The Malacological Society of London

128th Annual General Meeting
and symposium, via Zoom, on the theme of

Molluscs in Extreme Environments

Wednesday **March 24th** 2021

Cernuella virgata escaping soil-surface heat; Heinz-R Kohler, Ecology & Evolution doi.org/10.1002/ece3.5607

Cocculina enigmadonta and Lepetodrilus concentricus,
Kemp Caldera hydrothermal vent; ROV MARUM-QUEST

Programme.

1000 Welcome to the Symposium – John Grahame, outgoing President of the Society.

Chair: **Katrin Linse**

1015 – **Crispin T.S**. **Little**, School of Earth and Environment,
University of Leeds, UK: **The evolutionary history of molluscs in chemosynthetic environments**

1045 – **Darren Fa**, University of Gibraltar: **Saving a species from extinction one boulder at a time: Advances in the conservation of the Mediterranean ribbed limpet *Patella ferruginea* Gmelin, 1781**

1115 – **Nikolay Aseyev**, Institute of Higher Nervous Activity and Neurophysiology, Russian Academy of Sciences, Moscow, Russia: **Adaptive Changes in the Vestibular System of Land Snail to a 30-Day Spaceflight and Readaptation on Return to Earth**

1145 – General discussion

1200 - Break for lunch during which we will be holding the Annual General Meeting of the Society; this is for members of the Society

Chair: **John Grahame**

1415 – **Douglas J. Eernisse**, Dept. of Biological Science; California State University, Fullerton; Fullerton CA 92834 USA: **Are some chitons extremophiles, or mere opportunists on the fringe of hostile deep-sea habitats?**

1445 - **Heinz-R Köhler**, Institute of Evolution and Ecology, University of Tübingen, Germany: **Solar radiation stress in terrestrial snails – from thermodynamics to microevolution**

Chair: **Jonathan Ablett**

1515 – **Quick fire presentations**

1545 – General discussion

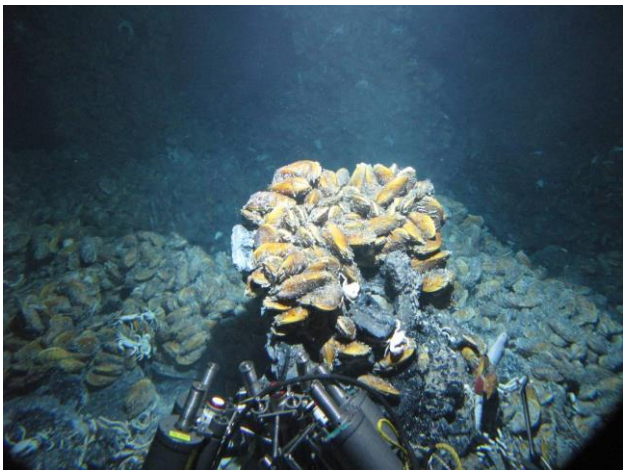
1600 – Closing remarks – Jonathan Ablett, incoming President of the Society

The evolutionary history of molluscs in chemosynthetic environments

Crispin T.S. Little

School of Earth and Environment, University of Leeds, Leeds, UK

Molluscs are abundant constituents of modern chemosynthetic communities (hydrothermal vents, hydrocarbon seeps and organic-falls) and this is partially because of the adaptation of many taxa to a symbiotic relationship with chemoautotrophic bacteria in their gills or oesophagus. The taxonomic diversity of molluscs in chemosynthetic environments tends not to be high, but is dominated rather by a few groups, for example bathymodiolin and vesicomyid bivalves, and provannid gastropods. Molecular divergence estimates indicates that some of these diverse taxa are relatively recent arrivals in chemosynthetic environments during the Cenozoic era, and this is supported by their fossil record. However, other groups are older, with Mesozoic origins. Molluscs are present in Palaeozoic vent and seep sites, but these belong to mostly extinct groups, showing that molluscan adaptation to, and extinction within chemosynthetic environments occurred regularly throughout Earth history.



Bathymodiolus thermophilus (and bythograeid crabs), hydrothermal vent site at 9°N, East Pacific Rise.

Archivesica s.l. puertodeseadoi, hydrothermal vent site in the Kemp Caldera, East Scotia Ridge.

Saving a species from extinction one boulder at a time: Advances in the conservation of the Mediterranean Ribbed Limpet *Patella ferruginea* Gmelin, 1781

Darren Andrew Fa, The University of Gibraltar

The limpet *Patella ferruginea* Gmelin, 1791 is considered the most endangered marine invertebrate along the western Mediterranean rocky intertidal and as such is listed in Annex IV of the European Union's Habitats Directive (92/43/EEC; EC 2004) as requiring 'strict protection'. Although it is commonly present in Palaeolithic and Neolithic deposits throughout the western Mediterranean (where it was presumably collected for food), a diversity of anthropic pressures have over recent decades dramatically reduced its present-day distribution to a fraction of its former range.

