Objectives of the WASP-3 project and outline of the EcoWasp ecosystem model

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This report is the second publication on the further development of the EcoWasp ecosystem simulation model. The first report is :

1- A.G. Brinkman (1991). EmoWad, the benthic submodel; an analysis of the description of biological processes in the bottom of a tidal system. Internal RIN report 91/35, 152 pp (in Dutch)

Within the ecosystem model development project, the IBN-DLO and NIOZ closely cooperate.
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1 Introduction

In 1990 the Wadden Sea Project (WASP) started, as a cooperation between twelve Danish, Dutch and German institutes and partly financed by the European Committee in the context of the Marine Science and Technology Program (MAST).
The aim is to develop physical and ecological models capable to simulate Wadden Sea key processes, and to perform necessary research.
By the end of 1992, the project has to be finished.

For practical reasons, the project is divided into three sub-projects :

WASP -1	: wave and current modelling
WASP -2	: sediment transport modelling
WASP -3	: ecosystem modelling.

The contributions of each institute to the sub-projects are listed in the WASP technical annex (1).

In this report, an outline of the ecosystem model development is given. Also, interactions with both the other sub-projects are enumerated.

2 Objectives of the ecosystem model

2.1 What should the ecosystem model make possible ?

The ecosystem simulation program has to be useful in answering a number of questions particularly related to system management. These questions may deal with all kinds of eutrophication problems; problems related to heavy metals or organic micro-pollutants lie outside the scope of the EcoWasp simulation program, at least for the time being.
During a WASP-3 workshop on Texel, January 1991 (2), it became clear that Dutch water authorities want to have more insight in the system's response to changing nutrient inputs, prior to other model applications.

The program should provide uncertainty analysis of the model calculations.

2.2 What should the ecosystem model include ?

The EcoWasp ecosystem model's objective is to simulate all the ecological key processes in a tidal system.
Nutrients, benthic and pelagic primary production, mineralization, benthic and pelagic micro- and macrobenthos activities have to be modelled.
The upper trophic level bounds are fish and birds; in the model both groups are included as forcing functions.
Attention is to be paid to the macrophytes.

In section 3.2.2 the modelled processes are outlined.

3 Outline of the ecosystem model EcoWasp

3.1 Introduction

First a schematic outline will be given of the ecosystem model to be developed.
This ecosystem model may be considered as a further development of the EmoWad-ecosystem model developed at the Netherlands Institute for Sea Research (Texel) (3,4), and will include a number of specific features from the freshwater ecosystem model TmSim, preliminarily developed at the University of Twente (8). EmoWad itself was derived from the Boede Ems-Dollard ecosystem model (5).

It should be clear that the model, as a mathematic abstraction of natural processes, is defined by the choice of all the variables to be calculated, as well as by the processes and the parameters.
The computer program determines the constraints, since processes that are not programmed cannot be calculated. At the other hand, processes may be left out of the calculation by setting appropriate switches. The number and the kind of the variables to be calculated may be chosen in a similar way: the choice is free up to the limits set by the program.

3.2 Main processes modelled in EcoWasp

3.2.1 Introduction

In EcoWasp, rather diverse processes are modelled. In fig.1, the main processes and system variables are

mentioned.
Most of the sediment/water exchange processes such as resuspension/sedimentation as well as the atmosphere water exchange processes have been left out of this scheme.

To give an impression of the details of a process, algae dynamics are shown in fig. 2.

3.2.2 Ecosystem processes

EcoWasp model processes include :

1- chemical processes related to nutrient and carbon dynamics, e.g.:
- adsorption
- pH buffering
- oxidation / reduction
- (dissolution)

2- physical processes
- vertical transport
  - pore water diffusion
  - leakage / seepage
  - resuspension / deposition
- horizontal transport
  - advection
  - dispersion / mixing

3- biological processes
- pelagic and benthic primary production dynamics
- zooplankton dynamics :
  - micro zooplankton
  - macro zooplankton
  - carnivorous zooplankton
- zoobenthos dynamics :
  - meiobenthos
  - filter feeders
  - suspension feeders
- mineralisation processes (aerobic and anaerobic) in the pelagic and the sediment (bacterial processes).
- effects of fish, birds and other higher trophic predators.

3.2.3 EcoWasp extensions compared to EmoWad

In the EmoWad ecosystem model some key ecosystem process descriptions are omitted or are to be improved.
It appears to be necessary to incorporate nitrogen processes (§3.2.3.1), and to improve the suspension feeder description (§3.2.3.2).
Macrophyte processes are not included in the EmoWad ecosystem model (§3.2.3.3).
In EmoWad the behaviour of solids (horizontal transport, deposition, establishment of vertical gradients) is modelled rather ad hoc. This description needs further improvement (§3.2.3.4).

3.2.3.1 Nitrogen processes

In the water column, nitrate and ammonium are used as a primary production nitrogen source. After mineralization, organic nitrogen is returned to the system as ammonium. By biochemical oxidation, nitrate is produced.
In the oxygen rich sediment top layer, the same processes take place. Deeper in the sediment (usually below a few millimetres) where oxygen is depleted, nitrate acts as the main electron acceptor, and is reduced to molecular nitrogen or nitrous oxide (N_2O). The latter is oxidized to nitrate later on.
Below this 'nitrate-layer', sulphate reduction occurs, as well as fermentation. In all these layers ammonium production as a result of the mineralization of organic material still takes place.

Transport of nitrate and ammonium (and all the dissolved components) takes place via diffusion, advection (seepage) and tidally induced dispersion and advection processes.

Ammonium may adsorb onto solid components (clays, oxides and humic materials).
The diffusion-reaction equations that describe the dissolved component concentrations in the sediment pore water are solved analytically (see e.g. 9,10).

