6TH NEREIS PARK

& INTERNATIONAL CONFERENCE
BIOTURBATION THEMATIC SCHOOL

22-26 August 2022 | Logonna Daoulas - France

Bioturbation in the past and present: from terrestrial to marine ecosystems

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THE NEREIS PARK ASSOCIATION

The Nereis Park story started in 1996 in Rimouski (Québec, Canada) when a funny cartoon of a Nereis specimen was hung up in the Gaston Desrosiers's research group student common room. Four years later, a website was launched including a logo inspired by the Jurassic Park movie, with the official authorisation from DreamWorks-SKG of course.

In 2002 (20 years ago!), an association aiming to «strengthen collaboration and knowledge exchange between scientists studying the bioturbation processes induced by the King Nereis, other animals and vegetal organisms in sediments and soils» was officially registered in France as a non-profit making association.

As well as providing an online portal for bioturbation researchers, Nereis Park also inspired the organization of the first international meeting on bioturbation in France (Carry-le-Rouet, 2004). This meeting was followed by the conferences in Renesse (The Netherlands, 2008), Fiskebäckskil (Sweden, 2011), Plymouth (UK, 2014) and Southampton (USA, 2017).

In addition to these meetings, a collaborative Nereis Park experiment was carried out in 2007 in order to acquire a world snapshot of the bioturbation activities by *Hediste diversicolor*.

After a one-year delay due to the COVID health crisis, it is time now for researchers in soil and sediment bioturbation to finally meet for the Sixth Nereis Park Conference, in Logonna-Daoulas. Be prepared to immerse yourself in the ancient and current sediments to discover its shadow workers!

Dr. Franck Gilbert

President of the Nereis Park Association

6TH NEREIS PARK INTERNATIONAL CONFERENCE

Bioturbation in past and present: from terrestrial to marine ecosystems

This 6th International Nereis Park conference aims to bring together the international scientific community of researchers working on bioturbation mechanisms in terrestrial, freshwater and marine environments, at all latitudes (polar, temperate, tropical) and at different geological times (from the Precambrian to the present).

It will be structured around five sessions:

1. Bioturbation-ecosystem services relationships
2. Bioturbation-biodiversity relationships
3. Micro-macro organism interactions in biogeochemical cycles
4. New approaches to analysis, observation and modeling for the study of bioturbation
5. Scale transfers.

This conference will take advantage of the international network of the «Nereis Park» and new scientific personalities to propose conferences and training of high international level, aiming at giving to scientists and students the keys to know the latest conceptual and technological advances on bioturbation in terrestrial, freshwater and marine environments. The understanding of the processes in their globality and their repercussions on the functioning of the ecosystems at different scales of time and space will be sought. Interdisciplinarity will be at the heart of this event to carry out such reflections and to allow new scientific collaborations between researchers.

Welcome to the 6th edition of the Nereis Park Conference, we hope you'll enjoy this week in Brittany!

Dr. Emma Michaud

6TH NEREIS PARK:
THE THEMATIC SCHOOL

The 2022 edition of the Nereis Park international conference will propose high level educational training aiming at giving researchers and students the latest informations on conceptual and technological advances on bioturbation. This event is intended for any scientist (researcher, student, engineer) or manager in the field of environmental sciences. It will consist of theoretical lectures in the form of keynote speeches and short presentations followed by discussions, poster sessions and practical workshops in the field and in co-working spaces. The hosting of scientists at Moulin Mer (Logonna Daoulas, Brittany, France), which has all the facilities in terms of educational rooms, will allow quick access to nearby study sites.

A wide range of studies related to research programs on global biogeochemical cycles, ecological engineering, ecosystem restoration and management, and paleo-evolution will be presented. The thematic school will bring together specialists of different ecosystems (terrestrial/aquatic; freshwater/marine; polar/temperate/tropical) emphasizing the richness of using a multidisciplinary approach.

This Nereis Park event will contribute to the update of fundamental knowledge on bioturbation in terrestrial, freshwater and marine environments, allowing a better understanding of the processes and their impacts on ecosystem functioning at different time and spatial scales. The scientific and educational meetings, by mixing the disciplines, will allow the creation of a network of expertise and the emergence of innovative approaches to answer fundamental and methodological questions.

Beyond a reinforced knowledge of the theoretical and ecological concepts, the school will propose a learning of the latest technologies aiming to visualize and quantify bioturbation in soils and sediments. In each workshop, the limits of the technologies will be specified, and a space of exchange will be set up to discuss the adaptations to be implemented for each ecosystem studied and to reflect on possible technological or digital adaptations.

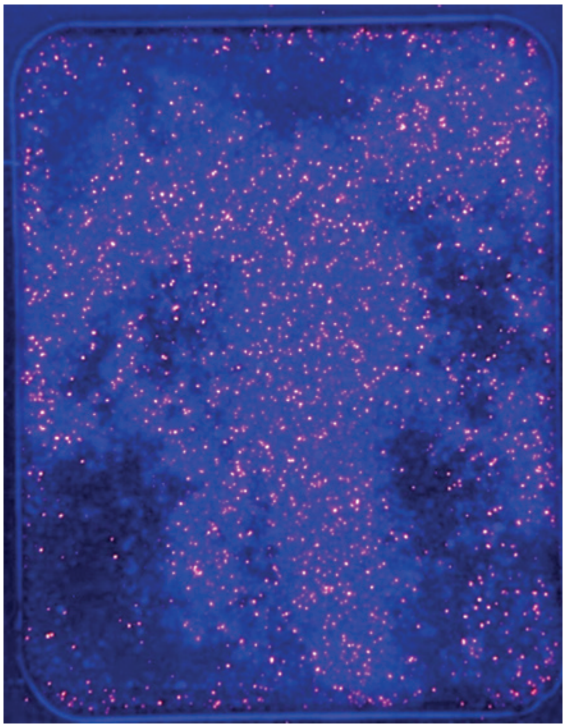
We believe this sixth edition of the Nereis Park international conference will promote exchanges, give the keys to set up interdisciplinary projects, and strengthen and federate our scientific community.

The organizing committee

	Monday 22 Aug.	Tuesday 23 August	Wednesday 24 August
7h30-8h30		Breakfast	Breakfast
8h30-8h45		**Introduction: E Michaud**	**SESSION 2** Keynote speaker: **Andrew Lohrer**
8h45-9h00		**SESSION 1** Keynote speaker : **Alison Cribb**	
9h00-9h15			
9h15-9h30			
9h30-9h45			
9h45-10h00		Talk 1: Buatois *et al.*	Talk 1: Capowiez *et al.*
10h00-10h15		Talk 2: Gougeon *et al.*	Talk 2: Howman *et al.*
10h15-10h30		Talk 3: Lewandowski *et al.*	Talk 3: Godbold *et al.*
10h30-10h45		Talk 4: Roman *et al.*	Talk 4: Bernard *et al.*
10h45-11h15		Coffee break	Coffee break
11h15-11h30		Talk 5: Bernard *et al.*	Talk 5: Szczepanek *et al.*
11h30-11h45		Talk 6: Coppock *et al.*	Talk 6: Williams *et al.*
11h45-12h00		Talk 7: Wazne *et al.*	Talk 7: Richard *et al.*
12h00-12h15		Talk 8: Forster *et al.*	Talk 8: Clemo *et al.*
12h15-12h30		Talk 9: Werna *et al.*	Talk 9: Dairain *et al.*
12h30-14h00		Lunch	lunch
14h00-15h00	Arrival	**SESSION 3** Keynote speaker: **Erik Kristensen**	**Biodiversity open forum** **E. Michaud** *et al.*
15h00-15h15		Talk 1: Shull *et al.*	
15h15-15h30		Talk 2: Kreuzburg *et al.*	
15h30-15h45		Talk 3: Dwyer *et al.*	
15h45-16h00		Talk 4: Benelli *et al.*	
16h00-16h30		Coffee break	Coffee break
16h30-16h45		Free time: Outdoor / fun activities	**Workshop** «Sediment mixing & models» **F. Gilbert**
16h45-17h00			
17h00-17h30			
17h30-18h00			
18h00-18h30			
18h30-20h00	Icebreaker	Poster session / tapas	Poster session / tapas
20h00-22h00	Dinner	Dinner	Dinner

Thursday 25 August	Friday 26 August	
Breakfast	Breakfast	7h30-8h30
Workshop «Bioturbation at Ordovician time» (fieldtrip at Crozon) **M. Vidal**	**SESSION 5** Keynote speaker: **Robert Aller**	8h30-8h45
		8h45-9h00
		9h00-9h15
		9h15-9h30
	Talk 1: Solan *et al.*	9h30-9h45
	Talk 2: Sanders *et al.*	9h45-10h00
	Talk 3: Garcia *et al.*	10h00-10h15
	Talk 4: Michaud *et al.*	10h15-10h30
	Workshop «Drone» **M. Jaud & J. Ammann**	10h30-10h45
		10h45-11h15
		11h15-11h30
		11h30-11h45
		11h45-12h00
		12h00-12h15
		12h15-12h30
Picnic at Crozon and transfer	lunch	12h30-14h00
SESSION 4 Keynote speaker: **Simone Pennafirme**	Synthesis and student awards	14h00-15h00
Talk 1: Dorgan *et al.*		15h00-15h15
Talk 2: Capowiez *et al.*		15h15-15h30
Talk 3: Gaeken *et al.*		15h30-15h45
Talk 4: Metzger *et al.*		15h45-16h00
Talk 5: Cooper *et al.*	Departure	16h00-16h30
Talk 6: Zhu *et al.*		16h30-16h45
Free time: Outdoor / fun activities		16h45-17h00
		17h00-17h30
		17h30-18h00
		18h00-18h30
Poster session / tapas		18h30-20h00
Dinner		20h00-22h00

6TH NEREIS PARK:
THE WORKSHOPS



Sediment reworking quantification

Franck Gilbert

This technical workshop will present sediment reworking quantification methods based on the use of luminophores (fluorescence inert tracers). More especially, three ways of luminophore counting will be available for participants: manual counting, photos and image analysis and using a microplate reader. This practical part of the workshop will also serve to open towards a collective discussion of the use of the different types of numerical sediment reworking quantification models.

Luminophores within sediment under UV light

© F. Gilbert

Ordovician Ichnofacies of the Crozon Peninsula

(Field trip at Crozon)

Muriel Vidal

The Crozon Peninsula is located in the western end of the Central-Armorican Domain which is part of the Variscan belt. It consists mainly of post-Cambrian Palaeozoic formations that rest unconformably on the Neoproterozoic / Cambrian basement (regionally named Brioverian), folded and faulted during the Variscan orogeny. The Ordovician succession (from ca.480 to 440 million years ago) outcrops along seashore cliffs and displays various deposit environments ranging from intertidal to distal platform settings. Two localities will be visited, the first one in the Armorican Sandstones, near Camaret-sur-Mer, with tracks, horizontal or vertical burrows in alternation of sandstones and shales; the second one near the Veryac'h locality, showing the transition from offshore deposits of the Postolonnec Formation (with rare and low diversified bioturbation) to the proximal and protected deposits of the Kermeur Formation with intensively bioturbated and poorly sorted sandstones.

