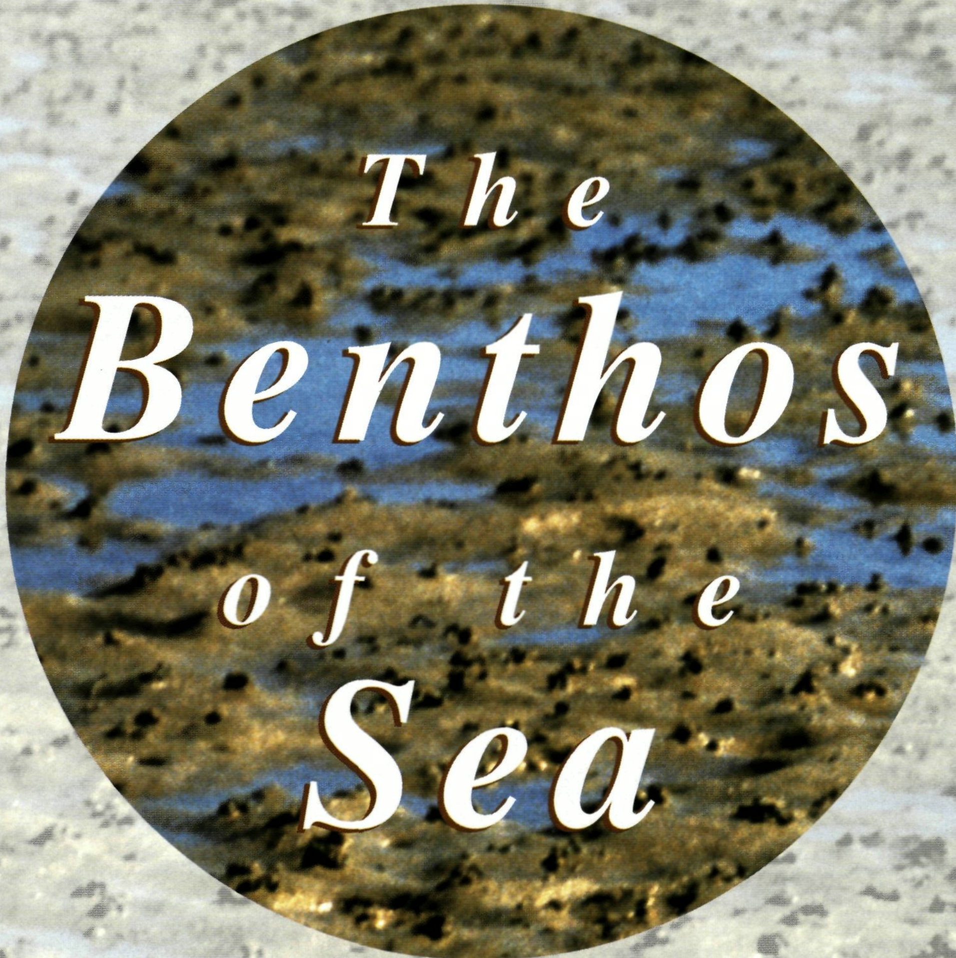
The Benthos of the Sea



Accompanying text to the illustrations (slides)
provided by the
MARINE BIOLOGY SECTION
of the
UNIVERSITY OF GENT
1997

Mariene Biologie
Instituut voor Dierkunde
UNIVERSITEIT GENT

Marine Biology Section, UNIVERSITY of GENT

The Marine Biology Section of the University of Gent is specialized in the **research** of the Benthos and its rôle in the food web of the sea. The North Sea as well as adjacent rivers, but also tropical mangrove areas of Kenya and Ecuador, the deep sea of the Atlantic Ocean and Antarctica are investigated.

The research includes a **morphological-taxonomic** part (i.e. description of new species and evolutive relationship between species) as well as an ecological part (biomonitoring and fundamental research). The biomonitoring aspects cover as well the research on the structure (i.e. changes in numbers and composition) of the biological communities as well as their relationship with different environmental factors. Several benthic communities are used as indicators of pollution.

The several aspects of the research are financed and/or supported by following institutions :

University of Gent (GOA- Concerted Actions), Fund for Scientific Research -Flanders (FWO), Ministry of Public Health (Belgica R.V.), Ministry of Science (Sustainable Management of the North Sea and Antarctica); European Union (MAST and ENVIRONMENT programs), Center for Estuarine and Marine Research (NIOO-CEMO, Yerseke, The Netherlands); Rijkswaterstaat (The Nederlands), Kenyan Marine and Fisheries Research Institute (KMFRI-Mombasa, Kenya), Kenya-Belgium Project (ABOS-VLIR), Institute for Science and Technology (IWT-Brussels), Algemeen Bestuur voor Ontwikkelingssamenwerking (ABOS-Belgium), Ministry of the Flemish Community, AMINAL (department of Nature), Institute of Nature Conservation (Brussels, Belgium).

The research in the Marine Biology Section is also important for **education**. Since 1972, 92 students prepared a M.Sc. and 15 Ph.D. have been delivered.

The research team of the Marine Biology Section contains 22 scientific and 10 technical staff members. The actual composition (April 1998) is :
Coordinator and responsible : M. VINCX & A. COOMANS, post-docs : André CATTRIJSSE, Jan MEES, Jan SCHRIJVERS, Sandra VANHOVE, Ann VANREUSEL; Ph.D. students : Bregje BEYST, Steven DEGRAER, Marleen DE TROCH, Ann DEWICKE, Nancy FOCKEDEY, Chen GUOTONG, Kris HOSTENS, Tom MOENS, Agnes MUTHUMBI, Julius OKONDO, Rianta PRATIWI, Jan SEYS, Maaike STEYAERT, Jan VANAVERBEKE, Enock WAKWABI; administrative and technical staff members : Myriam BEGHYN, Marcel BRUYNEEL, Régine COOLEN, Guy DE SMET, Wies GIJSELINCK, Yves ISRAEL, Danielle SCHRAM, Johan VAN DE VELDE, Dirk VAN GANSBEKE en Annick VAN KENHOVE.

K.L. Ledeganckstraat 35, B 9000 Gent ; tel 09 264.52.10; fax 09 264.53.44
email : magda.vincx @ rug.ac.be

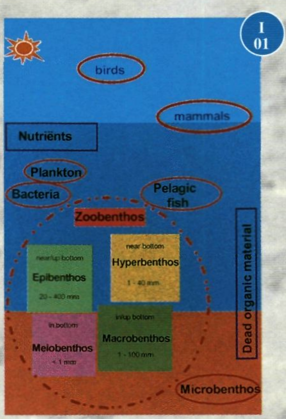
Contents

I. *Biodiversity* OF THE BENTHOS

Marine benthic animals or zoobenthos (shortly named **benthos**) are in large numbers present on or in all sediments of the sea. They can be divided into 4 groups:

- epibenthos (mainly fish, crustaceans and starfish)
- hyperbenthos (mainly mysids, amphipods and larvae of epibenthos)
- macrobenthos (mainly polychaetes, molluscs and crustaceans)
- meiobenthos (mainly nematodes and copepods).

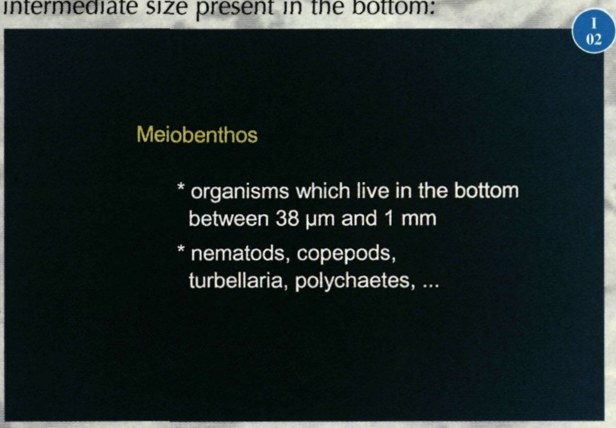
The small microbenthos (mainly bacteria and unicellular organisms) is not discussed in this text. **(slide I-01)**



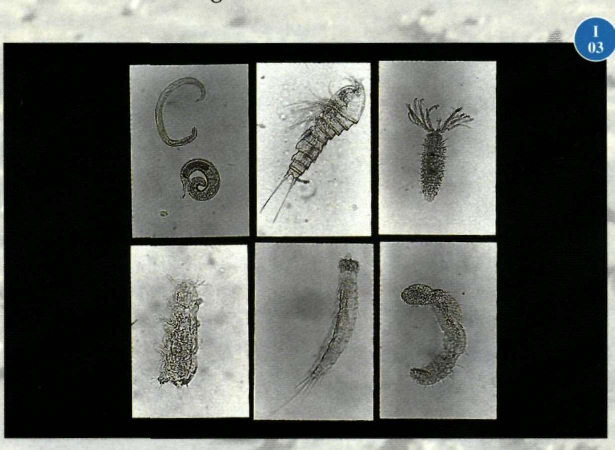
1. Definition and rôle of the different benthos groups

MEIOBENTHOS

Meiobenthos (Meio (Gr.)-smaller and Benthos (Gr.)-bottom) **(slide I-02)** is a general term for all living animals of intermediate size present in the bottom:

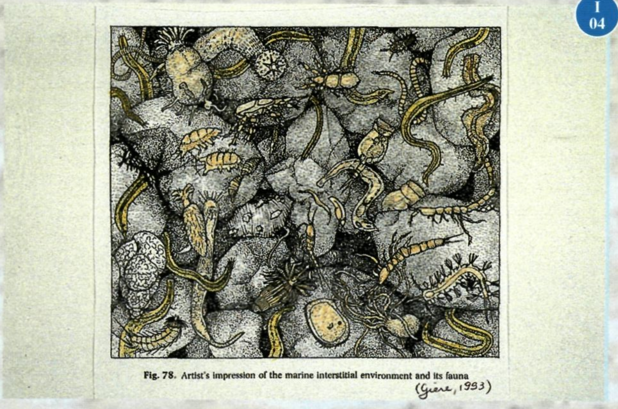


this means larger than microbenthos and smaller than macrobenthos (all benthic invertebrates larger than 1 mm). Practically, this means animals between 38 µm and 1 mm. Typical animals **(slide I-03)** belonging to the meiobenthos are nematodes, copepods, turbellarians or flatworms and small polychaetes. Others, more rarely found animals are oligochaetes, kinorhynchs, tardigrades, ostracods and gastrotrichs.



In most bottom types, nematodes are the dominant group and represent 50 to 100 % of the total meiobenthos community. These animals are very active in the regeneration and mobilisation (resuspension) of nutrients present in or on the bottom and make them available in the environment. Copepods are the second most important group of the meiobenthos.

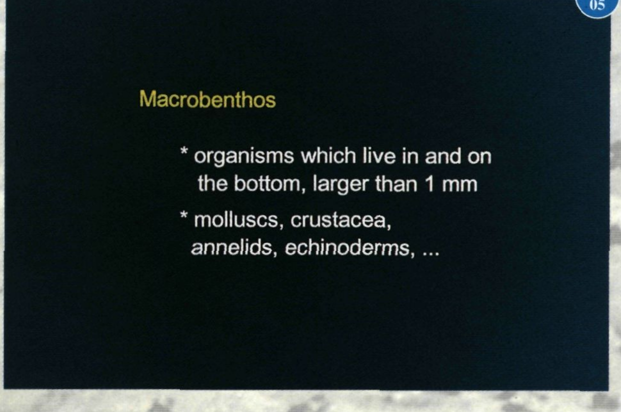
Meiobenthos lives in soft bottoms, where these animals are (dependent on their body size and the space between the grains of sand or mud) interstitial (living between the sediment particles) **(slide I-04)** or burrowing. Normally they live concentrated in the top five centimetres of the



sediment, but they could also appear at more than 50 centimetres deep in the bottom. Besides this, there are different species adapted to live on algae or seagrasses and even in extreme substrates as e.g. polar ice. They feed on small unicellular algae, bacteria and suspended organic matter, and are prey to larger benthic animals (macrobenthos) and small fish.

MACROBENTHOS

Analogous to the term 'meiobenthos', 'macrobenthos' **(slide I-05)** is the general term for those organisms living in or on the bottom, larger than 1 millimetre.

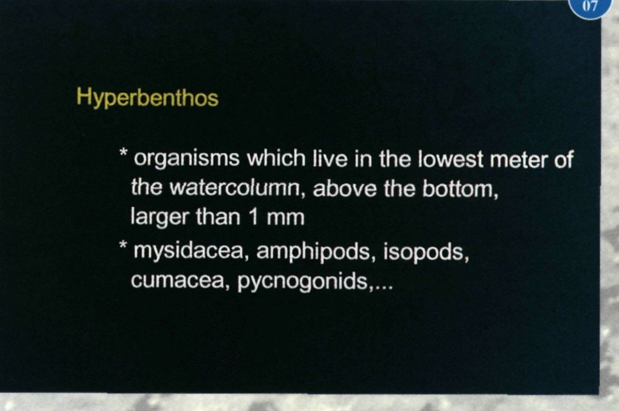


The most common macrobenthic groups **(slide I-06)** are molluscs, crustaceans, annelids and echinoderms.

Just like the meiobenthos, the macrobenthos is cosmopolitan from the beach to the deep sea and from polar regions to the equator. The only restriction on this distribution is the necessity of oxygen. That is the reason why they can only live at a maximum depth of 10 centimetres in the sediment.
Macrobenthos plays an important rôle in the ecosystem of the sea, on the one hand as consumer of dead organic matter, grazers on small algae or predators on small animals, and as food for benthic fish, crabs and birds.

HYPERBENTHOS

The hyperbenthos **(slide I-07)** includes all organisms larger then 1mm which are, on the contrary to the macrobenthos, living in the lowest layer of the water column, just above the bottom.



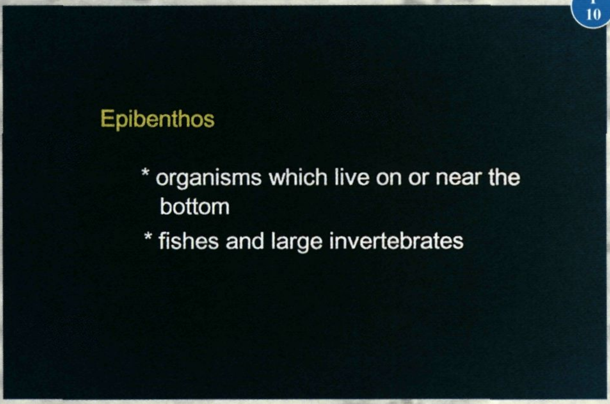
Two groups can be distinguished:

- The permanent hyperbenthos **(Slide I-08)** spends its complete life cycle in the lowest layer of the water column and includes among others, mysids, amphipods, isopods, cumaceans and pycnogonids.
- The temporal hyperbenthos **(Slide I-09)** is only present during certain periods (life stages) in the lowest waterlayer, mainly (post)larval stages of shrimp, crabs and fish.

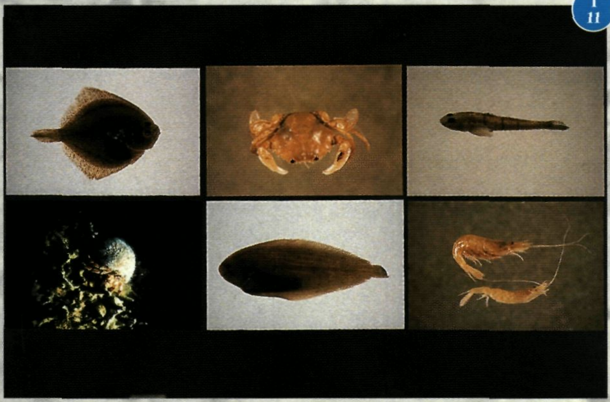
Until recently, the hyperbenthos was not studied. Although the importance of the hyperbenthos in estuaries and coastal ecosystems e.g. as reamer of detritus and as prey for benthic fish and shrimp is obvious.

EPIBENTHOS

The epibenthos **(Slide I-10)** includes fish and larger



invertebrate animals living on or near the bottom. Only the younger life stages of commercial and non-commercial fish, with an average size between 20 and 400 millimetre, are studied **(Slide I-11)**.



Take into account that the adults of epibenthic species live on the bottom and belong to the epibenthos, while the larvae and juveniles of these species swim freely in the lower parts of the water column. During these first life stages they are included in the hyperbenthos.

The North Sea fish research is concentrated on gobies, small fish species present in large numbers which form an important link in the food web.

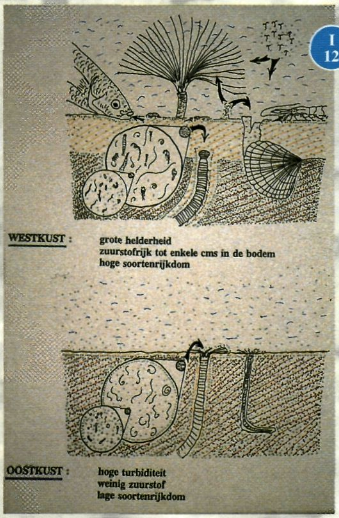
<u>*2. Biodiversity: the diversity of life in the sea*</u>

The species composition of ecosystems is only a part of the recent-popular term 'biodiversity'. Biodiversity is much more than species richness.
Biodiversity is the diversity of life in all its forms, from the genetic patrimonial to the ecosystems which construct the biosphere. All these levels of biological organisation have in common that their diversity decreases in a terrifying way. The convention of Rio de Janeiro (1992) on the 'Biodiversity program' and the composition of Agenda 2000 aimed to make different countries and their population aware of this irreversible loss of biological diversity.

The decline of the diversity of life in the sea is due to different causes like:

- intensive fishing and the elimination of the 'oceanic stock' of plants and animals
- chemical pollution (PCB's and heavy metals) and eutrophication of seawater (process of nutrient supply of human origin which stimulates primary production and disturbance of the food web)
- changes in the coastal landscape by constructing touristic centres resulting in erosion of dunes and decrease of coastal protection
- global climate changes (temperature increase)...

An important standard for the 'health of an ecosystem' is the diversity of living organisms **(Slide I-12)**.



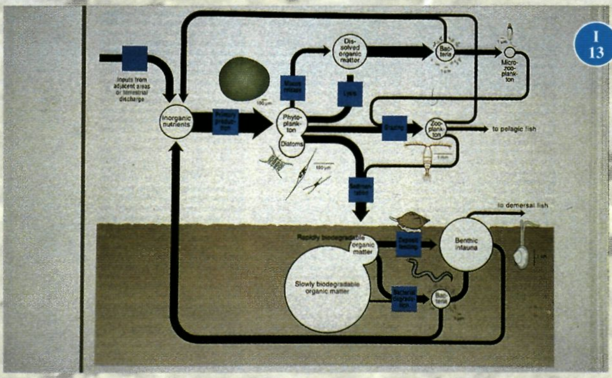
The first figure of this slide represents a typical North Sea

community. The arrows show the most important trophic interactions (see food web). The second figure is the situation of a polluted area of the North Sea (e.g. the East coast at the mouth of the Westerschelde estuary). This ecosystem is characterised by some species of 'deposit feeders'. This is typical for muddy bottoms where oxygen is limited to the top millimetres of the bottom. Diversity is low and the food web is not complex.
The richer condition can be found in sandy sediments with a larger oxygen rich layer, so that more species can survive.

To calculate Biodiversity of an ecosystem, scientists use mathematical indices as well as graphical methods to give information about the 'health' of an ecosystem.

3. The food web in the sea: to eat and to be eaten

Each 'autotrophic' food web **(Slide I-13)** starts with primary production (making of organic matter) by microscopic small plants (phytoplankton and/or phytobenthos).



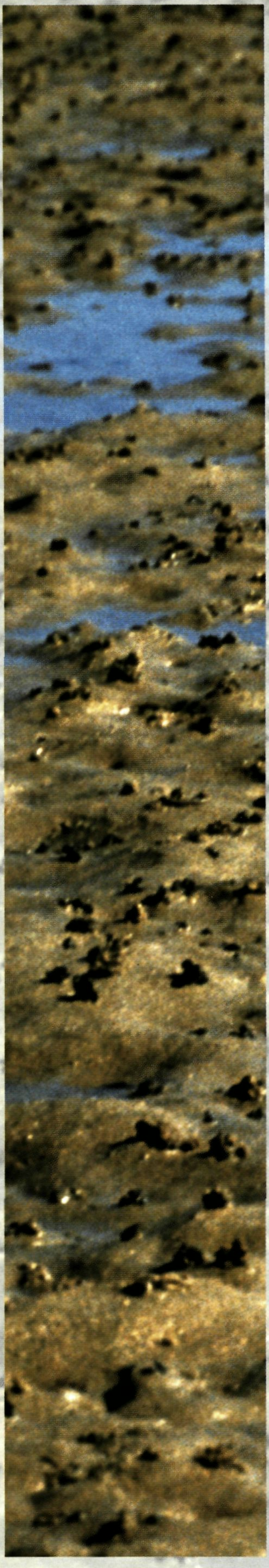
With enough daylight, carbohydrates are produced by phytoplankton. At insufficient light input diatoms continue the production of oxygen and organic material. The mucus (slime) produced by phytoplankton is an important source for bacteria. Also the decomposition (lysis) of phytoplankton is a food source for bacteria. These bacteria form an important step to the zooplankton (animals floating in the water mass). The microzooplankton feeds on these bacteria and are food for calanoids (planktonic copepods). These calanoids can, beside this 'grazing' of microzooplankton, also feed on phytoplankton.
The zooplankton is often found in large 'clouds' in the water column and form an important food source for some important pelagic (living in the water column) fish. These pelagic fish also feed on hyperbenthos.
On the other hand, these pelagic fish are prey to birds. These birds feed also on macrobenthos (in the bottom).

The coupling between this 'pelagic cycle' and the 'benthic cycle' is based on the sedimentation (deposition) of dead zooplankton and diatoms.

The turn-over of this detritus can be slow or fast: both are transposed to inorganic nutrients by bacteria. Only the easily decomposable detritus can be taken up by 'deposit feeders' in the benthos (meiobenthos and macrobenthos). Some representatives of macrobenthos are 'filter feeders' and feed on suspended matter (e.g. mussels). Starfish and crabs feed on macrobenthos especially molluscs. This benthic infauna (meio- and macrobenthos) is the step to epibenthos as demersal (living near the bottom) fish e.g. flatfish, gobies.

