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Macrobenthic populations along the estuarine gradient of the Schelde estuary: role of the abiotic (natural and human) environment

- Final Report -

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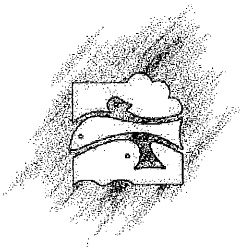

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TABLE OF CONTENTS

PART 4: ORGANIC AND INORGANIC CONTAMINANTS IN THE SCHELDE ESTUARY

PART 5: ECOTOXICOLOGICAL EVALUATION OF SEDIMENTS IN THE SCHELDE ESTUARY

INTRODUCTION

1. Estuarine ecosystem characteristics

Estuaries are transitional environments between rivers and the sea, which are characterized by widely varying and often unpredictable hydrological, morphological and chemical conditions (McLusky, 1989, 1993; Costanza et al., 1993). In most of the worlds estuaries, this natural stress is intensified by human activities. Especially land-claim, drainage of waste from domestic, industrial and agricultural activities, shipping and dredging are responsible for the direct and indirect loss of the estuarine environment (Davidson et al., 1991). Most of the world population resides in the coastal zone and the density of coastal economic development is increasing. This may have important negative effects on the biota and thus the ecological structure of the system.

The distinctive feature of estuarine ecosystems is the nature and variability (high-amplitude and unpredictable) of the physical and chemical forces acting on these ecosystems. This ‘natural’ stress tends to limit the number of species capable of adapting to these rigorous conditions. This natural stress is highest in the middle parts (mesohaline/oligohaline) of the estuary, where the mixing of salt water from the sea with freshwater from the rivers is highest. At both ends of the estuary, as well the seaward end as the riverine end, this natural stress is less, but still higher as compared to respectively the open sea and the river. Therefore, species distributions are dynamic and ever changing, as is the estuarine environment itself. E.g., the basic mesohaline macrofauna will sometimes be joined by predominantely marine or limnic species, depending on the salinity. For instance, in a winter with high river discharges large 'brackish' areas will potentially become 'fresh' and will cause mortality of the brackish-euryhaline species. When the salinity increases again, a recovery of the most tolerant species will occur by individual dispersion or by reproduction (Barnes, 1994).

In addition to this ‘natural’ stress, estuaries and coastal zone ecosystems are often subject to severe antropogenic influences, of which chemical pollution is one of the most important.

2. Measurement and evaluation of the ecological effects of stressors

Biomonitoring is a term that implies a biological system is used in some way for the evaluation of the current status of an ecosystem. The validation of the various approaches to predict the adverse effects of environmental stress on animals can only be done by effective monitoring of ecosystems.

Characteristics of the ecosystem can greatly modify the ultimate nature and distribution of the stressor. Therefore, a thorough understanding of the processes taking place in the abiotic environment is necessary.

The spatial and temporal distributions of ecological components should also be considered in an ecosystem characterization. Characteristics of ecological components that could influence their exposure to a stressor should be evaluated, including habitat needs, food preferences, reproductive cycles, and seasonal activities such as migration and selective use of resources. Spatial and temporal variations in the distribution of the ecological component (e.g. sediment invertebrate distribution) may complicate evaluations of exposure. Therefore, species-specific information about activity patterns, abundance, and life histories can be very useful in evaluating spatial and temporal distributions (see also Wayne & Yu, 1995; U.S. EPA Document 'A framework for ecological risk assessment').

As stressed above, especially in estuarine ecosystems, characterized by its highly dynamic and unpredictable nature, it is necessary to incorporate knowledge on both the natural abiotic environment and the spatial and temporal distributions of ecological components of interest, to be able to evaluate possible effects of chemical and/or physical stressors.

There is a continuum of monitoring points along the path an effect on an ecosystem takes. Techniques are available for monitoring at each level. It is possible to outline the current organizational levels of biomonitoring:

- bioaccumulatio/biotransformation/biodegration
- biochemical monitoring
- physiological and behavioral
- population parameters
- community parameters
- ecosystem effects

Each of these approaches gives only partial answers to the assessment of the (potential) hazards of a chemical and/or physical stressor. It is stressed by Underwood & Petersen (1988) that further research on the biological aspects of pollution effects should be focused on a combination of measures at different levels of biological organisation. Organismic measures potentially provide the earliest warning of possible future deterioration and may also be the most sensitive measure. Measures on communities may provide a better indication of the consequences of that pollution towards processes of economic value (Underwood & Petersen, 1988), and also towards the environmental quality of the marine and estuarine ecosystems.

Future studies should not only aim towards a combination of biological aspects but also towards a combination of chemical and biological aspects of pollution (Bayne, 1979). E.g., the Sediment Quality Approach (TRIAD) is a concept which combines these aspects (Chapman, 1986; Chapman et al., 1991). It incorporates three components: sediment chemistry which measures contamination, sediment bioassays which measure toxicity, and *in situ* parameters which measure benthic community structure and/or different population parameters. Each component of the Sediment Quality Triad is unique and complementary; a combination of the three components provides an assessment of sediment quality and in terms of biological responses it also provides strong evidence for determining pollution-induced degradation.

3. Outline and aims of the project

There is a clear need for integrated chemical/physical - biological field studies.

The aim of this study was a first attempt to follow a more integrative approach, in combining (1) a detailed field study on the community structure and population dynamics of benthic macroinvertebrates on seven intertidal locations along the estuarine gradient of the Schelde estuary with (2) field research on bioavailability of inorganic (metals) and organic (PCBs, PAHs) microcontaminants in sediment and porewater and their accumulation in benthic macroinvertebrates at these selected locations. A first ecotoxicological evaluation, based on laboratory bioassays, was also integrated.