Horizontal burrows (diameter of ca. 1 to 2 cm) in the armorican sandstones formation, lower ordovician, Camaret-sur-Mer

© E. Michaud

Drone and photogrammetry applied to benthic ecology

Marion Jaud and Jérôme Ammann

The first part of the workshop will present different types of drones (topography, thermal imaging, hyperspectral imaging...), their fundamental characteristics and their use. More specifically, we will carry out a topographic survey of a parcel of the foreshore by drone. This will involve preparing the field by installing targets on the ground and measuring their position with a DGNSS equipment, designing the flight plan, and realizing the automatic flight of the drone. The way to organize a campaign taking into account the scientific needs (desired precision, surface to be covered, environmment...) drones and sensors available on the market, as well as the regulation of drones will also be discussed.

The second part of the workshop will present the principles of Structure-from-Motion (SfM) photogrammetry processing in order to highlight the potential and limitations of this approach and also to understand the constraints it implies on the flights. Through examples, different types of analysis (notably using GIS tools) will be discussed.

This workshop will be divided into half-groups that will switch between a presentation on the preparation and realisation of drone flights and a presentation on photogrammetric processing and data analysis.

Aerial view of an intertidal mudflat from drone

© J. Fleury

International scientific committee

Dr. Stefano Cannicci (University of Florence, Italy)

Dr. Suzanne Dufour (Memorial University, Canada)

Dr. Stefan Forster (University of Rostock, Germany)

Dr. Franck Gilbert (CNRS | ECOLAB, France)

Dr. Boris Jansen (Amsterdam University, Netherlands)

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Dr. Thomas Stieglitz (IRD | CEREGE, France)

Local organizing committee

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NEREIS PARK

BOOK OF ABSTRACTS

Keynote Lecture

Talk

Poster

6TH NEREIS PARK | Bioturbation in past and present: from terrestrial to marine ecosystems | 22-26 AUGUST 2022 | LOGONNA-DAOULAS, FRANCE

Session 1

Bioturbation-ecosystem relationships

Keynote Speaker: Alison Cribb

PhD candidate| University of Southern Carolina, USA

In this session, the role of bioturbation for ecosystem evolution will be discussed with particular focus on the various ecosystem services provided by bioturbation in terrestrial, freshwater and marine ecosystems in the context of global change. The various effects of bioturbation will be addressed including: sediment erosion, stabilization and drainage, biogeomorphology, contaminants and cysts releasing, oxygenation, bioremediation of polluted sediments and soils, organic matter recycling. Functioning of past and extreme environments (Precambrian, Quaternary caves, mangroves, polar and deep environments, hyper-saline lakes…) could be considered.

Effects of repeated short-term marine heatwaves on benthic macrofauna bioturbation and associated solute fluxes

Guillaume Bernard *† [1], Laura Kauppi [2], Alicia Romero-Ramirez [1], Norman Goebeler [2], Alf Norkko [2], Joanna Norkko [2]

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[2] Helsinki University, Tvärminne Zoological Station – Finland

The occurrence of extreme climatic events such as marine heat waves (MHW) is by nature stochastic and thereby difficult to apprehend. Complete collapses of biological communities linked with exceptionally long and severe events are well-known but subtler effects of MHWs on the functioning of benthic habitats mediated by macrofauna bioturbation are still understudied. We performed a lab experiment in September 2020 aiming at assessing the consequences of repeated, short-term MHWs for benthic ecosystem functioning in the Baltic Sea while focusing on mechanistic understanding of sub-lethal behavioral effects on ecosystem processes and functions. Aquaria (0.1 m^2) containing natural macrofauna community were exposed to either (1) ambient temperature (Control) during 26 days, (2) a single 6 d moderate MHW (defined based on the climatological mean) followed by 21 d at ambient temperature, or (3) two repeated 6 d moderate MHWs, each followed by 7 d periods at ambient temperature. Assessments of luminophore tracer redistribution along the aquaria walls and repeated bromide incubations allowed for the quantification of sediment reworking and biorrigation rates by the benthic community in response to simulated MHWs. Measurements of solute fluxes allowed linking these processes to ecosystem functioning. We show that short-term MHW events modify macrofauna bioturbation, as well as associated benthic solute fluxes. Recovery after the first heatwave varied between bioturbation metrics, as well as between solutes, thereby affecting the response to the second event. These results indicate that even at sub-lethal levels and over short time scales, marine heatwave events modify ecosystem functioning underpinned by bioturbation.

*Speaker
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Assessing bioturbation and bioerosion in the fossil record: the Cambrian Explosion and the Ordovician Radiation

Luis Buatois *† [1], Maria Mangano [2], Nicholas Minter [3], Kai Zhou [2], Max Wisshak [4], Mark Wilson [5], Ricardo Olea [6]

[1] University of Saskatchewan [Saskatoon] (U of S) – Canada
[2] University of Saskatchewan (U of S) – Canada
[3] University of Portsmouth (U of P) – United Kingdom
[4] Senckenberg am Meer (Senck) – Germany
[5] College of Wooster (C of W) – United States
[6] Retired (Retired) – United States

Bioturbation, a major force in macroevolution, plays a significant role in geobiologic feedbacks and geochemical cycles. Bioerosion, less explored from an evolutionary perspective, is a key factor in carbonate ecosystem health, predation pressure, ocean acidification and global warming. We quantify the role of bioturbation and bioerosion in ecospace utilization and ecosystem engineering during the the Cambrian Explosion (CE) and the Ordovician Radiation (OR), which are the most important evolutionary radiations in Paleozoic oceans. Our analysis is based on information from 1367 Ediacaran-Ordovician stratigraphic units. All ichnotaxonomic determinations were revised following standard practices to adopt a consistent approach. Occurrences were in turn subdivided into discrete trace-fossil assemblages for seven standardized environmental categories at Series level. The multidimensional ecospace and ecosystem engineering analysis has been used, assessing ichnodiversity, ichnodisparity, tiering, motility, feeding mode, mode of sediment interaction, and mode of sediment modification. An increase in all diversity metrics is demonstrated for the Ediacaran-Cambrian transition, followed by a decrease in most values during the middle to late Cambrian, and by a more modest increase during the Ordovician. A marked increase in ichnodiversity and ichnodisparity of bioturbation is shown during the CE, and of bioerosion during the OR. Innovations took place first in offshore settings and later expanded into marginal-marine, nearshore, deep-water, and carbonate environments. Differences in infaunalization in offshore and shelf paleoenvironments favor the hypothesis of early Cambrian wedge-shaped oxygen minimum zones instead of a horizontally stratified ocean. This study highlights the unique significance of the CE, despite its Ediacaran roots.

*Speaker
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Benthic fauna contribute to microplastic burial in coastal marine sediments

Rachel Coppock *† [1], Penelope Lindeque [1], Matthew Cole [1], Tamara Galloway [2], Pinja Näkki [3,4], Hannah Birgani [5], Saskiya Richards [1], Ana Queiros [1]

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[2] University of Exeter – United Kingdom
[3] Finnish Environment Institute, Marine Research Center – Finland
[4] University of Helsinki, Tvarminne Zoological Center – Finland
[5] University of the West of England – United Kingdom

Microplastics are ubiquitous in the marine environment, however, the mechanisms governing their uptake by, and burial within, seabed habitats are poorly understood. In this study, microplastic burial and its impact on fauna-mediated sedimentary processes was quantified at three coastal sites, the potential contribution of burrowing faunal communities to this process was assessed via functional trait diversity analysis of field data. In addition, laboratory exposures were used to assess whether sediment-processing undertaken by the brittlestar *Amphiura filiformis,* a key species in the sampled area, could explain the burial of microplastic fibres. Field observations confirmed broad-scale burial of microplastics across the coastal seabed, consistent across sites and seasons, with microplastic sequestration linked to benthic-pelagic exchange pathways, driven by burrowing fauna. Brittlestars were observed to bury and line their burrow walls with microfibres during experiments, and their burial activity was also modified following exposure to nylon fibres, relative to controls. Collectively, these results indicate that biodiverse and functionally important seabed habitats act as microplastic sinks, with burrowing fauna contributing to this process via well-known benthic-pelagic pathways, the rates of which are modified by plastic exposure.

*Speaker
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Utilization of the trace fossil record to understand bioturbators' ecosystem engineering impact over the last 560 million years

Alison Cribb *† [1], Sebastiaan Van De Velde [2,3], Aaron Celestian [1,4], William Berelson [1], David Bottjer [1], Frank Corsetti [1]

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[3] Royal Belgian Institute of Natural Sciences (RBINS) – Belgium
[4] Natural History Museum of Los Angeles (NHMLA) – United States

The trace fossil record of Earth history preserves the activity and behaviours of benthic animals over the last 560 million years. In palaeoecological studies, the trace fossil record has proven particularly useful for understanding how benthic soft-bodied animals – which interacted with the sediment but do not leave robust body fossil records – have evolved and responded to environmental perturbations. Recently, the trace fossil record has been used for understanding ecosystem engineering dynamics throughout Earth history. Ecosystem engineering refers to the behaviours of animals that modify resource availability, and bioturbators are considered key ecosystem engineers in modern oceans. By studying the trace fossil record through the lens of ecosystem engineering, we can better understand the ways in which bioturbators have impacted benthic ecosystem functioning throughout Earth history. Here, I present key studies from two time periods in Earth history that are critical intervals for changes in macroevolutionary processes: the Ediacaran-Cambrian transition (˜541 Ma) and the end-Permian mass extinction event (˜261 Ma). For both time intervals, I have compiled trace fossil data from the literature and my own field work to characterize trace fossils in t̄erms of their ecosystem engineering im-pacts. For trace fōssils from the Ediacaran-Cambrian transition, I have used μXRF analyses to identify geochemical characteristics of different bioturbation ecosystem engineering behaviours. I also have incorporated Ediacaran-Cambrian trace fossil data into biogeochemical models to predict the impact that early bioturbators had on benthic ecosystem resources. For trace fossils from the end-Permian mass extinction, I have analysed global trace fossil data to demonstrate that despite global warming, ocean anoxia, and ocean acidification, some shallow marine en-vironments could support complex, metabolically intensive bioturbating ecosystem engineering behaviours which may have contributed to maintaining local ecosystem functioning in the early Triassic. Finally, I present avenues for research in utilizing the trace fossil record for novel macroecological studies, including integrating the trace fossil and body fossil records together in spatially-explicit palaeoecological analyses to better understand how bioturbators have been fundamental ecosystem engineers in benthic ecosystems throughout Earth history.

*Speaker
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Trawl tracks or bioturbation traces? Confusing chlorophyll tracer peaks in the sediment.