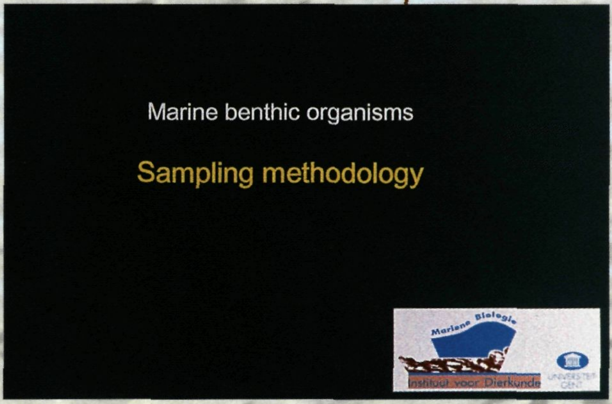
LIST OF SLIDES

BIODIVERSITY OF MARINE BENTHIC ANIMALS



I-00 Title: Marine benthic organisms
I-01 Distribution of marine benthic animals: overview of the relations between the different components
I-02 Meiobenthos : definition
I-03 Representatives of the meiobenthos: from top left to bottom right: nematodes, copepods, polychaete, tardigrade, kinorhynch and gastrotrich
I-04 The interstitial life of different meiobenthos groups
I-05 Macrobenthos : definition
I-06 Representatives of the macrobenthos : from top left to bottom : a polychaete, *Anaitides subulifera* (Polychaeta), *Diastylis bradyi* (Cumacea), *Leucothoë incisa* (Amphipoda), *Tellina fabula* (Bivalvia) and *Echinocyamus pusillus* (Echinodermata).
I-07 Hyperbenthos: definition
I-08 Representatives of the permanent hyperbenthos: *from top left to bottom* right: a mysid (Mysidacea), an amphipod (Amphipoda), an isopod (Isopoda), a cumacean (Cumacea), a pycnogonid (Pycnogonida), an arrow worm (Chaetognatha)
I-09 Representatives of the temporal hyperbenthos: form top left to bottom right: larval shrimp (postlarve), larval crab (zoe-larve), larval crab (megalope-larva), larval fish (herring-like), larval flatfish, larva of a polychaete (Polychaeta).
I-10 Epibenthos: definition
I-11 Representatives of the epibenthos: from top left to bottom right: Lozano's goby (*Pomatoschistus lozanoi*), swimming crab (*Liocarcinus holsatus*) turbot (*Scophtalmus maximus*), common shrimp (*Crangon cangron*), sole (*Solea solea*) and a hermit crab.
I-12 Effect of pollution on life in the sea: comparison between eastern coast and western coast
I-13 The food web in the bottom: to eat and to be eaten

II. Sampling Methodology OF THE BENTHOS



1. Introduction

Each ecological study starts by designing a sampling strategy. This means that a standard procedure has to be fixed, in function of the research purposes of the study: number of samples, sampling moment (season, day or night, low or high tide, ...), geographical positions of the stations, choice of environmental variables to measure, ... Sampling methodology needs to be studied thoroughly in advance, since samples are only useful if they are representative for the investigated population. Standardized and uniform sampling methodology is a necessary condition to compare results and draw conclusions.

Meiobenthos and macrobenthos are living in the bottom. Sampling is done by taking sediment samples; organisms are extracted by bringing the sample over a sieve. Hyperbenthic and epibenthic organisms are living in the water column in the proximity of the bottom. They are caught while towing a net over the sea floor. At each sampling station, a number of environmental variables is recorded (e.g. temperature, salinity, oxygen, ...). Once fieldwork is finished, samples are brought to the laboratory for further analyses.

2. Sampling methodology

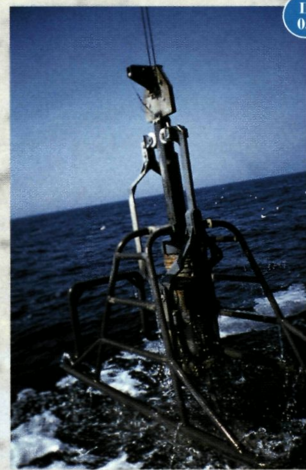
M E I O B E N T H O S

Meiobenthos samples are taken with a core (surface 10cm^2) **(slide II-01 and II-02)**. A bottom profile (approximately 20 cm deep) is obtained by pushing the core straight into the bottom. Further division of the sediment

II 01

II 02

in slides of 1 cm is often done to investigate the vertical distribution of organisms. This simple method is directly applicable to easy accessible sampling stations e.g. intertidal areas (mud flats, mangroves,...). However, most biotopes are sampled with special gear launched from a vessel: a boxcorer **(slide II-03)** or a multicorer. Different types of boxcorers exist, e.g. a standard boxcorer **(slide II-05)**, a Reineck boxcorer **(slide II-04)** and a multi-boxcorer **(slide II-08)**. All of them work according to the same principle: a metal box is pushed into the bottom by leverage. After closing the box, an undisturbed (not rummaged) sample of the sea bottom is brought on board **(slide II-07)**. Once the box is released on deck, a series of cores can be put in this undisturbed piece of sea bottom **(slide II-06)**. A Reineck boxcorer is a much smaller version of the standard boxcorer (and has a smaller box), but is easy to handle (e.g. for small vessels and by stormy weather). A multi-boxcorer is a combination of several boxcorers and is mostly used for deep-sea research. The advantage is that several samples can be taken simultaneously, since it can take hours to lower apparatus to the deep-sea bottom. Another type of gear used for deep-sea research is a multicorer **(slide II-09)**, cores are pushed separately into the bottom here.



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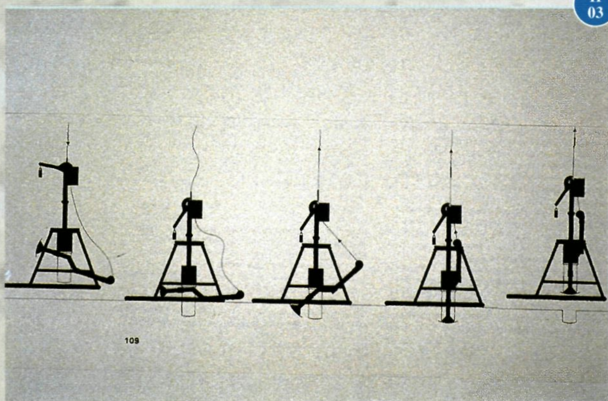

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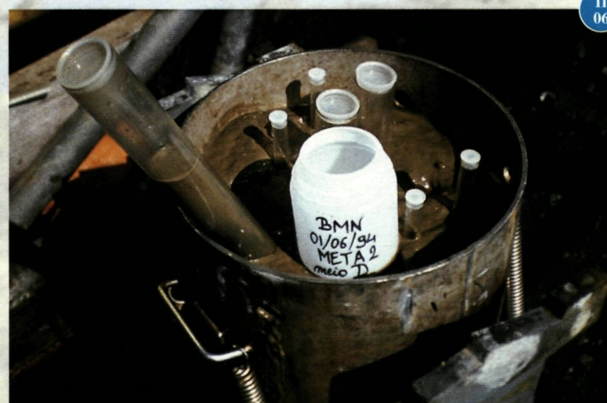

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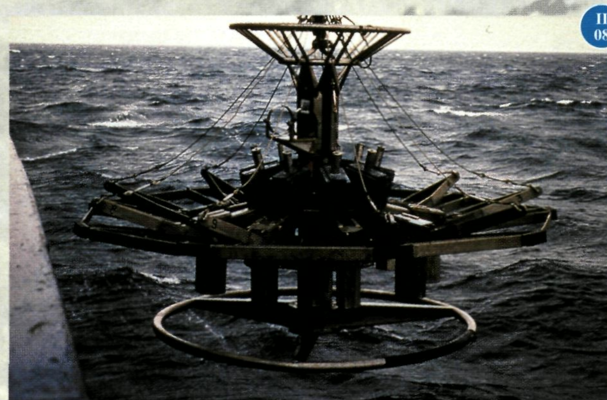


II 08

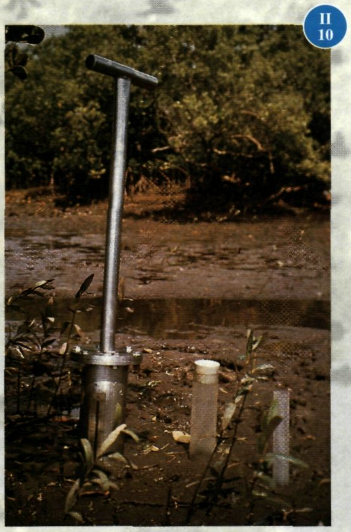
MACROBENTHOS

Several techniques exist for sampling macrobenthos, depending on the studied biotope. A core with a handle **(slide II-10)** is suited to sample in intertidal areas.

This core is much larger and stronger in comparison to the meiobenthos core. Another method consists herein by pushing a metal frame **(slide II-11)** of a certain height into the bottom and digging out the desired depth of the sediment.

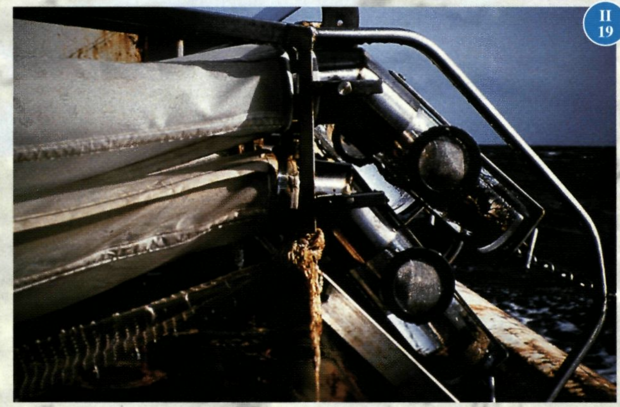
Sampling from a vessel happens mostly with a Van Veen grab **(slide II-12)** or a boxcorer **(slide II-05)**.

A Van Veen grab has two arms which close, when touching the bottom; a grab (with a certain surface) is taken from the seabottom.



HYPERBENTHOS

Hyperbenthos is sampled by means of a hyperbenthic sledge, which consists of a metal frame (1 m height) with two or four nets attached inside. Usually, mesh sizes of 0.5 or 1 mm are used. After lowering to the bottom, the sledge is towed for 500 m approximately. All organisms staying in the water stratum (lower 1 m) adjacent to the bottom, are caught. The beach sledge **(slide II-15)** has two nets and is designed for studying and sampling hyperbenthos inhabiting surf zones. This rather light model can be towed by two persons walking in the surf zone **(slide II-16)**. More specialized and heavier gear is needed to sample in estuaries and subtidal waters: the Sorbe sledge. This type of sledge consists of four nets, with an automatical opening **(slide II-18)** and closing **(slide II-17)** blind, controlled by bottom contact. The hyperbenthic fauna is only caught when the sledge is sliding effectively over the bottom, preventing contamination while lowering and pulling up. The end of each net is attached to a collector **(slide II-19 and II-20)** which contains the catch. The sledge is also equipped with an odometer (measures the exact towing distance) and a current meter (measures the volume filtered water). Sledges can only be used on rather smooth bottoms otherwise they can stick during sliding. The hyperbenthos of hard or uneven biotopes (e.g. rocky coasts, puddles, ...) is sampled with a simple handnet **(slide II-21 and II-22)** or with pumps. Passive fishing with a stownet is a sampling technique that is often used for sampling in salt marshes. The stownet **(slide II-23)** stands in a creek and all organisms transported by the tide, are catched.



E P I B E N T H O S

The epibenthic fauna is caught with a beamtrawl **(slide II-24)** launched from a vessel. A beamtrawl consists of a metal beam, mounted on two shoes. A fine meshed net (5x5 mm) is fixed between the two shoes, equipped with a tickler chain to start fish. Towing distance is usually 1000 meter; the catch is collected in the cod-end **(slide II-25 and II-26)** after pulling up the net. The beach beam-trawl **(slide II-27)** is a smaller version and is useful to sample the epibenthic animals living at beaches. Sampling is done on foot or even by horse **(slide II-28)**. In accordance to the beach sledge, the beach beamtrawl is towed in the surf zone for a certain distance. Fykes **(slide II-29)** are often used in salt marshes and mangroves, comparable to the stownet for hyperbenthos. Of course, mesh size is larger here and the fyke is adapted to sample epibenthic animals (accompanying nets, fish cannot escape). Fishing with a beach seine **(slide II-30)** (a long net equipped with lead at the bottom edge and floaters at the top edge) needs certain experience and is especially used in tropical bays. One end of the seine is fixed on the beach and while sailing in moon-shaped direction, the rest of the net is throwed out. All enclosed fish are caught by bringing the tips of the net together and drawing it tighter. The research vessel R.V. *Belgica* **(slide II-31)** (Belgian Ministry of Health) is often used for sampling the benthic fauna of the North Sea.

3. From sample to result

The first step in sample processing concerns the sorting of organisms. Meiobenthos samples are sieved over a

38 µm sieve and organisms are separated from the sediment by a flotation technique (based on the specific gravity of the animals). The small organisms are brought into microscopic slides for investigation. The volume of a macrobenthos samples is much larger (often the volume of a bucket) and is brought entirely on a special sieve to 'wash' **(slide II-13)**. The sieved organisms can be sorted by eye **(slide II-14)**. There is also a lot of sorting work for hyperbenthos samples, prior to the identification of the organisms. The content of a sampling container is brought into a sorting tray, each animal is picked out and sorted into the corresponding group (mysids, shrimp

larvae, fish larvae, ...). Catches of epibenthos are often sorted immediately on board of the sampling vessel.

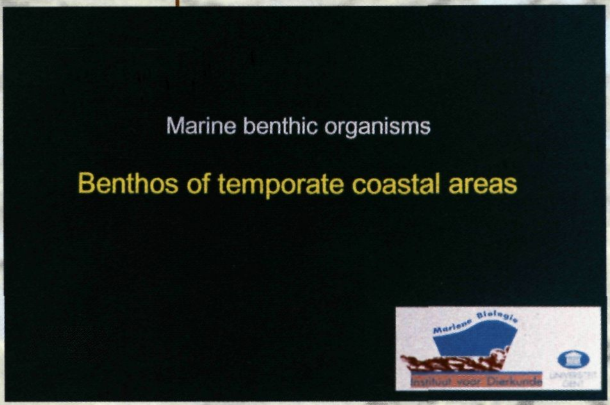
Secondly, all organisms of a sample are studied under a microscope (for microscopic preparations) or a binocular (for larger organisms). This means that all organisms are identified, counted and measured.

Finally, all data per species and per sample are brought together in tables, for densities and biomasses. Comparisons can be made between species, areas or periods; diversities can be calculated and compared; growth can be studied using length-frequency data; etc... all dependent on the objectives of the study. To analyze this kind of data properly, specific statistical packages are required. Obviously, the processing of the data is largely dependent on the aim of the study.

LIST OF SLIDES

SAMPLING METHODOLOGY

III. The Benthos of TEMPERATE COASTAL AREAS

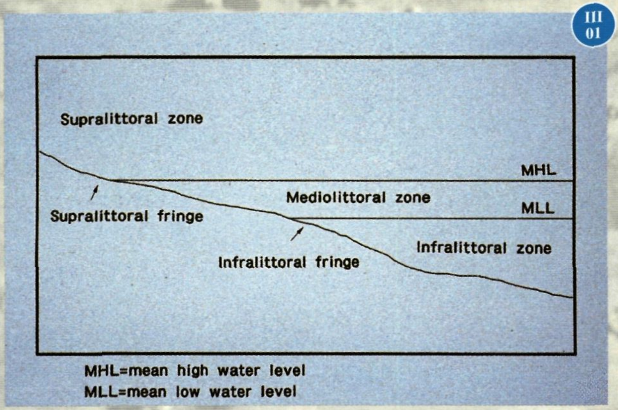


1. Definition

The coastal ecosystem is distinguished from all other ecosystems by the presence of a regulating phenomenon: the tides. An unique biotope which is characterized by a typical fauna and flora, is formed due to the influence of the tides. This biotope situated at the intertidal zone (= zone between the highest and the lowest spring tide level) is called the littoral zone. The littoral zone is, in contrast with the intertidal zone, defined in biological terms.

Because the littoral zone is the transitional zone between the marine and the terrestrial environment along a restricted distance ranging from a few meters until several hundreds of meters, it is characterized by a very distinct gradient of different environmental variables like salinity, emersion, light and temperature. This phenomenon results in a strong zonation of the fauna and flora because the dispersion of a large number of species is restricted to a certain part of this gradient. A further division of the littoral zone is therefore made based on the upper and lower limits of the occurrence of certain species.

According to the terminology of Stephenson & Stephenson (1972), the tidal zone consists of the supralittoral fringe (= lower part of the supralittoral), the midlittoral and the infralittoral (= upper part of the infralittoral) **(slide III-01)**.



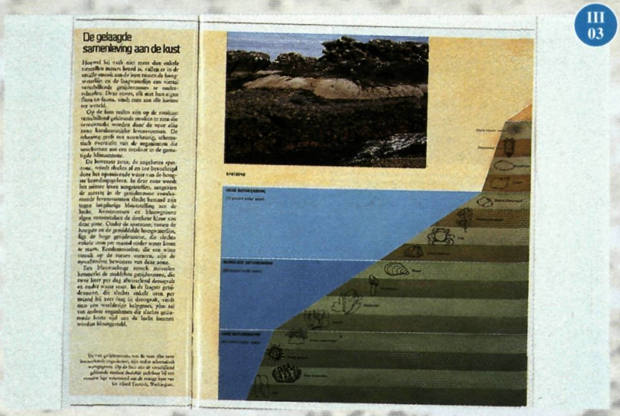
Roughly, intertidal areas along the coast can be divided into rocky shores and sandy beaches. In general, rocky shores are more diverse than sandy beaches due to their variety of microhabitats. A large offer of more or less sheltered biotopes for sessile as well as mobile organisms, is mainly provided by algae which overgrow the rocks. Furthermore, the grade of exposure of the different shore types to the waves has a severe influence on the diversity (see further). The two types of intertidal zones are discussed successively.

2. Rocky coasts

2. a. Zonation

Zonation of rocky coasts **(slide III-02)** is mainly determined based on the absence or presence of algae, lichens and sessile or attached organisms.

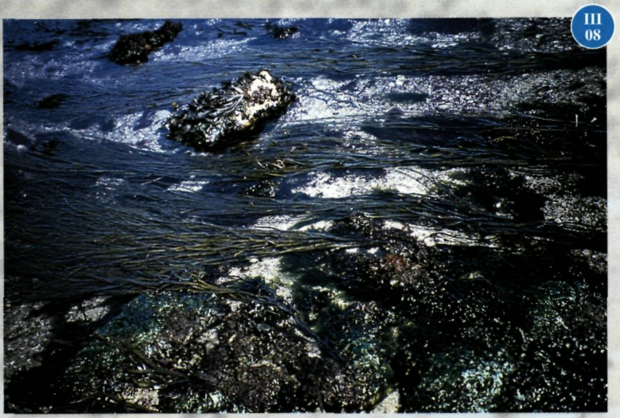
The borders of occurrence of mobile organisms is less restricted because they can make excursions to favorable microbiotopes before or beyond their proper dispersion area. For each zone, the characteristic communities are given by the enclosed diagram **(slide III-03)** . An additional distinction within each zone is made between



exposed and sheltered shores and possible intermediate situations. If exposure increases, the chance that organisms are washed out is getting bigger and therefore only those organisms survive which are properly attached to the exposed rocks. On the other hand, the chance of dehydration will diminish because the seawater splashes higher upon the rocks. The colonization of certain species can be disturbed by sedimentation of silt.

The supralittoral fringe is only submersed during spring tide. This area is the extreme inland border for marine organisms to survive and it is also the upper limit for the occurrence of barnacles (Crustacea, Cirripedia). The number of species within this zone is very limited: only those species which are capable to withstand dehydration and fluctuating temperatures can survive here **(slide III-04, 05, 06, 07)**.

The midlittoral zone is the middle area of the intertidal with the top of the barnacle zone as upper limit and the upper border of the *Laminaria* community (brown algae) as lower limit. According to the grade of exposure, different types of midlittoral communities can be distinguished. As the exposure increases, the communities can be dominated respectively by e.g. **brown algae (Fucacea), barnacles (Cirripedia) and limpets (Patella spp.) on the one hand and mussels (Bivalvia) and red algae (Rhodophyceae)** on the other, but in some cases intermediate situations occur.



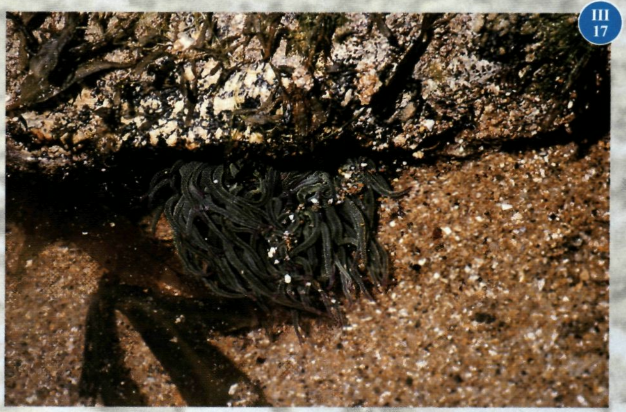
Finally, the infralittoral fringe **(slide III-08, 09, 10, 11)** is the small area of the infralittoral zone that is liable to the tidal forces. Characteristic for the area which is only revealed during spring ebb tide, are two large brown algae: *Laminaria digitata, L. saccharina or Himanthalea species.*

2.b. Adaptations

Organisms living on open rock surfaces are more exposed to the rigors of the physical environment than animals inhabiting soft sediments and therefore require several adaptations. Maintaining their position in the face of strong water movement frequently involves one or more of the following adaptive features:
(1) strong attachment devices, e.g. algal holdfasts, cementation (oysters, barnacles), byssus threads (mussels), tube-feet (urchins, starfish), the adhesive foot of gastropods and the modified sucker-like fins of many pool fish; (2) boring into the rock surface, e.g. some bristle worms; (3) changes in orientation to minimize shear stress; (4) use of crevices; (5) formation of dense aggregations to expose a smaller surface area; (6) increased flexibility, e.g. algal stipes; (7) irregular surface contours to reduce turbulence and minimize drag, e.g. the ridged or crinkle fronds of many kelp.

