FIRST NEREIS PARK CONFERENCE

Bioturbation: The Ever Changing Seafloor

Conference Book

November 7th - 9th, 2004
At Vacanciel «La Calanque»
Carry-Le-Rouet (France)

Bienvenue

A warm welcome to Carry-Le-Rouet for the First Nereis Park Conference "Bioturbation: The Ever Changing Seafloor" organized by the Nereis Park and le Centre d'Océanologie de Marseille.

Although a session dealing with bioturbation is often included in the benthic processes portion of programs at major international meetings, only a very few events are specifically organized on this very interesting and important topic (at least for all of us here today!). The last two were the "Organism-Sediment Interactions" Symposium/workshop (Georgetown, South Carolina, 1998) and the ACS Division of Geochemistry Symposium on "Biogeochemical Consequences of Dynamic Interactions Between Benthic Fauna, Microbes, and Aquatic Sediments" (San Diego, California, 2001). Who else besides the Nereis Park association, whose purpose is "to regroup and favor the contacts between all the scientists studying the bioturbation processes", could extend these beneficial exchanges and promote further progress?

We expect you will enjoy your time with us and that the conference will be rewarding, both scientifically and socially. We also hope that the Nereis Park Conference will become a tradition and not remain with a number #1. Thank you very much for coming and let the mixing begin!

The conference committee
Robert C. Aller (MSRC, Stony Brook University, USA)
Gaston Desrosiers (ISMER, Université du Québec à Rimouski, Canada)
Franck Gilbert (LMGEM, Centre d'Océanologie de Marseille, France)
Stefan Hulth (Department of Chemistry, Göteborg University, Sweden)
Jean-Christophe Poggiale (LMGEM, Centre d'Océanologie de Marseille, France)
Georges Stora (LMGEM, Centre d'Océanologie de Marseille, France)

PROGRAMME OF EVENTS

SCHEDULE

Saturday 6	
9:30 - 19:30	*Arrival and Check-in*
20:30	*Dinner*
Sunday 7	
7:30 - 8:30	*Breakfast*
9:30 - 10:00	*Introduction talk*
10:00 - 12:30	**Session A: Bioirrigation and solute transport**
	Chair: **Jean-Christophe Poggiale**
	Invited speaker: Carla Koretsky, Department of Geosciences, Western Michigan University, USA Incorporating complementary ecological and chemical information into bioirrigation models
	Coffee break
	Invited speaker: Erik Kristensen, Institute of Biology, University of Southern Denmark, Denmark Degradation of organic matter in irrigated burrows – what do we know?
	Filip Meysman, Netherlands Institute of Ecology, NIOO-KNAW, The Netherlands A new modelling approach to burrow ventilation in sandy sediments: a case study of *Arenicola marina* bio-irrigation
12:30	*Lunch and photo group of participants*
16:30 - 18:30	**Session A: Bioirrigation and solute transport (end)**
	Coffee break
	Anthony D'Andrea, College of Oceanic and Atmospheric Sciences, Oregon State University, USA Density-dependent impacts of burrowing shrimp on benthic fluxes in Yaquina Bay, Oregon (USA): Applicability for estuarine scale models
	Frank Wenzhöfer, Max Planck Institute for Marine Microbiology, Germany Microdistribution and total exchanges of O2 in coastal sediments: How does faunal activity influence benthic consumption rates?
	Session B: Movement of particles in the bioturbated zone
	Chair: **Gaston Desrosiers and Georges Stora**
	Invited speaker: Magali Gérino, Laboratoire d'Ecologie des Hydrosystèmes, Université Paul Sabatier, , France Local and non local biological particle transports in relation with functional diversity of the benthic communities
18:30 - 19:00	**Poster session**
19:00-20:30	*Cocktail and Dinner*
20:30 - 21:30	**Invited plenary talk**
	Bernard P. Boudreau, Department of Oceanography, Dalhousie University, Canada Quantitative and qualitative models for bioturbation: past, present and future perspectives
21:30 - 23:00	*Open bar*
Monday 8	
7:30 - 8:30	*Breakfast*
9:30 - 12:00	**Session B: Movement of particles in the bioturbated zone**
	Yoko Furukawa, Naval Research Laboratory, Seafloor Sciences Branch, Stennis Space Center, USA Particle movement in bioturbated microcosms revealed by computed tomography (CT)
	Stefan Forster, Baltic Sea Research Institute, Germany Species-specific effects of *Hydrobia spp*, *Marenzelleria viridis*, *Corophium volutator* on bioturbation and phosphate flux from the sediment
	Coffee break

	Nils Volkenborn, Alfred Wegener Institute for Polar and Marine Research, Germany Ecosystem engineering in marine benthos by the lugworm *Arenicola marina*: shifting from diffusive to permeable sediment characteristics
12:30	*Lunch*
16:30 - 18:30	**Session B: Movement of particles in the bioturbated zone (end)**
	Coffee break
	Lois Nickell, Scottish Association for Marine Science, Dunstaffnage Marine Laboratory, UK Organism responses to chemical cues present in phytodetritus
	Session C: Bioturbation and elemental cycling
	Chair: **Stefan Hulth**
	Invited speaker: **Lawrence M. Mayer**, Darling Marine Center, University of Maine, USA Food measurements and bioturbation
	Peter Stief, Max Planck Institute for Marine Microbiology, Germany Small-scale bioturbation/bioirrigation by midge larvae in freshwater sediments: implications for the benthic N-cycle
18:30 - 19:30	**Poster session**
19:30	*Dinner*
20:30 - 21:30	**Invited plenary talk**
	Martin Solan, Ocean Laboratory and Centre For Ecology, University of Aberdeen, UK Laboratory and *in-situ* instrumentation and detection systems for bioturbation: past, present and future perspectives
21:30 - 23:00	*Open bar*
Tuesday 9	
7:30 - 8:30	*Breakfast*
9:30 - 12:00	**Session C: Bioturbation and elemental cycling (end)**
	Greg Cowie, The Grant Institute of Earth Sciences, School of GeoSciences, University of Edinburgh, UK *In situ* and shipboard tracer incubation studies of benthic communities and carbon cycling across the Arabian Sea oxygen minimum zone
	Coffee break
	David T. Welsh, School of Environmental and Applied Sciences, Griffith University Gold Coast Campus, Australia Influence of bioturbation on metabolism, nutrient fluxes and nitrate reduction processes in organic matter loaded, bivalve farmed sediments
	Bjorn Sundby, ISMER, UQAR and McGill University, Canada Root induced cycling of lead in salt marsh sediments
12:30	*Lunch*
14:00 - 19:00	**Trip to Marseille**
19:30	*Dinner*
20:30 - 21:30	**Invited plenary talk**
	Robert C. Aller, MSRC, State University of New York at Stony Brook, USA Bioturbation and element cycling in surface deposits: past, present and future perspectives
21:30 - 23:00	End of conference talk and *Open bar*
Wednesday 10	
7:30 - 8:30	*Breakfast*
9:00	*Depart*

POSTERS PRESENTED
Official poster sessions: Sunday 7 and Monday 8
(N.B.: The poster room will be open all day long)

Movement of particles in the bioturbated zone

Kiara Burke *et al.*
Macrofaunal biodiversity, nutrient cycling and the impact of predation and opportunistic macroalgae on infaunal bioturbation: implications for ecosystem function

Aurélie Ciutat
Influence of cockle density and water current on sediment resuspension and the potential for release of contaminants

Aurélie Ciutat *et al.*
Stratigraphic effects of tubificids bioturbation in freshwater sediments

Eric Duport *et al.*
Benthic macrofauna and sediment reworking quantification at the Thau Lagoon

Patrick Gillet
Bioturbation of *Heteromastus filiformis* (polychaeta, capitellidae) in the Loire estuary, atlantic coast, France

Vincent Grossi *et al.*
Macrofaunal reworking activities and hydrocarbon redistribution in an experimental sediment system

Jenny Hedman *et al.*
The role of organic matter quality on invertebrate bioturbation activity and distribution of contaminants in Baltic Sea sediment

Pascal Lecroart
A numerical estimation of the error on the bioturbation coefficient in coastal environments by radioisotopes modeling

Volodymyr S. Malyuga *et al.*
General solutions for non-local exchange models of bioturbation: when mathematics meets biology

Cristian Mugnai *et al.*
Quantification of bioturbation in sediments of the Venice Lagoon (Italy)

Sabine Schmidt *et al.*
Tracing sediment dynamic on seasonal time at the water-sediment interface of the thau lagoon using Be-7 and Th-234

Sabine Schmidt *et al.*
Comparison of sediment reworking quantification using radionuclides and luminophores

Mark Shields *et al.*
Macrofauna abundance, biomass and bioturbation potential within the northern seas region: initial results

Bioirrigation and solute transport

Eric Breuer *et al.*
The relationship between faunal density and oxygen dynamics in deep-sea sediments along a North Atlantic latitudinal transect

Eric Breuer *et al.*
Benthic processes in the Arabian Sea: Mechanistic relationships between macrofaunal communities, sedimentary biogeochemistry, and organic matter cycling and distribution.

Suzanne Dufour *et al.*
The sulphide mining behaviour of chemosymbiotic thyasirid bivalves

Oleksiy Galaktionov *et al.*
Bio-irrigational transport of reactive tracers in permeable sediments: 3D flow patterns versus 1D model averaging

Stefan Hulth *et al.*
Imaging solute distributions in the bioturbated zone of marine sediments using plate fluorosensors

Emma Michaud *et al.*
The effects of the functional diversity of the *Macoma balthica* community on oxygen and ammonium fluxes at the sediment-water interface

Bioturbation and elemental cycling

Sarah Caradec *et al.*
Dietary impact of *Arenicola marina* on fatty acids and bacterial communities structure in marine sediments

Philippe Cuny *et al.*
Impact of marine polychaete bioturbation on Eubacterial communities' structure of coastal sediment: a molecular fingerprint approach

Sébastien Delmotte *et al.*
Effects of meiobenthos on the mineralization of organic matter and fluxes of nutrients at the water-sediment interface in a reservoir conditions: theoritical approach

Gaston Desrosiers *et al.*
Visualization and quantification of the major components of *Macoma balthica* communities in the sedimentary column using cat-scan

Marie Gagnoud *et al.*
Axial tomodensitometry (Cat-scan): a non-destructive method enabling sedimentary facies analysis of glaciomarine mud

Franck Gilbert *et al.*
Redox oscillation: an efficient way for the bioturbating infauna to control the nitrogen cycle

Satomi Kamimura and Makoto Tsuchiya
The role of opportunistic feeding gastropods in intertidal flat organic material fluxes

Anja Kamp and Ursula Witte
The importance of macrofauna for carbon processing in a fine-grained sandy shelf sediment (North Sea): experiments with 13C labelled phytoplankton

Sally Marsh *et al.*
Measuring, mapping and modelling bioturbation and denitrification

Karl Norling *et al.*
Importance of functional group biodiversity for mineralization of organic matter in two benthic ecosystems the Baltic Sea and the Skagerrak

Jean-Christophe Poggiale *et al.*
Reworking functional groups and nitrogen cycling: a model contribution

Caroline Tolla *et al.*
Interactions between macrobenthic and microbial communities through the sedimentary column, consequences on the organic matter fate: A modelling approach

Michael Townsend *et al.*
An experimental investigation into the relationship between bioturbator diversity and ecosystem function

Makoto Tsuchiya and Prosper L. Mfilinge
Particle transfer by sea cucumbers: bioturbation or biopurification?

PLENARY TALKS

In Alphabetical Order

EFFECTS OF BENTHOS ON BIOGEOCHEMICAL PROCESSES IN MARINE SEDIMENTS: PAST, PRESENT, AND FUTURE PERSPECTIVES

INVITED SPEAKER

Aller, R.C., Marine Sciences Research Center, Stony Brook University, Stony Brook, NY 11794-5000, USA; raller@notes.cc.sunysb.edu

Adaptations of metazoan benthos to infaunal existence during the late Precambrian transformed vast regions of relatively impermeable, biogeochemically stratified seafloor into geometrically complex, open-system reactors. Since that ecosystem revolution, the activities of macro- and meiobenthos have dramatically influenced the rates and extent of diagenetic reactions, affecting biogeochemical reaction pathways, elemental fluxes, and authigenic mineral storage patterns. Feeding, burrowing, and biogenic ventilation of anoxic deposits underlying oxygenated water create complex time-dependent, redox reaction distributions and biogeochemical heterogeneity. The spatial and temporal scaling of heterogeneity, redox reaction dominance, and coupling between reactions are dictated by species-specific life habit, trophic group, individual behavior, size distributions, population abundance, and community interactions. Biogenic effects are often contradictory, promotingcreating complicated patterns of material cycling. Oscillation of state and reflux isare the rule, whether it be physical or chemical properties. For example, the packaging of sediment into fecal aggregates during digestive processing locally compacts sediment, inhibits solute diffusion, and creates anoxic microenvironments; whereas the fragmentation and manipulation of particles during feeding and burrowing typically opens sediment structure, exchanges metabolites, and exposes occluded material to higher oxidants. Organic secretions can enhance microbial activity, leaving reactive mucoid contrails in deposits as macrofauna move about, or, may inhibit or otherwise limit remineralization as in the case of bromophenol-impregnated or refractory tube linings. The same biogenic materials differentially alter diffusion of inorganic and organic solutes, creating semipermeable, anisotropic diffusive properties, which may promote or inhibit reactions selectively selectively. Biogenic redox oscillations and open-system metabolite exchange appear to be particularly critical factors governing remineralization, enhancing decomposition efficiency, and controlling net elemental cycling. Dynamic heterogeneity and property variation over a wide range of spatial and temporal scales have made quantification of biogeochemical processes in the bioturbated zone extremely difficult and labor intensive. The advent of a range of optical sensors that allow multidimensional measurements of reactive particle and solute distributions at high resolution in real time are likely to substantially advance understanding of biogeochemical cycling in the bioturbated zone.