Stefan Forster *† [1], Claudia Runkel [1], Josephin Lempe [1], Laura Pülm [1], Martin Powilleit [1]

[1] Rostock University (RU) – Germany

We often interpret peaks displayed in vertical tracer profiles in the sediment as an indication of "non-local" biogenic transport. However, unless the spatial proximity of an organism suggests the process generating the peak to be bioturbation caution is warranted. Particle displacement by bottom-trawling fisheries may generate similar peaks. Presenting data from a mesocosm experiment and experimental in situ trawling, we show that trawling does produce peaks that may easily be taken for bioturbation traces. In our targeted core samples taken by scuba divers, the shape of the depth profile and local and local exchanges coefficients derived from it (Soetaert et al. 1996) are indistinguishable from peaks found in areas we commonly assume free of trawl tracks. We compare patterns, discuss the likelihood of misinterpreting a peak for bioturbation and implications for diagenetic process.

*Speaker
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The impact of sand extraction on sediment biogeochemistry: preliminary results of an experimental approach.

Nanou Goedefroo *† [1,2], Ulrike Braeckman [2], Kris Hostens [1], Jan Vanaverbeke [2,3], Emil De Borger [4], Tom Moens [2], Annelies De Backer [1]

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[2] Ghent University (UGent) – Belgium
[3] Royal Belgian Institute of Natural Sciences (RBINS) – Belgium
[4] Royal Netherlands Institute for Sea Research (NIOZ) – Netherlands

Sand extraction activities have a significant impact on the benthic environment through disturbance of the upper sediment layers. The ecological and physical impact of these activities in the Belgian Part of the North Sea (BPNS) are routinely investigated, but the effects on ecosystem functioning remains largely unknown.
In this study, we hypothesized that carbon and nitrogen cycles would be affected by sand extraction, and that this impact would differ between different extraction regimes. Therefore, three tidal sand banks in the BPNS, characterized by different extraction regimes and seabed morphology, were sampled in both impact and reference zones. Cores were incubated for six hours, sediment community oxygen consumption (SCOC) was continuously measured, and nutrient, dissolved inorganic carbon (DIC) and uranine were sampled at five time intervals, to investigate the bio-irrigation rate and the nitrogen and DIC fluxes. In addition to the incubation core, five sediment subsamples were taken per location and zone to measure granulometry, chlorophyll *a*, permeability, total organic carbon and total nitrogen.
On one sandbank, characterized by a continuous high extraction regime, a significant impact on seabed morphology with one meter deep drag head tracks was visible on the multibeam imagery. Nevertheless, the sediment remained well permeable in all impacted areas, which partly explains the absence of significant differences in SCOC between impact and reference samples for all extraction regimes. Data on carbon stocks, nitrogen content and nutrient fluxes are currently analyzed, which will allow to draw more holistic conclusions on how sand extraction influences the benthic ecosystem functioning.

*Speaker
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Development of the sediment mixed layer in deep time: a reading of the Ediacaran-Cambrian boundary type section

Romain Gougeon *† [1], Gabriela Mángano [1], Luis Buatois [1], Guy Narbonne [2], Brittany Laing [1], Maximiliano Paz [1]

[1] University of Saskatchewan (U of S) – Canada
[2] Queen's University – Canada

The mixed layer is a zone of fully homogenized sediment resulting from intense bioturbation. Below this zone, a transitional layer is characterized by discrete burrows. In modern settings, the mixed layer thickness varies according to depositional environments and controlling factors impacting on the benthos. The mixed layer was originally thought to appear at the start of the Fortunian (540 Ma), but recent studies estimate its development at the base of the Cambrian Age 2 (530 Ma) or after the Silurian (420 Ma). The Cambrian type section in Newfoundland, Canada, contains exquisitely preserved trace fossils. High resolution sedimentologic and ichnologic datasets were gathered in this section to assess depositional environments and ichnofabric development. Three lines of evidence allow the identification of a sediment mixed layer at the base of the Cambrian Stage 2. (1) Intervals of fully bioturbated sediment are identified in polished samples. (2) Sandstone tempestites host sharp-walled burrows, have diffuse tops, and are capped by homogeneous sandy siltstone, which is interpreted as being totally bioturbated. (3) Reconstruction of ichnofabrics allows the identification of mid- and deep-tier trace fossils with sharp outlines typical of the transitional layer overprinting on the mixed layer. The mixed layer in this succession is best identified below the reach of storm waves (shelf environment), but also in the lower and upper offshore. These results illustrate how empirical approaches and robust description and interpretation of sedimentologic and ichnologic datasets from various depositional settings are necessary to unravel the colonization of the marine seafloor by early animals.

*Speaker
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MELTING POTES Marine Ecosystem Engineers Long-Term Evolution ModellNG in resPOnse to climate change and sediment Transport in Seine Estuary

Amélie Lehuen *† [1], Francis Orvain [1]

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The Seine estuary is a dynamic ecosystem, where the physical conditions are of great influence on the habitats that can be found. Sediment and hydrological parameters have a direct impact on the spatial distribution and activity of benthic macrofauna.
Based on biological data collected over the years and a Hydro-Morpho-Sedimentary (HMS) model of the estuary, it is possible to identify the factors most likely to impact the spatial distribution of macrozoobenthos and build Species Distribution Models (SDM). They describe the Optimal Ecological Niches (SDM-NEO), which consider, for two key physical factors, the conditions to accommodate a maximum biological response, through quantile regression.

Benthic ecosystem engineers species modify their surrounding environment by processes called bioturbation. These effects and the degree of impact on the sediment resuspension is still to be accounted for at ecosystem scale. MELTING POTES proposes to combine the local and individual bioturbation of six species at the scale of the community, that represents the resultant of their biological interactions.
Bioturbation can contribute to the long-term evolution of the estuarine sediment floor. The project aims to integrate the bioturbation models into the HMS model, to reflect processes of sediment transport more accurately. The feedback loop involved in the fauna and habitat relationship have thus an impact on the Optimal Ecological Niches. By simulating climatic conditions, related to the IPCC scenarios, MELTING POTES will be able to evaluate the trend of evolution of NEO for the six species and the possible reduction or extension of the spatial niches.

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Multiple impacts of Chironomus plumosus on freshwater lakes

Joerg Lewandowski *† [1,2], Franz Hölker [1], Matthias Rothe [1,3], Viktor Baranov [1,4], Michael Hupfer [1]

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Tube-dwelling macrozoobenthos species such as *Chironomus plumosus* can severely impact lake ecosystems in many ways: (1) Chironomids are filter feeders and pump large volumes of lake water through their U-shaped burrows: When present at densities typical of lakes (1000 individuals m-2), they pump an amount of water equivalent to 1 m of water column through their burrows in a single day. (2) Because they are very efficient filter feeders, their feeding pressure has a significant impact on phytoplankton, but also on the entire food web. (3) Chironomids consume oxygen themselves, but they also increase sediment respiration by promoting bacteria and increasing the oxic-anoxic interface. Thus, the presence of chironomids accelerates oxygen consumption above the bottom. (4) In oxic microenvironments, such as burrow walls, dissolved phosphorus is efficiently immobilized by the scavenging activity of iron (oxy)hydroxides. Contrary to expectations, this phosphorus is not completely released to the overlying water body once the burrow is abandoned and reducing conditions re-established. Long-term phosphorus removal has been observed in lab experiments, likely due to the formation of the reduced iron phosphate mineral vivianite. Chironomids can thus have both positive effects on lake trophic levels by promoting natural phosphorus fixation and reducing phytoplankton abundance, and negative effects by decreasing oxygen concentrations above ground.

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Sediment reworking of two biodiffusors differ depending on habitat and environmental context

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The more frequent and intense heat waves under future global warming scenarios can negatively affect intertidal shellfishing beds at seagrass meadows. However, it is unclear how the interactions between commercial clams and seagrasses will respond to thermal stress during emersion. A mesocosm experiment was performed to assess the effects of a heatwave during low tide and recovery on the bioturbation and growth of juveniles of the infaunal biodiffusors *Ruditapes decussatus* and *Ruditapes philippinarum* and on their interactions with *Zostera noltei.* The dissipation of heat was greater in sediments below *Z. noltei* than below bare sand. Thermal stress during emersion caused decreases of Fv/Fm in *Z. noltei*, slower growth and lower sediment reworking of clams, and made clams to burrow deeper in sand than in seagrass, indicating that *Z. noltei* provided a refuge against heat and desiccation, what might favour their long-term growth. The lower sediment reworking by clams under thermal stress in emersion was caused by a reduction of their activity and the ceasing of filtration. The presence of *R. philippinarum* was linked to greater phosphate concentrations in pore waters under non stressful conditions, which could increase Fv/Fm in *Z. noltei* and suggested a facilitative interaction. The pore water nutrient contents tended to be greater in *Z. noltei* than in bare sand, highlighting its nutrient sink function. Our results revealed that heat and desiccation decreased bioturbation and growth of clams, but seagrasses buffered thermal stress of clams, which can contribute to their sustainability under future global warming scenarios.

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Microplastics in the freshwater ecosystem: implications for ”Tubifex tubifex” and its ecological functioning

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Plastic pollutants are ubiquitous in the environment, posing a threat to terrestrial and aquatic ecosystems. In freshwater environments, streambed sediments act as major sinks that can temporarily entrap microplastics, thus acting as a source of exposure for benthic organisms, such as deposit feeders. The ingestion of microplastics by deposit feeders has been widely reported, yet the physiological impacts of microplastics on bioturbators and their biogeochemical consequences remain unknown. Hence, the purpose of this study was to determine the long-term impact of microplastics on *Tubifex tubifex* bioturbators and their ecosystem services. Mescocosms experiment of eight different treatments was designed for 77 days with four different concentrations of microplastic mixture (0, 700, 7000, and 70000 particles kg-1) and in the presence or absence of *Tubifex* worms. Our results showed that microplastics had no effect on worm survival rates. However, a significant oxidative challenge was observed. Furthermore, we recorded a significant decrease in the feeding activities of bioturbators, which was associated with a decline in solute exchange at the sediment-surface interface. As a result, organic matter mineralization and nutrient fluxes were significantly reduced. Our study demonstrates that the adverse impacts of microplastics extend beyond the physiological performance of bioturbators and even pose a threat to the functioning of the entire ecosystem.

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Winner or Looser: which bioturbator will thrive in peatland restoration ?

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Rewetting of coastal peatlands is one crucial element in peatland restoration, which has been assigned a critical role in climate mitigation. Besides preventing peat oxidation and thus greenhouse gas emission, flooding coastal peatlands leads to the creation of new marine habitat to be colonized by macrobenthic infauna.

Here we present a pilot study combining field monitoring and a laboratory experiment to investigate how key bioturbator in the study area, *Hediste diversicolor, Marenzelleria neglecta,* and *Mya arenaria,* colonize and modify the biogeochemistry of the peatland of Drammendorf, Rügen Island, Germany, in comparison with marine sediment after flooding with sea water (10 psu).

We found a maximum burrowing depth of 2 cm performed by *Marenzelleria neglecta* in peat soil, while *Hediste diversicolor* prevailed in marine sediment (10 cm). Despite acidic conditions in the peat soil, the survival rate was relatively high (25-95%) for all tested species, highest in *Mya arenaria* treatment. Total oxygen uptake (TOU) was higher in the marine sediment (32.6 $\pm$ 2.3 mmol m-2d) than in the peat soil (12.8 $\pm$ 1.27 mmol m-2d). A significant release of ammonium was found in both substrates, while phosphate release was slightly influenced by bioturbation activity. After two years of flooding, peat soil structures were still well preserved, nonetheless the benthic community composition in the flooded area showed similarity with the neighboring sea, where *Hediste diversicolor* dominate the area. On this basis, we emphasize the importance of soil structure in shaping the community.