Many of the organisms which occur on rocky coasts are sessile (= permanently attached) **(slide III-12, 13, 14, 15, 16, 17, 18)**. The advantages of this on wave-swept shores are obvious, but on the other hand it limits the

possible methods of food acquisition. Not surprisingly, *suspension feeders are particularly prominent.* They develop various structures including gills (Bivalvia), setae (barnacles, Cirripedia) and tentacular crowns (tube-worms, Polychaeta and Bryozoa) to collect particulate material. Furthermore, herbivores (e.g. Gastropoda) and predators (e.g. starfish, Echinodermata, crabs, Brachyura and birds) are also present. Most marine species feed only when submersed, and reduced feeding time may



therefore limit the extent to which some species can penetrate the intertidal zone.

3. Sandy beaches

The sandy beach **(slide III-19, 20)** is considered here to be part of a system comprising:

- the sand body from the highest drift line near the dune/beach boundary out to beyond the break point of the waves and
- the moving water envelope of the surf zone.

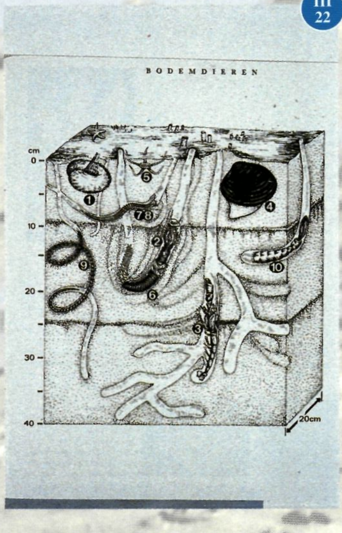
III 20

III 21

It does not include the dunes typical of many sandy coasts, although dune/beach interactions are important within the coastal ecosystem. The term sandy beach covers a range of environments from high energy <u>open</u> ocean beaches to extremely <u>sheltered</u> estuarine sand flats. The intertidal sand body of open sandy beaches is characterized by a mobile substratum and the absence of attached plants. The most important communities are (1) the interstitial fauna (= the fauna living within the porous system of the sand body) and the macrobenthos of the sand body, (2) the hyper- and epibenthos and phyto- and zooplankton of the surf zone and (3) the birds of the beach and dune margin. The top of the food chain (excluding the smaller interstitial food web) is represented by fish (e.g. plaice *Pleuronectes platessa*), birds (e.g. sanderling *Calidris alba*), invertebrate top predators (e.g. shore crab *Carcinus maenas*) and mammals (e.g. man by consuming the common shrimp *Crangon crangon*). The interstitial fauna represents a separate community since there is little exchange with higher trophic levels, especially on exposed beaches.

Besides the absence of attached plants, open sandy beaches are characterized by a negligible primary production by benthic microflora. Primary production in the water column can be important, especially when phytoplankton blooms (e.g. *Phaeocystis*) occur.

III 22

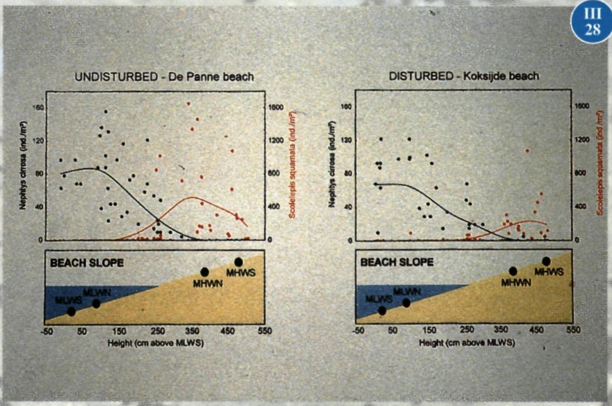


III 23

M A C R O B E N T H O S

Approximately 90% of the intertidal macrobenthos is situated in the upper 5 cm of the sediment. Molluscs (Mollusca), crustaceans (Crustacea) and bristle worms (Polychaeta) are the main representatives **(slide III-22, 23, 24, 25, 26, 27)**. The numbers and diversity of the species present are mainly determined by the degree of exposure of the beach. The more the beach is exposed to the waves, the more adaptations are necessary. The main characteristics of macrobenthos of exposed beaches are therefore a high degree of mobility and the performance of migrations with the tide.

Investigations along the Belgian coast (De Panne, 1995-1996) reveal that two distinct communities can be distinguished: one in the high intertidal area and one in the low intertidal along with an intermediate community in between **(slide III-28)**. The high intertidal community is mainly characterized by *Scolelepis squamata* (Polychaeta) and a.o. *Eurydice pulchra* (Isopoda), while *Nephtys cirrosa* (Polychaeta), Pennant's swimming crab *Portumnus latipes* (Brachyura) and *Urothoë poseidonis* (Amphipoda) represent the community of the low intertidal area. Total densities range from a few hundred ind./m² until maximal numbers of 5000 ind./m².



H Y P E R B E N T H O S

Data on intertidal hyperbenthic communities are very scarce. Besides the typical intertidal hyperbenthic species (e.g. the mysid *Leptomysis lingvura*), a distinction can be made between local endobenthic species that perform active vertical migrations (e.g. the amphipod *Corophium acherusicum*) and tidal migrants carried in from sublittoral habitats by tide (e.g. the mysid *Schistomysis spiritus*). These migrations can be related to foraging or mating activities. Some mysid species (Mysidacea, Gastrosaccinae) which inhabit the swash zone, swim actively when a wave covers the substratum and bury themselves quickly when the water retreats. In case of stormy weather, some intertidal species migrate towards subtidal areas where the wave activity is less extreme, while subtidal species (which are less adapted to these circumstances) can be thrown upon the beach. The most important representatives of the permanent hyperbenthos of sandy beaches are mysids (e.g. *Mesopodopsis slabberi*), amphipods (e.g. *Atylus swammerdami*), isopods (e.g. *Eurydice pulchra*) and cumaceans (e.g. *Cumopsis goodsiri*). The temporary hyperbenthos is mainly represented by (post)larval and small juvenile fish, like the flounder *Pleuronectes flesus*, plaice *P. platessa* and sole *Solea solea*, but also includes gobies *Pomatoschistus* spp., sandeel *Ammodytes tobianus* and

Nilsson's pipefish *Syngnathus rostellatus*. Larval crustaceans like the common shrimp *Crangon crangon*, and the different crab species (e.g. swimming crab *Liocarcinus holsatus* and the shore crab *Carcinus maenas*) as well as the postlarval stages of bristle worms (Polychaeta, e.g. *Lanice*) also belong to the temporary hyperbenthos **(slide III-29, 30, 31, 32, 33)**.

An important function of intertidal areas is that they can act as 'nurseries', mainly for fish and shrimp which migrate towards shallow areas during early life stages thereby representing the temporary hyperbenthos. Two hypotheses explain these migrations:

- the 'foraging hypothesis': the early life stages make use of the high food amounts in the intertidal areas;
- the 'refugium hypothesis': less extensive predation within these areas results in higher surviving chances of the juveniles.

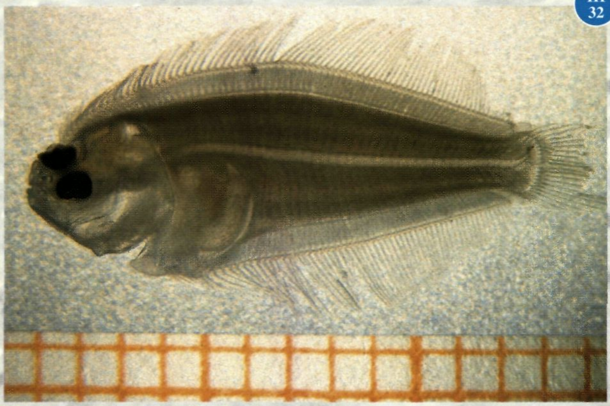
EPIBENTHOS

The intertidal epibenthos mainly consists of shrimp and juvenile fish (mainly plaice *Pleuronectes platessa* and clupeids like herring *Clupea harengus* and sprat *Sprattus sprattus*), but also adult fish (like gobies *Pomatoschistus* spp., the weever *Echiichthys vipera* and the sea scorpion *Taurulus bubalis*) as well as crabs are representatives of this group. However, only a very small amount of species is restricted to depths less than 5m **(slide III-34, 35, 36, 37, 38, 39, 40, 41)**. Important migrations can be observed: mainly juvenile plaice *Pleuronectes platessa*, but also flounder *P. flesus* and brill *Scophthalmus rhombus* perform tidal migrations which allow them to feed on the sand flats during flood or to avoid larger predators. This is in contrast with more pelagic fish like sandeel *Ammodytes tobianus* and herring *Clupea harengus*: their occurrence in the intertidal zone is probably more due to random dispersion. Most marine fish perform basically diurnal rhythms, only 'typical' intertidal species are more influenced by the tidal movements of the water column.

III 30

III 31

III 32



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III 33

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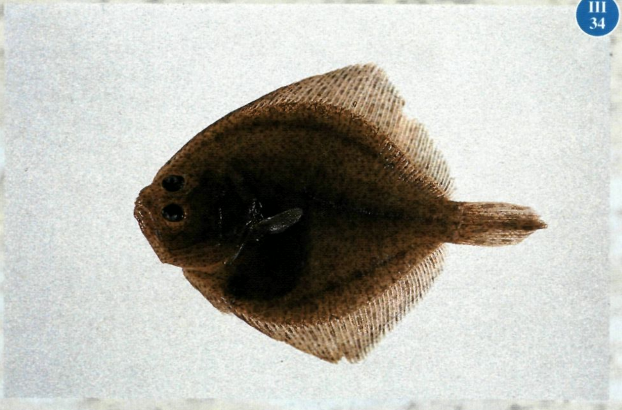

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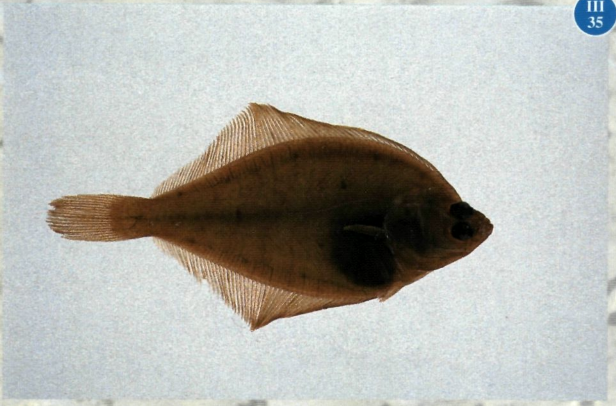

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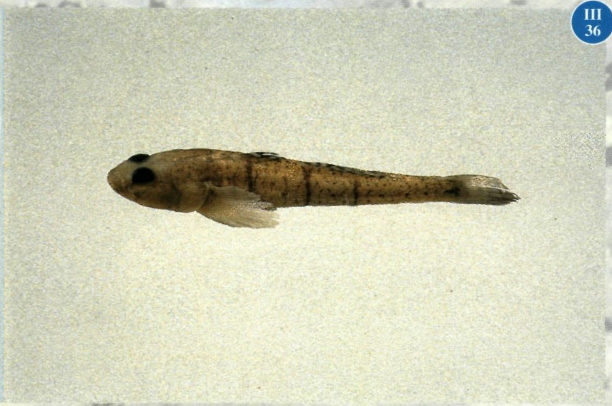

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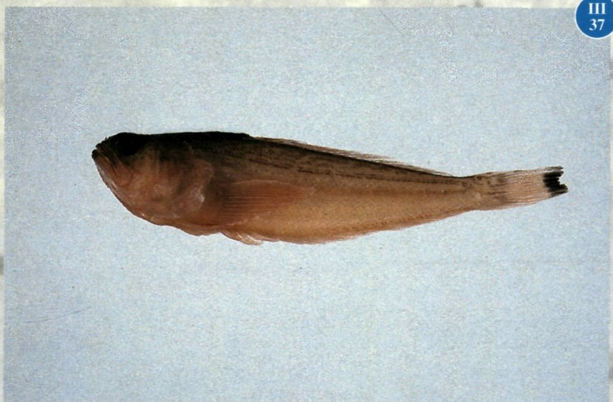


III 38

III 39

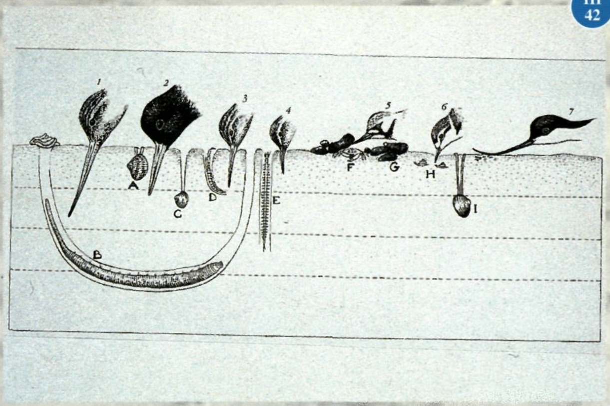
III 40

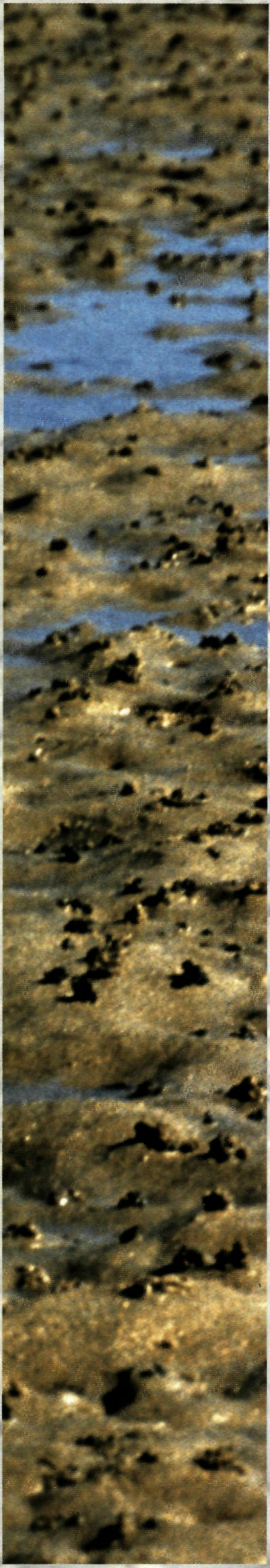
III 41

BIRDS

Three main groups of birds can be observed within the intertidal area: seagulls, waders and more dune-related birds like e.g. the horned lark *Eremophila alpetris*, which are not directly dependent on the intertidal area. Seagulls are mainly scavengers, but they are also perfectly capable of breaking the shells of molluscs by throwing them from great heights onto groins. Waders are important predators on sandy beaches: they forage mostly during low tide gathering mainly macrobenthos out of the sediment (an example is the sanderling *Calidris alba* which follows the water edge continuously while searching for food). Other common waders are the oystercatcher *Haemotopus ostralegus* and the turnstone *Arenaria interpres*. The latter is mainly found on wave breakers. The large heterogeneity between the different wader species can give information about their foraging techniques **(slide III-42)**.

III
42





LIST OF SLIDES

THE BENTHOS OF TEMPERATE COASTAL AREAS

III.00 Title
III.01 Diagram intertidal area: littoral zone

Rocky coast: zonation

III.02 Example of a rocky coast (Bretagne- France)
III.03 Zonation diagram
III.04 Wall of Pointe de la Crèche (N-France): *Verrucaria maura* (lichen), *Blidingia minima, Porphyra umbilicales, Enteromorpha compressa, Fucus spiralis* (on the ground lots of *Ulva* -green algae- and *Fucus* -brown algae-)
III.05 Intertidal area of an exposed rocky coast: without vegetation, but Balanus (cirriped) and *Patella* (mollusc) are present as well as algae in the puddles
III.06 Intertidal puddle (extreme ecological circumstances) with *Ulva* and *Enteromorpha* (green algae)
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Rocky coast: examples benthos

III.12 Burrows of Polychaeta (*Sabellaria alveolata*) constructing a layer on the rocks
III.13 Alcareous tubes of a bristle worm species (Polychaeta)
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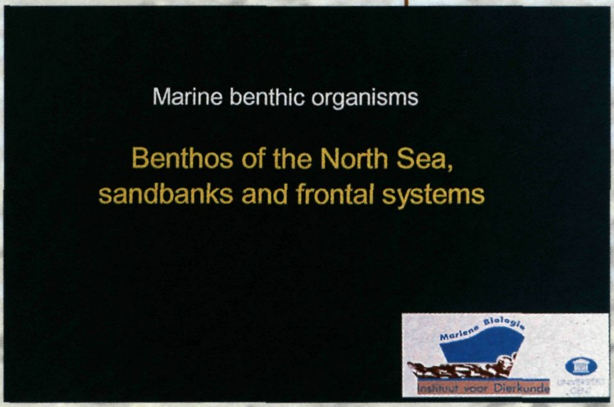
III.16 Barnacle association (Cirripedia) with sponges (Porifera)
III.17 Sea anemone (Actinaria): *Anemona sulcata*
III.18 Mussel *Mytilus edulis* (Mollusca, Bivalvia)

Sandy beach

III.19 Example of a sandy beach (Oostduinkerke) with a very broad intertidal zone and a number of distinct gullies (depressions parallel with the water edge, which are filled with water during longer periods) and ridges
III.20 Driftline on sandy beach
III.21 Wave breaker on sandy beach: origin of microhabitats

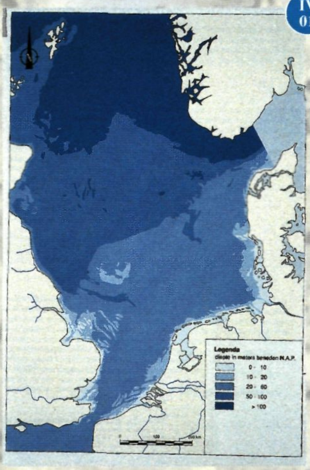
IV. The benthos of the North Sea, SANDBANKS AND FRONTAL ECOSYSTEMS



1. General introduction

The North Sea **(slide IV-01)** can be considered as a shallow, continental sea, constricted by the coastlines of the UK, Norway, Sweden, Denmark, Germany, the Netherlands, Belgium and France.

IV 01



The North Sea is connected with the Atlantic Ocean with an open connection in the north and through the English Channel in the south and with the Baltic Sea in the east. Its depth generally increases towards the north till a maximum of about 200 meter is attained. The maximal depth of the Southern Bight of the North Sea, which is the zone between the Doggerbank and the English Channel, is only 70 meter.

The North Sea is an area with intensive anthropogenic activities, rich in natural resources and surrounded by dense populated countries. These facts imply high stress on the marine ecosystem.

The Southern Bight of the North Sea and more specific the Belgian, Dutch, German and English coasts do not differ at all. The Southern Bight can be regarded as the center of heavy commercial activities, directed to the exploitation of mineral (oil, gas, gravel, etc.) and living (fish, etc.) resources, transport (pipelines, commercial shipping, etc.), infrastructure activities (drilling platforms, buoys, etc.) and recreation (yachting, coastal tourism, etc.).

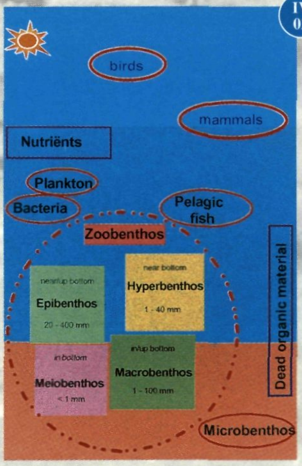
Nevertheless, some areas with extremely high ecological importance occur in the North Sea. Sandbank- and front systems are part of it.

2. The benthos of the North Sea

The marine benthos **(slide IV-02)** comprises all organisms living associated with the bottom of the sea during at least a period of their life.

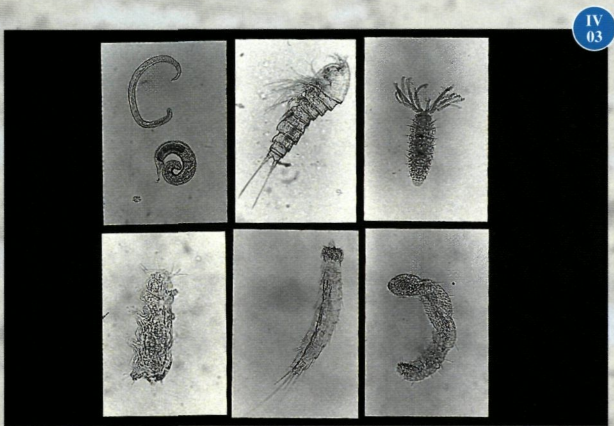
Because all living organisms have specific requirements towards the environment, the environmental conditions determine the spatial distribution of the benthos. Some of the most important environmental parameters are sedimentology, hydrodynamics, temperature and availability of food.

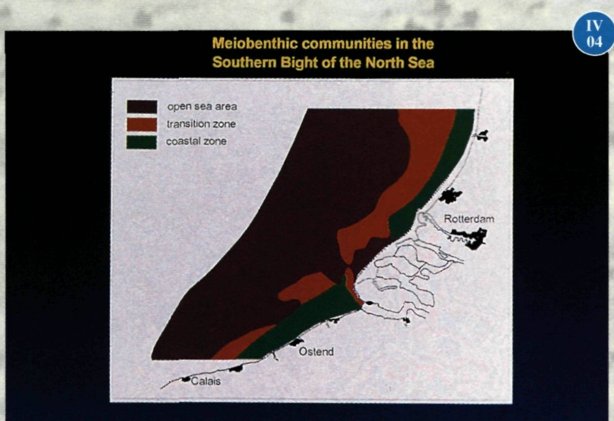
IV 02



MEIOBENTHOS

The meiobenthos consists of all organisms, living in the bottom of the sea, passing through a sieve with a 1 mm mesh size, but retained on a sieve with a 38 μm mesh size. The round worms (Nematoda) and, to a lesser extent, the copepods (Copepoda) are the most important representatives of the meiobenthos **(slide IV-03)**. By means of the distribution of the Copepoda in the Southern Bight of the North Sea, three different communities are recognized: a clearly different open sea and coastal community with a transition community in between **(slide IV-04)**.



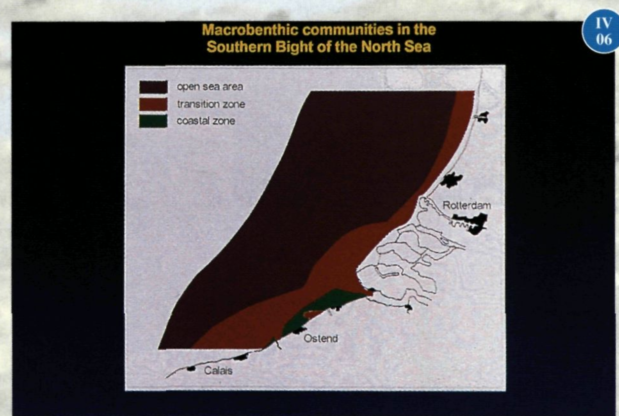


MACROBENTHOS

The macrobenthos is considered as all organisms living in the bottom of the sea and retained on a sieve with a mesh size of 1 mm. These organisms are mainly bristle worms (Polychaeta), echinoderms (Echinodermata) and amphipods (Amphipoda) **(slide IV-05)**.