Perhaps surprisingly, this highly protected species has a tendency to establish itself along artificial harbour walls and breakwaters, provided prevailing conditions are suitable for settlement and survival. However, this tendency, coupled with the legal status of the species, has on several occasions unfortunately resulted in serious (and frequently costly) standoffs when competing priorities collide.

Previous attempts by other researchers to move the limpets to other locations had resulted in unacceptably high mortality rates as the animals failed to re-attach and/or settle on the new substrates. This work reports on the results of field experiments, supported by the Government of Gibraltar, which involved relocating entire boulders upon which the limpets were attached during low tide episodes when the animals were inactive. The experiments yielded significantly positive survival results, with over 80% of the translocated animals still alive and growing 10 months after the move, comparing favourably with growth/mortality data from a control population.

This method has the potential to provide not only a practical solution to address some conflicts generated by this species' preference for harbour breakwaters, but more importantly, provides opportunities for active conservation management, including the creation of 'stepping stones' of pockets of reproducing individuals that could connect currently fragmented populations.

Adaptive Changes in the Vestibular System of a Land Snail to a 30-day spaceflight and Readaptation on return to Earth

Nikolay Aseyev, Institute of Higher Nervous Activity and Neurophysiology, Russian Academy of Sciences, Moscow, Russia

The vestibular system receives a permanent influence from gravity and reflexively controls equilibrium. If we assume gravity has remained constant during the species' evolution, will its sensory system adapt to abrupt loss of that force? We address this question in the land snail Helix lucorum exposed to 30 days of near weightlessness aboard the Bion-M1 satellite, and studied geotactic behavior of postflight snails, differential gene expressions in statocyst transcriptome, and electrophysiological responses of mechanoreceptors to applied tilts. Each approach revealed plastic changes in the snail's vestibular system assumed in response to spaceflight. Absence of light during the mission also affected statocyst physiology, as revealed by comparison to dark-conditioned control groups. Readaptation to normal tilt responses occurred at ~20 h following return to Earth. Despite the permanence of gravity, the snail responded in a compensatory manner to its loss and readapted once gravity was restored.

Are some chitons extremophiles, or mere opportunists on the fringe of hostile deep-sea habitats?

Douglas J. Eernisse
Department of Biological Science; California State University, Fullerton; Fullerton CA 92834 USA

In their seminal 2020 review of Mollusca, Winston Ponder and David R. Lindberg emphasized low oxygen (hypoxia), high or low temperatures, and desiccation as the most extreme environmental challenges for molluscan adaptation in marine environments. Most of the approximately 1000 recognized extant species of chitons are found in shallow water, and even in this supposed comfort zone there are some chitons that live on the underside of rocks embedded in fine sediment whose foot and gills are noticeably colored red by a tissue hemoglobin, which is likely an adaptation to hypoxic conditions. But chitons are also present in diverse deep-sea habitats, including the deepest ocean trenches. Despite the remoteness of deep-sea habitats, recent faunal expeditions have accelerated the availability of specimens suitable for both morphological and molecular studies. For chitons, we have collectively made progress recognizing that deep-sea chitons long thought to be cosmopolitan species are instead species complexes whose members can be geographically restricted to only portions of particular ocean basins. Typical deep-sea chitons have drab white shell plates that are generally lacking in distinctive features, but subtle differences can be discerned with a combination of light microscope and SEM examination, with DNA sequencing helping to sort out often confusing morphological variation. Collectively, we are just beginning to understand chiton distribution well enough to evaluate whether or not deep-sea chitons have adaptations to the hypoxic conditions associated with biogenic substrates or high temperatures near hydrothermal vents. An emerging view suggests that it is just as likely that chitons are opportunistically occurring or even thriving on the fringe of truly extreme habitats, but evidence is still lacking that they are part of the known specialist communities associated with such extreme conditions. Two chiton species have been described from a hydrothermal vent system near Japan, but it is unknown whether these are like the approximately 200 gastropod or 20 bivalve species summarized by Ponder and Lindberg that are found nowhere besides such a habitat. One interesting hypothesis is that animals living on biogenic habitat are able to colonize productive but isolated and geologically ephemeral vent systems. In studies with my colleague, Anthony Draeger, we have found one such example for chitons. Greg Rouse and colleagues at Scripps Institution have allowed us to study multiple ROV-collected chiton species from methane seeps off the Pacific coast of Costa Rica, and we have identified one of these chitons as *Tripoplax balaenophila* (Schwabe & Sellanes, 2004), which was originally described from a fallen whale bone habitat off Chile. Likewise, we are describing a new chiton species from sunken wood that was experimentally deployed off the Big Sur coastline in California by Craig McClain and colleagues, which not only provides evidence for recruitment availability, but also points to how much is still unknown. A combination of molecular and morphological study has allowed us to greatly expand the known geographic distribution of this particular chiton genus, *Ferreiraella* Sirenko, 1988, which is exclusively associated with fallen wood. These examples are illustrative of approaches that we expect will be required to address the question of just how extreme chitons might get.