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Session 2

Integration of bioturbation processes into biodiversity patterns and functions

Keynote Speaker: Pr. Andrew M. Lohrer

NIWA, New Zealand

The influence of the bioturbation activities on the ecosystems depends on the benthic structural and functional diversity strongly linked to the environmental variables. This session will address the different approaches (i.e., species, functional diversity, biological traits…) used for evaluating the effects of biodiversity on the ecosystems functioning through experimental and field studies. This will be the initial statement for an open forum session based on two questions: How do we integrate the role of individual species characteristics on benthic processes at the community scale? How do we upscale the effects of benthic communities at the ecosystem level ?

Experimental and in situ assessments of the interactions between an invasive mussel (Arcuatula senhousia, benson1842) and resident biota controlling benthic ecosystem functioning in an intertidal seagrass meadow.

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The invasive mussel *Arcuatula senhousia* has successfully colonized shallow soft sediments worldwide. This filter feeding mussel modifies sedimentary habitats while forming dense populations and efficiently contributes to nutrient cycling. We studied the present and potential future effects of *A. senhousia* within an intertidal *Zostera noltei* seagrass meadow in Arcachon Bay (France), where the species currently occurs at levels corresponding to an early invasion stage. We manipulated the density of the invasive mussel in intact sediment cores in order to test the effects of *A. senhousia* invasion on (1) bioturbation (bioirrigation and sediment mixing) as well as on (2) total benthic solute fluxes across the sediment–water interface. Two *in-situ* sampling campaigns were also carried out in April and August 2021 along cross-shore gradients within an intertidal *Z. noltei* meadow. They aimed at assessing the interactive effects of established *A. senhousia* populations and other species constitutive of the benthic communities on sediment porewater nutrients concentrations. Overall, results showed that increasing densities of *A. senhousia* clearly enhanced phosphate and ammonium effluxes, highlighting the ability of *A. senhousia* to control nutrient cycling with potential important consequences for nutrient cycling and benthic–pelagic coupling at a broader scale. However, it appears that the variability in the different measured solute fluxes were underpinned by different interactions between the manipulated or *in-situ* density of *A. senhousia* and several faunal and/or environmental drivers. It therefore underlines the complexity of anticipating the effects of an invasion process within a realistic context.

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Definition of earthworm functional groups using X-ray tomography and bioturbation data

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The ecological categories of earthworms (endogeic, anecic and epigeic ones) were defined by Bouché (1972) using only morpho-anatomical traits. However this classification is often used as a proxy for functional groups assuming each categorie had very different influences on the main soil functions (macroporosity, organic matter burial, cast production). We tested this classification with forty earthworm species incubated in repacked sil cores for one month. Then, the 3D burrow systems were analyzed using X-ray tomography and some functions were assessed (litter burial, water infiltration, bioturbation intensity). We were able to define 6 novel functional groups (anecics, epi-anecics, epigeics, epi-endogeics, hypo-endogeics and intermediate) that ony marginally fit with the classical ecological categories. These groups will improve the assessment of the ecosystem services provided by earthworm communities in soils.

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Impacts on infaunal communities and habitat structure following a hurricane disturbance

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Shallow coastal sediments are important habitats for infauna, which contribute to nutrient cycling and carbon storage. These sediments are also susceptible to large-scale disturbances such as hypoxia and storm-driven resuspension. Infauna tolerant of hypoxia-induced sulfidic sediment have been shown to increase sediment oxygenation, allowing recolonization by less-tolerant species. However, little is known about how physical disturbance impacts sediment habitat suitability and whether disturbance-tolerant infauna influence sediment restabilization and community recovery. We investigated temporal changes to infaunal community and sediment physical structure at 5m, 12m and 20m depths in the northern Gulf of Mexico following Hurricane Sally, which made landfall on September 16, 2020. We expected that surviving and early-colonizing infauna would drive temporal changes in sediment stability and community structure. We also expected community and sediment structure at 12m to be the most impacted due to these sediments being deep enough to avoid frequent resuspension occurring in shallower sediment while experiencing greater hurricane disturbance than deeper sediments. Here we present preliminary data on temporal changes to infaunal community structure from sediments collected offshore of Alabama 6 days before and 10, 40, 85, 162 and 251 days after Hurricane Sally. These results may provide insight into the dynamics of animal-sediment interactions, better prediction of how physical disturbance affects short and long-term sediment ecosystems and allow for comparison of infaunal community succession following hypoxia versus physical disturbance.

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Is there a tipping point for the effects of parasites on bioturbating organisms?

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During the last Nereis Park conference, L. Pascal, A. Dairain et *al.* questioned the importance of parasitism as a key interaction influencing the physiology and behaviour of bioturbators and consequences for their ecosystem engineering role. At that time, experimental works assessing the role of parasitic isopods on large decapods evidenced detrimental effects of parasitism on the host fitness, burrowing and ventilating activities. Since then, this work has continued by focusing on diverse functional host-parasite systems. Recently, we have studied bioturbating bivalves since they host a large diversity of parasites, of which most are trematodes. Studies evaluating the effects of trematodes on the host physiology and behaviour show significant discrepancies, with impacts ranging from very little effects to increase of host mortality rate. Although trematodes are naturally very prevalent, the number of parasites per host can be highly variable. We thus experimentally evaluated whether there is a density tipping point for trematode impacts on the physiology and behaviour of bioturbating bivalves. The Peppery furrow shell *Scrobicularia plana* was chosen as a model bioturbator and organisms naturally exhibiting different infection intensities were used. The effects of parasite load on the bivalve condition index, sediment reworking and bioirrigation activities were assessed. Additionally, we estimated the indirect trait-mediated effects of parasites on ecosystem processes by measuring nutrient fluxes at the sediment-water interface. Overall, this study aims to better understand the role of parasitism in the functioning of marine soft-bottom environments by estimating potential density-depend effect and thus identifying a threshold for parasite detrimental impact.

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Does trematode parasites influence sediment stability?

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In soft-bottom environments, benthic bioturbating organisms can both promote and hamper the erosion of sediments because their presence and activity impact bed topography, i.e. the bed roughness, and sediment erodability. Bioturbators also play indirect roles in the sediment fate while interacting with other organisms which are also of critical importance for the stability of sedimentary environments. Among them are microphytobenthic organisms. Benthic algae form biofilms at the sediment surface and lower the sediment susceptibility to erosion. Through their activities, bioturbators can both mechanistically disrupt biofilms and enhance their production by stimulating nutrient fluxes at the sediment-water interface. Hence, complex interactions between bioturbators and microphytobenthic organisms occur and the latter modulate their respective and combined influence on sediment stability. The influence of bioturbators on the fate of sediments and their interaction with microphytobenthic organisms depend on the magnitude of their activities and inherently on their physiological state. Various stressors can modify the physiology and activity of bioturbators with consequences for ecosystem functioning. Among biotic factors, the influence of parasites has been largely overlooked. In this study we thus conducted flume experiments to investigate the indirect influence of the trematode *Bucephalus minimus* parasitising the common cockle *Cerastoderma edule* on the dynamics of sediments enriched or not with microphytobenthos. Parasitism annihilated the detrimental effect of cockles on microphytobenthos growth with no consequences for sediment dynamics. Nonetheless, our study has revealed that parasitism reduces the destabilizing role of cockles by interfering with the effects of the bivalves on both sediment erodibility and roughness.

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Long-term differences in climate drive intraspecific trait expression and ecosystem function

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Functional trait-based approaches are increasingly adopted to understand ecological responses to environmental change. However, most assume that trait expression is constant irrespective of context, potentially jeopardising projections of ecosystem functioning and service delivery. We challenge this assumption, using a benthic system to demonstrate differences in trait expression in two co-occurring species of invertebrate (the brittlestars *Amphiura filiformis* and *Ampihura chiajei*) maintained in ambient (ambient temperature / 400 ppm atmospheric CO2) and anticipated future (ambient + 2 ◦ C / 550 ppm atmospheric CO2) environmental conditions in either monoculture or mixture. We find significant intraspecific variation in trait expression in response to altered climate condition and biotic context with functional implications on water column nutrient concentration. Righting and burial rates are faster under near future conditions, but responses depend on whether individuals are maintained in a monoculture or mixed species treatment. Our findings demonstrate that conspecific individuals express traits differently depending on abiotic and biotic context, which has implications for their impacts on ecosystem functioning.

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Combined effects of ocean acidification and seasonal hypoxia on the behaviour of the brittle star Amphiura chiajei

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Many coastal and shelf ecosystems are experiencing short-term, seasonal declines in oxygen and pH on top of the long-term consequences of warming, yet we have relatively little understanding of the combined impacts of these on the behaviour of marine organisms and the associated implications for ecosystem functioning, such as nutrient cycling. Here we will present the results of an experimental study investigating the impact of a 2-week hypoxia event on the burrowing behaviour of the brittle star *Amphiura chiajei* following acclimation to ambient (10∘C, pH 8.1) or anticipated future (+2∘C, pH 7.95) environmental conditions. Our findings indicate how future climate conditions affect *A. chiajei* burrowing behaviour during and after the hypoxia event. This information is vital in reducing uncertainty when projecting the context dependent ecological consequences of climate forcing.

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†Speaker

Benthic bioturbation by key species and the upscaling of functions in a heterogeneous world

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There is no single natural scale at which ecological phenomena can be observed. The patterns that we observe are affected by our own perceptual filters. Furthermore, patterns and the mechanisms underpinning them do not necessarily occur at the same scales, as patterns can be influenced by both large-scale environmental forcings and the collective activities of organisms interacting on fine scales. In marine systems, bioturbation by benthic macrofauna can profoundly influence the sedimentary environment. Relationships between macrofauna and ”ecosystem functions” have been demonstrated in numerous small-scale experiments, but verification of these results at ecosystem scales is rare. We cannot safeguard key marine ecosystem functions until we have reliable information on where they are being delivered and in what quantities, therefore, upscaling and mapping of ecosystem functions and services is a major need in environmental management at present. This talk will provide three to four examples from New Zealand that attempt to link small-scale experimental results to ecosystem-scale processes. Although this is a daunting task due to the complicated and idiosyncratic relationships between organisms and their environments, there are aspects of organisms and ecosystems that are self-similar across a wide range of spatial and temporal scales that offer the promise of scaling relationships. Ways to harness new technology to increase the spatial and temporal scales of sampling, and to better incorporate natural environmental drivers, will also be discussed.