A holistic top-down approach was followed by looking at real phenomena taken place in the field. Basically, this study investigates

1. the occurrence and concentrations of different contaminants, and their distribution among sediment, pore water, and animal tissue;
2. the possible effects of these chemical stressors, using benthic community structure and population characteristics of some key species

A baseline study on the abiotic environment of the sites investigated is incorporated and integrated in both parts, because, as already stressed above, the environment itself will determine the behaviour of both the stressor as the ecological component in an important way. Possibly the effect of the environment itself on the structure and characterization of the ecological component can overrule the effect of the chemical stressor.

Macroinvertebrates were chosen because they play a central role within the estuarine foodweb, acting as one of the most important primary consumers. The (macro)benthos, in their turn, is the main food item of most of the estuarine fish and bird species, and e.g. molluscs are also consumed by men.

Besides its central role within the estuarine foodweb, the benthos is also relatively sensitive towards antropogenic influences, both on a species, population and community level (see further).

The understanding of the dynamics of benthic invertebrates is of great importance to the studies of trophic relations. Estuaries are of vital importance for several bird species during one or several stages of their life cycle (Piersma, 1987; Smit & Piersma, 1989; Davidson et al., 1991). Especially waders depend almost exclusively during their stays on the occurrence of macroinvertebrates in these estuaries. Top predators in the aquatic foodchain are especially at risk for biomagnification and possibly secondary poisoning by contaminants.

Therefore, also some attention is paid to the distribution and occurrence of water birds in the Schelde estuary. Waterbirds are from a management point of view interesting species, not only because they are situated high in the estuarine foodweb and therefore being important consumers which will react on changes or human interventions in the water system (sensitive indicators), but also because the general public is sensitive to birds.

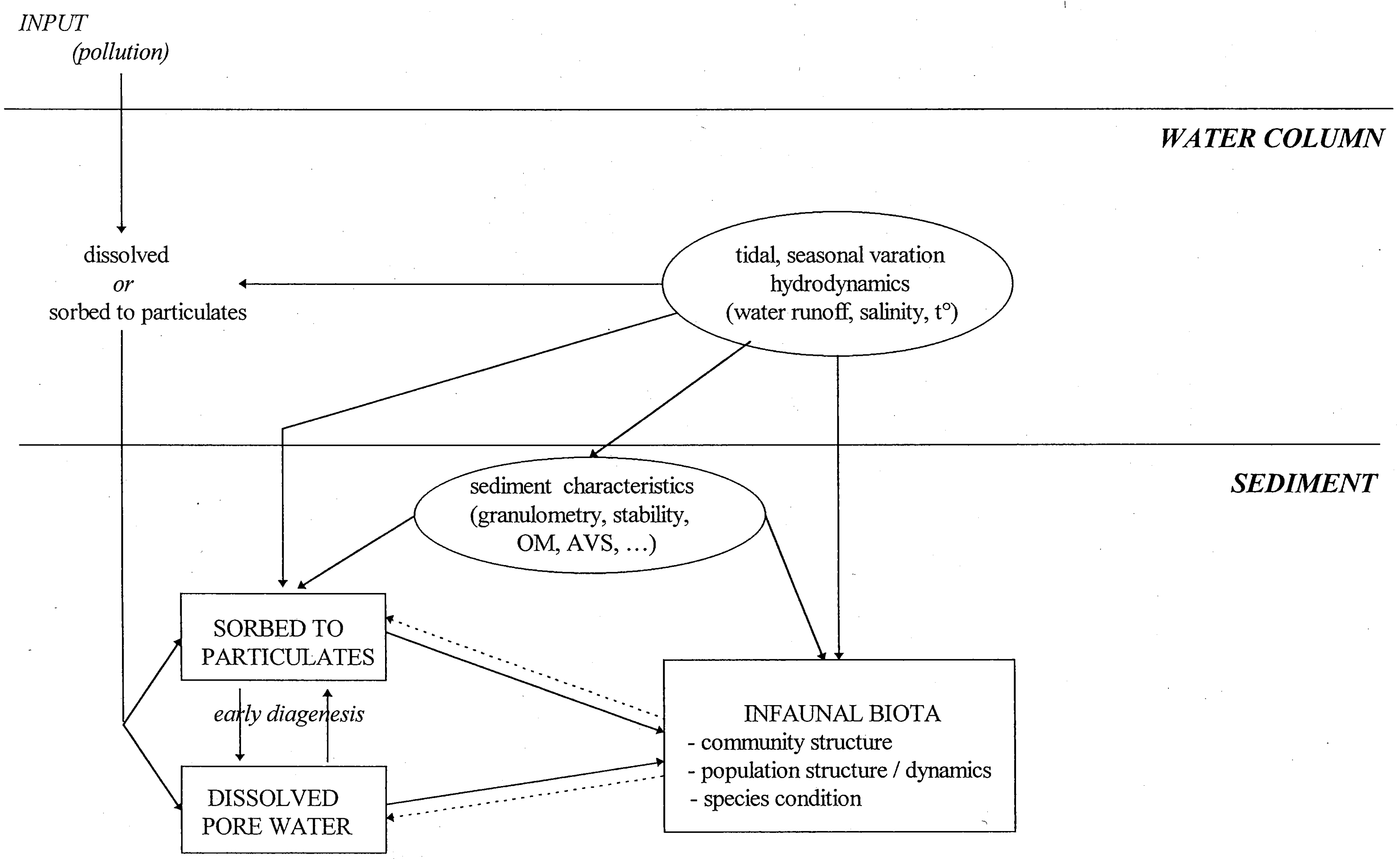
4. Conceptual model

Figure 1 shows a conceptual model in which the different pathways and interactions are shown which are studied within this project.

