cosa

Coastal Sands as Biocatalytical Filters

EU-funded Research on the Baltic and North Sea Coasts

MAX-PLANCK-GESELLSCHAFT
Max Planck Institute for Marine Microbiology

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Introduction

Sandy permeable sediments are typical for the shallow coastal zones of the North Sea and Baltic, and are common in shallow shelf areas world-wide. Waves and bottom currents push water through the upper layers of these sands, thereby carrying dissolved matter as oxygen and nutrients and small particles, such as organic debris, planktonic algae, and bacteria through the sediment. This process affects the quality of the water that is filtered through the sand bed as well as sediment biogeochemistry, and provides food to the benthic community from bacteria to large bottom-dwelling organisms.
Although this filtration is thought to be important for coastal ecosystems, quantitative *in-situ* measurements revealing the magnitude of this process and its influence on sedimentary organic matter turnover so far have not been available. This has led to the initiation of the EU-funded project COSA focussing on "COastal SAnds as biocatalytical filters".

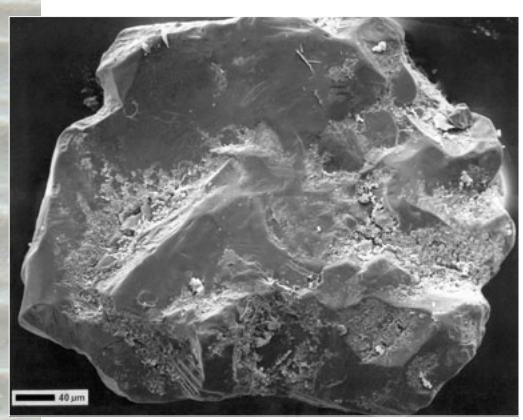
Research team at the Polish Baltic Sea coast

Within the COSA framework, scientists from Poland, Denmark, the Netherlands and Germany conducted research at two study sites located at Hel Peninsula/Poland in the southern Baltic and at Sylt/Germany on the North Sea Coast. Research included time series measurements of biogeochemical and biological parameters at the two field sites as well as laboratory studies on the details of the biocatalytic filtration process. Results of this research were directly transferred to a Polish and a German coastal zone management agency that participated actively in the project. COSA thereby improved monitoring and protection of the European coastal zone, and promoted awareness of the public by an intense outreach programme.

The Concept of COSA

COSA was designed to elucidate the functioning of coastal sands as biocatalytical filter systems and to promote sustainable use of coastal sandy sea floors by

- quantifying the sedimentary filtration process and the associated turnover of organic matter
- characterizing the biogeochemical processes in coastal sands and reaction rates
- developing a transport-reaction model that includes pore water exchange caused by bottom currents and benthic invertebrates
- facilitating exchange of knowledge and technologies
- instigating implementation of the scientific results into coastal management concepts and
- increasing the awareness of the public and policy makers regarding the ecological role of the coastal sand filter.



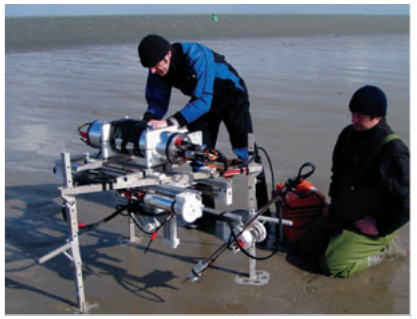
One grain of sand under an electron microscope.
The "valley" to the left is inhabited by algae (diatoms of approx. 0.01mm size).
The smaller white spots are bacteria that typically excrete sticky material to adhere to the grain surface.

Between November 2002 and October 2005, the multidisciplinary team of scientists visited the two study sites and conducted a broad spectrum of biogeochemical, biological and physical measurements in the sandy sediments and the overlying water column. The environmental agencies participating in COSA organized a diverse outreach program that drew the attention of the public to the results of the scientific investigations. Participating institutions included the Institute of Oceanology of the Polish Academy of Sciences, the Netherlands Institute of Ecology, the Alfred Wegener Institute for Polar and Marine Research, the University of Copenhagen, the Nadmorski Park Krajobrazowy, the National Park Schleswig Holstein Wadden Sea and the Max Planck Institute for Marine Microbiology in Bremen, which also coordinated the project.

