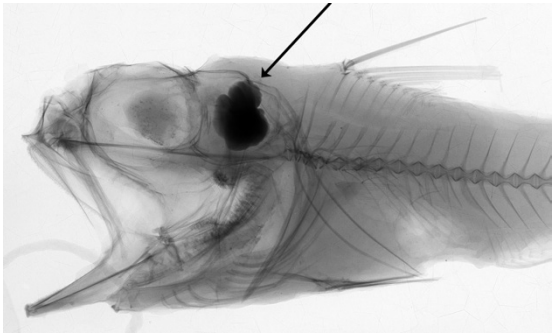
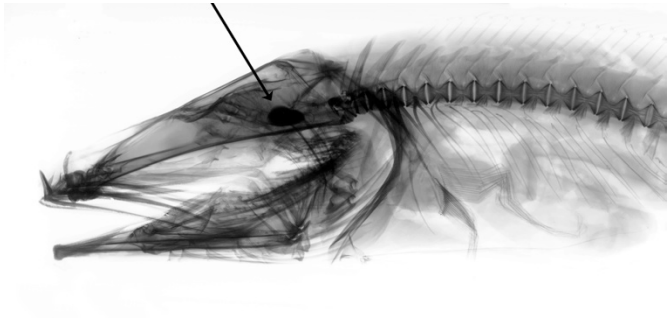
The use of otolith morphology in ichthyology

by Werner Schwarzhans



Hymenocephalus



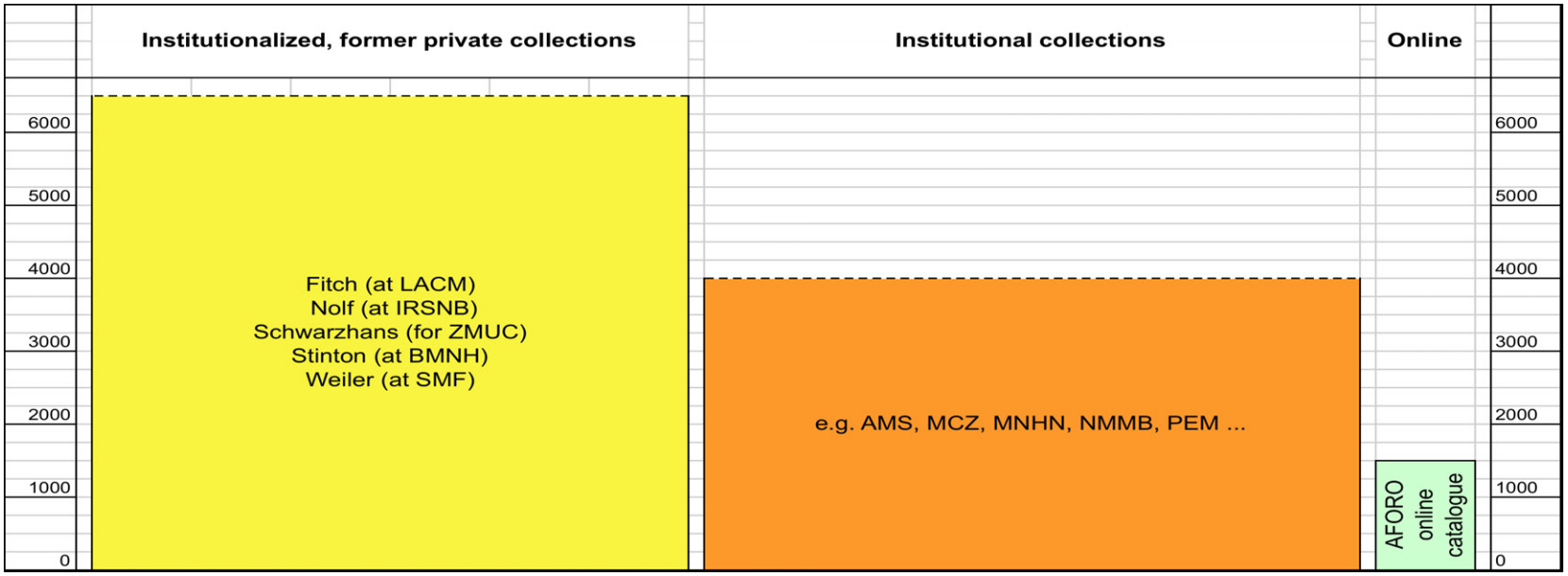
Porogadus

Introductory Notes

- Otoliths are a tool in paleontological systematics since 1884
- Otolith morphology is species and genus diagnostic in about 80% of all studied cases known to me (this is near the lower limit of ranges mentioned in literature)
- Ontogenetic changes can be significant with otoliths of juveniles exhibiting a more generalized morphology, and as a result the diagnostic value of juvenile otoliths is often low
- Intraspecific variability is very inconsistent from one species to another and hence requires investigation of more than one otolith specimen per species
- Sexual morphological dimorphism is rare (e.g. *Neobythites*)
- Morphological side dimorphism occurs in certain Pleuronectiformes
- Ontogenetic morphological dimorphism is rare (e.g. *Pycnocraspedum, Spectrunculus*)
- The term “Otolith” in this context refers to the “Sagitta” otolith

Knowledge Base

- The knowledge of Recent otoliths has risen significantly in recent years



- Publications dealing with Recent otoliths are still lagging behind:
  - **Otolith atlases** cover some 3000 species: NE-Atlantic (CHAINE & DUVERGIER 1934-1958 in NOLF et al. 2009, HÄRKÖNEN 1986), NW-Atlantic (CAMPANA 2004), Japan (OHE 1985), Indo-Pacific (RIVATON & BOURRET 1999), South Africa (SMALE, WATSON & HECHT 1995), West Africa (VEEN & HOUDEMAKERS 2005), Taiwan (CHIEN-HSIANG & CHIH-WEI 2012), AFORO online catalogue
  - **Systematic reviews** including approx. 1000 species: Sciaenidae (SCHWARZHANS 1993), Pleuronectiformes (SCHWARZHANS 1999), Ophidiiformes (NOLF 1980, SCHWARZHANS 1981)
  - **Otolith descriptions routinely included in ichthyological studies** (approx. 200 species) only by Møller, Nielsen and Schwarzhans

