Size matters: Scaling of processes and implications for climate change (adaptations, senses, temperature, oxygen)

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Visibility : Light camouflage in the deep-sea

- Cryptic colouration : Red absorbs the blue light best
- Silvering: for opaque bodies - guanine plates
- Transparency
- Counter-illumination
- Being black

Marranzino, A. N. 2018. Flow sensing in the deep sea: The lateral line system of stomiiform fishes. Zoological Journal of the Linnean Society, 183: 945–965.

Bird, N. C., and Webb, J. F. 2014. Heterochrony, modularity, and the functional evolution of the mechanosensory lateral line canal system of fishes. EvoDevo, 5: 1–22.

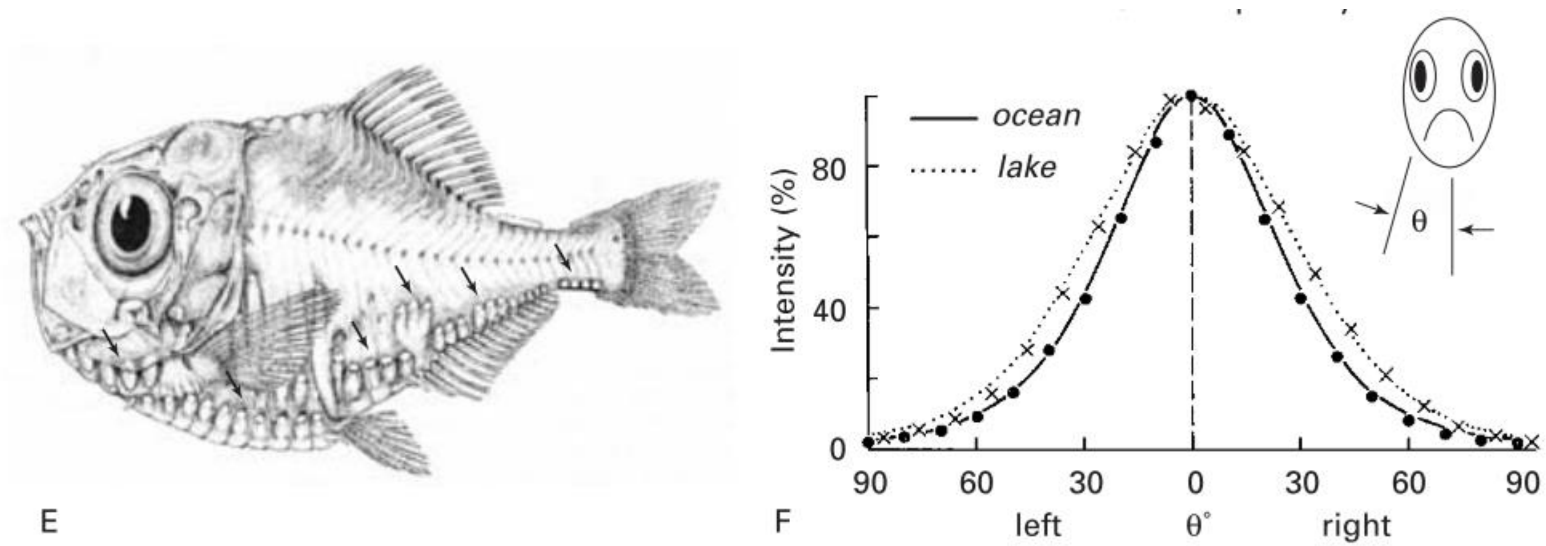
Marshall, N. J. 1996. The lateral line systems of three deep-sea fish. Journal of Fish Biology, 49: 239–258.

Davis, A. L., Thomas, K. N., Goetz, F. E., Robison, B. H., and Osborn, K. J. 2020. Report Ultra-black Camouflage in Deep-Sea Fishes Report Ultra-black Camouflage in Deep-Sea Fishes. Current Biology, 30: 1–7.

Warrant, E. J., and Locket, N. A. 2004. Vision in the deep sea. Biological reviews of the Cambridge Philosophical Society, 79: 671–712. http://www.ncbi.nlm.nih.gov/pubmed/15366767.

Cavallaro, M., Battaglia, P., Guerrera, M. C., Abbate, F., Levanti, M. B., Ammendolia, G., Andaloro, F., *et al.* 2019. Structure and ultrastructure study on photophores of the Madeira lanternfish, Ceratoscopelus maderensis (Lowe, 1839), Pisces: Myctophidae. Acta Zoologica, 100: 89–95.

