Nereis Park – V

Oral presentations – Titles and Abstracts

BIOTURBATION AND ORGANIC MATTER MINERALIZATION PATHWAYS IN THE BERING SEA

David Shull

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The Bering Sea is one of the most productive marine ecosystems on the planet supporting large fisheries and abundant benthic communities. But, what happens to the food produced in the water column after it arrives at the seafloor? And, how does bioturbation influence the metabolic pathways taken by this organic matter? To better understand these processes and the role of the benthos in Bering Sea ecosystem function, we measured rates of oxygen consumption, denitrification, manganese, iron, and sulfate reduction across the Bering Shelf and slope. We observed strong regional variation in organic-matter mineralization pathways that correspond to differences in organic matter export to the benthos and variation in the rate of bioturbation. We also observed that mineralization processes that are less important for oxidizing organic matter nevertheless have significant consequences for primary productivity in this large ecosystem. In particular, benthic processes appear to drive the shift from nitrogen to iron limitation of primary productivity in deeper water.

BIOTURBATION OF THREE INVASIVE SPECIES OF MARENZELLERIA (POLYCHAETA) AND CONSEQUENCES ON THE CYCLES OF C, N AND P IN SEDIMENTS FROM THE BALTIC SEA

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After almost four decades of the invasion of *Marenzelleria* in the Baltic Sea, we have reached a broad knowledge of ecological consequences in the Baltic Sea system. However, due to morphological similarities, the three occurring *Marenzelleria* species in the Baltic Sea, *M. viridis*, *M. neglecta* and *M. arctia*, were often considered as a single functional trait. Recently, though, it has been found that the bioirrigation patterns of the three species are different and they cannot be considered as a single group. This study investigated the bioturbation effects of *M. viridis*, *M. neglecta* and *M. arctia* on the biogeochemistry of Baltic Sea sediments. *M. viridis* had deeper, higher bioirrigation (11 L m^{-2} d^{-1}) and survival (71%) in sand, while *M. arctia* had shallow, but higher bioirrigation (12 L m^{-2} d^{-1}) and survival (88%) in mud. M. neglecta had problems living in both sediment types (bioirrigation: 5−6 L m^{-2} d^{-1}, recovery: 21-44%). The deep *M. viridis* bioirrigation enhanced microbial total CO_2 (TCO_2) production in sand by 175% with a net efflux of NH_4^+ (7 mmol m^{-2} d^{-1}) and PO_4^{3-} (0.3 mmol m^{-2} d^{-1}), 3 to 30-fold higher than the other worms. Although the shallow and effective bioirrigation of *M. arctia* in mud did

not stimulate a high microbial TCO_2 production (61%) with nutrient fluxes close to zero, it may have played a relevant role preventing P release. The higher Fe(III) content in mud (40 mmol m^{-2}) combined with the oxygenation effects associated to the M. arctia bioirrigation increased up to 3-fold the mud capacity to retain P compared to sand (i.e. Fe(III) = 15 mmol m^{-2}). The sharp contrast in the impact of *M. viridis* and *M. arctia* on the C, N and P cycling should, thus, be critically taken into account to estimate accurately their implications in the whole Baltic Sea system.

CARBON AND NUTRIENT CYCLING IN SHALLOW ANTARCTIC BENTHIC COMMUNITIES SUBJECT TO GLACIER RETREAT

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The western Antarctic peninsula (WAP) is one of the fastest warming regions on Earth. Potter Cove is a small fjord on King George Island (northern tip of the WAP), strongly influenced by the Fourcade Glacier. This glacier has been actively retreating since the 1950s, exposing the underlying soft sediments to glacier calving disturbances, increased discharge of sediment-laden melt waters and to wave action. As a result of these locally altered conditions, benthic communities range from colonist to medium-developed assemblages. Benthic microalgae and large macroalgae are the main primary producers in this area. Their biomass eventually ends up in the sediment, where it is recycled to the basic nutrients. It can be expected that the gradient in development of benthic communities in Potter Cove will be somehow reflected in the local patterns in carbon cycling. In 2015-2016, we performed a seasonal cycle of in situ carbon and nutrient cycling measurements (summer, winter under ice measurements, and spring) in this area. Divers deployed benthic chambers over the sediment and measured fluxes of oxygen (Total Oxygen Uptake, TOU), DIC and nutrients at the sediment-water interface. A profiler was deployed in summer and spring, measuring vertical oxygen profiles in the sediment, from which diffusive oxygen uptake (DOU, representing microbial and chemical oxygen consumption) was calculated. The sediment was further sampled to assess environmental variables and benthic assemblage structure. Preliminary results show that DOU rates only contribute ~10% to the TOU, which points at a major role for macrobenthic communities, as compared to microbial communities. Carbon cycling in winter was remarkably lower than in spring and summer, which probably relates to a lower benthic activity and/or biomass. Sites most frequently disturbed by the glacier calving were characterized by the least developed communities and lowest carbon cycling. We are currently looking into the functional aspects (sediment reworking mode) of the macrobenthic communities to explain the spatio-temporal variability in biogeochemistry. This seasonal set of carbon cycling measurements along a gradient of benthic assemblage statuses in Potter Cove represents a unique study of direct and indirect effects of glacier retreat on benthic ecosystem functioning in the Western Antarctic Peninsula region. Finally, it contributes to the currently limited knowledge on the role of macrobenthos (bioturbation) in carbon and nutrient cycling in fjord systems in the Southern Ocean.

SPATIO-TEMPORAL VARIATION IN BIOTIC CONTRIBUTION TO ESTUARINE BENTHIC ECOSYSTEM FUNCTIONING

Sebastiaan Mestdagh

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Biodiversity in coastal ecosystems is currently dealing with great pressure caused by human presence. The importance of coasts and estuaries for economical, ecological or recreational purposes has inspired research focusing on the relationships between biodiversity and ecosystem functioning. These relationships and their spatio-temporal variation are important topics of investigation. In the estuary of the Scheldt (Belgium, the Netherlands), we performed an experiment based on a sampling campaign, during which we collected sediment cores for laboratory analysis. Cores were collected in each major salinity zone and in different habitats and seasons. In subsequent experiments, environmental parameters, biodiversity and biotic processes, were measured, such as bioturbation (measured and potential) and bioirrigation. As functional variables, we determined sediment community oxygen consumption (SCOC) and nutrient fluxes, and calculated nitrification and denitrification. All variables were tested for their variation along the different gradients in the estuary, and linear models were constructed to link functioning to biotic and abiotic variables. Results show a decrease in species richness with decreasing salinity, but consistent high macrofaunal densities and bioturbation potential in low-dynamic intertidal habitats along the estuary. Bioirrigation was highest on high-dynamic intertidal sites and during winter. Furthermore, SCOC and nitrification dropped to lowest average values in winter for low-dynamic intertidal and in summer for high-dynamic intertidal habitats. Denitrification was highest in high-dynamic intertidal habitats. Linear models suggest that species richness predicts functioning better than biotic activity (bioturbation and bioirrigation) for the overall data, even though nitrification and denitrification in low-dynamic intertidal habitats seems to be rather determined by bioturbation potential. In high-dynamic intertidal and subtidal habitats, abiotic variables explain most of the functioning. Our results show that ecosystem functioning is greatly dependent on biotic and abiotic variables, but their relative contribution appears to vary among habitats. Further research remains paramount to understand spatio-temporal variation of ecosystem functioning.

S**EDIMENT REWORKING OF *ARENICOLA MARINA* INDUCES BURIAL AND ACCUMULATION OF MICROPLASTIC PARTICLES IN MARINE SEDIMENTS**

Christopher Gebhardt

University of Rostock, Rostock, Germany The processes which determine the transport of microplastic are still poorly known, despite of the widespread occurrence of these particles. It is hypothesized that a large proportion of disposed plastic particles will reach the sea floor, however, investigations on the further fate of once deposited particles received little interest so far. To investigate the effects of bioturbation on microplastic distribution in marine sediments, specimens of the polychaete Arenicola marina were exposed to three different artificial particle tracers (luminophores, polystyrene (PS) and polyamide (PA)) with different particle sizes (luminophores: 130

µm, PS: 1000 µm, PA: 500 µm) in a long-term mesocosm experiment. Burial of particles showed great variation according to individual sediment reworking rates, but also indicated that vertical displacement of luminophores and plastic particles occurred at similar rates, despite of their different physical properties (size, shape and density). Downward transport rates reached up to ~1 mm·d-1. Contrary to luminophores, plastic particles accumulated at the sediment depth where feeding activity of A. marina occurred and were completely retained within these layers. An overall increase of the median grain size in all feeding layers after a time interval of 240 days suggests that this accumulation process was due to the selective feeding of A. marina by discriminating larger sediment and plastic particles. These findings emphasize that the distribution of microplastic can be considerably affected by sediment reworking processes. The selective feeding behavior of A. marina provides an effective pathway for the burial of relatively large plastic polymers, rendering marine sediments a potential sink for marine litter. The permanent burial of plastic particles may reduce their accessibility for some marine organisms, but may also support a long-term conservation in marine systems.

BIOTURBATION IN TWO CONTRASTING ENVIRONMENTS: NON-TIDAL VERSUS INTERTIDAL

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Coastal areas are complex systems that provide essential ecosystem services. However, they are under pressure from various anthropogenic disturbances that reach from global (e.g. sea-level rise) to local (e.g. local dredging, bottom trawling) scales. It is an important task to extend our general knowledge of these ecosystems for assessing and developing management strategies. Bioturbation is one of the key processes for ecosystem functioning that can be expressed by local and non-local sediment mixing. The latter transports particulate matter faster and to deeper horizons of the sediment, thus potentially stimulating ecosystem services, such as nutrient cycling, more intensively. We present modeled bioturbation data obtained by vertical chlorophyll a profiles and compare two contrasting systems within salinity gradients: (1) the non-tidal, brackish Southwestern Baltic Sea and (2) the intertidal, estuarine Westerschelde (Netherlands). In the Baltic Sea, the extent of non-local sediment mixing increases significantly with decreasing salinity and increasing abundance of gallery biodiffusing organisms. In the context of global warming and ocean desalinization, this could potentially result in an enhancement of non-locally mixed sediments. In order to substantiate this statement on a more global scale, this study aims to determine whether these relationships of non-local sediment mixing depending on biotic (i.e. the abundance of certain functional groups) and abiotic (i.e. salinity) factors can also be found in a remarkably different system (Westerschelde estuary).