The macrobenthos of the Southern Bight of the North Sea can be divided into three zones. From the coastline towards the open sea these zones are defined as (1) the coastal zone, (2) the transition zone and (3) the open sea zone **(IV-06)**. The spatial distribution of these three zones can be explained by the hydrodynamical properties of the area and more specific by the residual and tidal currents.

The coastal zone communities mainly consist of species-poor communities, with the polychaetes *Pectinaria koreni* and *Nephtys hombergii* and the bivalves *Macoma balthica* and *Abra alba* as most important representatives.



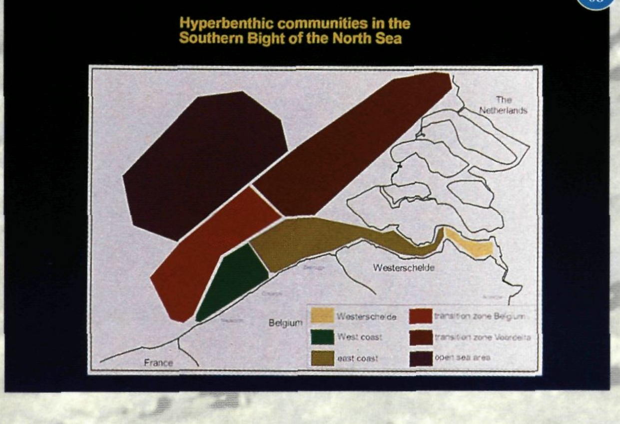
The transition zone is dominated by polychaetes, mostly *Lanice conchilega, Nephtys cirrosa, Spiophanes bombyx* and *Magelona papillicornis* and bivalves, such as *Tellina fabula* and *Abra alba*. On its part, the open sea zone is mainly characterized by the presence of a lot of polychaete worms, e.g. *Spiophanes bombyx* (over 50% of the total density), *Hesionura augeneri*, etc., but also by the presence of echinoderms, e.g. *Ophiura affinis*, and amphipods, e.g. *Bathyporeia guillamsoniana*.

HYPERBENTHOS

The hyperbenthos consists of all organisms retained on a sieve with a 1 mm mesh size and living in the lower layers of the water column. Opossum shrimp (Mysidacea), amphipods (Amphipoda), Isopoda and Cumacea are well represented in the hyperbenthos **(slide IV-07)**. On the Belgian Continental Platform four communities are identified **(slide IV-08)**: (1) an eastern coastal community, (2) a western coastal community, (3) a transition community and (4) an open sea community. Both of the coastal communities are dominated by mysid shrimp. Though, the densities and biomass of the eastern coastal community is only half of these of the western community. Next to this east-west gradient another gradient perpendicular to the coastline is influencing the hyperbenthos. A number of groups, e.g. crabs and shrimp, respectively Brachyura and Caridea, become more dominant in the transition community, while the dominance of the mysid shrimp decreases. This transition community has a density comparable with the density of the eastern coastal community, but has a lower biomass because of the high number of small, larval crabs and shrimp.

IV 07

IV 08

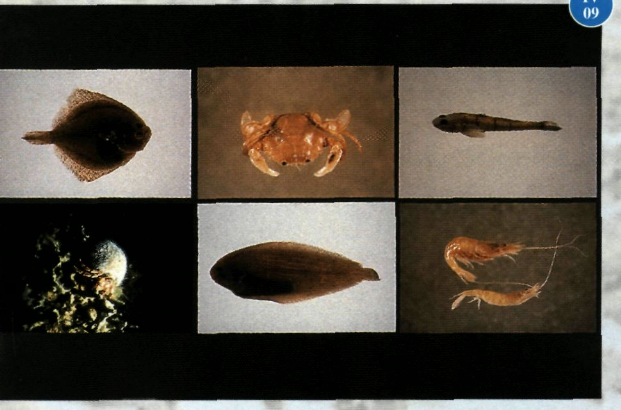


The open sea community has the lowest densities and biomass, but is the most diverse of the four communities, with Brachyura, Mysidacea, Caridea, Amphipoda, Anomura and Chaetognatha.

E P I B E N T H O S

The epibenthos is defined as all organisms living on and just above the bottom of the sea and retained on a net with a mesh size of 5 mm. Important representatives are: demersal fish (Pisces), shrimp and crabs (Decapoda) and echinoderms (Echinodermata) **(slide IV-09)**.
Although fish communities in the North Sea are not clearly geographically defined, the epibenthos, just like the meio-, macro- and hyperbenthos, shows differences in density and biomass according to the geographical situation in the North Sea. The next paragraph briefly describes (1) the spatial distribution of one epibenthic species and (2) its temporal variation caused by natality, mortality, immigration and emigration.

IV 09



Gobiid fish (Gobiidae) are an abundant family in almost all shallow seas worldwide. In the Southern Bight of the North Sea four species are found **(slide IV-10)**, e.g. *Pomatoschistus minutus, P. lozanoi, P. norvegicus* and P. *pictus*, of which P. *minutus* is very abundant up to a depth of about 40 meter.

IV 10

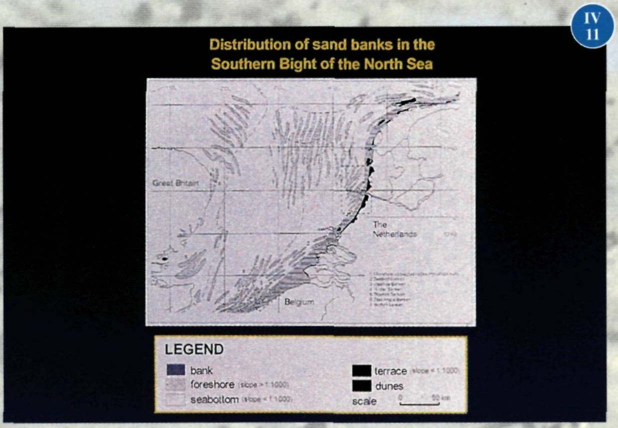
During the months April till May (1972-1973) densities from 10 to 100 individuals per 1000 m^2 were encountered between the Dutch coast and the Doggerbank. During autumn and winter higher densities (hundreds per 1000 m2) were found in the whole area. These higher densities can partly be explained by immigration out of the Waddensea and the shallow coastal zone. Though, all seasons revealed decreasing densities from the coastal zone towards the open sea.

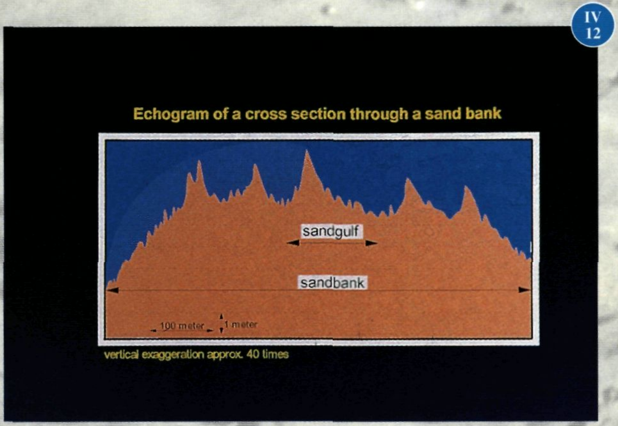
3. Unique marine ecosystems

Considering the characterization of the different benthic communities in the North Sea, a clear gradient from the coast over a transitional zone to the open sea zone can be observed. This fact creates the idea that the whole North Sea can be divided into three zones. Though, the bottom of the North Sea is not a plain where the environmental factors (sedimentology, hydrodynamics,...) only change following a gradient from the coasts towards the open sea. In this way, because of their different environmental variables, sandbanks and frontal ecosystems create variation within the benthic communities of the North Sea.

S A N D B A N K   S Y S T E M S

PHYSICAL FEATURES: The occurrence of a lot of sandbanks is a remarkable characteristic of the bottom of the Southern Bight of the North Sea **(slide IV-11)**. These sandbanks have a width of 1 to 3 km and a length of 10 to 60 km. Their height varies from about 3 tot 40 meter. A cross section of a sandbank **(slide IV-12)** often reveals an asymmetrical profile with a gentle and a steep slope. According to their geographical position and orientation the sandbanks can be grouped into different sandbank complexes. On the Belgian Continental Platform four of these sandbank complexes can be found: (1) the Coastal Banks, (2) the Flemish Banks, (3) the Hinder Banks and (4) the Zeeland Banks.

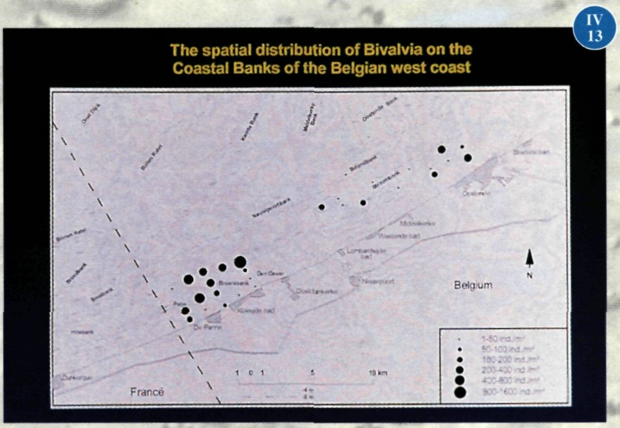




Typically, strong currents, up to 1.4 m/s, occur on the sandbanks. Consequently, these areas are highly dynamic especially when considering sediment transports. Although these sediment transports cause a movement of big 'sand waves', the general morphological features of a sandbank remain quite stable in time.

ECOLOGY: The ecological importance of sandbank ecosystems is clearly demonstrated by the presence of big concentrations of seabirds. On the Belgian Coastal Banks for instance high numbers of wintering common scoters (*Melanitta nigra*), up to 16000 individuals, together with lots of great crested grebes (*Podiceps cristatus*), guillemots (*Uria aalge*), divers or loons (*Gavia* spp.), etc. can be observed. Two reasons for the high number of seabirds on sandbanks are (1) the low degree of shipping because of the shallow environment and, maybe even more important, (2) the presence of a lot of food for the seabirds.

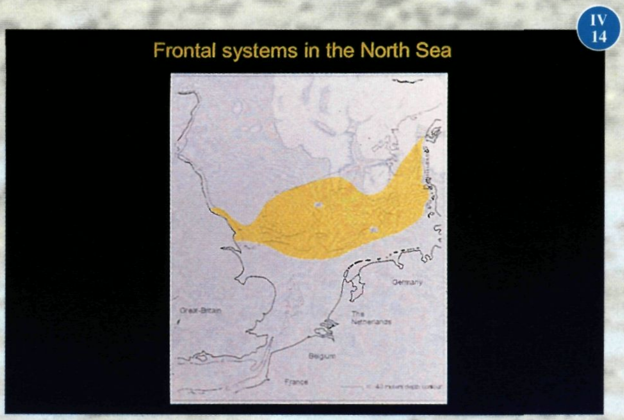
On the western Belgian Coastal Banks areas extremely rich in shellfish (Bivalvia) occur. These shellfish, e.g. *Spisula subtruncata*, can be found in shallow waters in densities up to some hundreds individuals per meter square **(slide IV-13)**. 95% of the diet of the Common scoter is composed of shellfish. Therefore, the western Belgian Coastal Banks are an exquise, quite and food rich, wintering area for the Common scoter. The presence of grebes, guillemots and divers, feeding on pelagic fish in the open sea, but also with epi- and hyperbenthos in shallow environments, indicates towards a rich epi- and hyperbenthic life.



F R O N T A L   S Y S T E M S

PHYSICAL FEATURES: In the North Sea two main residual currents can be found: (1) a northeastern directed current coming out of the Atlantic Ocean, passing the English Channel towards the Southern Bight and (2) a southeastern directed current coming out of the northern Atlantic Ocean and passing Scotland and the eastern English coastline. This last residual current is also bent towards the northeast when reaching Norfolk. The border between the two masses of water (fronts), with different salinity and temperature, can be observed between Norfolk and the Skagerrak crossing the whole North Sea **(slide IV-14)**.

Also bottom texture is influenced by the currents. Generally sandy sediments occur in the Southern Bight of the North Sea: the highly turbulent water disables the suspended, finer materials in the water column to settle. When transported in northeastern direction by means of the residual currents this suspended material settles down as soon as the water current slow down enough. That is how the mud plume, derived from the eroding

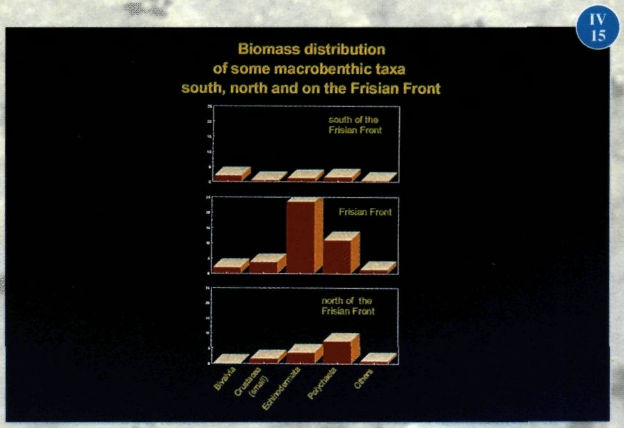


Norfolk coastline, disappears. This site is called the Frisian Front, just north of Texel (the Netherlands). Consequently, the bottom at that site is very rich in mud and organic materials (nutrients). Following this organic enrichment a rich benthic life, with a clear zonational pattern following the depth lines, is encountered.

ECOLOGY: To present more information about the ecology of frontal systems the well known and described Frisian Front, north of Texel, has been chosen as an example.

Because of the bottom rich in nutrients, a very high primary production can be observed at the Frisian Front. Even during generally nutrient poor summer periods peaks of primary production can be shown. This high primary production is caused by two factors: (1) by the release of nutrient from the bottom to the water column and (2) by mixing of the two different masses of water, when the limiting factors for primary production are differing. Copepods(Copepoda) are dominant when considering the zooplankton, but during spring the water column contains a lot of planktonic larvae of bottom dwelling organisms, such as bristle worms, and in summer larvae of echinoderms and herbivores, such as *Oikopleura* are dominantly present. Macroplankton peaks, dominated by a variation of organisms going from fish larvae to sea-gooseberries (Ctenophora), can also be observed. The differences in species composition between the two sides of the Frisian Front are another remarkable feature.

The macrobenthos of the Frisian Front is special for its density, biomass and species composition **(slide IV-15)**.



The bottom linked to the front, which is rich in nutrients, is characterized by high densities of consumers of organic material, such as the brittle-star (*Amphiura filiformis*) and the white furrow shell (*Abra alba*). Consequently, the biomass of macrobenthos at the front is considerably high. Next to this fact, the Frisian Front can be considered as a transition between northern and southern macrobenthic communities. The number of epibentic species, such as dab (*Limanda limanda*), swimming crab (*Liocarcinus holsatus*), and seabirds, feeding on this epibenthos, are considerably higher at the Frisian Front in comparison with the surroundings.

4. Some anthropogenic 'stress' factors

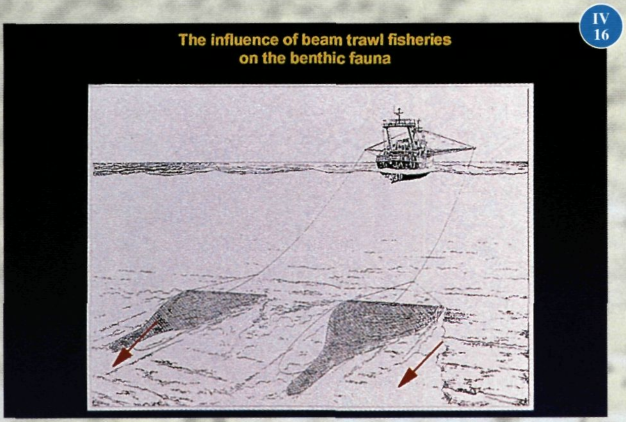
Besides the spatial distribution of benthic communities, as mentioned above, the variation within time is an important phenomenon for every benthic community. Natality and mortality are thought to be of prime importance for the natural temporal variation. In addition to these natural variables, anthropogenic impacts, including eutrophication, pollution and physical disturbance by dredging or fishing activities, may have a substantial influence on the benthic communities. Particularly coastal areas are subject to pollution, mostly caused by suspended material discharged from rivers.

F I S H E R Y

Despite the rather small dimensions, the North Sea forms one of the important fishery areas of the world, taking into account the high productivity and fish catches.

Fishing will influence directly the fish communities. The catches of plaice (*Pleuronectes platessa*), which is a commercially exploited demersal fish species, amounted to 110.000 to 170.000 ton in1990-1994, three times higher compared to the catches of 1910-1930. A more intensive fishery started in the early nineties and resulted in the collapse of the plaice communities. Similar situations could be recognized for other fish species as well and led to the formulation of fish quota.

Fishery can not only cause serious damage to non-exploitable demersal fish communities, but may also effect benthic communities drastically, e.g. through fishing by beam trawls **(slide IV-16)**, the sea floor is plugged up by tickler chains up to 10 cm depth. As such, all organisms that live in the upper layers of the sediment (meio-, macrobenthos) will be dug up, washed through the net and will consequently sink to the bottom with the turbated sediment. If not too damaged, for some organisms it is possible to burrow and re-establish into the bottom, however their chance to survive will be species dependent, e.g. some bivalves, which are enclosed by



strong valves, will have a significant higher chance to survive compared to sea-potatoes (Echinodermata: *Echinocardium cordata*), surrounded by fragile chalk tests, or bristle worms (Polychaeta), which are lacking any skeleton. Moreover, every square meter of the North Sea sea floor is turbated by beamtrawls once a year while the Belgian coastal zone is trawled more than 10 times a year. These figures stress once again the impact of the beam trawl fishery on the benthic communities.

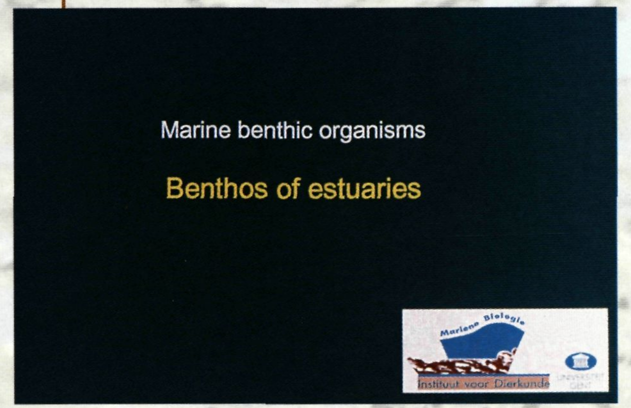
SAND EXTRACTION

The extraction of sand on the Belgian and Dutch coastal zone has doubled within the period of 1985 to 1990 and has reached final values of 1.000.000 and 10.000.000 m^3/year respectively, which proves the importance of mineral sources in the North Sea. Nowadays, several sandbanks on the Belgian Continental Flat are still being dredged in order to gain sand and gravel for different purposes e.g. building industry, land reclamation, raising of beaches, ... The impact of dredging on the sandbank ecosystems is translated through the loss of habitat for the benthic organisms. The organisms, together with the sediment in which they live are transferred to dredging ships and dumped in a different area where re-establishment is occasionally possible if not too damaged (see above). The impact of dredging on the sea floor is also significant in terms of morphology and structure of the bottom and composition of the sediment. By pumping up sediment, fine material suspended in the excess water will arrive in the seawater and deeper original sediment layers will be exposed. This will result firstly in turbid waters, which makes breathing for filter feeders impossible as their respiratory system will blocked up. Secondly, the changed and disturbed sediment can be inconvenient as a habitat for the original community and will inevitably lead to dead.

LIST OF SLIDES

BENTHOS OF THE NORTH SEA, SANDBANK- AND FRONTAL ECOSYSTEMS

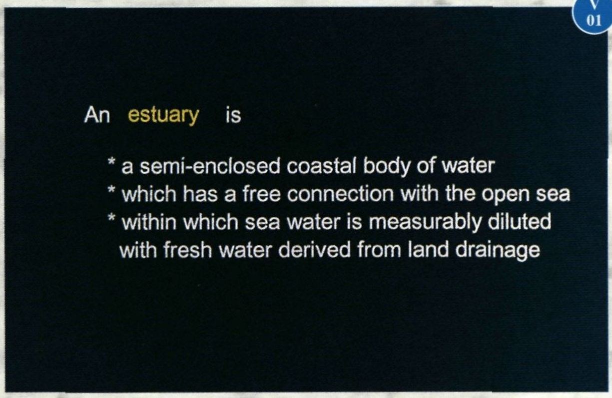
V. The benthos of ESTUARIES



1. Definition

An estuary is a coastal semi-enclosed water body in open connection to the sea **(slide V-01)**.Within an estuary seawater is measurably diluted with freshwater that runs off from terrestrial locations. Generally spoken, an estuary is the downstream stretch of the river before the latter flows into the sea. Here tidal impact can be observed and a gradient from fresh, over brackish to seawater exists. Locally, examples of estuaries can be found at the mouth of the River Yser and Schelde (Westerschelde-Zeeschelde).