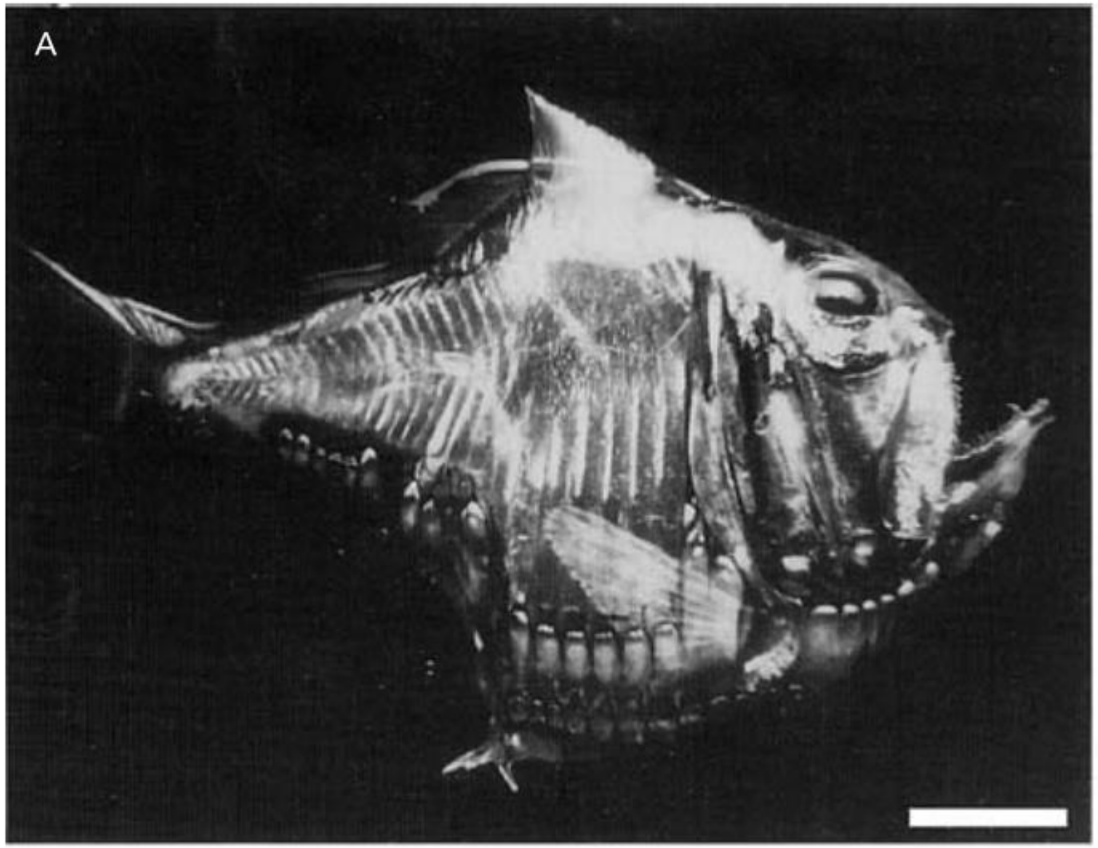
Stomiiform fishes

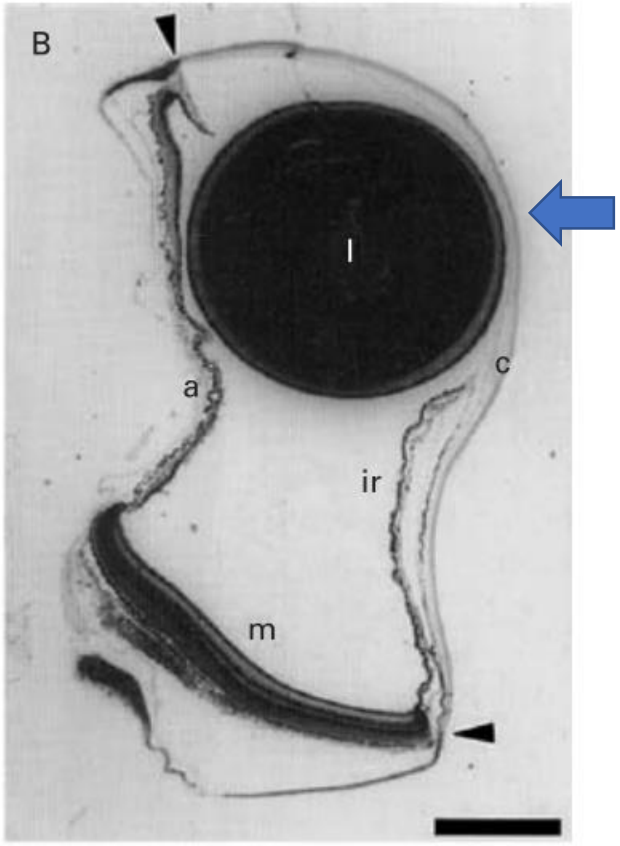


(E) The hatchet fish Polyipnus laternatus (approximately 40 mm long), showing the batteries of photophores along its ventral surface (arrows). Drawing from Marshall (1979). (F) The relative intensity of counter-illumination at different lateral angles (h), relative to the downward vertical direction (h=0x), for two mesopelagic fishes: the viper fish Chauliodus sloani (r) and the hatchet fish Argyropelecus affinis ($). The angular distribution of counter-illumination is remarkably similar to that found in the ocean (solid line) and in Lake Pend Oreille (dotted line), and thus provides excellent camouflage. Adapted from Denton et al. (1972).

Hatchetfish retina between black arrows – two regions : Hunting (m) and light correction (a)

Control photophor





Myctophidae

The innervation of the lens-scale

of *C. maderensis* and the other structures having a neurotransmitter function are probably implicated in the regulation of intensity and direction of light emission as well in playing a role in the counterillumination camouflage in the mesopelagic environment.

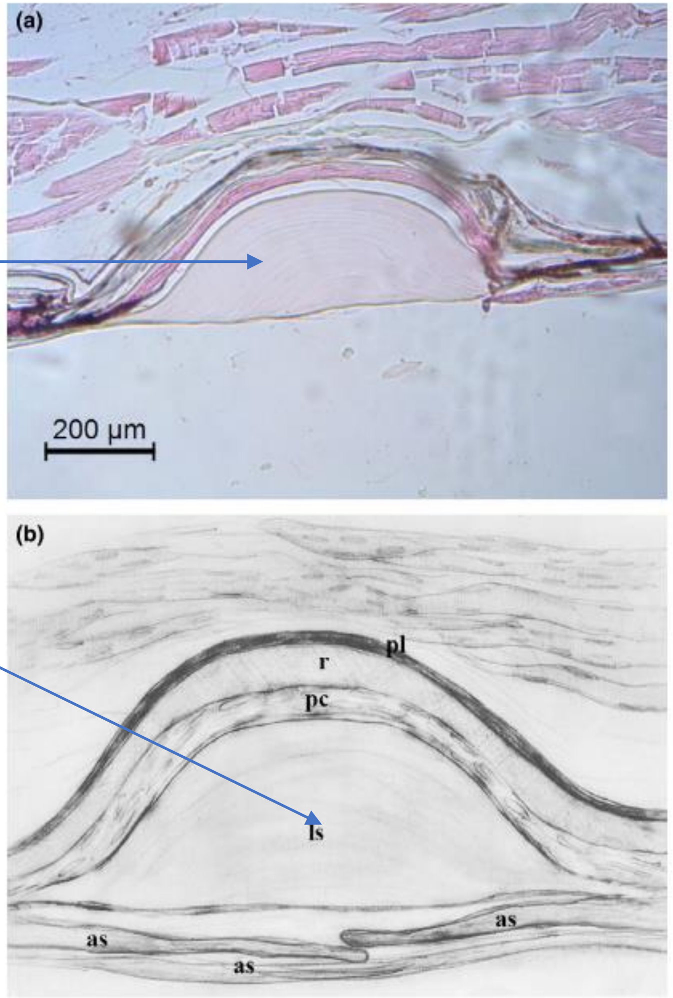
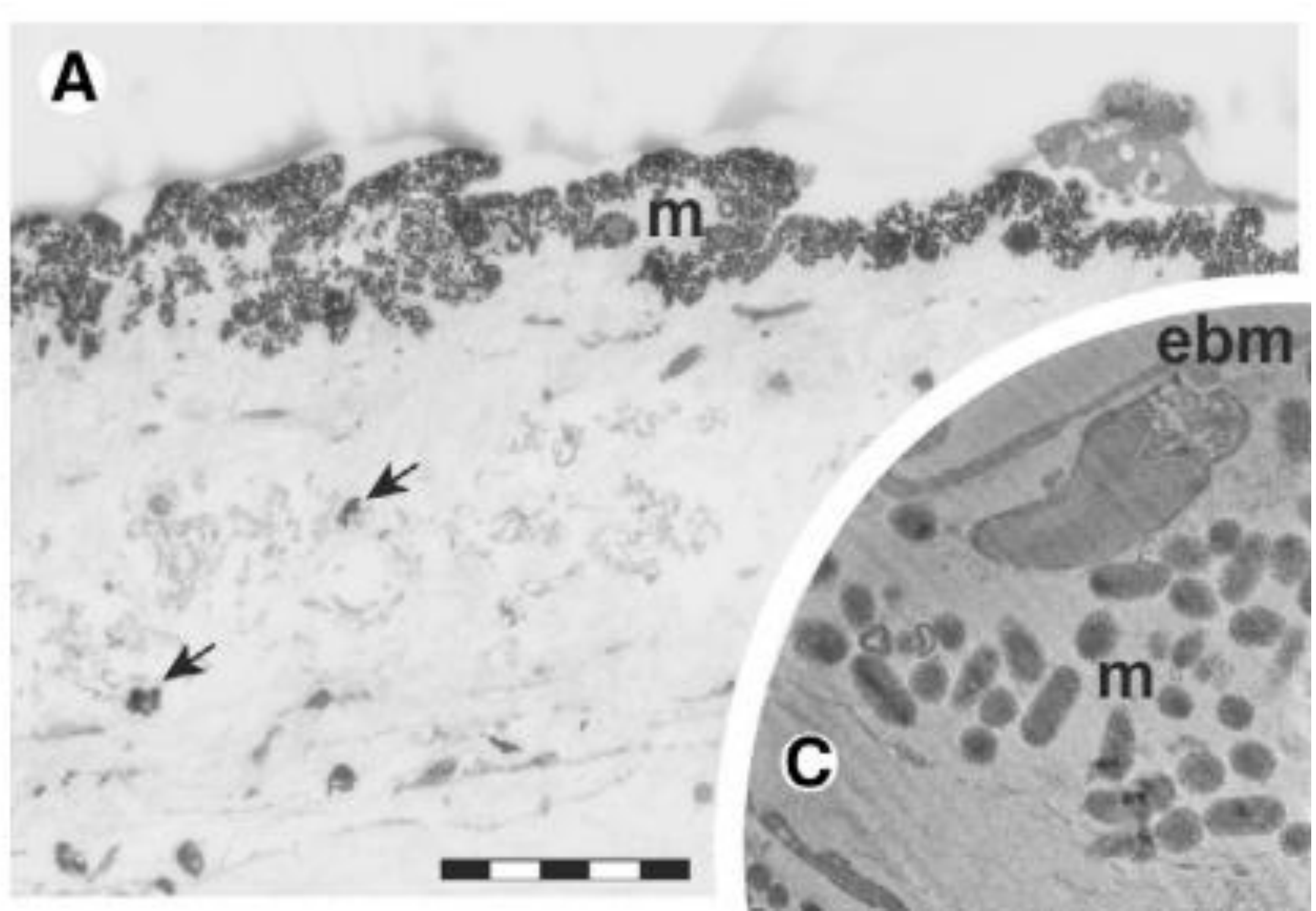
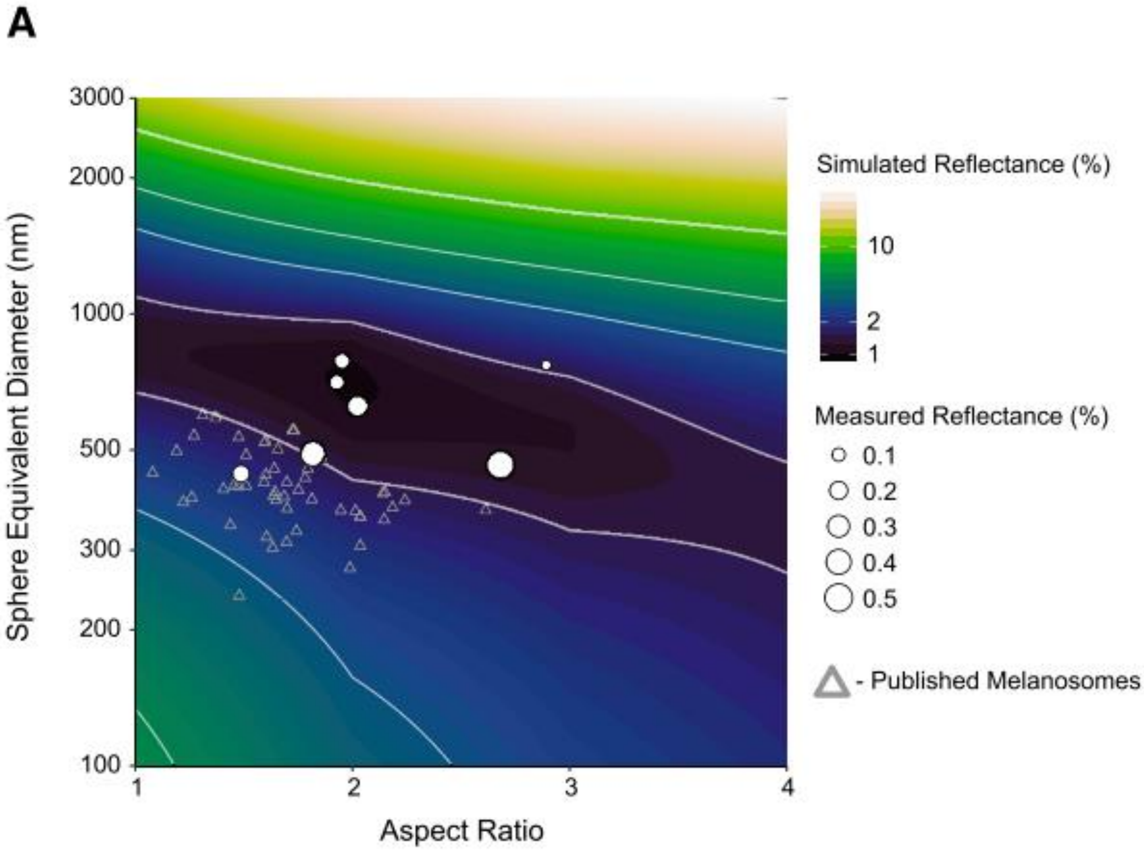