The fate and bioavailability of contaminants are determined in large part by their physical-chemical properties and the medium into which they are released. The environmental fate of many of the more persistent chemicals is ultimately deposition in aquatic sediments. The transport of contaminants (in solution or sorbed) to the sediment bed is strongly influenced by system characteristics like hydrodynamics, etc.

In the sediment bed, the contaminant is distributed among the sediment, porewater, and animal tissue (Figure 1). The spatial and temporal distribution of the contaminant among those three phases, together with the underlying processes, was studied in this project in detail along the salinity gradient of the Schelde estuary, especially concerning metal distribution.

As ecological component the macrobenthos was chosen (see above). Different measures of benthic community structure (e.g. diversity indices, multivariate analysis) have proven to give a good response to contamination along a pollution gradient (Gray et al., 1988; Heip et al., 1988; Warwick, 1988a,b). The idea is that the observed benthic community structure at a certain place reflects the effects of pollutants integrated over time. However, in the case of chronic effects or in the case of highly varying environmental variables (e.g. in esutaries and coastal zones), pollution effects can be masked or misinterpreted, based solely on a snapshot of the benthic community structure. Effects often appear at critical phases during the life cycle, e.g. during settlement and initial growth, reproduction, etc. (Obreski, 1979; Watzin, 1983; Weinberg, 1984). By measuring parameters such as recruitment, growth, condition, survival, migration, etc. one will better be able to detect possible moments of enhanced stress which will affect the population/community at a certain time, and will allow better understanding of natural (e.g. salinity) versus antropogenic (contaminants) induced stress. In this study the benthic community structure is studied on seven intertidal locations along the salinity gradient of the Schelde estuary, together with some detailed population studies on several estuarine key species. The role of the abiotic environment (hydrodynamics, temperature, salinity, sediment characteristics,etc.) takes a central place within the whole project (see Figure 1).


INPUT
(pollution)
WATER COLUMN
dissolved
or
sorbed to particulates
tidal, seasonal varation
hydrodynamics
(water runoff, salinity, t°)
SEDIMENT
sediment characteristics
(granulometry, stability,
OM, AVS, …)
SORBED TO
PARTICULATES
early diagenesis
DISSOLVED
PORE WATER
INFAUNAL BIOTA
- community structure
- population structure / dynamics
- species condition

5. Multidisciplinary research needs collaboration

To achieve our goals collaboration was necessary and therefore the Institute contacted several scientific institutes to achieve a multidisciplinary research group. Collaboration was established and financed by the Institute with different sciencitifc institutes, experienced in the following subjects:

- **Heavy metals**

Laboratory for Analytical Chemistry, Free University of Brussel
Pleinlaan 2, B-1050 Brussel, Belgium
Prof. Dr. W. Bayens, V. Srninetr

Metals were studied in collaboration with the Laboratory for Analytical Chemistry, where Prof. Dr. Bayens and his staff have already a long experience with metal chemistry in the Schelde estuary. The Institute cofinanced this collaboration and V. Srninetr was employed for four years to make a PhD on 'Bioavailability of sediment-associated metals to macrobenthic species of the Schelde estuary'. Parts of this study are inserted in this report as an appendix.

- **Organic micropollutants**

Provinciaal Instituut voor Hygiëne
Kronenburgstraat 45, B-2000 Antwerpen, Belgium
Dr. E. Rillaerts

Organic micropollutants were contracted to and analysed by this analytical laboratory, which has already long experience in analysis of organic micropollutants (PCBs, PAHs and OCPs) in sediments. The laboratory also set up a procedure to analyse organic micropollutants in animal tissue.

- **Ecotoxicology**

University of Ghent, Laboratory for Biological Research in Aquatic Pollution
J. Plateaustraat 22, B-9000 Gent, Belgium
Dr. C. Janssen, M. Vangheluwe, I. Vandemoortel, J. Van Waeyenberghe

A first attemt of an ecotoxicological evaluation was setup in collaboration with the Laboratory for Biological Research in Aquatic Pollution. This wellknown laboratory has already a long experience in the ecotoxicological evaluation of sediments in freshwater and marine ecosystems. Two thesis students were

- **AVS/SEM-analysis**

Vlaamse Instelling voor Technologisch Onderzoek (VITO)
Boeretang 200, B-2400 Mol, Belgium
M.P. Goyvaerts

As an important complementary part for the interpretation of the heavy metal data, the Institute was able to collaborate with VITO to conduct AVS/SEM analyses on a limited set of samples. The analysis of Acid Volatile Sulfide (AVS) together with Simultaneously Extracted Metals (SEM) is a recently introduced method with promising results towards a better understanding of the bioavailability of metals.