HOW DO MACROFAUNAL ACTIVITIES IMPACT BIOGEOCHEMICAL CYCLING IN ANTHROPOGENICALLY DISTURBED SEDIMENT?

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Marine coastal areas are important for ecosystem functioning because they provide a wealth of goods and services. Hence, it is a major challenge nowadays to understand and predict how human activities will affect marine sediment communities, benthic biogeochemical cycling and the link between them. In this study, we investigate biogeochemical fluxes and the contribution of macrofaunal activities (bioturbation and bio-irrigation) in sediment ranging from muddy to coarse, including two coarse sediment stations affected by human activity (installation of an offshore windfarm and aggregate extraction). For each station, we conducted triplicate closed-core incubations to measure oxygen, nutrients and DIC fluxes as well as bioirrigation rates by following the decreasing concentration of bromide in the water column over time. After the incubation, the macrofaunal community was identified and the bioturbation potential of the community calculated (BPc). Our results show the highest Sediment Community Oxygen Consumption (SCOC) in a fine sandy station inhabited by an abundant bioirrigating and bioturbating macrofaunal community and characterized by relatively high organic matter content. In the muddy station, the SCOC was 4 times lower and the DIC efflux much higher than the SCOC reflecting anaerobic mineralization processes happening in absence of bioirrigators. Within the coarse sediment stations characterized by poor organic matter content and inhabited by a limited macrofaunal community, the undisturbed station shows the highest irrigation rates associated with moderate SCOC and DIC efflux. In the disturbed stations, irrigation rate, SCOC and DIC efflux were low suggesting that physical disturbance decreases the efficiency of mineralization processes in coarse sediments. The overall results show that irrigation of the sediment affects biogeochemical cycling along a range of coastal sediments.

DO PARASITES IMPACT BIOTURBATORS?

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Bioturbation by benthic fauna is related to the intensity of their behaviour and their activity (filtration, ventilation, burrowing). The age (or size) of the investigated biological models is currently addressed but there is little attention on any other factor(s) that could affect bioturbator fitness. Among them, we propose to question the role of macroparasites. According to abstracts, we revisit the biological models that were presented in the 2015 Nereis Park conference in Plymouth. We identify ca. 9 bioturbator species belonging to polychaetes (*Nereis, Arenicola, Melinna*), bivalves (*Cerastoderma, Abra, Macomona, Ruditapes*) and crustaceans *(Eriocheir, Upogebia*). Our aim is to provide evidence from the literature that 1) these bioturbators can potentially be parasitized; 2) the prevalence (% of infected hosts) can be high; 3) involved parasite can significantly alter host fitness with obvious consequence on its bioturbating activity, with cascade effect on environment. If, for a given species, these three conditions are fulfilled, we can argue that studies on bioturbation need to incorporate this variable. Soft-sediment bivalves are now sufficiently documented; they are frequently parasitized with impact on ventilation and burying ability. Crustacean models rather concern peracarids (e.g. amphipods) but, for large decapods, some data are now available on

crabs and mud shrimp, highlighting a negative effect on physiology and activity. Data on polychaetes are still scarce and rather focused on the description of parasite life-cycle. In conclusion our message is to promote collaboration between both disciplines: certain variability in bioturbation results can be explained by parasite infection, and effects of parasites on their host and environment need bioturbation expertise.

PARASITISM OF ENGINEER SPECIES: A KEY FACTOR OF MARINE ECOSYSTEM FUNCTIONING

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Thalassinid crustaceans are among the most influential ecosystem engineers in marine soft-bottom communities. They are also common host of bopyrid isopods, which have severe detrimental consequences on their physiology and population dynamics. In this study, we test whether native parasite infesting ecosystem engineer species play a significant role in ecosystem functioning. We carried out an integrated experimental study to investigate the influence of the bopyrid parasite *Gyge branchialis* on the behaviour of its host, the thalassinid mud shrimp *Upogebia pusilla*, and through cascade effects on sediment bioturbation processes and benthic solute exchanges. We showed that mud shrimp activity (mainly devoted to burrow maintenance and ventilation) was significantly affected by bopyrid infestation, translating on average into a 3-fold decrease of its intensity. Reduced activity-level of parasitized mud shrimp caused a 5.5 and 2.9-fold decrease of sediment reworking and bioirrigation rates respectively. Consequently, the influence of parasitized mud shrimp on benthic biogeochemical dynamics was drastically reduced as compared to healthy ones. Given the worldwide distribution of sediment-dwelling mud shrimp and their key role in bioturbation processes, parasite-mediated alterations of their engineering behaviour may have profound and broad ecological consequences for the functioning of marine coastal ecosystems.

FUNCTIONAL CLASSIFICATION OF BIOTURBATING MACROFAUNA IN MARINE SEDIMENTS USING TIME-RESOLVED IMAGING OF PARTICLE DISPLACEMENT AND MULTIVARIATE ANALYSIS

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It is increasingly recognized that functional traits of fauna are critical for element transformations. An example of such functional trait is the capacity for particle transport across horizontal and vertical gradients in environmental characteristics. The present contribution describes a general procedure for functional classification of fauna using

multivariate analysis based on a suite of experimentally derived variables for particle reworking. The relocation of fluorescently labeled particles (luminophores) added to surface sediments was quantified by side-view imaging during a two-week experiment incubating several common bioturbating species of marine benthic macrofauna: *Glycera alba*, *Nephtys incisa*, *Lipobranchius jeffreysii*, *Scalibregma inflatum* (Annelida), *Brissopsis lyrifera* (Echinodermata), *Abra nitida*, *Nuculana pernula*, and *Thyasira sarsii* (Mollusca) in thin glass aquaria. Multivariate analysis revealed groups of species with similar mode of reworking based on reworking variables associated with quantity and time (bulk), as well as vertical distance (depth) of particle transport. Most pronounced effects on bulk transport were found in the *N. pernula*, *A. nitida* and *L. jeffreysii* treatments, while only a limited quantitative capacity to relocate particles was observed in the *T. sarsii* and *N. incisa* treatments. Although stochastic patterns were observed for some species, a prominent capacity for vertical transport of surface deposited particles was demonstrated for the annelids and *T. sarsii*. From these results, three main groups of fauna with common reworking behavior were identified. *B. lyrifera*, *A. nitida* and *N. pernula* were species with only a limited effect on the vertical transport of particles. In contrast, while *N. incisa* and *T. sarsii* were able to relocate particles vertically, they shared a restricted capacity for bulk sediment transport. Despite high intraspecific variation, *G. alba*, *L. jeffreysii* and *S. inflatum* had the capacity for bulk and vertical transport of particles. Despite the challenge to generalize species functionality and reworking capacity of benthic macrofauna, our results demonstrated that time-resolved high-resolution imaging of particle displacement, in combination with multivariate analysis, provides a general experimental tool for functional classification of benthic macrofauna.

BEHAVIORAL RESPONSES OF BENTHIC MACROFAUNA TO OCEAN WARMING AND ACIDIFICATION

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Estuaries are on the frontline of environmental change and become increasingly threatened by multiple stressors including CO2 induced changes in seawater temperature and pH. The effects of acidification and warming may be additive, synergistic or antagonistic and understanding how these stressors interactively affect the behaviour of benthic macrofauna will provide insight into future ecosystem functional capacities. Behavioural activities such as feeding, burrow ventilation and predator avoidance influence individual health and population dynamics, hence ultimately affecting the biodiversity-mediated ecosystem services and functions. We experimentally investigated the behaviour and condition of the edible cockle *Cerastoderma edule* and the peppery furrow shell *Scrobicularia plana* under current and future ocean scenarios predicted by IPCC. Survival of the examined cockles remained high and was not affected by elevated temperature (+3°C) or lowered pH (-0.3 units). However, the condition index of cockles incubated under combined warming and acidification was significantly reduced after six weeks of incubation. Respiration rates increased under low pH, with highest rates measured under combined warm and low

pH conditions. Calcification decreased under low pH while clearance rates increased under warm conditions and were generally lower in low pH treatments. These responses suggest that the reduced food intake under hypercapnia is insufficient to support the higher energy requirements to compensate for the higher costs for basal maintenance and growth in future high pCO2 waters. We used pressure sensors to obtain porewater signals generated by hydraulic activities of S. plana to document the species' behavioural responses to high pCO2. Frequency and duration of burrowing, manoeuvring, siphon relocation, expulsion of (pseudo)faeces, filter –and deposit feeding activities were quantified. Given that these behaviours affect functioning and diversity of soft-sediment habitats, the gathered data will provide insights into some of the biological mechanisms that determine ecosystem resilience in a high pCO2 world.

IMPACTS OF CLIMATE CHANGE AND PHYSICAL DISTURBANCE ON BIOTURBATION AND BIOGEOCHEMICAL PROCESSES

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Continental shelf sediments disproportionately contribute to the biogeochemical cycling of organic matter at a global scale, but human activity and environmental change within these regions is likely to fundamentally adjust physical, chemical and biological characteristics that are influential in determining the stocks and flows of macronutrients and carbon exchange. Here we report the findings from a series of laboratory experiments that consider the effects of indirect climatic pressures (temperature, ocean acidification) alongside changes in naturally assembled benthic communities associated with altered disturbance regimes (cohesive versus non-cohesive sediments, lightly versus heavily trawled). Intact sediment communities, representing the full variety of biogeochemical conditions typically observed in temperate shelf seas, were collected in the Celtic and Irish Seas, returned to the laboratory and exposed to present (ambient bottom temperature, CO2 380 ppm) and anticipated future climate conditions (ambient bottom temperature+4°C, CO2 1000 ppm) for 6 months. In this presentation, we will investigate how varying disturbance regimes in combination with anticipated climate change may influence benthic community structure, infaunal burrowing and ventilation activities and associated levels of macronutrients. These data will help identify areas where macrofaunal traits and biogeochemical variables are closely coupled, and in what way and where this becomes decoupled.