V 01

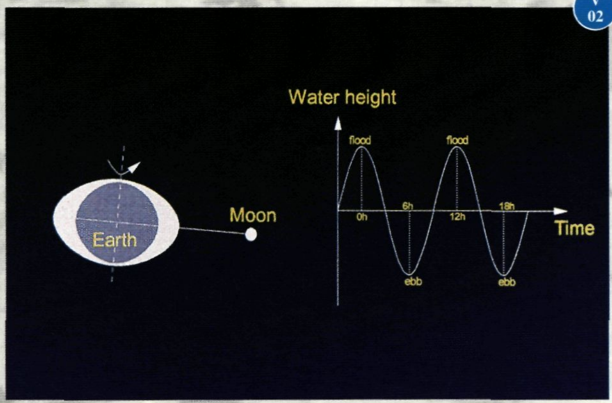


2.Estuarine gradients

Tidal movement

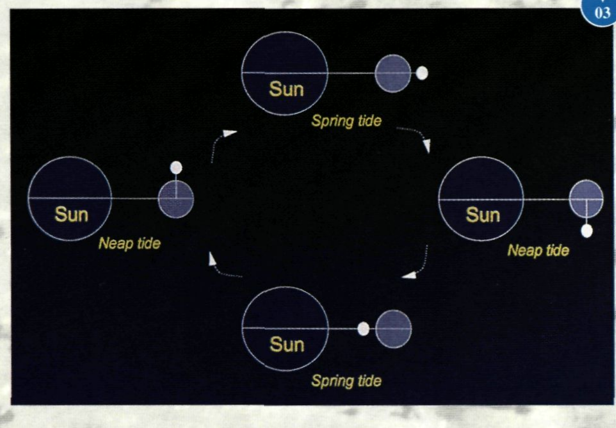
The tidal cycle is generated by the earth's axial rotation **(slide V-02)**. As a consequence of the moon's gravitation

V 02

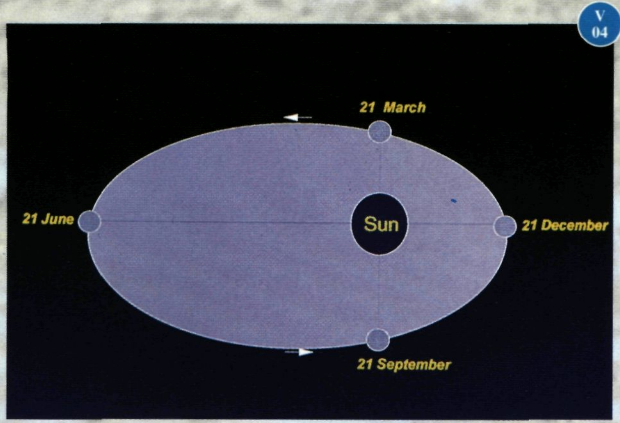


water masses on the earth's surface are attracted and the level of seas and oceans is raised (flood -high tide) and reduced again six hours later (ebb -low tide). A new cycle takes off every 12 hours. The height of the tides is determined by the position of moon and sun with respect to the earth **(slide V-03)**. When sun and moon are in line

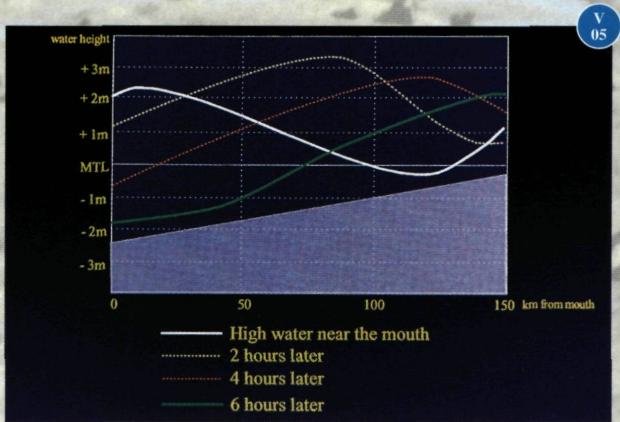
V 03



with the earth (new moon and full moon) the highest floods and lowest low tides are measured (spring tides). Then .the relative position of the moon to the sun will change gradually and their gravitations will start to work against each other. Approximately seven days later lowest high tides and highest low tides are observed (neap tides), resulting in a cycle of 15 days. Moreover spring tide elevation will also be influenced by the distance sun-earth **(slide V-04)**. Particularly the spring tides around March 21st and September 21st can produce very high water levels. During stormy weather when the wind blows the water into the estuary there is a risk of floods in the areas outside the dikes.

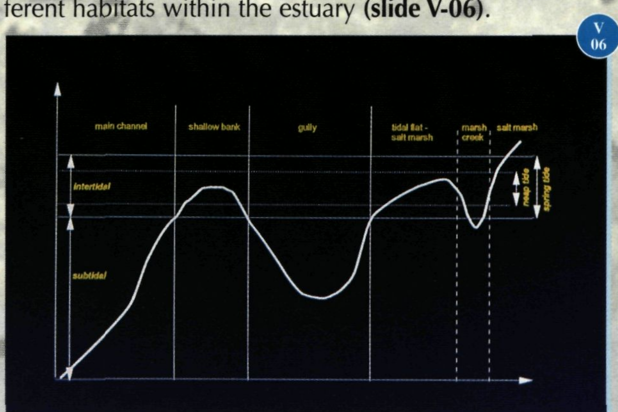


The tidal movement generates a wave of seawater entering the mouth of the estuary and pushed into the river **(slide V-05)**.



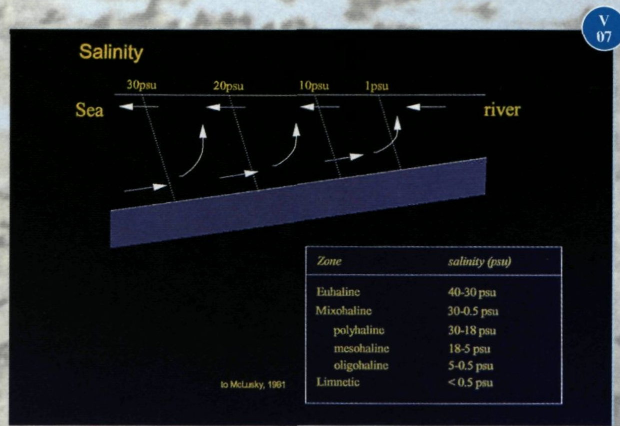
Consequently high tides occur a few hours later upstream than in the mouth, and go down in the mouth when the highest elevation is attained upstream.

At the mouth an estuary is wide and relatively deep, gradually becoming narrower and shallower upstream. Since the same watermass enters a channel with a smaller volume, the tidal wave is raised and high tides increase gradually until a maximal elevation is reached. Because the water loses part of its energy (by friction) tidal levels go down further upstream. By means of a cross section one can demonstrate the importance of the tidal impact for different habitats within the estuary **(slide V-06)**.



The deepest areas, called gullies, are permanently submerged. Shallows and tidal flats however do emerge during low tide and are covered during high tides twice a day. Here the dynamics of sediment transport prevent plants to grow. Salt marshes on the other hand are more elevated as a result of sedimentation and as a consequence less subject to tidal forces so that several plant species can settle here. Salt marshes are characterised by a network of creeks allowing the estuarine water to enter and leave the area on a daily base. The more elevated parts are inundated during spring and storm tides only.

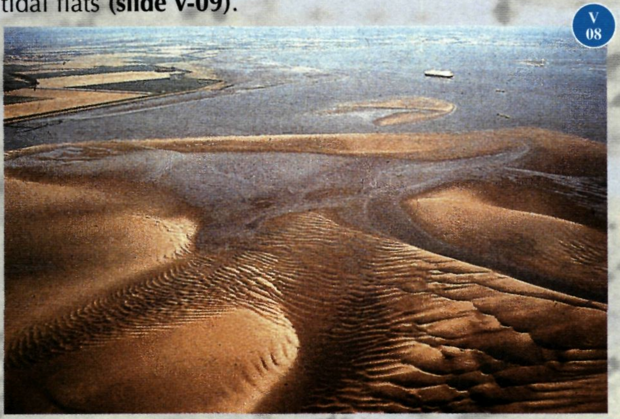
S a l i n i t y
(slide V-07)



Salinity is a measure of the amount of salts (in grams) per litre, expressed widely *in practical salinity units* or 'psu'. Seawater has a salinity of 35 psu, freshwater is defined as water with a salinity less than 0.5 psu. Rainwater runs into the river and mixes with seawater pushed into the estuary from the seaward side. This gradual mixing results in a salinity gradient. Water with a salinity between 35 and 0.5 psu is called brackish or mixohaline water. An estuary can be divided into different zones according to the ruling salinity (see table on slide). The salinity observed on a specific location is influenced by: 1) the tidal cycle: during flood salt water enters the estuary and maximal salinities are observed; minimal salinities are found during ebb tides, 2) the elevation and tidal amplitude vary throughout a cycle of 28 days and determine the amount of seawater entering the estuary: maximal salinities are measured during spring tides, minimal values at neap tide. Wind direction and force can also alter the tidal amplitudes: stormy weather will push the tidal wave further upstream, 3) seasonal variations in salinity occur due to fluctuations in river water discharge. In summertime when run-off is low, highest salinities are found. As a consequence waterbodies of different salinity will move throughout the estuary resulting in a very dynamic system. The gradient in salinity is the most characteristic one of estuaries and superimposes other abiotic and biotic gradients. Plants and animals must be adapted to these ever changing conditions.

Estuarine sediments

Sediment particles in an estuary are imported both from the river and the sea. Within the estuary fine particles start to accumulate and sink to the bottom. In the seaward part of the estuary where strong currents occur, only coarse sediment particles will settle (coarse and fine sand). At the mouth of the estuary extensive tidal flats and shallows will be found **(slide V-08)**. Finer particles (clays and silts) are transported further upstream and settle where current velocities are much lower, resulting in silty tidal flats **(slide V-09)**.



Turbidity
(slide V-10)

Huge loads of suspended sediments make estuaries look very turbid. In addition to sediment particles many other particles are transported in the water column. This seston comprises living (bacteria, fungi, phytoplankton and zooplankton) as well as dead material (transported by river or sea, but also bottom particles eroded locally and dead material form animal or plant origin).
In the oligohaline region where freshwater and seawater meet, suspended particles will flocculate, and a maximum turbidity zone can be observed. Further downstream and upstream turbidities are reduced.

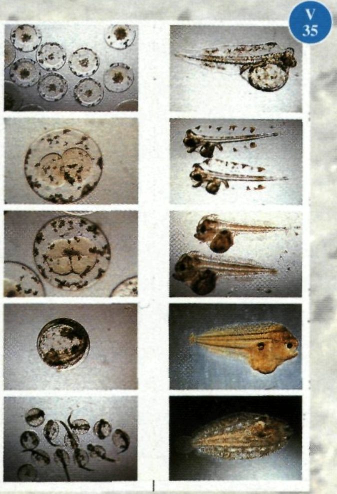
Nutrients, oxygen and temperature gradients

Nutrients (phosphates, nitrates and silicates) are more abundant in riverwater compared to seawater. Therefore one can observe a gradual decline in nutrients within the estuary when going downstream.
Oxygen (gas dissolved in water) enters the estuary with water from the river and the sea and a substantial local oxygen production by plants occurs in the estuary. However oxygen dissolved in the water column and the interstitial water (within the sediments) is depleted rapidly by living creatures.
River water, naturally rich in organic material, is often polluted with domestic and industrial organic loads. The organic material entering the estuary is processed by bacteria and other micro-organisms, requiring a lot of oxygen in this process. Oxygen deficiency is most common in summer when water temperatures are highest (the higher the temperature, the smaller the amount of oxygen that can dissolve in water). Also within the sediments oxygen is easily depleted (anoxic sediments). Only the top few millimetres remain oxic often reflected in a brown greyish colour, in contrast with the deeper, anoxic, black sediment.
The water temperature in an estuary is affected by the temperature of seawater and river water. Freshwater has a wider range in temperatures than the buffered seawater. In summer the river water is warmer resulting in a reduction in temperature when one goes downstream, in winter it's the other way around. Thermal pollution (e.g. by discharge of 'warm' cooling water of nuclear plants) can disrupt these patterns in winter time.

Estuarine organisms

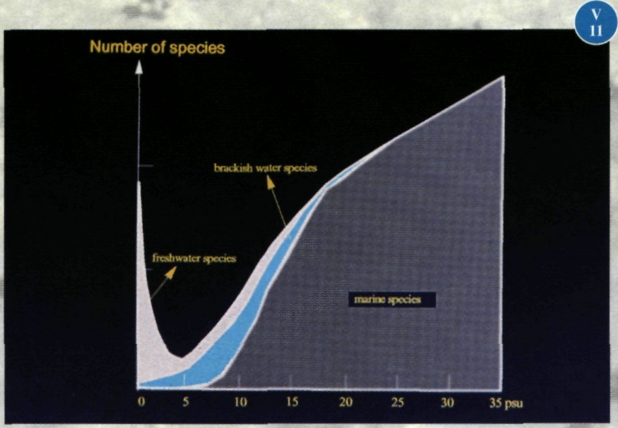
Salinity determines which organisms can occur in a defined area of an estuary. Therefore we can divide plants and animals into different categories:
Oligohaline organisms. These organisms can tolerate salinities of 5 psu, in contrast with many real freshwater species that will not survive values higher than 0.1 psu

Estuarine organisms are characteristic for the middle stretch of estuaries and are adapted to ever changing conditions in this highly dynamic system.
Euryhaline and stenohaline marine organisms are plants and animals that normally occur in the sea, but can survive under lower salinities (euryhaline marine organisms up to ca. 18 psu; stenohaline marine organisms up to 25 psu).
Migrants: some organisms will live only part of their life cycle within an estuary. The estuary is used by these species as a feeding area, as a nursery or a shelter. Estuaries are very productive in terms of food supply and these shallow areas do not harbour many predators, making these grounds very attractive as a stop-over.
An example is the sole (*Solea solea*) entering the estuary as egg or larva, and growing up here thanks to the generous food supply. At a certain length soles migrate to the sea where they will reproduce **(see slide V.35)**.



An estuary can also be used as a migration route for diadromous fish. Anadromous species will enter the river for the sake of reproduction (examples are: lamprey *Lampetra fluviatilis*, twaite shad *Alosa fallax* and salmonids *Salmo spec.*). Catadromous fish are freshwater species that reproduce in seawater (eg. eel *Anguilla anguilla*).

All estuaries show a characteristic biotic gradient **(slide V-11)**:



from the mouth onwards, species richness (or diversity) will decrease in upstream direction. Near the mouth and in the polyhaline region we find a high species diversity in planktonic as well as in benthic organisms Each species will occur in relatively small numbers. In the mesohaline part fewer species will be found, adapted to the ever changing conditions, characteristic in this zone. These species dominate and can become very abundant. In the oligohaline and limnetic zone the number of species will increase again.

Estuarine food-chains

At the mouth and in the polyhaline zone of an estuary the water is not all that turbid so that light can penetrate rather deep into the water column. The phytoplankton, consisting here mainly of large diatoms, will flourish. Additionally phytoplankton from onshore waters will enter the estuary. On shallows and tidal flats that emerge during low tide, microscopic algae will grow and reproduce in the sediments (phytobenthos). The phytoplankton and the phytobenthos are the primary producers in the estuarine food web.
In the brackish area the water is very turbid and light can not penetrate easily. In spite of the high nutrient concentrations, photosynthesis is prevented and the food web will be based - in contrast to the polyhaline zone - on the supply of decaying organic matter (detritus). This detritus is partly consumed by animals and to a large extent broken down by bacteria. These bacteria are the food source for many micro-organisms, that lay the foundation of an entire food web.
Upstream in the tidal freshwater part of the estuary a third type of food web occur, based on production of freshwater phytoplankton (mainly small diatoms, cyanobacteria, green algae and flagellates).

3. Example: the Schelde estuary (slide V.12)

The Schelde estuary is the most popular estuary near the University of Gent. It has an important economical function with a lot of shipping traffic to the port of Antwerpen, a concentration of industry and fish and shrimp catching activity. The River Schelde has its source in France (St-Quentin), runs through Belgium and flows into the North Sea off the Dutch Delta area. The three large European rivers, the Schelde, the Rhine and the Meuse, flow together and form a delta towards the North Sea.This Delta area has been the scene for major changes due to human activities: after a huge flood in 1953 three out of four sea arms were closed and dikes were built to prevent further flood disasters. The estuary of the Schelde is the only remaining river mouth that is still subject to the tidal movements of the North Sea.

From the mouth to the Belgian-Dutch border the estuary is called the Westerschelde, further upstream up to Gent it is called the Zeeschelde. The estuary can be divided in three successive zones: 1) The marine zone has a length of 70 km (Vlissingen to Walsoorden). In the mouth we can find two big gullies separated by shallow flats. 2) The central zone (Walsoorden to the mouth of the river Rupel) has a length of 50 km and is characterised by extensive brackish tidal flats and salt marshes, with the 'Verdronken Land van Saeftinge' as the biggest salt marsh of western Europe. The salt wedge (i.e. the salt water entering the estuary with the tides) can be observed until the area upstream Antwerpen. 3) The tidal freshwater area is the most upstream part of the estuary, situated between Gent and Rupelmonde. Here salinity is always lower than 0.5 psu (freshwater) and tidal impact is noticeable. The freshwater tidal flats and marshes are invaluable and rare habitats on a western European scale. Near Gent the river is stemmed by a weir, blocking any further tidal impact. At a distance of 160 km from the mouth of the estuary, the tidal amplitude is still substantial amounting to 1.96 m.
The water quality in the river Schelde and the Zeeschelde is extremely poor and improves gradually towards the Westerschelde. Huge loads of domestic and industrial waste is discharged into the water. The dissolved oxygen concentrations upstream the Belgian-Dutch border are very low due to the high organic pollution of the river. Recently the water quality is slightly improving thanks to an increased effort in waste water treatment.

4.Different habitats for benthic organisms

Note: In the following chapter examples will be given for the Westerschelde-Zeeschelde system. However this estuary has a limnetic zone with an impoverished benthic fauna due to low oxygen concentrations in the water column. Only few species are found here, a situation rather atypical for other western European estuaries.

Gullies

HYPERBENTHOS

The hyperbenthos of estuaries is dominated by mysids (Mysidacea) and amphipods (Amphipoda). In addition to the permanent hyperbenthic species, other species belonging to the temporal hyperbenthos can be encountered in certain periods of the year : larvae of crabs, fish and shrimp.
In a 'healthy' system three hyperbenthic communities can be distinguished along the estuarine gradient. Near to the sea in the marine part, the species richness is highest and densities are lowest. Mysids are represented here by *Schistomysis kervillei* **(slide V-13)**, *Schistomysis spiritus* **(slide V-14)** and *Gastrosaccus spinifer* **(slide V-15)**; the isopods present here include *Idotea linearis* **(slide V-16)**, *Eurydice pulchra* **(slide V-17)** and *Sphaeroma rugicauda* **(slide V-18)**. In addition many amphipods such as *Melitta obtusata* **(slide V-20)** are found. In certain months of the year larvae of many crabs **(slide V-20)** and fish **(slide V-21)** are abundant in the hyperbenthos.
In the brackish part turbidity is maximal preventing sunlight from penetrating far into the water column and restricting algal production. Moreover salinities can fluctuate widely. Under these harsh conditions few species will survive, but a few brackish water species are abundant, feeding on dead organic material. Characteristic species are the mysids *Mesopodopsis slabberi* **(slide V-22)** and *Neomysis integer* **(slide V-23)**. During certain months one can also find many larvae of plaice *Pleuronectes platessa* in the hyperbenthos **(slide V-24)**.
Finally the hyperbenthic community of the low-saline, less turbid area is characterised by a moderate species richness and relatively high densities. We find *Neomysis integer* **(slide V-23)** in large numbers and the amphipod *Gammarus zaddachi* **(slide V-25)**. Larvae of the Common goby *Pomatoschistus microps* are temporal inhabitants of this zone.
The hyperbenthos of the freshwater tidal system has not been studied so far.

A study and comparison of the hyperbenthic fauna of several West-European estuaries (Schelde: NL-B, Elbe: G, Eems-Dollard: NL-G and Gironde: F) revealed following results:
In all systems except the Schelde, three hyperbenthic communities are found. Only in the Schelde the low saline community is absent due to oxygen depletion caused by the bacterial activity and breakdown of organic material. A gradual improvement in water quality will probably restore this community in the future.

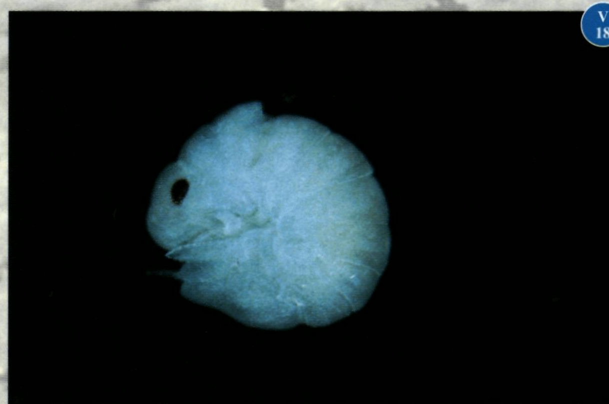
V 13

V 14

V 15

V 16

V 17



V 18

V 19


V
20


V
24


V
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V
25


V
22


V
26


V
23


V
27

E P I B E N T H O S

In estuaries at the latitude of the Schelde estuary one can expect about 75 epibenthic species. In the heavily polluted Westerschelde only 40 species are found. Particularly the freshwater species and the diadromic fish have disappeared due to oxygen deficiency in the Belgian part of the estuary.
In temperate areas one can find a correlation between species richness and the density at one hand, and sediment type, food availability and salinity on the other hand. Highest numbers are found on silty bottoms (low current velocities, mostly brackish water), while the number of species is higher in the more saline (and sandier) parts of the estuary. The most important estuarine epibenthic species are shrimp (e.g.: the common shrimp *Crangon crangon*: **slide V-27**), crabs (e.g.: the shore crab *Carcinus maenas* and the Swimming crab *Liocarcinus holsatus*: **slide V-28**), flatfish such as plaice (*Pleuronectes platessa*: **slide V-29**), dab (*Limanda limanda*: slide **V-30**), sole (*Solea solea*: **slide V-31**) and flounder (*Pleuronectes flesus*), gobies **(slide V-32)** such as the common goby *Pomatoschistus microps* and the sand goby *Pomatoschistus minutus*, Clupeidae **(slide V-33)** like herring (*Clupea harengus*) and sprat (*Sprattus sprattus*) and Gadidae **(slide V-34)** such as bib (*Trisopterus luscus*) and whiting (*Merlangius merlangus*).
The epibenthos can be divided into functional groups, depending on their temporal distribution and feeding strategy. In autumn and winter the Westerschelde is characterised by permanent estuarine and overwintering species, while the estuary holds mainly juvenile individuals during spring and summer. The estuary acts as a nursery ground for many young organisms thanks to the rich food supply and shelter (examples: in May young sole: **slide V-35**, in June young herring and sprat).