Acknowledgements

The following documentation would have been impossible without the generous support of many colleagues and institutions, amongst others:

AMS, BMNH, BPBM, BSKU, CAS, IORAS, LACM, MCZ, MNHN, NMNZ, NMV, NSMT, NTM, SAIAB, SMNS, USNM, WAM, ZMMGU, ZMH, ZMUC

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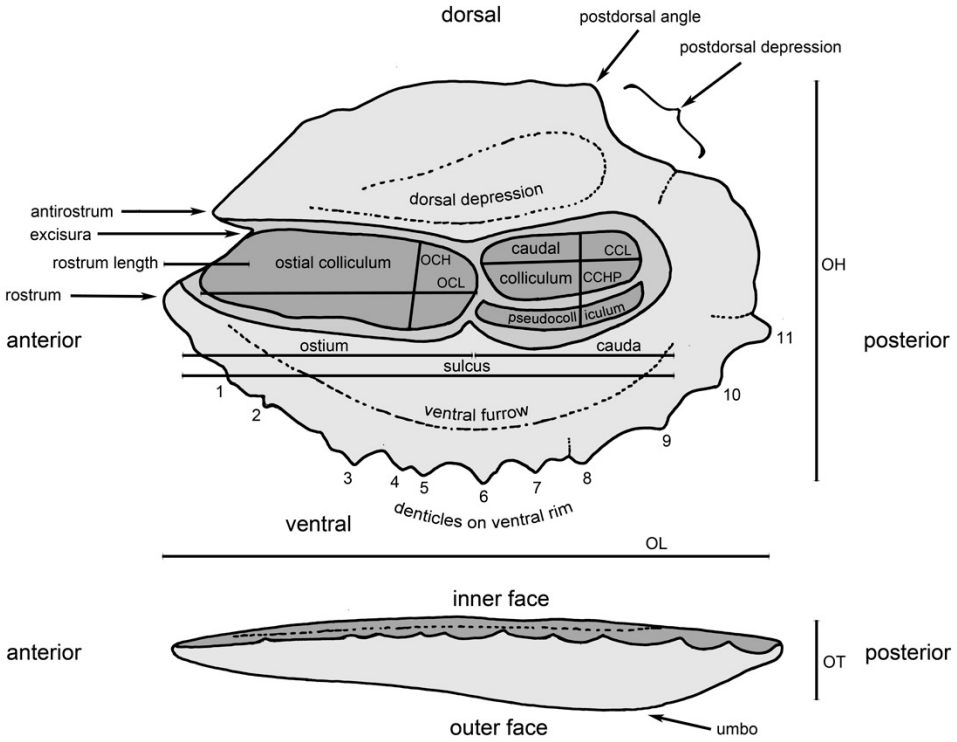
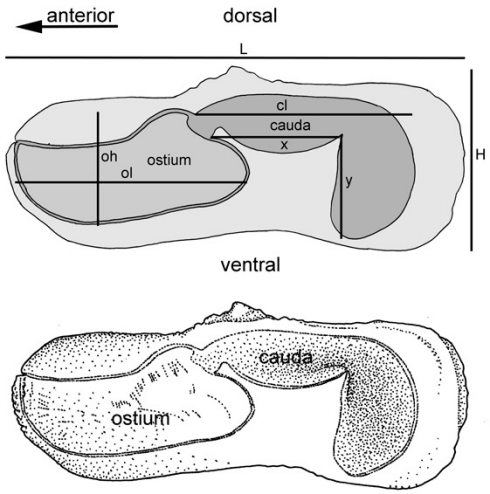
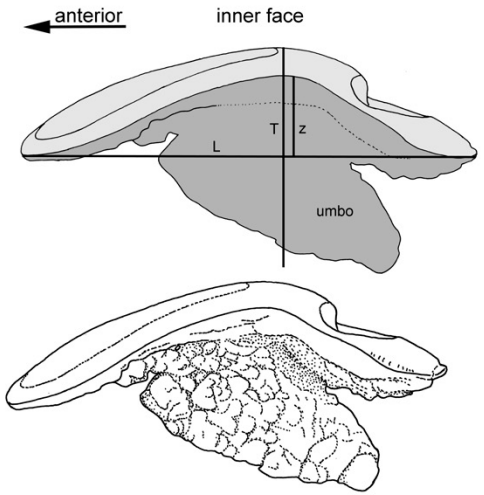
My sincere thanks to all of them.

Terminology (Sagitta)







Main morphological terms are:

