CHAPTER 226

INTEGRATED COASTAL RESEARCH IN THE SW NETHERLANDS

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ABSTRACT

The geomorphological and ecological response of the ebb tidal deltas of the SW Netherlands to implementation of the Delta Project during the last decades, has been the subject of an integrated research project. General observed geomorphological trends are: erosion of the delta fronts and of the relic tidal bars in the landward parts of the deltas, and sedimentation in the tidal channels and in longshore bars at the edges of the deltas. Ecologically, a general trend towards richer benthic fauna communities is observable.
The integrated approach in coastal research combining geomorphological analysis of field data with numerical modelling, and integrating hydraulic, geomorphological, sedimentological and biological data, has appeared very promising. Progress in this field would be stimulated by further research of the driving processes in the interaction of hydrodynamics - sediment - biota. The level of detail (spatial and temporal) in geomorphological contributions to such research will have to be much higher than usual in current coastal morphological studies.

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1. IMPACT OF DELTA PROJECT ON EBB TIDAL DELTAS OF THE SW NETHERLANDS

Implementation of the Delta Project in the SW Netherlands has induced major changes. The closure of the Haringvliet and Grevelingen estuaries in 1970 and 1971 respectively, and the completion of the Oosterschelde storm surge barrier in 1986, have initiated a dramatic change in hydraulic conditions and the geomorphology of the former ebb tidal deltas. The changes in physical boundary conditions affect the total ecosystem of the coastal area and entail consequences for various human activities. This environmental impact creates a challenge to integrated water- and coastal management (Hallie et al., 1990).

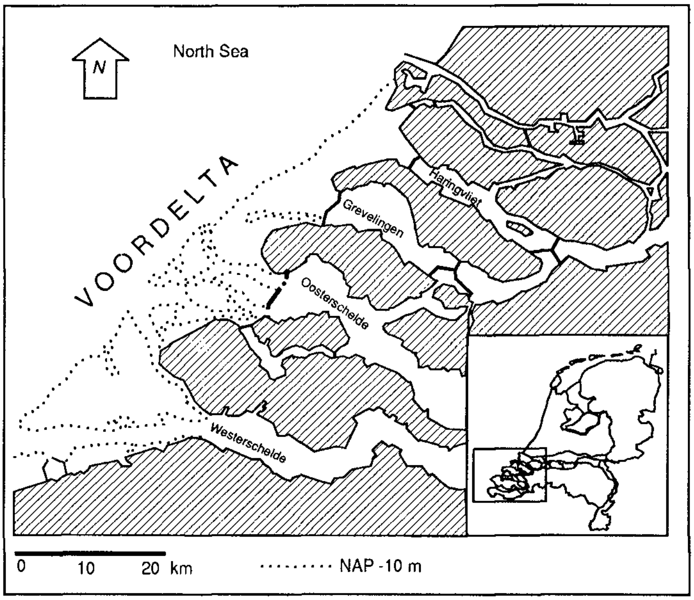

Fig. 1 Study area: the Voordelta

2. INTEGRATED RESEARCH PROJECT

The developments of the former ebb tidal deltas of the Grevelingen, Haringvliet and Oosterschelde - area known as the Voordelta (Fig. 1) have been the subject of an integrated research project, aimed at

- describing the recent developments and present situation of both geomorphology and ecology; and
- predicting on an intermediate time scale (1990 - 2010), the change in geomorphology and possible shift in ecological functioning of this area.

The results are being used as basic information to develop an integrated policy plan during 1990.

This paper summarizes the general results of the research project.

Specific results have been described in more detail by Kohsiek (1988), Steijn et al. (1989), Mulder (1989), Hallie et al. (1990), Louters et al. (1990), Postma et al. (1990), Craeymeersch et al. (1990) and Hamerlynck et al. (1990).

3. PHYSICAL CHARACTERISTICS OF THE STUDY AREA VOORDELTA

The actual geomorphology of the Voordelta is characterised by interlinked (former) ebb tidal deltas extending 10 - 15 km seaward from the coastline. The delta fronts are marked approximately by the depth contour of -10 mNAP [NAP= mean sea level as defined for Amsterdam]. Maximum depths of tidal channels range from -23 mNAP at the Oosterschelde -, through -14 mNAP at the Grevelingen -, to -10 mNAP at the Haringvliet ebb tidal delta. Maximum heights of longshore - and tidal bars range between -1 and +1mNAP.
The mean grain size in the area varies from 150 - 350 micron.

