Working group discussions

Suggested discussion topics

Before the workshop, a list of questions was compiled by the organizers and distributed to all participants in order to allow them to be prepared for the working group sessions and to contribute to them in a lively manner. The working groups were free to choose from the list of discussion items, to prioritize or modify them or to agree on additional/alternative topics. It was clear that within the given time restriction no group would nearly be able to address all or even the majority of the questions provided. Several questions were addresses to more than one group.

Working Group 1: Bioreactor

- How important are large gradients (in nutrients, light, turbulence) and what is their influence on the dynamics of ecosystems?
- What is the impact of inhomogeneities (i.e. patchiness of microorganisms) on small spatial scales?
- Which microbial processes and (geo)chemical transformations occur in the anoxic (deep) sediment horizons and how significant are they for the total system?
- How is the terrestrial influence reflected in the composition of organic matter in the sediment and in pore waters?
- Do the tidal flat sediments act as a filter system (pore water, particles, subterranean estuaries)?
- Which of the microbial communities in deep sediment layers is active *in situ* and how are these organisms adapted to their habitat?
- How are the organisms at depth affected by and how do they influence horizontal and vertical transport?
- Which microbiological and geochemical methods are required for the analysis of structure and function of microbial communities within deep sediment layers?
- Which are the best tracers for exchange processes between dissolved and particulate matter in tidal flats?
- How can we adequately measure and describe the processes of sedimentation, bioturbation and resuspension?
- How complex should an integrated tidal flat model be to incorporate the small-scale physical and analytical data and still be able to provide information on long-term trend?
- What is the impact of stochastic fluctuations and extreme events (e.g., storms, ice winters)?

Working Group 2: Water column processes

- How important are large gradients (in nutrients, light, turbulence), and what is their influence on the dynamics of ecosystems?
- What is the influence of periodic forcing with different frequencies (tides, daily and yearly changes) on the stability, complex dynamics, coexistence of species and coupled systems (synchronization)?
- What is the impact of stochastic fluctuations and extreme events (e. g., storms, ice winters)?
- Are the “physical” and “biological“ water masses identical?
- How important are exchange processes (adsorption, desorption)?
- How important are dissolved and particulate inputs from land and open sea for biogeochemical processes in the bulk water and on aggregates?
- How are the dynamics of aggregate formation and decomposition/disintegration affected by hydrodynamic forces and biological processes?
- How are the size structure, sinking rate, biological composition and bacterial colonization of aggregates modified on different time scales (tidal, diurnal, seasonal)?
- How complex should an integrated tidal flat model be to incorporate the small-scale physical and analytical data and still be able to provide information on long-term trends?
- Which are the best tracers for exchange processes between dissolved and particulate matter in tidal flats?
- What is the importance of North Sea water, terrestrial run-off and pore water for hydrography and biochemical budgeting of the backbarrier tidal flat system?
- Do the tidal flat sediments act as a filter system (pore water, particles, subterranean estuaries)?
- How can we adequately measure and describe the processes of sedimentation, bioturbation and resuspension?

Working Group 3: Transport and particles

- What is the impact of inhomogeneities (i. e. patchiness of microorganisms, microhabitats) on small spatial scales?
- What is the impact of stochastic fluctuations and extreme events?
- The distinction between single and aggregated particle groups is crucial for the understanding and modeling of transport behavior, deposition, and resuspension processes. What are the most reliable procedures for the identification and quantification of the two particle groups, considering that both (destructive) mechanical and (non-destructive) remotely sensed measurements are required for overall budget calculations?
- The calculation of import/export budgets of suspended matter through a tidal inlet (or across a channel cross-section) relies heavily on the extrapolation of remotely sensed data collected continuously at a single ADCP-station calibrated by time-limited reference profiling, pump sampling, and turbidity metering. What would be the most appropriate statistical procedure to perform such extrapolations, irrespective of the expected accuracy (or inaccuracy) of the calibrations?
- How important are exchange processes (adsorption, desorption)?
- How are the dynamics of aggregate formation and decomposition/disintegration affected by hydrodynamic forces and biological processes?
- How are the size structure, sinking rate, biological composition and bacterial colonization of aggregates modified on different time scales (tidal, diurnal, seasonal)?
- Which microbial processes and chemical transformations occur in the anoxic (deep) sediment horizons, and how significant are they for the total system?
- How are the organisms at depth affected by and how do they influence horizontal and vertical transport?
- Numerical simulation and observations of suspended sediment transports are somewhat ambiguous so far. What essential processes do we miss in the sediment transport module, and what else should we potentially observe in the field and parameterize in the model?
- How complex should an integrated tidal flat model be to incorporate the small-scale physical and analytical data and still be able to provide information on long-term trend?
- What is the importance of North Sea water, terrestrial run-off and pore water for hydrography and biochemical budgeting of the backbarrier tidal flat system?
- Which are the best tracers for exchange processes between dissolved and particulate matter in tidal flats?
- Is the transgressive nature of the system reflected by stratigraphy, i. e. the vertical succession of fine-grained sediments in the backbarrier tidal flats?