FIGURE 1 Structure of the photophore of *Ceratoscopelus maderensis*. Figure 1a. Structure of the photophore observed by light microscope. Figure 1b. Scheme of the photophore showing the different functional parts: (pc) photogenic cells, (ls) lens-scale, (as) accessory scales, (r) reflector and (pl) pigmented layer [Colour figure can be viewed at wileyonlinelibrary.com]

Ultra-dark fish : Among the darkest animals on Earth

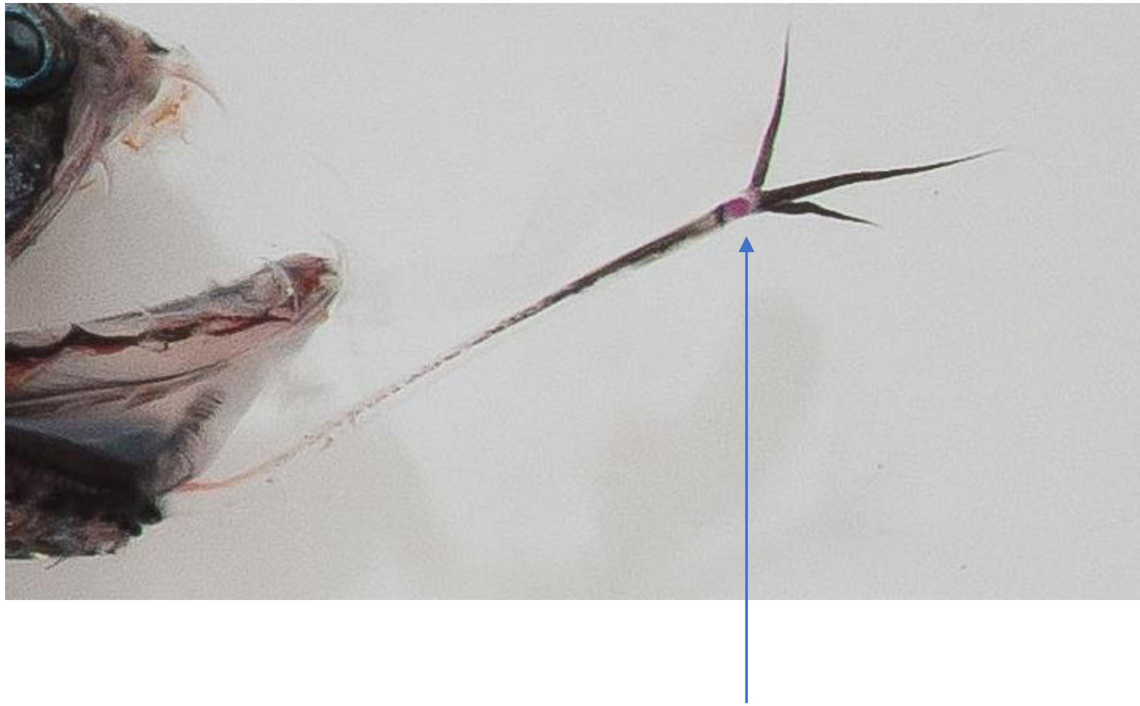
Layer of melanosomes under cuticula (m), size and shape ideal to absorb light





Stomias boa : Flashes for mating

Visibility of flashes for mating: Why eyes still need to be of a certain size!



