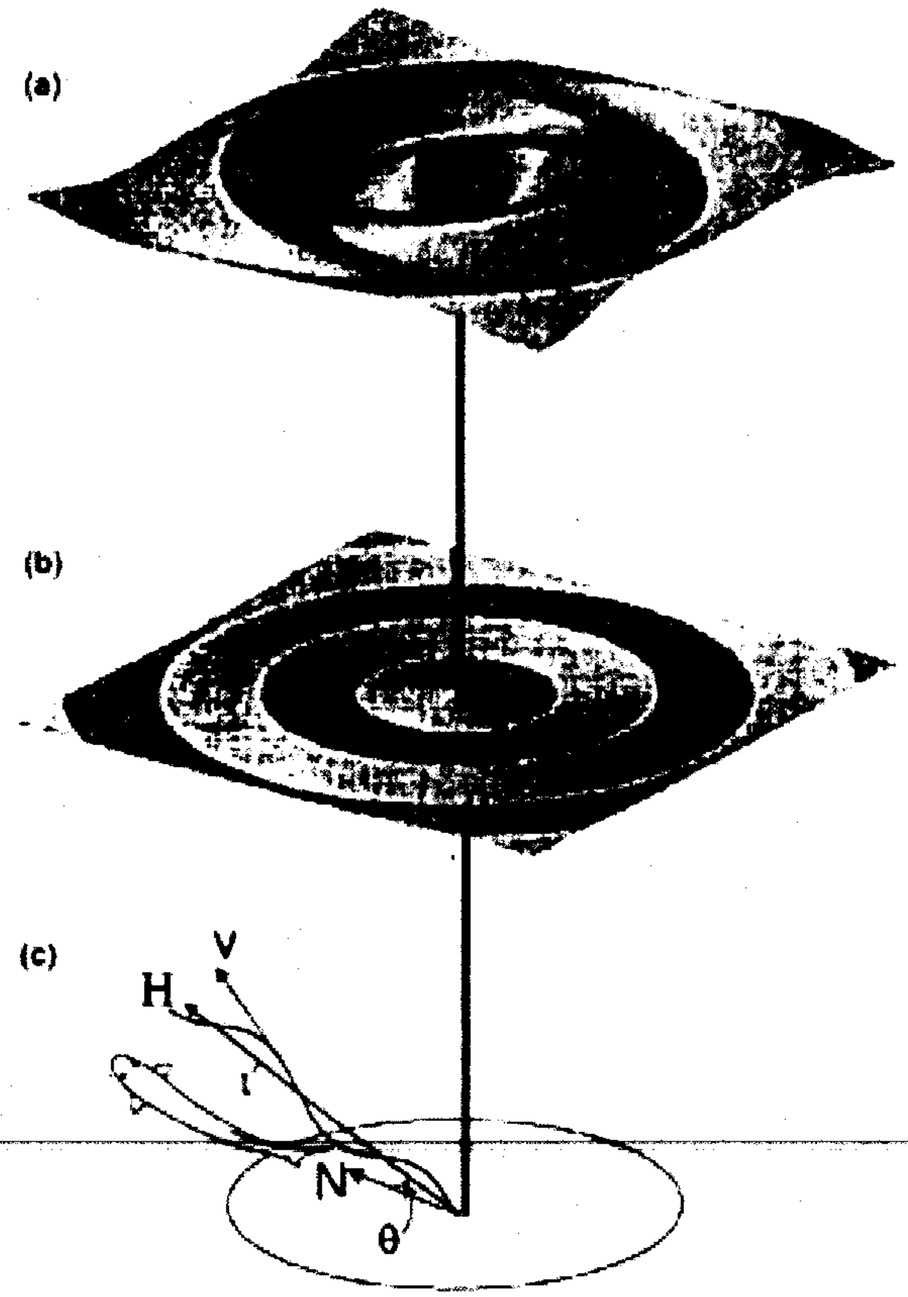


Kalmijn 1974

Sharks may use geomagnetic induction of electric signals for navigation

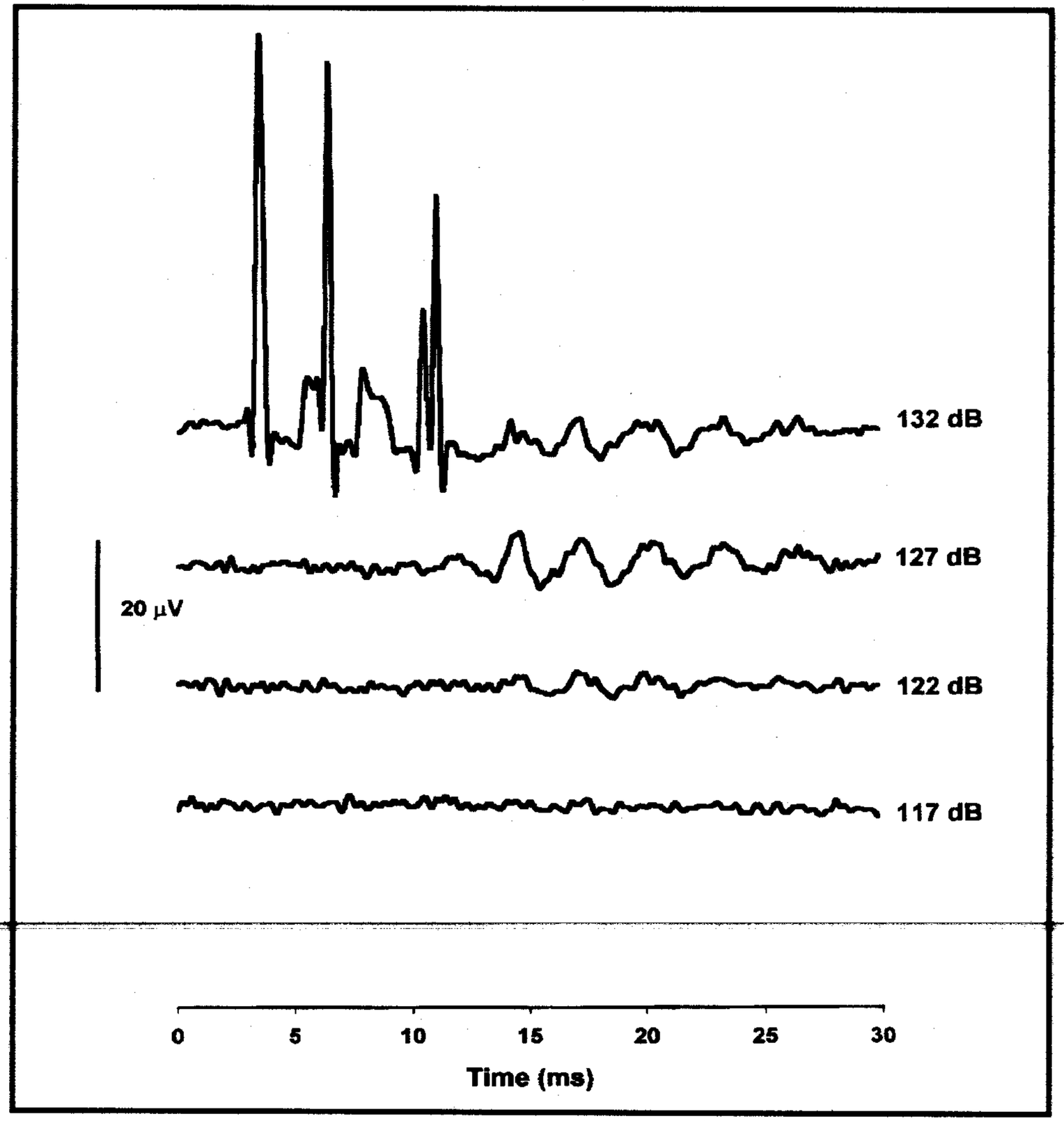