3.2.3.2 Suspension feeders

After the EmoWad development is was concluded that suspension feeding organisms in the subtidal part

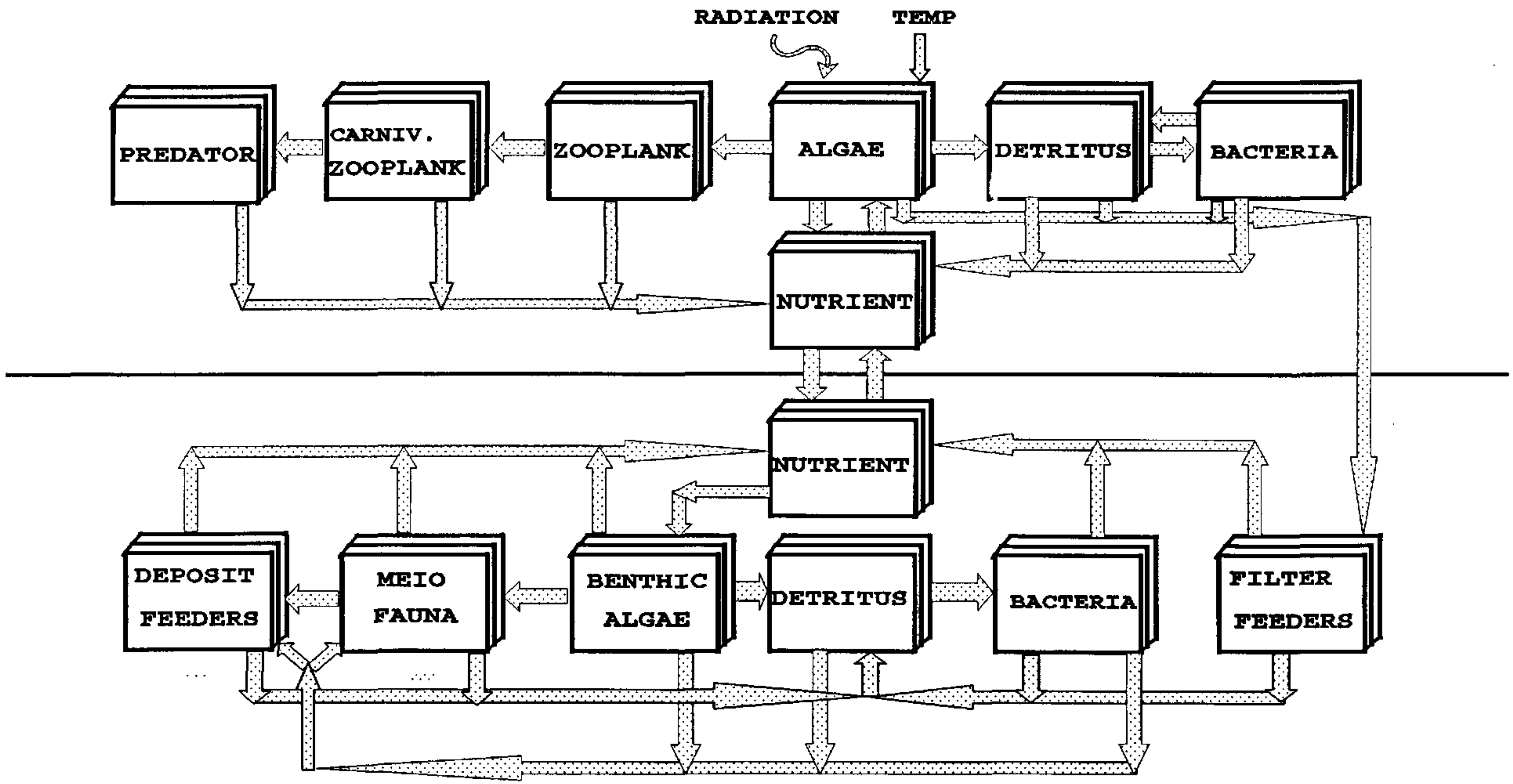

Figure 1. EcoWasp key variables and interrelations

of the system were not simulated correctly. The assumption of an extra food supply by increasing the food concentration near the sediment surface was necessary to keep suspension feeders growing.
This part of the model is to be improved.

3.2.3.3 Macrophytes

In the Dutch Wadden Sea macrophytes are not important since they disappeared in the thirties. However, in the German and Danish areas of the Wadden Sea macrophytes may cover (large) parts of the tidal areas, and should also be modelled.
This will probably be a first attempt, since macrophyte dynamics are not understood very well.

3.2.3.4 Solid transport

In a tidal system solid transport and erosion / deposition are very important for sediment composition and thus for benthic food supply. In EmoWad these distribution processes are modelled rather ad hoc. Cooperation with the WASP-2 project should result in better cohesive and non-cohesive sediment redistribution modelling (§ 5.2).

3.3 Spatial schematization

3.3.1 Vertical schematization

In fig. 3 the vertical schematization used by the simulation model is shown.

The water column is assumed to be very well mixed vertically. Input of components from (output to) the atmosphere is possible.

The sediment is divided into a number of layers. The solid as well as the dissolved components present may be transported from one layer to another and may disperse or diffuse into the overlying water.

For each layer, an extensive bookkeeping is performed.

For the solution of the mathematical equations describing the behaviour of solid and dissolved components appropriate methods are applied.

3.3.2 Horizontal schematization

In fig. 4, the model's horizontal schematization is shown.
The system to be simulated is thought to consist of a number of compartments. Each compartment has a vertical structure as described in the previous section. At the compartment boundaries inputs or output are possible via the water column, contributing to the compartment mass budget.

3.4 Definition of compartments

3.4.1 Topographically defined compartments

In the EmoWad model (EON-report 2,3), the area covered is divided into a number of compartments (actually twelve), each having their own characteristics (location, area, average depth, etc.). Also, in EmoWad each compartment consists of three sediment sub-compartments : the tidal flats, the sub-tidal area, and the tidal channels. The pelagic sub-compartment covers all these three sediment sub-compartments, although some minor differences are modelled for the water covering the tidal flats and the water covering the sub-tidal areas.
Regarding the sub-compartments, EmoWad discerns 36 sediment areas.