QUANTITATIVE AND QUALITATIVE MODELS OF BIOTURBATION: PAST, PRESENT AND FUTURE PERSPECTIVES

INVITED SPEAKER

Boudreau, B.P., Dept. Oceanography, Dalhousie University, Halifax NS B3H 4J1, Canada; bernie.boudreau@dal.ca
in collaboration with:
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Bioturbation moves sediment. Anyone who has visited a mud flat at low tide usually sees abundant evidence of that simple truth. As with many phenomena of interest to the natural sciences, early studies of bioturbation were qualitative and first applications were also descriptive, such as the use of trace fossils for environmental interpretation by paleontologists. However, bioturbational transport of sediment has a multitude of consequences, and benthic scientists soon realized that these needed to be quantified. These first quantitative models (versus conceptual models) attempted to account for the affects of biological mixing on isotope and opal distributions in sediments as if bioturbation was a diffusive process. As time passed, specific types of infaunal activity suggested non-diffusive modes of bioturbation, and other types of models were consequently formulated. Today there appears to be a near plethora of models, perhaps reflecting the wide variety of observed sediment transport modes, but also to some extent, the "tastes" of the modeller. All these models can, nevertheless, be placed into a logical framework that identifies and highlights the links between the models. This framework allows us to evaluate what are truly different models in terms of mechanisms and processes, as opposed to those that are merely mathematical variants. The framework also identifies types of models that have not been exploited or not fully exploited to date and the limitations inherent to each type of model within the framework.

BIOTURBATION IN THE MARINE BENTHOS: APPROACHES FROM THE PAST AND CHALLENGES FOR THE FUTURE

INVITED SPEAKER

Solan, M., Oceanlab, University of Aberdeen, Main Street, Newburgh, Aberdeenshire, Scotland, AB41 6AA, UK; m.solan@abdn.ac.uk

The burrowing, feeding, irrigation, construction and locomotory activities (= bioturbation) of marine benthic dwelling invertebrates play a significant role in the redistribution of pore water fluids and sediment particles which, in turn, influence benthic community structure, nutrient cycling and the marine food web. Understanding the mechanisms of bioturbation and the functional role of individual species within the benthic community is therefore a primary research goal, particularly as many coastal ecosystems are under intense pressure from human activity. Although a wide variety of laboratory and in-situ methods have been used to study bioturbation, most investigations have adopted one of three approaches: (1) descriptive, where biogenic signatures and/or infaunal species behaviour are observed and described, (2) quantitative, where changes in porewater chemistry and/or sediment particle displacement associated with infaunal behaviour are measured and (3) predictive, where numerical simulation techniques are used to determine the distribution and exchange rates of tracers across the sediment-water interface. These alternative approaches have necessarily relied on a variety of laboratory and *in-situ* techniques capable of observing and quantifying biogenic activity, but the development of each methodological approach has tended to proceed in isolation. Recently, however, instrumentation capable of linking biogenic features to individual species, and behavioural observations to high resolution data on the frequency and lengths of fluid/particle exchange, is yielding new information that can significantly improve existing models of bioturbation. Here, I briefly consider some of the latest technological developments for simultaneously observing and quantifying particle bioturbation and offer some perspectives on future challenges in benthic research.

TALKS

In Alphabetical Order

Speaker In Bold

Attendees Underlined

IN SITU AND SHIPBOARD TRACER INCUBATION STUDIES OF BENTHIC COMMUNITIES AND CARBON CYCLING ACROSS THE ARABIAN SEA OXYGEN MINIMUM ZONE.

Cowie, G., The Grant Institute, University of Edinburgh, Edinburgh EH9 3JW, UK; glcowie@glg.ed.ac.uk
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The transformations, mixing and irrigation associated with the feeding and digestive processes of benthic fauna make seafloor faunal communities key influences on sediment texture and redox state, on microbial processes, on C cycling and burial, and on sediment-water fluxes of nutrients, gases and other solutes. Food supply and oxygen are known to be important controls on faunal communities, but details of the contributions of fauna to seafloor biogeochemical processes remain poorly constrained, particularly due to lack of *in situ* studies on whole communities. Using benthic landers and recovered cores, parallel *in situ* and shipboard sediment incubation studies were conducted during 4 recent *RRS Charles Darwin* cruises to the Arabian Sea. Known quantities of ^{13}C-labeled diatoms were added to the benthic interface at the beginning of 2-5 day incubations. Overlying waters were maintained at ambient oxygen concentrations and sampled periodically, and sediments were sectioned post-incubation. C isotopic analyses are being conducted on both overlying waters and porewaters, and also on sediments and various classes of benthic organisms (bacteria plus meio- and macrofauna). This approach permits quantitative tracking of C cycling and determinations of process rates, community function and the importance of different fauna in C turnover. Tracking ^{13}C into lipids, amino acids and carbohydrates in fauna is also yielding new molecular-level information on digestive transformations. Incubations were also conducted with the addition of a mixture of three size ranges of inert particles, from clays to fine sands, each with a distinct fluorescent colour. These are being used to assess the rates and size-selectivity of rapid faunal particle ingestion and sediment mixing, to be compared with results of radiochemical analyses. Studies on the Pakistan margin were carried out at station depths (140 to 1850m) spanning the mid-water oxygen minimum zone, and thus extremes in oxygen concentration and faunal communities. Studies at the same sites during monsoon and intermonsoon periods permitted assessment of system response to varied food supply. An overview of the cruises and incubation studies will be presented, as well as an interpretation of preliminary results. These show dramatic changes in communities and sediment characteristics across the margin, as well as clear differences in community C uptake and remineralisation rates, and variable, depth-related system response times.

DENSITY-DEPENDENT IMPACTS OF BURROWING SHRIMP ON BENTHIC FLUXES IN YAQUINA BAY, OREGON (USA): APPLICABILITY FOR ESTUARINE SCALE MODELS OF NITROGEN CYCLING

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Thalassinid burrowing shrimp (predominantly, *Neotrypaea californiensis* and *Upogebia pugettensis*) inhabit large expanses of tide flats in North American Pacific estuaries, from British Columbia to Baja California. Feeding, burrowing, and burrow irrigation by burrowing shrimp can increase the remineralization rates of organic material (OM) and the interfacial solute fluxes. By virtue of their great abundance, wide distribution, and impacts on sediment geochemistry, burrowing shrimp have the potential to significantly affect the fate of OM and fluxes of nutrients on a whole-ecosystem scale in these estuaries. In this contribution, we summarize studies conducted to quantify the impacts of burrowing shrimp population density on oxygen uptake and nutrient fluxes from the sediment to the water column. This work includes measurement of OM remineralization and nutrient flux in shrimp-dominated sediments, GIS mapping of burrowing shrimp populations, and modeling to estimate the contribution of benthic-derived nitrogen to water-column nitrogen relative to other sources (i.e., the Pacific ocean and the watershed, including human inputs). Benthic oxygen uptake increased linearly with *Upogebia* burrow density from 29 mmol O_2 m^{-2} d^{-1} in no-shrimp plots to 198 mmol O_2 m^{-2} d^{-1} in the high density treatments (>350 burrows m^{-2}). Dissolved inorganic nitrogen (DIN = ammonium and nitrate-nitrite) flux from sediments to overlying water increased an order of magnitude with *Upogebia* population density (from 1.3 mmol N m^{-2} d-1 in the absence of shrimp to 24 mmol N m^{-2} d^{-1} at the highest densities). At mid and high *Upogebia* densities, nitrate became proportionally more important to DIN efflux from the sediments indicating a potential density-dependent increase in nitrification. Both oxygen uptake and DIN efflux are higher in *Neotrypaea*-dominated sediments than in shrimp-free sediments; we are currently characterizing the effect of population density on fluxes for this species and preliminary data on these relationships will be presented. Burrowing shrimp occupied >80% of the euryhaline and mesohaline intertidal flats and covered >600 ha of tide flats over a distance of 17 km upriver in the Yaquina estuary. Aerial coverage for both species was similar within the Yaquina, though *Upogebia* dominated tide flats in the lower estuary and *Neotrypaea* dominated upriver. Coupling the population distribution data to nutrient flux measurements, we estimate that shrimp-dominated tide flats are the second largest source of DIN to the water column during the summer (exceeded by the ocean).

SPECIES-SPECIFIC EFFECTS OF *HYDROBIA SPP, MARENZELLERIA VIRIDIS, COROPHIUM VOLUTATOR* ON BIOTURBATION AND PHOSPHATE FLUX FROM THE SEDIMENT

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We investigated the impact of three macrofauna species displaying different specific bioturbation depths, *Hydrobia spp., Marenzelleria viridis* and *Corophium volutator*, on processes relevant to the biogeochemistry of their subtidal sediment habitat. Animals were kept in the laboratory in microcosms at their natural abundances during 10 days. The effects of each species were investigated in 4 parallels for single species and in species combinations. We observed species-specific effects on oxygen distribution (micro-profiling), particle mixing (bioturbation), development of surface topography structure, and the flux of dissolved inorganic phosphate to the overlying water. *C. volutator* increased oxygen availability in the sediment by irrigation activity and yielded highest particle mixing coefficients. When species acted in combination, their combined effects could not described by simple arithmetic. Particle mixing was lower than for *C. volutator* when *M viridis* and *C. volutator* were combined. Phosphate release in combinations depended on the identity of species; it both surpassed and fell short of the highest release by single species *M. viridis* (HC, HM < M und CM, HCM > M). Our results illustrate the impact of diversity on ecosystem functioning and support the notion that identity of species is important for the way processes function.

BURROW SHAPE AND SEDIMENT PARTICLE MOVEMENT IN BIOTURBATED MICROCOSMS REVEALED IN COMPUTED TOMOGRAPHY (CT) IMAGES

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Burrow network geometry and sediment particle movement was quantified in a series of benthic microcosms from Computed Tomography (CT) images. Polychaete worms created U-shaped burrows within microcosms that were loaded with sandy sediments and submersed inside an aquarium with circulating artificial estuarine water. To evaluate sediment particle movement, high density mineral particles were added to the microcosm and the locations of these particles was tracked in three dimensional CT images at successive time steps of ~1 day. Two types of CT systems, both housed at Naval Research Laboratory, were used for this study. HD-500 micro CT is a high resolution industrial micro CT system that is capable of the spatial resolution down to ~ 60 micrometers for the 6-cm diameter microcosms. The locations of individual tracer particles were determined at this resolution. The other system is a Picker PQS medical CT system with 1.0 millimeter spatial resolution. This system can be use d to track the dispersion of particle tracers as a change in density. Whereas the X-ray used in the high resolution 3D imaging of HD-500 CT system did not completely kill the worms, it did make the worms sluggish as observed by the slow return of fecal mounds after CT imaging. Consequently, the “time-series” imaging was accomplished by sacrificing one microcosm each time the imaging was conducted. True time series was attempted by using lower X-ray energy (and thus lower spatial resolution), however. The results, with the detailed 3D burrow morphology and high resolution (in both space and time) particle movement data, call for new mathematical expressions for the modeling of bioturbation.

LOCAL AND NON LOCAL BIOLOGICAL PARTICLE TRANSPORTS IN RELATION TO THE FUNCTIONAL DIVERSITY OF THE BENTHIC COMMUNITIES

INVITED SPEAKER

Gerino, M., UMR CNRS-UPS 5177 Laboratoire d'Ecologie des Hydrosystèmes, 29 rue Jeanne Marvig - 31055 Toulouse, France; magali.gerino@ecolog.cnrs.fr

The integration of all components, which include diffusion and bio diffusion, advection and conveying, downward non-local transport and bio-irrigation, of local and non-local transports in mechanistic transport models, allows the quantification of transport mediated by diverse communities of aquatic sediments of continental and marine ecosystems. It has been found that invertebrate communities of shallow and deep marine sediments (Mediterranean sea and the Atlantic Ocean), and of fresh water (streams and natural and artificial wetlands) produce the same types of transport, although with variable intensities as a function of local environmental conditions. In both continental and marine sediments, the size of the particle determines the diversity of the biological transport; that is, when particles are too large to be ingested by benthic invertebrates in the river bed sediments, non-local transport does not exist any more and organisms act as biodiffusors. In all other environments, sediment transport generated by benthic invertebrate organisms is connected to their life style, their movement, their nutrition and the construction of biogenic structures.
An explanation of the recorded transport rates created by complete communities would be useful in order to allow the transport models to reach a predictive level. For this task, the direct estimation of transport rates based on knowledge of the community composition requires us to be able to state the type of relationship that relates rates to organism diversity and density. The study of such relationships with the whole community is made difficult by the occurrence of positive and negative interspecific reactions that interfere with the recorded transport. Given this fact, a functional classification of benthic invertebrates is proposed, based on the organisms' mechanical interventions on their immediate environmental structure. A classification based on mechanical functions provides the opportunity to sort organisms according to mechanisms at the sources of their intervention without taking into account the diversity of related modifications of physical, chemical and biological properties of the benthic layer. The relevance of properties of functional groups implies the occurrence of transport redundancy between organisms inside a group (the same type of transport with different species intensities). Identification of species that belong to one group allows us to test the type of relation that exists between organism composition and the transport rate within a functional group.

