EARTHSCIENCES

The meiofauna frontier: pushing the limits of computed tomography in invertebrate morphology and systematics

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Key words:	meiofauna, invertebrate morphology, computed tomography, nanoCT, synchrotron tomography, integrative taxonomy
Research theme(s):	Palaeobiology and Evolution
Eligible courses for this project:	• DPhil in Earth Sciences • Environmental Research (NERC DTP) • Interdisciplinary Bioscience (BBSRC DTP)

Overview

Figure 1 – A diversity panel of photomicrographs of a few representative phyla – Gnathifera, Kinorhyncha, Annelida, and Platyhelminthes – characteristic of marine interstitial meiofaunal communities.

One of Earth's great remaining frontiers of animal biodiversity can be found in the communities of invertebrates living in the interstices of aquatic sediments and soils (Swedmark, 1964), in the so-called "meiofauna" (animals <1 mm). These communities house representatives of 2/3rds of the extant animal phyla (Laumer, 2024), of which 7 are exclusively meiofaunal – these animals therefore have outsized importance for understanding the events of early animal evolution. Ecologically, meiofauna can be extraordinarily abundant and can even rival macrofauna as a source of secondary production, due to their short life cycles. At the species level, meiofauna show exceptional diversity (with 10-100s of species in a liter of sand), which can vary at a spatial scale of meters.

Taxonomically, most of these remain unnamed even in the best-sampled habitats in the world, and DNA has implied meiofauna also show very high levels of "cryptic" speciation; by some estimates, millions of meiofaunal species thus exist (Blaxter, 2016). Despite this, meiofauna draw fractions of the amount of research attention other animal groups receive, and for many taxa the number of experts capable of identifying and describing meiofauna species are dwindling, with several groups already taxonomically "orphaned" (Giere and Schratzberger, 2023). In the present era, countless meiofauna species thus face a silent

extinction – the present generation is presented with a closing window of opportunity to sample, preserve, and understand much of this diversity.

Advances in high-throughput, high-resolution 3D imaging technologies show considerable promise in remedying this taxonomic impediment. In particular, nano-scale X-ray computed tomography instruments capable of resolving down to 150 nanometers in just a few hours of scan time are now commercially widely available (Ferstl et al., 2020; Gross et al., 2019; Müller et al., 2017), and national synchrotron radiation infrastructure push these limits even further. Given appropriate fixation and soft-tissue staining techniques, these technologies may therefore allow rapid morphological identification and even primary alpha-taxonomic description of meiofauna. Moreover, since CT scanning is non-destructive, in principle recovery for nucleic acid extraction is possible (Hall et al., 2015), allowing both detailed morphology and molecular data to be collected from even the rarest specimens. Especially for soft-bodied taxa such as flatworms, which require study of live specimens under DIC microscopy, and at times histological sectioning for proper species description (Balsamo et al., 2020), this would be a considerable advance, permitting specimens sampled and fixed anywhere in the world to be subjects of simultaneous nanoscale morphological and genomic study.

In this primarily technological development project, the student will enjoy considerable latitude to drive the direction of the work, especially as concerns taxonomic focus, although Drs. Laumer and Parry can offer their own expertise in the systematics and morphology of spiralians, especially flatworms and annelids.

Optionally, the project may include a substantial molecular component, including whole-genome assembly and phylogenomic placement of CT-scanned specimens. Many meiofaunal animals occupy disputed or highly controversial branches of the animal tree of life (Laumer et al., 2019) and therefore have great relevance to understanding the origin of animal body plans.

Methodology

This project will call for a detail-orientated, experimental approach. Chief among our goals is the search for fixation, staining, and mounting protocols appropriate for maximal morphological resolution under nanoCT, ideally also maintaining the integrity of DNA and RNA at ambient temperatures. The NHM's Zeiss Versa 520 is available for in-house use, and will guide rapid development of appropriate protocols (i.e. staining and fixation) to be used in "production" with state-of-the-art nanoCT and synchrotron facilities as access to these instruments becomes available, e.g. Diamond Light Source (DLS) time. Initial scans will be visualized using volume rendering, or manual segmentation where necessary, as well as emerging techniques in automated segmentation permitting high-throughput applications. Opportunities for exploration of other nondestructive 3D imaging techniques such as confocal microscopy, or image stacking of cleared whole mounts, are also available.

Timeline

Year 1: Doctoral training courses (10 weeks), literature review, fixation and staining optimization experiments, familiarization with Versa 520 and segmentation software, domestic fieldwork, molecular lab training

Year 2: Domestic and international fieldwork, intensive CT data collection with Versa 520, dataset preparation and segmentation towards first manuscript(s), presentation at national conferences (e.g. ICIM)

Year 3: Domestic and international fieldwork (continued), research visit to imaging facilities, DLS time for high-throughput nanoCT.

Year 4: Data integration, thesis completion, papers for journals/conference presentation.

Training & Skills

Your supervisor at Oxford will offer expertise in comparative morphology, animal phylogeny, and 3-D morphology reconstruction. At the Natural History Museum you will benefit from expertise in wet-lab method development, meiofaunal biology, DNA taxonomy, genomics, and the systematics of flatworms and other soft-bodied meiofauna. You will learn state-of-the-art techniques in nano-scale CT imaging. Throughout the project you will have the opportunity to participate in domestic and international fieldwork.

References & Further Reading

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Further Information

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