- Do the tidal flat sediments act as a filter system (pore water, particles, subterranean estuaries)?
- How can we adequately measure and describe the processes of sedimentation, bioturbation and resuspension?

Results of discussions

Working Group 1: Bioreactor

Discussion Leaders: Carol Arnosti, Heribert Cypionka
Rapporteur: Henrik Sass

The discussion group "Bioreactor" dealt with microbiological and geochemical processes that occur in sediments. In addition to the 12 questions outlined in Section 3.1, a 13th question was considered significant as well at the beginning of the session:

- What is the source and nature of organic matter actually used by sedimentary microbial communities and how might it be identified?

These questions were grouped into four subject areas: geochemistry (1 to 6; following the order in Section 3.1), microbiology (7 and 8), methods (9 to 11), and modeling (12 and 13). The following is a brief summary of discussion results.

Microbiological investigations of Wadden Sea sediments should focus on the measurement of activity parameters as well as on the study of community composition. Activity parameters are a prerequisite for the understanding of the system. In future investigations they will play a more important role for the development and evaluation of a comprehensive sediment model. So far, we can analyze microbial communities and measure activities, but do not know what organism is actually doing what. For resolving this questions new methods have to be developed.

On the other hand, microbial community composition cannot be deduced in detail from geochemical data, but the presence of microbial metabolic groups can serve as a tracer for biogeochemical processes. Furthermore, microbiological investigations of pure cultures enable the study of the physiology of indigenous microbes and an understanding of how these organisms are adapted to their environment. Anyhow, the data should be used with caution since interactions between microbes, as they occur in nature, are usually ignored.

Despite the knowledge that active microorganisms thrive not only at the sediment surface but even at several meters depth, we currently do not know what substrates are degraded by these communities. It may be assumed that these microorganisms either solely grow on easily degradable organic material which is supplied by pore water transport or use refractory organic material. Therefore, a combination of microbiological and geochemical parameters is necessary for targeted investigations. For the quantification of porewater transport, geochemical tracers are needed. If the microorganisms in the deeper layers rely on porewater supply, total sedimentary organic carbon (TOC), as commonly determined by geochemists, would be an irrelevant parameter for the description of sediments, hardly giving information on the life conditions of microbial communities.

Holocene peat layers are present throughout the North German Wadden Sea system. They exhibit low hydraulic conductivity preventing vertical porewater transport. The influence of these layers on the water budget of the sediments has to be revealed. Recent progress enabled to characterize the origin of eroded peat material found in deeper sediment layers. These findings may help to determine the age and the depositional history of the sediments and possibly of the inhabiting microbial communities. The study of the reactivity of peat can give hints on its role as a possible substrate for microbial communities.

Besides the vertical dimension of the sediments, patchiness is an important topic which has to be investigated to understand Wadden Sea sediments. It has to be clarified which parameters change on a small spatial scale and influence microbial communities as well as the biogeochemical processes. Candidates are, e. g., O_2, Fe(III) or Mn(IV). It has to be considered, that even microbial communities may differ at sites only a small distance apart.

The influence of short-term events (e. g. storms) has also to be investigated. There is little information on the ecological elasticity of sediments and of how fast gradients or microbial communities reestablish after perturbation. These investigations have to be performed at different sites. It seems that muddy sediments offer highly reproducible and predictable conditions, whereas sandy sediments seem to be highly variable. These differences allow an intersystem comparison and possibly the identification of the driving forces controlling the gradients and microbial communities.

One of the most important aims of the Research Group "BioGeoChemistry of Tidal Flats" is the development of a model describing sediment processes and the interaction with the water column. To develop, in a reasonable time, a model which is useful and largely comprehensive, several aspects should be taken into account. Firstly, already existing models should be adapted wherever possible. Secondly, the model should be kept simple with a minimum set of variables which are necessary to describe the system. Thirdly, the model should be calibrated by field data. The latter should be done by integrated field work campaigns including sampling for and analyses of water column and sediment processes, involving all disciplines; such a campaign is meanwhile planned by the Research Group for July 2003.

So far, data series (and models) cover a relatively short time scale. It appears necessary to incorporate long-term data series into ecosystem modeling. Therefore, cooperation with international long term-ecological research programs (LTER) should be considered (e. g., within NATO long-term ecological program). Since the scientific program of the Research Group mainly focuses on basic research, a partner conducting routine monitoring in the study area should be involved for long-term measurements and modeling.