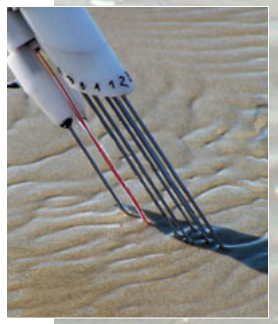
Max Planck Institute for Marine Microbiology

Research that initiated COSA

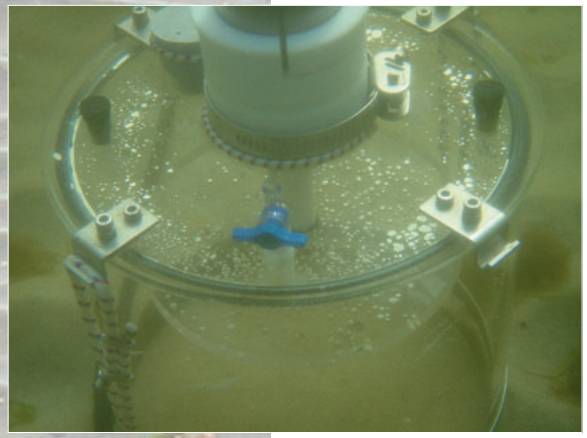
Hundreds of thousands of different microorganisms, including small invertebrates, minute algae, protozoans, bacteria and archaea live between and on the mineral grains forming the sandy marine sediments of coastal and shelf environments. This fascinating diversity at the micrometer scale has drawn the attention of many scientists. However, a realistic quantitative assessment of the metabolic processes, organic matter turnover and nutrient remobilization, so far was not achieved because these processes are intricately tied to the current- and wave-driven filtration of water through the sediment. These water movements fuel the food web within the sand bed and the release of metabolic products (e.g. nutrients, CO_2) to the water column. Investigations in the laboratory in the absence of waves and currents, thus, produce results that may not be representative for the natural environment. For a long time, suitable methods were missing for studying processes in sands and sediment-water exchange processes. Laboratory experiments conducted in flow channels and wave tanks at the MPI demonstrated the dramatic effects of flow and wave induced pressure gradients on pore water flows and solute and particle exchange between permeable sea beds and the overlying water.
Even minute pressure differences, equivalent to the pressure of a water column a few millimetres high, can drive water through the pores of marine sands. The development of instruments with very thin sensors and devices that mimic the natural pressure gradients now permit in situ measurements of sandy seabeds in the natural environment. COSA used such instruments for the investigations of the permeable sands at the two study sites.



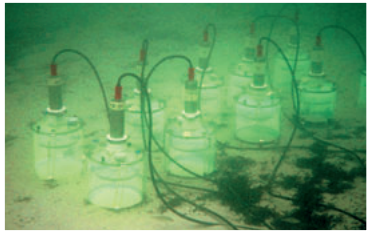
The instrument "Lance-A-Lot" maps structures at the sediment surface (e.g., ripples, mounds or pits) using a laser beam and a digital camera.



An array of long needle-sensors is used to measure pore water flow velocities within the sediment.



A benthic chamber (20 cm diameter) during an field experiment. The rotation of the transparent stirrer disk creates a pressure gradient that induces pore water flow in the enclosed sediment. The bubbles consist of oxygen that was produced by minute benthic algae.



COSA scientists returning with fresh samples that were collected at the field site at approx. one meter water depth.