Solar radiation stress in terrestrial snails – from thermodynamics to microevolution

Heinz-R. Köhler, Institute of Evolution and Ecology, University of Tübingen, Germany

Land snails, especially in Mediterranean and arid climates, are sometimes exposed to very strong solar radiation. Nevertheless, some species in these habitats occur in exceptionally high individual densities, suggesting effective adaptations of these animals to heat and drought stress. In addition, these snails may include highly polymorphic species, in which individuals can differ considerably in the pigmentation of their shells. In this lecture, adaptation mechanisms on the biochemical, physiological, behavioural and morphological levels will be explained on the basis of studies on the helicid land snail *Theba pisana*. The following questions will be addressed: When do land snails predominantly suffer from thermal stress and how can they limit it? Are different pimentation patterns actually biologically relevant in this context? Which conditions overstrain the capacity of biochemical and physiological defence mechanisms? Is there a thermal selection pressure on more intensely pigmented morphs and, if so, under which climatic conditions? And does this have implications for the future distribution of the species and phenotypic variation of *Theba pisana* at the continental scale in the context of climate change?

Structural flexibility and protein adaptation to temperature: Comparing mutagenesis and simulations of malate dehydrogenases of marine molluscs

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Analysis of structural and functional properties of 26 cytosolic malate dehydrogenase (cMDH) orthologs of marine molluscs adapted to temperatures ranging from −1.9 °C (Antarctica) to ~55 °C (South China coast) reveals the roles of protein flexibility in adaptation to temperature. *In vitro* site-directed mutagenesis approaches and *in silico* molecular dynamics simulations are shown to provide powerful means of examining adaptive change in protein evolution to temperature. Sequence regions involved in binding and catalysis show significant interspecific, temperature-related differences in flexibility. Whereas these key amino acid substitutions invariably lie outside of the mobile regions (MRs) essential for function, they transmit their flexibility-modulating effects to the MRs through linked interactions among surface residues. Thus, regions of the protein surface lying outside of the site of catalysis can help establish an enzyme's thermal responses and foster evolutionary adaptation of function. This study provides a new perspective on biochemical adaptation and distribution of molluscs.

Making the right decision: thermoregulatory behaviours to tackle heat stress in the tropics

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The intertidal system is highly dynamic, where species alternate between stable immersion in seawater and variable, often extreme, aerial exposure. When the tide recedes, surface temperatures on tropical shores can exceed 60℃, causing mass mortalities of various molluscan species. High shore littorinids (*Echinolittorina malaccana* and *E. radiata*) are, however, not victims of such extreme heat due to a wide repertoire of thermoregulatory (fight and flight) behaviours. These littorinids buffer themselves from reaching lethal body temperatures by standing and towering behaviours, the occurrence of which varies across temporal and spatial scales; being greater on the hottest days and the warmest sites. Since most molluscs on tropical shores are inactive when emersed, the time-lag between making these behavioural decisions and actually experiencing harsh environmental conditions begs the question of how the snails anticipate the oncoming threat of extreme heat and behave accordingly? To answer this, we are examining time-series of environmental temperatures to identify the possible cues that these snails use to prepare themselves for the extreme heat during emersion on tropical shores.

From the population boom to the extinction: a case study of *Vertigo moulinsiana* population in extreme environmental conditions

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Catastrophes are one of the factors responsible for extinctions of populations or even species. They can lead to a drastic decrease in the population size and irreversible changes in the habitat. Due to limited dispersal/migration capabilities, terrestrial gastropods are particularly sensitive to changes in vegetation structure. We present a case study on a population of endangered (IUCN Red List: VU) and protected (EU Habitat Directive) terrestrial Desmoulin's whorl snail (*Vertigo moulinsiana*) in Poland. It underwent a period of intense stress in extreme environmental conditions, experiencing three catastrophic events: flood, fire and intense mowing. The flood, that took place in 2010, was a result of unusually intense rainfall in the spring, whereas the fire that occurred in 2012, was probably a consequence of deliberate yet uncontrolled vegetation burning in the spring. Additionally, annual mowing of that area (under the EU agri-environmental scheme; AES) started in 2013.