The dominant tidal currents run parallel to the coast: northward during flood, southward during ebb. The semi-diurnal vertical tide has a mean range of ca. 2.6 m and can be classified as mesotidal.
Maximum current velocities at the Oosterschelde ebb tidal delta, still with a substantial east - west component to and fro the basin, presently amount 1 - 1.2 m/s; at the Grevelingen - and Haringvliet ebb tidal deltas maximum velocities range from .40 - .60 m/s. These values imply the significant velocity reductions that have occurred due to the construction of dams: the Oosterschelde storm surge barrier (1986) induced a reduction of ca. 30%, closure of Haringvliet and Grevelingen (1970/71) reductions of 45 - 80% (Kohsiek,1988).
For the prevailing winds (southwest to northwest), the wave climate is characterised by a significant wave height (H_s) of 1.2 m (Louters et al., 1990).

4. INTEGRATED APPROACH

The Voordelta research project has been characterised by an integrated approach at two levels (Fig. 2).
At the level of geomorphological research an integration took place of results from field data analyses and from numerical modelling. Ecological research was based on an integrated analysis of hydraulic, geomorphological, sedimentological and biological data.

4.1 Geomorphological research

Echo sounding maps of the study area have been recorded almost yearly since the early 60's. These soundings have provided the basic data for geomorphological research.
First a qualitative analysis has been performed comparing different sounding maps. Then, after preparing 200*200 m and 100*100 m grid squares with interpolated depth values, changes in sediment volume

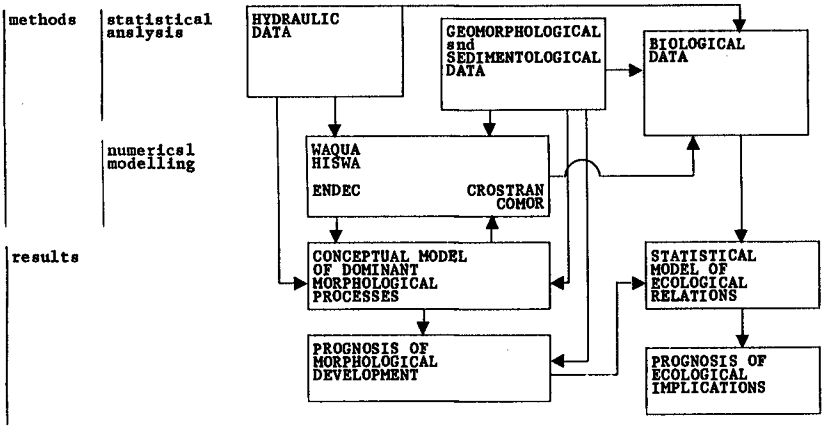

Fig. 2 Schematic representation of the integrated approach both in geomorphological and in ecological research

of the ebb tidal deltas and specific sub units have been quantified. Trends in these changes have been analysed statistically.
Parallel to the analysis of bathymetric data, numerical modelling has been applied to study the dominant processes: a 1D model of CROSs-shore TRANsport (CROSTRAN) to investigate the adaptation of the cross shore profile (Stive, 1986) and a 2DH model of COastal MORphology (COMOR) to study the spatial interaction between tide- and wave induced currents and sediment transports (de Vriend and Ribberink, 1988; Steijn et al., 1989).
Integrating results from bathymetric analyses and numerical modelling a conceptual model of the dominant processes and actual sediment transport patterns has been defined (Louters et al., 1990).

A prognosis of geomorphological developments on an intermediate timescale has been based on a procedure during which the following activities have been executed in an iterative way (Postma et al., 1990):
After defining a conceptual model of dominant processes, specific geomorphological units have been defined (e.g. the delta front and individual shoals and channels, or parts of these). Each unit definition, preferably was based on explicit geomorphological and process characteristics. Successively, each unit has been described by certain geomorphological parameters and the trend of each parameter since 1970, has been extrapolated towards the year 2010. Extrapolation mostly occurred according to an exponential function, fitted for the observed trends over the period 1970 - 1987. In each case the prognosis has been tested to be consistent with predicted developments of other units and with the earlier defined conceptual model. Finally, a check has been performed on the total sediment balances of the areas.