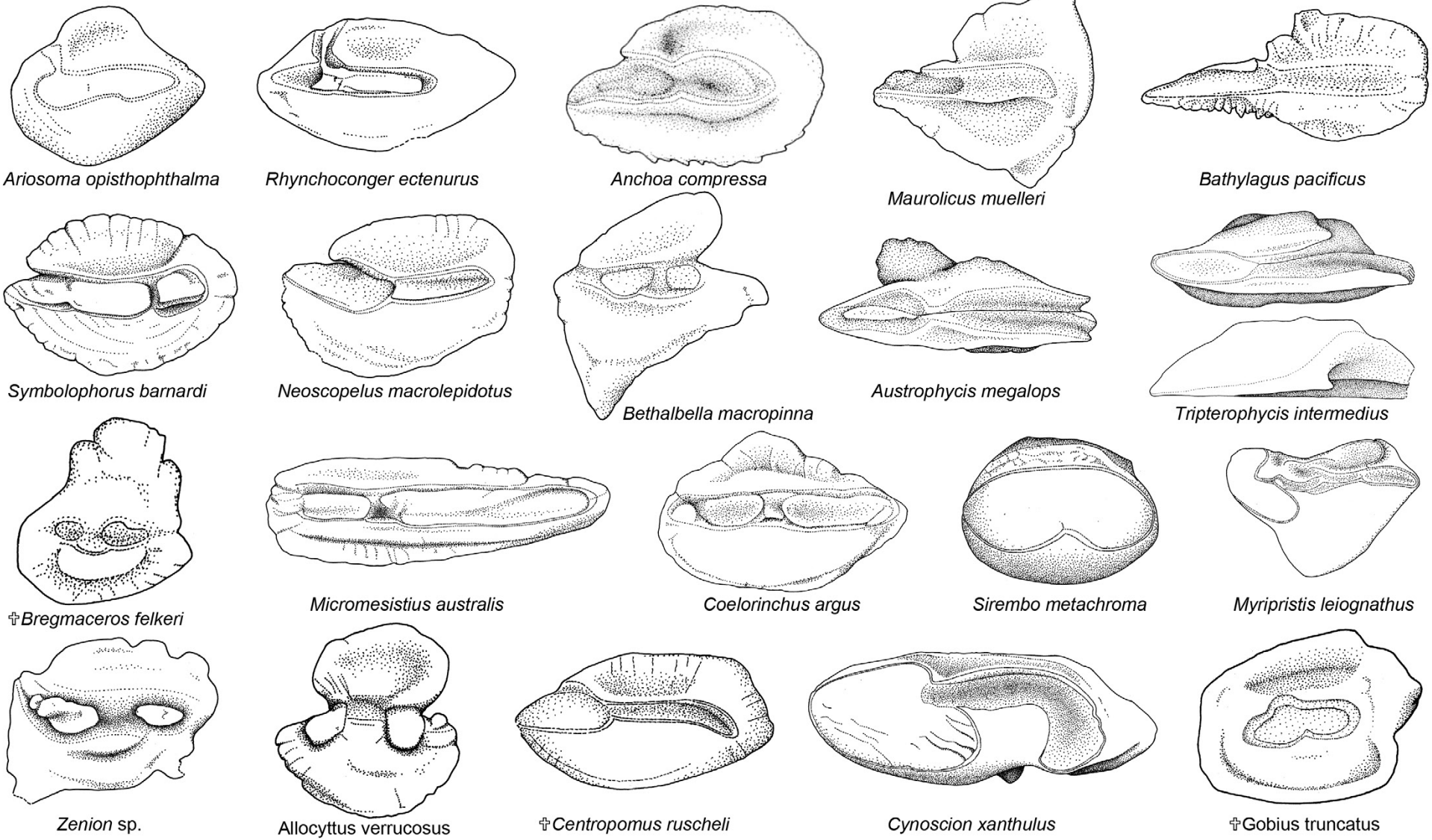
Sulcus, a grove, composed of **ostium** (anterior) and **cauda** (posterior), filled with the **colliculi** constituting the areas where the macula acustica touches the otolith

An additional colliculum, **pseudocolliculum**, is present below the caudal colliculum in Myctophidae or in the space ventrally between ostial and caudal colliculum in many Gadiformes

Rostrum, **antirostrum** and **excisura** are marks at the sulcus opening to the anterior rim of the otolith, when present

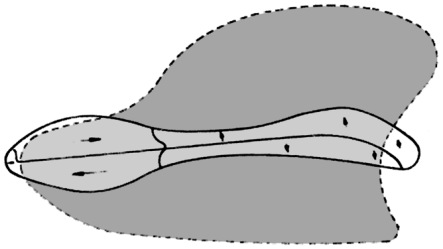
The shape of the dorsal and ventral rims as well as the surface of the inner face, thickness and curvature of otoliths and ornamentation of the outer face add many more diverse and varying characters

Otolith diversity

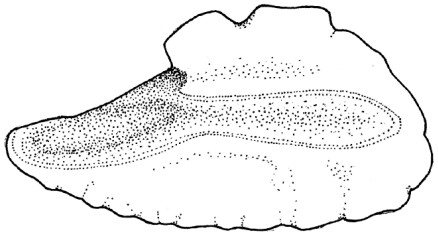


Function and functional morphology

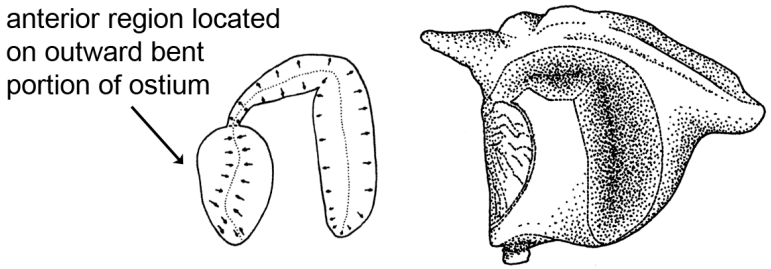
- The sulcus of the otolith mirrors the macula acustica, but the details of the hair cell regions do not seem to match morphological details in the sulcus



Macula acustica and orientation patterns of hair cells of different regions of the macula of *Coregonus clupeaformis*, overlying otolith shape (gray) (after Popper, 1976)

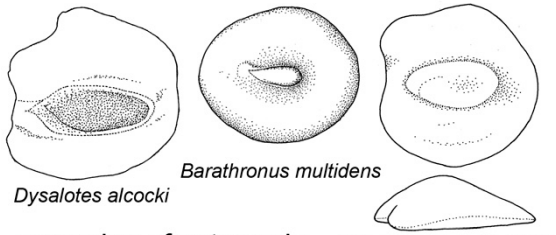


Otolith of *Megalops cyprinoides* for comparison. Note similarity of sulcus with shape of macula, but lack of differentiation of hair cell regions (left).