6. Outline of the Report:

INTRODUCTION

PART 1: MACROBENTHIC POPULATIONS ALONG THE SCHELDE ESTUARY

1. Seasonal and spatial distribution of macrobenthic communities along estuarine gradients in the Schelde estuary
   (Ysebaert, T., P. Meire & N. De Regge)

2. Life history and population dynamics of some indicator species in the Schelde estuary
   - *Macoma balthica*
   - *Scrobicularia plana*
   - *Mya arenaria*
   - *Corophium volutator*

   (Ysebaert, T., P. Meire & N. De Regge)

3. Short note on the macrobenthos observed in the oligohaline and freshwater tidal zone of the Schelde estuary
   (Ysebaert, T., J. Seys, R. Samanya & P. Meire)

PART 2: WATERBIRDS ALONG THE SCHELDE ESTUARY

1. Waterbirds along the estuarine gradient of the Schelde estuary
   (Ysebaert, Meininger, Meire, Devos, Berrevoets, Strucker)

PART 3: ABIOTIC CHARACTERIZATION OF INTERTIDAL MUDFLATS ALONG THE SCHELDE ESTUARY

1. A description of the abiotic environment of some intertidal mudflats along the salinity gradient of the Schelde estuary
   (Ysebaert, T., P. Meire & N. De Regge)

PART 4: ORGANIC AND INORGANIC CONTAMINANTS IN THE SCHELDE ESTUARY

1. Bioavailability of sediment-associated metals to macrobenthic species of the Schelde estuary: research framework
   (Srinetr, V., T. Ysebaert, P. Meire & W. Bayens)

2. Spatial and temporal variation of Acid Volatile Sulfide (AVS) and Simultaneous Extracted Metals (SEM) in intertidal sediments of the Schelde estuary .
   (Ysebaert, T., M.P. Goyvaerts, V. Srinetr, & P. Meire)

3. Spatial and temporal variation of organic microcontaminants in intertidal sediments of the Schelde estuary
   (Ysebaert, T., E. Rillaerts, & P. Meire)

PART 5: ECOTOXICOLOGICAL EVALUATION OF SEDIMENTS IN THE SCHELDE ESTUARY

1. Ecotoxicological evaluation of intertidal sediments along a salinity gradient of the Schelde estuary: summary
   (Tom Ysebaert, Marnix Vangheluwe, Ilse Vandemoortel, Jeroen Van Waeyenberge, Nico De Regge, Vihtet Srinetr, Colin Janssen & Patrick Meire)

APPENDIX:

'Bioavailability of sediment-associated metals to macrobenthic species of the Schelde estuary': draft concept of PhD thesis of V. Srninetr
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Seasonal and spatial distribution of macrobenthic communities along estuarine gradients in the Schelde estuary

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1. Introduction

The ecological study of the macrobenthos in the Schelde estuary has been mainly restricted to the general spatial distribution along the estuarine gradient (Vermeulen, 1983; Meire et al., 1991; Ysebaert et al., 1993, in prep.). The knowledge on the temporal distribution of the macrobenthos and the population dynamics of macrobenthic species in the Schelde estuary is at present unknown. However, knowledge on the temporal fluctuations of the macrobenthos is necessary to get insight into the structure and functioning of macrobenthic communities, which instead can help to understand the functioning of the estuarine ecosystem as a whole.

This study is part of a multi-disciplinary project in which macrobenthic populations of the Schelde estuary are studied in relation to the abiotic environment, and more specifically towards the role of pollution and morphodynamical variabels. The following questions are addressed in this paper: (1) what is the diversity, density and biomass along the estuarine gradients; (2) what is the seasonal fluctuation of the macrobenthos and does it differ spatially (3) what is the secondary production of the benthos; (4) which environmental variabeles correlates with the observed macrobenthic communities.

2. Material & Methods

2.1. Study area

The Schelde estuary, a macrotidal coastal plain estuary, is situated at the border between the Netherlands and Belgium. It measures 160 km between the mouth in Vlissingen and Gent, where it is artificially stemmed by a weir (Figure 2.3.1). The surface area of the estuary (excluding the tidal tributaries) is approximately 350 km^2, including a freshwater tidal area of about 17 km^2. The mean tidal amplitude increases from 3.8 m at Vlissingen to a max. of 5.2 m at Kruibeke. It diminishes more upstream to ± 2 m near Gent. The river discharge varies from 20 m^{3}s^{-1} during summer to 400 m^{3}s^{-1} during winter, with a mean yearly average of 105 m^{3}s^{-1}. The total volume of the estuary (2.5*10^9 m^3) is large in comparison with the volume of the water that enters each day from the river (9*10^6 m^3). The residence time of the water in the estuary is rather high, ranging from one to three months, depending on the river discharge. The mean annual chlorinity decreases from ± 16.6 g Cl$^-$/l near Vlissingen to ± 4.5 g Cl$^-$/l at the Belgian-Dutch border, and near the tributary Rupel the water becomes fresh (< 0.3 g Cl$^-$/l).

The lower and middle estuary, the so-called Westerschelde between the Dutch-Belgian border and Vlissingen (55 km), is a well mixed region characterized by a complex network of flood and ebb channels surrounded by several large intertidal mud- and sandflats. Tidal flats and marshes cover 34 % of the Westerschelde. The water column is moderately to well oxygenated, with oxygen saturation increasing from 20-60 % at the border to 90-100 % at the mouth of the estuary. Especially the middle and inner estuary is subject to extensive dredging and dumping.

The upper estuary, the so-called Zeeschelde between the Dutch-Belgian border and Gent (105 km), is characterized by a single channel, bordered with mudflats and marshes (28 % of total surface). Besides a brackish zone (mesohaline and oligohaline) between the border and the tributary Rupel, it has a freshwater tidal area of app. 60 km lenght. It forms an unique ecosystem, being one of the latest freshwater tidal areas of North-western Europe. However, this section is heavily polluted by domestic, industrial and agricultural waste loads. An important feature of a large part of this section is the presence of an anoxic water column during most of the year.

The chemical, physcial and biological properties of the Schelde estuary have been documented in detail by Heip (1988, 1989), Van Eck et al. (1991), Meire et al. (1992), and several papers in Meire and Vincx (1993).