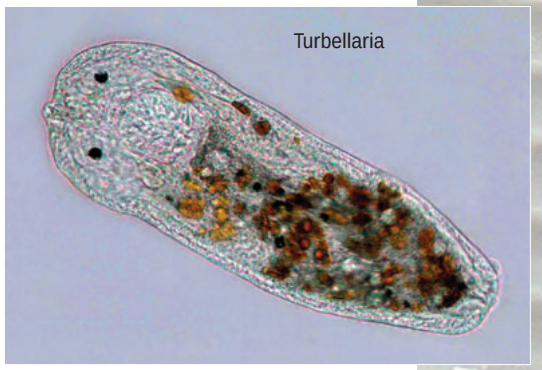
Advective sediment-water exchange processes

Within the COSA field campaigns, scientists from MPI deployed pressure calibrated benthic chambers to quantify sediment-water solute exchange for the range of natural pressure gradients. The results revealed the increase of solute fluxes, oxygen consumption rates and CO_2 production rates with increasing water filtration through the sediment. The chamber incubations also highlighted the strong influence of the microalgae inhabiting shallow water sand sediments on the oxygen dynamics in the sea bed. A several-fold oversaturation of oxygen in the upper sand layer during the day was replaced by hypoxic conditions during the night. "Lance-A-Lot", an instrument developed in the COSA project, permitted determination of the surface topography of the sand beds *in-situ*, while measuring pore water flow underneath the scanned surface. Data produced by this device were used to link bottom flows interacting with surface topography to pore water flows. These results were integrated into two-dimensional transport-reaction models to predict the relationship between bottom flows, topography, pore water transport and sedimentary biogeochemical reactions.

IOPAS - Institute of Oceanology of the Polish Academy of Sciences

Investigating the role of the benthic fauna and flora for transport and reaction in coastal marine sands

Shallow marine sands that appear to consist of clean mineral grains only harbour a microscopic community of meiofauna organisms that in its diversity rivals that of terrestrial ecosystems. Every single individual of this sedimentary community affects the processing of organic matter within the sediment and thereby enhances the biocatalytical filtration capacity of the permeable sand beds. Specialists on meiofauna and flora from the Institute of Oceanology brought the expertise to COSA that is essential for the characterization of this microscopic community inhabiting the sands.



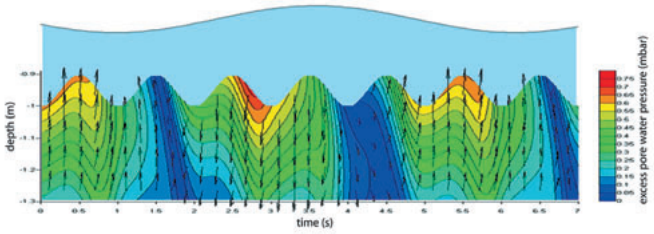
Nematods, turbellarians, oligochaetes and at Hel also gastrotrichs populate the small spaces between the grains of sands in the North and Baltic Sea.

Through feeding on the small organic particles and bacteria within the sand bed, minute crustaceans, nematodes and ciliates are critical links in the cycles of nutrients in the shelf environment. The scientists from IOPAS compared the sand communities of the Baltic and the North Sea site. They found similar functional groups at both sites but higher abundances at the more nutrient-enriched North Sea site. Surprisingly, the Baltic site had a similar diversity when looking at the nematode species, though the abundance of animals was lower. Surface deposit feeders, animals feeding on the organic particles in the sediment surface layer, profited most from particulate organic matter filtered into the sediment.

How active are Baltic sublittoral sands during different seasons?

To fulfil COSA's goal to estimate the effectiveness of the sedimentary filtration process, the seasonal cycle of production and decomposition of organic matter was monitored at both study sites. Compared to the Sylt sublittoral, Hel was biologically less active in summer, probably due to lower nutrient concentrations in this environment. Deploying a new wave recorder together with other measurements helped to understand the hydrodynamic influences on the biogeochemical coupling between the water column and the sediment.
In order to facilitate the studies on benthic primary production, IOPAS established a data base on the microphytobenthos recorded at the study site. This searchable web-based data base (http://www.iopan.gda.pl/~wiktor/cosa/index.html) provides information and pictures of the diatoms that inhabit the sands at the Sylt and Hel study sites. Scientists from IOPAS also conducted the time series measurements at the Baltic site, which was initiated to track the seasonal variability of transport and reaction rates in the sands.