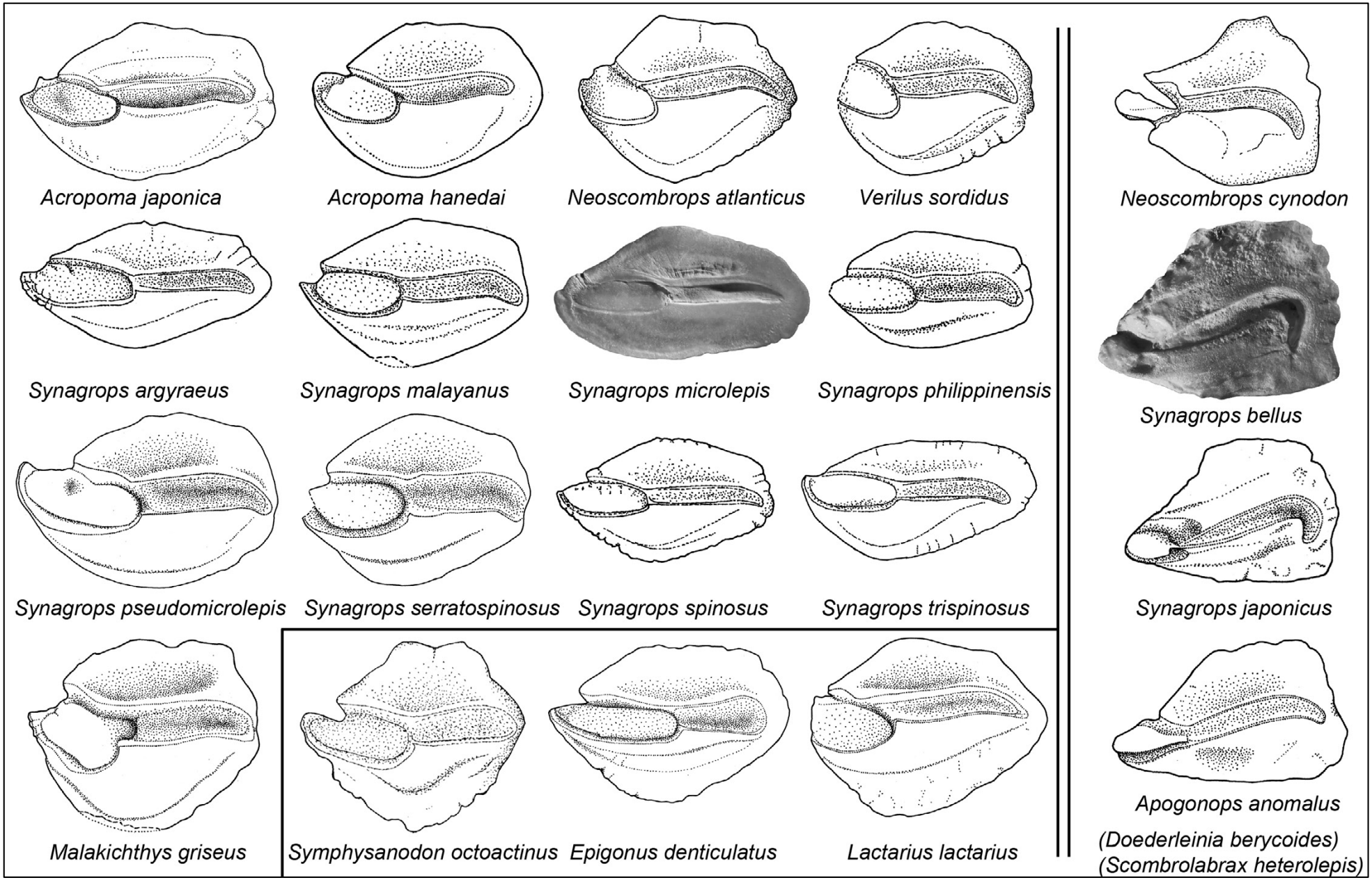
Comparison of macula with sulcus shape of *Bairdiella chrysoura*, one of the most aberrant otolith morphologies. The median line separating the hair cell regions follows the deep axis in the cauda and the outward bending in the ostium. (macula acustica after Ramcharitar et al., 2004)

- Recognition of functional morphological dependencies of otoliths are still at its infancy. Empirically, the following has been discussed:
  - Epipelagic fish tend to have thin, delicate otoliths; fast epipelagic swimmers small otoliths
  - Benthic fish tend to have large, massive otoliths and tend to develop simple sulcus morphologies with fused colliculi located at the center of the otolith
  - Fishes living at or below the CCD tend to develop small, thick otoliths with a flat inner face, a conical outer face and a simple oval sulcus
  - The highest morphological diversification is observed in otoliths of benthopelagic fishes



examples of extremely reduced otolith morphologies

Acropomatidae – clearly two different families

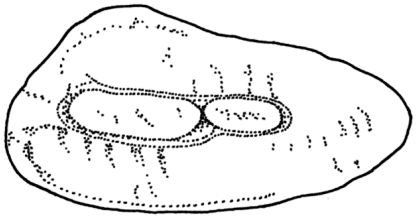


work in progress by Prokofiev & Schwarzhans

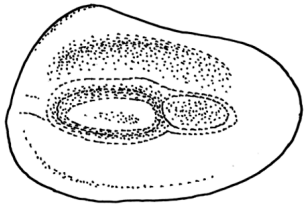
Ophidiiformes – recurrent patterns and varying degrees of diagnostic value

Porogadus: Otoliths represent a key character for species distinction and identification of lineages

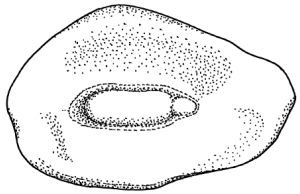
Note: Fusion of the two colliculi into a single oval colliculum occurs in at least 30 separate lineages. It sems likely that such recurrent evolution has some functional morphological background, which is not yet understood.