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Bioturbation impact of estuarine benthic macrofauna on microphytobenthos dynamics

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In intertidal mudflats, microphytobenthic biofilms play a substantial role in many ecosystem functions, being one of the most important primary producers and modulating sediment biogeochemistry and stability. Deposit-feeding and bioturbation processes are known to modulate growth benthic primary dynamics and productivity. However, macrofaunal bioturbation activities and their impact on sediment biogeochemistry and microphytobenthic dynamics have never been quantified simultaneously.
In this study, we experimentally investigated the influence of sediment reworking and bioirrigation activities of two dominant estuarine species, the annelid *Hediste diversicolor* and the bivalve *Scrobicularia plana,* on sediment biogeochemical fluxes and microphytobenthos biomass and photosynthetic capacities. Additionally, three density levels for each species were tested.
Our results showed that the extensive grazing pressure and strong sediment reworking performed by *Scrobicularia plana* drastically reduced microphytobenthos biomass, with weak stimulation of nutrients fluxes. Contrariwise, the presence of *Hediste diversicolor* did not seem to affect the microphytobenthos biomass, and even improved the physiological state of microphytobenthic cells. Hence a complex interaction between two opposite processes, which seem to compensate each other, is suggested: one negative related to grazing and sediment reworking activities and one positive related to strong bioirrigation and nutrient fluxes stimulation. These processes are clearly density-dependent. Indeed, an increase in bivalve density accentuated the observed negative impact on microphytobenthos dynamics, without any evidence of intraspecific competition, within this range of density. Conversely, no significant difference was observed between the different polychaete densities on microphytobenthic biomass, which can be explained by trophic and/or territorial competitions.

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Mechanisms controlling sediment reworking rates in the southern Baltic Sea

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The aim of this study was to assess the mechanisms controlling sediment reworking rates in five coastal areas of the southern Baltic Sea, affected by different level of riverine influence and anthropogenic pressure. The ex-situ experiments with luminophore addition on sediment cores containing natural benthic assemblages were conducted. Sediment cores and other environmental samples were taken during three campaigns in spring, autumn and winter (2019-2020). A modified gallery diffusor model was used to estimate the coefficients of biodiffusion (Db) and non-local transport (r). To explain the spatio-temporal variability in sediment reworking rates, a wide set of environmental variables together with benthic community characteristics and biological traits was used. In sandy sediments, both biodiffusion and non-local transport were detected, with Db from 0.1 to 0.25 (cm2 y–1) and r up to 4.7 (y–1). At sandy-mud stations, the r coefficient was highly variable (0.25 to 13.5 y–1). Db was there only noted once for samples collected from a coastal lagoon in spring (0.1 – 2.2 cm2 y–1). In the same experiment, also the highest r in our study was observed, presumably due to higher food abundance. The intensity of sediment reworking was correlated with benthic biomass, however, at each location different functional group dominated the assemblage: gallery-building polychaetes in sandy locations, mostly bivalves in sandy-muds, and chironomids and ostracods in the lagoon. The results of the study add the knowledge about the actual sediment reworking rates in temperate, non-tidal coastal zones, its relationships with environmental gradients and seasonal dependencies.

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Disparities in behavioural trait expression between and within species confound benthic ecosystem functioning under a near-future climate scenario

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Polar ecosystems are rapidly transforming in response to climate change, but how environmental forcing affects the way in which species mediate ecosystem functioning is not well constrained. Here, we examine the ecosystem ramifications of changes in sediment-dwelling invertebrate behaviour in response to anticipated near-future environmental conditions (+1.5 ◦C, 550 ppm (pCO2)). We find, for species from both the Arctic (Barents Sea) and Antarctic (Rothera Point), that changes in behaviour (surficial activity, particle reworking and burrow ventilation) do not necessarily lead to changes in nutrient release. Instead, we find interspecific behavioural responses across all species, intraspecific responses in two species (*Astarte crenata; Ctenodiscus crispatus*) collected from locations of contrasting environmental variation in the Arctic, and climate-driven changes in intraspecific trait variation in two species (*Pectinaria hyperborea*; *Aequiyoldia eightsi*). Though this study did not investigate the mechanisms behind such divergence in responses, we propose that interspecific behavioural plasticity is likely the result of differences in both passive (environmental tolerances) and active (compensation vs cost) means, and intraspecific behavioural plasticity is likely due to localised acclimation capacities to environmental change. Ultimately, this study demonstrates that climate-driven changes in the functional role of species are complicated by inter- and intraspecific variations in behavioural trait expression, both of which are instrumental for successful persistence in stochastic ecosystems. We therefore emphasise that future assessments must explore the abiotic and biotic drivers of variation in animal behaviour to better predict the functional consequences of a rapidly changing environment.

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Session 3

Micro / macro-organisms interactions for the biogeochemical cycles

Keynote Speaker: Pr. Erik Kristensen

University of Southern Denmark, Denmark

Bioturbation activities modify microbial diversity and processes involved in the sediment organic matter degradation and recycling. The latter have an influence, at larger scales, on biogeochemical fluxes and budgets (carbon, nitrogen, sulfur, phosphore, silica, iron). Organic matter quality (refractory versus labile) and environmental variables drive the benthic microbial processes. This session will focus on the interactions between the micro-organisms (e.g. procaryotes, cable bacteria, archae, eucaryotes, and co-occurrence networks) and macro-organisms involved in sediment biogeochemistry.

Burrowing macroinvertebrates decrease pore water phosphorus and iron concentration and promote their recycling to bottom water

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In shallow water ecosystems, the functioning of benthic compartment depends on the interactions between the physico-chemical environment and the community of micro and macroorganisms. This environment displays steep redox gradients and multiple interfaces, where fully oxic layers may be adjacent to reduced sediments. Biological communities have evolved adaptations, creating a network of coupled processes and multiple feedbacks. Indeed, benthic macroinvertebrates create horizontal and vertical heterogeneities in sediments and affect the benthic-pelagic coupling through their bioturbation activities. Bioturbation regulates benthic functioning via direct and indirect effects on sediment properties, microbial activities and nutrient turnover and mobility. The effects of macrofauna on nitrogen have been deeply investigated whereas those on soluble reactive phosphorus (P) are understudied. In this work, reactive P fluxes and pore water chemistry were measured in reconstructed sediments, without or with surface (*Corophium insidiosum*) and deep (*Alitta succinea*) burrowing macrofauna. Both species stimulated reactive P recycling (by a factor of ¯˜2) and nearly halved the porewater concentrations of this nutrient and of the reduced forms of dissolved iron and manganese. Sediments in bioturbated cores were more oxidized, but the analysis of solid phase iron pools (ferric and ferrous iron) did not reveal significant differences among treatments. We conclude that bioturbation promotes simultaneously higher P recycling and higher sediment oxidation, ensuring the recycling of a limiting nutrient and preventing the accumulation of reduced chemical species in the upper sediment horizon, by keeping the geochemical buffer capacity of sediments.

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Evaluating Drivers of Iron Cycling in Oregon Continental Margin Sediments Using an Early Diagenetic Model

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Continental shelf sediments have recently been suggested to be an important source of dissolved iron to coastal marine ecosystems, and there is evidence that bioirrigation may play an important role in enhancing dissolved iron flux from sediments. To better assess the influence of Oregon shelf sediments to dissolved iron in the overlying water column, an early diagenetic model based on the model framework outlined by van de Velde and Meysman (2016) was developed using a combination of data inclusive of benthic chamber fluxes, pore water and solid volume fraction concentration profiles, and bioirrigation, bioturbation, and sedimentation rates from a mid- and an outer shelf site offshore of southern Oregon on Heceta Bank. The model sensitivity to changes in organic matter oxidation rates, organic matter fluxes, and bioirrigation was tested while holding bioturbation equal across model runs. Simulations for both the mid-shelf and outer shelf sites show that the addition of denitrification and the inclusion of bioirrigation are essential for depicting iron cycling in Oregon shelf sediments, as these model outputs provided chemical profiles of Fe2+ that could nearly match observed profiles of dissolved iron, particularly at the outer shelf site. Bioirrigation greatly enhanced dissolved iron fluxes out of the sediment for both the mid-shelf and outer shelf sites. The sensitivity tests further highlighted the importance of bioirrigation, as all simulations that produced chemical profiles of dissolved iron most similar to observations included bioirrigation.

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Seasonal trends in spatio-temporal bioirrigation patterns and subsequent effects on oxygenation patterns in permeable marine sediments

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Bioturbators play a critical role in the supply of oxygen to anoxic sediments. This oxygen supply affects biogeochemical processes including diagenesis, elemental cycling, and organic matter remineralization. In permeable sediments, advection transports oxygenated water relatively far from burrows, resulting in relatively large volumes of intermittently oxic sediment. Burrow ventilation patterns ultimately determine oxygenation patterns, but data regarding the spatio-temporal patterns of burrow ventilation and its geochemical effects are rare, especially across multiple seasons. In a series of laboratory experiments with a model organism, *Clymenella torquata*, we used high-resolution planar optode imaging to characterize oxygen dynamics induced by the activities of these head-down, pocket-injection bioirrigators in temperature-controlled mesocosms with field-collected sediment in summer and winter. Intermittently oxic feeding pockets were shallower under summer temperatures (*Clymenella* were collected. Active irrigation interval durations were related to temperature, ranging from ˜˜4 min at 21○C to ˜˜12 min at 5-6○C. Quiescent intervals between irrigation events showed a similar relationship with temperature, but were notably longer (22-34 min) in winter-collected sediments than in summer-collected sediments (9-17 min) at winter temperatures (5-6○C). Therefore, temperature was not the sole driver of seasonal differences in the temporal patterns of bioirrigation behavior, and other seasonal factors are likely at play. These results underscore the importance of using animals and sediment collected in-season and held at in-situ temperatures when performing laboratory experiments to ensure natural and representative behavior and geochemical effects.

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Bioturbation as an essential process for Carbon Dioxide Removal Techniques

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To limit the effects of global warming, policymakers worldwide have pledged to keep the global temperature increase below 2∘C above pre-industrial levels. To achieve this, CO2 removal techniques are crucial. A widely accepted CO2 removal method is enhanced silicate weathering (ESW). By introducing fine-grained, fast-weathering silicate minerals into sediments in coastal areas, a CO2 sink could be created via artificial enhancement of the seawater alkalinity. It has recently been proposed that faunal activity could increase the dissolution rate of silicate minerals due to bioturbation and ingestion. To investigate the effect of bioturbation on silicate mineral weathering rates, we are performing long-running sediment mesocosm incubation where the deep-burrowing lugworm *Arenicola marina* is exposed to different concentrations and grain sizes of the fast-weathering mineral olivine. Initially, the sedimentary alkalinity release was significantly higher in mesocosms with than without added olivine. Additionally, significantly higher alkalinity fluxes in incubations with lugworms compared to non-bioturbated sediments have been observed throughout the experiment, revealing that bioturbation is essential for the sedimentary alkalinity release into the surface water. On the other hand, the treatment with small-grained (10-63 μm) olivine resulted in a decrease in the adult lugworm population and an increase in juveniles. To better understand the impact of additional silicate on macrofaunal activity in our mesocosms experiment. Our measurements provide a clear evidence that bioturbation is an important source of alkalinity for the tidal flats, and that the addition of olivine has multiple effects on macrofaunal activates and thus on alkalinity fluxes.