INCORPORATING COMPLEMENTARY ECOLOGICAL AND CHEMICAL INFORMATION INTO BIOIRRIGATION MODELS

INVITED SPEAKER

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A growing body of evidence demonstrates that benthic macrofauna have a profound influence on the geochemistry and microbiology of the sediments that they inhabit. This occurs as a consequence of activities including grazing, excretion, burrow construction and flushing of inhabited burrows with overlying waters. The rapid solute transport engendered in particular by the last of these activities (“bioirrigation”) has a demonstrable effect on the depth-dependence of porewater composition and fluxes of dissolved O_2, nutrients and other solutes across the sediment-water interface. Furthermore, the acute spatial and temporal heterogeneity imposed by bioirrigation is likely to have an enormous influence on organic matter degradation rates and mechanisms, secondary redox reactions, precipitation and dissolution of solids and microbial community structure at the burrow-water interface. With the increasingly widespread recognition of the significance of bioirrigation has come commensurate growth in the development of more sophisticated bioirrigation models. One of the earliest of these, the Aller tube model, is particularly notable because it incorporates ecological information. Although relatively simple, with burrows represented mathematically as equally spaced and sized, perfectly flushed cylinders, the tube model does a remarkably good job of predicting solute profiles and fluxes. However, it cannot represent mixed populations of large and small organisms, nor can it account for complex burrow geometries, although these are commonly observed in natural systems. Also, it is a deterministic model and so cannot easily take advantage of ecological information regarding the spatial or temporal variability of burrow networks. Thus, Koretsky et al. (2002) developed a stochastic bioirrigation model in which burrow networks are parameterized with respect to density and size according to ten “endmember” shapes, using available ecological data. Burrow networks are stochastically simulated, and mean depth-dependent burrow radii and surface areas as a function of depth are calculated based on many (e.g. 10,000) model realizations. Burrows of many common benthic infauna, including, a thalassinid shrimp, an echiuran worm, fiddler and mud crabs, and polychaete worms have been parameterized. Depth-dependent bioirrigation coefficients for dissolved oxygen and sulfate have been extracted for subtidal and intertidal sediments using the stochastic network simulator, together with the equation

$$\alpha_i(x) = \frac{D_i r_1}{\left(r_2^2 - r_1^2\right)\left(\bar{r} - r_1\right)}$$

where $\alpha_i(x)$ is a depth-dependent non-local bioirrigation coefficient, D_i the diffusion coefficient of solute i, r_1 the mean burrow density, r_2 the mean burrow separation distance, and $\bar{r}$ the time-averaged distance from the burrow wall to the lateral distance where the solute concentration becomes equal to the laterally-averaged concentration. These irrigation coefficients are in remarkably good agreement with those obtained using inverse modeling of chemical data according to

$$\frac{\partial(\phi C)}{\partial t} = \frac{\partial}{\partial z}\left(D\phi\left(\frac{\partial C}{\partial z}\right)\right) + \alpha_i(x)\phi\left(C_b - C_{avg}(x)\right) + R$$

where t is time, z is depth, ϕ is porosity, C_b is the concentration of solute i within the burrow, C_{avg} is the laterally-averaged concentration and R is a reaction term (Meile et al., 2001). Results of this work suggest that integration of available chemical and ecological data can yield accurate assessments of biologically-enhanced transport. Better knowledge of burrow flushing and ventilation activities, burrow water and burrow wall geochemical conditions and microbial community composition will promote the development of more sophisticated bioirrigation models.

DEGRADATION OF ORGANIC MATTER IN IRRIGATED BURROWS – WHAT DO WE KNOW?

INVITED SPEAKER

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Many studies have examined benthic metabolism and solute fluxes in bioirrigated sediments within the last two decades. Most of these agree that the presence of irrigating infauna enhances benthic metabolism to a greater extent than can be explained by respiration of the burrow inhabitant itself. However, the extent of the stimulated organic matter degradation by microorganisms not only varies depending on the physical structure of the burrow and how the wall is lined (thin mucus layers versus thick and leathery tubes), but also on the intensity and pattern by which the burrow is irrigated with oxic water. The presence of mucus secretions along burrow walls in association with the introduction of electron acceptors into and removal of metabolites out of burrows have routinely and uncritically been the favorite explanation for the enhanced microbial activity. Not many studies have actually tested whether these mechanisms are valid or not. Recently, it has been suggested that the introduction of oxygen into burrows by irrigation can be responsible for the observed enhancement due to increased degradation rate of aged organic matter, which otherwise is relatively refractory under anoxic conditions. However, it has also been argued that decreased diffusion scales induced by the presence of irrigated burrows may increase anaerobic microbial processes by e.g. efficient removal of inhibitory metabolites. This phenomenon has been examined in detail in our laboratory. We found an apparent rapid increase in volume specific anaerobic microbial activity with decreasing thickness (diffusion scale) of sediment plugs. However, a closer examination revealed that the effect was largely caused by the activity of microbial biofilms along the walls of incubation chambers. The role of biofilms becomes increasingly important for thinner sediment plugs. In conclusion, we found no significant effect of diffusion scales on anaerobic microbial activity, and believe that introduction of oxygen is the key to enhanced microbial activity in irrigated burrows.

FOOD MEASUREMENTS AND BIOTURBATION

INVITED SPEAKER

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Much if not most bioturbation results from the ingestion of sediments as food items. Measurements of sediment food value thus have potential value in understanding patterns of bioturbation. Application of various food indicators suffers from differences between the abilities of deposit-feeders to select particles for ingestion and scientists to select particles for analysis. We discuss these considerations using data from an ongoing project in the Gulfs of Maine and Mexico, USA. Spring bloom algal deposition results in nonlocal mixing of pigments but not ^{234}Th, indicating that pigment analyses provide useful information for bioturbation of pigment-rich particles but perhaps little indication of bulk sediment movement. More rapid downcore loss of fucoxanthin than chlorophyll supports selective ingestion of diatoms, being as both pigments show similar loss kinetics in animal gut fluids, and implies that even chlorophyll measurements may provide too broad an indicator of food substrate. Bulk nutritional quality measures - e.g., enzymatically hydrolysable amino acids (EHAA) - are likely influenced by both highly dispersed food, such as microbially reprocessed material, and numerically rare particles such as recent algal inputs. They thus likely provide better indication of nutritional opportunities for nonselective deposit-feeding. The large background of proteinaceous material in sediment, derived from by microbial reworking of previous inputs of algal material, makes these measurements integrators of longer term input and relatively insensitive to new algal inputs. EHAA concentrations thus correlate better with pheophytin, another integrator of algal inputs, than with chlorophyll. Downcore decreases in EHAA, to levels approximating laboratory-determined requirements for dietary protein, may help to explain the depth limitation of bioturbation, especially if subsurface deposit feeders are relatively nonselective ingesters. While progress has been made in understanding and mimicking deposit-feeder digestion, further progress will be enhanced by similar attention to the ingestion step.

A NEW MODELLING APPROACH TO BURROW VENTILATION IN SANDY SEDIMENTS: A CASE STUDY OF ARENICOLA MARINA BIO-IRRIGATION

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Marine and estuarine sediments are inhabited by bottom dwellers that create burrows or burrow networks penetrating deeply into the anoxic zone of the sediment. The oxygen needed for their metabolism is supplied through bio-irrigation, i.e. the flushing of the burrows with oxygen-rich water from the overlying water column. The nature of bio-irrigation will strongly depend on the permeability of the sediment.

Fine-grained sediments are characterized high hydromechanical dampening, and consequently, any macroscale flow induced by an organism in its burrow will not significantly penetrate the sediment. In order to ensure a sufficient oxygen supply, burrow networks will generally have two or more open connections to the sediment-water interface (SWI), ensuring a continuous conduit. The U-shaped burrow is the archetypal example of such burrow architecture. Moreover, the actual physical process that drives solute exchange is molecular diffusion of substances across the burrow wall. This diffusive transfer of solutes across burrow walls was described via the tube-irrigation model of Aller (1980), which proved a milestone in the quantitative approach to bio-irrigation. To date, it essentially remains the only mechanistic treatment of solute transport across the SWI induced by burrow ventilation.

The Aller tube-irrigation mechanism is however not applicable in sandy environments. Due to the higher permeability, any macroscale flow will penetrate the sediment more easily. Therefore, organisms can actively pump water across the burrow wall into the surrounding sediment. The reduced resistance to flow allows tubes to be closed at one end, so that after passing the organism, the burrow water percolates through the sediment upwards. The J-shaped burrow is the archetypal example of this burrow architecture. The physical process that causes the exchange of substances across the burrow wall is advective. Accordingly, the “diffusive” picture of bio-irrigation in muddy environments needs to be replaced by an “advective” one in sandy sediments.

Here, we present a detailed case-study of the advective bio-irrigation mode in permeable sediments. We investigate the mechanism and magnitude of these advective flows in permeable sediments generated by the ventilation of macrofaunal burrows. In order to describe the process quantitatively, we advance the “advective” counterpart of Aller’s “diffusive” burrow irrigation model, i.e. the point-source-injection bio-irrigation model. We selected the lugworm *Arenicola marina* as a case study object because lugworms constitute the dominant type of bio-irrigators in temperate near-shore sandy environments. Velocity and concentration patterns are derived from a 3D finite element model of the environment surrounding the lugworm’s burrow. These model results are then compared to data obtained from two separate tracer experiments with inert solutes. In a first experiment, tracer was added to the overlying water and its subsequent “injection” in the sediment due to Arenicola pumping was evaluated. In a second experiment, Arenicola specimen were added to a sediment that was already preloaded with solute tracer. The subsequent “flushing” of the sediment, i.e. the appearance of the tracer in the overlying water, was monitored.

ORGANISM RESPONSES TO CHEMICAL CUES PRESENT IN PHYTODETRITUS

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In 2001, the Scottish Association for Marine Science established its Northern Seas programme, part of which focuses on bioturbation. Work has been carried from the Scottish sealochs up to the Arctic fjords of Svalbard and seeks to determine how this process varies in response to environmental forcing and what the consequences are for sediment geochemistry and the redistribution of anthropogenic contaminants. As part of this, field experiments were carried out in a Scottish sealoch to investigate the responses of the echiuran worm *Maxmuelleria lankesteri* to additions of phytodetritus. This megafaunal species is a locally dominant member of sealoch soft sediment fauna and is a surface deposit feeder, able to select for particle size and type. It was hypothesized that such organisms may show sensitivity to the chemical cues which are indicative of the arrival of phytodetritus on the sea bed. When a phytoplankton bloom reaches senescence, dimethylsulphonioproprionate (DMSP) contained within cells is liberated to the water column. Bacterial action then subjects this dissolved chemical to rapid turnover forming dimethylsulphate (DMS). This sulphur compound is a known attractant for organisms such as sea birds (Nevitt *et al.*, 1995) and could also provide a signal to benthic organisms, allowing rapid exploitation of a high quality but ephemeral food resource. Work was carried out in Loch Creran during the spring of 2002. Paired burrow openings were identified and sediment ejection rates were recorded by collecting sediment expelled from the burrow in a 48-hour period. Evidence of feeding, in the form of ‘spoke’ traces made by the animals’ proboses, was also recorded. Sediment slurries enriched with phytoplankton, known to produce high levels of DMS, were then added around the burrow feeding opening and recording of burrow sediment ejection and feeding was repeated. The results demonstrated that sediment ejection rates varied greatly between individuals (0 – 56.26 g dry sediment d^{-1}) and no significant difference could be detected between rates pre- and post- addition of treated sediment. The low sample numbers and variability in feeding cycle were thought to be contributing factors to this result. Further laboratory work is now in progress to address these issues.

SMALL-SCALE BIOTURBATION/BIOIRRIGATION BY MIDGE LARVAE IN FRESHWATER SEDIMENTS: IMPLICATIONS FOR THE BENTHIC N-CYCLE

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Bioturbation/bioirrigation activities by small freshwater macrofauna may be restricted to a particularly narrow sediment layer. Nevertheless, some invertebrate species with mass occurrence in their habitat have been shown to significantly affect benthic microbial processes and nutrient dynamics up to the ecosystem level. Here we show that solute-specific microsensors can be used to reveal the mechanisms underlying such large-scale bioturbation/bioirrigation effects, i.e. mechanisms that work in micro-scale dimensions. For instance *Chironomus riparius*, an abundant midge larva in many freshwater sediments, tends to oxygenate sediment layers which they pass through with their burrows. At the same time though, O_2-dependent nitrification is considerably reduced in the presence of these larvae. Microsensor measurements inside burrows demonstrated that this unexpected discrepancy might be due to the loss of NH_4^+ from the sediment to the overlying water, a process that is temporally coupled to larval irrigation activity. Moreover, it was shown that the periodic ventilation pattern of the larvae created at most hypoxic conditions inside the burrows that did not support net production of NO_3^- (i.e. nitrification). In contrast, NO_3^- was introduced from the overlying water into the burrows and then net consumption of NO_3^- (i.e. denitrification) took place during larval resting periods. Chironomid larvae affected microbial N conversions also outside their burrows: Microsensor measurements within the narrow feeding layer at the sediment surface indicated lower metabolic activity (but not abundance) of nitrifying bacteria. We assume that particle-attached bacteria are quantitatively ingested by the detritivorous chironomid larvae and then get metabolically inactivated during the gut passage. After feces egestion, the recovery of the evacuated nitrifier populations will be particularly slow due to their long doubling times. Future studies should also aim at supplementing the pure process analysis with a structural community analysis using molecular tools for the *in situ* identification and quantification of bacteria involved in the benthic N-cycle.