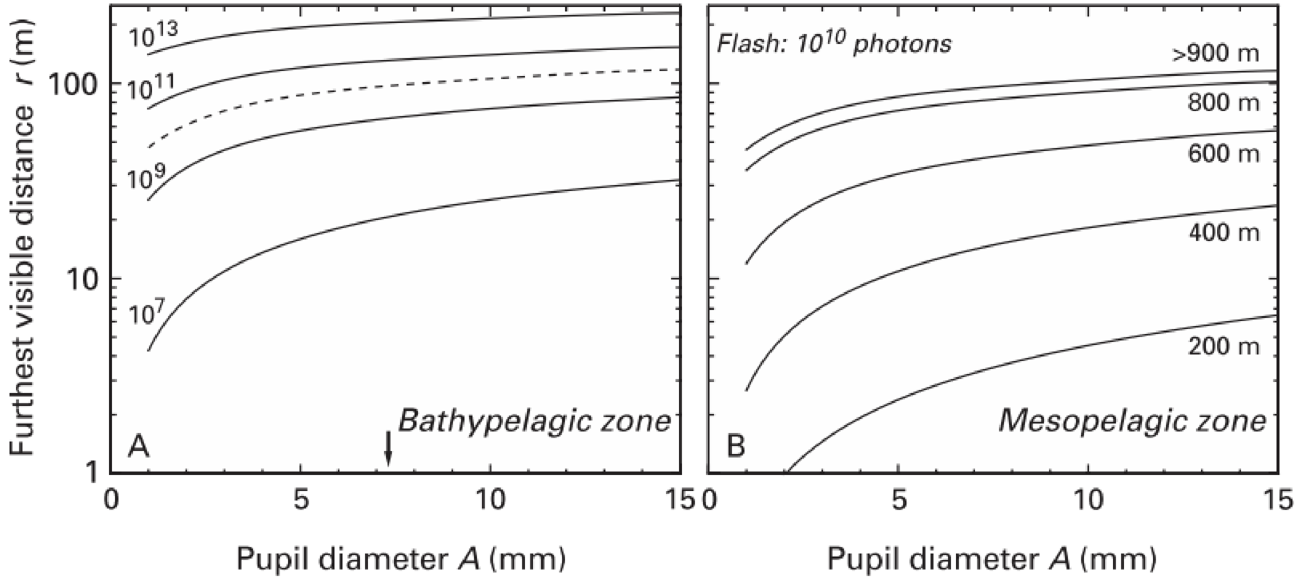


Fig. 3. The visibility of bioluminescent point sources in the ocean for fishes of pupil diameter *A*. The furthest distance *r* that a fish can see a given point source is plotted as a function of *A*. (A) Visibility in the bathypelagic zone for flashes of different intensities (solid lines, 10^7–10^{13} photons; dashed line, 10^{10} photons, an average intensity). The arrow marks an average bathypelagic pupil diameter of 7.3 mm. (B) Visibility against background light at different depths in the mesopelagic zone (200 to >900 m) for a 1 s flash containing 10^{10} photons.

The lateral line organ

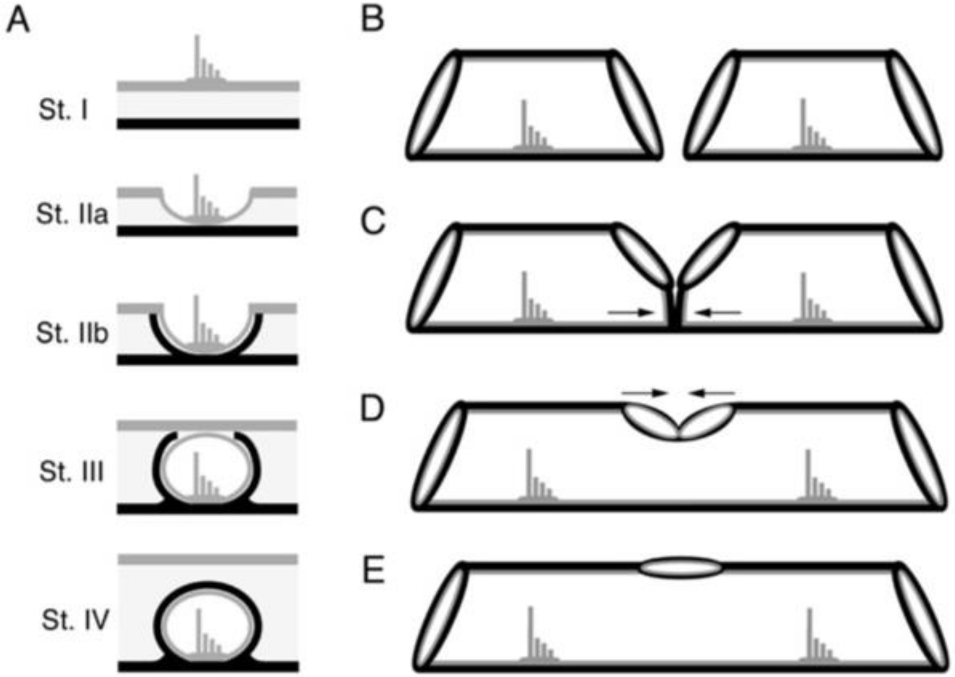
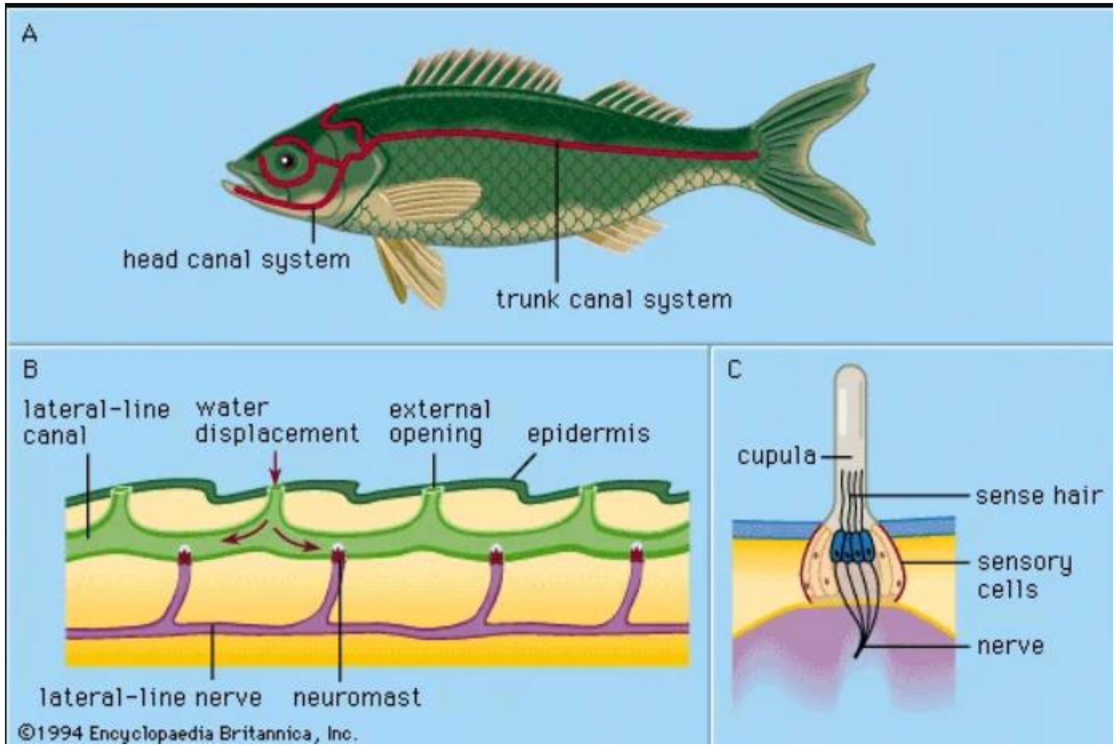