S h a l l o w s a n d t i d a l f l a t s

Shallows are raised sandy areas in the estuary that emerge during low tide. They are most frequent in the marine and middle part of the estuary. During flood, water flows at high current velocities over these shallows. They are composed of coarse sandy sediments with sand ripples and (sometimes) mega ripples. Few benthic invertebrates can survive in these hostile environment. At the edges of the shallows current velocities are reduced and silty, flat areas occur that are much more favourable for sediment dwelling organisms.
Tidal flats along the edges of the estuary emerge during low tides. They consist mainly of sediments rich in fine silts in the brackish and freshwater part and become increasingly sandy towards the mouth of the estuary. On the most elevated parts of the tidal flats a few plant species can persist: glasswort Salicornia europea and rice-grass Spartina townsendii in the mesohaline and polyhaline zones and sedges in the oligohaline and freshwater areas.
Animals living in the sediment must be adapted to temporal exposure of the bottoms they are living in. When the water retreats at ebb tide a certain amount of interstitial water will remain in between the sand grains. This water is subject to large temperature and salinity fluctuations, depending on weather conditions. When the sun shines temperature can rise tremendously and salinity will increase due to evaporation of interstitial water (up to 80-125 psu).When it rains interstitial water is being diluted and salinity can drop drastically. Macro- and meiobenthos living in these sediments must be adapted to these extreme conditions.

M A C R O B E N T H O S
(slide V-36)

The species richness of the macrobenthos of the Schelde estuary decreases when one moves upstream from Vlissingen to Dendermonde, while less polluted estuaries show a recovery in the limnetic part. In the polyhaline and mesohaline zones several species can be found such as : *Pygospio elegans, Nereis diversicolor* (the ragworm) and *Macoma balthica* (the Baltic tellinid). The edible cockle *Cerastoderma edule* and the polychaetes *Arenicola marina* (the lugworm), *Eteone longa, Nephtys hombergii* and *Capitella capitata* are found almost exclusively in the marine part of the estuary. In the lower saline part the amphipod *Corophium volutator* and the polychaete *Heteromastus filiformis* and *Polydora ligni* are dominant. The oligohaline and freshwater tidal part of the Zeeschelde is very poor in terms of species richness, due to very low oxygen concentrations in the water column and in the sediments. Only oligochaetes ('sludge worms') are able to tolerate these anoxic conditions. Other less polluted estuaries are inhabited by larvae of insects, freshwater molluscs and small crustaceans.
Birds can be observed along the entire gradient of the estuary while feeding on the rich macrobenthos in the intertidal flats **(slide V-37)**.

M E I O B E N T H O S

Within this faunal group one can discover a characteristic estuarine gradient as found in other groups.
Brackish water communities consist of a smaller number of species than marine and freshwater communities in an estuary. Which species of meiobenthos are present in the tidal flats depend on salinity and sediment type (grain size and interstitial water volume). The coarser sediments

(polyhaline tidal flats) have larger interstitial pores with many different types of organisms. In the top layer of these sediments oxygen in the interstitial water is not a limiting factor. Silty sediments of the mesohaline, oligohaline and freshwater tidal zone however consist of small clay and mud particles that stick together and do not leave many interstitial space. Exchange of oxygen with the water column or the atmosphere is difficult. Hence anoxic conditions become dominant particularly in oxygen-deprived waters (e.g.: Schelde) and only the upper few millimetre contain oxygen. Under these extreme conditions only highly adapted organisms can survive (certain small nematodes and other species tolerant to anoxic environments). On the surface of intertidal flats and shallows a thin green or brownish film of microphytobenthos can often be observed with the naked eye. These small diatoms can serve as food for meiobenthic organisms living near to the surface. Deeper down other food sources such as bacteria and detritus associated with the sediment grains, or other meiobenthic species are harvested.

Saltmarshes

The Schelde estuary has very interesting salt arshes (e.g.: the 'Verdronken Land van Saeftinghe': **slide V-38**; and the 'Groot Buitenschoor' near the Belgian-Dutch border) and freshwater marshes (e.g.: the 'Kramp' near Vlassenbroek: **slide V-39**). In the former a typical vegetation of salt tolerant plants occur, such as Sea Club-rush, Saltmarsh-grass, Sea-blites, Sea Purslane and Reed. These plant species can tolerate either long periods of inundation with salt water, or long dry periods.

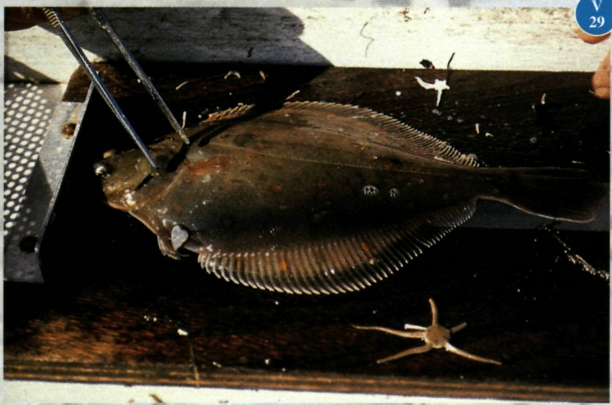
In the freshwater marshes shrubs and trees grow in addition to herbs and grasses. Most conspicuously are willows and reed. Rich marsh vegetation's are an important habitat for different bird species partly because of the difficult access. The creeks fill with water twice a day whereas the more elevated parts of the marshes will only submerge during high high tides.

The benthos of salt marshes is here described as the organisms living in the creeks and in the creek bottoms. The hyper- and epibenthos are sampled with a fyke net. It is a passive sampling technique : the net is fixed on the bottom of the creek with the entrance crosswise to the direction of incoming or retreating water. Hence all organisms present in the water column are sieved out of the water. Macro- and meiobenthos are sampled by means of cores (the benthos of freshwater marshes is not further discussed). Dominant macrobenthic species of salt marshes are the amphipod *Corophium volutator* **(slide V-40)** and several polychaete species. The burrow in the fine silt of the creek bottoms and rely mainly on decaying organic material (detritus). An important hyperbenthic species of these creeks is the oppossum shrimp *Neomysis integer* **(slide V-23**). At the onset of the flood they enter the creeks in large numbers and stay there till the end of the flood period, when they leave the marsh again. The two dominant epibenthic species are the common shrimp *Crangon crangon* **(slide V-27)** and the common goby Pomatoschistus microps, but in addition also Shore crabs *Carcinus maenas* **(slide V-41)**, juvenile bass. *Dicentrarchus labrax* **(slide V-42)**, mullets, postlarval flatfish (e.g. young flounder *Pleuronectes flesus*: **slide V-43**) and prawns.(e.g.: *Palaemonetes varians* and *Palaemon elegans*) occur.

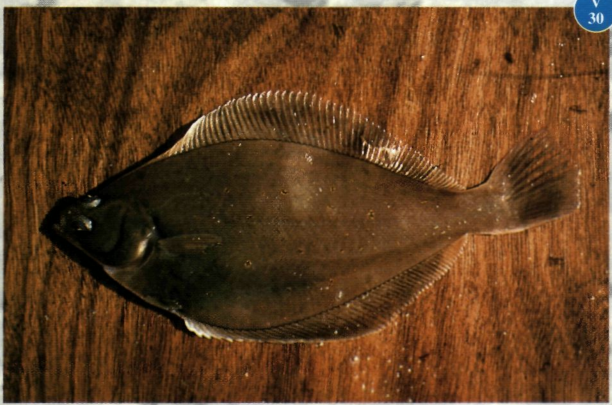
The reason for the migration of hyper- and epibenthos from the estuary into the salt marsh can be food, shelter or nursery. Larvae of common shrimp **(slide V-44)** seem to use the saltmarsh in their first twenty days of life. All individuals present in the salt marsh are smaller than 10 mm. They take advantage of the rich food supply and the shelter. Larger shrimp return to the estuary and the shallow coastal regions.

V 28

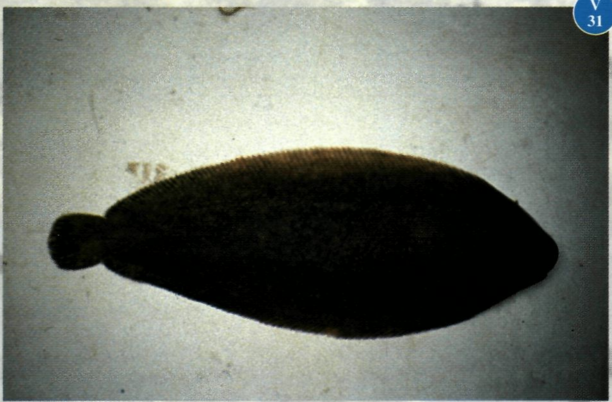
V 29



V 30



V 31



V 32

V 33

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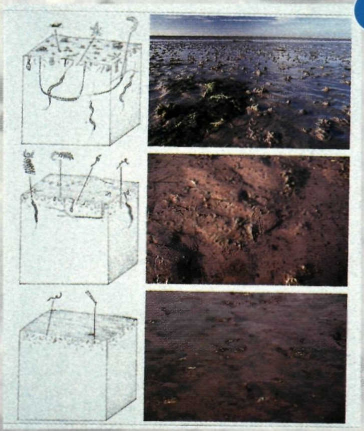
V 36



LIST OF SLIDES

ESTUARINE BENTHOS

V-00 Title
V-01 Definition: how can we define an estuary ?
V-02 Tidal movement: daily ebb- and flood cycle
V-03 Tidal movement: spring tide and neap tide
V-04 Tidal movement: seasonal impacts
V-05 The tidal movement along the length axis of the estuary
V-06 Cross-section of an estuary: gullies, shallows, tidal flats and saltmarshes
V-07 Salinity along the length axis of an estuary
V-08 Shallows with coarse, sandy sediments at the mouth of the estuary
V-09 Silty tidal flats more upstream
V-10 Turbidity along the length axis of an estuary
V-11 Species richness along the length axis of the estuary
V-12 Satellite image of the Westerschelde and Zeeschelde

The hyperbenthic community of the marine part of estuaries

V-13 The opposum shrimp *Schistomysis kervillei*
V-14 The opposum shrimp *Schistomysis spiritus*
V-15 The opposum shrimp *Gastrosaccus spinifer*
V-16 The isopod *Idotea linearis*
V-17 The isopod *Eurydice pulchra*
V-18 The isopod *Sphaeroma rugicauda*
V-19 The amphipod *Melitta obtusata*
V-20 The megalopa-larva of the shore crab (*Carcinus maenas*)
V-21 Larval stage of clupeids (*Clupeidae*)

The hyperbenthic community of the brackish part of estuaries

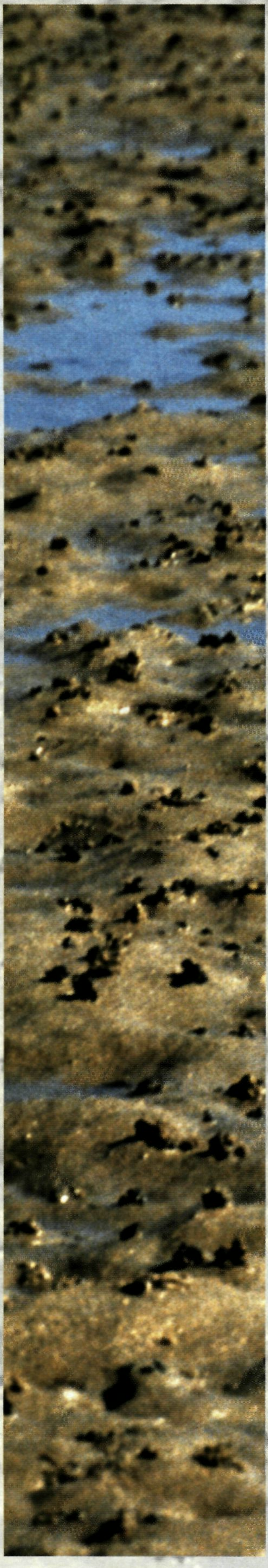
V-22 The opposum shrimp *Mesopodopsis slabberi*
V-23 The opposum shrimp *Neomysis integer*
V-24 Larvae of the flatfish *Pleuronectes platessa* (plaice)

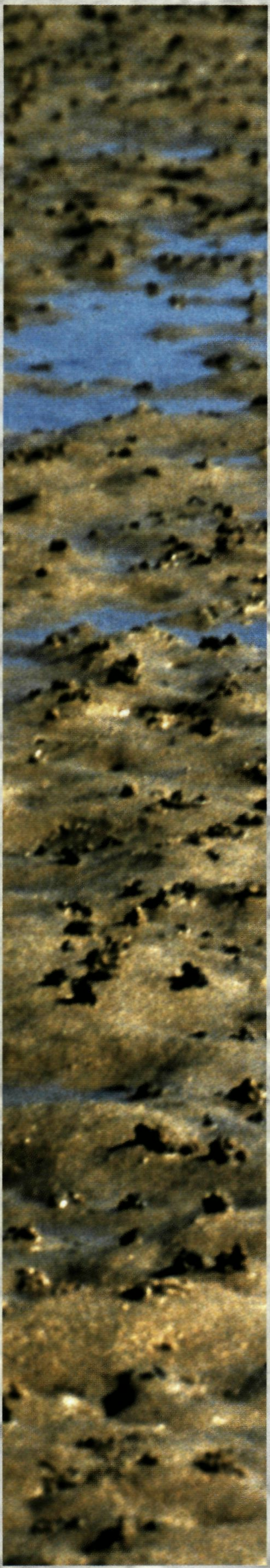
The hyperbenthic community of the low-saline part of estuaries (0-5 psu)

V-25 The amphipod *Gammarus zaddachi*
V-26 Larval stage of the common goby *Pomatoschistus microps*

The epibenthos of the Westerschelde-estuary

V-27 The adult* stage of the common shrimp *Crangon crangon*
V-28 The adult* stage of the shore crab (*Carcinus maenas* - above) and the swimming crab (*Liocarcinus holsatus* - below)
V-29 slide III-35: The adult* stage of the plaice (*Pleuronectes platessa*)





V-30 The adult* stage of the dab (*Limanda limanda*)

V-31 slide III-38: The adult* stage of sole (*Solea solea*)
(* notice that the adult stage of many epibenthic species live ON the bottom and belong to the epibenthos. The larvae and juveniles swim in the lower layers of the water column and are considered to be part of the hyperbenthos)

V-32 Gobies (Gobiidae of the genus *Pomatoschistus*)

V-33 Clupeids (Clupeidae)

V-34 Gadoids (Gadidae)

V-35 The development of the sole (*Solea solea*) from egg to juvenile fish takes place within the estuary

The macrobenthos of tidal flats in the Westerschelde estuary

V-36 The macrobenthic fauna of intertidal flats along the length axis of the estuary.
Above: the marine community very rich in species.
Central: in tidal flats of the brackish part a few species occur adapted to the strongly fluctuating environmental conditions.
Below: in the tidal freshwater flats of the Schelde estuary only oligochaetes can survive

V-37 Birds on tidal flats: the macrobenthos as an attractive food source

V-38 Aerial photograph of a brackish water saltmarsh in the Westerschelde: the 'Verdronken Land van Saeftinge'

V-39 Tidal flats and (on the background) tidal marshes in the freshwater tidal part of the Zeeschelde: the marsh of the 'Kramp' (a natural meander of the Schelde) near Vlassenbroek

The benthos of the saltmarsh the 'Verdronken Land van Saeftinge'

V-40 The amphipod *Corophium volutator*

V-41 The shore crab *Carcinus maenas*

V-42 The bass *Dicentrarchus labrax*

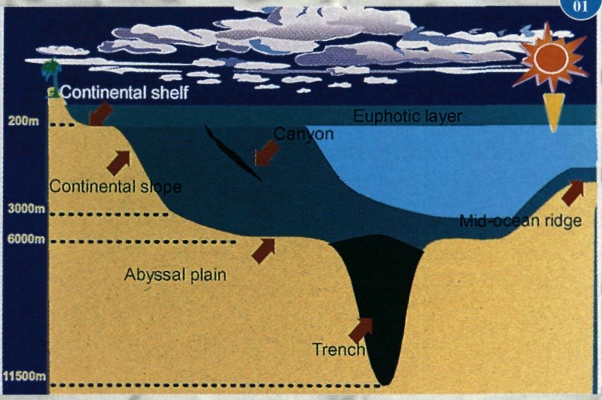
V-43 Larval stage of the flounder *Pleuronectes flesus*

V-44 The larval stage of the common shrimp *Crangon crangon*

VI. The benthos from THE DEEP SEA

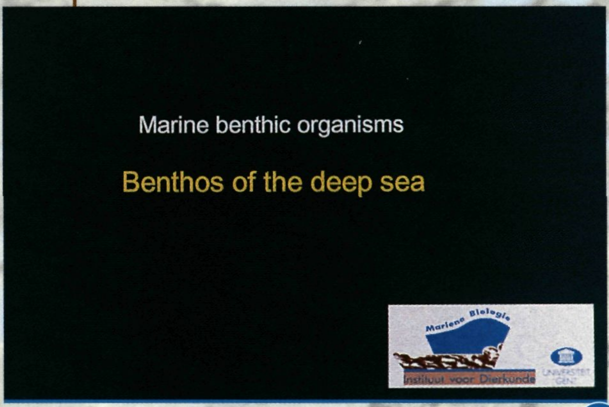
Topographical profile of the deep-sea floor

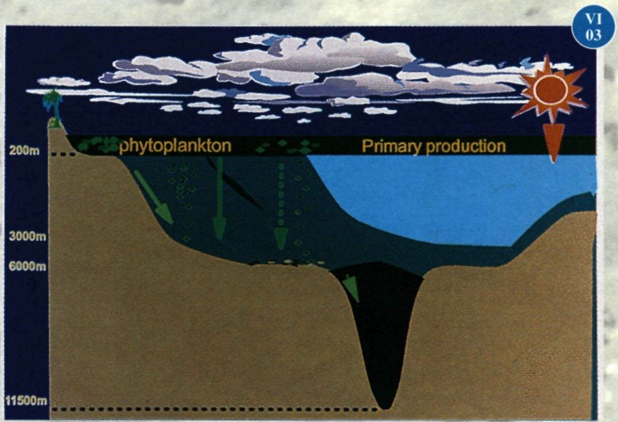
The bottom of the deep sea is subdivided into different regions according to depth : there is a continental slope, that stretches from the edge of the shelf at 200 meters depth to an abyssal plain at 4500 up to 6000 meters depth. In particular areas of the deep sea typical topographical structures are present such as canyons, trenches (up to nearly 11 500 m depth), sea mounts and mid ocean ridges **(slide VI.01)**.



Biological activity in the water column of the Atlantic Ocean

Up until the middle of this century scientists believed that the deep-sea floor was biologically very impoverished, characterized by a low numbers of specimens and a low biodiversity. Since the sunlight only reaches to a water depth of maximum 200 m (Euphotic zone), the development of microscopically small algae (the phytoplankton) is restricted to the upper layers of the water column. Because plants, as the main primary producers, form the base of nearly all food webs, life deeper down in the ocean is dependent on the flux of organic material from the overlying surface waters. In the past it was assumed that by the time the organic plant material reached the seafloor of the abyssal plains, their bacterial breakdown would already have been complete, and the material which was finally deposited at 4000 m depth, would have no energetic value. Therefore the idea arose that with exception from the upper water layers, life in the deep ocean was virtually non existent **(slide VI. - 02, 04)**.



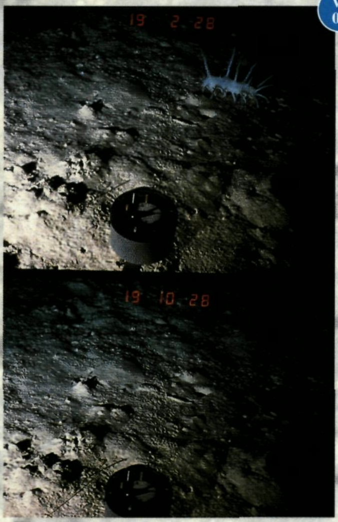


Sea cucumber Echinodermata) between relics of a rich and varied benthic life in the NE Atlantic Ocean.

Recent technological development associated with an increasing economical interest in deep-sea exploration, has stimulated deep-sea research from the early sixties. At that time it became obvious that life on the deep-sea floor was far more richer than previously thought.

Relatively high standing stocks (densities and biomass) of benthic organisms suggested a strong coupling between pelagic surface waters and the deeper benthic parts of the ocean. The organic material supplied from the euphotic zone of the water column to the deep sea was significantly higher than originally estimated. That part of the primary production that reached the seafloor at depths of 4000 m and more, proved to be sufficient to maintain a rich and diverse benthic fauna. In the early eighties it was suggested that the supply of organic material to the deep sea was often a seasonal event, linked to the processes taking place at the water surface. This was confirmed by the use of time-lapse photographical moorings, which remained for long periods of up to more than 1 year on the deep-sea floor, in order to picture the environment within a fixed time interval (e.g. every 24 h). From these photographs it could be seen that following the spring bloom, phytoplanktonic particles formed aggregates and sank much faster to abyssal depths than previously estimated. These aggregates of organic material can reach the sea floor in a period of days. They can form a fluffy mat of more than one cm height and are often described as marine snow, It is evident that deep-sea organisms behave in a particular way in response to the sudden increase in food supply **(slide VI.04)**..

VI 04



Belgium does not has a research vessel that allows deep-sea sampling at depths deeper than the upper continental slope (1000 m). Therefore Belgian deep-sea research only results from international co-operation with countries such as the UK, France and Germany supplying the necessary logistics. The average length of a deep-sea research vessel is about 100 m, and it supplies accommodation for about 50 passengers among which half are scientists. The ships needs to be stable in order to reduce the loss of expensive seatime during bad weather. Deep sea expeditions mostly take about 30 days, since the deep sea areas are often located a few days sailing offshore **(slide VI.05)**.

VI 05

Activities on board of a research vessel

Beside the basic infrastructure of all research vessels such as an accurate navigation system, and a crane to bring the sampling gear over side, deep-sea research vessels need extra equipment such as extra strong winches to support more than 10 000 m of wire. Sampling at 5000 m such as trawling, requires 10 000 m of wire in order to touch the bottom. It takes at least 1.5 hours before a piece of gear will reach the seafloor, and sampling or observation can take place **(slide VI.06)**.

VI 06

The recovery of a catch after one night trawling over the bottom at 5000 m depth in the NE Atlantic.

Larger animals living on and near the bottom of the deep sea (epi- and hyperbenthos) are sampled by trawling a net with a fixed mesh size for a few hours along a particular distance. Taking into account the mesh size, the length of the transect and the chance to escape for mobile animals , a reliable estimation of the present communities in a particular area is achieved in terms of standing stock and biodiversity **(slide VI.07)**.

Part of a catch achieved after one night trawling over the bottom at 5000 m depth in the NE Atlantic.