THE PROTRACTED DEVELOPMENT OF BIOTURBATION THROUGH THE EARLY PALEOZOIC

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Well-bioturbated sediments have long been assumed to appear at the Precambrian–Cambrian boundary with the first occurrence of the index fossil and three-dimensional

burrow *Treptichnus pedum*. Recent field-based analyses, however, synthesizing ichnological, stratigraphic, sedimentological and taphonomic data collected from a range of lower Paleozoic siliciclastic successions spanning four paleocontinents, indicate that sediment mixing in marine shelfal environments remained limited until at least the late Silurian, 120 million years after the Precambrian–Cambrian transition. The protracted development of the sediment mixed layer holds important implications for contemporaneous biogeochemical (e.g., C, S and P) cycling. For instance, stratigraphically derived mixed layer depths for the early Paleozoic are consistent with sulfur data and supported by global sulfur model simulations which indicate that bioturbation exercised a first-order control upon Paleozoic sulfur cycling. The delayed development of intensive sediment mixing may also be linked to the anomalous preponderance of exceptionally preserved soft-bodied Lagerstätten characteristic of the lower Paleozoic stratigraphic record. These bioturbation data indicate that, in spite of concurrent advances in infaunalization, mixed layer development was a protracted process and did not occur with the first appearance of three-dimensional burrows, and that evolutionary advances in sediment colonization significantly outpaced advances in sediment mixing. This provides support for the previously hypothesized (Thayer, 1979, Science) late onset of infaunal mobile deposit feeding (biological 'bulldozing'). Ecosystem restructuring caused by the onset of significant bulldozing, unlike other major paleobiological and paleoecological innovations, appears to have occurred well after both the Cambrian Explosion and the Great Ordovician Biodiversification Event.

FLOW FROM IMAGES, AND ITS ROLE IN SHAPING A BIOGEOCHEMICAL MOSAIC

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Intermittent pumping activity of benthic macrofauna shapes the distribution of solutes in surface sediments, and can lead to complex patterns in the distribution and rates of redox reactions. I will discuss some modeling efforts that account for spatial heterogeneity, including the implications for benthic fluxes and process rates, and present ongoing work to quantify process rates from spatially and temporally resolved measurements as obtained with planar optodes.

DOES BURROWING BEHAVIOR EXPLOIT SEDIMENT FRACTURING OR FLUIDIZATION?

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The burrowing behaviour of organisms that inhabit the ocean floor exert considerable control on global biogeochemical cycles and the sedimentary record, but no direct observation has been made that relates burrowing activity to the response of the medium in natural sediment. Here we will present the findings of an investigation where we used time resolved high speed synchrotron radiation computed tomography to quantify repeat cycles of burrowing of the polychaete worm *Hediste diversicolor* in a natural cohesive sediment and applied a digital volume correlation to determine the mechanics of sediment deformation.

OXYGEN TRANSPORT IN PERIODICALLY VENTILATED POLYCHAETE BURROWS

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Burrowing organisms play a critical role for the functioning of coastal marine sediments, in part due to their pumping of oxygenated water through the burrow. In cohe-sive sediments, oxygenated burrow water allows for the dif-fusive flux of oxygen across the burrow wall and into the sediment, where it is consumed. In this study, we quanti-fied the burrow excurrent velocities, volume of water ven-tilated and oxygenation patterns within the burrow of the polychaete Alitta succinea. We determined that periodic ventilation of the burrow results in oscillations of the flux of oxygen across the burrow wall and oxygen concentra-tion within the sediment near the burrow wall. Addition-ally, we investigated the effects of temperature changes on oxygen dynamics in the burrow. The volumetric flow rate and frequency of burrow ventilation increased with tem-perature. Correspondingly, the frequency of the oscillations in oxygen flux across the burrow walls also increased with temperature. However, the time-averaged flux of oxygen across the burrow wall did not change with temperature (1.5 ± 0.3ol m−2 d−1), and the distance of oxygen penetra-tion into the burrow wall decreased with temperature (from 3.4 ± 0.5 at 6 °C to 1.6 ± 0.1 at 33 °C). Thus, seasonal changes in the volume of oxygenated sediment, as well as the pattern of oxygenation that sediment experiences, are expected to be significant while the total oxygen flux is expected to remain relatively uniform. We show that burrower ventilation behavior mediates the effects of temperature on sediment oxygen uptake.

BIOGEOCHEMICAL REACTIONS AND BIOIRRIGATION IN SEDIMENTS ALONG A SKAGERRAK-KATTEGAT-BELT SEA TRANSECT

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Four stations were sampled on a Skagerrak-Kattegat-Belt Sea transect cruise (R/V Aurora). Sediment samples were taken for benthic fauna abundance, anaerobic incubations (C, N and S reactivity), porewater solutes (TCO2, NH4+ and SO42-), and onboard bromide bioirrigation incubations. Station SKA 1 (386 m) was dominated by subsurface-feeding bivalves (79%); SKA 2 (586 m) was dominated by deep tube-dwelling and suspension-feeding polychaetes (66%); SKA 4 (45 m) was dominated by suspension-feeding brittle stars (52%); and SKA 5 (38 m) was azoic due to bottom water anoxia. The overall anaerobic reactions decreased with water depth, and fitted a double exponential decay pattern with sediment depth at all stations. The depth-dependent decay equations were coupled with a diagenetic porewater solute model containing an exponentially decreasing non-local exchange component. The porewater model fitted the measured porewater profiles perfectly when non-local exchange was included. Exchange coefficients were highest near the surface at SKA 1 and 4 due to intense bivalve and brittle star activity and much slower at SKA 2 where small tube-dwellers dominated. Depth attenuation of non-local exchange was strongest at SKA 1 reaching the level of SKA 2 below 10 cm depth. The results emphasize the importance of identifying the dominating infaunal species to fully understand the bioirrigation mechanisms. Modeling of onboard bromide profiles showed completely different non-local exchange with very low bioirrigation at SKA 1 and 2, and extremely high near-surface activity at SKA 4. These results indicate that the bromide approach is invalid for cores retrieved and incubated onboard a moving ship probably due to burrow and tube damage by coring as well as ship-vibration stress during incubation.

SPECIES COMPENSATORY RESPONSES DEPEND ON THE CAUSE OF EXTINCTION AND THE EXTENT OF BIODIVERSITY LOSS

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There is now strong evidence that ecosystem properties are influenced by altered biodiversity and that the form of the biodiversity-functioning relationship follows a saturating curve. However, the majority of studies have not accounted for the ability of surviving species to respond to changes in community composition and structure that can further moderate ecosystem functioning. Here, we use marine sediment invertebrate communities to experimentally assess whether post-extinction compensatory mechanisms alter biodiversity-ecosystem function relations following random and non-random extinctions. We find that compensatory dynamics lead to trajectories of faunal mediated sediment mixing and associated nutrient concentrations that diverge from those without compensation, and that the form, magnitude and variance of the biodiversity-function curve is highly influenced the functional composition of surviving species. Further, we find that the capacity for compensation is not

necessarily sufficient to fulfil the role of the extinct species and is dependent on the relative distribution and expression of functional traits in the surviving community. Further, we show that the importance of compensatory responses is highly dependent on the distribution of species within a community. Our findings indicate that the generalized biodiversity-function relation curve is likely to be an insufficient estimator of post-extinction ecosystem properties in natural systems.

ASSESSING BIOGEOMORPHOLOGY USING DRONES: NEW PERSPECTIVES FOR LARGE-SCALE BIOTURBATION STUDIES

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BURROW DIMENSIONS AND NETWORK PROPERTIES IN HETEROGENEOUS HABITATS

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The use of computed tomography for assessment of sediment bioturbation, through the differentiation of volumes of sediment with contrasting densities, has allowed the characterisation of bulk burrow metrics allowing statistical comparison of burrow surface area and volume across replicated treatments. Connected *Hediste diversicolor* burrow galleries show similar properties to network structures, with points in three-dimensional space, “nodes”, connected by burrow tunnels. Here we show that by treating burrow galleries as a network they can be converted into a mathematical representation (adjacency matrix) and we can interrogate these matrics to make statistical comparisons on burrow structure. Individuals of *Hediste diversicolor* (n = 20) were allowed to burrow in soft sediment for 24 hours across in sediment enriched in 5 different configurations (n = 4); homogenous non-enriched, homogenous enriched, bottom half enriched, top half enriched and quartered. We find that the networks were mostly “trees” with no loops or repeated motifs. Burrow surface area, volume and node number of largest in the homogenous non-enriched treatment, and branching indices show that the most branching occurs in more heterogenous networks (half enriched). Environmental conditions therefore have the potential to fundamentally change how an organism interacts with and behaves in it’s environment with consequences for nutrient regeneration and carbon sequestration and other ecosystem functions.

PEEPING INTO THE BLACK BOX: USING A “SMART” TRACER TO ENLIGHTEN OXYGEN CONSUMPTION IN BIOTURBATED SEDIMENTS

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Bioturbators and bioturbation are important drivers of respiration in aquatic sediments. Not only animals themselves are contributing to the total oxygen uptake of the sediment (TOU) with their own respiration, but also transport of solutes and sediment reworking caused by bioturbation are facilitating bacterial respiration in sediments. Activities of bioturbators such as bloodworms can lead to 490% increase of sediment respiration, which has a considerable impact on sediment biogeochemistry and the entire ecosystem. Despite the important impacts of bioturbation on aquatic respiration, still considerable unknowns exist. The increase of the TOU in bioturbated sediment is largely a black box – we know that the animal's activity is increasing the TOU, but why? Which part of the oxygen is consumed by animals, which by bacteria's, and how much of the oxygen consumption is due to inorganic reactions? Most of the methods used to measure TOU are not capable of distinguishing between respiration of bioturbators and aerobic bacterial respiration in the sediment. Furthermore, most methods also do not allow to discriminate between inorganic and biotic sources of oxygen consumption. To overcome this shortcoming, we have adopted the fluorescent "smart" tracer resazurin for the needs of bioturbation studies. This tracer is reduced to the also fluorescent Resorufin proportionally to the amount of aerobic respiration in the system, changing its colour from blue to pink. The tracer reduction is highly correlated with the amount of aerobic respiration in the system (r=0.96). Tracer reduction is impervious to inorganic sources of TOU. It is also impervious to the respiration of some animals (i.e. aquatic insect larvae). Thus, we can use resazurin to measure the bacterial respiration created "de novo" in bioturbated system. These properties of resazurin are allowing us to break down the increase in oxygen uptake in bioturbated sediment, and peep into the black box.