The 20-130 µm long diatom *Navicula palpebralis* occuring at Hel and Sylt is a common species living in sandy sediments in shallow marine and brackish waters.



The distribution of pore water pressure in the top layer of porous sea bottom sediments, induced by propagating surface waves. The arrows indicate the direction of the instantaneous flow. The colors indicate the pore water pressure.

NPK - Nadmorski Park Krajobrazowy

Information and involvement of the local population and Hel tourists

The team of young scientists and managers of the Nadmorski Park Krajobrazowy, a landscape park with several nature reserves, ensured that the COSA results were transferred immediately and efficiently to the public. This was accomplished mainly through enthusiastic involvement of the NPK personnel who developed several strategies designed to generate public interest in the scientific program of COSA.
One example is the Blue School program held several times a year, where school classes were introduced to the processes in the Baltic Sea and in the sandy sediments of the coast. In order to expand the outreach NPK produced a website in Polish and diverse printed materials and lecture slides for education and training.
Several CDs, brochures and posters were produced for the general public, and beach screens and poster boards were used to disseminate information on the COSA project and the importance of coastal sands and the animals and plants that inhabit these sediments. The local and regional press was involved, especially during annual events like the Baltic Festivals of Science and the Big May Picnic for which NPK organized exhibitions attracting a large number of people. Finally there were several visits and diverse exchanges of personnel and experience between NPK and the German national park office.

A "Blue School class" in NPK headquarters, receiving explanations about the threats and protection needs of the Baltic Sea.

During the Baltic Festival of Sciences a boy is studying the small animals living in the sand, helped by a IOPAS scientist.

The influence of science on nature protection

People in Poland are aware that there are lot of pressures on their short stretch of coastline. The relatively large number of tourists that visit the beaches every summer threatens the fauna and flora of the shallow water habitats.
Coastal water pollution due to increased nutrient input from adjacent farmlands promotes algal blooms and hypoxic conditions. According to COSA suggestions, new objectives have been added to the NPK management concept concerning the regular monitoring of coastal sands, the documentation of changes in coastal environments, and the identification and elimination of threats.
Using COSA as one incentive, a special group for Puck Bay close to Hel formed integrating all institutions responsible for managing and developing this beautiful coastal zone. Several scientific results have already led to recommendations on the conservation of the Polish coastal sands. Furthermore the group tries to find ways of ensuring that protection already starts during the planning stage for new developments. This group will continue working after the ending of the COSA project.

The COSA project was interesting for large and small visitors during the "Big May Picnic" and other events.

NPO - National Park Schleswig Holstein Wadden Sea

Implementation of COSA results in coastal management strategies

The NPK in Poland and the National Park Schleswig Holstein Wadden Sea in Germany directly implemented results of the project into management and monitoring of their respective areas, and effectively spread the findings of COSA to local authorities and the public. This combination of scientific research and direct communication of the results to the National Parks and the public significantly contributed to the success of COSA.
The initial step was the integration of COSA scientific results into a data base that is jointly used by NPO and NPK.
Coworkers of both environmental agencies translated – in collaboration with COSA researchers – the scientific results into information understandable for the public and policy makers.
In a second step, strategies were developed to include sandy sublittoral sediments into the ongoing monitoring programmes at both study sites.
Finally, a variety of publications were produced including electronic formats (DVD), printed information materials and contribution to TV and radio programmes that emphasized the importance of the coastal sands and its protection. NPO was further involved in outreach activities like producing and distributing flyers and documentation materials to the public including information boards at the Sylt field site.

This information board produced by NPO informes tourists and local people about COSA directly at the Sylt field site.

Using scientific results for international Wadden Sea management

Despite the high socio-economical value of coastal sands as fishing grounds, sources for raw materials (water, oil, gas) and sand for tourist beaches, they are poorly protected and overexploited. The limitations of this ecosystem are not well known and this missing knowledge base is partly to blame for the missing protection. A better understanding of the role of the coastal sands for water quality and fisheries production will also increase awareness of policy makers and improve the protection of this valuable environment.