4.2 Ecological research

The ecological impact of the change in physical boundary conditions has been studied mainly on developments in benthic fauna.
The study has concentrated on macrozoobenthos, representing a vital link at the base level of the food chain in the marine ecosystem. Macrozoobenthos are animals of sizes over 1 mm, living in the toplayer (ca. 10-20 cm) of the sediment. Main repesentatives are worms (Polychaeta), small shrimps (Crustacea), shellfish (Bivalva) and echinoderms (Echinodermata).
Beside macrozoobenthos, attention has been paid to epibenthos (animals living on top of the sediment surface or in permanent contact with it: demersal fishes like flat-fish, cod and gobies, and adult shrimps, crabs and starfish) and on hyperbenthos (animals living in the lower parts of the water column, dependent on the vicinity of the sediment surface: macrozoobenthos larvae, mysids, eggs and larval stages of fish).

Basic data for the macrozoobenthos research were provided by an inventory sampling campaign during 1984,1985 and 1986 covering a total of 457 locations scattered randomly over the Voordelta, including the ebb tidal delta of the Westerschelde (Fig. 1). During 1987 and 1988 monthly sampling was performed at a total of 150 sites in two key areas on the Grevelingen - and Oosterschelde ebb tidal delta respectively.
At each location have been determined from direct sampling: macrozoobenthos biomass and species composition, soil parameters (silt content, median grainsize, sorting) and water depth. Other hydraulic parameters (maximum current velocity, wave heights, near bottom orbital velocity) have been derived indirectly from numerical modelling. Water quality parameters (salinity, chlorophyl-a and suspended matter) were determined from data supplied by a campaign of water quality sampling at 60 locations, executed with monthly intervals during 1986.
All macrobenthos samples taken in autumn were classified according to macrobenthic species composition by a statistical classification program. Then, canonical correspondence analysis and multiple discriminant analysis were applied to correlate the animal assemblages to abiotic environmental variables (Craeymeersch et al., 1990; van der Meer, 1988).

Epibenthos and hyperbenthos data were sampled in the Grevelingen and Oosterschelde key areas during campaigns of 1987 and 1988. Sampling was performed with a specially constructed 'hyperbenthos sledge' (Hamerlynck and Mees, 1990). Statistical analysis has been applied to investigate correlations with abiotic variables.

An indicative prognosis of a future shift in ecological functioning of the Voordelta has been based on the statistical relations derived for the study area.

5. GENERAL RESULTS

5.1 Geomorphological development

Sediment balances of the Haringvliet and Grevelingen ebb tidal deltas indicate a mean yearly sedimentation surplus of respectively circa 3 and 2 million cubic meters since 1972. Between 10 and 30 percent of this surplus has been estimated to be marine mud, deposited mainly in former ebb tidal channels. A major part of the sedimentation surplus most probably is due to a net northward longshore sediment transport from the south (Louters et al., 1990).
A continuing sedimentation in the relic tidal channels (Fig. 3) is a typical phenomenon of the geomorphological changes in the study area.

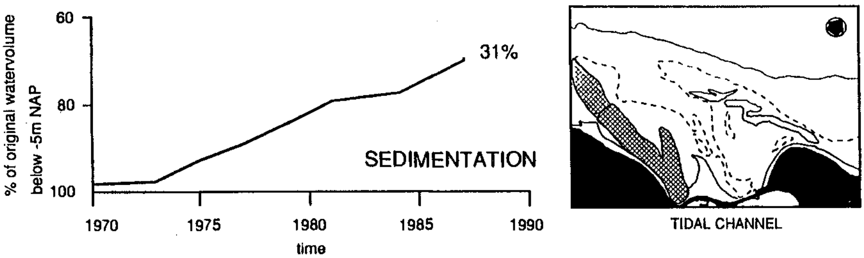

Fig. 3 Sedimentation in the the former main tidal channel of the Grevelingen ebb tidal delta since 1970

Typical erosive areas are the delta front, indicated by a continuing landward shift of the -5 mNAP depth contour, and the relic tidal bars in the landward parts of the deltas (Fig. 4).