IMAGING BIOIRRIGATION USING A NOVEL LIFETIME-BASED LASER INDUCED FLUORESCENCE (TLIF) TECHNIQUE

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Burrow ventilation by tube-dwelling benthic animals introduces oxygen-rich water through a burrow inlet and releases plumes of deoxygenated water, which creates complex three-dimensional concentration distribution in the sediment as well as flow fields above the burrow. Mapping a high resolution of O2 concentration in the presence of benthic faunal activities is challenging. Here the dynamics of near-sediment O2 distributions around natural burrows inhabited by Chironomus plumosus was observed

in a series of laboratory experiments using a lifetime-based laser induced fluorescence (tLIF) technique. With its high-spatial (84 um) and -temporal (2 s) resolutions, the persistence of burrow ventilation-induced changes in the O2 dynamics above the sediment have been revealed. For a range of larvae densities which is frequently observed in ponds and lakes, the areal O2 uptake rates of the sediment inhabited by Chironomids increased by up to 2.5 times. The enhanced O2 flux into the sediment exceeded the demand by up to a factor of 4, which confirms the potential importance of burrow ventilation for mineralization rates and therewith for nutrient and carbon cycling.

THE INFLUENCE OF MYA ARENARIA ON SEDIMENT OXYGEN AND NUTRIENT DYNAMICS: A MULTI-SENSOR APPROACH

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Quantifying the effect of bioturbation on sediment oxygen dynamics requires detailed measurements of oxygen concentration at the fauna-sediment interface. This has successfully been accomplished by applying oxygen micro-sensor and planar optodes in bioturbation studies, facilitating an improved understanding of the complex tempo-spatial interaction between bioturbation and sediment biogeochemistry. However, the successful application of both approaches can be limited due to difficulties in applying the sensors directly at the fauna-sediment interface. This is especially true for bivalve's studies, where placement of the sensors at the interface can be obstructed by the fauna geometry and movement. To perform a detailed study of the bivalve Mya arenaria on sediment oxygen and nutrient dynamics we applied a multi-sensor approach. To document the highly complex and dynamic oxygen conditions around the buried bivalve, we directly attached an array of thin (Ø<230 µm) flexible fiber mico-optodes at different positions on the bivalve shell. This allowed real-time oxygen measurements directly at the fauna-sediment interface. Simultaneous to the micro-optodes we used 3-axis accelerometers and siphon video recordings to document bivalve movement in order to correlate the behavior to the oxygen environment around the bivalve and total sediment oxygen and N-fluxes. By combining the different sensors and approaches it was possible to identify different behavior modes that each had different effects on the sediment biogeochemistry. The study highlights the need for multi-sensor/approach studies in order to fully appreciate the complex interaction between bioturbation and sediment biogeochemistry.

ASSESSING CHANGES IN ANIMAL-SUBSTRATE INTERACTIONS THROUGH GEOLOGIC TIME: APPROACHES AND POTENTIAL

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The study of trace fossils has much to contribute to our understanding of the changing ecology of the past by providing a perspective of animal-substrate interactions in deep

time. Although the majority of ichnologic studies dealing with macroevolutionary implications has focused on secular changes in degree of bioturbation, a more sophisticated set of tools is currently available. Also, because trace fossils typically display a close link with environmental factors, and facies analysis has become an increasingly refined technique, it is possible to provide a more nuanced characterization of facies constrains. As a result, the ichnologic toolkit has contributed valuable insights into macroevolutionary trends. Analysis of changes in ichnodiversity (a measurement of ichnotaxonomic richness) through the Phanerozoic has shown that the three main evolutionary radiations in the marine realm (Cambrian Explosion, Great Ordovician Biodiversification Event and Mesozoic Marine Revolution), originally recognized based solely on body fossils, are also characterized by significant increases in behavioural innovations at ichnogeneric level. Increases in ichnodisparity (a measurement of the variability of trace fossil morphological plans, quantified as the number of architectural designs) are linked to the colonization of empty ecospace, as illustrated by the Cambrian Explosion for softgrounds, the Great Ordovician Biodiversification Event for hardgrounds, and the colonization of soils by insects during the end of the Mesozoic. Integration of concepts from evolutionary paleoecology and ecology resulted in a new approach to analyze benthic ecospace occupation and ecosystem engineering in space and time. This approach has shown that Paleozoic marginal-marine and continental environments were colonized by repeated early burst patterns of maximal ichnodisparity, ecospace occupation and level of ecosystem engineering prior to maximal ichnodiversity. In short, comparative analysis of the trace-fossil record through time allows detecting recurrent patterns and secular changes that may help to further increase our understanding of the underlying evolutionary dynamics of animal-substrate interactions.

ACOUSTICS AS A TOOL FOR STUDYING INFAUNAL IMPACTS ON SEDIMENTS

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Infaunal organisms alter their sediment environments by burrowing through and feeding on sediments and constructing and irrigating tubes and burrows. Irrigation and burrowing alter pore water chemistry and geochemical cycling. Tubes that extend above the sediment-water interface, feeding pits and fecal mounds have been shown to alter bottom boundary layer flow and consequently influence suspension feeding and erosion and deposition of sediments. Impacts of infauna on subsurface physical properties of sediments have been less well studied, however. We apply high-frequency acoustics to characterize the physical impacts of infaunal activities. Sound speed and attenuation were measured in laboratory mesocosms with single species and combinations of tube-building and burrowing taxa. Burrowing species such as the brittle star, Hemipholis elongata, increase porosity, whereas tube-building species such as the polychaete, Owenia fusiformis, increase the structure of sediment grains. Increased porosity is predicted to decrease sound speed, whereas structuring by tubes is predicted to increase sound speed. Depth of impact and spatial variability were determined by measuring sound speed at varying orientations and depths in mesocosms. Acoustic

propagation in sediments is a promising method for characterizing and quantifying physical ecosystem engineering in visually opaque sediments.

EFFECTS OF BIOTURBATION ON THE GLOBAL PHOSPHORUS CYCLE

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There has been extensive speculation concerning the environmental and geological effect of bioturbation on phosphorus burial in marine settings. It has been proposed that the evolutionary onset of extensive sediment mixing could have increased marine phosphorus burial and, in the long term, have led to decreased oxygen levels in the ocean-atmosphere system. However, the quantitative biogeochemical models upon which this view of Earth's evolution are founded do not explicitly account for carbonate fluorapatite (CFA) burial. Thus, previous attempts to model the effects on bioturbation on global phosphorus burial do not account for what is, in modern marine settings, the primary burial sink for phosphorus. Here we present a new diagenetic model with full phosphorous cycling. The model includes CFA burial and accounts for the influence of pH and carbonate ion activity on the phosphorus burial flux. We find that although bioirrigation and sediment mixing can, independently, push phosphorus burial in opposing directions, the overall impact of increased bioturbation is to decrease the extent of phosphorus burial in continental margin sediments. In this light, the evolutionary onset of bioturbation might have, in contrast to the current paradigm, have led to increased ocean oxygenation.

CU TOXICITY FOR THE FRESHWATER OLIGOCHEATE TUBIFEX TUBIFEX – INSIGHTS GAINED VIA SIMPLE BIOTURBATION MEASUREMENTS AND CLASSIC ENDPOINTS

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We investigated the effects of copper (Cu), an essential but potentially toxic metal, omnipresent in sediments on the common freswater oligochaete Tubifex tubifex using both simple bioturbation and more conventional ecotoxicological endpoints. Two experiments (A and B) were conducted using similar designs with 7 day exposures of worms to clean or Cu-spiked sediment (added as CuCl2) in concentrations ranging from 1 to 650 µg Cu g-1 dw sed) in small plastic cuvettes (10 x10x45 mm). These concentrations represent a range from naturally occurring background to moderately contaminated sites. In Experiment A we investigated Cu bioaccumulation and effects of Cu on worm mortality, feeding rate (egestion) and growth. In Experiment B we investigated Cu effect on worm bioturbation (particle diffusion and maximum penetration depth) by adding a tracer, i.e., green microparticles, on top of the sediment and following particle transport. Adverse effects were detected for all assessed endpoints (bioturbation, egestion, growth and survival) at higher concentrations. The 24 acute toxic level, LC50, was estimated to be 256 µg Cu g-1 dw sed and while effects

concentrations, EC50's, for the other endpoints (over 7 d) were typically observed for our middle exposure concentrations of 16-37 µg Cu g-1 dw sed). Surprisingly, a slight positive effect was observed at the lowest Cu concentrations indicating hormesis. All endpoints were consistent in showing the effects of Cu. Furthermore, it is likely that changes in feeding rate, as indicated by changes in bioturbation, were related to the detrimental (and positive) effects of Cu. The reasons for the changes in feeding rate are not clear, but it is likely that both direct effects on worm physiology as well as avoidance behavior led to a reduction in feeding at higher Cu levels. This has potential implications for ecological role of this important freshwater bioturbator in polluted sediments.

RELEASE OF NUTRIENTS AND METALS FROM SHELF SEDIMENTS IN THE BLACK SEA AND BALTIC SEA: CONTRASTING ROLES FOR MACROFAUNA

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Macrofauna can strongly impact the release and retention of nutrients and metals from shelf sediments. For example, bioirrigation can enhance solute transport across the sediment-water interface. Both bioirrigation and bioturbation can also lead to alterations in the sediment redox zonation that ultimately can reduce solute transport. These contrasting effects hamper predictions of the impact of macrofauna on benthic fluxes. Here, we assess the impact of macrofaunal activity on the release of nutrients (NH_4, NO_x, PO_4, $Si(OH)_4$), metals (Fe, Mn) and dissolved inorganic carbon at 6 stations along a water depth gradient on the North-Western Black Sea shelf and at 4 shelf stations in the Baltic Sea (Baltic Proper and Gulf of Finland). Benthic flux measurements using whole sediment cores and in-situ benthic landers and Br-tracer experiments reveal large contrasts in the effect of macrofauna on benthic fluxes. In the Black Sea, macrofaunal abundance and activity and benthic fluxes of all solutes are highest at our near coastal sites and decline offshore. While bioirrigation at the coastal sites enhances benthic fluxes over those expected due to molecular diffusion alone, results for individual benthic flux chambers suggest an inverse correlation between the number of macrofauna and the release of nutrients and metals. This suggests that at higher abundances of macrofauna, retention mechanisms gain importance. Macrofaunal abundances in the Baltic Sea are significantly lower than in the Black Sea and we find that the impact of macrofauna on benthic fluxes is limited. Other factors, such as bottom water oxygen and organic matter input are dominant controls on solute exchange in this setting. Our results highlight that the abundance and activity of macrofauna can determine their impact on benthic fluxes. We discuss how this may impact the biogeochemistry of the Black Sea and Baltic Sea.