Sand ripples are the most typical structure of submerged coastal sands and important for the pore water flow.

In order to reach this goal, NPO has been working on integrating COSA results into a database. This database is part of the COSA website, which provides background information on the project and functions as a data server for all participating institutions.
To transfer COSA's results to management and policy experts several meetings and workshops with scientists and policy makers were held. A highlight was the presentation at the trilateral Wadden Sea Commission conference in 2004. Finally COSA helped NPO and NPK to establish joint activities through exchanges of personnel and several visits of directors and staff.

For this small multicellular algae one sand grain is basis enough to start growing.

Managers from both nature protection and environmental agencies met several times to compare their sites and exchange their management experiences.

AWI - Alfred-Wegener Institute, Wadden Sea Station on Sylt

Coupling of North Sea water and sublittoral sand sediment processes

The team from the Alfred Wegener Institute for Polar- and Marine Research conducted the time series measurements at the North Sea study site on Sylt and investigated the links between water column and sediment processes. Two dedicated PhD students produced their thesis research on the two year measurement series. Samples were taken at least once every month, either using the research vessel "Mya" at high tide, or by wading to the sampling station during low tide. Samples were immediately processed after return to the lab located in walking distance from the study site. Analyses included determination of sediment characteristics (e.g. permeability, porosity, grain size), organic matter (chlorophyll a, carbohydrate content, particulate organic carbon and nitrogen), and nutrients (concentrations in pore water and overlying water). In addition, animals and plants inhabiting the sediments were recorded.
This time series, as well as the time series conducted by IOPAS at the study site at Hel, established the reference data base for the detailed measurements that were conducted during the intensive field campaigns involving all institutions participating in COSA. During these campaigns, up to 23 scientists joined the research teams at the respective study sites. This joint effort facilitated simultaneous deployment of special instrumentation (e.g. instruments monitoring flow, sediment oxygen distribution, topography, pore water flow, and sediment-water solute exchange). During this intensive collaboration, Europe-wide contacts were established that resulted in new joint projects and laid the foundation for future cooperation between COSA partners.

Five strong persons were regularly needed during field campaigns to bring the heavy but sensitive equipment to the site.

COSA scientist stoppering a freshly taken sediment core from the coastal waters of Sylt.

Comparing water and sediment in the North Sea and the Baltic Sea

After completion of the analytical work and data processing, the results obtained from the North Sea and the Baltic site were entered into the web-based data base http://www.iopan.gda.pl/projects/cosa/. The compiled results now permit the comparison of the Sylt and Hel sites, evaluation of seasonal trends and the links between water column processes and the sediment. At Hel, the nutrient concentrations in the water column were generally lower than at Sylt, and followed a similar, although less pronounced seasonal cycle, with maximum concentrations in the winter. At both sites, the contribution of the sediment to the primary production was significant, with higher photosynthetic activity in the first surface centimeter of the sediment than in the entire ~1.6 m water column. This was mainly due to the high activity of sediment diatoms.

A German-Polish COSA team carrying equipment from the AWI field station to the beach.

Auliscus sculptus a 50-90µm long sediment diatom occuring in the sand at Sylt. It is missing in the Baltic Sea but was recently found in the Kattegat.

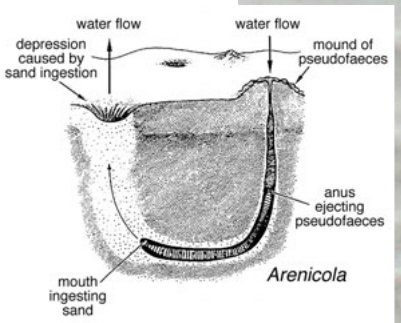
NIOO - Netherlands Institute of Ecology, Centre for Estuarine and Marine Ecology

Modelling transport and solute distribution by benthic invertebrates

The scientists from the NIOO focused on the modeling of transport and biogeochemical reaction processes in sandy sediments, validating model results using lab experiments and *in-situ* measurements. Insight into the biogeochemistry and ecology of sandy sediments crucially depends on a quantitative description of the pore water flow and the associated transport of soluble components as well as algae and bacteria. *In-situ* measurements in permeable sediment are difficult to peform. This is due to the inherent three-dimensional nature of the flow pattern in the sediment. Also the measuring devices can create artificial obstructions to the flow. Therefore, mathematical modeling coupled with targeted laboratory experiments provide a valuable and complementary tool to quantify flow patterns and assess their biogeochemical effects.