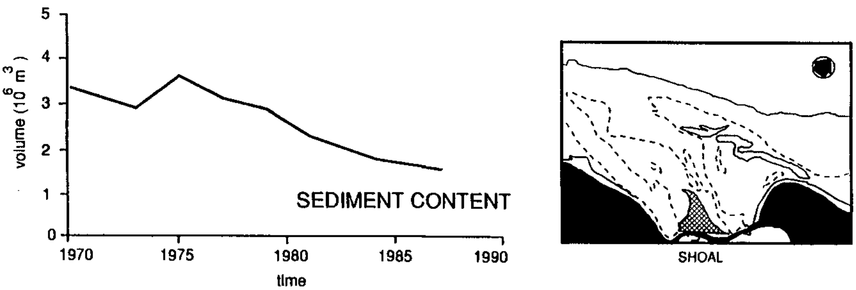

Fig. 4 Erosion of the main relic tidal bar in the landward part of the Grevelingen ebb tidal delta since 1970

The most striking phenomenon however is the development of large long shore bars at the edges of the Haringvliet and Grevelingen ebb tidal deltas (Fig. 5). The sedimentation trend at these bars is continuing but the growth rate is stagnating at a height around mean sea level. This stage had been reached circa 1980. From then on the

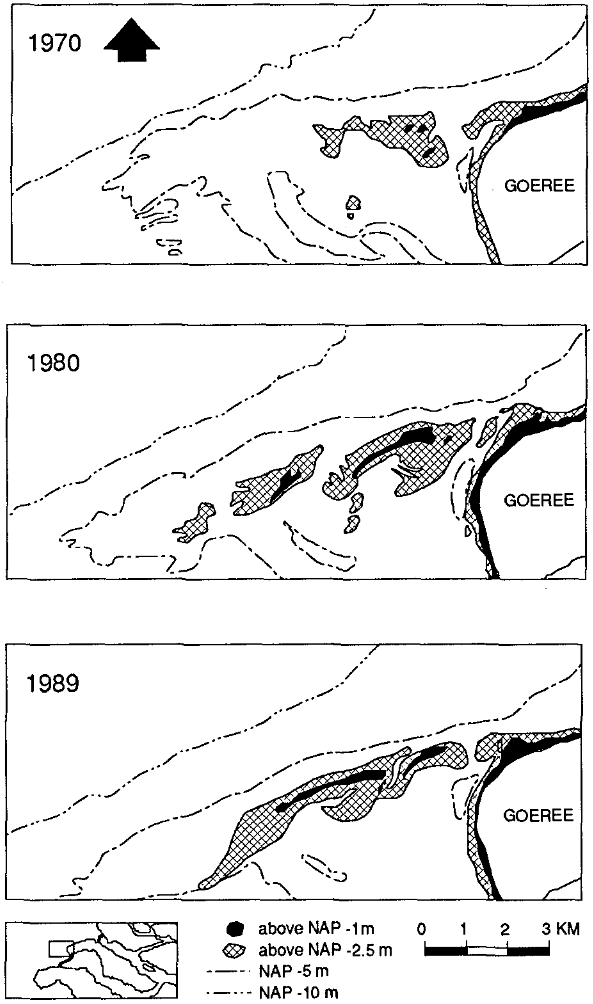

Fig. 5 Development of longshore bars at the edge of the Grevelingen ebb tidal delta since 1970

longshore bars are only showing a tendency towards a continuing shift in landward direction (Kohsiek, 1988; Louters et al., 1990). The total geomorphological change apparently is to a large extent due to a local redistribution of sediments.

The first observations of the Oosterschelde ebb tidal delta after completion of the storm surge barrier in 1986, indicate a tendency of changes similar to the changes of the Haringvliet and Grevelingen deltas: erosion of the delta front and tidal bars in the landward parts of the ebb tidal delta, and sedimentation of the channels. However, until now no indication has been derived of developing long shore bars.

Among the driving forces of the geomorphological changes observed at the Haringvliet and Grevelingen ebb tidal deltas, a prominent one is represented by the asymmetrical wave orbital motion, inducing upslope sediment transport responsible for the initial development of long shore bars (Stive, 1986; Kohsiek, 1988). At later stages this bar development is depending on the equilibrium of four different mechanisms (Kohsiek, 1988): (-) a decrease in upslope sediment transport by the mentioned force due to an increase of the time mean of seaward flow under breaking waves; (-) a wave driven landward sediment transport over the crest of the longshore bars during storms, especially from the northwest; (-) a residual tide induced seaward sediment transport over the crest of the longshore bars; and (-) a wave induced longshore sediment transport during low water on the seaward side of the longshore bars. Since the prevailing winds are from westerly directions the residual longshore sediment transport is to the northeast.
Analyses of COMOR model results largely have confirmed this picture (Steijn et al. ,1989). The mentioned mechanisms represent the main components of the conceptual model of dominant processes, as defined for the area (Louters et al., 1991).