The reason to do so mainly is

- the existence of a freshwater inlet that might determine part of the systems behaviour.
- the wish to obtain detailed model results.

3.4.2 Functionally defined compartments

Presently, the idea proposed is to allow the use of functionally defined compartments. This means, for example, that the existence of tidal flats, sub-tidal areas and channels are assumed, irrespective of their geographic position. When there is a need to distinguish between some tidal flats, sub-tidal areas or channels each having their own chemical and/or physical characteristics, more than one tidal flat, etc., may be defined.

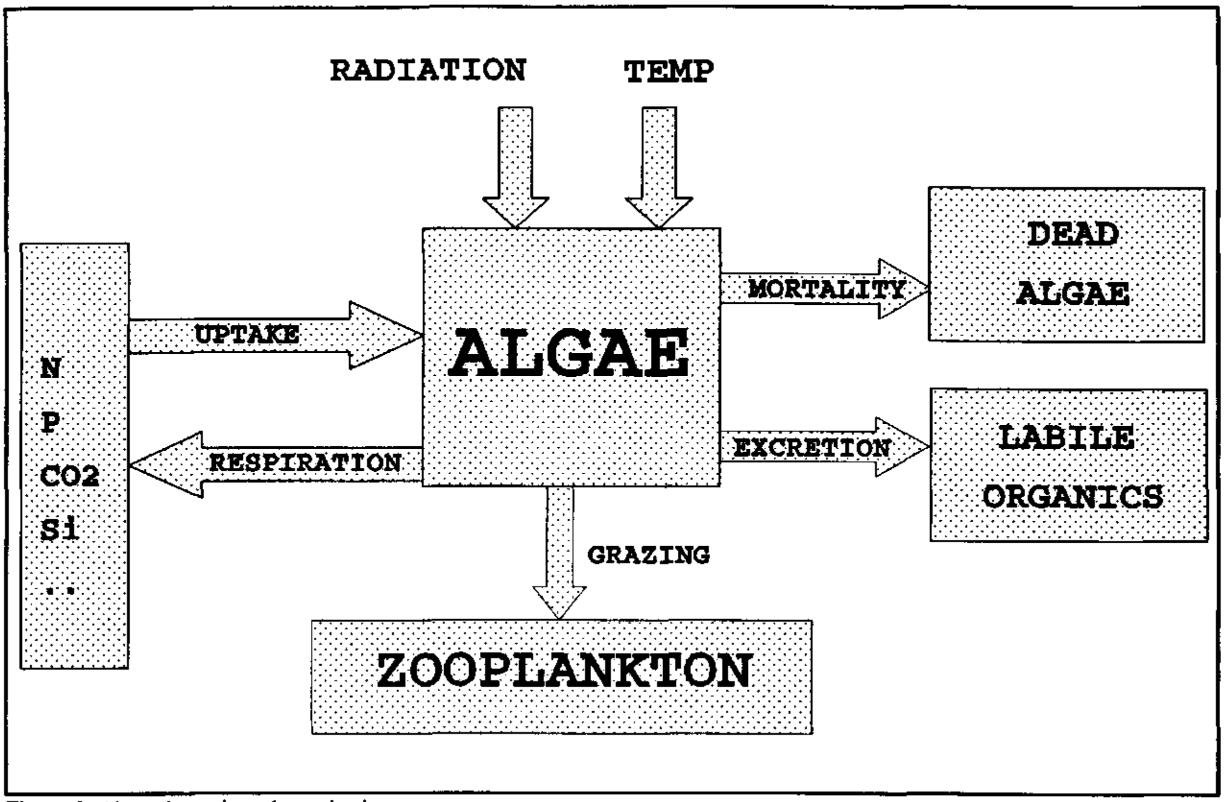

Figure 2. Algae dynamics schematization

The tidal water exchange between separate functional compartments is, again, part of the model input, and has to be calculated using some flow model (e.g. WASP-1 input). Analogously, sediment transport behaviour and resuspension/deposition characteristics should result from WASP-2 calculations and be fed to EcoWasp simulations.

In figures 5 and 6 examples of both the standard compartment choice and the proposed functionally determined compartment choice are given.

3.4.3 Implications for hydrodynamical calculations and interface

Whatever type of compartment choice will be used in EcoWasp calculations, water flows and exchange rates must be calculated using some flow model. Since flow models - as do all the physical models - use a rather fine grid defining a large number of compartments, the calculated flow characteristics are not suitable to be used in the ecosystem model runs. So, an interface has to be programmed, calculating all the relevant ecosystem flows and exchanges. This means that, when flow calculations are available, only the software interface is needed for the relevant data recalculation. Thus, irrespective of the compartment choice -and also the type of compartment choice- , just one flow calculation is needed from which all the relevant data may be derived.

This job is part of the WASP-project (Technical Annex, subject. WASP3/DE2)

3.4.4 Conclusions

In the present EmoWad model each compartment is thought to have a tidal, a sub-tidal and a channel part. This construction causes some difficulties, since on one hand it is assumed that a compartment is more or less a unit, a well mixed sub-system and on the other hand the program distinguishes between the tidal flats and the sub-tidal part and the channel by assuming partly different process characteristics. This construction implicitly is part of the EmoWad model and of the EmoWad program as well.