The deep-sea sediment consists of very fine silt particles. This results in a muddy appearance of the retrieved catch. After the net is opened, the collected material first needs to be rinsed properly, in order to start the taxonomical sorting of the sample. A first look already reveals the present biodiversity. Besides fish representing the vertebrates, nearly all higher invertebrate taxa are present in the deep sea. Echinoderms, such as seacucumbers, seastars and featherstars are very important in certain parts of the Atlantic Ocean. Especially the seacucumbers (Holothurioidea) represents high numbers and biomass. Because of the high pressure in the deep sea (increase of 1 atmosphere each 10 meters), the gas filled swimming bladder of deep-sea fish becomes extruded during decompression **(slide VI.08)**.

Seacucumbers collected at 5000 m depth in the NE Atlantic

The fact that seacucumbers are important in the deep sea is illustrated by their high numbers and biomass (up to 90 % of the total community). Seacucumbers are closely related to seastars and their name is derived from their elongated, cylindrical bodyform. They are more mobile than their appearance may suggest. They forage almost continuously, swallowing large amounts of sediments. In their gut the digestible parts are utilised while the inorganic parts are egested in their original form. In this way large amounts of sediment are reworked. Seacucumbers are therefore responsible for a large part of the bioturbation (disturbance of the micro-environment by biological activities) taking place in the surface sediments of the deep-sea floor. The second sample , only partly visible, illustrates how even the deep sea is not excluded from anthropogenic disturbance. The retrieval of coal clinkers, relics of the steam·age is not unusual **(slide VI.09)**.

Biodiversity of the deep sea

The benthos of the deep sea is characterised by a high biodiversity, which is occasionally considered comparable to the species richness of tropical rainforests and coral reefs. An explanation for this phenomena is not obvious. At first glance the monotonous, desertlike appearance of the seafloor suggests the opposite tendency. At present the heterogeneous and changing character of the food supply in time and space is considered as the most plausible explanations for the unexpected biodiversity. The retrieved sample contained two deep sea shrimp, a galathide crab, two pail anemonies, from which one is stalked, two seastars and some seaspiders, recognisable by their long, threadlike legs **(slide VI.10)**..

Giants from the deep sea

Another typical phenomena among deep-sea organisms is the tendency of gigantism. This is illustrated by these giant amphipods. Amphipods are best known as the small sandflees colonizing the stranded seaweed on beaches. Shallow water species never exceed two to three cm in length. In the deep sea, however, some amphipod species grow up to 20 cm in length. This tendency of enlarged body sizes in the deep sea was observed among several crustacean taxa, such as shrimp, isopods and amphipods. By increasing their body size, their mobility improved in accordance. In this way their foraging area is extended in order to find the rare food sources **(slide VI.11)**.

The scavengers of the deep sea

Typical deep-sea fish with extremely width mouths according with respect to their body size are most typical for open waters. On the bottom of the deep sea, fish species such as rat tails are best adapted They feed on dead animals and therefore can be considered as the scavengers of the deep-sea ecosystem **(slide VI.12)**.

Sampling the deep-sea sediments

Samples from the deep-sea sediments can be taken by means of a multi-corer. This type of gear carries 6 to 12 plexi tubes. These are pressed in the soft sediment by the heavy weight of the gear when it touches the seafloor. As the wire of the gear is stretched again by recovery, the tubes are closed automatically when leaving the bottom. In this way undisturbed sediment samples are obtained, which is an important aspect for ecological research of the soft bottom benthic communities **(slide VI.13)**.

Deep-sea sediments

The deep-sea floor consists mainly of very fine silt particles (smaller than 0.063 mm). A highly diverse benthic fauna (from micro-over meio-to macrobenthos) lives in depths of up to 10 cm within the sediment. But due to the low food supply, 90 % of the organisms live in the upper most sediment layers (upper 3 cm) **(slide VI.14)**.

VI 14

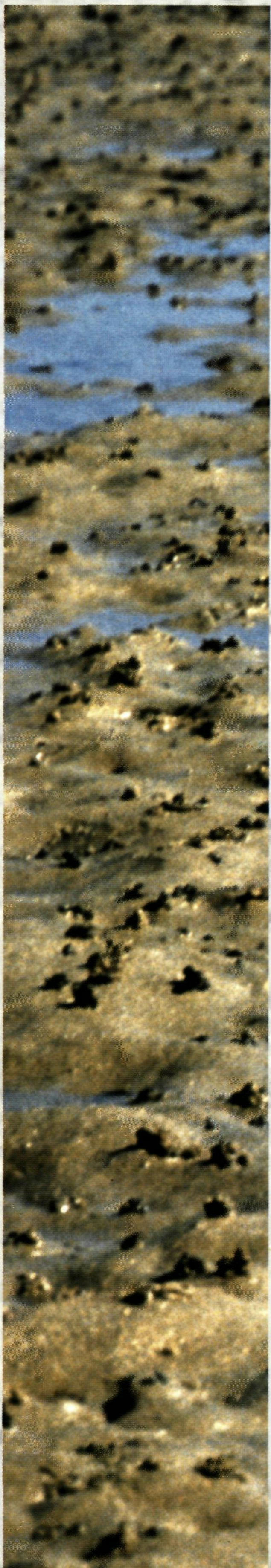
Deep-sea meiobenthos or deep-sea dwarfs

Deep-sea meiobenthos (organisms between 0.03 and 1 mm) shows the opposite trend to what is observed for epibenthic taxa. Animals tend to have a much smaller body size compared to the shallow water fauna. The fact that animals tend to be two times smaller than their shallow water relatives has been explained by the decrease in food supply, but research is still going on. Also the number of organisms decreases with depth **(slide VI.15)**.

VI 15

Importance of deep-sea research

Because of the increasing pressure towards the economical exploration of the deep sea it is important to estimate the ecological importance it may have. Only in this way can we evaluate the impact of anthropogenic activities on the deep-sea environment.



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VI.02 Biological activity in the water column of the Atlantic ocean
VI.03 Coupling between the primary production in the water column and life on the deep-sea
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VI.04 Seacucumber (Echinodermata) between relics of a rich and varied benthic life in the NE Atlantic ocean.
VI.05 The german research vessel SONNE
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VI.07 The recovery of a catch after one night trawling over the bottom at 5000 m depth in the NE Atlantic
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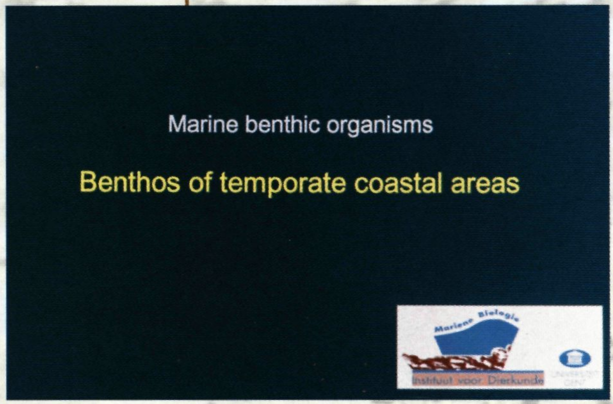
VI.14 Deep-sea sediments
VI.15 Deep-sea meiobenthos or the dwarfs of the deep sea

VII. The benthos of TROPICAL COASTAL SYSTEMS

For most biological taxa, biodiversity increases spectacularly in tropical areas as compared to temperate regions. This is also the case for marine benthic communities. Several hypotheses have been formulated to explain this diversity gradient (see also below), but one of the most important factors is undoubtedly the higher habitat heterogeneity in tropical ecosystems. Tropical shallow marine environments can be sub-divided in three typical biotopes, which are interlinked through the exchange of nutrients, dead organic matter and living organisms: mangrove forests, seagrass meadows, and coral reefs. Each of these biotopes is characterised by a specific bottom fauna.



Mangrove forests

(slide VII-01, 02, 03, 04, 05, 06, 07, 08)

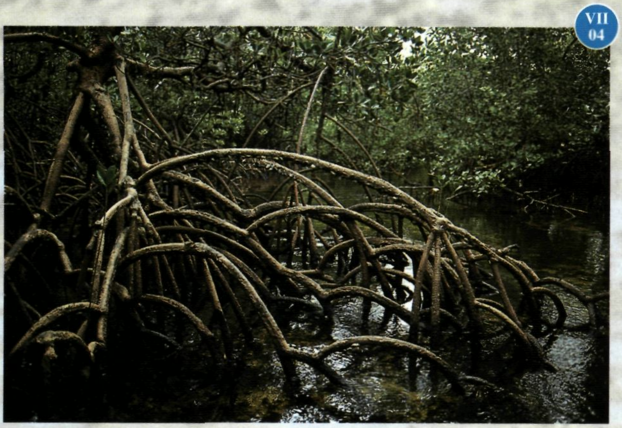
Mangroves or mangals are a typical vegetation along sheltered coasts of tropical and subtropical regions. They are specialised communities of salt-tolerant, terrestrial trees and only occur in the marine intertidal zone. In this respect, they are comparable to the salt marshes of temperate to sub-polar regions. Their complex rooting systems, and the silty sediments on which they occur,

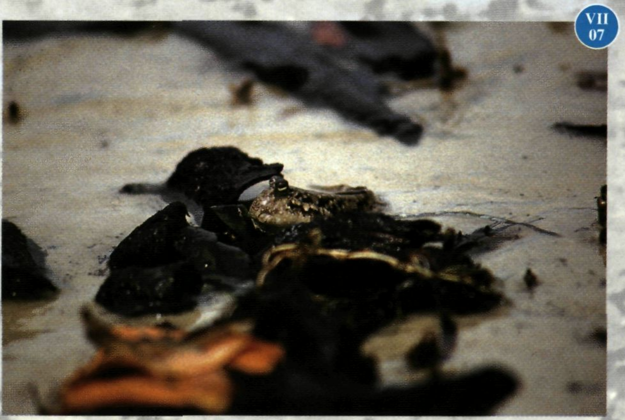
VII 01

VII 02

VII 03

provide suitable habitats for a variety of marine invertebrates. Highly characteristic for the mangrove vegetation - and for the associated benthos - is the occurrence of species or groups of species in discrete zones along the marine-terrestrial gradients. The most important of these are tidal action, salinity and geomorphology.
The macrobenthos of mangroves is dominated by molluscs, crustaceans and fish. Gastropods and a variety of sedentary organisms such as barnacles, oysters, ascidians and sponges colonise the roots and trunks of the trees. Shrimp, prawns, ghost crabs, fiddler crabs and other terrestrial crabs make burrows in the soft sediment. Other animals utilise the mangrove environment during specific parts of their life cycle, or migrate in and out of the





forest with the tides. Especially the larvae and juveniles of bony fish and crustacean species - many of which eventually recruit to commercially exploited stocks - use the mangrove environment to find adequate food resources and/or protection against predators. Mangroves thus function as so-called 'nursery areas' for these species, since they depend on the habitat to complete the critical early phase of their life history. Furthermore, mangroves are important to human populations as sources of wood, charcoal and tannins and for the protection of the coast line (stabilisation of the sediments reduces the erosion impact of tropical storms). Throughout the world, mangroves are thus threatened by a plethora of human activities. The most important of these are the felling of trees for the production of fire wood, building materials and pulp, and large scale deforestation for the construction of aquaculture plants and infrastructure for tourism.

Seagrass meadows

(slide VII-09, 10, 11, 12)

Extensive seagrass beds characterise the shallow lagoons between the mangrove forests and the coral reefs. Tropical seagrasses occur on mud, sand and coral rubble, both in the intertidal zone and subtidally. Their ecological role can be summarised as follows: they function as sediment traps that stabilise the bottom and improve the transparency of the water, they are important primary producers, and they function as direct food sources for a variety of animals. For benthic organisms, four relevant sub-habitats can be distinguished: (1) the epibenthos of the leaves mainly consists of smaller organisms like *nematodes, polychaetes and crustaceans, but also* of many other sessile (polyps, anemones and bryozoans) and vagile (gastropods, echinoderms and fish) forms; (2) the biota of the stems and rhizomes mainly consist of polychaetes, amphipods and bivalves; (3) animals that swim between the leaves, e.g. fish, cephalopods and crustaceans and (4) the fauna that burrows in the sediments can be quite different from the benthos of non-vegetated areas.

VII 09

VII 10

VII 11

VII 12

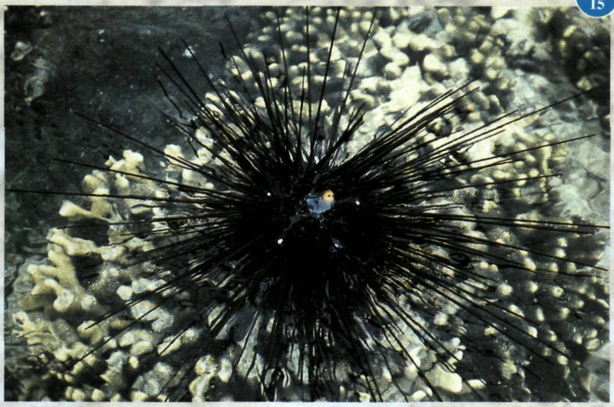
Coral reefs

(slide VII-13, 14, 15, 16, 17, 18, 19)

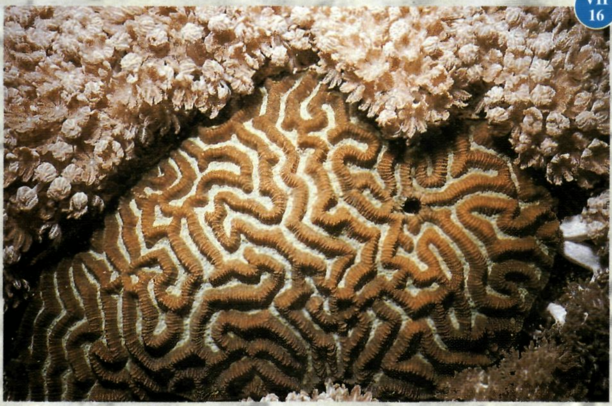
VII 13

VII 14

VII 15



VII 16



VII 17

Coral reefs are among the most diverse and productive ecosystems of the world. Their complex *three-dimensional structure* provides suitable habitats for a variety of benthic organisms. Furthermore, they are old (atolls can be over 60 million years old) and evolutionary stable systems, allowing sufficient time for the co-evolution of numerous specialised and subtle interactions between species.

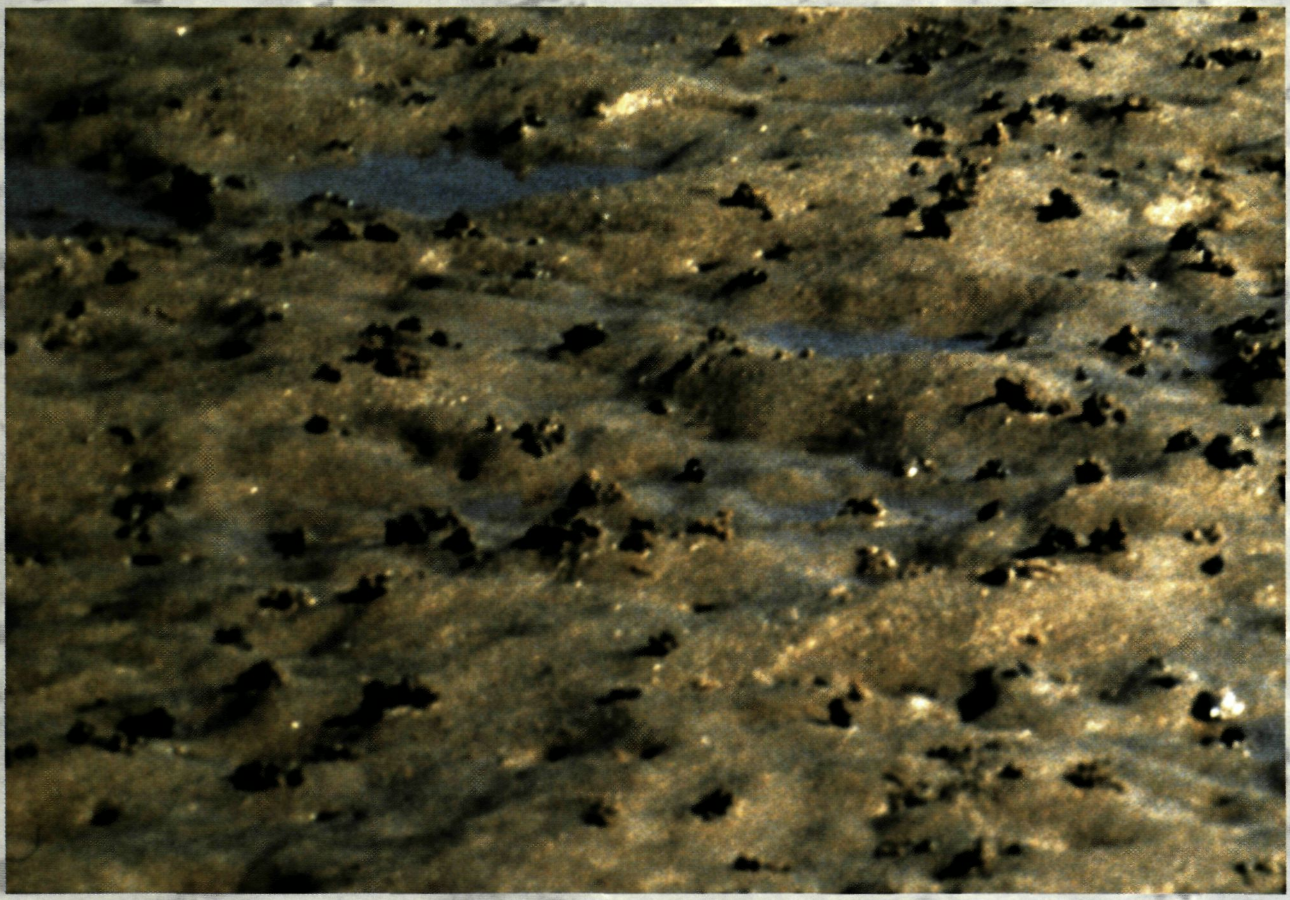
Coral reefs originate almost exclusively through biological activity. The dominant reef building organisms are hard corals or Scleractinia. These colonial coelenterates grow by producing a rigid exoskeleton. Calcium carbonate is excreted continuously at the basis of the polyps, resulting in an upward growth of 0.2 to 0.8 mm per year. Encrusting algae also contribute significantly to the maintenance of the structural integrity of the reef. Coral reefs thus mainly consist of dead, biogenic limestone that has been produced over many years. The living coral only constitutes a thin upper layer of interconnected polyps. The polyps themselves are characterised by the presence of unicellular algae (*zooxanthellae*) in the body cavity. The products of the photosynthetic activity of the algae (glucose, glycerol, alanine,...) are used directly by the coral. Actually, a continuum of coral types exists, from strictly carnivorous species to species that almost exclusively live from the products of their symbiotic algae. Zooxanthellae also contribute to the calcification process, but the precise mechanism remains largely unexplained.

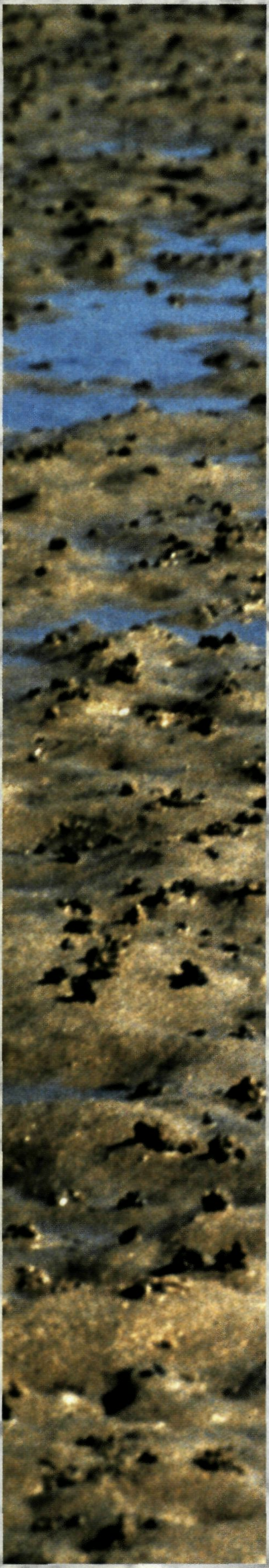
Coral reefs can be classified in three major types: *fringing reefs, barrier reefs* and *atolls.* The former two types are not easy to distinguish and are often called coastal reefs. Fringing reefs grow in a seaward direction, thus creating a shallow plateau between the coastline and the actively growing edge of the reef. Barrier reefs also run perpendicular to the coastline, but these are separated from the land by a shallow bay. An example is the Great Barrier Reef in Australia, which has a length of almost 2000 km and covers an area of more than 200000 km2. Atolls are circular reefs that enclose a central lagoon. The latter reef type occurs in deep water and is not associated with land masses. These three reef types represent different phases in the development of reefs: fringing reefs are early phases, while barrier reefs and atolls are later phases. Charles Darwin already suggested that atolls originated from fringing reefs that developed on the edges of sinking, volcanic islands. Through upward growth of the corals, first a barrier reef and later - when the island is completely submerged - an atoll comes into being.

Coral reefs develop maximally at *temperatures* between 23 and 25°C and reef building stops completely when seawater temperature drops below 18°C. The strong upwelling of cold water along the Atlantic coasts of Africa and South America explains the absence of reefs in these tropical areas. *Light* is essential for the photosynthetic activity of the zooxanthellae. Since light

penetration in the sea decreases exponentially with depth, no reef building takes place below 20-30m. Further, coral reefs are very sensitive to low *salinities* and high *turbidities* of the water. Indeed, an increased turbidity reduces the penetration of light, and the sedimentation of fine particles clogs the feeding apparatus of the polyps. Coral reefs thus don't occur in areas where turbid, freshwater enters the sea (mouth regions of major rivers). Finally, corals only occur in areas were sufficient *wave action* prohibits sedimentation the sedimentation of particles and results in well-oxygenated water.

Coral reefs are also characterised by a distinct zonation. Wide, overlapping zones run parallel to the coastline. Coral reefs throughout the world are threatened by overfishing for aquaria and collectors, and - especially - by very destructive fishing techniques like dynamite, muro-ami and poisons (e.g. cyanide).





LIST OF SLIDES

THE BENTHOS OF TROPICAL COASTAL SYSTEMS

VII.00 Title

VII.01 A tropical bay in Kenya. On the landward side the bay is bordered with mangrove forests that are intersected by a network of smaller and larger creeks. A coral reef (note the breaking of the waves) separates a shallow lagoon from the Indian Ocean.
In the shallow bay between the coast and the reef, as well as in the lager mangrove creeks, the bottom is covered with extensive seagrass beds.