ROOT INDUCED CYCLING OF LEAD IN SALT MARSH SEDIMENTS

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Plants growing in water logged soil and sediment are capable of extracting lead and other heavy metals and accumulating them in their tissue. The extraction of metals is generally believed to be related to the ability of these plants to oxidize the sediment in the vicinity of their roots. This is accomplished with molecular oxygen, supplied via the aerynchema, a continuous gas filled space in which oxygen is transported from the aerial parts of the plants to the tips of the roots. Oxygen not required by roots for respiration can leak into the soil environment and oxidize reduced soil components. Roots are thus the plant equivalent to the burrows that are created and irrigated by animals.

Oxidation of metal sulfides, which are highly insoluble, renders the metals soluble and available for transport through the pore water to the root. In soils and sediment that contain iron minerals, oxygen also reacts with soluble iron to produce insoluble iron oxides. Iron oxides have strong affinity for heavy metals, and coprecipitation with and sorption on iron oxides may immobilize these metals. The relative importance of mobilization of metals by sulfide oxidation and immobilization by iron oxides is poorly understood, and it is difficult to predict the net effect of these opposing processes on the uptake of metals by plants.

This paper reports direct measurements of dissolved lead in the pore water of salt mash sediments in the Tagus Estuary, Portugal, obtained with a voltammetric microelectrode. We use simultaneous measurements of dissolved oxygen, iron, and sulfide to elucidate the annual cycle of mobilization and immobilization of lead and its relationship to the growth and decay cycle of roots. We use stable lead isotope analysis to determine the origin of the lead, and elemental analysis of sediment, rhizoconcretions, and roots to calculate mass balances and quantify the cycling of lead between sediment and roots.

ECOSYSTEM ENGINEERING IN MARINE BENTHOS BY THE LUGWORM *ARENICOLA MARINA*: SHIFTING FROM DIFFUSIVE TO PERMEABLE SEDIMENT CHARACTERISTICS

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Intertidal sands are highly active systems where organic material is degraded and nutrients are released into the overlying water. Sediment permeability is an important factor influencing exchange rates between the overlying water and the sediment. In permeable sediments, rates of organic matter degradation can be enhanced by advection, driven by waves, currents and the sediment surface topography. Processes in impermeable sediments, like intertidal mudflats, are often limited by molecular diffusion.
In this study, the influence of benthic macrofauna on the sediment was assessed by comparing an intertidal sandflat with high abundance of the lugworm *Arenicola marina* and a 400 m² sandflat where lugworms were removed experimentally two years before the present study. Former lugworm exclusion experiments on a smaller scale showed that large scale exclusion is necessary to reveal the full spectrum of potential effects due to lateral transport of surface sediment. In a multidisciplinary approach sediment properties (grain size, organic content, permeability, porosity, chlorophyll content), oxygen and sulphide dynamics (using a microsensor lander, a planar oxygen optode system and chamber incubation experiments), bacterial density and porewater nutrients were analysed.
Absence of *Arenicola marina* strongly decreased the permeability of the sediment (approx. 7-fold, from $2.2x10^{-12}$ to $0.35x10^{-12}m^2$). A higher content of fine particles (<63µm) in the upper 5 cm and a higher organic content incorporated in the sand matrix and clogging the pore water space may be the main factors responsible for this observation. Additionally, higher microphytobenthos biomass in the *Arenicola*-free sediments may stabilize sediments and accumulate fine particles. Under calm conditions, both sites exhibited similar *in situ* oxygen penetration depths (5-10mm) and oxygen consumption rates (OCR) ($3\text{-}9mmol.m^{-2}.h^{-1}$). However, when exposing sediment to different water pressures experimentally, oxygen could penetrate significantly deeper in the bioturbated site, suggesting that the areal OCR could increase significantly under more dynamic conditions (e.g. a storm). While low nutrients concentrations (NH_4, PO_4, SiO_2) in the *Arenicola* sediments indicate rapid flushing, nutrients are accumulating in the absence of the worm. Highest microbial density could be found in the exclusion area. The density of bacteria in the subsurface sediment was twofold in the lugworm exclusion area compared with the lugworm tidal flat. Sulphide concentrations were measured only on the exclusion area below 7 cm.
The experiment suggests that the lugworm influences the sediment by facilitating an efficient exchange of oxygen and nutrients between the sediment and the overlying water. This is done directly by pumping oxygenated water into its burrows, but also, and perhaps more importantly, indirectly by maintaining higher permeability of the sediment, thus shifting the sediment from diffusion-dominated towards a more advective one.

INFLUENCE OF BIOTURBATION ON METABOLISM, NUTRIENT FLUXES AND NITRATE REDUCTION PROCESSES IN ORGANIC MATTER LOADED, BIVALVE FARMED SEDIMENTS.

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Farming of filter-feeding bivalves leads to intense biodeposition of organic matter to the sediments as faeces and pseudofaeces. However, the effects of this localised eutrophication may be modified by the farming system used. In this study we compared two farming systems, suspended mussel cultivation (biodeposition alone), sediment cultivation of clams (biodeposition & bioturbation) with an unfarmed control station in the Sacca di Goro, a eutrophic lagoon of the Northern Adriatic.
Whilst, both farming systems stimulated benthic metabolism and nutrient recycling, with fluxes of up to –15, 17, 3 and 0.2 mmol m^{-2} h^{-1} recorded for oxygen, CO_2, ammonium and phosphate respectively, in summer, the sites differed considerably. At the mussel-farmed station fluxes showed clear seasonal trends with temperature, anaerobic processes dominated benthic metabolism with sulfate reduction rates varying seasonally from 0.5 to 3 mmol m^{-2} h^{-1}, and the sediment was highly sulfidic (50-150 µmol S cm^{-3}). In contrast, at the clam-farmed station, sediment-water column fluxes were influenced more by the biomass of clams present than seasonal temperature changes. Additionally, although benthic metabolism was higher than at the mussel-farmed site, there was little stimulation of sulfate reduction rates (0.2-0.6 mmol $m^{-2}h^{-1}$) and sediment sulfide pools (5-10 µmol S cm^{-3}) were similar to those at the unfarmed control station.
There were also considerable differences in the pathways of nitrate reduction and the sources of nitrate, which drove these processes. In winter, when the water column nitrate concentration was high, the highest rate of nitrate reduction of ~270 µmol m^{-2} h^{-1} occurred at the mussel-farmed site. This nitrate reduction was driven almost exclusively by nitrate diffusing from the water column and ~30% the nitrate was recycled to ammonium via dissimilatory nitrate reduction to ammonium (DNRA) rather than denitrified. At the control and clam-farmed sites, nitrate reduction rates were lower and similar in winter (~180 µmol m^{-2} h^{-1}), nitrification supplied ~30% of the nitrate reduced, denitrification was the dominant process and DNRA accounted for less than 5% of total nitrate reduction. In summer under low water column nitrate conditions, nitrate reduction rates were below 10 µmol m^{-2} h^{-1} at the control station. The highest nitrate reduction rate of 130 µmol m^{-2} h^{-1} again occurred at the mussel-farmed station, but this activity was completely dependent upon water column nitrate, most of the nitrate was reduced via DNRA and less than 5% was denitrified. In contrast, although overall activity at the clam-farmed station was lower (75 µmol m^{-2} h^{-1}), DNRA was not important and more than 90% of the nitrate was denitrified. Additionally, at this station nitrification was the most important source of nitrate (>70%) for denitrification. Consequently, whilst the mussel-farmed sediments gained N as DNRA of water column nitrate was always greater than coupled nitrification-denitrification, the clam-farmed sediments efficiently eliminated N via coupled nitrification-denitrification and had very low rates of DNRA.
In conclusion, whilst both types of farming stimulated benthic metabolism through biodeposition, bioturbation by the clams greatly reduced the effects of this stimulation on sediment redox conditions and nitrogen retention and loss processes.

MICRODISTRIBUTION AND TOTAL EXCHANGES OF O_2 IN COASTAL SEDIMENTS: HOW DOES FAUNAL ACTIVITY INFLUENCE BENTHIC CONSUMPTION RATES?

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The sediment–water interface is one of the most important transition zones for solute exchange in marine sediments; it is characterized by steep gradients and extensive spatial and temporal heterogeneity. As diagenetic reactions in surface sediments are dramatically affected by biogenic activity, degradation of organic matter and nutrient remineralisation can be rapidly accelerated within the biogenic mixing zone. These processes strongly influence solute flux to and from the sediment and, consequently, play an important role in mediating marine nutrient cycles. A fundamental understanding of the biogeochemical processes in sediments therefore requires a quantitative assessment of *in situ* rates of benthic processes.
We present in situ measurements of three different techniques to determine the influence of faunal activity on benthic processes at a diel cycle: (1) Benthic chamber incubations were used to determine the total oxygen exchange of the sediment. (2) Oxygen microelectrode measurements were performed to determine the oxygen penetration depth and to calculate the solely diffusion driven O_2 uptake. (3) Planar oxygen optode measurements were performed to investigate the spatial and temporal heterogeneity within the sediment in a 2D perspective. The combined data set reveal an extremely patchy and variable benthic O_2 distribution primarily due to variations in fauna activity. Total benthic O_2 uptake was strongly affected by the diel faunal activity pattern, with elevated rates at the onset of darkness, while microprofiles showed a characteristic temporal dynamic for the O_2 penetration depth and the diffusive uptake. The fauna-stimulated consumption rate, calculated from the 2D O_2 concentration images, varied strongly over a 24-hour cycle, closely related to the diel faunal activity pattern. This spatial and temporal variability on sediment O_2 consumption rates, at a diel scale, is highly significant for any budget calculations on coastal carbon mineralization.

POSTERS

In Alphabetical Order

Presenter In Bold

Attendees Underlined

THE RELATIONSHIP BETWEEN FAUNAL DENSITY AND OXYGEN DYNAMICS IN DEEP-SEA SEDIMENTS ALONG A NORTH ATLANTIC LATITUDINAL TRANSECT

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This poster presents data of oxygen and nutrient fluxes with concurrent benthic faunal density at 4 stations along a Northern Atlantic latitudinal transect (Voring Plateau (VP; 67N 07.5E), Bear Island Fan (BIF; 73N 13.5E), Svalbard Margin (SM; 78N 42.4E) and the Yermack Plateau (YP; 80N: 07.4E)). The water depth was approximately 1400 meters for all stations except the YP (approx. 960m). Bottom water temperature was < 0°C at all stations. The simultaneous analysis of Mn and Fe, Chl *a*, ^{210}Pb, nutrients (nitrate, phosphate and ammonium) and organic carbon are also presented. Data was obtained by means of a benthic lander, shipboard oxygen profiling, sediment core incubations and sediment core slicing. The relationship between diagenetic processes and faunal density with changing latitude, while maintaining constant depth, is examined. Total oxygen consumption rates (TOCR) were 4.6 (VP), 4.2 (SM), 3.9 (BIF) and 2.9 (YP) mmol $m^{-2}d^{-1}$, and oxygen penetration depth of 25 mm (SM) to approximately 80mm for the three other stations. TOCR determined by whole core incubation exceeded calculated diffusive flux rates by 1.5 (SM), 2.9 (BIF; YP) and 4.4 (VP) times. While caution must be exercised with regard to spatial and temporal variability with lander and corer deployments, along with pressure effects on whole core incubations these data show a correlation exists between faunal density and oxygen and nutrient dynamics at all stations except the Svalbard margin. The difference observed here may be a result of input from the overlying water mass supporting the theory that pulsed inputs of OM to near shelf sediments exerts a major control on oxygen regulation within deep sea sediments. This poster will present data collected and examine the relationship between benthic communities, geochemical parameters and solute transport.

BENTHIC PROCESSES IN THE ARABIAN SEA: MECHANISTIC RELATIONSHIPS BETWEEN MACROFAUNAL COMMUNITIES, SEDIMENTARY BIOGEOCHEMISTRY, AND ORGANIC MATTER CYCLING AND DISTRIBUTION

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Processes occurring across the water-sediment (benthic) interface in the world's oceans are of major importance to global cycling and burial of carbon and other bioelements, to the make-up of sedimentary records, and as a coupling between the sedimentary and water-column environments. Organisms living in or on the surface sediments, from bacteria to the largest surface-dwelling and burrowing creatures, strongly influence these biogeochemical processes, and therefore the redox conditions and chemical composition of the sediments. Yet, because the benthic interface is remote, investigations to date have largely been conducted on recovered sediment cores and, at best, individual organisms removed from their natural environment. As a result, our understanding of the mechanisms and rates of benthic biogeochemical processes, and especially the roles of benthic communities, remains comparatively poor.
A project that is addressing these issues and involves biologists, geochemists and engineers from the Scottish Association for Marine Science (SAMS), the University of Edinburgh, Liverpool University and Southampton Oceanography Centre was funded by the Natural Environmental Research Council and the Leverhulme Trust. This team, along with collaborators from the USA, the Netherlands, Pakistan and India, participated in 4 research cruises to the Arabian Sea on *RRS Charles Darwin*, in spring and autumn of 2003.