LONG-TERM CHANGES IN A PRISTINE MANGAL ECOSYSTEM IN EASTERN AFRICA

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THE FOSSIL RECORD OF ECOSYSTEM ENGINEERS: EXCEPTIONALLY PRESERVED FECAL MOUNDS FROM THE UPPER JURASSIC OF SPAIN

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Ecosystem engineering species are thought to have played a key role in the history of the biosphere, ecosystem performance, and the evolution of biodiversity. However, there is little direct evidence of their occurrence in the fossil record. Exceptionally preserved fecal castings are present in a medium- to very fine-grained sandstone of the Upper Jurassic Lastres Formation of Asturias, northern Spain. The mounds, which are associated with vertical burrows, occur on a surface covered by straight to sinuous-crested ripples. Thirty-five structures are present on a surface of approximately 1m2, defining a distinctive pit-and-mound topography. Specimens preferentially occur on ripple troughs (74%), with secondary distribution on ripple slopes (21%), and very rarely on ripple crests (5%). The mounds consist of conical to semispherical accumulations of spaghetti-like fecal castings reaching up to 9 mm in height. Diameter of the mounds is 14.9-42.4 mm; fecal casting diameter is 0.9- 2.5 mm. An apical or displaced subcircular depression or vertical burrow outlet is present in many specimens. These Jurassic trace fossils are identical to those produced by arenicolid polychaetes (e.g., *Arenicola marina*) in modern tidal flats. Preservation of biogenic structures on the sediment surface exhibiting the original three dimensional morphology is extremely unusual in the fossil record. The preservation of the fecal mounds and feeding funnels may have resulted from the interplay of four factors: (1) the dominantly low-energy conditions of the protected embayment within a river-dominated delta; (2) mud blanketing of the sandy coastal-plain deposits; (3) the absence of bulldozing species; and (4) the role of microbial binding. Bioturbation by modern *Arenicola marina* has been shown to modify the sedimentary habitat resulting in changes in benthic communities and ecosystem functioning. The occurrence of Jurassic fecal mounds in combination with new insights in how these organisms affect the functioning of modern intertidal flats may help to assess their potential role as ecosystem engineers during the Mesozoic Marine Revolution. For example, through their irrigation activity, lugworms are known to provide intermittently oxic microhabitats. In addition, lugworm sediment reworking largely influences the stability of the sediment and the microtopography of the sediment surface. Micro-XRF imaging analyses of thin sections of fossil arenicolid burrows and modern tidal flat worm burrows show iron- and manganese-rich zones along the edges

of the burrows. This is consistent with chemical precipitation resulting from steep redox gradients generated by introduction of oxygen into anoxic sediments. Considering biogenic habitat transformations by ecosystem engineering species may improve our ability to interpret the fossil record and to reconstruct Jurassic benthic systems.

BACTERIAL REOXIDATION IN BIOTURBATED AND ELECTROGENIC SEDIMENTS

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INCREASED DENSITIES OF THE BIO-IRRIGATOR LANICE CONCHILEGA AFFECT COMPOSITION AND DIVERSITY OF NOSZ TRANSCRIPTS

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The presence of the piston-pumping polychaete *Lanice conchilega* can induce short term oscillations in oxygen and nitrate availability at deeper sediment layers, affecting the functional properties of local microbial communities. Here, we investigated the effect of *Lanice conchilega* densities on the expression of the nosZ gene, a gene encoding for the enzymes involved in the last step (reduction of N2O) of the denitrification pathway. Sediments with “high” , “low” and no Lanice individuals were collected from the intertidal and incubated submerged (reflecting the high water tide) in the lab, to measure vertical oxygen profiles and oxygen oscillations during 35 minutes at 1.5 mm sediment depth before slicing the sediment, and extracting RNA for Illumina sequencing the nosZ gene. We found 502 unique amino acid sequences (“nosZ-UAT), only 21 of them were abundant (>1% relative abundance). nosZ-AUT based community analyses showed that high densities of Lanice significantly affected the nosZ transcript composition. In addition, higher variability was observed in the high density treatments as well. Further differences were observed between the top layer of the sediment (0-0.5 cm) and the investigated deeper layers. The difference in nosZ-AUT Shannon diversity between deeper sediment layers and the upper sediment layer increased with *Lanice* density. The observed differences in nosZ-AUT composition and diversity at small horizontal (m) and vertical (cm) scale can thus be attributed to differences in bio-irrigator densities. We hypothesize that this due to stronger oscillations of both O2 and NO3- availability in the presence of high densities of bio-irrigators. Oscillations of O2 concentrations at a single spot in otherwise anoxic environments create microhabitats where coupled nitrification-denitrification is possible, while providing the environment with NO3- provides substrate for denitrification. As such, the presence of high densities of bio-irrigators increase the effect of already reported tide-related redox oscillations during periods of submersion.

INVERTEBRATE MUCOPOLYSACCHARIDE FUELS THE SEDIMENT MICROBIAL NITROGEN CYCLE

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Sediment nitrogen cycling is a microbially mediated biogeochemical process that plays a key role in regulating benthic and pelagic productivity. Mucopolysaccharides are produced by many sediment invertebrate taxa to aid locomotion and burrowing, and these protein/polysaccharide rich secretions have the potential to be an important source of organic carbon and nitrogen to sediment ecosystems. Yet, we have a limited understanding of how mucopolysaccharides impact general sediment microbial communities and specific microbial functional groups that mediate nitrogen cycling processes. To address this knowledge gap, sediment was incubated with and without Nereis diversicolor-derived mucus. Changes in the concentration of nitrogen compounds (ammonia, nitrite, and nitrate) and in the structure of the bacterial community were then assessed over a two week incubation period. With the addition of the mucopolysaccharide, sediment carbohydrate concentration increased and the sediment was able to support a more abundant bacterial community with a distinct community structure. We also observed an increase in the abundance of bacterial and archaeal ammonia oxidisers in the presence of mucus, and a concomitant increase in nitrite and nitrate concentrations. N. diversicolor mucopolysaccharide can enhance sediment nitrification rates by fuelling and stimulating key nitrifying microbial groups. We therefore propose that benthic invertebrate mucopolysaccharides should be considered an important and specific functional trait when assessing the contributions that species make to sediment ecosystem structure and function, to encompass the wider secondary effects that result from species behaviour.

ON THE NON-EQUIVALENCE OF NONLOCAL TRANSPORT AND MICROSTRUCTURE MODELS OF BIOIRRIGATION

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Following Emerson, et al (1984; JMR) and Boudreau (1984; JMR), the effects of bioirrigation on sedimentary solutes have been commonly quantified using non-local transport models. This parameterization has been incorporated into increasingly sophisticated models of sedimentary diagenesis in the bioturbated zone and global estimates of elemental cycling. Unfortunately, the underlying approximations in this compellingly simple model have been generally ignored and many, but not all, applications of non-local transport are fundamentally flawed and misleading. While non-local parameters derived from conservative tracer distributions such as Br- or Cl- are measures of the averaged intensity of bioirrigation on solute transport, they cannot be used to accurately model coupled redox reactions such as N, Mn, Fe, and S diagenesis given oxic-anoxic zonal interactions, reactions having nonlinear kinetics, microbial distributions, or any diagenetic process strongly dependent on structure and temporal-spatial scaling.

HOW TO MAKE SOIL: ADD PARENT MATERIAL, SOIL ANIMALS, ROOTS, WEATHER, AND SET THE BLENDER ON LIQUEFY

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In his seminal expostulation of the factors affecting soil formation, Hans Jenny rightly included organisms as one among five or six that are demonstrably important. Earth's soils are now widely understood to be the product yielded up by interactions between organisms (microbes, plants, and animals) and other factors such as parent material, topography, climate, and time. Notably, the influence of plants and animals on soil formation can be mediated through their physical interactions with the matrix, including mixing and movement of soil particles. In this presentation, we make the (possibly erroneous) assumption of a naïve audience and give an overview of the diversity of organisms involved in terrestrial bioturbation along with a discussion of the physical mechanisms involved. We present mid-term results of a long-term study established at Down House in southern England where we have observed the burial of surface applied objects through the action of earthworms (and other organisms) during the past 10 years. We discuss the results from several of our studies examining the ecological consequences of bioturbation of soil by an invasive earthworm species. Finally, we present preliminary results from an ongoing study of how perturbations of surface soil horizons through differing land management and land use histories can impact soil faunal assemblages and their resultant effects on ecosystem function.

SOIL BIOTURBATION: HOW DO EARTHWORMS REWORK …REGARD TO THEIR MARINE HOMOLOGUES?

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In order to investigate bioturbation generated by earthworms, a laboratory experiment involving four earthworm species individuals belonging to two different ecological types: anecic (*Aporrectodea nocturna* and *Lumbricus terrestris*) and endogeic (*Allolobophora icterica, Aporrectodea caliginosa*) was carried out. Experimental soils consisted in reconstructed soils (15 cm of topsoil and 15 cm of deep soil), with discrete layers of fluorescent inert tracers (luminophores) at the surface (orange colour), 3 cm deep (green colour) and 15 cm (pink colour), and food (wheat straw) provided at the surface. The topsoil contained about twice as much organic matter that the deepsoil. Earthworms were added to soils, and after 26 days of incubation both the construction of biogenic structures (X-Ray tomography) and particle reworking (luminophores technique) were quantified. Results clearly showed different behaviours between the ecological groups, with the endogeic species producing denser and complex networks of galleries regard to the anecic species, and more especially in the topsoil. Particle

reworking occurred both through the cast production and worms' movements within the soil column but appeared weak and linked to the density of galleries. This apparent weak reworking could be explained by the behaviour of studied earthworms (feeding mode, gallery building procedure...) but also by the inadequacy of the quantification technique used.