VII.02 A dense mangrove forest in Kenya. The bottom of the shallow subtidal creek is covered with seagrasses and macro-algae.

VII.03 A mangrove forest at low tide. The conspicuous pneumatophores allow the trees to grow in the quasi anoxic sediment and provide shelter for benthic animals.

VII.04 The supporting prop roots of mangrove trees are colonised by oysters and barnacles.

VII.05 The trunk of a mangrove tree with a cluster of gastropods.

VII.06 Fiddler crabs Uca are very abundant in the mangrove sediments.

VII.07 Mudskippers live in burrows and follow the water line with the tides. They climb over the roots and crawl or jump with their modified pectoral fins and tail. Their large, frog-like eyes are adapted to functioning in the air, and vascularised sacks in their mouth and gill chamber allows them to breath air.

VII.08 A clearing in a mangrove forest. The wood of mangroves is harvested for the production of tannins and charcoal and for the building of houses. World-wide deforestation for the construction of aquaculture ponds and the development of tourist infrastructure is increasing fast.

VII.09 A sea cucumber on a sparse seagrass vegetation.

VII.10 A mysid shrimp finds shelter between seagrasses.

VII.11 The epibenthos of seagrasses was sampled with a beam trawl. The catch consist of tens of species of bony fish (here a pufferfish) and invertebrates (mainly swimming crabs, prawns, nudibranchs, starfish and sea cucumbers).

VII.12 A typical inhabitant of Kenyan seagrass beds: the bartail flathead.

VII.13 Coral reefs are characterised by a complex three-dimensional structure, providing a high diversity of habitats for the benthic animals.

VII.14 An example of symbiosis. An anemone fish finds shelter between the poisonous tentacles of an anemone. These small fish gradually cover themselves with the slimy excretions of the anemone (mimicry); their bright colours and typical behaviour attracts predators that are an easy prey for their host.

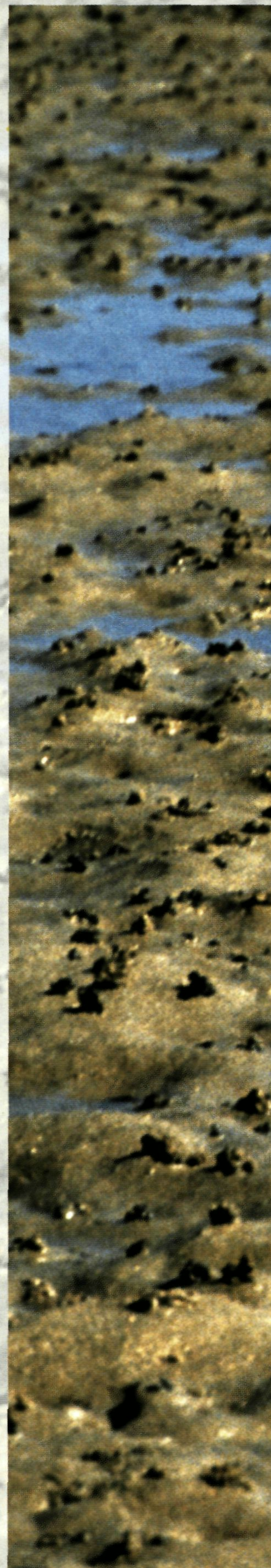
VII.15 Overfishing on coral reefs often results in explosive outbreaks of sea urchins and starfish. These feed on living coral, thus causing an increased erosion of the reef.

VII.16 The proximity of tourist infrastructure leads in many countries to an over-exploitation of beautiful hard corals and shells.

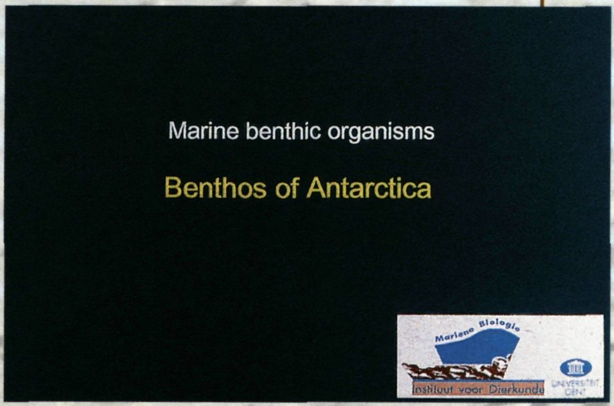
VII.17 Cowry shells are amongst the most spectacular and beautiful gastropods of coral reefs and seagrass beds. The panther cowry *Cypraea pantherina* is one of the commonest species in the Red Sea.

VII.18 This brightly coloured devil firefish has venomous fin spines that can cause very painful wounds.

VII.19 Top-predators, like this moray eel, also find shelter in the crevices of coral reefs.



VIII. The benthos of ANTARCTICA



The research of Marine Biology Section is also extended to the Antarctics. Despite the rather long scientific history, dating back to more than one and a half century, the amount of research activities in this 'last continent' is still low when compared to other geographical areas. Only a limited number of investigators were able to overcome the long distances and the hostility of the environment.

Some terms, figures and dates about the white continent

Terminology :
ARCTOS = bear (in the north);
ANT = the opposite of
Surface :
14 x 106 km2 (twice that of Australia)
Antarctic Circle : boundary at 66°30' South
Icecap : maximum thickness 4776 m (15 670 ft); average thickness 1880 m (7000 ft)
Minimum temperature: -88.3°C
Largest inner seas: Weddell Sea and Ross Sea
First discoverers : 7th century AD by Polynesian people travelling with primitive boats
August 16, 1897: the 'Belgica' leaves for Antarctica led by the Royal Belgian Navy lieutenant, Adrian Victor Joseph de Gerlache
December 15, 1911:
triumphantly arrival on the South Pole of the Norwegian explorer Roald Amundsen, and one month later that of the British Robert Scott

Antarctica is a continent of superlatives. It is the coldest, the driest, the windiest, the iciest, and averages as the highest in altitude of all the major land masses of our world. It is the continent with the longest nights, the longest days, the least amount of soil, the greatest amount of freshwater, and it is surrounded by the stormiest ocean on earth- the Southern Ocean.' (Moss SA, 1988)

		90° S	*60°*
day length (h)	*January*	*24*	*17.5*
	July	*0*	*7*
temperature (°C)	*maximum*	*-27.7*	*+0.5*
	minimum	*-59.7*	*-10.5*
	average	*-49.3*	*-4.3*

Antarctica is a huge island surrounded and isolated from the rest of the world by the Southern Ocean **(slide VIII.01)**. Each year the area of sea-ice around Antarctica increases to a maximum of 20 million km2 in September and decreases to a minimum of 3 million km2 by the end of summer in February. Furthermore, the number of daylight hours change considerably throughout the year with complete darkness in winter and the opposite in summer. Despite these extremes an astonishing amount of organisms survive in this harsh ecosystem **(slide VIII.02, 03)**. Often a simplified marine trophic chain shows diatoms (unicellular organisms with the shape of cheese boxes), microflagellates (unicellular algae with a long flagellum) and *Phaeocystis* (planktonic organisms like those that are also abundant in Belgian coastal waters) at the base. Krill (small crustaceans) occupy a central position and are linked to the higher animals which include icefish, penguins, petrels, seals, elephant seals, leopard seals, sperm whales, baleen whales, etc. **(slide VIII.-04, 05, 06, 07, 08)**.

VIII 07

VIII 08

But there is more than that. Besides the already mentioned micro-, macro- and megafauna, a lot of other organisms have colonised the different compartments of the marine habitat, building up a diverse and complex web of interacting plants and animals. Many of them are much less well-known, though therefore not the least important. As far it was stated above trophic pathways were mainly situated in the water column. However, in the sediments, many 'benthic' organisms take use of the considerable amount of food that is deposited; they include macro-, meio- and microbenthos. The sediment dwelling fauna is highly important during the long Antarctic summer days (November-April) when primary production reaches its maximum. For these organisms are also involved in the gradual refinement of organic particles and final reintroduction of nutrients into the water column, they prevent that most of the deposited matter ends up in a dead organic heap on the seabottom.

Despite the fundamental importance of nutrient recycling, not a lot is known about the microbial communities who are traditionally known to be responsible for such processes in Antarctica. This holds also for the meiobenthos. The Marine Biology Section of the University of Gent concentrates its research, among other aspects, on the role of this fauna in Antarctica. Therefore, the sediment samples are triated and the different organisms are counted and identified. A lot of the meiobenthic specimens are unknown to science and yet a name is given to the new species. The diversity (species richness, richness of life forms) and biomass is measured and finally the role in the processing of food is investigated. Apart form the descriptive analysis of the fauna, experiments make it possible to qualify the food that is consumed, to quantify the energy (under the form of oxygen respiration) that is needed, to determine which organism feed upon the meiobenthos, etc..

This makes it possible to find answers on the following questions:

1) How many meiobenthic organisms are there in Antarctica ? Answer : an amazing number reaching 20.000.000 in a piece of seabottom of 10 cm deep and with a surface of 1 square metre.

2) Are these meiobenthos influenced by the strong seasonal changes in the environment? Answer : yes, their densities are extremely high in the trace of the productive water column during the summer season, but decline as rapidly as winter starts.

3) Are meiobenthos important in Antarctica? Yes, the remineralisation of organic food to primary nutrients is strongly enhanced by the meiobenthos.

4) Are the Antarctic meiobenthos communities diverse? Yes, but the lack of sufficient literature on identifications makes it impossible to quantify exactly how many species exist in Antarctica.

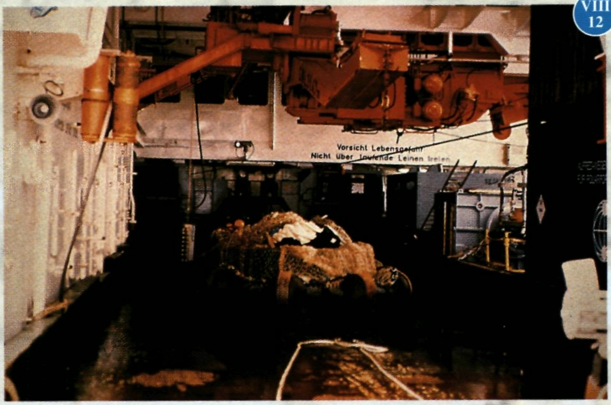
5) Do the same answers hold for the entire Antarctic region? No, but much more research is needed to find (dis)similarities among different Antarctic sites.

The logistics needed for effective operation in the Antarctic are expensive investments, currently available only to a few countries. Realisations of scientific purposes of the Marine Biology in Gent are, therefore, next to the financial support of the Belgian government, only possible due to the offer of British and German counterparts. In this way, our lab has the opportunity to work in the Antarctics ones every two years on board of the ice vessel 'Polarstern' **(slide VIII.09, 10, 11, 12, 13)** or at a base ashore, for example Signy Island **(slide VIII 14-15)**.

VIII 09

VIII 10

VIII 11



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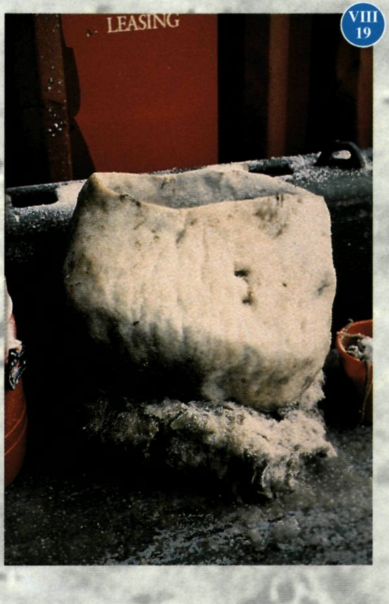


But, protection of the environment has priority over scientific research. In the trace of 'the Antarctic Treaty', executed since 23 June 1961, many efforts were done to reduce human impact on the pristine environment. Noise has to kept to a minimum, breeding animals should be left alone, waste is reduced, packed and transported back to the north ***(slide VIII.16)****,.. Scientists, logistic personnel and crew are carefully educated to be sensible 'visitors' of this pristine environment.*

LIST OF SLIDES

BENTHOS OF ANTARCTICA

VIII-00 : title

VIII-01 : Map of Antarctica. The study sites for meiobenthos research are situated in the Weddell Sea (Kapp Norvegia and Halley Bay, 71-75 °S, 12-29°W, 200-2000 m, January-March 1989 and 1996) and Signy Island (South Orkney Islands, 60°S, 45°W, January-February 1994). Co Geisler/Herrmann, Karlsruhe 1985.

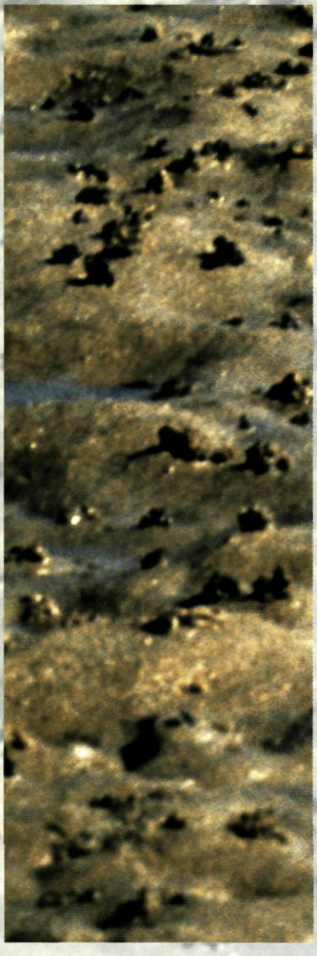
VIII-02 : Colony of chinstrap penguins (*Pygoscelis antarctica*) on North Point at Signy Island. Population estimate at Signy c. 80 000 pairs.

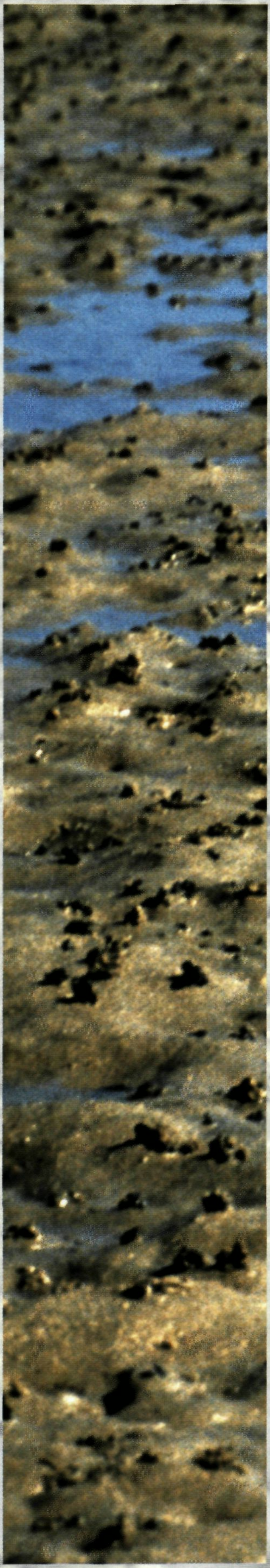
VIII-03 : Weddell Seals (*Leptonychotes weddelli*) on a piece of packice nearby the German base George von Neumayer in the Eastern Weddell Sea.

VIII-04 : Young elephant seals (Mirounga leonina) on Signy Island. Adult males reach lengths of 5 metres and have a weight of 3500 kg, adult females measure 3 metres and weigh 900 kg.

VIII-05 and 06 : Emperor penguins (*Aptenodytes forsteri*) on the icecap near the German research station.

VIII-07 : The Greater sheatbill (*Chionis alba*) greatly resembles the domestical chicken from our farms. Population size at Signy Island is estimated at c. 150 pairs. Sheatbills breed in crevices around Chinstrap colonies. They hatch mid-January, fledge March. Dispersal occurs in May; the birds that feed at base during winter are probably from the Peninsula or farther south (Rootes, D, BAS).





VIII-08 : Adelie penguin (*Pygoscelis adeliae*). Population estimate at Signy c. 37 200 pairs.

VIII-09 : The German icebreaker *'Polarstern'* from the Alfred-Wegener-Institute in Bremerhaven is a multidisciplinary floating research station and logistic base for short- and long- term operations in polar seas. She is approx. 118 m long and max. 25 m wide. With continuous cruising speed the ship can break ice of up to 3-4 metres thick.

VIII-10 : Exploration of an iceberg (to precise the coordinates and depth). The *'Polarstern'* usually carries two helicopters which are stationed in a hangar on the first deck. They serve also for ice-reconnaissance work during passage through ice and for scientific tasks on the ice and on land.

VIII-11 : Spanish research group working in the wet lab on the *'Polarstern'*.

VIII-12 : Giant bottom trawl to sample benthic fauna (fish, crustaceans, sponges,..).

VIII-13 : Sampling of the meiobenthos with a multibox corer.

VIII-14 : Antarctic research base (Signy island, South Orkneys Islands) from the British Antarctic Survey in Cambridge.

VIII-15 : Sampling of the meiobenthos by SCUBA diving at Signy Island.

VIII-16 : Sorting of waste before the arrival of a ship at Signy Island (JCR or Bransfield). The waste is carried away to the Falkland Islands.

VIII-17 : Seaspiders and crinoids from the deep sea (Weddell Sea).

VIII-18 : Sponges from the deep sea. The species presented has because of its resemblance the common name lollipop.

VIII-19 : Huge cuplike sponges from the Weddell Sea.

VIII-20 : Isopods (upper) and other crustaceans (bottom) from the Weddell Sea.

VIII-21 : Isopods and amphipods from the Weddell Sea.

VIII-22 : Piece of sampled seabottom with on top a light coloured layer of sponge-spicules and bryozoan debris. Immediately under this layer the real sediment is visible. The sample is taken with a multibox corer. Meiobenthos is extracted from this sample.

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University of Gent, Department of Biology, Marine Biology Section, K.L. Ledeganckstraat 35 B 9000 Gent, Belgium.

Notes

Notes

Errata

Following slide figures have been presented in a wrong position in the brochure or need to be added to the text: (slide numbers are unique)

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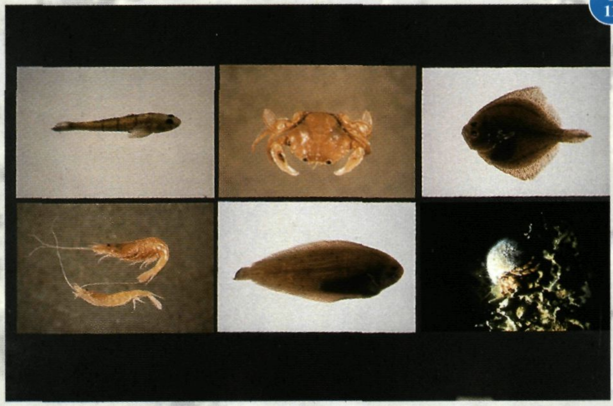

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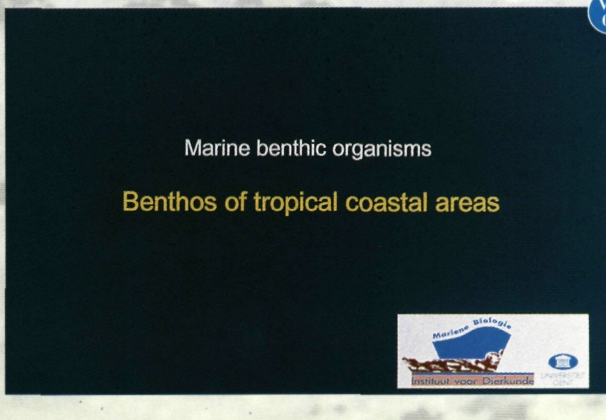

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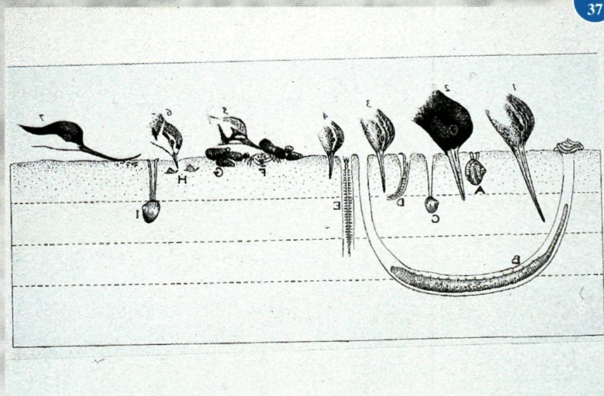

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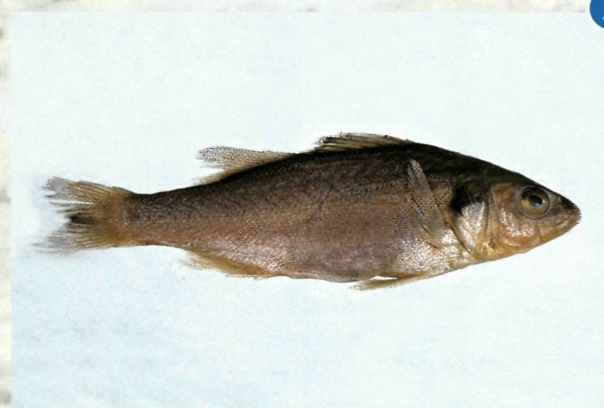

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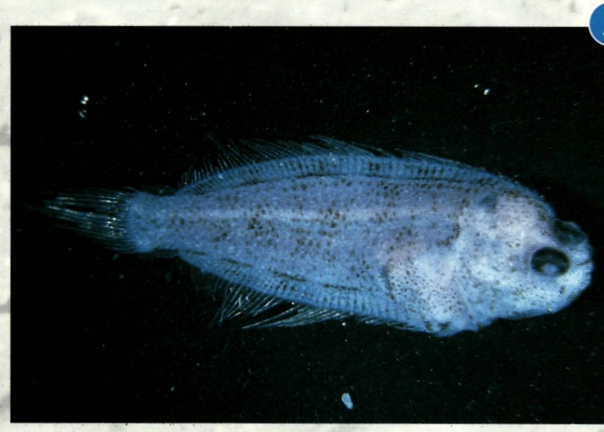

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Federal Office for:
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Wetenschapsstraat 8 - rue de la Science B-1000 Brussels

Ministry of the Flemish Community
Science, Innovation and Media Department
Science and Innovation Administration

University of Gent, Zoology Institute, Marine Biology Section
K.L. Ledeganckstraat 35 • B-9000 Gent • Belgium
Tel.: 09•264.52.10 - Fax: 09•264 53 44