MACROFAUNAL BIODIVERSITY, NUTRIENT CYCLING AND THE IMPACT OF PREDATION AND OPPORTUNISTIC MACROALGAE ON INFAUNAL BIOTURBATION: IMPLICATIONS FOR ECOSYSTEM FUNCTION

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Sediment bioturbation is one of the most important factors controlling nutrient cycling. The effect of macrofaunal biodiversity on sediment mixing and nutrient cycling was investigated using a replicated mesocosm approach. Benthic macrofauna were collected from an intertidal mud flat community and were artificially assembled to form a gradient of species richness (ranging from 1-3 species). Each level of species richness was replicated to allow any observed effects of diversity to be separated from any effects caused by species identity. The flux of nutrients (NH_4-N, NO_3-N and PO_4-P) from the sediment to the water column were analysed as a measure of ecosystem function. However, infaunal activity is highly variable and may covary with other factors such as the presence of a predator or the encroachment of opportunistic macroalgae. If such species interactions do cause changes in the relationship between biodiversity and ecosystem function, it is important to determine the more relevant effects of biodiversity loss on benthic processes for such scenarios. We assembled equivalent species richness gradients that included either the presence of: (i) a natural predator, the shore crab *Carcinus maenus*, (ii) the opportunistic macroalgae, *Enteromorpha intestinalis* or (iii) a combination of predator and macroalgae.
Results not available at time of going to press.

DIETARY IMPACT OF ARENICOLA MARINA ON FATTY ACIDS AND BACTERIAL COMMUNITIES' STRUCTURE IN MARINE SEDIMENTS

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A feeding experiment was conducted with the marine lugworm Arenicola marina to investigate the fate of phytoplanctonic lipids and bacterial community structures during gut passage and aging of fecal material. A first series of polychaetes was fed with a mixture of sediment and Emiliania huxleyi cells (Haptophyceae) and the released fecal pellets were then incubated in the dark for 19 days (AI treatment). A second series of polychaetes was fed with non-enriched sediment and the fecal pellets formed were incubated with the food mixture in the dark for 19 days (AF treatment). Changes in fatty acid composition and molecular fingerprint (RISA) of bacterial communities were characterized by analyses of the food mixture and the faeces using gas chromatography - mass spectrometry and molecular biology techniques respectively.

Results showed that ingestion and/or incubation selectively removed polyunsaturated fatty acids (PUFAs) and $C_{14:0}$ fatty acid from the diet. A bacterial contribution to the sediment was evident since bacterial vaccenic acid ($C_{18:1\omega7}$) and branched odd-carbon number (C_{15}-C_{17}) fatty acids were detected in all fecal samples. On the other hand, $C_{20:4}$, $C_{20:5}$ and $C_{22:6}$ fatty acids were only produced in the incubated AF treatment and were related to dietary-induced modifications of the structure of bacterial communities. These results shows that A. marina feeding activities (ingestion, fecal egestion) can affect sedimentary distribution of PUFAs and bacterial fatty acids. Results also suggests that the polychaete can inoculate enteric bacteria and/or select ingested bacteria during gut transit.

INFLUENCE OF COCKLE DENSITY AND WATER CURRENT ON SEDIMENT RESUSPENSION AND THE POTENTIAL FOR RELEASE OF CONTAMINANTS

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Coasts and estuaries from the South-West of England contain historically contaminated sediments. The aim of our study was to quantify the impact of bioturbation by cockles (*Cerastoderma edule*) on sediment resuspension when exposed to simulated tidal current cycles in an annular flume. Furthermore, it aimed to investigate how bioturbation can affect the release of contaminants from such contaminated sediment to the overlying water. Cores of undisturbed muddy sediment were taken from mid shore under the Tamar Bridge (Tamar river, Devon, SW England) and introduced into annular flumes. Cockles were collected from Exmouth (Exe estuary, Devon, SW England) and introduced into each flume to obtain four different densities: 0 and 312 animal/m^2 in the first experiment and 47 and 141 animal/m^2 in the second experiment. Small mussels (*Mytilus edulis*) were collected from Whitsand Bay (Cornwall, SW England) and then suspended in each flume to measure their clearance rate after 3 days. Sinusoidal water currents from (3 to18 cm/s) were generated into the flumes to mimic 6h tidal cycles of currents. At the end of each experiment an erosion run was performed. Water current was increased from 5 to 45 cm/s in 10 steps to measure the suspended sediment concentration (SSC) and the mass of sediment eroded as a function at each current velocity. Water samples were taken in each flume after 2 and 6 days at high and low current velocity and analysed for organic compounds on GC/MS. Results show an increase of the sediment resuspension with the cockles density during sinusoidal cycles but no difference was observed between the two higher densities. Mean SSC at the max current (18 cm/s) were respectively 12.7, 36.0, 67.6 and 67.7 mg/L for 0, 47, 141 and 312 animal/m^2. During the final step-wise erosion run the SSC was cockle density-dependent from 0 to 141 cockles/m^2 (99, 420 and 950 mg/L at 33 cm/s), but the SSC at 312 cockles/m^2 was lower than that observed for 141 cockles/m^2 (572 mg/L). This was probably due to the additional mucus secretion stabilising the sediment. Current induced resuspension of contaminated sediment was therefore dependent on the density of the cockles. The maximum clearance rate of the mussels (0.24 ± 0.08 to 0.29 ± 0.08 L/h/mussel with one mussel = 9.1 ± 2.4 mg) did not vary significantly with the SSC in the various conditions indicating that the contaminated sediments were not inducing a sublethal toxic effect.

STRATIGRAPHIC EFFECTS OF TUBIFICIDS BIOTURBATION IN FRESHWATER SEDIMENTS

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Tubificids oligochaetes are one of the major agents of bioturbation in freshwater ecosystems. They ingest particles at depth, in the anoxic zone, and eject fecal pellets at the sediment surface. This type of bioturbation is called conveyor-belt feeding. The aim of our experimental study was to measure bioturbation effects by tubificids oligochaetes on the primary sediment structure and to strengthen the knowledge of the feeding behaviour of these worms. Two complementary techniques were applied: X-ray radioscopic analysis to visualize the structure of the sediment and grain-size determination by laser diffraction. After 93 days within indoor microcosms, tubificids totally modified the sediment facies to a depth of at least 13 cm. The homogeneous clay-silt-sand sediment at time zero was remodeled into three superposed zones: (i) the upper zone (4.3 cm thick), much hydrated, and made up of an accumulation of fecal pellets ejected by the worms, based on clays and fine silts extracted from the ingestion zone; (ii) the underlying ingestion zone (9 cm thick), made up of fine sands, which had not been ingested by the worms; (iii) the bottom zone corresponded to the original sediment. The size spectrum of particles ingested by the tubificids revealed that 78% were less than 63 µm in diameter and the maximal ingestion size was 260 µm. The strong modifications induced by bioadvection may generate bedding-like structure that can lead to an erroneous sedimentological interpretation as it mimics a true stratification resulting of physical processes.

IMPACT OF MARINE POLYCHAETE BIOTURBATION ON EUBACTERIAL COMMUNITIES' STRUCTURE OF COASTAL SEDIMENT: A MOLECULAR FINGERPRINT APPROACH

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It is now well established that bioturbation influences composition, biomass, productivity and activity of microbial communities within the sediments. Impact of bioturbation on microbial activities have been extensively studied and are based mainly on modelling of the distribution and exchange rates of pore-water solutes across the sediment–water interface. Effect of bioturbation on bacterial distribution has been relatively well documented. On the other hand, relatively few reports deal with the effect of infaunal animals on the structure of bacterial communities. In this preliminary work we used the Ribosomal Intergenic Spacer Analysis (RISA) DNA fingerprinting approach, combined with multivariate analysis, to study the impact of marine polychaete bioturbation on the structure of Eubacterial communities of coastal sediments. *In situ* samples of faecal casts, internal and surrounding sediments of burrows belonging to *Arenicola sp.* and *Nereis diversicolor* have been analyzed. The results clearly show the differences between the structure of the bacterial communities of the internal and surrounding sediments of the burrows, feces and gallery bacterial communities been closer. The RISA appears to be a suitable and useful genetic fingerprinting technique to survey the spatial and temporal changes of eubacterial communities related to polychaete bioturbation.

EFFECTS OF MEIOBENTHOS ON THE MINERALIZATION OF ORGANIC MATTER AND FLUXES OF NUTRIENTS AT THE WATER-SEDIMENT INTERFACE IN RESERVOIR CONDITIONS: A THEORETICAL APPROACH

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Reservoirs within the river continuum constitute sites of strong potential for planktonic production thanks to the long retention times for water and nutrient enrichment from the upstream watershed. In these lentic conditions, high sedimentation rates and thin water columns enhance the linkage between the water column and benthic processes *via* cycling of organic matter components. Benthic fauna, represented by meiofauna, can also play a central role in activation of element cycling in such ecosystems.
The Malause reservoir, on the Garonne River in the south of France, is representative of these conditions. Within the framework of a multi-disciplinary program on the functioning of this river, a part of the research focuses on the influence of meiobenthos on the cycling of organic matter stocks in this reservoir. Our general approach is to identify and quantify biological transport in the reservoir and to estimate meiobenthos influences on the kinetics of transformation and recycling of organic deposits in these conditions. The first step was to develop a deterministic numerical model of biophysical transportation and reactions in sediment. All the components of local and non-local transport are included: diffusion and biodiffusion, advection and conveying, downward non-local transport and bio-irrigation. The classical scheme of a succession of oxic and anoxic mineralization reactions in a vertical profile of the sediment is chosen. Numerical simulations of nutrient dynamics in the sediment are carried out by applying this model under known reservoir conditions with pulse inputs of organic matter at the sediment surface. The effects of different biological transport on oxic and anoxic mechanisms of organic matter transformation are explored under different scenarios. These simulations are run to understand better the biotic and abiotic conditions of the benthic compartment that may drive nutrient and oxygen fluxes through the water-sediment interface. These theoretical results will serve as exploratory bases to optimize future experimental design.

VISUALIZATION AND QUANTIFICATION OF THE MAJOR COMPONENTS OF *MACOMA BALTHICA* COMMUNITIES IN THE SEDIMENTARY COLUMN USING CAT-SCAN

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Between land and sea, intertidal zones share different habitats such as intertidal mud flats, muddy sand flats, *Spartina* salt marshes and *Zostera* beds, which are directly under the influence of hydrodynamic forces and tides. These forces affect the distribution of organic matter and its availability to suspension- and deposit-feeders; as a result, intertidal faunal communities are seen to vary in composition in relation to organic matter availability. At high latitudes in the northern hemisphere, intertidal sediments are inhabited by the main species of the *Macoma balthica* community. The benthic organisms which form these communities play significant ecological roles through bioturbation, bioirrigation and sequestration of organic matter in the sediment. For example, molluscs modify sedimentary structures through bioturbation, and increase sedimentation at the surface by biodeposition. By oxygenating their burrows, polychaetes such as *Nereis virens* actively participate in biogeochemical reactions such as organic matter mineralization in the sediment. Although this activity is known to be important, it has been difficult to visualize infauna and the extent of their bioturbation in the sediment. Here, CAT-scan is used to visualize in 3-D the space occupied by molluscs and polychaete burrows in different types of habitats, and a new calculation is used to quantify the volume occupied by biogenic structures in the sediment. The 3D digital reconstructions show that 1) in the sandy muddy sediments of the Ha! Ha! Bay (Parc du Bic, Québec), the density of individuals, as well as their depth in the sediment column can be observed; the spatial orientation of *Mya arenaria* and *Macoma balthica* and the Y-shaped burrows of *Nereis virens* are clearly visible 2) in the organic matter-rich muddy habitat of Saint-Siméon (Québec), we observed an absence of bivalves and a high density of *N. virens* burrows and 3) in the *Zostera marina* beds at Barachois (Québec), polychaetes and bivalves are lacking, and the sediment is occupied by roots and organic matter. These results illustrate the changes in benthic macrofaunal communities in relation to increases in sediment organic matter content. This precise quantification is indispensable to calibrate and validate any model of the fate of organic matter in the sediment considering the influence of bioturbation processes.

THE SULPHIDE MINING BEHAVIOUR OF CHEMOSYMBIOTIC THYASIRID BIVALVES

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Several invertebrate species are known to inhabit sediments rich in organic matter. Whereas the presence of many such species is thought to be due to an opportunistic colonization of available space, some species might derive a different type of benefit from sites rich in organic matter. Invertebrates which live in symbiosis with chemoautotrophic bacteria, for example, may thrive in organically-enriched environments due to the abundance of reduced chemical compounds required for the metabolism of the symbionts. However, unambiguous confirmation of reduced compound harvesting by these invertebrates, by means of behavioural specializations, is lacking.
Here, X-radiography of thin aquaria containing different species of thyasirid bivalves in microcosms with variable amounts of sulphide is used to demonstrate their sulphide mining behaviour: burrowing activity was only observed near species with symbionts, and this activity was more intense when sulphide levels were low than when they were high. Also, 3D reconstructions of CT scans are used to compare the burrowing behaviour and relative space occupation of the chemosymbiotic species *Thyasira flexuosa* when maintained at variable densities within sediment microcosms. The results are discussed in an ecological context, where the role of benthic, chemosymbiotic species in sediment detoxification is put into perspective.