Working Group 2: Water column processes

Discussion Leaders: Timothy Shaw, Meinhard Simon
Rapporteur: Rainer Reuter

- *How important are large gradients (in nutrients, light, turbulence) and what is their influence on the dynamics of ecosystems?*
  Light: a) vertical gradients limit primary production,
  b) horizontal gradients from open sea to tidal flats affect the photic zone,
  c) ratio of primary to heterotrophic production <1,
  d) size and abundance of aggregates may affect the onset of spring bloom due to different shading from light scattering.
  Turbulence: vertical mixing further limits primary production.
  Nutrients: not a limiting factor in tidal flats.
- *Are the „physical“ and „biological“ water masses identical?*
  Advection of water volumes (physics) induces chemical and biological processes which can rapidly alter the dissolved and particulate constituents (cf. Fig. 1).
  The term "water mass" should be avoided.

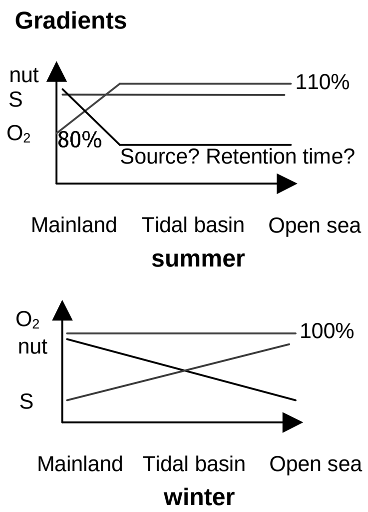

Fig. 1. Properties of tidal flat and adjacent water masses in different seasons leading to different gradients of oxygen (O_2), nutrients (nut) and salinity (S).

- *What is the impact of stochastic fluctuations and extreme events (e. g., storms, ice winters)?*
  Can be dramatic in a given year, but less relevant on a longer time scale.
  Storms:
    a) increase turbidity, which reduces primary production in summer,
    b) exposure of large reservoirs of particles to the water column leading to release and binding of dissolved matter.
  Ice winters:
    a) affect morphology,
    b) destroy filter feeders, but:
    benthic primary production not much affected due to lack of predators,
    biomass accumulation due to temperature limitation of respiration.
  Long periods of low wind:
    a) cause higher benthic production
    b) as a consequence can lead to anoxic conditions.
  Calm wind and low water:
    in winter: sediment can freeze, affects stability, releases organic matter
    in summer: increases benthic and pelagic primary production due to deeper photic zone
    possible consequence: anoxic conditions.
  Exceptional algae blooms:
    cause large amounts of organic matter on sediment surface.
    Stochastic non-extreme events: relevance of annual/ seasonal variability due to weather on PP is unclear, must be compared with nutrient standing stock.
- *How important are dissolved and particulate inputs from land and open sea for biogeochemical processes in the bulk water and on aggregates?*
  Allows to understand the system with element tracers.
  May control distribution pattern of some constituents, e. g. manganese, yellow substance.
- *Do the tidal flat sediments act as a filter system (pore water, particles, subterranean estuaries)?*
  Not a filter but retention system: a bioreactor, a chromatographic column.
- *How can we adequately measure and describe the processes of sedimentation, bioturbation and resuspension?*
  See Working Group “Bioreactor”.
- *How complex should an integrated tidal flat model be to incorporate the small scale physical and analytical data and still be able to provide information on long-term trend?*
  Relevant times scales must be considered.
  Long-term and small-scale processes must be addressed separately.

Working Group 3: Transport and particles

Discussion Leaders: Burghard W. Flemming, Filip Meysman
Rapporteur: Thomas M. Church

Introduction (B. Flemming)
The East Frisian Wadden Sea is a highly engineered coastal system composed of a shoreface, 7 barrier islands and associated tidal basins comprising back-barrier tidal flats and channels. On the landward side, dikes that protect reclaimed land formerly consisting of mud flats and salt marshes, line the shore. Sea-level rise (currently 18 cm/century) creates a sediment deficit in the tidal basins which has to be compensated if the system is to remain in dynamic equilibrium. Because too little sediment is imported from external sources, the East Frisian barrier island system responds by shoreward displacement in the course of which sediment is released on the upper shoreface and transported into the tidal basins at a rate corresponding to the sea-level rise. Knowledge of the sediment budget is thus a basic requirement in coastal dynamics. The budget, in turn, is a function of the rate of sea-level rise and the rate of sediment supply from external sources. Since the intertidal sediments display a progressive shoreward fining trend, only grain sizes corresponding to this energy-controlled gradient can be imported. Currently, most of the sands are supplied from the upper shoreface, whereas muds (silt and clay-sized particles) are imported from remote sources. This fine fraction consists of sortable silt (single particles coarser than about 8-10 µm) and larger aggregates, which are composed of particles smaller than 8-10 µm. These aggregates have equivalent settling diameters corresponding to quartz grains in the range from about 10 to 160 µm with a mean around 30 µm.