Kalmijn 1974



Paulin 1995

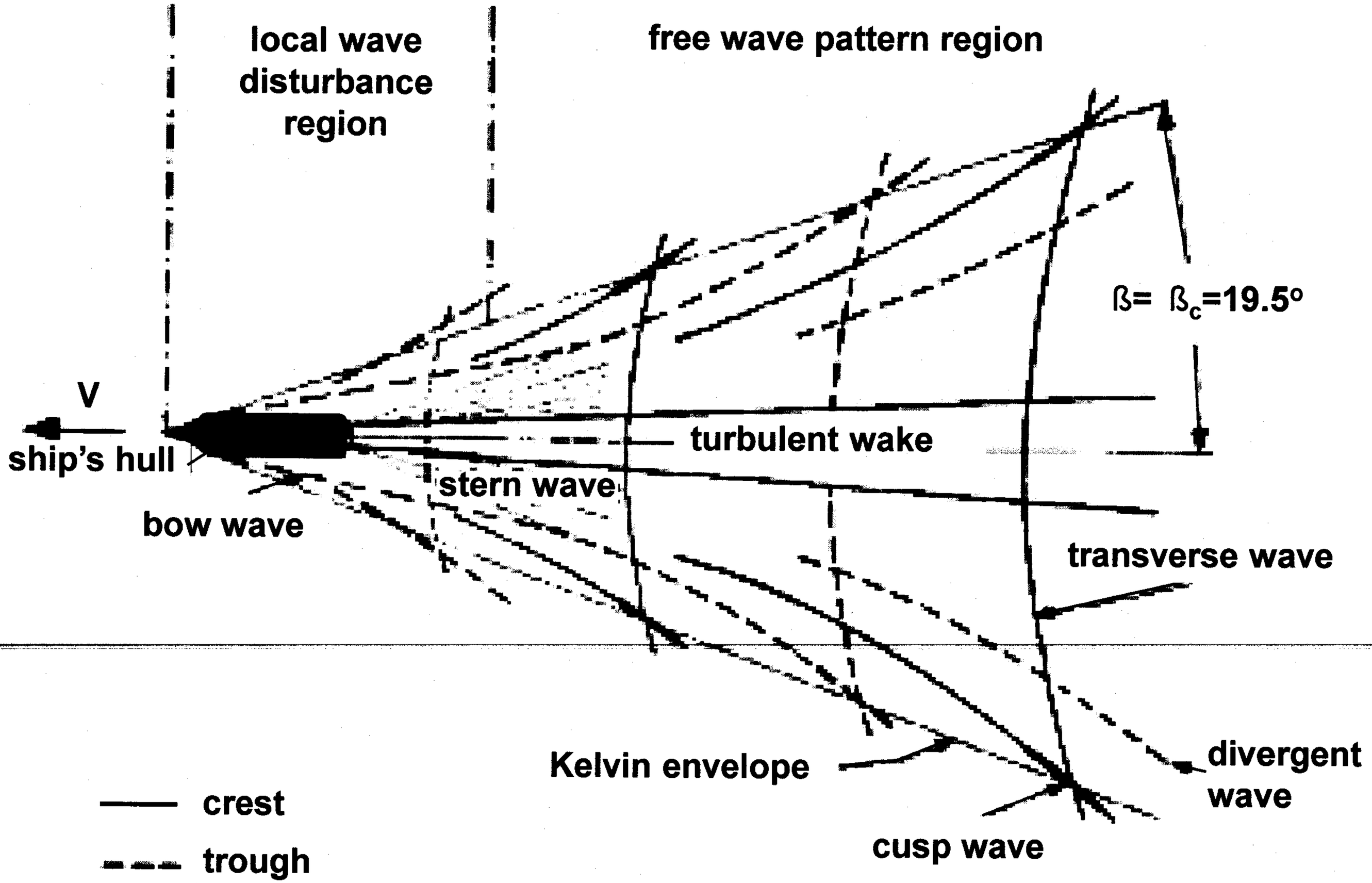
Example of Direct Readout from The auditory nerve of a small skate



ABR is an electrophysiological method that records evoked potentials generated along the auditory pathways in the brainstem of a fish in response to sound stimuli.