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Burrowing lifestyles and biogeochemical cycles: Local to global implications

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Burrow-dwelling marine fauna are important facilitators of sediment biogeochemical processes on various scales. They inhabit various types of burrows, ranging from intensively ventilated open-ended burrows to extensively ventilated or non-ventilated blind-ended burrows. This presentation will focus three cases within these burrow types and describe how they can affect C, N, S and Fe biogeochemistry and emphasize their potential influence on scales from the local sediment environment to the regional ecological functioning and the global climate situation. The first case deals with the nereidid polychaete *Hediste diversicolor*, a common and widely explored inhabitant of the open-ended burrow type. Its very active ventilation leads to intense bioirrigation that radically changes sediment redox conditions by injection of oxygen into otherwise anoxic subsurface sediment. Consequently, C oxidation and N transformations are strongly enhanced, while S and Fe biogeochemistry is modified to dominance of more oxidized forms. The second case has the spionid polychaete *Marenzelleria viridis* in focus, a typical and representative inhabitant of ventilated blind-ended burrows. It inhales water through the burrow opening and drives percolation of the exhaled water through the sediment to the surface. Despite a relatively slow ventilation, the bioirrigation effect is remarkably immense. The upward percolated anoxic water stimulates sulfate reduction, and the produced sulfide is in the sandy sediment forced to the sediment surface where white and purple sulfur bacteria enjoy a rich energy source. However, the near-surface sulfide enrichment affects and hampers the recruitment of other infauna species and may therefore modify the biodiversity of the entire benthic ecosystem. In the third case we move to intertidal mangrove forests where a wealth of sesarmid crabs inhabit non-ventilated blind-ended burrows. These burrows are filled with stagnant anoxic water during high tide, but they will in many cases drain to considerable depth at low tide, allowing oxygen to penetrate deep into the sediment. Such intermittently drained and oxic burrows may change the balance between carbon oxidation processes in favor of aerobic respiration and iron reduction at the expense of sulfate reduction. Moreover, the drained and air-filled burrows act as effective conduits for emission CO2 and CH4 derived from microbial degradation deep into the sediment. In fact, the rapid emission of these greenhouse gases from burrows to the atmosphere may strongly counteract the otherwise important role of mangrove forests for carbon sequestration, and thus potentially affect the global climate situation.

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In situ oil contamination in Guianas' mangroves: biodegradation of petroleum hydrocarbons and effects on the microbial and benthic communities, an experimental study in French Guiana.

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In order to gain knowledge on the potential effects that would have an oil spill on the Guiana's mangroves an in-situ experiment was carried out in a young mangrove forest with no history of oil contamination in the Sinnamary estuary in French Guiana. Control and oil-contaminated sediments were sampled one month after oil contamination to evaluate the effects of oil on the benthic compartment and to determine the hydrocarbon biodegradation capacity of the microbial community. Results indicated a 90 % decrease in the infauna densities in the oiled sediments (20,000 ppm of light crude oil in the first 2 centimeters), with the total disappearance of sensible taxa of Annelid and Crustacea, but a quite good resistance to tolerant taxa as the foraminifera and larvae insects. Decreasing in fauna densities was significantly correlated to lower particle displacement coefficients in oiled sediments. Profiles of fluorescent microspheres however showed a persistent sediment reworking activity within oiled conditions below 6 cm deep highlighting a strong burial of oil by the still alive bioturbation community. Simultaneously, we observed a strong n-alkanes and polycyclic aromatic hydrocarbons (PAHs) biodegradation (removal of 88 to 99 %) which was correlated to the bloom of putative oil-degrading bacteria belonging to several bacterial taxa (HB2-32-21, BD2-13, *Spongiibacter*, *Pseudomonas*, *Oleibacter*, *Alcanivorax*, and *Marinobacter*). Through functional inference, we have observed subtle changes in the microbial populations functions that indicate that an oil spill can significantly impact the functioning of the whole mangrove ecosystem.

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Bioirrigation and nutrient and contaminant transport in a polluted estuary

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The Duwamish River estuary in Seattle, WA, USA, is a significant source of polychlorinated biphenyl (PCB) contamination for the food web in the Salish Sea. Concentrations of PCBs in the sediment this estuary are high, but the transport mechanisms responsible for delivering PCBs to the Salish Sea food web are uncertain. We quantified bioirrigation rates using profiles of Rn-222 and silica and used these rates to model the transport of dissolved PCBs in this estuary. Fluxes of PCBs calculated by the bioirrigation model were at odds with estimates assuming passive diffusion. At sites with high rates of bioirrigation, the diffusion model underestimated the PCB flux, compared to the bioirrigation model. At sites with low rates of bioirrigation, the diffusion model predicted a higher flux than the bioirrigation model.

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Advances in transitory FeS species identification

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Bioirrigation activities produce redox oscillations in sediment at time scale about few minutes by providing rapidly oxygen in depth, before progressive return into euxinic conditions. In this delay, only faster chemical reactions occur, including Fe redox cycling and its interactions with other cycle. In particular the possibility for FeS formation is important (*tau*1/2-Fe(II) -˜ 10 ms, in H2S rich conditions) starting with cluster of FeSaq, then by nanoprecipitate of poorly crystalline mackinawite (FeS) that further aggregates on larger size. This dynamic implicate that any sample from dynamic environment, actively flushed burrows being archetypical, may contains large amount of transitory unstable FeS solid species in the filtered fraction. This distribution is poorly described in the literature, in particular because efficient methodological methods are lacking. We here propose two new methodological approaches to address the challenge, one that fit the *in situ*, fast and low cost criteria based on ligand competitive exchange (here with Ferrozine) with different pre-treatment conditions illustrated by Loire Estuary sediment cores. The second, more accurate and validating the first method on laboratory experiments, is based on new generation single particle ICP MSMS in order to tackle the challenge of monitoring highly interfered elements such iron. In less than 60-100 seconds and direct infusion of diluted aqueous media, we make the complete iron containing nanoparticles characterization (size distribution and concentration) by working in reaction cell mode for iron detection (mass shift or MSMS), so called SP-ICP-CRC-MultiQuadMSMS.

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Session 4

New approaches of observation, analysis and modeling for bioturbation studies

Keynote Speaker: Dr. Simone Pennafirme

Univ. Federal do Fluminense, Brazil

This session will focus on the different tools allowing to deal with ecosystem heterogeneity:

- 1D and 2D optical and infrared sensors to measure micro-heterogeneity of solutes in porewaters (oxygen, manganese, sulfur, CO_2, pH…)
- Biogeochemical fluxes at the sediment-water and sediment-air interfaces
- Remote sensing to visualize microtopography and benthic diversity at the sediment surface
- Tomography imaging to visualize in 3D biological structures within sediments and soils
- Mechanistic and stochastic models to simulate biogeochemical processes associated to animals behavior.

We will also consider the potential limitations of these tools and how they can be overcome for specific field study or experimental set up.

From actors to actions. The utilization of infrared reflectance spectroscopy for the study of bioturbation in tropical soils.

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Most of the soil biodiversity is in the tropics, where earthworms, termites, beetles and ants deeply impact the soil structure though the construction of soil biogenic aggregates and mound nests, and via the production of subterranean burrows and chambers. This bioturbation activity has important impacts on several key ecological functions (e.g., the cycling of nutrients, the dynamics of water and the erosion of soil). Unfortunately, studying the ecological processes associated with bioturbation faces two major problems. The first is the difficulty to identify the 'bioturbating species' (the actors) and the second is the rapidity of the biogeochemical cycles fastening the evolution of 'bioturbated structures' and their impacts on the soil systems (the actions). The presentation focuses on recent advances in the study of soil bioturbation using infrared reflectance spectroscopy. We show that actors and actions can be differentiated from their specific chemical fingerprints, thus providing a useful tool for (i) understanding "who's doing what" in soil, (ii) the path from biogenic to physicogenic soil structures, and (iii) the consequences in terms of soil organic matter dynamics and soil erosion.

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Applying 224Ra/228Th Disequilibrium to Investigate Faunal Contributions to Benthic Flux Processes

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The benthic flux of nutrients underpins marine food webs, influences conditions for life in the oceans, and contributes to climatic feedbacks. Process estimates are however, limited and highly variable, representing one of the largest sources of biogeochemical uncertainty within current modelling efforts. Traditional techniques for benthic flux quantification each have potentially significant limitations, including neglecting the influence of external advective processes, perturbing natural conditions, and most notably omitting contributions of benthic faunal activity. Conversely, biologically-focussed approaches often fail to undertake detailed chemical analyses, relying on bulk water column nutrient samples to indicate flux magnitudes.

The new 224Ra/228Th disequilibrium technique is promising in its potential to incorporate a wider range of benthic flux drivers, and to provide detailed rate estimates with greater accuracy than previous methodology. This approach examines deficits of soluble radium in relation to its sediment-bound parent, thorium, comparing this to porewater measurements of the solutes of interest. As yet, however, this technique has not been applied to investigate the influence of benthic fauna on flux dynamics.

We present first results using the 224Ra/228Th disequilibrium approach to examine the influence of five macrobenthic infaunal invertebrate species on the flux of nutrients (NH4+, NO3-, NO2-, PO43-) between the sediment and overlying water column, investigating inter- and intra-specific variability in contributions. On the basis of this work and a review of recent benthic flux literature, we propose a more holistic approach to benthic flux quantification, utilising the 224Ra/228Th disequilibrium technique and giving due consideration to both biological and geochemical components.

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From automatic detection of biogenic landforms on earth to the search of Martian signatures of life in rocks

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The search for past and/or present signatures of extra-terrestrial life is primarily focussed on turning up direct evidence for fossilized microorganisms, biologically influenced minerals, or organic chemical or stable isotopic biomarkers at the surface or in the atmosphere. Due to the similarities between Mars Noachian period (-˜3.6 Ga) and the young Earth at that time, the recognition of signatures of life on Mars in rock records may be possible. This approach is based on reasoning via abductive inference. Microorganisms play a role in the construction of various types of biogenic landforms. They are especially notable for forming Microbially Induced Sedimentary Structures (MISS). Such microbial structures have been considered to be amongst the most likely biosignatures that might be encountered on the Martian surface which is currently explored using rovers equipped with cameras. A Convolutional Neural Network (CNN) has been designed and tested to recognize MISS structures *versus* abiotic structures in images of rocks and sediment surfaces from Earth. The study was based on expertise and images taken during an *ex situ* experiment as well images taken at different natural sites where present and fossilised microbial mat cracks and abiotic desiccation cracks were observed. The model showed excellent prediction of biotic and abiotic structures derived from the images. The key areas of interest of the model matched well with human expertise for distinguishing biotic and abiotic forms. This first step of an innovative approach will be extended to other sources of biogeomorphological signatures among which bioturbation forms are excellent candidates.