Although *V. moulinsiana* is a terrestrial species, the flood in 2010 turned out to be beneficial for the population. In all types of studied habitats it resulted in a significant increase in the number of snails compared to 2009. Surprisingly, the "population boom" did not extend over a perspective longer than the duration of the flood phenomenon itself: in the following year the population significantly decreased. The effects of the fire were devastating for the studied population. Although it did survive, there was a sharp decline in the number of individuals, by as much as two orders of magnitude. Analysis of the data collected immediately after the fire did not reveal any significant differences in the numbers of snails between the analyzed habitat types. This suggests that there are no vegetation-related refugia for this population. After the fire no increase in snail numbers was observed.

Differences between mowed and unmown habitat were significant regarding both the number of all recorded individuals and the number of live individuals. In the mowed habitat all snails were recorded in the swathe, with not a single individual found in the stubble. Absence of individuals in the stubble suggests that they had probably been removed along with the mowed vegetation. In the following years the entire area was mowed annually, with collection of the material. It probably has led to a significant habitat loss, and consequently to the total extinction of the local *V. moulinsiana* population. Since 2019, no live individual has been found. This, in turn, implies that the obligatory removal of the swathe within 2 weeks after mowing, required under the AES, may have a strong negative impact on the population size of *V. moulinsiana*.

Exploring the symbiotic relationship that underpins the success of a hydrothermal-vent gastropod

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The peltospirid gastropod *Gigantopelta chessoia* lives in one of the most extreme environments on Earth – Antarctic deep-sea hydrothermal vents. To survive this harsh landscape, *Gigantopelta* is specially adapted to chemosynthetic energy sources, housing chemoautotrophic bacterial endosymbionts in an enlarged, specialised organ adapted from the oesophageal gland, known as the trophosome. Such adaptations are key to the success of this unique species, yet very little is known about the relationship between the host snail and its symbionts. We employed profiling proteomics to analyse the protein expression of the *G. chessoia* holobiont to provide new insights into host-symbiont interactions, and the specialised physiological mechanisms and biochemical responses underpinning this symbiotic relationship. By applying 'omics' techniques to explore the physiological interdependencies between host and symbiont, we can improve our understanding of the complex relationships that underpin the success of molluscs in extreme environments.

Molecular insights into the powerful mucus-based adhesion of limpets (*Patella vulgata*)

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Limpets such as *Patella vulgata* L. are renowned for their powerful attachments to rocks on wave-swept seashores. Unlike adult barnacles and mussels, limpets do not adhere permanently; instead, they repeatedly transition between long-term adhesion and locomotive adhesion depending on the tide. Recent studies on the adhesive secretions (bio-adhesives) of marine invertebrates have expanded our knowledge on the composition and function of temporary and permanent bio-adhesives. In comparison, our understanding of the limpets' transitory adhesion remains limited. In this study, we demonstrate that suction is not the primary attachment mechanism in *P. vulgata*; rather, they secrete specialized pedal mucus for glue-like adhesion. Through combined transcriptomics and proteomics, we identified 171 protein sequences from the pedal mucus. Several of these proteins contain conserved domains found in temporary bio-adhesives from sea stars, sea urchins, marine flatworms and sea anemones. Many of these proteins share homology with fibrous gel-forming glycoproteins, including fibrillin, hemolectin and SCO- spondin. Moreover, proteins with potential protein- and glycan-degrading domains could have an immune defence role or assist degrading adhesive mucus to facilitate the transition from stationary to locomotive states. We also discovered glycosylation patterns unique to the pedal mucus, indicating that specific sugars may be involved in transitory adhesion. Our findings elucidate the mechanisms underlying *P. vulgata* adhesion and provide opportunities for future studies on bio-adhesives that form strong attachments and resist degradation until necessary for locomotion.

The role of thermal stochasticity in shaping the physiological performance of *Mytilus californianus*

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Climate change is forecasted to increase thermal stochasticity, yet we know little about how thermal stochasticity influences the physiological performance in intertidal organisms. We acclimated the mussel *Mytilus californianus* to either submerged conditions or a tidal cycle that included either predictable, unpredictable or no thermal stress during daytime low tide, and compared performance to wild mussels. We measured glycogen, heat shock protein 70, malate dehydrogenase activity and succinate just before low tide to assess preparedness for stress and measured cardiac responses during warming. Mussels acclimated to the unpredictable regime most closely aligned with performance of wild mussels, and relied on elevated glycogen to tolerate unpredictable low tide conditions, rather than priming stress or anaerobic mechanisms. Cardiac thermal performance was shaped by tidal cycle and thermal stochasticity. Our results suggest that incorporating key elements of the intertidal environment (tidal cycle and stochastic temperatures) is crucial for assessing organism responses to climate change.