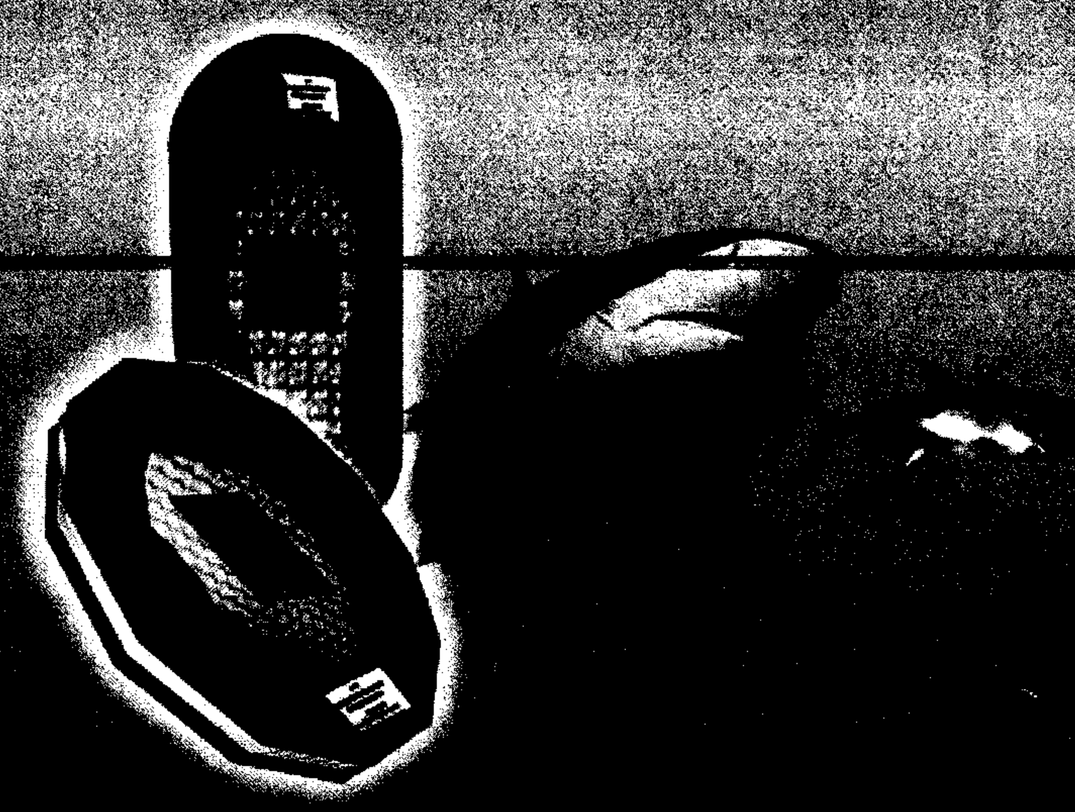
Kenyon et al. (1998) established the use of the auditory brainstem response (ABR) method for testing hearing sensitivity in fishes and it has been used to obtain audiograms for a variety of species (Ladich & Yan 1998, Yan 1998, Ladich 1999, Yan & Curtsinger 2000, Yan et al. 2000, Mann et al. 2001, Scholik & Yan 2001).

Example of ABR waveforms obtained from the skate, *R. erinacea* at 200 Hz. As the intensity of the sound stimulus decreases, the voltage output obtained from the auditory nerve decreases until 117 dB re 1 μPa where a repeatable ABR signal cannot be obtained. Therefore, 122 dB re 1 μPa is the lower hearing threshold. The sharp peaks from 0-13 ms at 132 dB are artifacts due to the suprathreshold intensity of the sound stimulus being played. *from Brandon, Lobel & Yan in press*