The models that are developed provide a description of the pore water flow in the sediment and the resulting tracer dynamics. Pore flows were either physically induced or resulted from biological activity. A generic modeling procedure was applied to different case studies of reactive transport in permeable sediments. One focus was on bio-irrigation, induced by burrowing animals that are actively pumping oxygen-rich water into their burrow. The lugworm, *Arenicola marina*, was used in lab experiments and for two of the modeling simulations. The other focus was on pore water flows induced by unidirectional flow over a sequence of ripples.

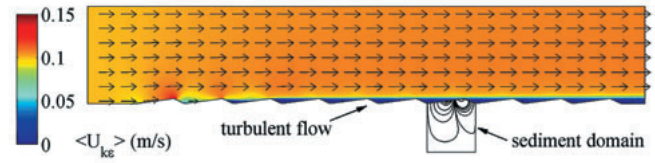
Tidal sand flat with typical signs of *Arenicola marina*. The darkish sand piles are called pseudofaeces.



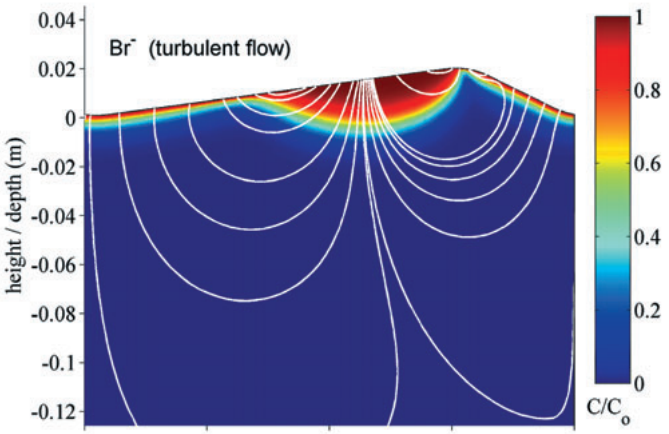
Schematic drawing of the lugworm *Arenicola marina* living deep in its burrow.

Dynamic environmental factors impede transfer of model results to coastal management routines

Results showed that bio-irrigation and bottom flows over ripple fields are critical for sediment-water exchange processes in permeable sandy sediments. Model simulations promoted understanding of the complex three-dimensional transport within the pore water and their biogeochemical consequences. Detailed model verification and validation also led to an increase in confidence and generality of modeling approaches used for the investigation of transport phenomena in permeable sediments. Nevertheless, due to the highly dynamic coastal environment, where physico-chemical as well as biological parameter change very fast, model development is still in an early stage.
These models are far from being usable as a routine tool for coastal studies or management.



Unidirectional flow over sand ripples causes pore water flow in the underlying sediment. A model simulation of the velocities in the water column over a sediment surface with ripples.

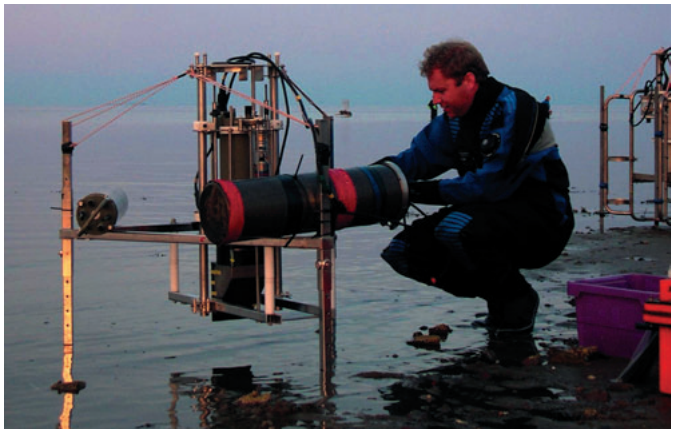


Details of the intrusion of a dissolved substance from the overlying water into the sediment beneath one of the ripples.