FACTORS THAT INFLUENCE EARTHWORM SENSITIVITY TO GLYPHOSATE

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Many researchers have analyzed the effects of glyphosate and glyphosate-based formulations on earthworm health. They have variously found negative effects, positive effects, and no effects. Pilot studies from our lab have produced similar inconsistencies. This project aimed to determine which factors might drive earthworm sensitivity to Roundup-Ready-To-Use®, a popular herbicide. Taking cues from the literature and our pilot work, we examined the effects of soil temperature, initial earthworm size, and the interaction between the two on final earthworm weight after a month of exposure to contamination. We also examined the effects of those variables on earthworm survival in a stressful environment. We found that initial body size, soil temperature, and the interaction between the two affected earthworm sensitivity as measured by growth and by response to a stress test. Large worms grown in heated soil responded to contamination by growing significantly larger than their uncontaminated counterparts. Also, regardless of initial body size, earthworms living in unheated soil lived significantly fewer number of minutes during the stress test, with herbicide-exposed worms surviving for the shortest number of minutes overall. This study shows that earthworm sensitivity to a glyphosate-based formulation varies with very specific environmental conditions. This may explain the variation in the published literature, where neither initial earthworm body size nor soil temperature is generally considered.

BIOTURBATION AS A BIOREMEDIATION SOURCE IN FRESHWATER SEDIMENTS

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Bioturbation provides opportunities to develop nature based solutions for marine and in freshwater ecosystems bioremediation. In continental systems, the target of water quality is a major concern and the natural service of water quality regulation is just beginning to be quantified. The benthic invertebrate communities together with primary producers (macrophyte, algea and biofilms) are the main biodiversity groups that originate this service. The hot places, where this real benefit to people is reducing pollutant loads, are wetlands and river bed sediments. With in laboratory and in field experiments, we demonstrated that bioturbation not only promotes the nutrient retention in the water flowing through these habitats, but also may favor heavy metal phytoextraction and pesticide transformation. The invertebrate influence varies depending on the sediment granulometry, with biotransports as a major process in wetlands and biofilm grazing in macroporous sediment. Two case studies illustrate this biodiversity influence in experimental microcosms. The DETOX project highlights the

effects of interaction between microbial, macro- and meiofauna on N-NO3− in macroporous stream sediment. After 56 days, N-NO3− reduction rates ranged from 3.76 ± 0.35 in sediment without invertebrates to 8.92 ± 0.69 mg N d−1 kg−1sediment (fresh weight) in the treatment with meiofauna and macrofauna grazing. The SMART-CLEAN-GARDEN project promotes the integration of invertebrates in biofilters of sewage water that usually involve only macrophytes. Coupled bioturbation and phytoremediation were previously tested in laboratory with tubificids and an aquatic plant as engineers in microcosms reproducing each water sediment interface of wetlands. After 30 days under a bio-advection of 16 to 18 cm.year-1 the plant root bioaccumulation of Cadmium is significantly increased. In a second experiment, although the total concentrations of 14C-[atrazine + metabolites] in the Typha latifolia seems to be not different with bioturbation tubifidids, the number of metabolites increased in the plant's root.

Poster

PARASITE INTERFERENCE WITH BIOTURBATION ACTIVITY: A STUDY OF TRACE-METAL REMOBILIZATION

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Sediments can act as major sinks or sources of contaminants for aquatic system, with several factors influencing direction and intensity of contaminants fluxes at the water-sediment interface. Among them, impact of bioturbation can be substantial by alteration of sediment chemical and physical properties (through bioirrigation and sediment reworking). Although the influence of bioturbation on chemical exchanges between the sediment and the overlying water has been extensively studied, intrinsic parameters of bioturbators (sex, age, fitness, stress) have rarely been considered in these studies. However, in natural environment, several factors could deeply impair the bioturbation behaviour of benthic organisms. Among possible stressors, parasitism is of major concern. Indeed, parasites are widespread in coastal environments and their major influence on individual fitness, population regulation and community structure is now well documented. Accordingly, parasitism should be considered when investigating host bioturbators activity. Here we propose to study the influence of a macroparasite species (*Gyge branchialis*) on mud shrimp host (*Upogebia pusilla*) capabilities to resuspend a contaminant (cadmium) from the sediment to the overlying water. Indeed, the parasite species *G. branchialis* is known to alter U. pusilla condition index and to impair its burrowing behaviour, with potential consequence on bioturbation activities. Non-parasitized and parasitized mud-shrimp have been placed in cadmium-spiked sediments. Effects of mud shrimp (non-parasitized vs parasitized) on cadmium resuspension and bioavailability have been followed for 15 days by measuring concentrations of total and dissolved cadmium in the water column. At the end of the experiment, cadmium concentrations have been determined in mud shrimp burrow walls and in surrounding sediments in order to compare sediment reworking and bioirrigation processes between non-parasitized and parasitized animals. Cadmium concentrations in mud shrimp have also been quantified in order to evaluate parasite influence on contaminant bioaccumulation (trophic contamination).

TAKING PICTURES OF MUD: BIOTURBATION IN ACTION

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Bioturbated marine sediments are highly heterogeneous environments chemically, physically, and biologically. In such a medium, point measurements are simply not adequate for quantifying the spatio-temporal dynamics of the system. In the Volkenborn Lab, we are working on multiple novel approaches to quantifying the effects of

bioturbation on the structure and dynamics of bioturbated sediments in two and three dimensions with high temporal resolution.

SPATIAL AND TEMPORAL VARIATION IN BIOIRRIGATION AND BIOTURBATION AND RELATIONSHIPS WITH ENVIRONMENTAL VARIABLES ALONG THE ESTUARINE GRADIENT OF THE SCHELDE ESTUARY

Xiaoyu Fang

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To quantify the relative contributions of macrofauna population densities and the abiotic environment to community wide benthic activities (bioturbation and bio-irrigation), seasonal surveys were carried out at 9 locations between September 2015 and June 2016 in the Schelde estuary (the Netherlands, Belgium). Locations comprised the three major ecotopes (low dynamic intertidal flats, high dynamic intertidal flats, and the subtidal channel) in the three salinity regions (poly,- meso-, and oligohaline). Luminophore particles and bromide tracers were used in laboratory incubations to quantify bioturbation and bioirrigation activity in the different communities. Principle component analysis on faunal data underlined a strong relation between the macrofauna community and the abiotic environment with the two main axes characterized by salinity and sediment granulometry. Considering all locations and sampling moments, the mean bioturbation coefficient (Db) was 0.0061cm2.day-1 and the mean bioirrigation rate was 0.059ml.min-1.. Particle mixing ranged from 0 to 0.104cm2.day-1 and bioirrigation ranged from 0.002 to 0.387 ml.min-1. Spatial and temporal variability in benthos activities were prevalent with generally low irrigation and particle mixing rates in the subtidal ecotopes. Bioirrigation peaked at high dynamic intertidal locations with maximal rates in wintertime in the polyhaline region. Bioturbation rates were generally highest in the low dynamic intertidal ecotopes, except for the polyhaline region where highest rates were found in the high dynamic intertidal ecotope in most seasons. Regression analysis indicated that population densities of species *Hediste diversicolor, Bathyporeia pilosa, Macoma balthica, Corophium volutator* and *Corophium arenarium* contributed significantly to the spatio-temporal variability in benthic activity. When examined separately for each ecotope, seasonal dynamics in macrofauna species population densities explained 24-81% of variation in bioturbation and 26-90% of the variation in bioirrigation found throughout the year. In general, better model performance was found for polyhaline and mesohaline locations. From the abiotic and biotic variables tested, abiotic properties (salinity and sediment mud and chlorophyll a content solely explain 25.2% of the bioirrigation variability, while 50.4% of the variability can be solely be explained by biotic variables. Abiotic (29%) and biotic (21%) contributions explain together 33% of bioturbation variability. This high shared explained variation indicates a close linkage between species sediment reworking traits and the environment.

THE EFFECT OF MACROFAUNAL BEHAVIORAL RESPONSES TO A DIURNAL OXYGEN CYCLE ON SEDIMENT METABOLISM

Kara Gadeken

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Oxygen availability is a critical factor affecting macrofaunal behaviors and metabolic processes in marine sediments. Hypoxia (dissolved oxygen concentrations below 2 mg/L) decreases total macrofaunal bioturbation and bioirrigation activity and lowers sediment metabolism rates. Shallow water oxygen patterns often follow a diurnal cycle as dissolved oxygen drops to hypoxic levels at night due to respiration and then increases during the day with photosynthesis, creating recurring, potentially stressful suboxic conditions. Sediment oxygen flux is known to depend on ambient dissolved oxygen concentration, but behavioral responses of organisms to hypoxia can be complex and diverse, introducing variability into sediment metabolism rates. In this study, sediment oxygen consumption rates were measured via in situ flow-through metabolism chambers throughout a diurnal cycle in natural and artificially oxygenated shallow subtidal sediments. The macrofauna present in the chambers were collected, identified and counted, and the relative bioirrigation activity level of each taxa was described. We hypothesize that sediment metabolism rates will recover from nighttime low oxygen conditions (fluxes of oxygen into sediments will increase) more rapidly in sediments with actively bioirrigating species than in sediments without those species. The multiple potential responses of macrofauna to short-term oxygen variability may be an important factor driving shallow sediment metabolism rates and macrofaunal behavior.

CROSSED-EFFECT BETWEEN TEMPERATURE AND PESTICIDES ON FISH: BEHAVIORAL AND PHYSIOLOGICAL RESPONSES OF CARASSIUS AURATUS

Gandar Allison[1], Jean Séverine[1], Canal Julie[1], Marty-Gasset Nathalie[2], Gilbert Franck[1], *Sanchez-Perez José Miguel[1], Laffaille Pascal[1]*

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Climate change has been identified as one of the major drivers of biodiversity and ecosystem functioning in the coming decades. At the same time, agricultural and industrial development has led to an explosion of pollutants in aquatic and terrestrial ecosystems. In France, the fourth largest world consumer of pesticides, the chronic contamination of surface water is reported especially in wetlands. Importance of crossed-effects between climate and pollutions has been identified, both on distribution and abundance of species and on ecosystem functioning. However, studies on crossed-effects between temperature and pesticides on fish are often limited.

In this study we experimentally assessed behavioral and physiological responses of a common freshwater fish of wetlands, *Carassius auratus*, to individual and combined thermal and pesticides stresses. We exposed juveniles at two temperatures and to a mixture of seven common pesticides at two different concentrations. We followed sediment reworking behavior during 96h and measured several physiological endpoints (condition factor, hepato-somatic index, protein concentrations in liver and white

muscle). We found that temperature warming significantly modifies the behavioral and physiological responses of the goldfish to pesticides.