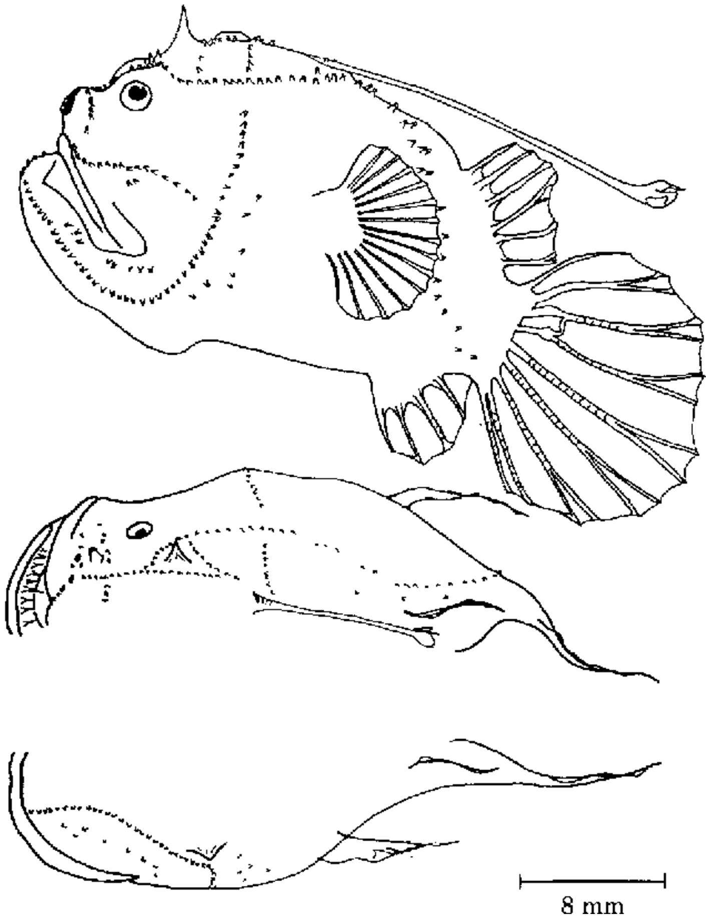
Figure 2 Neuromast-centered canal morphogenesis and fusion of adjacent canal segments. A) Stages of neuromast-centered canal morphogenesis (Stages I-IV [29,31]): Stage I – neuromast found in general epithelium, Stage IIa - neuromast sinks into depression, Stage IIb - neuromast in groove with ossified canal walls forming on either side of neuromast, Stage III - neuromast enclosed by soft tissue canal roof, Stage IV - neuromast enclosed in canal and canal roof ossified over neuromast. Canal morphogenesis continues with the gradual fusion of adjacent canal segments. Adjacent canal segments grow toward one another **(B)** and make contact **(C)**. The two adjacent segments fuse **(D)**, leaving a pore between them **(E)**, thus forming a continuous lateral line canal. Black = bone, Gray = general epithelium and neuromasts.

The canal system acts as filter and indicates the direction:

Large canals – low frequencies

Narrow canals – high frequencies





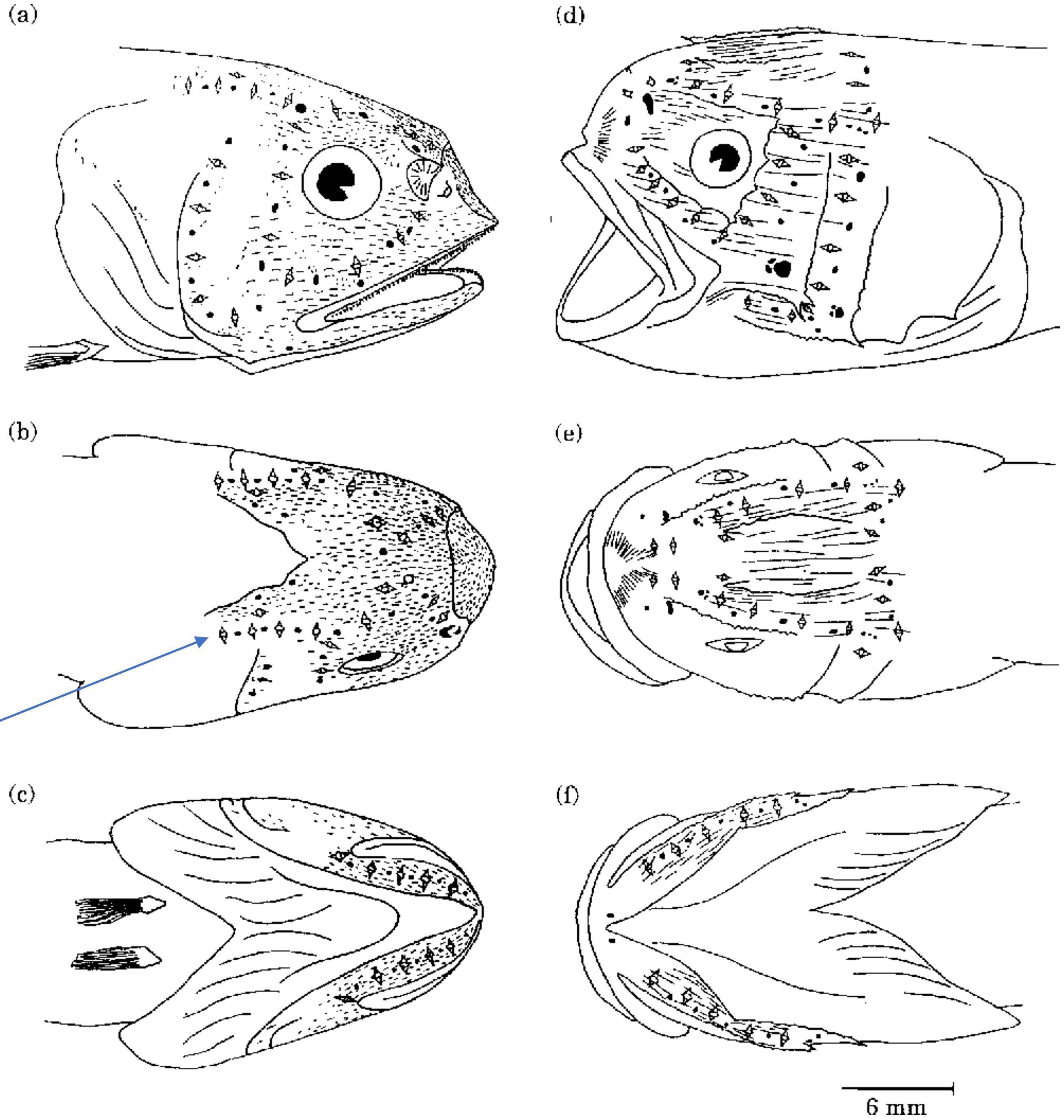
Primitive forms:

superficial neuromasts only

Some species expanded canal system on head:

Melanonus zugmayeri (left) and Melamphaidae (right)

Pores to canal system



In most deep-sea fishes both types present:

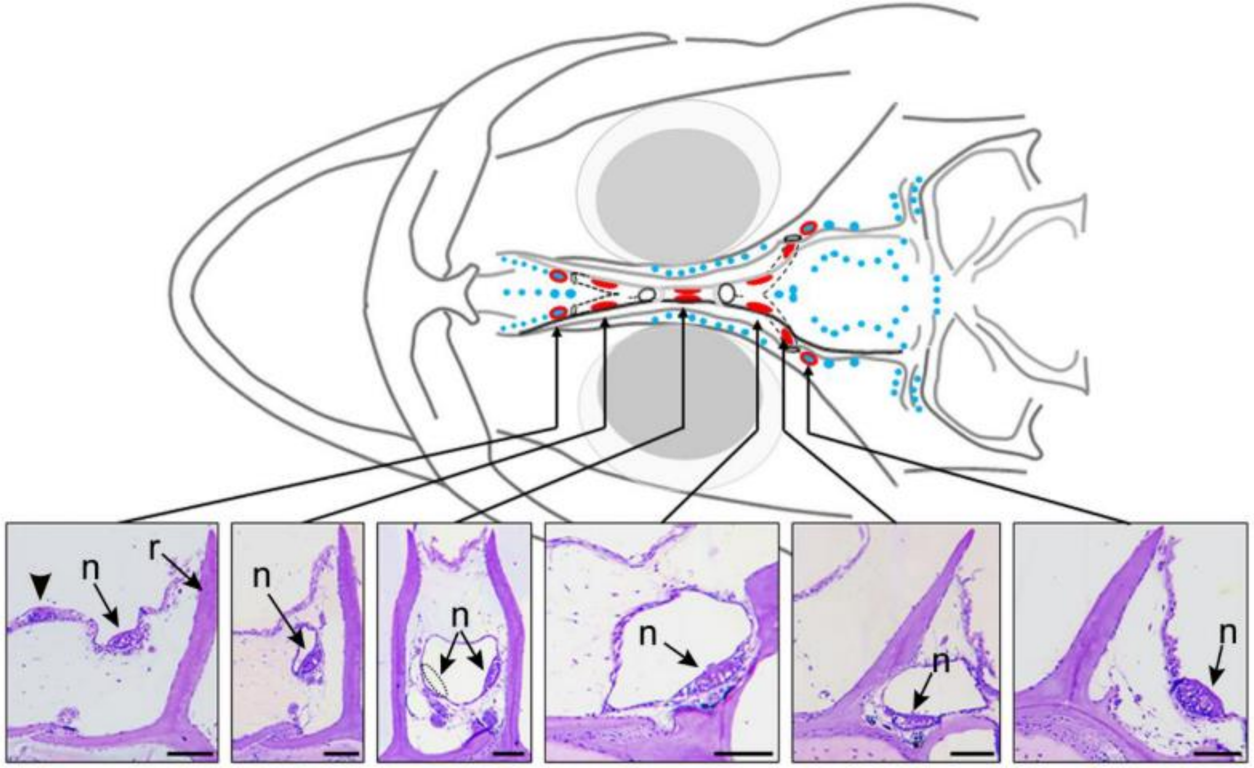
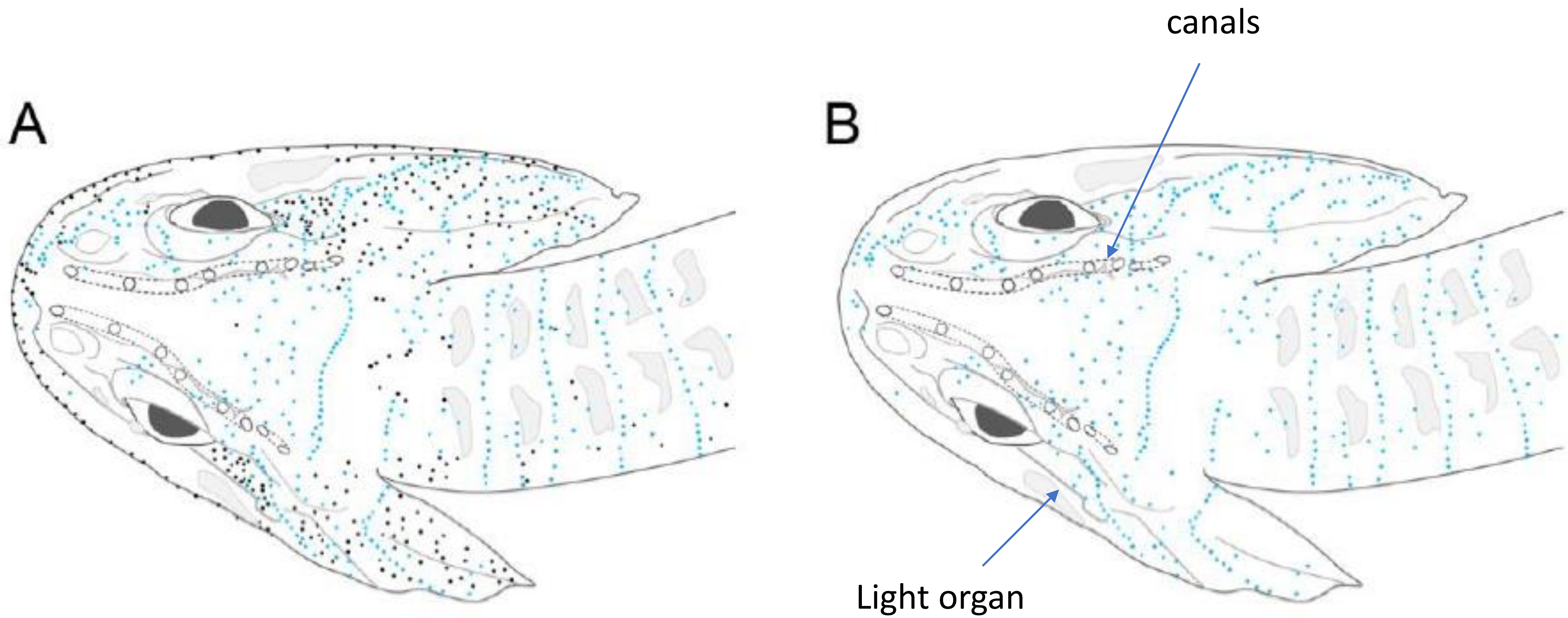


Figure 1.8: Supraorbital canal and neuromast morphology in *Argyropelecus aculeatus*. Line drawing (in dorsal view) derived from a 3-D µCT reconstruction of one specimen (MCZ 137835, size unknown). SO canal and superficial neuromast distributions based on histology (3 individuals) and examination of 11 whole specimens. Superficial neuromasts (blue), canal neuromasts (red), canal neuromast homologues on the skin surface (blue circles with red outline), canal boundaries (black dotted lines), canal pores (black open circles). Representative transverse histological sections of (MCZ 159086, 39 mm SL specimen) at the level of each neuromast (n) from left to right (= rostral to caudal) showing the canal moving from the medial to the lateral side of a bony ridge (r). n = SO canal neuromasts, black arrowhead = superficial neuromasts. Scales = 100 µm.