2.2. Sampling

The macrozoobenthos was sampled on a monthly basis in the period March 1993 - June 1994 at five locations along a salinity and sediment gradient of the Schelde estuary (Figure 1 and Table 1). The location Paulinaschor (PAU) is situated in the polyhaline zone of the estuary, the locations Baalhoek (BH) and Valkenisse (PVV) in the poly-mesohaline transit zone, and the locations Groot Buitenschoor Left (GBL) and Groot Buitenschoor Right (GBR) in the mesohaline zone. All locations are situated in the intertidal zone. More details on the abiotic environment of the locations are given in Part Three of this report.

The sampling methods were different between the locations, and based on a pilot sampling. At the stations Paulina, Baalhoek and Valkenisse 15 small cores (diameter 4.5 cm) were taken to a mean depth of 25 cm and 5 large cores (diameter 15 cm) to a mean depth of 40 cm. At Groot Buitenschoor Left and Groot Buitenschoor Right only 15 small cores (diameter 4.5 cm) were sampled. The large cores were taken at stations were large, deep living individuals occurred like some bivalve species (e.g. *Mya arenaria*) and polychaete species (e.g. *Arenicola marina*).

The large cores were sieved in the field through a 3 mm mesh, the small cores were taken to the laboratory. All benthic samples were preserved in 4 % neutralised formalin. Different samples and measurements were taken for the characterization of the abiotic environment. Sediment characteristics, sedimentation/erosion processes, water and sediment quality parameters were considered. For a detailed description of the methods used see Part Three of this report.

In the laboratory the samples of the small cores were sieved through a 1 mm mesh and sorted after staining with 0.02 % Rose Bengal. The organisms of all samples were identified to species level, except *Nemertea* and *Oligochaeta*, and counted. Since Annelids are often broken due to handling, only parts with a head structure were counted and used in determining density. For most species only these small cores were used to determine density and biomass. For the bivalves *Mya arenaria*, *Macoma balthica*, *Cerastoderma edule*, and *Scrobicularia plana* a combination of the small cores with the large cores was used to determine density and biomass. The density of small individuals (for *M. arenaria* < 5 mm, for *M. balthica* < 4 mm, for *C. edule* < 2 mm and for *S. plana* < 3 mm) was complety determined based on the small cores, whereas density of the larger individuals was complety based on the large cores. To determine total density of these species both the results of the small cores and the large cores were added. For *Arenicola marina* only the large cores were used. The ash-free dry weight (AFDW) biomass was measured by drying all specimens at 105 °C for 12 h and ashing at 550 °C.

All species were classified in terms of feeding guilds. Feeding guilds distinguished are surface deposit feeders, deposit feeders, suspension feeders, omnivors and predators. In Table 1 the classification of all species into feeding guilds is given.

Of several selected species also body size measurements and/or life stage determinations were conducted in order to better understand the population dynamics of these species. Length measurements were done on all bivalve species, including the determination of age based on the counting and measurement of the yearrings. Length measurements were done for the gastropods *Hydrobia ulvae* and *Retusa obtusata*. For the crustaceans, length measurements were conducted on the amphipod *Bathyporeia spec.* and the isopod *Cyathura carinata*. Detailed measurements, including life stage determination, was done on the amphipods *Corophium volutator* and *C. arenarium*. For *Nereis diversicolor* and *N. succinea*, the width of the fifth segment was measured of all individuals, and body length of complete individuals. In this paper no detailed analysis on the population dynamics of these species are given, but some of the information is used to better understand the seasonal variation observed.

Table 1. Names and codes of the sampling locations. Distance (from the mouth of the estuary) and estuarine division is given.

Location	**Code**	**Distance (km)**	**Estuarine division**
Paulina	PAU	15	polyhaline zone
Baalhoek	BH	40	poly/mesohaline transit
Valkenisse	PVV	43	poly/mesohaline transit
Groot Buitenschoor Right	GBR	60	mesohaline zone
Groot Buitenschoor Left	GBL	60	mesohaline zone

2.3. Data analysis

Diversity was calculated as Hill's diversity numbers (Hill, 1973). Hill (1973) showed that several diversity indices are members of the equation:

$$Na = (pa + pa + ...pa)1/1-a$$

where $a>0$. When $a=0$, $N0 = S$, when $a=1$, $N1 = \exp H'$, when $a=2$, $N2 = 1/C$ and so on. With an increase of *a*, the dependence on the number of species S decreases, and, hence, on the sampling errors caused by the lower probability of counting the rarest species. For instance, N2 is less dependent on the number of species than N1. The last member of Hill's series ($N\infty$) which is the reciprocal of Berger-Parker's dominance index, is completely independent on the species richness.

Patterns on relative species abundances were produced by *k*-dominance curves. These *k*-dominance curves plot cumulative ranked abundances against (log) species rank (Lambshead et al., 1983). The purpose of such curves is to extract information on the dominance pattern within a sample, without reducing that information to a single summary statistic, such as a diversity index.

The following multivariate analyses were applied: classification by TWINSPAN cluster analysis (Hill, 1979) and by an agglomerative clustering method (group average sorting GAS of Bray-Curtis dissimilarities) and ordination by non-metric multi-dimensional scaling (MDS). The adequacy of the MDS representation was evaluated by the stress value (stress < 0.05 excellent representation; stress < 0.1 good; stress > 0.2 little better than random points). Plotting of the TWINSPAN/GAS clusters on the 2-D ordination planes aided in evaluating the divisions imposed. The significance of spatial and seasonal changes was assessed by randomisation/permutation (ANOSIM) tests, using a two-way crossed lay-out (Clarke, 1993). This layout allows the separation of the effect of the community changes along the salinity gradient from any changes associated with seasonal variability. Density and biomass data were subjected to fourth root transformation prior to analysis.