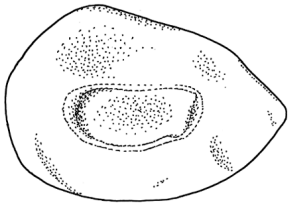
Porogadus miles



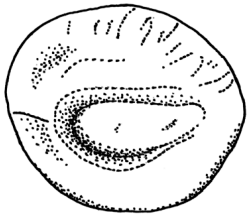
Porogadus nudus



Porogadus guentheri



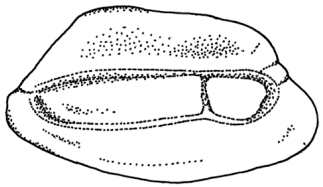
Porogadus n.sp. 3



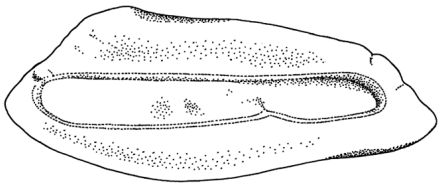
Porogadus subarmatus

Neobythites: Otoliths diagnostic for genus, on species level often depending on subtle characters

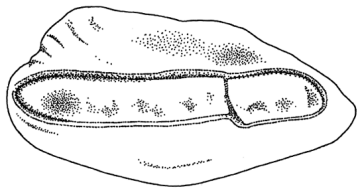
Note: Complicating character is commonly observed sexual dimorphism in otolith morphology. Altered morphology mainly observed in otoliths of males, which are not used for identification purposes.



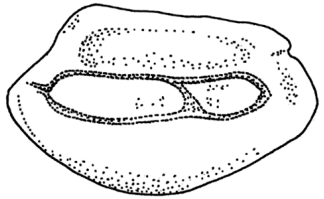
Neobythites malayanus



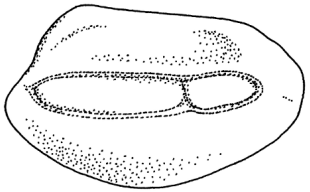
Neobythites longipes



Neobythites nigriventris



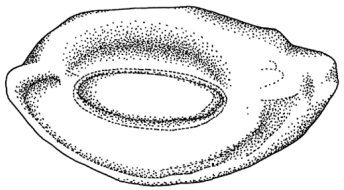
Neobythites somaliensis



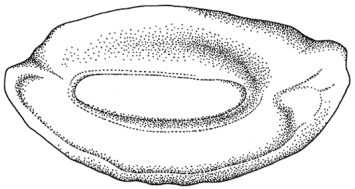
Neobythites bimaculatus

Diancistrus: Most species in this genus can not be securely distinguished by means of otoliths alone

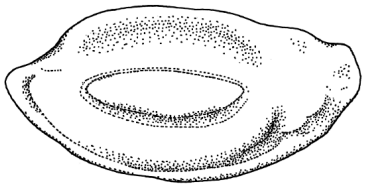
Note: Prime character for species and genus distinction in Dinematichthyini is the pseudoclasper morphology