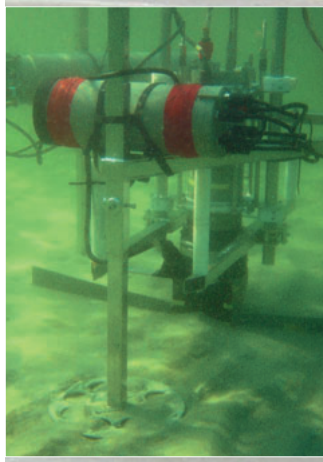
MBL - Marine Biological Laboratory, Zoological Institute of the University of Copenhagen

Fine scale in-situ measurements reveal the dynamics of sedimentary biogeochemical processes

The Danish scientists working within COSA deployed data-logging instruments that autonomously measured profiles of oxygen with high spatial resolution in the sandy sediments. An electrode microprofiler was used which resulted in data revealing strong benthic photosynthetic activities in the sands at both study sites. Oxygen profiles measured over 24-hours revealed a strong oxygen dynamic in the sands at both sites with benthic photosynthetic activities at daytime. Supersaturation of oxygen was reached in the uppermost sediment layer enhancing the oxygen penetration into the sediment during daytime. This oxygen, produced by benthic diatoms (microalgae) provides electron acceptors for the aerobic (micro-) organisms degrading organic material within the sediment. At night, this production ceases and benthic (micro-) organisms as well as the algae consume oxygen.

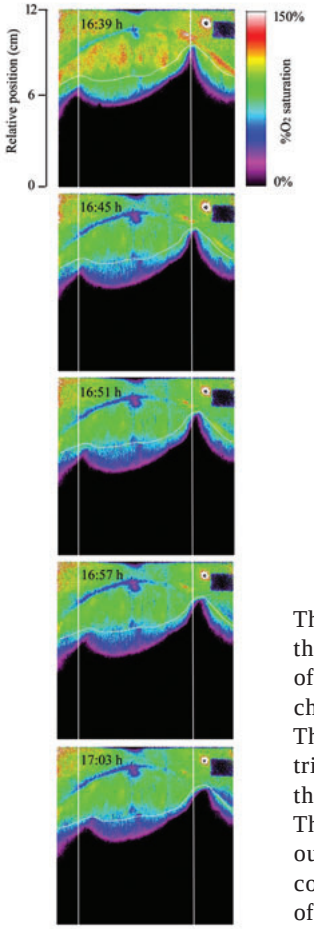


The microprofiler carries very sensitive microsensors, mostly glass capillaries mounted underneath the silver electronic-cylinder. The sensors are automatically lowered into the shallow coastal sediment with steps of 1 mm, for a full tidal cycle.



Here the sediment camera can be seen *in-situ*, with the vertical part in the back lowered into the sand.

As a result, oxygen concentration in the sediment drops sometimes even to zero below the sediment water interface depending on the complex pore water flow within these permeable sandy sediments. Using a planar optode module, a device that maps the oxygen distribution two-dimensional along a vertical plane across the sediment water interface, the close coupling between sediment ripples, bottom currents, pore water flow and oxygen penetration depth could be investigated.



A series of planar optode images showing *in-situ* O_2 distribution around moving ripples measured at Hel station in spring 2004. The white line marks the sediment surface.

The planar optode module carries a CCD-camera which looks into the sediment in a vertical plane and can, due to an oxygen-sensitive sensorfoil mounted in front of the inverted periscope, measure oxygen concentrations in two dimensions.