BENTHIC MACROFAUNA AND SEDIMENT REWORKING QUANTIFICATION AT THE THAU LAGOON (MICROBENT PROGRAM)

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The active bioturbation processes such as construction of biogenic structures, irrigation of burrows, sediment mixing, production of fecal pellets influence the distribution and the fate of organic matter and pollutants at the water-sediment interface and within the sediment. In order to bring information on the potential contaminant distribution and movements at the water-sediment interface in the Thau Lagoon, relationships between macrobenthos and sediment reworking was investigate and quantify in course of "Microbent-PNEC Program: Biogeochemical processes at the water sediment interface in eutrophicated environment".
During this study, three cores were sampled at two stations (affected or not by the shellfish farming activity) of the Thau Lagoon, in December 2001, April 2002, August 2002, January 2003 and May 2003. Process intensity of reworking sediment was measured by using fluorescent inert tracers (luminophores), and quantified by biodiffusion (D_b) and biotransport (r) coefficients. Macrobenthos was characterized and features were specified for each species : phylum, trophic group, reworking functional group, ecological meaning.
Results have shown differences in density and affinity of assemblage between the two stations. For each station, changes in the population composition are linked to different factors: trophic structuration, granulometry, oxygen depletion, temperature. If significant differences in particle biodiffusive-like transport were observed with time for each station, no significant difference was found between the two stations for both mixing coefficients.
Analyses of macrobenthos and sediment reworking quantification allowed to put in evidence: (1) similar sediment mixing intensities for different species composition at Sts C4 and C5; (2) the major role of the functional bioturbation groups and environmental factors on the intensity of sediment mixing. The sediment reworking has also been found variable with time, showing, for instance; (3) an increase of intensity in Summer suggesting potentially different redistribution, bioaccumulation and chemical fate (e.g., speciation) of deposited contaminants.

AXIAL TOMODENSITOMETRY (CAT-SCAN): A NON-DESTRUCTIVE METHOD ENABLING SEDIMENTARY FACIES ANALYSIS OF GLACIOMARINE MUD

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Glaciomarine mud deposited during the Late-Wisconsinian postglacial marine transgression of eastern Quebec (Goldthwait Sea) is ubiquitous in the sedimentary column of intertidal zones of the St.-Lawrence Estuary. This mud is very compact and thus limits the penetration of organisms composing the modern community of *Macoma balthica*. Axial tomodensitometry (CAT-Scan) is a non-destructive method that provides high resolution 3-D digital images of the characteristics of these sediments (grain size, mineralogy, primary and secondary sedimentary structures, fabric, shape and roundness, bedding contact) from multiple angles. CAT-Scan images allow a visualization of the recent, highly bioturbated sediment layer, which can be distinguished from the underlying Goldthwait Sea mud. This technique, which reports the density values of analysed materials, is used to discriminate between the different lithologies, lithofacies, bioturbations and organisms composing the deposit, thus allowing a quantification of the volume occupied by the different components of the material. The CAT-Scan images also provide information on the distribution, orientation and imbrication of thanatocoenosis shell beds that alternate with massive or faintly laminated glaciomarine mud beds, as well as on ichnofacies characteristics. When coupled with conventional sedimentary (grain size statistics) and radiochronological (14C) analysis, this data provides valuable data for identifying depositional processes and depositional sedimentary environments.

BIO-IRRIGATIONAL TRANSPORT OF REACTIVE TRACERS IN PERMEABLE SEDIMENTS: 3D FLOW PATTERNS VERSUS 1D MODEL AVERAGING

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The nature of bio-irrigation strongly depends on the permeability of the sediment. In sandy environments, due to the high permeability, organisms (e.g. *Arenicola marina*) can actively pump water across the burrow wall into the surrounding sediment. Here we investigate the biogeochemical effects of these advective flows generated by the ventilation of macrofaunal burrows. To this end, we have developed 1D, 2D and 3D reactive transport models using a finite element approach, and performed simulations for tracers that are described by linear and non-linear (monod-type) kinetics. One important aspect is that bio-irrigation is clearly a three-dimensional mechanism, while the conventional biogeochemical models are typically one-dimensional (simulating depth profiles of concentrations). Accordingly, we investigate whether three-dimensional irrigation flows can be adequately described by horizontally-averaged 1D models. Overall, we find that the averaging procedure induces complex interrelations on the apparent 1D model parameters. Apparent “transport” parameters in the 1D model are not only dependent the 3D transport parameters, but also on 3D reaction parameters. Conversely, apparent “reaction” parameters in the 1D model are dependent both on 3D reaction parameters and 3D transport parameters.

REDOX OSCILLATION: AN EFFICIENT WAY FOR THE BIOTURBATING INFAUNA TO CONTROL THE NITROGEN CYCLE

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Previous works on the effects of redox oscillation on sedimentary OM remineralization have demonstrated that the presence of oxygen alone is not sufficient for Chl-*a* to completely degrade (Sun *et al*., 1993) and that periodic re-exposure of sediment to oxygen results in a more complete (and sometimes more rapid) decomposition compared with constants redox conditions (Aller, 1994). These results suggested that the redox oscillation process induced by bio-irrigation, and associated to the mixing of particles, may allow aerobic bacteria to facilitate the degradation of compounds by anaerobic bacteria and inversely, resulting in an overall stimulated metabolic activity (Aller, 1994).
In the present study, we investigated the responses of microbial populations involved in the nitrogen cycle to redox oscillations, by measuring both the bacterial metabolic activity rates and the exchanges of dissolved compounds between the overlying water and the porewater. Both aerobic (nitrification: oxidation of NH_4^+ to NO_3^-) and anaerobic (denitrification: reduction of NO_3^- to N_2 and dissimilatory nitrate reduction to ammonium: reduction of NO_3^- to NH_4^+) metabolisms were taken into account. The experimental setup was designed to mimic permanent or oscillating redox conditions corresponding to three different locations inside a burrowed sediment: (1) the oxic surface sediment, (2) the anoxic sediment out of reach from the burrow and (3) the wall layer of a inhabited burrow subjected to intermittent irrigation.
To summarize, we found that the redox oscillation process induced by burrow bio-irrigation creates unique environmental conditions inside the sediments. The burrow walls are the only place where both aerobic (nitrification) and anaerobic (denitrification) metabolisms keep expressed. This cohabitation allows the N-mineralization rate inside the “oscillating zone” to be 4.8 times higher than observed in the oxic surface sediment.

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BIOTURBATION OF *HETEROMASTUS FILIFORMIS* (POLYCHAETA, CAPITELLIDAE) IN THE LOIRE ESTUARY, ATLANTIC COAST, FRANCE

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In 1999, a survey was carried out to study the bioturbation of the polychaete *Heteromastus filiformis* in the Loire estuary. Each month, samples were collected in the intertidal zone of Mindin harbour. The mean density was 2,184 individuals.m^{-2} with a minimum of 1,104 ind.m^{-2} in December and a maximum of 3,216 ind.m^{-2} in March 1999. Most of size frequency histograms could be considered as formed by a single cohort excepted in May and November/December 1999. The density of the population of *H. filiformis* decreases during summer and winter which are mortality periods and increase during spring and autumn which are recruitment periods. The life time for a cohort was from 6 to 9 months depending on the recruitment period. In 1999, the secondary production estimated by the method of Crisp (1971) was P = 104.3 g.m^{-2} with $\overline{B}$ = 15.4 g.m^{-2} and P / $\overline{B}$ = 6.8. The estimation of the sediment reworked monthly by *H. filiformis* is 9.4 l.m^{-2}.month^{-1} or 5.5 kg.m^{-2}.month^{-1}. The sediment reworked was high in spring with 8.3 kg.m^{-2} in March, very low during summer with 2.0 kg.m^{-2} in July, high in autumn with 7.6 kg.m^{-2} in October and 8.0 kg.m^{-2} in November followed by a sharp decrease in December with 2.9 kg.m^{-2}. The quantity of sediment reworked by *H. filiformis* in the Loire estuary was 116 l.m^{-2}.year^{-1} or 65 kg.m^{-2}.year^{-1} which is approximately a deep-sediment layer of 12 cm transported to the surface annually. In conclusion, the density and the structure of the population largely control the amount of sediment reworked. *H. filiformis* plays an important role in reworking sediment in the "slikke" and in the sedimentation processes in the Loire estuary.

INFLUENCE OF MACROBENTHIC FUNCTIONALITY ON HYDROCARBON REDISTRIBUTION IN MARINE SEDIMENTS

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The influence of macrofaunal reworking activities on the redistribution of particle associated hydrocarbon compounds (HC) was experimentally investigated. Two distinct hydrocarbon mixtures adsorbed on montmorillonite particles (< 4µm diameter) were added to the surface and deeper (2.5 cm) sediment layers. For comparison, luminophores (100-160 µm diameter) were added in the two deposit layers. At the start of the experiment, four macrobenthic species (the bivalve *Abra nitida*, the polychaete *Scalibregma inflatum*, and the echinoderms *Amphiura filiformis* and *Echinocardium cordatum*) were added to the sediment surface. Added macrofauna rapidly transferred HC from the surface sediment down to ~5cm depth by both continuous (biodiffusion) and non-continuous (biotransport) transport. Hydrocarbon compounds initially added to the deeper sediment layer were only subject to biodiffusion-like transport. Apparent biodiffusion coefficients (*Db*) quantified by using a 1-D model were between 0.5 and 8.4×10^{-3} cm^2 d^{-1}, and biotransport coefficients (*r*) ranged from 2.0 to 27.6×10^{-3} d^{-1}. Thus, the four studied species did not have the same effect on particle redistribution and thus on HC repartition in the sediments. *E. cordatum* was the most efficient reworker. The present study demonstrated the importance of particle size selectivity by benthic fauna, and verified that macrofaunal reworking activities may redeposit sediment from deeper sediment layers on the sediment surface. Both processes have obvious implications for rates and pathways during organic matter mineralization in marine sediments.

THE ROLE OF ORGANIC MATTER QUALITY ON INVERTEBRATE BIOTURBATION ACTIVITY AND DISTRIBUTION OF CONTAMINANTS IN BALTIC SEA SEDIMENT

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Settling organic matter (OM) constitutes an important food source for benthic animals. The quantity and quality of organic matter deposition is highly variable both spatially and temporarily. In temperate systems, such as the Baltic Sea, pulses of highly nutritious OM reach the seafloor following phytoplankton blooms and trigger an intensive competition for labile OM in benthic organisms. The benthos also receives OM from other sources, such as terrestrial OM or resuspended sediment, which are generally of lower nutritional quality. Since most deposit-feeding animals are selective feeders, their feeding activity, and thus bioturbation activity, may be correlated not only to the quantity but also the quality of the OM. Because many metals and hydrophobic persistent contaminants have a strong affinity to OM, the OM nutritional quality can thus play a major role in determining the distribution of contaminants in marine sediments.
The two main objectives of this study were: 1) to examine the role of settling OM quality on the fate of the hydrophobic flame retardant PBDE-99 and the metal cadmium and, 2) to compare contaminant mixing and transport following bioturbation by three different benthic invertebrates with diverse feeding strategies: a) *Macoma baltica*, a facultative deposit- and filter-feeding bivalve, b) *Monoporeia affinis*, a semi-pelagic benthic deposit-feeding amphipod, and c) *Marenzelleria viridis*, an invasive deep-burrowing, surface-feeding polychaete. Animals and sediment were collected in winter and the experiment was run for one month in core tubes (9 cm Ø, 50 cm high) filled with sieved (1 mm) coastal Baltic Sea sediment and water. Each animal group was added to three replicate core tubes, except for three replicate control cores with no animals. Equal TOC amounts of three different carbon sources: a) *Tetraselmis* spp., a green algae, b) lignin, wood fibres, and c) surface sediment, were spiked with trace amounts of ^{14}C-labelled PBDE-99 and the radioisotope cadmium-109 and added to the core tubes. Preliminary results of the distribution of ^{109}Cd and ^{14}C-PBDE in relation to OM quality and bioturbation activity are presented.

IMAGING SOLUTE DISTRIBUTIONS IN THE BIOTURBATED ZONE OF MARINE SEDIMENTS USING PLATE FLUOROSENSORS

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The last few decades, technical developments in resolving pore water distributions at a sub-mm resolution by micro–scale optical, biological and electrochemical sensors, and water/gel–filled equilibration probes have made available important information to improve the overall understanding of macrofaunal reworking in marine sediments. By the assumption that vertical gradients represent a steady-state situation, high-resolution (temporal and spatial) reaction-diffusion models can be used to estimate e.g. rates of aerobic respiration, nitrification and denitrification, and to calculate the importance of these processes in relation to the observed solute distribution patterns. Two-dimensional plate sensors, so far developed for O_2 and pH, provide important complementary micro-scale level information on the temporal and spatial variability of bioturbation and bioirrigation, particularly close to the oxic/anoxic transition and in the suboxic layer of the sediment. The basic idea of 2-D fluorosensors is to immobilize solute specific fluorescent indicators (often already in use within health sciences) onto thin-layer hydrogels, foils or membranes and fix these on transparent supports. The sensor system is immersed directly into the sediment and once equilibrium with the sediment/pore water matrix is established, the probes are scanned (excitation) non-destructively (without further sampling and/or extraction procedures) and fluorescence emission detected by a CCD camera to obtain a 2-D “picture” of solute distribution patterns. Image analysis techniques are used to quantify and model concentrations patterns pixel by pixel. The technique of 1- and 2-D fluorosensors and direct fluorescence imaging rivals most existing techniques of solute detection, e.g. in terms of temporal (minutes or less) and spatial (50-100 µm) resolution, low cost (developed sensors are disposable), fabrication time (minutes), total effort of labor (minutes compared to several hours), and the fact that several analytes can be determined simultaneously in multi-element fluorosensors. A future ability to simultaneously and non–destructively scan 2–D distributions of biogeochemically important solutes like O_2, ΣCO_2, nutrients, Mn, Fe, and pH would significantly improve the understanding of complex reaction cycles during organic matter degradation in bioturbated deposits.