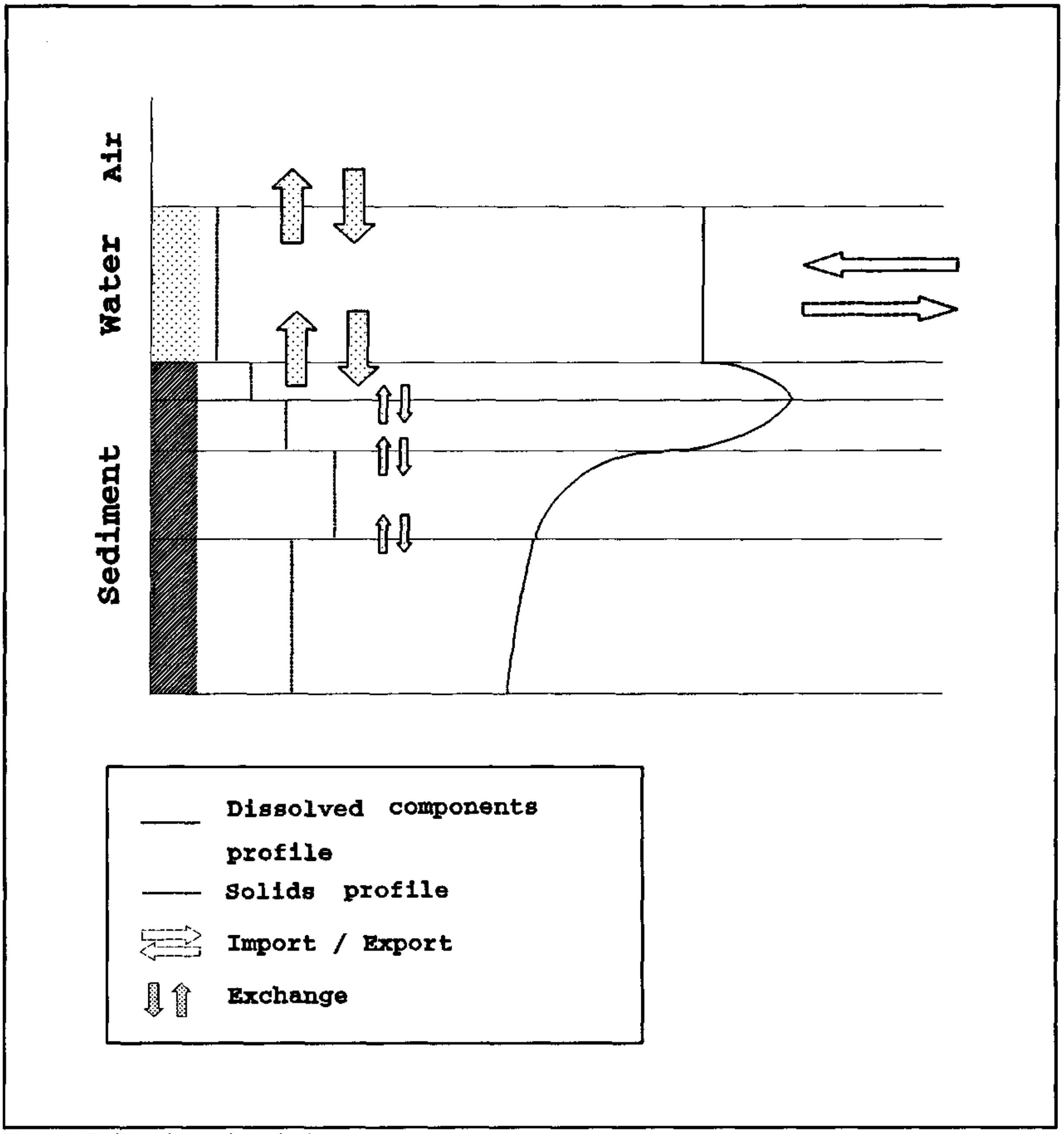

Figure 3. EcoWasp layer schematization.