Diversity measures, k-dominance curves, group average sorting of Bray-Curtis dissimilarities, and MDS were performed using the statistical package

PRIMER (Carr et al.,1993).

To examine the rate of change in biotic structure from month to month, a method based on coenocline similarity projection was used. This method was presented by Boesch (1977) to look at zonation of the estuarine ecocline based on changes in biotic assemblages rather than species ranges. Coenocline similarity projection (CSP) is a simple graphical technique which projects a between-site or between-month similarity matrix as a series of curves plotted for sites ordered along an environmental (or seasonal) gradient. Similarity was measured with the above mentioned Bray Curtis coefficient. To have a more simplified presentation of these series of curves, the average slope of all projected similarity curves was computed for each between-site interval (see also Ysebaert et al., in prep.).

3. Results

3.1. Diversity indices

A total of 35 macrobenthic species were recorded (Table 2) in the five locations. Annelids were most diverse, being represented by 15 species. Of the remaining phyla, Molluscs were represented by 11 species and Crustaceans by 8 species. Nemertea makes the list complete. At all locations Annelids account for 40-50 % of the observed species. The number of mollusc species diminish from the polyhaline location Paulina towards the mesohaline locations (Table 2). Valkenisse is typically rich in crustacean species. In terms of feeding guilds, respectively twelve and five species are characarterized as surface deposit and deposit feeders. Seven species are suspension feeders, and both predators and omnivors are represented by five species.

Most species were observed in the polyhaline station Paulina and a downward trend is observed towards the mesohaline zone with the lowest number of species observed at GBR (Table 2). At all locations several species were observed in very low densities (1 or 2 individuals found) and only one to three times and could be therefore considered as accidental caughts (Table 2). *Carcinus maenas* and *Crangon crangon*, two epibenthic crustaceans, were excluded from all further analysis.

Table 3 and Figure 2 show Hill's diversity numbers (N0, N1 N2 N_∞) for each location in each month. In general, on a spatial scale a decreasing diversity (for all measures) is observed from the polyhaline zone towards the mesohaline zone (Figure 2). On a temporal scale the number of species (N0) is higher in the summer period as compared to the winter period (Figure 2a). This variation is much more pronounced in the mesohaline locations. At Valkenisse, the number of species (N0) doubles during summer time, and at GBL and GBR it even triples (Figure 2a). The other diversity measures show different patterns depending on the location. In GBL N1, N2 and N_∞ tend to be higher in spring and winter and drop in summer, indicating that fewer species were dominating the community numerically in summer as compared to the spring and winter situation (Fig 2b-d). More or less the same pattern is observed at Baalhoek, but here the different diversity measures stay also low during winter. The opposite occurs at GBR where N1, N2 and N_∞ are lowest during spring and winter and increase during summer, indicating that in summer time more species contribute to the total density than in winter and spring. At Valkenisse a short but deep drop in N1, N2 and $N\infty$ is observed during spring, after which a steep increase towards summer and winter occurs. This indicates that during spring the community becomes numerically dominated by a few species, while towards the winter time species are numerically more evenly distributed. At Paulina highest values of the different diversity measures are observed during summer.

3.2. k-dominance curves

Figure 3 shows the *k*-dominance curves for the five locations considered, based on a yearly average. The curves of the mesohaline locations GBL and GBR are very steep and reach the plateau first, whereas the polyhaline location Paulina shows the least steep curve. The poly/mesohaline locations Baalhoek and Valkenisse takes an intermediate position. These observations are consistent with the diversity measures, indicating an increasing dominance of only a few species from the polyhaline zone towards the mesohaline zone.

On a seasonal scale, the *k*-dominace curves of the five locations show a different pattern. Figures 4-8 shows *k*-dominance curves for each location, showing the spring situation (Mar-Jun), the summer-early autumn situation (Jul-Oct) and the late autumn-winter situation (Nov-Feb). The polyhaline location Paulina shows almost no seasonal pattern in the *k*-dominance curves, indicating no clear change in the dominance pattern. At Baalhoek a relatively small change in dominance pattern is observed during spring, when the most abundant species is less dominant as compared to the summer and winter situation. The other three locations show a clear seasonal pattern. At Valkenisse the community becomes numerically dominated by one species (80 %) during spring time, after which this dominance becomes more evenly spread over more species (steeper curves) during summer and, even more pronounced, during winter. At GBR the dominane curve is also least steep during spring time, with one species dominating the community with 80%. During summer and winter this dominance becomes is divided between two to three species. At GBL the summer situation is characterised by the dominance of one species (± 80 %), whereas in spring and winter the community is numerically dominated by respectively three and two species.

3.3. Density

The total density of the macrobenthos is highest in Valkenisse (4946-91841 N/m^2), followed by Paulina (12300-33500 N/m^2), GBL (4653-28797 N/m^2), Baalhoek (10400-27000 N/m^2) and GBR (1844-14504 N/m^2), but shows a clear seasonal variation in all locations (Figure 9). In general terms, low numbers are observed in winter and spring, high numbers in summer and autumn. However, the observed variation is much higher at the mesohaline locations Valkenisse, GBR and GBL, where an increase in density during summer time is observed of respectively 20, 8 and 7 times (Figure 9). At Paulina this increase in density during summer time is much less pronounced (± 2 times). At Baalhoek only a slight increase during June is observed, whereas the rest of the year density stays relatively stable.