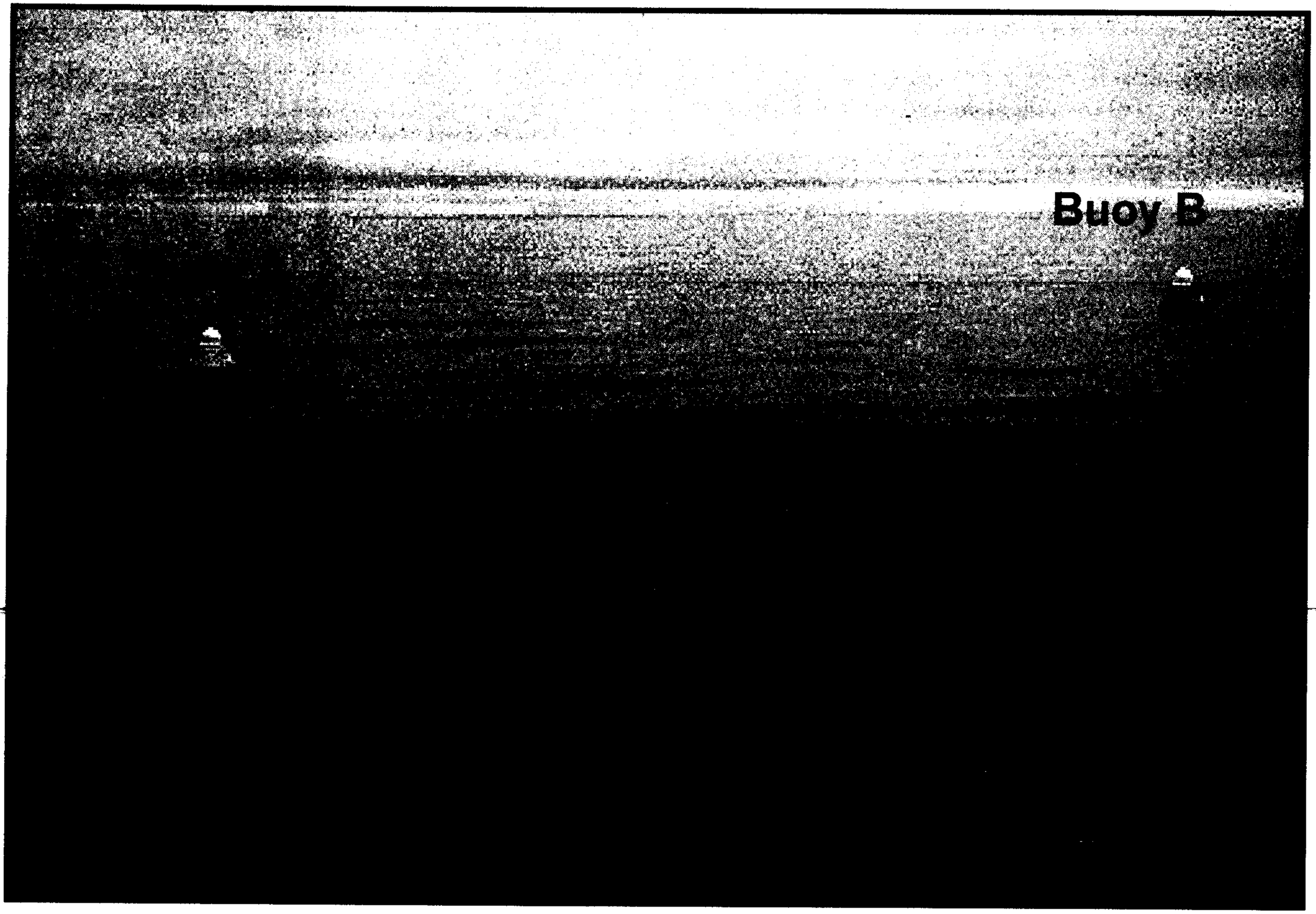

local wave disturbance region
free wave pattern region
ß= ß$_c$=19.5°
V
ship's hull
bow wave
stern wave
turbulent wake
transverse wave
Kelvin envelope
divergent wave
cusp wave
crest
trough