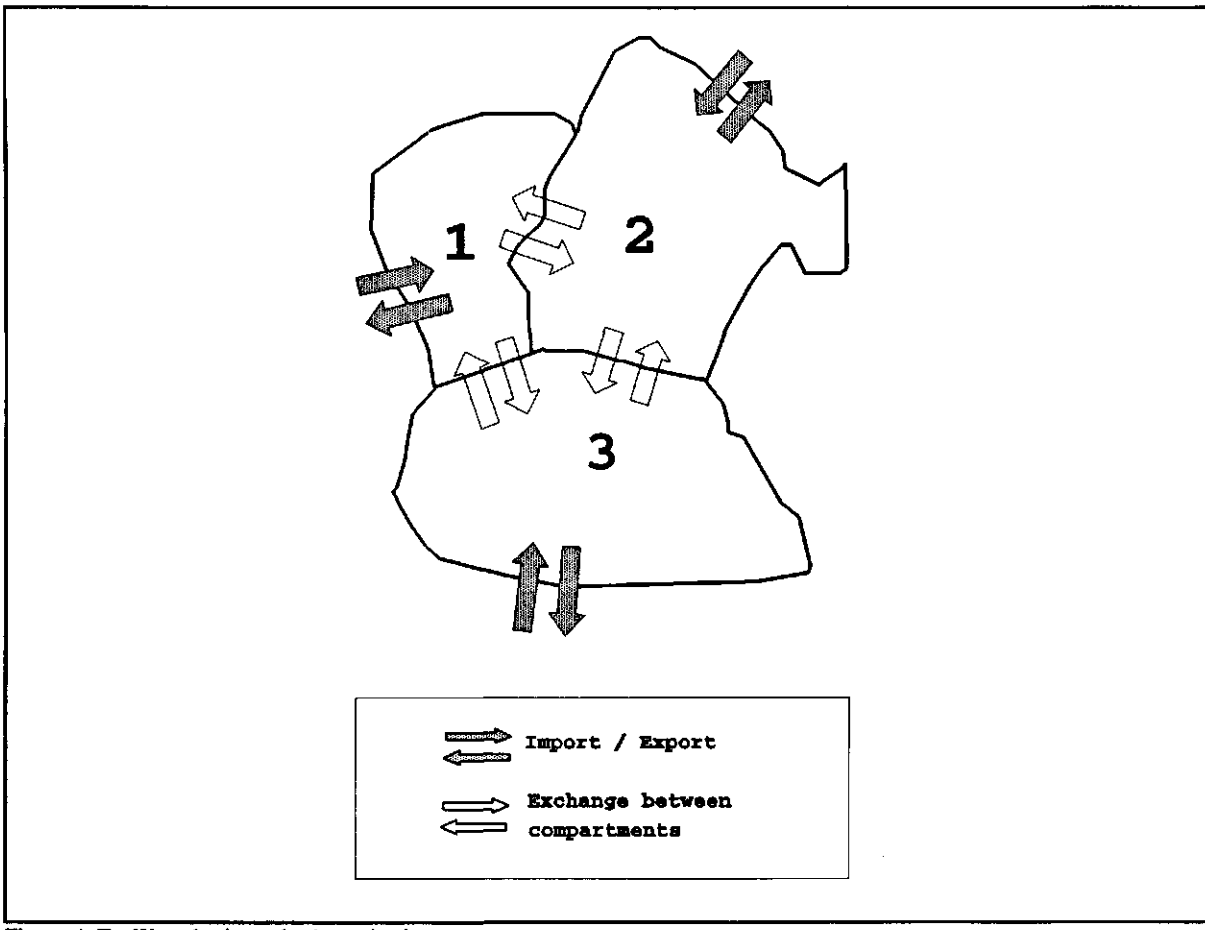

Figure 4. EcoWasp horizontal schematization

The proposed spatial schematization is somewhat easier to realize, since no special care is needed for programming sub-compartment processes.
Also, the user is able to define a number of tidal flats, each having their own specific emergence time and/or resuspension/sedimentation characteristics.

The future structure also allows for the choice of a very fine grid; the calculations are only limited by computer memory and run-time restrictions.

4 Outline of the simulation program

It is stressed that a simulation program contains a simulation model (the ecosystem abstraction) and also allows a number of additional calculations, e.g. uncertainty analysis. Input of field data is then required; an estimate of the reliability of model simulation results is provided (§6).
In fig. 7 a schematization of the simulation is given.

The EmoWad structure hardly allowed model extensions; so this structure needed some basic adjustments. EcoWasp will allow the free choice of variables (nutrients, algae, etc), as well as the addition of new nutrients, algae, etc., as long as no new processes are involved.

The EcoWasp simulation program will also allow the user to choose between a pure dynamic calculation of processes and the use of forcing functions for system variables. This is very useful in a number of cases.

5 Activities

5.1 Specific WASP-3 process study activities

In the WASP-3 project part, actually four specific study activities have begun.

1- development of a description of nitrogen processes in the sediment. This includes nitrification of ammonia in the oxygen containing upper sediment layer, and denitrification in the oxygen free layer where nitrate is the main mineralization process electron acceptor.
This part is carried out by the IBN and the NIOZ in close cooperation. Research workers : A.G. Brinkman (IBN), W. van Raaphorst (NIOZ).

2- development of a better description of suspension feeding organisms' dynamics and growth. This part is carried out by the IBN. A large number of field data on lengths and weights is available, and being processed. WASP-research worker involved : A.G. Brinkman.

3- development of a macrophyte-description, with special emphasis on *Zostera marina* and *Z. noltii.*
This part of the project will be carried out by Delft Hydraulics (DH). Literature data and, among others, Water Quality Institute (WQI) research results will be used. Realization: D. Jonkers (DH).

4- development of a more sophisticated bioturbation and bioirrigation description. Among others, the TURBOZO-description by (D. Jonkers, Delft Hydraulics) will be used.

5.2 Process study activities closely related to WASP-2 and WASP-1 project

1- data collection and literature study on erodibility as influenced by diatom beds and by *Corophium volutator.* Data collection will be done using laboratory and in situ experiments. Carried out by Water Quality Institute (WQI). Realization: K. Madsen.

2- process study on resuspension / sedimentation. Directly resulting from WASP-2 activities. Contacts : J. Krohn (GKSS- Forschungszentrum Geesthacht, BRD).

5.3 Model calibration and validation activities

1- model calibration. The EcoWasp model has to be calibrated. For this, data available for the western part of the Dutch Wadden Sea will be used, more or less the same dataset as was used for the EmoWad calibration. Many EmoWad parameter values will be used for EcoWasp since a large part of the descriptions will remain unchanged.

2- model validation. The calibrated EcoWasp model will be validated using more recent Dutch Wadden Sea data.

3- data assessment. For calibration, datasets are available. For validation, however, data from existing Dutch Tidal Water Division (Rijkswaterstaat) databanks are to be used.

5.4 Uncertainty analysis activities

A very important part of simulation model calculations is to elucidate the reliability of the results. Probably the most proper way to perform such analysis is to use an 'unknown-but-bounded' method, together with the Monte Carlo simulation technique (6,7).
When measurements of system variables are available, upper and lower limits for the relevant calculation results may be chosen. Parameter sets that give proper simulation results are stored, and re-used later on when performing scenario simulations.

Such an analysis will yield a lot of parameter combinations; each combination roughly having the same simulation accuracy.
Since the EcoWasp simulation model contains many parameters, only a restricted number of parameters can be the subject of such an analysis.

6 Necessary system characterising data

The EcoWasp simulation program allows the user to define his own model by choosing the number of algae species, sediment layers, compartments, etc, and by assigning particular values to the relevant process parameters. Situation dependent data should be provided by the user.