The prognosis of future geomorphological changes (see e.g. Fig. 6) indicates that on an intermediate timescale (1990 - 2010), the generally observed trends will continue. The rate of change however, will reduce due to the assumption of exponentially decreasing process velocities. It then appears that, on an intermediate timescale, nor the available space between neighbouring geomorphological units, nor the spatial interaction between driving processes does impose definite limits to the development of any defined unit or to the activity of any presently acting process.
On longer time scales the geomorphological developments are less certain, as these are influenced by uncertainties in e.g. the effects of an increased sea level rise or a change in the net northward longshore sediment transport to the study area (Louters et al., 1991).

5.2 Ecological development

The intermediate position of the Voordelta on the ecological gradient estuary - open sea, becomes apparent from its macrozoobenthos characterisitics; both its diversity and its total biomass. In the Voordelta a total of 150 different species of macrozoobenthos have been observed, with a mean total biomass of ca. 20 $gADW/m^2$ (ADW= Ash free Dry Weight i.e. the weight of biologically active parts). A total number of species which is significantly lower than generally observed in the North Sea, but higher than in the estuaries of the SW Netherlands. On the other hand the mean total biomass observed in the Voordelta appears approximately twice as high as in the open North Sea, but twice as

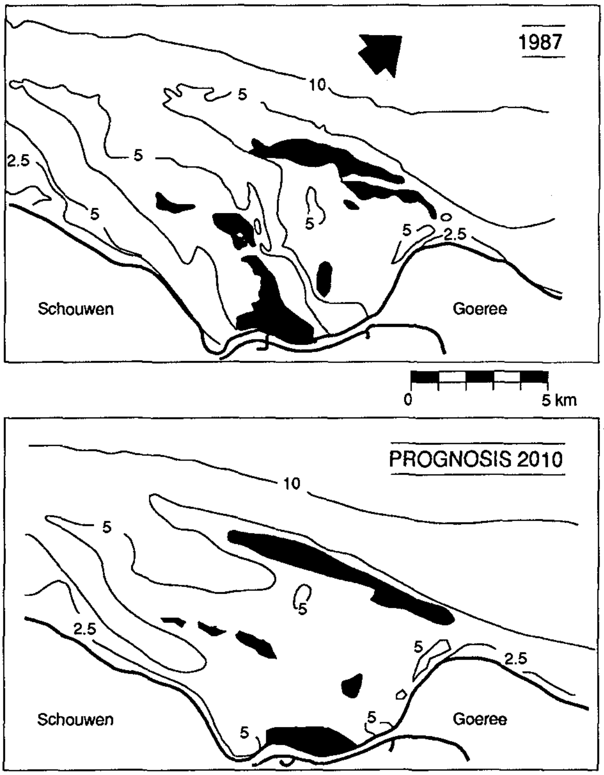

Fig. 6 Actual (1987) and predicted (2010) geomorphology of the Grevelingen ebb tidal delta. Indicated in black are the sandy shoals (above -2.5 mNAP).

low as in e.g. the Oosterschelde estuary.

Epibenthos observations showed a total of 48 different species, of which 40 species of fish.

Statistical analysis has demonstrated that the total Voordelta (including the Westerschelde ebb tidal delta) may be characterised by 6 different communities of macrozoobenthos, of which 4 communities occur in the key areas at the Grevelingen and Oosterschelde ebb tidal deltas. Each macrozoobenthos community has its own typical species composition, density (individuals/m^2) and total biomass (Fig. 7).
The spatial distribution appears significantly correlated with sediment composition (especially mud content) and with water depth (Fig. 8) (Craeymeersch et al., 1990).