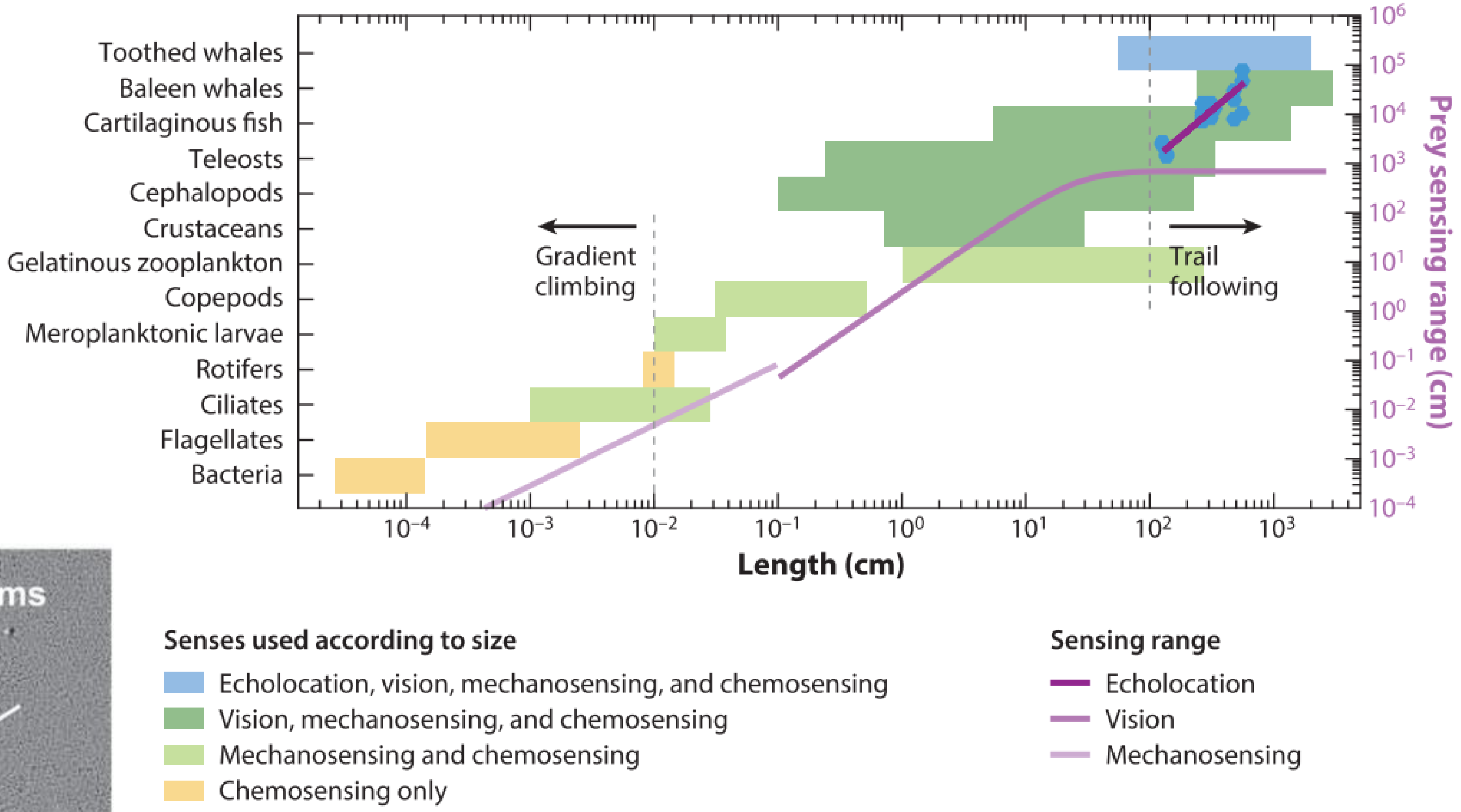


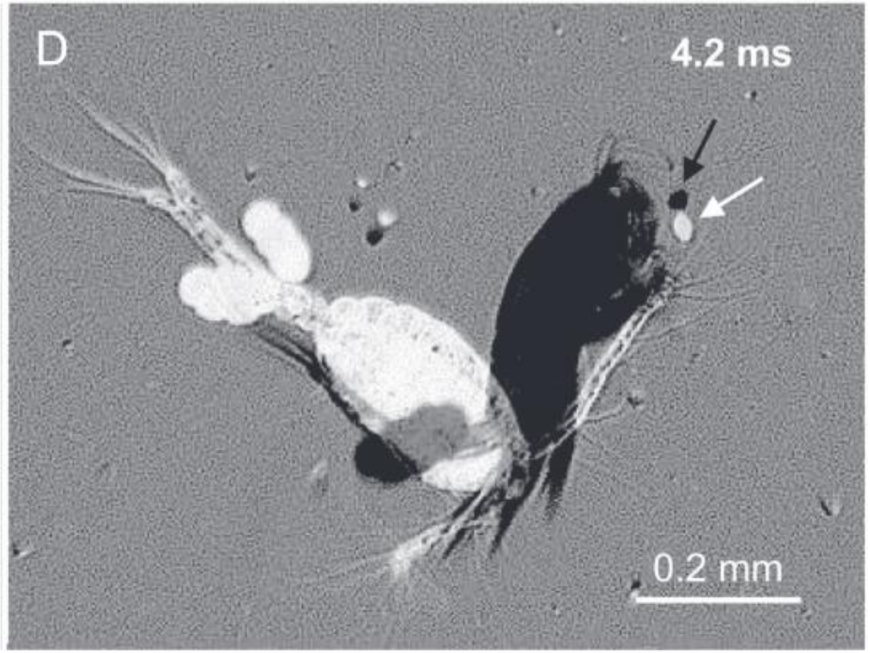
Canal, neuromast and photophore distribution in *Idiacanthus antrostomus* (Stomiidae: Stomiiformes). A-B) Dorsal view of *I. antrostomus* showing superficial neuromasts (blue dots), and likely locations of lateral line canals (black dotted lines) based on location of canal pores in the epithelium (open black circles). Prominent luminescent organs = light grey and photophores = closed black circles.

Scaling of senses

Blind copepods, ambush predators

Shear stress on the surface is measured through sensory hairs,
Limit set by sensitivity to measure turbulent shear stress at U*=33 µm/s
i.e. for animals in viscous environments of size 500 - 1000 µm



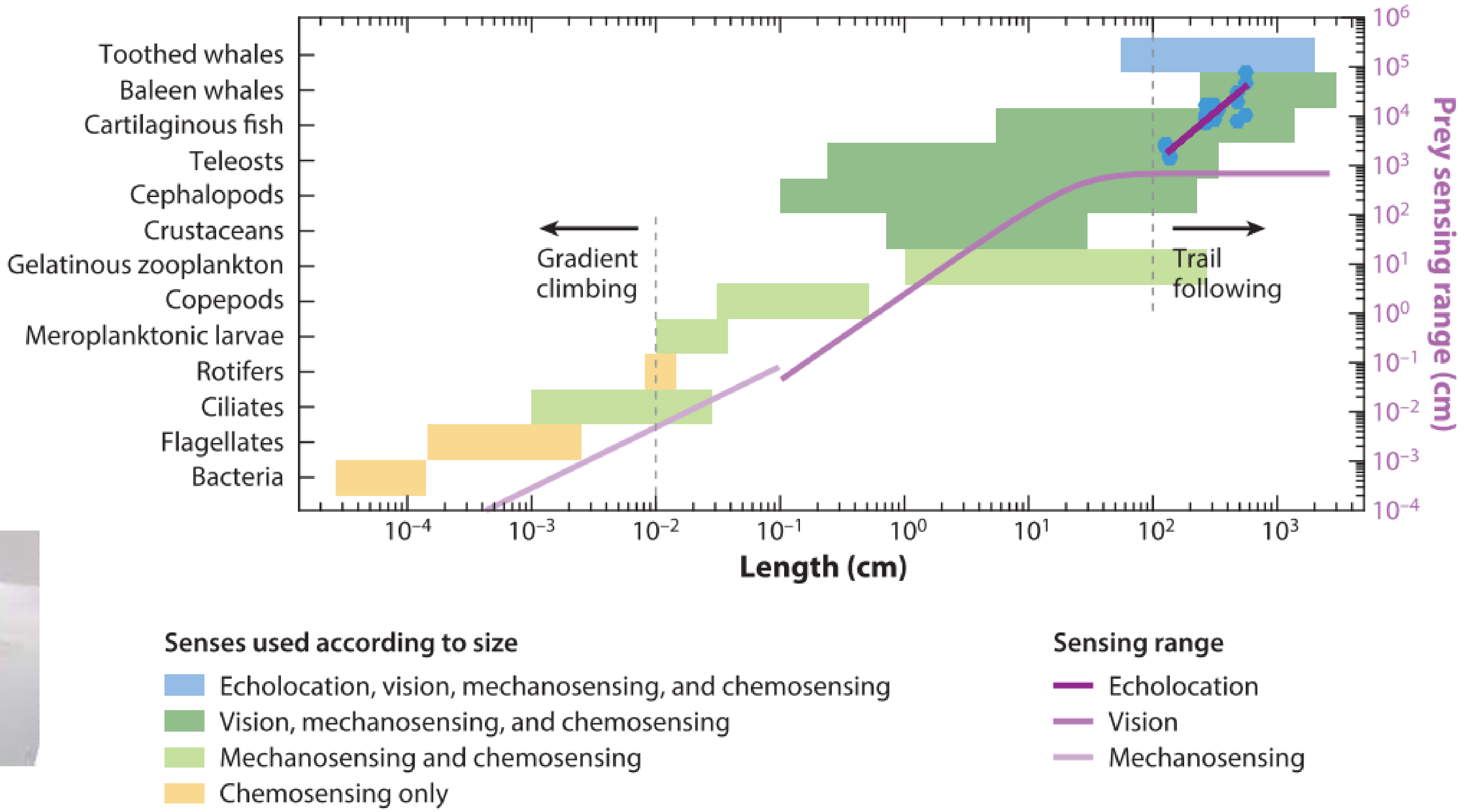


Svetlichny L et al. Fluids. 2020;5. doi:10.3390/fluids502
Kiørboe T et al. PNAS. 2009. pp. 12394–12399.
Andersen KH et al. Ann Rev Mar Sci. 2016;8: 217–241.

Scaling of senses

Fish larvae, visual predators

For sufficient image formation of (for example) 100^2 results in a retina size of $d_r \approx$ 0.1 mm. This is approximately one-tenth the size of the smallest aquatic organisms with camera eyes: larval fish and cephalopods. Were fish larvae smaller, they would not have well functioning eyes and be outcompeted by copepods.