BENTHIC DIAGENESIS IN A SCOTTISH LOCH: EFFECTS OF INFAUNAL ACTIVITY

Ronnie Glud

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Microprofiles, chamber incubations and eddy covariance measurements conducted at 65m depth in Loch Etive, UK revealed an intense spatial and temporal variation in benthic solute exchange. The variation was mainly related to high densities of brittle star *A filiformis* (1070 ± 280 m-2). The numerous burrows were intensively irrigated enhancing the benthic O2 uptake by ~50%, and inducing highly variable redox conditions and O2 distribution in the surface sediment. This was confirmed by laboratory investigation using Coumputer-Aided Tomography (CAT) and planar optodes, that also revealed changes in irrigation activity by *A filiformis* depending on availability of suspended food particles. This observation partly explained the in situ flow dependence of benthic O2 uptake as resolved by the non-invasive eddy approach. The complex O2 dynamics of the burrow environment concurrently enhanced the efflux of phosphorus and silicate and furthermore stimulated nitrification and coupled denitrification rates making the sediment an efficient sink for bioavailable nitrogen. The highly dynamic redox conditions presumably also facilitated an efficient degradation of both terrestrial and marine derived organic material. The study combined a range of "state of the art" complementary measuring approaches and documented the pivotal role of infaunal behavior and activity for benthic diagenetic processing.

CHASING RAINBOWS: BIOTURBATION AND BIOIRRIGATION AT HIGH ENERGY BEACHES

Angelos Hannides

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The nearshore zone (the area where land and ocean interact) is extremely important to the economic and ecological health of human societies, as reflected by the majority of the world's population concentrated within 50 km from the coasts. The high-energy sandy beaches that are the dominant ecosystem of the South Atlantic Bight coastlines are also the main attraction for the vibrant tourism industry, and many human activities can place considerable strains on them and the way they respond to major natural disturbances, such as hurricanes and floods. Evaluating the state of sandy shores and their vulnerability to human activities and impacts requires an understanding of their geophysical, biogeochemical and ecological function. The permeable nature of the sandy columns characterizing these beaches sets the stage for enhanced exchange between sand and overlying water. My presentation focuses on the relative importance of (geo)physical vs biologically-mediated exchange at this challenging to study setting. Preliminary data reveal deep and broad profiles in porewater constituents, such as dissolved phosphate, and deep penetration of sedimentary Chl *a*, presumably produced

near the surface. Such features could be driven by purely physical mixing, but observations confirm the presence and activity of infauna to similar depths, perhaps stimulated by seasonal productivity cycles. Even though methods to study resulting infaunal bioturbation and bio-irrigation remain elusive at present, these processes cannot be ignored until proven negligible.

OMEN-SED (ORGANICE MATTER ENABLED SEDIMENT MODEL): A NEW, NUMERICALLY EFFICIENT SEDIMENT MODEL FOR COUPLING TO ESMS

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Marine surface sediments host the largest carbon reservoir within the surficial Earth system, provide the only long term sink for atmospheric CO2, recycle nutrients and represent the most important geochemical archive used for deciphering past changes in biogeochemical cycles and climate. Most biogeochemical cycles and reactions in the surface sediments can be related either directly or indirectly to the degradation of organic matter. Despite its fundamental importance, an appropriate Earth System model (ESM) of the coupled atmosphere-ocean-sediment system which is able to model all relevant processes and feedbacks over geological time-scales currently does not exist. The major problem is the high computational cost of simulating the essential redox reactions in marine sediments which are important to calculate burial of organic matter and benthic recycling fluxes of chemical compounds. In most ESMs sediment-water dynamics are either neglected or treated in a very simplistic way. To provide a more realistic description of organic matter degradation and nutrient cycles in marine sediments we have developed OMEN-SED, a new, one-dimensional, numerically efficient reactive transport model. OMEN-SED is the first analytical model to explicitly describe OM cycling as well as associated dynamics of the most important TEAs (i.e. O_2, NO_3, SO_4), related reduced substances (NH4, H2S), the full suite of secondary-redox reactions, macronutrients (PO4) and associated pore water quantities (ALK, DIC). To represent a redox-dependent sedimentary P cycle we consider the formation and burial of Fe-bound P and authigenic Ca-P minerals. Thus, OMEN-SED captures most of the features of a complex, numerical diagenetic model, however, its computational efficiency allows the coupling to global ESMs and therefore the investigation of coupled global biogeochemical dynamics over different timescales. This presentation provides an overview of the new sediment model and it's coupling to the ESM cGENIE.

SEDIMENT BIOGEOCHEMISTRY CONTROLS RELEVANCE OF BIOTURBATION FOR PHOSPHOROUS CYCLING IN LAKE

Valentyna Inshyna

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Non-biting midges' larvae (Diptera, Chironomidae) are bioturbating ecosystem engineers in freshwater sediments. Chironomidae larvae occur typically in densities of 1,000 m-2, but in exceptional cases densities of up to 200,000 m-2 are possible.

Chironomidae larvae impact on nutrient cycling in lakes, lagoons and estuaries and are highly relevant for phosphorous cycling. Some experiments revealed that bioturbation is increasing phosphorous release from sediments. In contrast, other experiments showed increased retention of phosphorous in sediments bioturbated by Chironomidae. We hypothesize that the sediment composition is the primary control of Chironomidae impacts on phosphorus cycling. Basically, the availability of iron(oxy)hydroxides as binding partner for phosphorus controls whether sediments act as sources or sinks of phosphorus. To test this hypothesis we conducted a series of mesocosm experiments in which Chironomidae larvae dwelled in sediments with manipulated iron(oxy)hydroxide content. For that purpose either the iron content of the sediment or the sulphate concentration of the overlying water was manipulated. Sulphate reduces the iron availability due to fixation of sulphide by pyrite formation. Sulphate concentrations are a main control for the Chironomidae impact on phosphorous cycling. Bioturbated sediments with high SO4 concentration have shown high to medium phosphorous release, while mesocosms with low sulphate concentration have shown phosphorous retention. Changes of the iron content within the environmentally relevant boundaries have lesser effect on phosphorous cycling in bioturbated sediments.

BENTHIC MACROFAUNA STRUCTURE AND BIOTURBATION ACTIVITIES IN THE ARCTIC OCEAN ACROSS DEPTH GRADIENTS

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Ongoing climate change influences the structure and functioning of the Arctic ecosystems. Decreasing sea ice cover extent and thickness is expected to lead to drastic changes in primary productivity. Changes in the quality and quantity of the particulate organic matter (POM) availability will have repercussions for the structuren and functioning of benthic communities. This study aimed to assess bioturbation as indicator of changes in ecosystem function in relation to macrobenthos characteristics in the Arctic Ocean. Samples were collected during the spring to summer transition (May/June), at 10 stations, during two cruises: the R/V Polarstern PS92 "TRANSSIZ", north off Svalbard, and R/V Helmer Hanssen "ARCEx" in Svalbard fjords and in the Barents Sea. Stations were located in contrasting environments along the depth gradient, from Svalbard fjords (min. depth: 60m), through shelf, to deep basin (max. depth: 1630m). Sediments mixing rates were quantified using the luminophores method associated to the gallery-diffuser model of Francois et al (2002). The remaining sediment from each core samples was used for benthic community structure analysis. The highest values of biodiffusion (0.76 cm2 y-1 ± 1.59 SD) and non-local transport (2.12 y-1 ± 2.23 SD) were found at the Barents Sea shelf stations (~220m). The lowest values of nonlocal transport (0.28 y-1 ± 0.08 SD) and no biodiffusion were noted at deepest station in the Nansen Basin. Quality and intensity of bioturbation were related

to macrobenthic biomass. There were changes in benthic bioturbation along the depth gradient, possibly related to the changing POM flux to the sea floor. Along with decreasing sea ice cover and thickness, the structure and functioning of benthic communities will likely be changing with potential implications for the bioturbation activities, especially in the deep ocean.

THE RESPONSE OF EARTHWORMS (EISENIA FETIDA) AND SOIL MICROBES TO THE CRUMB RUBBER MATERIAL USED IN ARTIFICIAL TURF FIELDS

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Municipalities have been replacing grass fields with artificial turf, which uses crumb rubber infill made from recycled tires. Crumb rubber contains hydrocarbons, organic compounds, and heavy metals. Water runoff from crumb rubber fields contains heavy metals. These components can damage the environment. We contaminated topsoil with new crumb rubber and measured its impact on earthworms and soil microbes. Specifically, we compared soil microbe activity and earthworm health, survivorship, and longevity in heat and light stress under two soil regimes: clean topsoil and clean topsoil contaminated with crumb rubber. We then characterized levels of metals, nutrients, and micronutrients of both soil treatments and compared those to published New York soil background levels and to levels set by the New York State Department of Environmental Conservation (DEC) as remediation goals. We found that: 1) contaminated soil did not inhibit microbial respiration rates, 2) earthworm survivorship was not impacted by exposure to contaminated soil, 3) earthworms' ability to cope with heat and light stress remained unchanged after living in contaminated soil, but 4) earthworms living in contaminated soil gained 14% less body weight than did earthworms living in uncontaminated soil. We also found that, with the exception of zinc, heavy metals in our contaminated soil did not exceed the background levels found throughout New York State or the remediation targets set by the DEC.

ON THE NECESSITY OF SIMPLIFICATION WHEN BIOIRRIGATION IS TREATED AS AN ECOSYSTEM FUNCTION

Judith Renz, Claudia Morys, Martin Powilleit, Stefan Forster

University of Rostock, Germany

Bioirrigation – the animal induced exchange of solutes between porewater and overlying water is a key process to evaluate the ecological function of sediments. As such it has pronounced implications for biogeochemical processes such as nutrient cycling and organic matter regeneration at the sediment water interface. Therefore, if the ecological function of sediments is of importance to society, it is unavoidable to understand how a changing environment will affect the irrigation activity of macrofauna. A shift in species composition e.g. from deep burrowing species to smaller, more opportunistic and shallow burrowing species will have large effects on ecosystem function. For a better understanding of transport and exchange processes between water and sediments in

the German coastal sea the project SECOS Synthese addresses the assessment of these sedimentary ecosystem services that e.g. may be implemented into a sustainable and integrated coastal zone management. In this context of a better applicability of complex scientific data on pore water exchange and related effects for e.g. modelling purposes, a uniform scoring system on bioirrigation may be useful to compare community effects and describe seasonal or interannual variability in functioning of marine sediments. To assess the potential for bioirrigation with an index, a theoretical approach founded on biological traits that represent behavior and ecological functionality of generic key species is used. In analogy to the particle related community bioturbation potential of Solan et al. (2004), context dependent life modes that affect the purposes of bioirrigation (feeding type, morphology of burrows, and burrowing depth) are combined with data on abundance and biomass of the respective species and are summed up to a community bioirrigation potential. The condensation of scientific data to an index is inevitably accompanied with simplification. Therefore, a balance is needed between applicability in terms of abstraction and extrapolation on the one hand, and the precise mechanistic description of processes or activities leading to these processes (species specific investigations). The presentation focuses on considerations of ecological traits relevant for bioirrigation purposes and their classification into a bioirrigation index. In this context, benefit and loss due to simplification and abstraction are discussed.