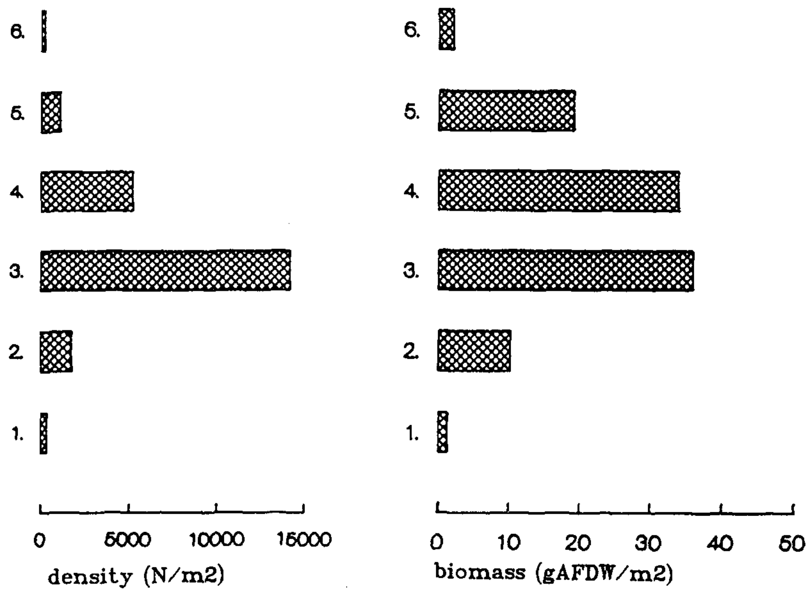

Fig.7 Characteristics of the six typical macrozoobenthos communities of the Voordelta

Spatial differences may be quite large. This is illustrated e.g. by observations of both hyperbenthos and macrozoobenthos. The Oosterschelde ebb tidal delta appears much poorer in this benthic fauna than the Grevelingen ebb tidal delta: the densities are about half, the total biomass about one third to one half of the Grevelingen values (Hamerlynck and Craeymeersch, 1990; Hamerlynck and Mees, 1990).

This difference is directly related to the changes in physical boundary conditions as induced by the Delta Project (see section 3). The Oosterschelde, which has remained partly open, only has known a relative small reduction in hydraulic energy conditions (current velocities ca. -30%); the hydrodynamic climate of the Grevelingen ebb tidal delta however, has become drastically calmer after closure of the estuary. This has induced large scale sedimentation of fine sediments especially in the tidal channels (see 5.1). Together with mud and silt sedimentation, organic material is deposited and several suspended juvenile stages of marine organisms are imported. Thus creating a very rich benthic fauna in this area (Hamerlynck and Craeymeersch, 1990).

The prognosis of future ecological changes indicates that, consistently with the expected, relatively small change in geomorphological characteristics for the next 10 - 30 years, also ecological changes most probably will be only gradual.