Since land reclamation has removed most of the mud flats and salt marshes from the system, the imported fine-grained sediments lack sufficient accommodation space in the existing tidal basins. Notable exceptions are mussel banks around which biogenic aggregates are temporarily deposited in mud patches composed of feces and pseudo-feces, and artificial ponds along the dikes constructed for the very purpose of trapping fine-grained sediments. Energy levels at the foot of the dikes are currently so high that a progressive depletion of particles smaller than about 100 µm is observed. As a result, only the larger aggregates, i. e. those which are hydraulically equivalent to the local quartz sands, are deposited along the energy gradient. This explains why mud contents rarely even reach 50% in the tidal basins.

Applying the principle of hydraulic equivalence, the definition of the grain-size cut-off along the mainland shore is best illustrated by the settling velocity, i. e. particles (single or aggregated) which have settling velocities smaller than those defining the local cut-off, lack appropriate accommodation space in the tidal basin and must ultimately leave the system. However, since the settling velocity is a function of water temperature, the particles are more mobile in winter (higher kinematic viscosities = lower settling velocities) than in summer (lower kinematic viscosities = higher settling velocities). The grain size distributions in the Wadden Sea must hence be adjusted to low winter temperatures. This is enhanced by the fact that total energy flux is, in addition, higher in winter. As a result, the elimination of excess fine-grained sediment must take place during winter months, although it is unclear at this stage under what hydrodynamic conditions the elimination process is most effective. Particle flux measurements have revealed that at least up to wind speeds of Beaufort 7 there is a net import of sand and suspended sediment into the basins. As a result, it is postulated that mass export of fine-grained material must take place during stormy weather conditions (>Beaufort scale 9).

Another basic question is the response time of the system. Dikes have been in place for nearly 1000 years. During this time, the barrier islands and tidal basins have changed their position and size in response to changing tidal prisms. It is currently not clear to what extent the system has achieved a new dynamic equilibrium or whether local adjustments are still in progress. Yet another basic question is to what extent biology plays a role. At least during summer, mussel bank formation is one example when bio-aggregation and mud deposition is effective. In addition, the long-term effects of local biostabilization (or destabilization) of intertidal sediments are still uncertain.

General discussion

The source, transport, and fate of particles in the Wadden Sea can be evaluated as follows. The sources and sinks are generally a question of completing a particle mass balance. However the true fate may be termed “biohydrodynamics”, the complex interplay of physical forces of erosion and biological forces of aggregation, particularly of fine material. The biogeochemical processing of fine particles in the Wadden Sea is the result of the tidal flat “bioreactor” in front of the dikes. The question of whether or not fine particles aggregate can be viewed on a variety of scales, and the success of this answer will depend on modeling at these various scales.

At the small scale (nano- to micrometer), there are the forces of physics (shear, kinematic viscosity), chemistry (surface redox reactions including Mn), and biology (gluing properties of extra-cellular polymeric substances).

At the intermediate scale (milli- to centimeter), there are the physical forces of accumulation and deposition, the result of reworking by reactive transport, the result of the quality and quantity of organic matter.

At the basin scale (meters to kilometers), there is the budget of particles, particularly the finer fraction. This starts with the importance of the landward input (including subterranean and atmospheric), and ends with the seaward output (such as during extreme events).

The ultimate success of modeling the transport and fate of particles in the Wadden Sea depends on understanding the bioreactor represented by the tidal flats. To accomplish this requires methods (e. g. tracers of carbon, use of isotopes) and comprehensive modeling combining biological processes and physical transport. Such coupling may be studied in the laboratory followed by development of a “biohydrodynamic” model of aggregation and disaggregation of fine particles.

Practical Issues

The biogeochemical transport and fate of particles must include all biological factors, including the human/ anthropogenic element. Foremost is the existence and maintenance of dikes. The effect of dikes is to cut off both landward fluvial sources and natural sinks such as intertidal areas. Physically the dikes increase the dissipation of energy from tidal and storm forces before the dikes, accelerating the erosion around the barrier islands. This requires some evaluation of a non-dike control, which may not exist in the area, but may be simulated such as with a computer model. One issue might be how to reverse the adverse effects of the dikes, including revised engineering of existing or future dikes that could accommodate fine material before or behind the dikes. The latter may involve returning some of the reclaimed land to intertidal areas, or creation of wetlands with dredged material. In fact the effective partnering with agencies charged with maintenance of navigational channels should be an integral part of the overall reverse engineering of the Wadden Sea tidal flats. Such efforts need to look forward to forces of global change including increased temperature and salinity. In the case of these more practical matters, the Wadden Sea basic science can serve as a case study.