Poops and coughs by worms and clams: Hydraulic activity and geochemical dynamics in marine sediments

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Over the last years we have studied some of the most important bioturbating infaunal groups with respect to their hydraulic activities and the related porewater advection in permeable sediments. Most of the investigated crustaceans, bivalves, and polychaetes cause very dynamic porewater pressurization over distances of tens of centimeters and bidirectional transport of interstitial water away and towards the organisms. As a consequence, sediment adjacent to the organisms as well as the sediment-water interface experience frequent oscillations between oxic and anoxic conditions. Our results suggest that in dense beds of e.g. thalassinids, tellinids, or arenicolids, porewater bioadvection is ubiquitous and oscillatory conditions are the rule. Based on time-synchronized time-lapse photography, porewater pressure sensing and planar optode imaging of oxygen, this poster will visualize the strong link between infaunal behavior, porewater advection and biogeochemical dynamics in marine sediments.

N_2 production and fixation in bioturbated muds of Great Peconic Bay

Stuart Waugh, Robert C. Aller

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Global marine N budgets often show deficits due to dominance of benthic N2 production relative to pelagic N2 fixation. Recent studies have argued that benthic N2 fixation in shallow water environments has been underestimated. In particular, N2 fixation associated with animal burrows may be significant as indicated by high rates of N2 fixation reported in muddy sands populated by the ghost shrimp, Neotrypaea californiensis (Bertics et al 2010). We investigated whether N2 fixation occurs at higher rates in the burrow-walls of the deep-burrowing (~0.5 - 4 m) mantis shrimp, Squilla empusa, compared to ambient mud, and measured seasonal in-situ N2 concentrations in burrow-water relative to bottom-water in Great Peconic Bay, Long Island. Acetylene reduction assays showed lower N2 fixation in burrow-walls than in un-populated sediments. Dissolved N2 was also higher in burrow-water than proximate bottom-water at all seasons, demonstrating a consistent balance of net N2 production relative to fixation in these deep-tier biogenic structures. In the upper tier (0 – 20 cm), the activities of the ophiuroid Amphioplus abditus also generally increased net N2 production with the highest fluxes at animal densities below 300 m-2. In each of the 3 seasonal periods investigated, N2 production increased with higher Amphioplus densities. Thus, N2 production exceeds N2 fixation in both the shallow and deep tier of these bioturbated muds.

PUMP, POOP, PAUSE, REJECT, REVERSE: NON-INVASIVE ACTIVITY METRICS FOR INFAUNA

Sarah Woodin, David Wethey

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Mortality is a satisfying metric of the effects of extreme events on populations, but sublethal effects are critically important to evaluation of environmental stress. Sublethal impacts on sedimentary organisms are difficult to measure without invasive techniques, although an increasing number of activity-based measures are being employed using video analysis of surfaces or flow sensors to quantify pumping rates or porewater pressure sensors to quantify hydraulic activities. Other techniques are less useful given the restriction of animal movements by attached sensors and their cables, such as with heart rate monitors (Burnett et al. 2013). As stresses associated with environmental change occur, we increasingly need techniques that allow us to distinguish normal from stressed behavior in untethered animals within sediments. In particular we need techniques that allow us to measure activities associated with bioirrigation and bioturbation, which are often the drivers of community structure; this was the original impetus for the development of field-deployable porewater pressure sensors. These sensors allow quantification of rates of hydraulic activities both in the laboratory and in the field in unrestrained animals (Volkenborn et al. 2016). Using an array of pressure sensors, one can calculate both the physical location of the active animal and its effect on porewater flux (Wethey et al. 2008). One can also quantitatively determine alteration of rates of hydraulic activities, such as feeding in tellinid bivalves, in response to environmental stress (Woodin et al. 2012). Recently, we have found that under some stresses, animals exhibit novel hydraulic activities which vary with the intensity of stress.

Veneriid bivalves exposed to low salinity alter the frequency of all behaviors and also generate high frequency positive porewater pressure transients not seen previously in bivalves. These behaviors may be analogous to hyperventilation in terrestrial organisms in response to stress.

An Irreversible Planar Optical Sensor for Multi-Dimensional Measurements of Sedimentary H_2S

Hang Yin, Robert C. Aller, Qingzhi Zhu

School of Marine and Atmospheric Sciences, Stony Brook University, USA

A novel H_2S optical sensor based on a diphenylcarbazone (DPCO) indicator was developed to readily and rapidly resolve a wide range of H_2S distributions in natural sediments in multi-dimensions. 2-D sensing membranes were prepared by immobilizing DPCO-Zn^{2+} complex in polyurethane hydrogel (D4) on transparent polyester sheets. A gas permeable silicone layer was applied as an outmost layer to eliminate or minimize possible interfering reactions. The immobilized DPCO-Zn^{2+} complex has a maximum absorbance at 530 nm, but DPCO shows no absorption at this wavelength. The working principle of the sensor is competition (ligand replacement) between DPCO and sulfide ion with Zn2+ to form the more stable ZnS. After exposure to H_2S, the absorbance of the sensor is inversely correlated with H2S concentration and the time of reaction. By simple manipulations of exposure times (1 – 20 minutes) and DPCO-Zn^{2+} loading, high resolution (50×50 μm), 2-D or 1-D H_2S distribution profiles are readily obtained in natural sediment over a very wide range of H_2S concentrations (~5 – 4000 μM).

1st Nereis Park Film Festival

Nils Volkenborn

School of Marine and Atmospheric Sciences, Stony Brook University

Buried Alive

The secret life of burrowing animals documented by time-lapse photography and planar optode imaging.

Lucie Pastor

Ifremer, Brest, France

LIFE ON THE DEEP OCEAN FLOOR

This video will present organisms living at several thousands of meters and their potential for bioturbation, largely unknown so far. This video will focus on chemosynthetic megafauna living on cold fluid seeps in the Gulf of Guinea and also in the organic-rich turbiditic system of the lobes of Congo. Sampling and doing in situ experiments at 5000m depth is not easy...

Kelly Dorgan

Dauphin Island Sea Lab, Dauphin Island, AL, United States

Worms in Jell-O

Ian Dwyer

School of Marine and Atmospheric Sciences, Stony Brook University, USA

TWO YEARS IN THE HOLE: A RESEARCHER'S RETROSPECTIVE

Something of a research slideshow, this video takes a look back at my first two years of grad school and the projects to which I have contributed. Mixed video & photo, set to music.

Erni Murniati

University of Koblenz-Landau, Landau in der Pfalz, Germany

IMAGING BIOIRRIGATION USING A NOVEL LIFETIME-BASED LASER INDUCED FLUORESCENCE (TLIF) TECHNIQUE

Burrow ventilation by tube-dwelling benthic animals introduces oxygen-rich water through a burrow inlet and releases plumes of deoxygenated water, which creates complex three-dimensional concentration distribution in the sediment as well as flow fields above the burrow. Mapping a high resolution of O2 concentration in the presence of benthic faunal activities is challenging. Here the dynamics of near-sediment O2 distributions around natural burrows inhabited by *Chironomus plumosus* was observed in a series of laboratory experiments using a lifetime-based laser induced fluorescence (tLIF) technique. With its high-spatial (84 um) and -temporal (2 s) resolutions, the persistence of burrow ventilation-induced changes in the O2 dynamics above the sediment have been revealed. For a range of larvae densities which is frequently observed in ponds and lakes, the areal O2 uptake rates of the sediment inhabited by Chironomids increased by up to 2.5 times. The enhanced O2 flux into the sediment exceeded the demand by up to a factor of 4, which confirms the potential importance of burrow ventilation for mineralization rates and therewith for nutrient and carbon cycling.

Nils Volkenborn

School of Marine and Atmospheric Sciences, Stony Brook University

The Sound of the Seafloor

“The Sound of the Seafloor” is a film about burrowing organisms. The activities of these animals are critical for the function of benthic systems but difficult to study. The film presents new technologies that have become available to study these activities and their effects on geochemical dynamics in marine sediments.

Emma Michaud

Laboratory of Marine Environmental Sciences LEMAR, Plouzane, France

Using drones to study benthic habitats and bioturbation

W. Cyrus Clemo

Dauphin Island Sea Lab, Dauphin Island, USA

JAWS: JUST WHEN YOU THOUGHT IT WAS SAFE TO GO BACK IN THE MUD...

Unknown to many, tiny toothed worms roam beneath the mud. Their jaws bristle with stacks of fang-like pincers and serrated saw blades, ready to sever a piece of algae or masticate an unsuspecting mollusk. Species in the order Eunicida possess these complex, rigid, articulated jaws consisting of multiple pairs of maxillae and a pair of mandibles. While all Eunicida have this general jaw structure, several characteristics of the jaws vary considerably among families. These differences, described for fossilized and extant species’ jaws, have been used to infer evolutionary relationships, but current

phylogeny shows that similar jaw structures are found among several families that are distantly related. Little has been done, however, to relate jaw functional morphology and feeding behavior to diet. To explore these relationships, we compared the jaw kinematics of two distantly related Eunicidan taxa with similar jaw structures: *Diopatra* (Onuphidae), predominantly herbivorous and tube dwelling, and *Lumbrineris* (Lumbrineridae), a burrowing carnivore. W observed jaw kinematics by filming individuals biting in a number of orientations. Differences in jaw structure and kinematics between *Diopatra* and Lumbrineris can be interpreted to be consistent with their differences in diet. Relating jaw morphology to diet would improve understanding of early annelid communities by linking fossil teeth (scolecodonts) to the ecological roles of extant species with similar morphologies. In the meantime, films of Eunicidan jaws more terrifying than any monster movie will continue to fascinate and fuel the imagination.