The seasonal pattern is however clearly different between the different locations. The time of increase and the time of peak densities differ between locations (Figure 9). At Paulina, a significant increase is observed in May (from ± 15000 to 30000 N/m^2), aftere which densities stay high and relatively stable until September. During winter time numbers slightly drop. At Baalhoek, an increase is observed in June, but in July densities drop already to the same value as before and stay relatively stable year round. At Valkenisse, a steap increase from ± 10000 ind/m^2 to 80000 ind/m^2 is observed between May and June. Total density remains high until August, after which it drops to 55000-35000 ind/m^2 in September-November, and further to 15000-5000 ind/m^2 in December-April. In GBL, an increase in density is first observed in May and reaches a peak in July-August (28500 ind/m^2), after which numbers drop steady towards winter. In GBR, a clear increase in density is only observed from July onwards and a peak is reached in September (14500 ind/m^2), after which densities only slightly drop.

In terms of dominance of the different systematic groups, all locations are numerically dominated by Annelids, except for GBL which shows a clear dominance of Crustaceans (Figure 10). At the other locations Crustaceans take about 10 % of the total density (Baalhoek, Valkenisse and GBR) or ar neraly absent (Paulina). Molluscs take about 15 % of the total density in Paulina, Baalhoek and Valkenisse, whereas at GBL and GBR Molluscs are not important in terms of density. On a seasonal scale, this dominance of one systematic group is in general consistent trough the year. Only at GBL their is a shift in dominance of Crustaceans during summer towards Annelids during winter and spring. At GBR the community is characterized by a 100 % dominance of Annelids during spring and winter, whereas in summer also Crustaceans and Molluscs appear in the community.

In terms of dominance of the different feeding guilds, surface deposit and deposit feeders dominate at all locations, but in a different ratio: surface deposit feeders dominate at Paulina, Valkenisse, and GBL, whereas deposit feeders dominate at Baalhoek and GBR (Figure 11). Omnivors are only important at Baalhoek, GBR and GBL with resp. 23, 15 and 26 % of the total density observed. At these three locations, no suspension feeders were observed. On a seasonal scale, this dominance of one feeding type is in general consistent through the year, except at GBL where a shift from deposit feeders and omnivors dominating the community in winter and spring towards a community dominated by surface deposit feeders in summer is observed (Figure 12). At Valkenisse the spring and winter period is characterized by a 100 % dominance of surface deposit feeders, but in summer time other feeding guilds are observed in the community too. At GBR the community becomes also more diverse in summer time, when also surface deposit feeders are observed.

3.4. Community analysis: spatial and seasonal patterns

3.4.1. Spatial pattern

By combining all monthly data from each location into one dataset, the spatial pattern was studied. The general pattern is illustrated with the group average sorting of Bray-Curtis similarities and the MDS on density data (Figures 13-14).

The cluster analysis (Figure 13) shows a distinct and complete seperation between the five locations. In a first seperation, two highly dissimilar cluster groupings are distinghuished with resp. the locations Paulina-Baalhoek-Valkenisse and the mesohaline locations GBL and GBR. In a second division, the first cluster is then further divided into a Paulina cluster and a Baalhoek-Valkenisse cluster, after which the latest two locations are also seperated from each other in a third division. The cluster GBL-GBR is in a second division seperated into two distinct locations. Each 'location cluster' is composed of seasonal groupings at decreasing dissimilarity levels (see temporal pattern).

The MDS ordination is in general agreement with the cluster analysis (Figure 14) and has a stress value of 0.10, providing a good representation. The same clusters can be identified in the ordination plane formed by the first and second axes (Figure 14). Paulina-Baalhoek-Valkenisse are clearly segregated from GBL and GBR along the first axis. GBR and GBL are segregated along the second axis. Based on the tightness of the different groups, this figure also confirms more pronounced seasonal variations in PVV, GBL and GBR, as compared to Paulina and Baalhoek.

3.4.2. Seasonal pattern

For the seasonal pattern each location was analysed seperately, since the spatial pattern clearly showed distinct and complete seperation between all five locations. The general pattern is illustrated with the group average sorting of Bray-Curtis similarities and the MDS on density data (Figures 15-24). At all locations their is a clear seasonal pattern and the stress values of the MDS ordinations provides good representations. In the MDS ordinations, the months move along the first and second axis in a more or less circular movement, but the spring months do not necessarily return to same position from year to year.

The index of faunal change (Figure 25) also clearly demonstrates seasonal variation at all locations, especially in spring time. Variation is much higher at Valkenisse, GBR and GBL.

At Paulina all months show a relatively high similarity (Figure 15), indicating small seasonal changes in the community. Months are more or less clustered in a successive way, with clusters being March-April 1993, May-June 1993, July-August 1993, October 1993 - January 1994, February-May 1994, and June 1994. The same pattern is also observed in the MDS ordination (Figure 16), with summer and winter months being more tight together as compared to the spring months (March-June). Therefore, community changes appear to be more pronounced during spring months. Both the cluster analysis as the ordination also show that the spring months of the second year (Mar-May-Jun 1994) are different from the spring months of the first year 1993, which means that the community is different from spring time in 1993 to spring time 1994.

Baalhoek is characterized by the highest similarity between months, indicating relatively small changes in the macrobenthic community from month to month (Figure 17-18). However, spring, summer and winter months are segregated from each other and the spring months in 1994 (Feb-May 94) are different from those in 1993.