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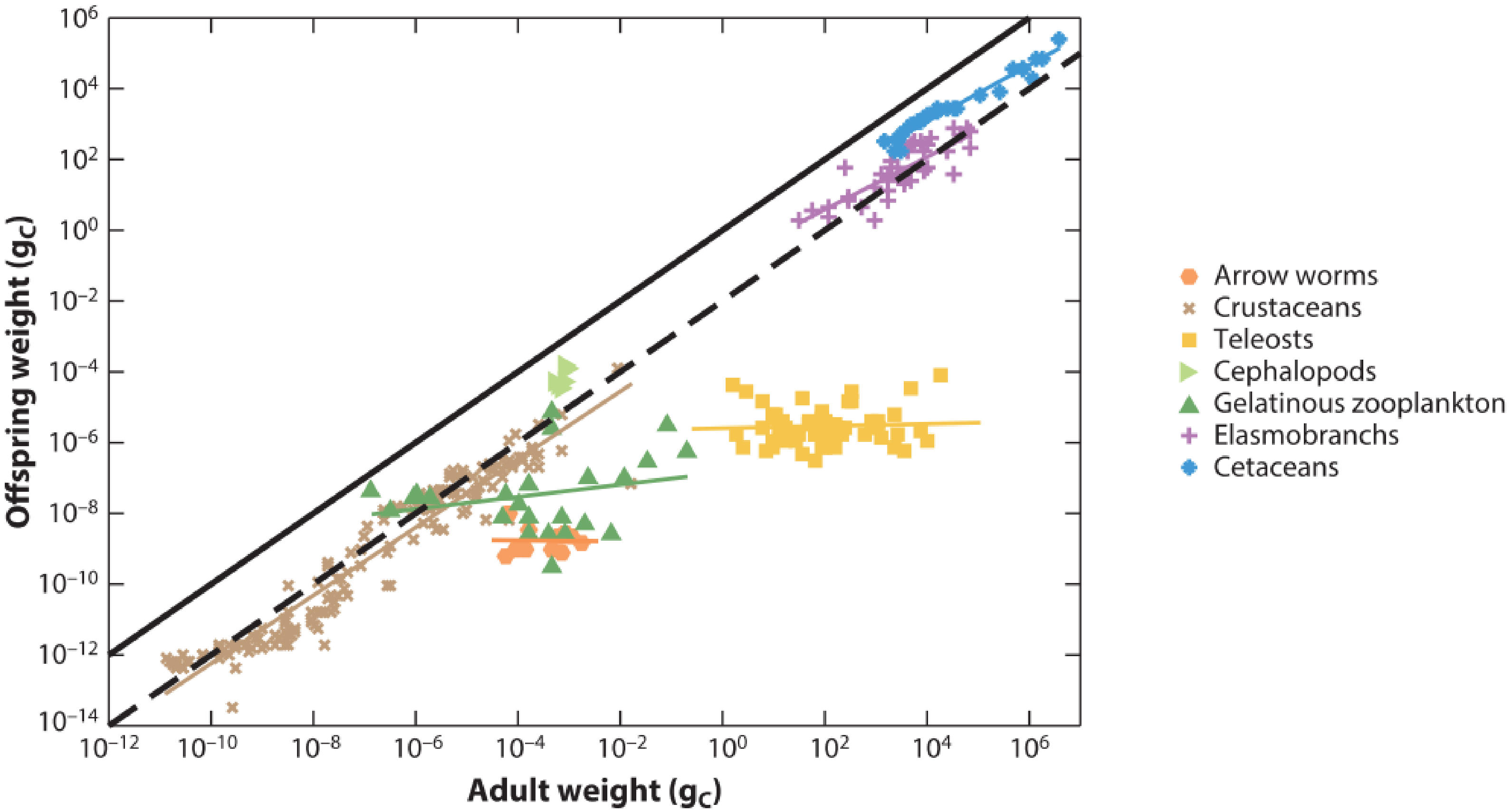
Scaling of offspring size

Fish take their chances

A fixed ratio of 1:100 in offspring size is sufficient in terms of density dependent regulation of offspring survival.

Fish exceed by far and try to generate high numbers of offspring that they spawn often at multiple times to increase their chances to built of larger stocks.



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Scaling in relation to deminshing oxygen supplies

Fish shrink

Fish have a certain maintenenace metabolism to obtain all functions.

(1) If demand is rising , body mass must become smaller.

(2) If oxygen supply is decreasing, but mass must also decline

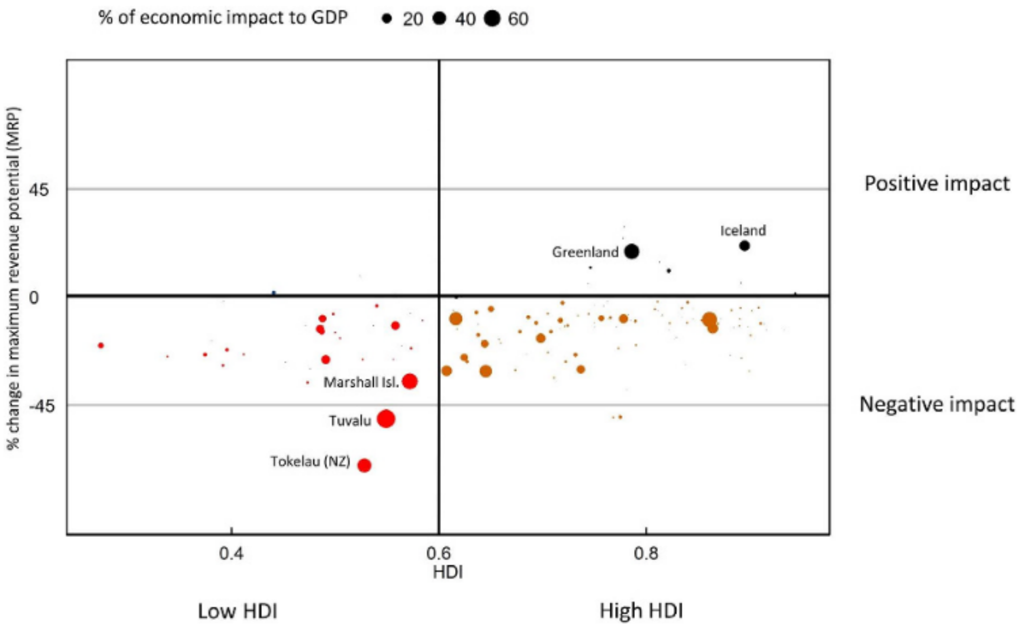
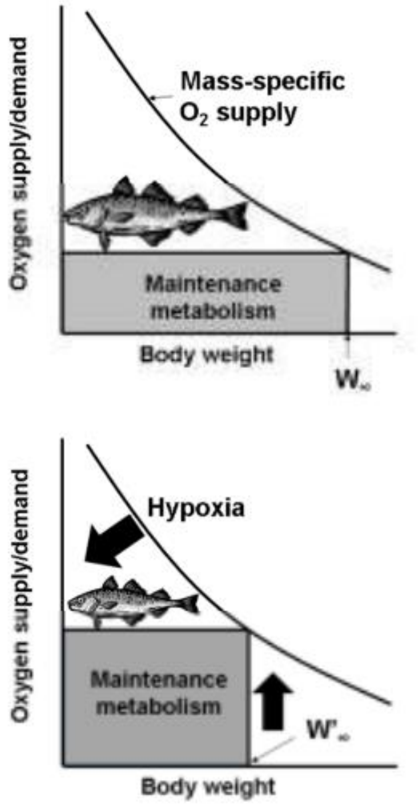


Figure 3. Percentage change in fisheries Maximum Revenue Potential (MRP) is mapped against Human Development Index (HDI) of countries. The bigger the size of the bubble the larger the percentage of economic impact of the fisheries sector to the total Gross Domestic Product (GDP).



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Lam VWY, et al. Sci Rep. 2016;6: 6–13.