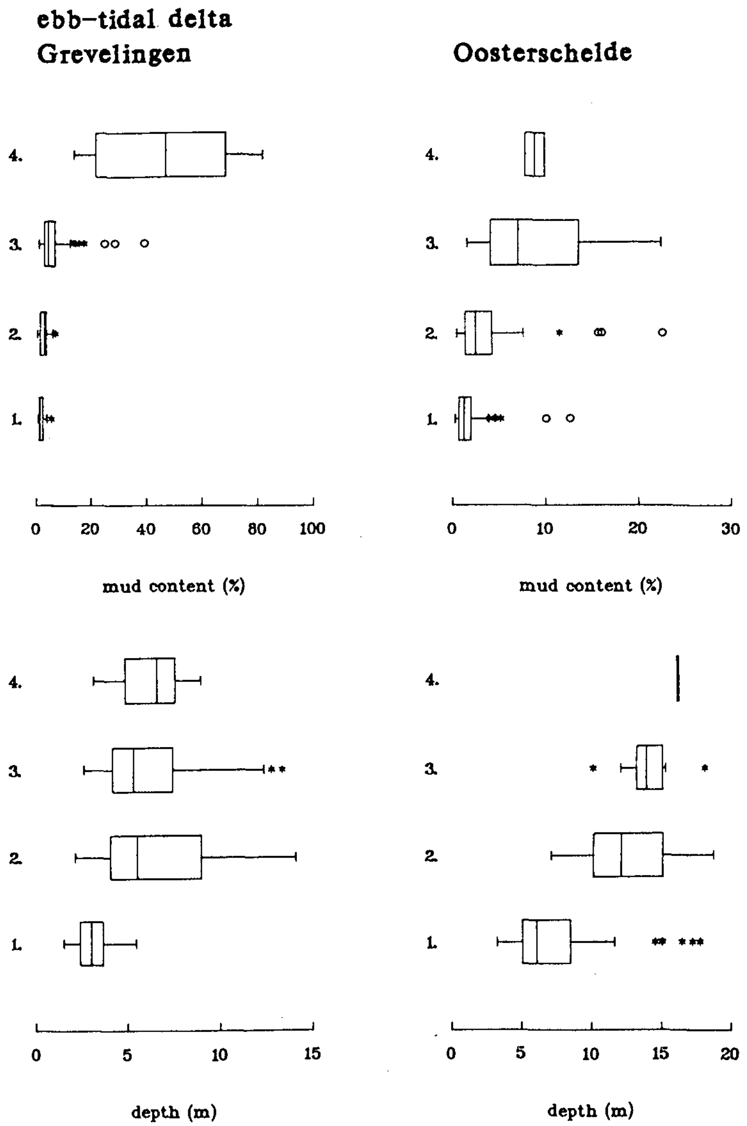

Fig. 8 Distributions of mud content and depth over the four typical macrozoobenthos communities of the Grevelingen - and Oosterschelde ebb tidal deltas, indicated by box-and-whisker plots. The median is marked by the central vertical line. The right and left edges of the box divide the distributions at the 25% and 75% level. The end of the whiskers denote the minimum and maximum values, unless there are outside values denoted by stars and circles.

6. CONSEQUENCES FOR WATER AND COASTAL MANAGEMENT

The observed and predicted changes in geomorphology and ecology of the Voordelta affect a series of (potential) human activities in the area. The main implications concern the following interests, each illustrated by an example (Hallie et al., 1990):

- shore protection; longshore bars and sand banks are reducing direct wave attacks on beaches and dunes, especially during storms. The resulting reduction in dune erosion has been calculated to amount locally 15 -25 percent.
- natural environment and landscape; the relative abundance of food, the extent of intertidal sand bars and shallow waters with a relatively mild hydraulic climate provide favourite conditions to several bird species and (potentially) to seals.
- recreational uses;enlargement of beaches has a positive, mud deposition around low water slack a negative effect on beach recreation. Shipping and surfing is stimulated by the attractive morphological variation and hydraulic conditions in the Voordelta.
- fisheries; the shallow, protected conditions make the area a potential nursery for some commercially interesting fish species (plaice, sole). Potentials for shellfish culture might develop.
- shipping; silting up of tidal channels and migrating sand bars affect shipping traffic towards local harbours.
- sand mining;the growth of sand bars near shore, provides a relatively cheap source of sands for several purposes (e.g. beach nourishments or land fills).

Obviously many of these interests are conflicting, at least potentially.

7. DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

Benthic fauna appears to be significantly correlated to abiotic variables. The distribution of macrozoobenthos of the Grevelingen area shows the highest correlation with mud content of the sediment top layer; on the other hand, macrobenthos of the Oosterschelde ebb tidal delta with water depth (Craeymeersch et al., 1990; also see Fig. 8). This illustrates that the established statistical correlations do not necessarily represent causal relationships. Possibly the variable water depth on the Oosterschelde ebb tidal delta, is a 'derived variable' from the driving variable current velocity.
In fact the ignorance of causal relationships between environmental variables and benthic fauna, poses a sincere problem once a prognosis of future developments is required. The statistical relation established for an open estuary (e.g. the Oosterschelde) does not necessarily have to be valid after the estuary has been closed (e.g. the Grevelingen).

This stresses the need of specific research of the driving processes in the relation between hydrodynamics - sediment (morphology and composition) - biota.
In this type of research, the level of detail (spatial and temporal)

in the geomorphological contributions, will have to be much higher than usual in current coastal morphological studies: for example, the need for hydrodynamic information near bottom, close to the benthos sampling locations, will eventually lead to hydrodynamical modelling at grid sizes of say 50 m or less. Another example is supplied by the statistical analyses of macrozoobenthos (Craeymeersch et al., 1990). As shown by the Grevelingen area (Fig. 8), 3 out of 4 macrozoobenthos communities (and among them the richest community) are correlated with mud contents between 2 and 10% . This indicates that in future research of this type, and in comparable environments, the distribution of mud content of the sediment has to be established at intervals between 2 - 5% !
These examples reveal the shortcomings of the applied integrated approach, and at the same time indicate possible ways of future progress in this field.

In general it may be concluded that the integrated geomorphological - ecological approach in coastal research as presented in this study, has appeared to be promising. The approach seems indispensable in view of the development of integrated coastal zone management.

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