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Bioturbation in cohesive sediments: the role of geotechnical properties in resisting particle mixing

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Bioturbation, the mixing of sediments by animals, is driven by the presence, abundance, and activities of animals. Physical processes such as particle mixing occur when a driving force, in this case the activities of animals, exceeds a resisting force. Here we examine the role of sediment structure in "resisting" bioturbation. We propose that the geotechnical properties of sediments affect bioturbation rates by determining the extent to which particles are freed from the cohesive matrix of muddy sediments. Burrows are extended through muddy sediments by fracture, and crack branching or microcracking at the tips of burrows are ways in which particles can be freed from the matrix. We use the finite element modeling program, Abaqus, to test the hypothesis that sharp gradients in sediment geotechnical properties, stiffness and fracture toughness, cause cracks to deviate from a straight path and branch. We also test the hypothesis that worms can "steer" the direction of crack propagation by applying asymmetrical forces to burrow walls. Modeling results indicate that neither variability in stiffness nor varying "behaviors" or model worms are likely to result in crack steering or branching. Instead, sharp gradients and small-scale variability in fracture toughness are important in crack tortuosity and branching. This study indicates that further study of the fracture toughness of muddy sediments and the variability in fracture toughness on the scales of burrowing animals has potential implications to understanding and predicting bioturbation.

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Distinguishing between mixing modalities of a small deposit feeder

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Models of bioturbation typically operate under the assumption of diffusive particle movement. Though mixing appears diffusive over long time scales, short study periods may be better represented by nonlocal models, and individual species may exhibit nonlocal mixing regimes. Few studies have considered the cohesive properties of sediments that resist bioturbation. This study aims to develop a better understanding of the transition from nonlocal to diffusive mixing over time as well as the role cohesion plays in resisting bioturbation. Capitellid worms (Annelida: Capitellidae) are conveyor-belt deposit feeders that ingest sediment at depth and defecate at the surface, clearly contributing to nonlocal particle movement. However, they are small and abundant, so their activities follow some of the assumptions of diffusive mixing. We developed a novel method to observe small worms such as capitellids in the lab using a thin aquarium padded with clear gelatin to reduce wall effects. Preliminary observations suggest that nonlocal (advective) mixing by capitellid worms changes to more extensive and diffusive sediment mixing over time as worms disrupt the cohesive sediment matrix. This study sheds light on the distinction between local and nonlocal sediment movement, suggesting that mixing patterns along this spectrum are mediated by animal behaviors and the mechanical properties of sediments.

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Aligning metabolic measurements with subsurface complexity in seagrass sediments

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Sediment metabolism is a critical metric of marine ecosystem function. However, it can be challenging to measure and highly variable, particularly in sediments with complex subsurface structures and burrowing faunal communities such as seagrasses. Our objective is to use a novel combination of methodologies to connect variability in sediment metabolism to the variability in the physical and biogeochemical structure of the sediment belowground environment. Dense, complex root mats may oxygenate sediments more and drive higher sediment metabolism rates, and the 3D structure of the roots may control what fauna can live there and by extension the metabolism-enhancing activities the fauna perform. Sediment metabolism will be measured with a custom-built in situ flow-through chamber system designed to capture higher temporal resolution than single deployment chambers and greater spatial resolution than eddy correlation methods. Then, detailed maps of the sediment subsurface environment will be produced with noninvasive scanning (MRI) and chemical sensing techniques (planar optodes and geochemical profiling). Patterns of metabolism may then be compared with the structure and composition of the below-ground environment to identify features that may drive variability in sediment metabolism. This research will not only shed light on the drivers of metabolic variability in seagrass sediments, but also demonstrate a new framework for improving our ability to link differences in small scale sediment features to larger ecosystem processes.

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Pre-processing methods for Hyperspectral-UAV data - Application to Guianese Equatorial mudbanks colonized by pioneer mangroves

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As unconsolidated mudflats are challenging environments for in situ measurements, high-resolution remote sensing methods, such as drone imagery, appear particularly useful as a non-destructive data acquisition technic. Hyper-DRELIO (Hyperspectral DRone for Environmental and LIttoral Observations) is a custom, mini-UAV (unmanned aerial vehicle) platform. Nevertheless, because of the sensors specificities (push broom) and the particularities of UAV surveys (low flight altitude, small spatial scale, and high spatial resolution), dedicated processing methods have to be developed when reconstructing hyperspectral imagery. These specifically developed methods for geometric and radiometric corrections were tested during a survey above mudflats colonized by pioneer mangroves in Awala-Yalimapo (French Guiana). The efficiency of the radiometric corrections is assessed by comparing spectra from Hyper-DRELIO imagery to in situ spectrometer measurements above the intertidal benthic biofilm and mangroves. The shapes of both spectra are consistent, while the spectral angle mapper (SAM) distance is 0.039 above the benthic biofilm and 0.159 above the mangroves. These preliminary results provide new perspectives for quantifying and mapping mangroves and the benthic biofilm, partly related to bioturbation activity, at the scale of the Guianese intertidal mudbanks system. The latter plays a key role in the coastal food webs, biogeochemical cycles, and sediment stabilization.

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Bioturbation model of Cerastoderma edule based on fauna activity as well as its habitat, a meta-analysis.

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Modeling the dynamic of an estuary and its morphology evolution takes physical processes description, but the role of benthic fauna on the sediment characteristics is yet to be accounted for at a ecosystem scale. This study proposes an approach for modelization of bioturbation effect on sediment transport for the macrozoobenthos species *Cerastoderma edule*. Previous works are based on metabolic rate which is a good proxy to describe activity of individuals, thus their effects on sediment rework. But the activity of fauna is linked to their habitat and how the sediment fits their need. So this model defines the quantity of reworked sediment regarding the activity of the present fauna, via the total metabolic rate (mW.m-2), as the proxy of the total metabolic energy of the fauna, and the sediment characteristic Silt rate (%), known to explain species distribution. To build this model, five different erosion data sets have been collected to have various experimental conditions. The equations have been selected among several possibilities to achieve the best performance. Having a set of data covering a large span of condition, including intermediates values, are keys for the robustness of this model. The result is a model that can be implemented in larger contexts of species populations and habitats, as well as climatic conditions.

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Optimal Ecological Niche model as intermediate between fundamental and realized niche : the SDM-NEO applied to Cerastoderma edule

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The benthic macrofauna is an important element in the food web of the Seine estuary. This study identifies the factors most likely to have an impact on macrozoobenthic spatio-temporal distribution in order to build Species Distribution Models (SDM). Among the dominant species in this estuary, the study is focused on *Cerastoderma edule*. The SDM built describes the habitats suitable for the species, through an Optimal Ecological Niche approach (SDM-NEO), which considers, for key physical factors, the conditions that allow a maximum biological response. This result is obtained using the quantile regression. Usually used by combining several factors in a linear equation, the result does not consider the nature of the biological response to each environmental stimulus independently. Generally, this response is modelled by a normal distribution, which describes the response according to the mean of the predictor and its standard deviation. The benefit of this equation is powerful with two factors chosen with little correlation between them, i.e. they do not contain the same descriptive information of a habitat. This model then literally defines an optimum biological response for the combination of the two chosen environmental factors. The two factors selected for our results are: (1) the daily maximum current, which reflects the protective conditions of *C. edule* in sediment (too much current risks too much erosion and thus entrainment), but need water renewal to feed by filtration (2) the percentage of time the sediment is covered by the tide, which positions the species in the foreshore.

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2D gel probes: an alternative method to assess bioirrigation fluxes and production rates for redox sensitive species

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During the last decade our group, among others, developed a series of new methods to map porewater chemistry at a (sub)millimetre scale. Our approach is based on the combination of gel-based sampling techniques (Davison et al., 1991) and colorimetry using densitometry or spectral analysis for quantification. Here we present examples of field-based applications of these techniques to better take into account non-diffusive benthic fluxes of dissolved manganese and iron focusing on bioirrigation in contrasted environments: an intertidal mudflat of the Loire estuary in France and the Gullmar Fjord in Sweden. In the Loire estuary, bioirrigation generated by polychaetes can count up to 70 and 90% of iron and phosphorus benthic effluxes respectively. In the fjord, according to saturation of bottom waters, the contribution of bioirrigation on sediment water efflux ranges from 50 to 80% for oxic and hypoxic waters respectively. Although spatial and temporal significance of gel-based techniques has to be taken into consideration, combined with multi or hyper spectral imagery, they can assess geochemical processes at the scale of the interface between the sediment medium and its perturbation.

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Unveiling the role of bioturbation on bacterial activity in metal-contaminated sediments by Microcomputed tomography and Synchrotron-based 2D µXR

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Interactions among macrofauna, biogeochemistry, and microbiology of marine sediments are essential for the full functioning of benthic marine ecosystems. The biogenic structures of macrofauna (such as galleries, tunnels, and burrows) and interactions among organisms are of great relevance in studies aimed at understanding ecological processes in sedimentary environments. The modalities of benthic animal activities reflect on the interaction with the sediment and its associated microorganisms. The trophic mode of bioturbation of benthic fauna is essential because it controls the gallery structure and irrigation rate, which affect the composition of the microbial communities and associated biogeochemical processes. The interaction between micro-and macrofauna often impacts sedimentary processes, including transport, solutes flow, and remineralization of organic matter. In metal-contaminated areas, contaminant mobilization may also occur, altering the behavior of metals in sediments and microbial communities. These activities, in many cases, result in both positive and negative feedback controls on the fauna itself. Although it is known that bioturbation affects microbial communities and that bacteria, in its turn, have strategies to immobilize contaminants, little is known about the mechanisms behind these interactions. This session will address the different tools allowing to deal with ecosystem heterogeneity, focusing on the use of Microcomputed tomography and Synchrotron-based Micro x-ray fluorescence (SR-μXRF), associated with biomarkers and biological analysis. Micro-computed tomography (μCT) has greatly improved Computed tomography image resolution to the micrometer scale, allowing accurate estimations of several morphometric parameters of very small objects. μCT has vast potential as a bioturbation monitoring tool because it is a non-destructive technique, allowing to follow the development of biogenic structures such as tubes and galleries through time with micrometric resolution. Monitoring gallery properties using μCT would contribute to a broader understanding of how bioturbation and organism behavior may affect ecosystem properties by providing quantitative parameters with biological significance. Geometric properties of galleries could be correlated with quantifications of nutrients, particulate matter, solutes, and pollutants to reveal how geochemical and microbiological processes interact with bioturbation. Further, μCT allows quantifying key aspects of bioturbation, such as gallery wall surface, gallery perimeter, and volume - all 2D and 3D gallery geometric aspects intimately related to bioturbation mucous lining, bacterial colonization, and bacterial metabolic activity, to better understand their interactions. These

*Speaker

findings could broaden our understanding of how marine bioturbation contributes to benthic systems, as well as how anthropogenic impacts can affect this process. In metal-contaminated areas, Synchrotron-based Micro x-ray fluorescence (SR-μXRF) can be a useful tool to identify and quantify metals in bioturbated sediments. For example, this technique, associated with MicroCT, allows for a better understanding of the influence of bioturbation on metal sequestration by bacterial biofilm colonizing gallery surface. Further, SR-μXRF allows mapping metal distribution within the bacterial biofilm, and, associated with biomarkers, helps us to unveil the mechanisms of metal sequestration by bacteria in bioturbated sediments. Overall, new and creative interdisciplinary research is needed to address the empirical challenges of discerning the connection between bioturbation, bacterial assemblages, and the integrity of ecosystem function in bioturbated environments contaminated by metals.