These measurements permitted for the first time to calculate the volume of the oxidized sediment and its changes with bottom flow velocity. The data also allow assessing the contribution of the benthic microalgae to the oxygen supply to the sediment. The results from MBL have improved our understanding how permeable coastal sands contribute to the cycles of matter and help to ensure the sustainable use of this important coastal environment. Based on the results on microbial and geochemical processes quality indicators for monitoring and management concepts for sandy coastal ecosystems can be provided.

Glossary

Advection: directed transport of matter along pressure gradients (in this context water including the substances that are suspended or dissolved)

Biogeochemistry: chemical conditions and processes in the seafloor which are also influenced by the inhabiting organisms

Biocatalytical filtration: Removal of substances (e.g., organic matter, nutrients) by filtration of the water through the sediment and biologically mediated conversion of the co-transported matter (like algae, bacteria, organic debris)

Benthic: organisms or processes that are located at seafloor are referred to as “benthic”

Bottom flow: currents in the lowermost part of the water column directly above the seafloor

Pore water flow: water movement through the spaces between the grains of coarse sediments (sand, gravel)

Diatoms: Single-celled microscopic algae with a silicate shell

Flux (solute flux): net rate at which a substance (like oxygen or nutrients) is transported per time and area (e.g., per square meter of seafloor surface)

Hypoxic: containing oxygen in tiny amounts

Hydrodynamics: characteristics of moving waters including currents and waves

Invertebrates: animals that do not have vertebrae (such as crustaceans, molluscs, all kind of worms. In the sea basically all animals except fish and marine mammals

Particulate organic carbon: organic compounds that get retained if the water is filtered including living plankton organisms (e.g., bacteria, algae, larvae) and their remains (“organic debris” or “detritus”)

Shelf: shallow waters surrounding the continents, usually down to 200 m water depth

Sublittoral: the part of coastal waters situated below the low water line (i.e., where the seafloor stays submerged also at low tide)

Supersaturated: containing more of a substance in solution than there would be under normal conditions (e.g., if algae add more oxygen to water than you would dissolve if you bubbled it with air)

Time series: experiments that follow a process over time.

Tracer dynamics: spatial or temporal changes of the distribution of a substance that serves to trace a process (e.g., a dye that is added to a sediment in an experiment to follow the movement of the pore water)

Turnover: in this context the amount of organic matter that gets decomposed by organisms in a given period of time

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A European project investigating the function of COastal SAnds as biocatalytical filters

In the research project COSA, funded by the European Union's Fifth Framework Programme (contract nr. EVK3-CT-2002-00076), scientists from Germany, Denmark, the Netherlands and Poland investigated the function of coastal sands as biocatalytical filter systems in order to assess the role of these sediments in the nearshore cycles of matter. Starting in 2001, participants of the project regularly visited two study sites, one located in the southeastern North Sea, the other in the southern Baltic Sea, to conduct a broad spectrum of biological, biogeochemical and hydrodynamical measurements designed to elucidate transport and reactions in the permeable sea beds. Large volumes of water are pumped through the uppermost layers of the sublittoral sands by waves and bottom currents, thereby carrying organic particles and oxygen into the bed. Bottom dwellers like polychaete worms and small crustaceans benefit from this food input, and the bacteria that colonize the surfaces of the sand grains degrade the organic substrates that are trapped in the pores of the filtering sediment. Water that is forced into the troughs between sand ripples flows on curved paths towards the ripple crests, where the fluid, now loaded with degradation products like carbon dioxide and inorganic nutrients, is released to the water column. This COSA research for the first time produced quantitative *in-situ* data on this biocatalytical filtration process, showed the central role of this filtration for the recycling of nutrients in the coastal zone, and demonstrated the universality of this process through the comparison of the study sites. Two stakeholders participating in COSA, the Nadmorski Park Krajobrazowy (Poland) and the National Park Schleswig Holstein Wadden Sea (Germany) directly translated the scientific results into recommendations for management and monitoring. When COSA ended in November 2005, it had significantly enhanced communication between European research institutions, initiated numerous new collaborations and projects, and had generated effective links between research facilities and environmental protection agencies.

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