Here, we present recent examples on the use of 2-D plate sensors to image solute distributions in the bioturbated zone of marine sediments.

THE ROLE OF OPPORTUNISTIC FEEDING GASTROPODS IN INTERTIDAL FLAT ORGANIC MATERIAL FLUXES

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Feeding behaviors of the gastropods *Batillaria zonalis* and *Batillaria flectosiphonata*, opportunistic feeders (suspension and deposit feeders), were studied to examine their effect on dynamics of suspended materials, chlorophyll-*a* (chl-*a*), pheopigments (pheo), total nitrogen (TN) and total organic carbon (TOC) in sediments. Suspension feeding in *B. zonalis* was observed in detail visually, as it had been previously unreported. During feeding observations, suspension feeding *B. zonalis* formed a mucus "food cord", to entangle particulate materials, which was subsequently ingested. *B. flectosiphonata* also have the same mechanism. The feeding modes of *B. zonalis* and *B. flectosiphonata* are hence categorized as ctenidial filter feeding.
These gastropods were cultured for 2 weeks in the system using natural seawater. In one treatment, gastropods were restricted to suspension-feeding only, and in another treatment gastropods were free to suspension-feeding and deposit-feeding (dual-feeding). Filtration rates in both species were higher in the suspension-feeding treatments than in the dual-feeding treatments. After culturing, the accumulation of chl-*a*, pheo, TN and TOC were higher in the surface sediment suspension-feeding treatments than in the dual-feeding and control treatments. "Freshness" indicated as the chl-*a* / pheo ratio were higher in control treatments than in other treatments. These gastropods uptook most of the TN from surface sediments, and contribution of TN from seston was three times less that of surface sediment. This study indicates that the opportunistic-feeding gastropods play a significant role in materials fluxes in marine sediments, through the increase of biodeposition and reprocessing of accumulating biodeposited organic materials on surface sediments.

THE IMPORTANCE OF MACROFAUNA FOR CARBON PROCESSING IN A FINE-GRAINED SANDY SHELF SEDIMENT (NORTH SEA): EXPERIMENTS WITH ^{13}C LABELLED PHYTOPLANKTON

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In situ and on board experiments with ^{13}C labelled diatoms were carried out in order to investigate the processing of algal carbon by the macrofauna community of a sandy shelf site in the southern German Bight (North Sea). The time series (12, 30, 32, and 132 h incubations) was supplemented by additional lab experiments on the role of the dominant macrofauna organism, the bivalve *Fabulina fabula* (Bivalvia, Tellinidae), for POM subduction to deeper sediment layers. The specific uptake of algal ^{13}C by macrofauna organisms was already visible after 12 h and constantly increased during the incubation times. *F. fabula*, a facultative (surface) deposit and suspension feeder, *Lanice conchilega* a suspension feeder and the (surface) deposit feeder *Echinocardium cordatum* were responsible for the majority of macrofaunal carbon processing. Predatory macrofauna organisms like *Nephtys* spp. (Polychaeta, Nephtyidae) also quickly became labelled. The rapid subduction of fresh organic material by *F. fabula* down to 4-8 cm sediment depth could be proven and it is suggested that entrainment by macrofauna in this fine-grained sand is much more efficient than advective transport.

A NUMERICAL ESTIMATION OF THE ERROR ON THE BIOTURBATION COEFFICIENT IN COASTAL ENVIRONMENTS BY RADIOISOTOPES MODELING

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A time-dependent model is developed to test the accuracy of the classical method used to calculate the bioturbation coefficients from ^{7}Be and ^{234}Th profiles in coastal environments. The model simulated activity profiles influenced by either seasonal or episodic input of radionuclide flux at the sediment-water interface and calculated the apparent bioturbation coefficient from these disrupted activity profiles following the classical procedure based on the steady-state approximation. The error induced by this approximation is then characterized by the difference between the apparent *Db* and the actual one initially introduced into the time-dependent model. This study shows that the relative error reaches significant values with the set of parameters classically encountered in coastal environments: The relative error can get up the extreme values of 163 % with the ^{7}Be and 74 % with the ^{234}Th. Moreover, this error is inversely proportional to the flux variations at the sediment-water interface and is more sensitive to the amplitude of the flux oscillations than to the actual value of the bioturbation coefficient. Finally, the classical procedure adopted to determine the biological mixing remains applicable to coastal environment if, and only if, necessarily cautions are taken, in particular, if flux variations at the sediment-water interface are precisely measured in order to constrain the impact of this transient-regime on the bioturbation coefficient calculation.

GENERAL SOLUTIONS FOR NON-LOCAL EXCHANGE MODELS OF BIOTURBATION: WHEN MATHEMATICS MEETS BIOLOGY

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Bioturbation is a dominant transport process for solid particles in aquatic sediments. Therefore, an adequate mathematical description of bioturbation is a prime interest in the development of reactive transport models. A very general and powerful description of bioturbation is provided by the non-local exchange formalism, which describes an arbitrarily complex particle exchange between different depths in the sediment (Boudreau and Imboden, 1987; Boudreau, 1997). Effectively, the non-local exchange model comprises a master model, from which other bioturbation models can be derived as special cases (Meysman et al., 2003). Despite its generality, and its potential to describe complex bioturbation phenomena, the non-local exchange model has only been implemented sporadically. The conservation statement for the non-local transport process leads to an integro-differential equation, and an important obstacle for the application of the exchange formalism is the lack of available solutions for these integro-differential equations.

We present a general solution procedure for the non-local exchange model based on:

- reformulation of the problem in terms of a jump length distribution and an average waiting time;
- reduction of the governing equation to an integro-differential equation of the convolution type;
- solution of the latter equation using the Fourier transform technique.

Using this procedure, we simulate transport of (reactive) solid tracer particles for specific bioturbation mechanisms, i.e. deposit-feeding by polychaetes and surface threading by crabs. Mechanistic particle displacement models are presented that are based on a description of the locomotion and feeding activity of these organisms.
In the case of deposit-feeding by large worms (up to 20 cm), the sediment particles are displaced over large distances and in a directional fashion, which violates the assumptions of the corresponding bio-diffusion approximation (Fick's Law). Performing the numerical simulations, we show that, at short time-scales, the non-local model diverges considerably from the classical bio-diffusive model. Over larger times, the non-local simulations converge to the diffusive solutions, as predicted by theory.
In the case of the surface bioturbation by crabs, we compare solutions of both the biodiffusion model and the non-local exchange model to the luminophore data of Solan et al. (2004). The model simulations indicate a rapid down-mixing of the luminophores, leading to large mixing intensities. Although more complex, a clear advantage of the non-local model over is that it allows to estimate a characteristic time scale (i.e. the average time between two bioturbation events) and a spatial scale (i.e. the average displacement length of a particle in a bioturbation event). For the crab mixing, this characteristic time was 40 min and the characteristic mixing distance was 3 mm. Overall, the non-local model allows to extract three types of biological information from the data (i.e. the mixing length, the waiting time and the mixing intensity), where the biodiffusion model only provides one type of information (i.e. the mixing intensity).

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MEASURING, MAPPING AND MODELLING BIOTURBATION AND DENITRIFICATION.

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There is growing evidence that in a variety of sediments benthic denitrification is a significant sink for combined nitrogen, and may even have the potential to counteract the effects of eutrophication.
Denitrification has important connotations for global biogeochemical cycling. The role of N_2O has long been recognised as contributing to the destruction of the Stratospheric ozone and has a global warming potential over 300 times that of CO_2.
Through a variety of mechanisms bioturbation is recognised as a factor influencing rates of denitrification. However previous methods employed to measure denitrification have been criticised furthermore bioturbator distributions, interactions and the consequences for nitrogen cycling has not been thoroughly examined.
This study employs an interdisciplinary approach to measure, map and model the affect of bioturbating species on denitrification in shallow water coastal sediments.
The Isotope Pairing Technique (Nielsen 1992) will be used to calculate rates of denitrification.
Manipulative mesocosm experiments will be used to quantify and discern the effects of bioturbator species diversity and identity on denitrification, contributing to the topical field of biodiversity and ecosystem functioning.
Geographical Information System in conjunction with spatial analysis techniques will be used to spatially and temporally map; bioturbator distributions, in situ denitrification data with physical and chemical properties of the benthos and overlying water. Although essentially descriptive, the map will point towards mechanisms that underpin the distribution of bioturbator species in coastal waters.
Results will be modelled to discern the relationship between bioturbators and denitrification in an enclosed coastal water body, with predictive capability.

THE EFFECTS OF THE FUNCTIONAL DIVERSITY OF THE *MACOMA BALTHICA* COMMUNITY ON OXYGEN AND AMMONIUM FLUXES AT THE SEDIMENT-WATER INTERFACE

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To link benthic ecosystem functioning to benthic biodiversity, we have studied the effects of the *Macoma balthica* community on oxygen consumption and ammonium fluxes at the sediment-water interface using the functional group approach. The *Macoma balthica* community, which is widely distributed in intertidal soft sediments bordering the north-eastern Atlantic, is dominated by two bioturbation functional groups with different sediment mixing modes: two biodiffusors (*Macoma balthica* and *Mya arenaria*) and one gallery-diffusor (*Nereis virens*). We used experimental mesocosms containing different functional assemblages with similar biovolumes. The results show that biodiffusors and gallery-diffusors have different effects on benthic fluxes, and that the two biodiffusors have the same effect on benthic fluxes in spite of their different space occupation and feeding, ventilation and burrowing modes. Different mixing mode and different irrigation pattern of biodiffusors and gallery-diffusors explain different benthic fluxes. Our results confirme that bioturbation functional group approach is a useful tool for quantifying the effects of intertidal benthic communities on benthic fluxes.

QUANTIFICATION OF BIOTURBATION IN SEDIMENTS OF THE VENICE LAGOON (ITALY)

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Experiments were carried out in June 2001 and October-November 2002 at two sites (E and E1) in the Venice Lagoon close to the industrial district. At each site 4 tubes were inserted into the bottom, one full of sediment without macrofauna (as a control). The luminophores, fluorescent sediment particles (63-350 μm), were supplied as tracer pulse inputs at the sediment surface. Short experiments (15-20 days) provide tracer profiles that can be simulated with a diffusion-advection and non local model applied under non-steady state conditions. This allowed the estimate of coefficients D_b (cm^2 y^{-1}), V (cm y^{-1}) and k (g cm^{-3} y^{-1}) that account for the rates of biodiffusion, bioadvection and non-local transport (regeneration), respectively.
Result shows that at both experimental locations bioadvective processes are less effective in the autumn 2002 experiment, as well as regeneration at site E. This could be ascribed to the effect of a lower temperature, since the previous experiments were carried out in summer. The biodiffusive component, in spite of a great heterogeneity, increases its importance at site E in the last experiment, whereas E1 shows an opposite pattern. Furthermore, regeneration processes were absent at E1 in both experiments. This can be attributed to differences in benthic community composition between the two experiments. In particular, we found that at site E1 conveyor-belt -like organisms are less represented in autumn 2002 than in summer 2001, whereas *Hediste diversicolor* polychaete has been found only at site E in both seasons.

IMPORTANCE OF FUNCTIONAL GROUP BIODIVERSITY FOR MINERALIZATION OF ORGANIC MATTER IN TWO BENTHIC ECOSYSTEMS THE BALTIC SEA AND THE SKAGERRAK

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The work describes the importance of marine benthic fauna and diversity of macrofaunal bioturbators for mineralization in marine sediments by measuring solids and solutes in and above the sediment. The species were classified into functional groups in relation to where they feed, their mobility, and their feeding habit. The aim was to determine different functional groups individual and combined ecological effect on benthic mineralization of organic matter due to bioturbation and microbial activity. Baltic Sea and Skagerrak fauna-assemblages were put in mesocosms with different functional group biodiversities in organically enriched Baltic Sea sediments. Marine benthic ecosystems on deep bottoms in Skagerrak, are inhabited by several hundred species of macrofauna and have ~20 functional groups of benthic macrofauna. In comparison have the Baltic Sea ecosystems fewer species of macrofauna and lower functional biodiversity ~5 functional groups of benthic macrofauna. The overall content of organic matter in the bulk sediments is 2-3 times higher in the Baltic Sea than the Skagerrak. The main hypothesis of the experiment was that rates and pathways during benthic mineralization of organic matter in Baltic Sea ecosystems were different from those in Skagerrak ecosystems, and that this discrepancy is strongly related to the community structure and number of functional groups in the two benthic ecosystems.