Alkaline extractable silicon fractions in marine sediments and its association with clay mineral content

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Silicon (Si) is removed from the ocean through the burial of amorphous biogenic silica (bSi, i.e. diatom, siliceous sponges, radiolarians) into marine sediments and reverse weathering. Accurate determination of the bSi content is particularly challenging due to the interference of non-biogenic silica fractions, such as different clay minerals and the authigenic aluminosilicates formed via the reverse weathering process. Recent evidence suggests that the contribution of non-biogenic sources of Si released during alkaline digestions can be substantial, yet it is not corrected by the standard silicate mineral dissolution correction protocols. To evaluate the effect of different Si fractions on bSi determination, Si and aluminum (Al) were monitored simultaneously during the alkaline extraction using sediment obtained from different depositional environments and clay mineral compositions (Kaolinite, Illite, Montmorillonite). Our results indicate that the extractable Si from clay minerals represents more than 100% of the Si previously considered to be solely biogenic. The influence of different clay mineral compositions on the determination of bSi and its Si:Al ratio varied, from the lowest to highest, Kaolinite (Si/Al = 1-1.5) > Illite (Si/Al = 2-3) > Montmorillonite (Si/Al = 3-5). This study suggests that the influence of non-biogenic Si composition and its influence on bSi determination in future studies, especially for samples enriched in silicate minerals, should include a mineralogical analysis.

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Session 5

Scales transfer

Keynote Speaker: Pr. Robert C. Aller

Stony Brook University, USA

Integrating the outcomes of the conferences and the workshops of the thematic school, this session will focus on downscaling and upscaling (scale transfer) referring to:

- the importance of a specific bioturbation process within diagenetic models
- the representation of the species or functional traits in the community
- the transfer from controlled experiments to in situ studies integrating the ecosystem as a whole
- extrapolation of results obtained from a local study at ecosystem level taking into account its spatial and temporal variability.

Biogeochemical structure and function in the bioturbated zone: scaling and methodological approaches.

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Sedimentary biogeochemical processes in the bioturbated zone are characterized by a vast range of time-dependent spatial scales, ranging from individual infauna -˜ 0.1 – 1 cm, to excavations and burrow gallery complexes -˜10 – 100 cm, to distinctive communities -˜100 – 1000 m, to basin scales 100 – 1000 km. The biogeochemical expression of these scales depends on the physical sedimentation regime, reactive carbon supply, overlying water oxygen, species compositions, and inherent biases of the study methods. For a given overall reactive organic C flux, the local mechanistic basis for biogeochemical reaction balances and material fluxes is typically determined at the individual scale. A single species can have substantially different impacts depending on age-size-dependent scaling and population densities, for example, nitrification – denitrification balances. These effects are optimally revealed and understood using modern imaging methods such as planar optodes and CT or MRI that resolve the reaction structure and provide a basis for probability density functions suitable for modeling reaction balances and net fluxes. When they are sufficiently stable and geometrically predictable, for example, in the case of large crustacean burrows, the biogeochemical properties of individual structures can be extrapolated to 100 – 1000 m scales using drones and equivalent survey methods. The more typical methods applied by most investigators, which include use of conservative tracers such as Br- or particle tracers such as 234Th to resolve bioirrigation and particle mixing in individual cores, seldom reveal underlying local mechanistic interactions but paradoxically are useful for community and basin scale analyses. For example, when used together with radiochemical tracers that have known sources and geochemical behaviors, particle mixing parameterizations, for example, DB can be used to demonstrate major patterns of reactive substrate capture (reactive inventories) and predict remineralization magnitudes and pathways at the basin scale. Viewed from the perspective of scale, it seems likely that reactive particle capture at basin scales was a contributing evolutionary force driving community – level bioturbation activities.

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Scale-dependency in biodiversity and ecosystem functioning: how 30 years of research in the White Sea support expectations

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Despite wealth of evidence linking biodiversity and ecosystem functioning (BEF), models to date have had limited success in effectively advising over the repercussions of human-induced biodiversity loss at temporal and spatial scales relevant for decision-making. A main impediment is the mismatch between the simplified, small-scale experiments at which biodiversity effect on function are regularly investigated and well-understood and the complex, large scale seascapes at which management decisions are made. Current theory for scale-dependency within BEF identifies several expectations but only a few have been subsequently verified by empirical data. Here, we use over 30 years of intertidal soft-bottom benthic community data in the White Sea (North – East Russia) to test whether observations match the theoretical predictions across aggregated temporal scale. Our results reveal the expected characteristic change of diversity and ecosystem function (bioturbation potential) respectively with increasing scale and, to some extent, also agree with the prediction that BEF slopes become steeper as scale increases. Predictions, however, collapse during a regime shift which has seen a proliferation of green algae and marine plants and disturbed the community. Nevertheless, the point in time at which observations no longer match predictions precedes the arrival of algae. Our results suggest that the theory on BEF scale-dependency is mature enough to yield robust seascape-wide predictions but highlight the need to corroborating expectations with empirical data as a mismatch between empirical data and theory serve as an early warning of an impending regime shift.

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Spatio-temporal variability of fiddler crab bioturbation activity along a mangrove-ocean continuum in French Guiana using UAV-based Structure-from-Motion Photogrammetry

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The structure of benthic intertidal habitats within mangroves and tropical mudflats is a mosaic of creeks, platforms, and depressions along the land-ocean continuum modulated by a wide range of physical and biological variables related to the tidal cycle. Functional compositions of benthic communities and associated bioturbation activities differ in response to this habitat diversity. The former are still under-evaluated because of their strong spatio-temporal heterogeneity at the small scale. This study evaluated bioturbation by fiddler crabs along a mangrove maturation gradient during low tide using UAV-based Structure-from-Motion (SfM) photogrammetry in a highly dynamic area of the French Guiana coast (South America). Digital Surface Models (DSM) and orthophotomosaics (6 mm/pixel), allowed identifying the benthic habitats, spatial distribution of crab burrows and temporal variability of their bioturbation activity. A spatial analysis using GIS showed higher densities of small and medium-sized burrows over the upper half of the mudflat, where the network of creeks was much more pronounced. A major proportion of burrows was located near to the creeks. The distance separating burrows from each other increased with increasing burrow size, and between burrows actively used by the crabs. The proportion of active burrows showing mounds of fresh excavated sediments was greater during ebb tide. Fiddler crabs rework the internal structure at each low tide, thus enhancing sediment oxygenation and water renewal in the burrows differently according to their position on the shore. This study demonstrated importance of small-scale heterogeneity for evaluating the impacts of crab burrows communities and crab species-specific behavior.

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Benthic contribution to estuarine silica budgets: results from measurements and modelling

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Increasing the understanding of silica (Si) cycle at land-sea interfaces is necessary to quantify their buffering capacities and their role in biogeochemistry and ecosystem functioning of the coastal zone. Sediment cores were sampled at six sites and four seasons along the Elorn and Aulne estuaries (North-Western France). Vertical profiles of porosity, amorphous silica (aSiO2) and silicic acid (Si(OH)4), and burrowing depth, biodiffusive coefficients, and aSiO2 dissolution rates were measured. A diagenetic model was developed to fit measured aSiO2 and Si(OH)4 profiles. This model allowed quantifying benthic Si fluxes, e.g. aSiO2 deposition fluxes that are difficult to assess through direct measurements, and their seasonal contribution to benthic-pelagic coupling. Results show that sites sampled along the two estuaries constitute significant net deposition areas (1-4.5 mmol Si m-2 d-1), particularly during winter (upstream) and summer (midstream and downstream). Year round, reprecipitation is negligible while burial retains ˜ 30-80 % of deposited aSiO2. In winter, burial dominates the benthic Si budget. As benthic fluxes are low compared to riverine fluxes, Si export to coastal waters is high. In contrast, in summer, Si(OH)4 export from the sediment is observed as a result of enhanced benthic recycling and bioirrigation. During extreme summer conditions, estuarine internal processes, e.g., benthic and pelagic primary production, dissolution and benthic Si fluxes, however surpass river fluxes in magnitude. Overall, Elorn and Aulne estuaries are efficient Si filters, retaining about 50% of aSiO2 in sediments, but with transient exports during winter.

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Intraspecific functional trait variability is driven by seasonality, geographic origin and conspecific density but not future climate exposure

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Individual trait variability is an integral component of ecological dynamics, yet it is often ignored in projective modelling approaches and management applications. Meta-analyses underpinned by theoretical models have highlighted the need to incorporate intraspecific variability into the trait-ecosystem function framework, however this has been hampered by a deficiency in appropriate empirical data at the individual level. We conducted two mesocosm laboratory experiments on 8 species of benthic infauna and reveal differences in bioturbation activity between geographically isolated populations, summer and winter, and with increasing individual densities. Differences in trait expression were not observed under future compared to ambient climate treatments however, and the magnitude of within-species variability was species-specific. Intraspecific variability in bioturbation activity correlated with benthic organic matter mineralisation rate but exhibited a weaker relationship with water column nutrient concentrations. Overall, our findings reveal individual trait expression in benthic macrofauna to be spatially and seasonally dynamic and dependent on prevailing population structure. These findings have significant implications for predicting the ecosystem consequences of changing biodiversity and suggest that management recommendations based on species mean-trait values lack accuracy. We contend that efforts to understand and manage functional diversity and ultimately, the provisioning of ecosystem services under altered environmental conditions will require the integration of inter-individual trait variability, rather than species means, into biodiversity assessments and environmental management.

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Global distribution of marine bioturbation intensity and sediment mixing depth

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The activities of sediment-dwelling invertebrates play a fundamental role in mediating major biogeochemical cycles, yet the spatial distribution of the mixed layer and intensity of bioturbation is poorly constrained. Here, we apply tree-based ensemble machine-learning techniques to the global inventory of faunal activity and the sediment mixed layer to determine which environmental factors are most important in regulating bioturbation. We find that a subset of environmental factors are more important in shaping mixing intensity than they are in determining mixed layer depth, and that there are regional patterns of bioturbation. Our analyses provide the most comprehensive map of bioturbation intensity and the sediment mixing depth and will help reduce uncertainty when addressing the ecological consequences of altered biodiversity and climate challenges at scales relevant to spatial planning.

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AUTHOR INDEX

6TH NEREIS PARK

Bioturbation in past and present: from terrestrial to marine ecosystems

The aim of this event is to bring together the international scientific community of researchers working on the mechanisms of bioturbation in marine, freshwater and terrestrial environments, at all latitudes (polar, tropical, temperate), and taking different time scales into account (from Precambrian to present). This event is in the framework of the international Nereis Park association gathering worldwide scientists working on bioturbation.

This 6th edition proposes an international thematic school on bioturbation with conferences and high-level training. It will allow promoting exchanges and giving scientists and students the latest conceptual and technological advances on bioturbation processes through conferences, posters sessions, small workshops, debates and practical studies.