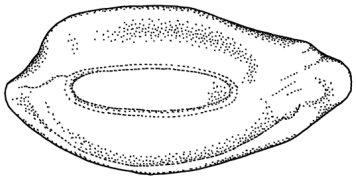
Diancistrus altidorsalis



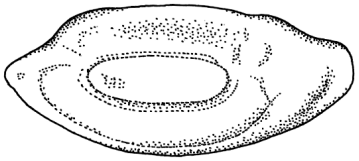
Diancistrus beateae



Diancistrus alleni



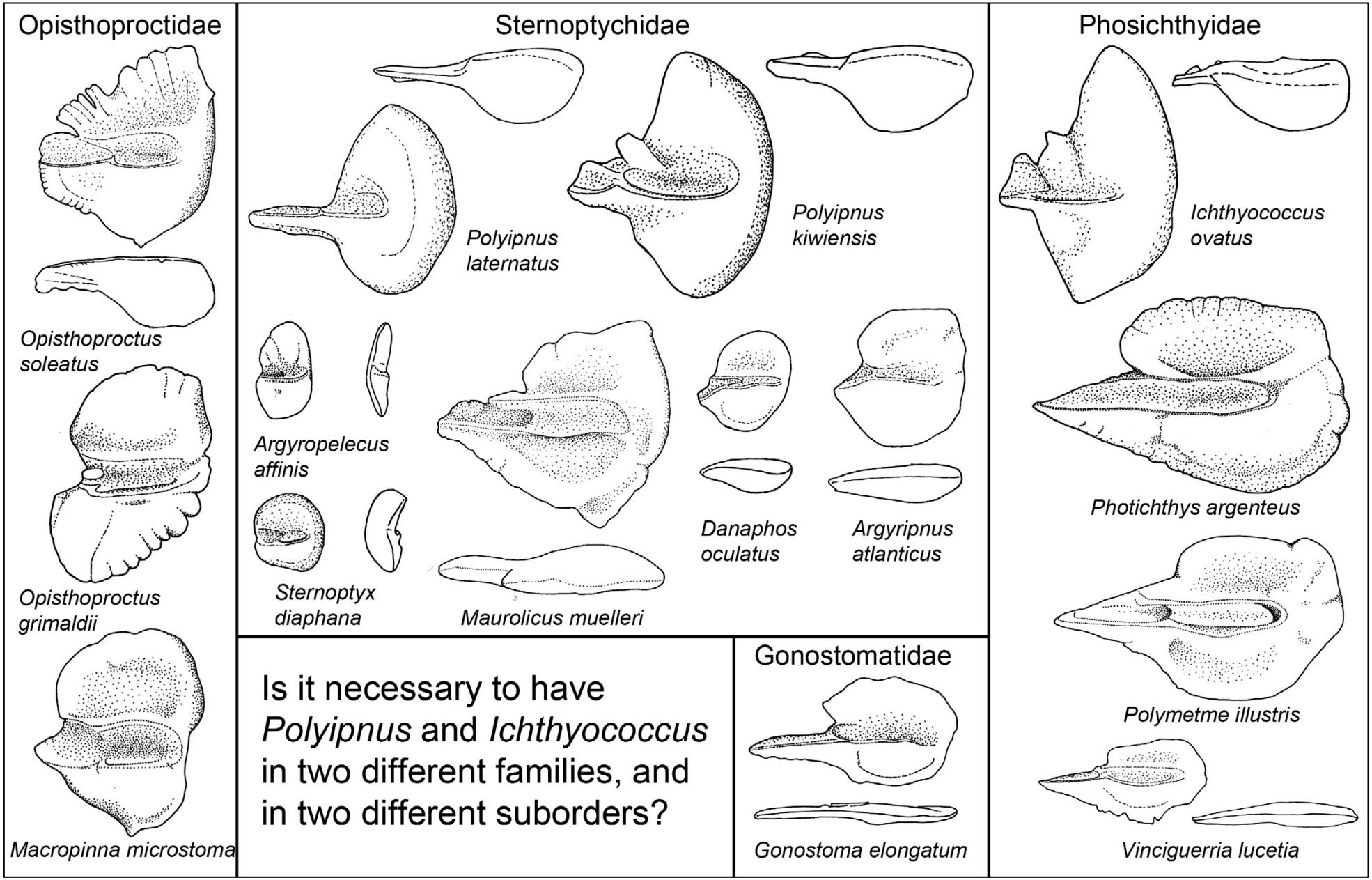
Diancistrus jeffjohnsoni



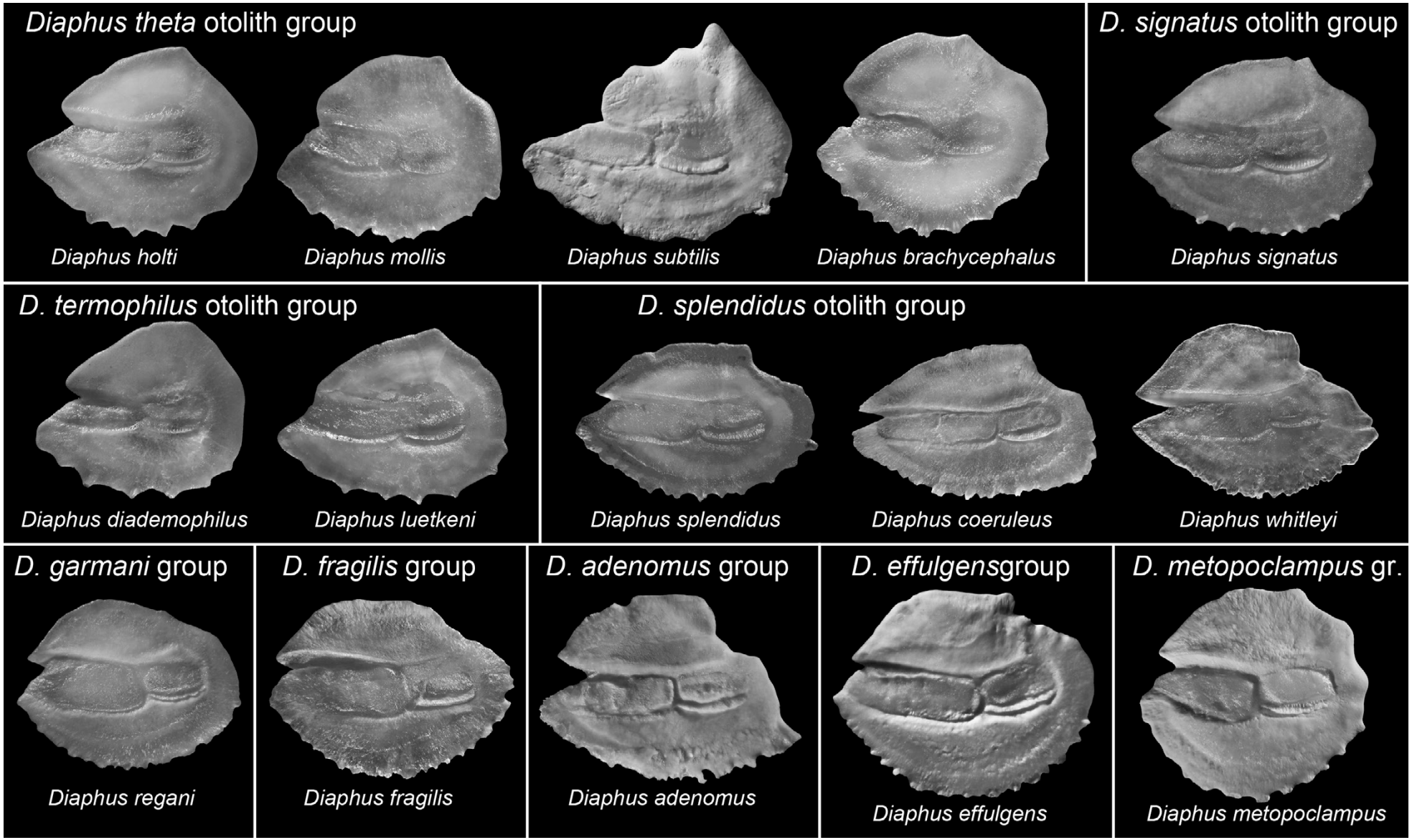
Diancistrus niger

Porogadus: work in progress by Schwarzhans & Møller - *Neobythites* and *Diancistrus*: published by Nielsen, Schwarzhans & Møller, various papers

A unique pattern – homology or analogy ?