DARPA

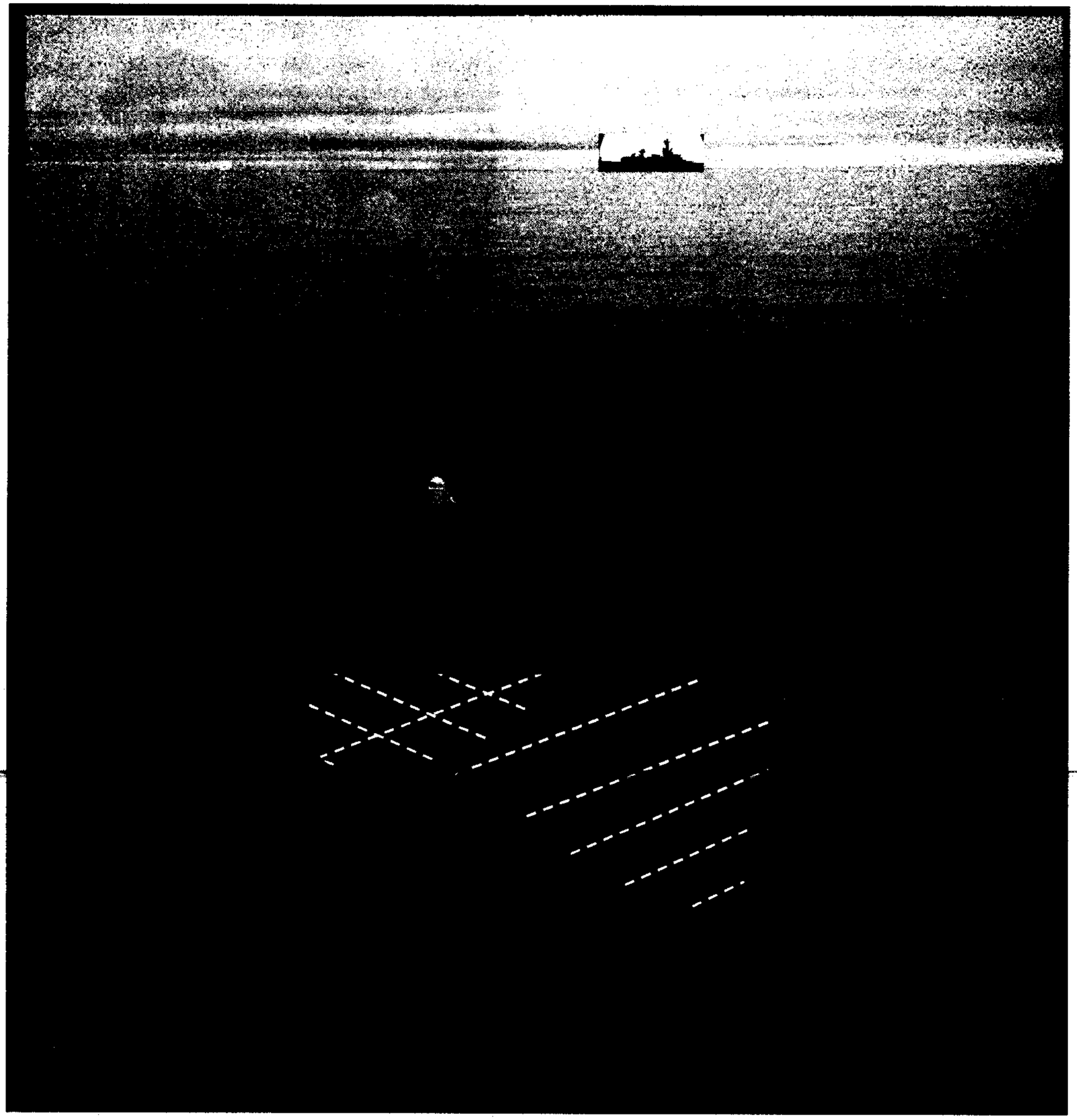
Advanced Tec[illegible]nce



Sharks provide: TOA_A, TOA_B, Temp, Depth, & Light.