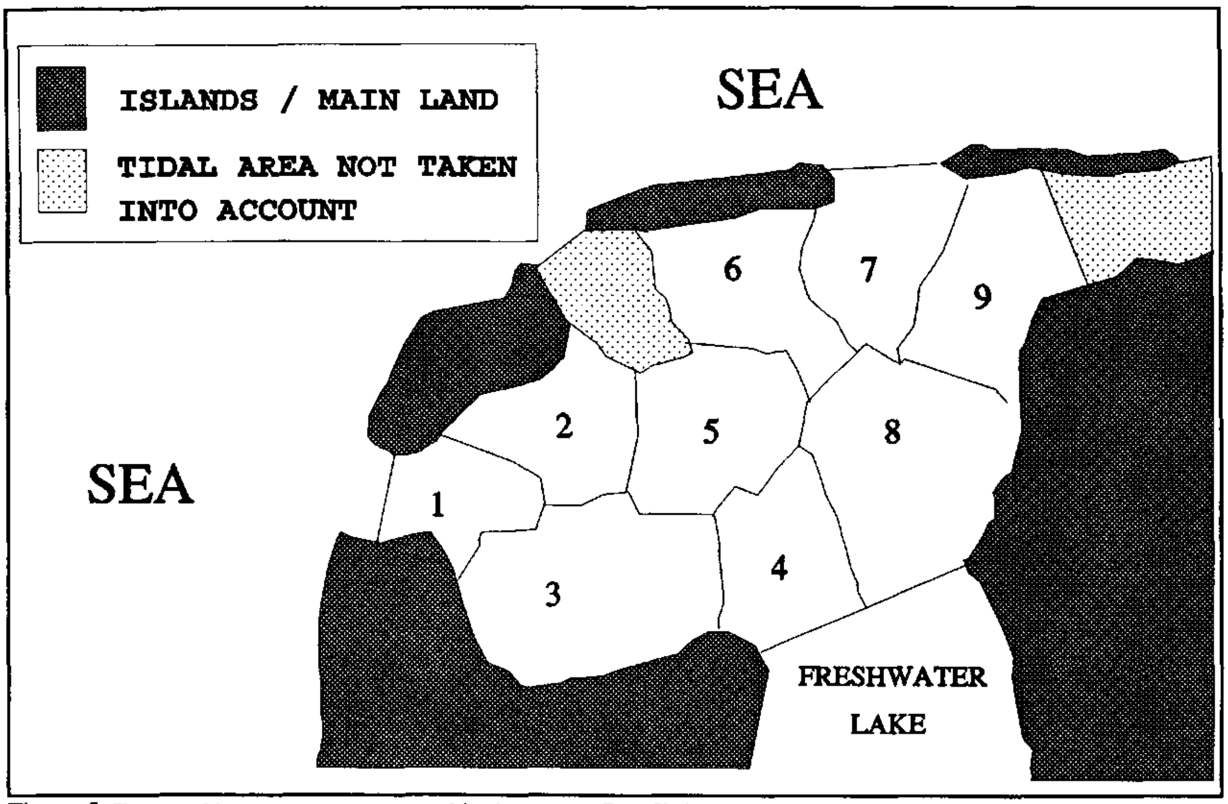

Figure 5. Topographic compartments, as used in the present EmoWad model

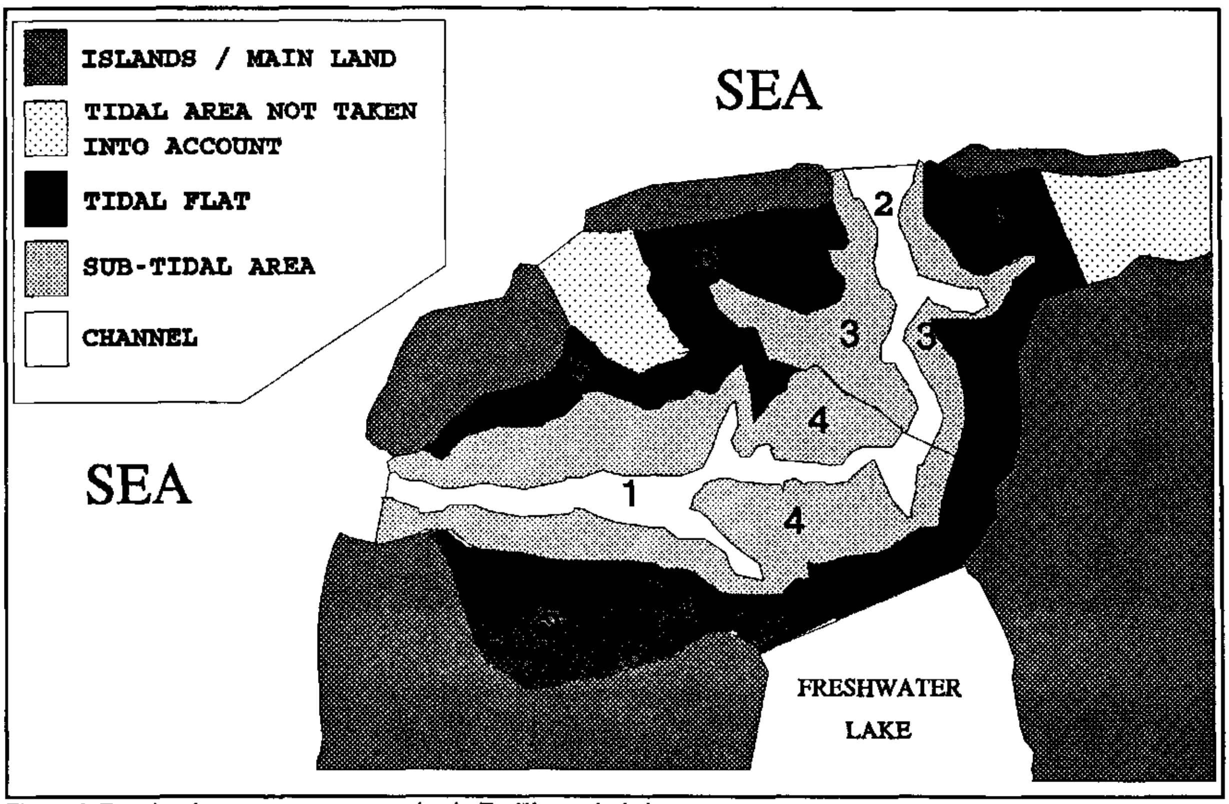

Figure 6. Functional compartments, an option in EcoWasp calculations

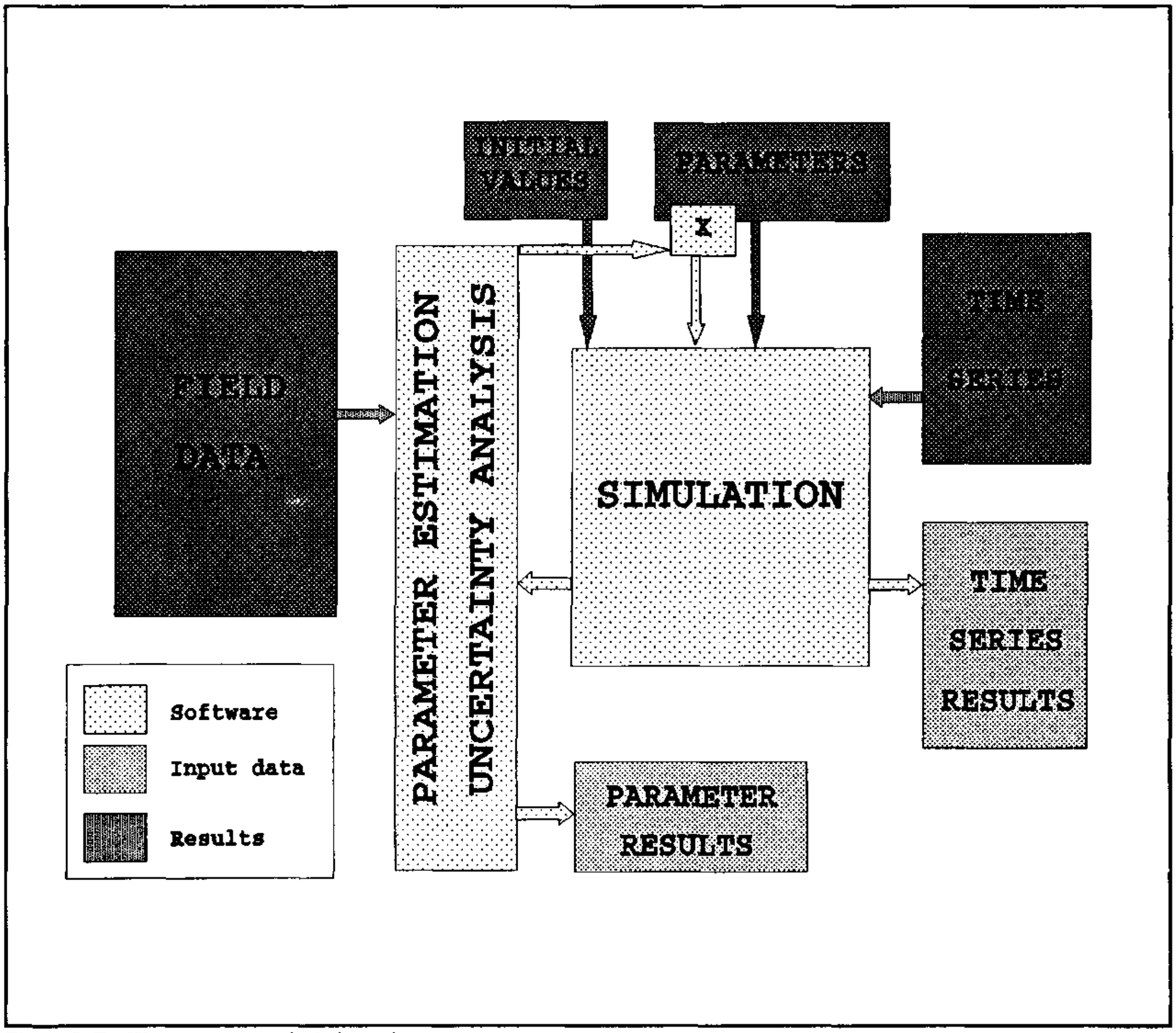

Figure 7. EcoWasp program calculation scheme.

When all the included processes are run, the data summed up in table 1 should be available.

The chosen compartments have to be characterized by variables such as mean depth, percentage of emergence time in the case of tidal processes, etc. Water flows and exchange coefficients are required.

7 WASP-1, -2 and -3 interactions and common research area

7.1 Interactions between WASP-3 and WASP-1 and -2

For the WASP-1, -2 and -3 projects a number of interactions exist:

1- the occurrence of diatom mats influences erodibility characteristics.

2- bacteria cause sediment particles to stick together. Bacterial growth is driven by high organic material concentrations, which are found in sedimentation regions (low erosion). Thus, low erosion is enhanced by bacterial growth; fine grained sediment and organic material trapped in these regions is cohesive, thus preventing easy resuspension.

3- presence of seagrass fields influences bottom friction and wave fields. The occurrence of eelgrass may especially effect physical properties. As a second effect, sedimentation is enhanced and resuspension tempered.

4- presence of mussel beds influences current fields, wave actions and erodibility.