REWORKING FUNCTIONAL GROUPS AND NITROGEN CYCLE: A MODEL CONTRIBUTION

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Most of the models dealing with elements cycling in the sediment column pay attention to the role of the bioturbation. Often, the bioturbation effect is taken into account by the mean of a diffusion term which describes the random reworking induced by the benthic communities. Moreover, a biodiffusion coefficient is generally calculated by comparison with data to evaluate the intensity of the reworking. In order to analyze the fate of organic matter in the sediment column, it is however useful to give a more precise description of the bioturbation. For instance, different functional groups have been described according to the way of reworking used by the different species. Among them, we can refer to the biodiffusors, the gallery-diffusors, the downward conveyors, the upward conveyors and the regenerators. The combination of these various behaviors leads to the presence of microniches in the sediment where the bacterial metabolisms are changed. For instance, we can find oxic regions in depth where bacterial populations can use oxygen instead nitrogen as electron acceptors. The permanent reworking induces variations in the oxic - anoxic environmental conditions and these variations may have an impact on the microbial activities and consequently on the fate of organic matter. We shall discuss these points by considering a modeling point of view. Various models shall be discussed in order to show their advantage and the problems that they raise.

TRACING SEDIMENT DYNAMIC ON SEASONAL TIME AT THE WATER-SEDIMENT INTERFACE OF THE THAU LAGOON USING Be-7 AND Th-234

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We present an investigation of the short-term sediment dynamic at the water-sediment interface of the Thau Lagoon. This shallow basin, located on the French Mediterranean coast, is of notable interest related to economic activities: tourism, industry and shellfish production. Results are based on detailed depth profiles of two short-lived radionuclides, ^{234}Th (24.1 days) and ^{7}Be (53 days), in sediment cores collected at different seasons. These data are interpreted in order to provide bioturbation rates (D_b).
Two sites with contrasting characteristics were selected: C4 in the middle of the lagoon and C5 nearby oyster farming. Both sites were visited six times between December 2001 and May 2003. Sedimentation rates derived from $^{210}Pb_{xs}$ indicate a rather good from 0.15 cm yr^{-1} at the edge of the basin (site C5), to 0.25 cm yr^{-1} at the central site. ^{234}Th in excess ($^{234}Th_{xs}$; i.e. supplied to sediment by settling particles) and ^{7}Be both show seasonal variations in activities and in penetration within sediment. With their very short half-lives and the moderate sedimentation rates at both sites, $^{234}Th_{xs}$ and ^{7}Be should be present only at the water-sediment interface. However all the profiles show penetration of both short-lived radionuclides to variable depths, from 1 up to 8 cm, that indicates efficient mixing of upper sediments. The simplest way to calculate D_b from radionuclide profiles assumes bioturbation as a diffusive process occurring at a constant rate within a surface mixed layer under steady state. For site C4, steady-state bioturbation rates range between 1 and 12 cm^2 yr^{-1}, with a weak seasonal signal. The mixing of surface sediments at site C5 presents a greater range (1 – 31 cm^2 yr^{-1}) with the highest values observed in summer. Higher bioturbation rates at site C5 may be in relation with the proximity of shore and oyster cultivation. Radionuclide fluxes at the water-sediment interface show too seasonal variations, particularly marked at site C5 in relation with its position. The interest of ^{234}Th is to have a rather well constrained input due to its continuous production from ^{238}U. It is then possible to compare fluxes at the water-sediment interface, calculated from ^{234}Th profiles in sediment, to its production rate in the overlying water column. For site C4, fluxes are always lower to production rate. On the opposite, at site C5, the highest fluxes measured in the sediment in summer far exceed production rates. This observation seems to indicate that site C5 could act seasonally as a deposit center for particle-reactive elements.

COMPARISON OF SEDIMENT REWORKING QUANTIFICATION AT THE WATER-SEDIMENT INTERFACE OF THE THAU LAGOON USING RADIONUCLIDES AND LUMINOPHORES

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The Microbent programme focused on biogeochemical processes that control the fate of contaminants at the water-sediment interface of the Thau lagoon. Two stations with contrasting characteristics were selected: C4 in the middle of the lagoon and C5 nearby oyster farming. They were repeatedly visited between December 2001 and May 2003. An important task was to determine sediment reworking as a key parameter to interpret the distribution of chemical species at the water-sediment interface before their archiving within the sedimentary column. Two indirect methods using sampled 20-cm height cores were applied: radionuclides and luminophores.
Particle-reactive radionuclides have been often used, during the last two decades, as chronometers for estimating accumulation and mixing rates in marine and lake sediments. With short half-lives, ^{234}Th (24.1 days) and ^{7}Be (53 days) are well appropriate to study sediment dynamic in nearshore sediments. Sediment layers were measured downcore, using a low background-high efficiency well type γ-detector, until a rather constant ^{234}Th activity was reached, and the disappearance of ^{7}Be. Both ^{234}Th and ^{7}Be showed seasonal variations in activities and in penetration, up to 8 cm, within the sediment, which indicated efficient and variable mixing of upper sediments with time. Bioturbation rates (D_b) were calculated from these profiles assuming mixing as a diffusive process occurring at a constant rate within a surface mixed layer under steady-state. Due to low levels, and therefore limited precision of radionuclide activities, non-local mixing was not considering.
The second method relies on the deposition of luminophores at the surface of sampled sediments. The sediments were 9-days incubated at *in situ* temperature and then sliced. Modelling of obtained tracer profiles allowed the calculation of both biodiffusion (D_b) and biotransport (r) coefficients.
Radionuclide-derived bioturbation D_b range was 1 - 12 cm^2 yr^{-1} and 1 - 31 cm^2 yr^{-1} for stations C4 and C5, respectively. At stations C4 and C5, mean luminophores-*Db* ranged respectively between 0.7 and 2.9 cm² y^{-1}, and between 0.5 and 3.1 cm² y^{-1}. Even if radionuclide-D_b present higher values, the two methods reproduce the same trend with time.
These different scales could be explained by the specificities of each tracer and method: (i) Radionuclides are deposited *in situ* and rather continuously at the water-sediment interface by fines particles. Due to their half-live, ^{234}Th and ^{7}Be integer biological and physical sediment mixing over few weeks; (ii) on the other hand, luminophores are 160-200 µm diameter particles introduced out from the fields as a single input. Their distribution in the sediments due to biological mixing is quantify after an 9-days incubation. When considering these constraints on each method, we can consider that radionuclides and luminophores provide a rather coherent picture of sediment mixing of the water-sediment interface of the Thau lagoon.

MACROFAUNA ABUNDANCE, BIOMASS AND BIOTURBATION POTENTIAL WITHIN THE NORTHERN SEAS REGION: INITIAL RESULTS.

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The marine environment of the Northern Seas region is under ever increasing pressure from human exploitation and rapid climate change. This region is defined as extending from the north of the Wyville Thomson Ridge, Northeast Atlantic to the marginal ice zone off Svalbard. Previous studies have described the macrofaunal community structure at selected sites within this region. However, few studies have described the bioturbation potential of the macrofaunal community over such a large geographical gradient and comparisons between previous studies are difficult due to differences in sampling gear and sample sorting techniques employed. The abundance, size distribution and taxonomic composition of the benthic community determine the rate and mode of bioturbation. In turn, the structure of the benthic community is determined by sediment type, organic carbon cycling and local hydrodynamics. Variations in benthic community structure and bioturbation regime over such a large geographic gradient will determine the influence of distinct definable properties. Fjords are ideal for studying the response of the benthic community to anthropogenic pressures because catchments are large and exchange is often limited. Comparisons between a sub-Arctic (Kongsfjord, Svalbard) and temperate (Loch Etive, Scotland) fjord are drawn in terms of bioturbation potential of the macrofauna community. Additionally, changes in benthic macrofauna community structure over a south-north latitudinal gradient were investigated. Quantitative samples were collected in the summer of 2002 from four continental margin stations along a south-north latitudinal transect. Stations were selected for similar depths at the Vøring Plateau, Bear Island Fan, Svalbard Margin and the Yermak Plateau. Analysis of samples allowed for identification of possible key bioturbators for further investigation to determine bioturbation potential and influence on the benthic community at the continental margins.

MICROBIAL COMMUNITIES AND ORGANIC MATTER INTERACTIONS IN AN ENVIRONMENT SUBMITTED TO A BIOTURBATION ACTIVITY: A MODELLING APPROACH

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The organic matter fate is conditioned by physical, biological and biogeochemical properties of the environment which all interact. Due to this complexity and to understand the environment changes, it's crucial to model the microbial communities dynamic responsible for biogeochemical processes. At the moment, the early diagenetic models (Berner 1980, Soetaert *et al.* 1996, Boudreau 1996, Boudreau 1997), the most employed for benthic system, allow us to analyse and quantify the reworking mechanism at the macroscopic scale. They formulate, however, simplistic assumptions, offer bad description of biological mixing and none of them take explicitly into account bacterial dynamic communities (at microscopic scale). My aim is to improve the present models analysing the organic matter fate in the sediment by taking explicitly into account the functionality, the temporal dynamic and the spatial repartition : of both bacteria and macrobenthic fauna. Firstly, It consists in the construction of a mechanistic model of bacterial communities dynamic in sediments based on the DEB theory (=DEB, Kooijman S.A.L.M., 2000). And more precisely, it consists in describing microbial processes and confronting the new model with experimentation. A simple models fitting is realised, making them more complex by easy stage. For each of them, we take an interest in qualitative and quantitative fit and more precisely in determining growth kinetics on carbon substrate limited by nitrate.

AN EXPERIMENTAL INVESTIGATION INTO THE RELATIONSHIP BETWEEN BIOTURBATOR DIVERSITY AND ECOSYSTEM FUNCTION

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A mesocosm experiment has been conducted to investigate potential redundancy, saturation of function (nutrient cycling), and species interaction from a subtidal coastal soft-sediment ecosystem.
To investigate the effects of species diversity independently from the effects of functional diversity, the 3 bioturbators used in this experiment are all deep burrowing species that construct permanent burrows. The species used were the polychaete *Nereis virens* and the Thalassinidean shrimps *Callianassa subterranea* and *Upogebia deltaura*. The bioturbators were added to undisturbed cores (30cm in diameter) of sandy mud which were maintained within the Plymouth Marine Laboratory mesocosm. Eight experimental treatments were used; single species treatments, each species pair combination, all three species as a multi-species assemblage and controls containing no bioturbating species. Each treatment was replicated 8 times. After the addition of the bioturbators, the experiment ran for 60 days allowing the bioturbators ample time to establish their natural burrow systems. After this period, each core was simultaneously isolated and 5 consecutive samples were taken from the overlying water during a 24 hour period. Nutrient concentrations were determined for all samples and the rate of nutrient flux (nitrate, nitrite, ammonia, silicate and phosphate) across the sediment/water interface was calculated from this.
The results of this experiment will be analysed through a statistical model which will test for over-yielding or under-yielding within specific treatments. The later may imply saturation of function whilst over-yielding may be caused by a synergistic or facilitative interaction between species. The analysis of the results will also show if species are functionally analogous i.e. do all pair-wise treatments contribute equally? Although the bioturbators used in this experiment can be grouped in one functional group (burrow constructors) in other aspects they differ such as trophic guild (deposit and filter feeders). The concept of functional types will be reviewed and discussed in light of the results obtained.

SEDIMENT TRANSPORTATION BY THE DEPOSIT FEEDING SEA CUCUMBER *HOLOTHURIA LEUCOSPILOTA* AND *H. ATRA* IN CORAL REEFS: BIOTURBATION OR BIOPURIFICATION?

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In coral reefs, sea cucumbers play an important role as deposit feeders in maintaining a beautiful coral reef environment. A huge amount of sand or fine particles is transported on the coral reefs, and the amount of organic material present in the sand particles is reduced by sea cucumbers feeding activity. *Holothuria leucospilota* is the most common sea cucumber species followed by *H. atra* in Okinawan coral reef, Japan. We studied their sediment reworking activity from the viewpoint of their feeding activity. In aquarium experiments *H. atra* consumed significantly higher amount of sediments than *H. leucospilota*. However, due to its small population size (10× less than that of *H. leucospilota*), *H. atra* sediment reworking potential remains insignificant compared to that of the most abundant species, *H. leucospilota*, in Okinawan coral reefs. Comparison of the amount of organic material in the sediments, consumed as food, and in the feces, showed a decrease of carbon and nitrogen contents for both species. Although their food sources are considered to be bacteria and organic materials, these species indicated differences in the sizes of particles ingested. *H. atra* consumed significantly smaller particles than *H. leucospilota*. For example in *H. leucospilota*, granule gravels of 2-4 mm in diameter was frequently found in the fecal pellets together with sandy particles. By considering the grain size distribution of sediments and feces, and their ability to reduce organic material contents in the surrounding coral sediments, the contribution of these species to coral reef environment purification was evaluated. In a coral reef of ca. 15 ha, 11,500 individuals (0.08 inds./m2) of *H. leucospilota* were counted and the amount of sediment consumed by this population was estimated to be 92 kg/day or 33.6 tons/yr. When sediment containing 10.6 mg C/g or 1.5 mg N/g were fed to a sea cucumber, these organic materials were assimilated and feces containing 2.5 mg C/g or 0.6 mg N/g were produced. In this coral reef, 272.4 kg of carbon and 31.3 kg of nitrogen were removed from the sediment surface in a year, thus helping to maintain a beautiful and a healthy coral reef environment. Since sea cucumbers remove significant amounts of organic matter in the coral sediments through their feeding activity, we regard this as biopurification rather than bioturbation.

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