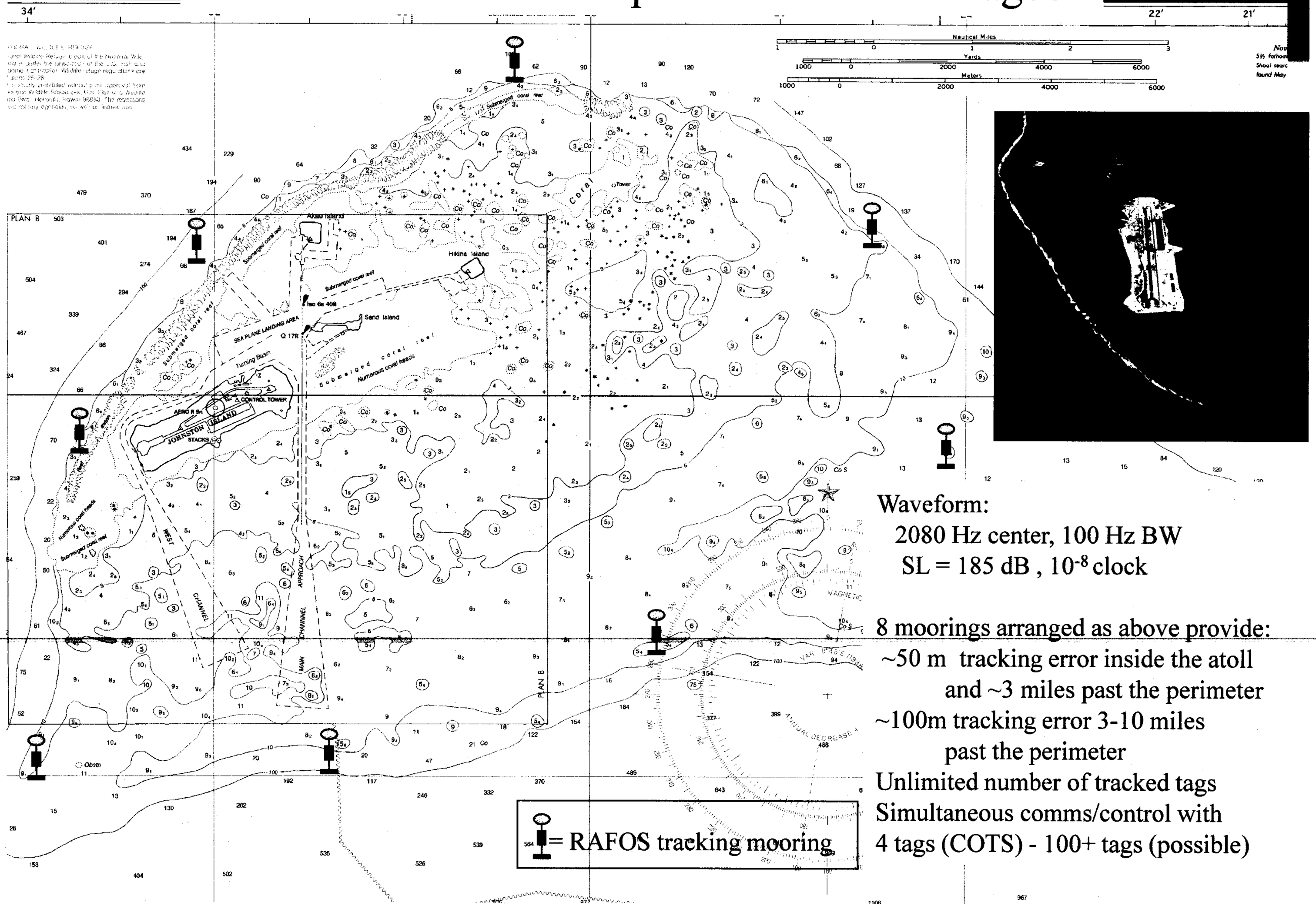
Acoustic Communications (ACOMMS) Tag



High Data Rate Acoustic Communications Download

Micropower acoustic transmitter may allow 1 Mbit data transfer @ 1 Joule IFF a fish can be coaxed to within 10 m of deployed reader.

Littoral/small scale example: Johnston Atoll lagoon



Waveform:
2080 Hz center, 100 Hz BW
SL = 185 dB , 10^{-8} clock

8 moorings arranged as above provide:
~50 m tracking error inside the atoll
and ~3 miles past the perimeter
~100m tracking error 3-10 miles
past the perimeter
Unlimited number of tracked tags
Simultaneous comms/control with
4 tags (COTS) - 100+ tags (possible)