5- bioturbation (sediment reworking by benthic organisms) makes fine particles to be buried in the sediment. Resuspension is prevented.

7.2 Common research area

In section 7.1 it has been explained that for WASP-2 and -3 a common model exercise area is necessary because of the frequent interactions. Since WASP-1 model focusses on wind, waves and currents, it should produce the data needed by the resuspension / sedimentation calculations, and the ecosystem transport sub-model. So, also WASP-1 models should be applied to this common research area.
The choice is important particularly for the EcoWasp-model exercises since the number of field and process data needed largely exceeds that of both the other project parts.

Possible areas are

1- Western Wadden Sea. Positive : large amount of ecological data available (1979, 1986).
Negative: no new data available.

2- Friesche Zeegat. Positive : extensive current and non-cohesive sediment transport studies carried out presently. Negative : no ecological data available.

3- Esbjerg Bight. Negative : only some biological data available, no opportunity for further extensive research.

4- Nordeney area. Research being done by the University of Oldenburg. Maybe future cooperation; presently not a real possibility.

5- Sylt - Rømø area. Positive: data collection is going on (German SWAP-project = Sylter Wattenmeer Austausch Prozesse). Access to data through GKSS-Forschungszentrum Geesthacht (BRD) (D. Murphy). Possibilities to discuss research topics (partly).