Diaphus – otolith diversity in a species-rich genus



A high degree of diversity allows recognition of otolith species groups, which partly correlate with other groupings.

Certain species may not be distinguishable by means of otoliths, specifically in the *D. theta* group.

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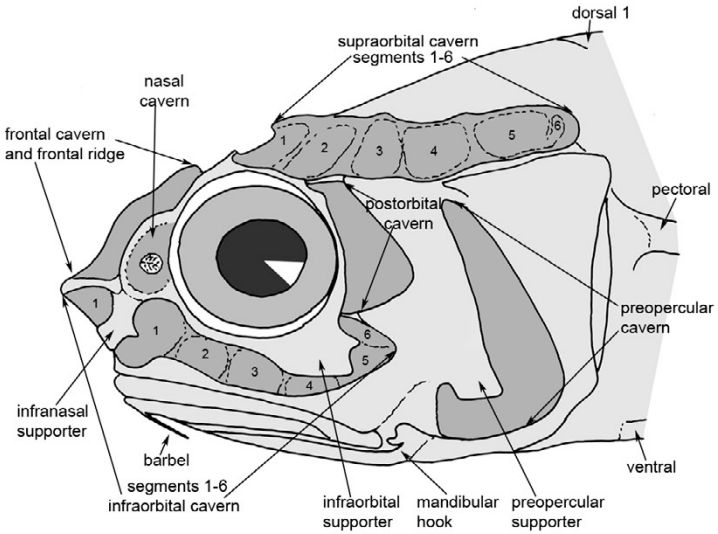
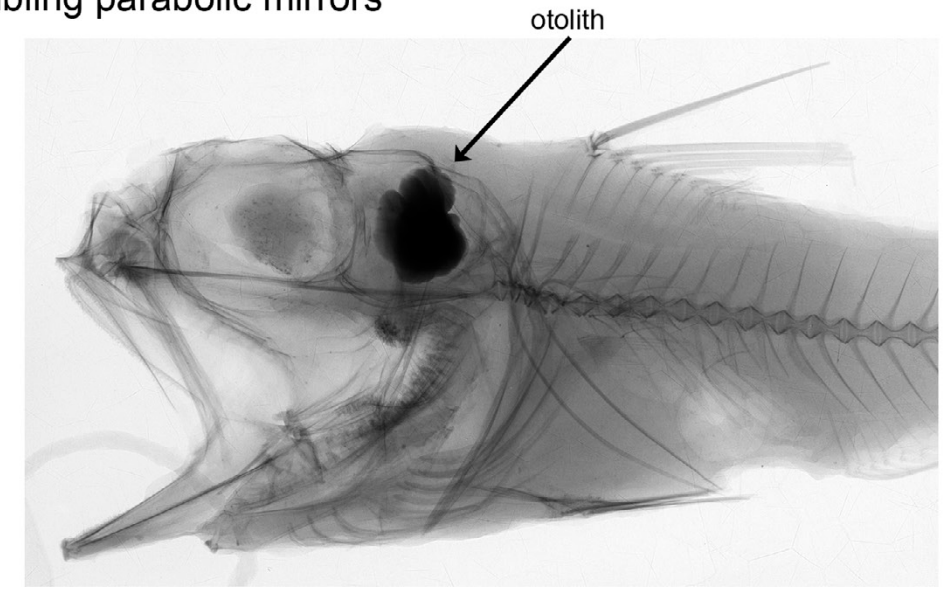
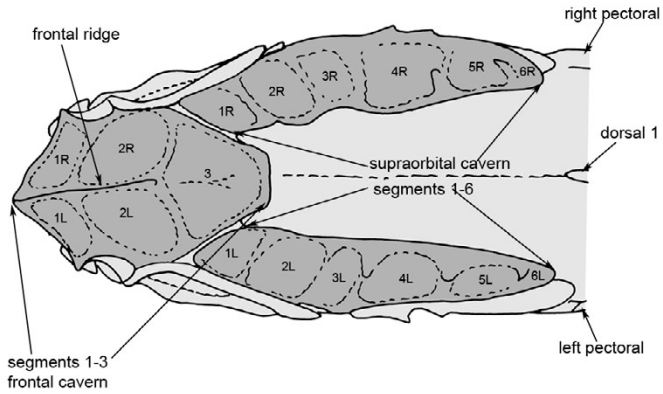
Hymenocephalus – sensual specializations

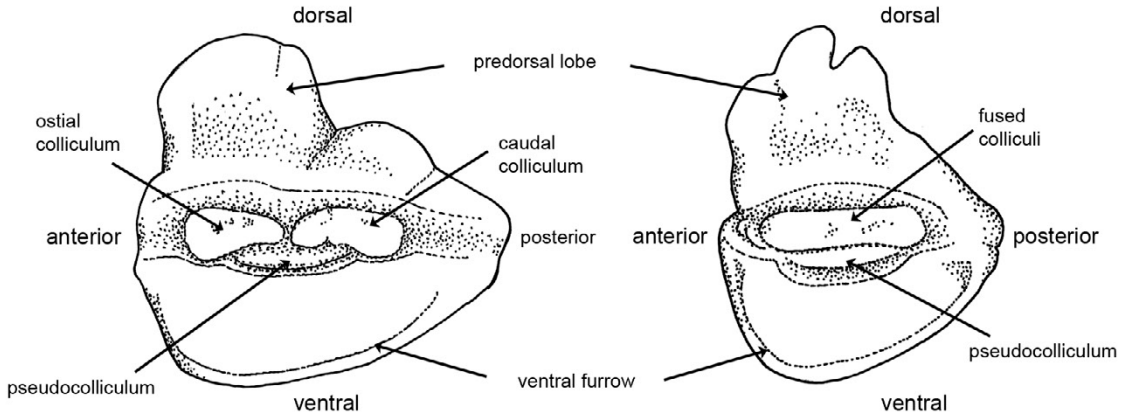
Hymenocephalus is remarkable for an advanced development of head sensory organs:

1. Very large head canal system covered by thin skin ("hymen"), which is rarely well preserved
2. Very large and diverse otoliths, amongst the largest compared to head size found in teleosts
3. Very large eyes located in caverns resembling parabolic mirrors









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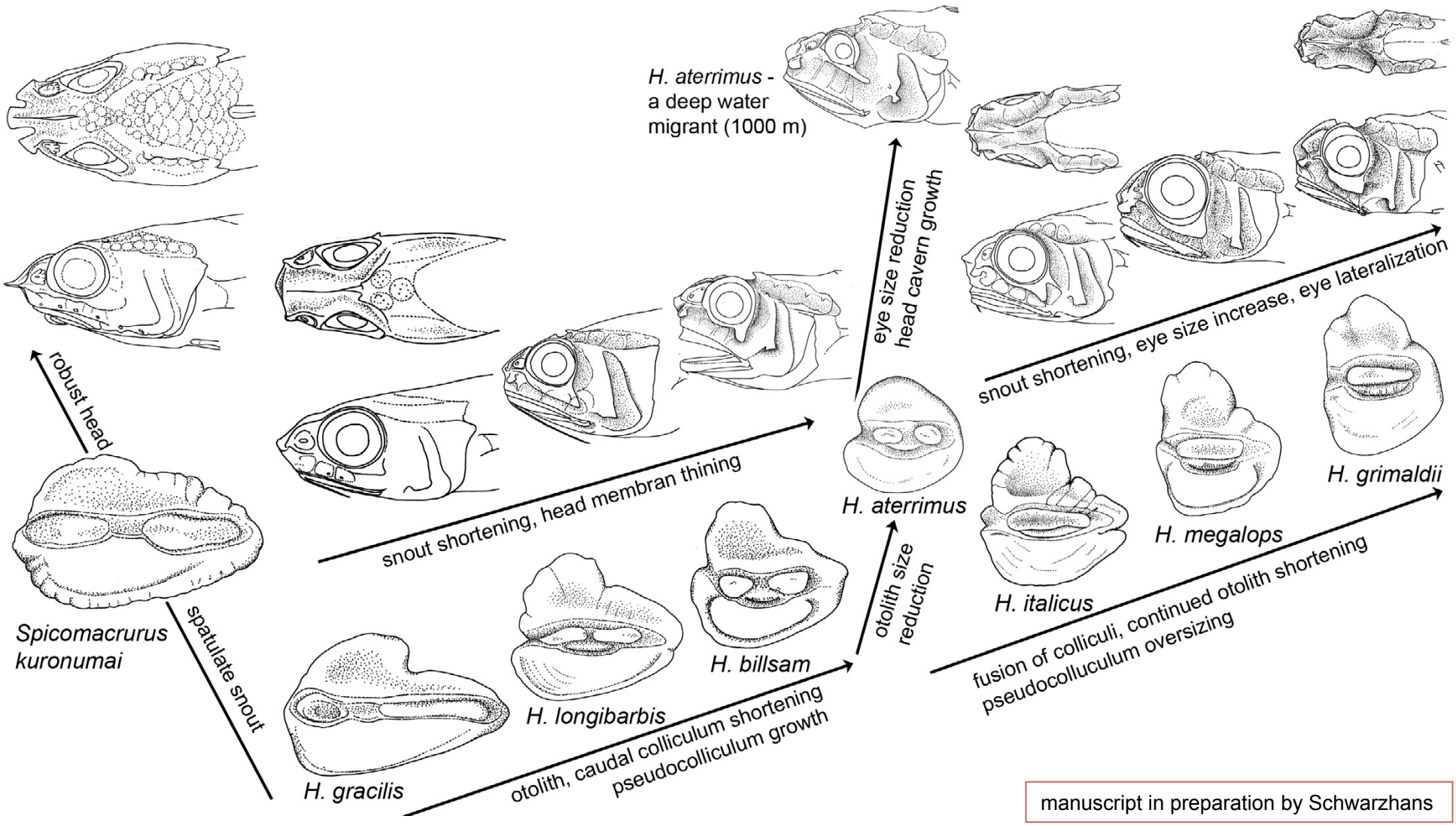
Hymenocephalus – phylogenetic polarity in head and otolith morphology

Eye size, head shape and otolith morphology exhibit a remarkable parallel evolution and polarity



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Otolith extraction and preservation

Otoliths are extracted from one side (usually the right side) through the gill opening by applying a cut in front of the first gill arch into the otic capsule

Otolith extraction is easy in:
- Myctophiformes
- Gadiformes
- Ophidiiformes
- Beryciformes
- most Scorpaeniformes
- most Percoidei
- Gobioidei
- ...

Otolith extraction is moderate,
because of narrow gill opening:
- Anguilliformes
- Pleuronectiformes

because of hard bones:
- some Percoidei
- many Trachinoidei

small or delicate otoliths:
- Clupeiformes
- Cypriniformes

Otolith extraction is difficult,
because of no gill opening:
- Lophiiformes

because of very thick bones:
- some Scombroidei
- Siluriformes

very small otoliths:
- Syngnathiformes

Otoliths are dissolved by formalin. Even after transfer to alcohol, some formalin may remain in the brain capsule and continues its destructive work, but at a lesser pace (years instead of weeks or few months).

Therefore, please extract an otolith before this valuable character is lost, particularly in rare species.