It is suggested that the Sylt-Rømø area be the subject of the simulation model computations for all the three WASP projects.
It is the most promising part of the Wadden Sea which is presently the subject of a more broad investigation. The assessment of necessary data is an extremely time consuming job, and cannot be carried out as part of the WASP project alone.
WASP-3 and WASP-2 both prefer this region.

8 Questions asked to WASP-1 and WASP-2 project

8.1 Questions to WASP-1 project

The WASP-1 project should result in current models and current calculations.

8.2 Questions to WASP-2 project

WASP-3 needs resuspension characteristics, cohesive and non-cohesive transport data, calculations on re-allocation of all kinds of solid matter.

9 Project results

Model revision. The EmoWad revision to EcoWasp is in progress. The nitrogen cycle is added to the model and a flexible environment is being realized.

Reports. The model adjustments are reported as soon as possible. Presently, an analysis of the benthic model part of the EmoWad ecosystem model is available (11); a second report on the calculation of mussel growth data from length-frequency distributions and lengte-weight relations is in progress. By the end of 1991, the calculation of pore water profiles will be reported.

10 Cooperation with other project

There is a close cooperation with the MAST project nr.0021 (ERSEM), especially concerning the description of benthic processes and the development of a new program shell.

References

(1) WASP-technical Annex to EEC-contract MAST 0026-C;

(2) Minutes WASP-3 workshop Texel, 1991/Jan/22-25

(3) EON (1988). Ecosysteemmodel van de Westelijke Waddenzee. EMOWAD-I/NIOZ-rapport 1988-1, 88 pp. (in Dutch)

(4) EON (1988). The ecosystem of the Western Waddensea: Field research and mathematical modelling. EMOWAD-II/NIOZ report 1988-11, 139 pp.

(5) Barretta J., P. Ruardij (eds) (1988). Tidal flat estuaries. Springer Verlag Ecological Studies 74, 353 pp.

(6) Straten, G. van (1986). Identification, uncertainty assessment and prediction in lake eutrophication. PhD-thesis, University of Twente, 240 pp.

(7) Keesman, K. (1989). A set-membership approach to the identification and prediction of ill-defined systems: application to a water quality system. PhD-thesis University of Twente, 133 pp.

(8) Brinkman, A.G. (1989). TmSim, een integraal waterkwaliteitsmodel voor simulatie van eutrofiëringsprocessen in ondiepe meren, University of Twente report CT89/047/133, 109 pp. (in Dutch)

(9) Brinkman, A.G., W. van Raaphorst (1986). De fosfaatkringloop in het Veluwemeer. PhD thesis, University of Twente (NL), 700 pp. (in Dutch)

(10) Raaphorst, W. van, P. Ruardij, A.G. Brinkman (1988). The assessment of benthic phosphorus regeneration in an estuarine ecosystem model. In: EON-EMOWAD-II/NIOZ-report 1988-11, pp 23-36

(11) Brinkman, A.G. (1991). EmoWad, the benthic submodel; an analysis of the description of biological processes in the bottom of tidal systems. Internal RIN-report 91/35, 152 pp.

APPENDIX 1

Minimum amount of data necessary for applying ECOWASP in e.g. Sylt/Rømø area.

The total number of data are divided into 4 major groups:

- Boundary conditions (North Sea);
- External inputs and forcing functions;
- Calibration and validation data;
- Miscellaneous (Morphology, ecological characteristics, exchange coefficients).

For optimal use the data should represent one and the same full annual cycle. If validation is to be performed an extra year is needed. Obviously, the frequency at which the data are to be collected differ from variable to variable, and possibly also over the season (e.g. high frequency during phytoplankton blooms, lower frequency out of the growing season). We roughly indicated the desired data frequency.

1: BOUNDARY CONDITIONS.

Variable (North Sea)	Frequency
dissolved inorg. P, NH4, NO3+NO2, Si	every two weeks
total P, total org. N	every month
Chlorophyll-a algal speciation (diatoms, flagellates, ...)	every two weeks every two weeks in periods of major succession
POC, DOC	every month
zooplankton biomass	April-May: every two weeks, otherwise every month.

2:EXTERNAL INPUTS AND FORCING FUNCTIONS

Variable	frequency (time, space)
Irradiation Temperature (air, water)	daily, total area daily, total area
suspended matter concentrations (particularly fine grained)	every two weeks, several representative locations
Inputs of nutrients (P, NH4, NO3+NO2) from atmosphere	as much as possible
Inputs of nutrients from mainland - Dissolved inorganic P, NH4, NO3+NO2, SI - Total P, total organic N	 weekly averages weekly averages
Inputs of water from mainland	weekly averages

3:CALIBRATION AND VALIDATION DATA

Benthic data should include both tidal flats and subtidal areas!!

Variable	frequency (time,space)
As boundary conditions	April-May: every two weeks, otherwise every month. For at least 2 representative locations.
extra:	
Primary production - pelagic - benthic	 as above as above
Dark O2 respiration in water column Benthic O2 respiration O2 penetration in sediment	as above every month, two sites every month, two sites
Benthic nutrient fluxes (P, NH4, NO3+NO2, Si) Pore water profiles of nutrients (upper 15 cm)	every 2 months, two sites every 2 months, two sites
Sea grasses (biomass, production, extension)	every 2 months, representative areas
Benthic fauna (mussels or suspension feeders, deposit feeders, meiobenthos), biomass	every 2 months, representative areas

4:Miscellaneous

Characteristics of area and its tidal basins

grain size distribution and organic C,N contents of sediments and porosity (representative areas, both tidal flats and subtidal areas)

Fe, Ca, Mn, P contents of sediments, again at representative areas

morphology, depth of basins, surface areas of tidal flats etc., emersion time of flats, ...

composition of benthic fauna

hydrodynamical parameters such as exchange coefficients (between basins and with adjacent North Sea), retention times and other characteristic time scales