In Valkenisse, a relatively large dissimilarity is observed between certain groups of months. Based on the cluster analysis, the spring months of both 1993 and 1994 (Feb-May) are seperated from all other months (Figure 19). The other months are clustered in a successive way: a June cluster, a July-August cluster, a September-October-November cluster and a December-January cluster. This successive change in the community is clearly demonstrated with the MDS (Figure 20). The spring cluster is widely spread along the horizontal and vertical axes, whereas especially the summer months forms a more tight grouping.

In GBR, the cluster analysis show basically the same pattern as for PVV and GBL. However, May and June are now clustered in the same cluster as the winter and spring months (Figure 21), indicating that a change in benthic community occurred later in the year as compared to PVV and GBL. A successive change in the community is also demonstrated for GBR by the MDS-ordination (Figure 22).

In GBL, the cluster analysis seperates in a first division the winter and early spring months (Jan-Mar) from all other months (Figure 23). Like Valkenisse, the other months are clustered in a successive way: a May cluster, a June-July-August cluster and a September-October-November-December cluster. These clusters are clearly observed in the MDS (Figure 24).

3.4.3. Characterization of the benthic communities

The multivariate analysis clearly show distinct spatial and temporal variation of macrobenthic communities along the Schelde estuary. For each location a characterization of the macrobenthic community of each location is given based on the seasonal pattern of most common macrobenthic species at each location. Figures 26-36 give for each location the seasonal pattern of the most important macrobenthic species.

Paulina

In Paulina the community is numerically dominated by Annelida, but molluscs are also present in relavitely high numbers. Crustaceans are nearly absent. In terms of feeding types present, surface deposit feeders dominates the community yearround, followed by deposit feeders. Suspension feeders, omnivors and predators form a minor part of the community.

Paulina is characterized by the highest diversity of all locations studied. In general, both diversity and density increases towards summer and drops in winter and early spring. Most species show distinct peaks in densities. The month when these peaks occur, differ however between species. However, most of these peaks last for only one to two months, after which a clear drop in density is observed.

In the period March-April 1993 total density is low (12500-14500 N/m^2) and density of a few species start to increase (e.g. *P. elegans* and *E. longa*), whereas other species are still decreasing in numbers (*H. filiformis*). For the bivalve *S. plana* high numbers are observed in this period, most of the individuals being young individuals (0+), indicating that spatfall of this species occurred before March. In the period May - June 1993 several species reach already peak densities, resulting in an increase of the total density to 25000-29500 N/m^2. Peak densities are reach for the molluscs *S. plana*, *A. tenuis*, and *H. ulvae* and the Annelid *P. elegans*. In this period also an increase in density is observed for the Annelids *T. marioni*, *E. longa* and *P. ligni*, whereas densities of *H. filiformis* further decreased. In the period July-August 1993, new species appear and show peaks in density, whereas all species which peaked in May-June show already a distinct decrease in density. Therefore, total density remains around 29500-33500 N/m². Species which reach peak densities in this period are the bivalves *M. balthica* and *C. edule*, the gastropod *R. obtusata*, and the Annelids *N. diversicolor*, *P. ligni* and *Spio spec.* In the period September - December 1993 total densities drop slightly and vary between 19500-31500 N/m². Densities of several species, which reached a peak in the previous period, stay relatively high troughout this period (*M. balthica*, *T. marioni*, *E. longa*). The same holds for *H. filiformis* which reach peak densities in this period. Other species, like *C. edule*, *R. obtusata*, *N. diversicolor*, *P. ligni* and *Spio spec.* show a clear decrease in this period. In the period January - March 1994 numbers of most species either stay low or decrease further. Only *Oligochaeta* show an increase in this period. The period May-June 1994 clearly do not show a similar increase as it was observed in the same period in 1993. Densities of most species stay low. Only *M. balthica* show a remarkable increase in June, reaching much higher densities as the year before. *N. diversicolor, E. longa* and *Oligochaeta* show a slight increase in this period.

Baalhoek

In Baalhoek the benthic community is numerically dominated by Annelida the whole yearround. Deposit feeders are the most important feeding guild, but both surface deposit feeders and omnivors are also present in important numbers in the community. No suspension feeders are observed. Numbers of most species do not show distinct increases or peaks in spring or summer time. Only the spionids *P. elegans* and *P. ligni* show a short but distinct peak in June, resulting in an increase of the total density to 27000 ind/m² in this month. The rest of the year the total density fluctuates around 15000-18000 ind/m². In spring 1994 total density drops further to 10500 ind/m².

Numerically most important species yearround is *H. filiformis*, followed by *P. elegans* and *N. diversicolor*. Most important bivalve species is *S. plana*, most important crustacean is *C. carinata*. Between March and June 1993 *H. filiformis* dominates the community with densities between 5750 and 7500 ind/m² (25-40 %). In this period *P. elegans* takes ± 30 % of the total density, with a peak of 40 % in June 1993. From April on, an increase in the numbers of *S. plana* is observed and in May and June densities of 850 N/m² are observed. From July 1993 until January 1994 densities of *H. filiformis* fluctuates between 8150 and 10350 ind/m² and it numerically dominates the community with 50-60 % of the total density. Numbers of *P. elegans* drop in this period and the account of this species in the total density diminish to 5-15 %. Numbers of *S. plana* stay at a same level in July and August (800-900 N/m²), but afterwards they drop to 275-525 N/m². From February until May 1994 densities drop and *H. filiformis* becomes numerically less dominant, whereas *P. elegans* shows an increase in dominance. The numbers *of N. diversicolor* do not fluctuate much during the year, with only a slight drop in numbers in the winter period (Jan-Feb 94). This species accounts for 10-25 % to the total density. The numbers of C. carinata fluctuates between 450-850 ind/m² in the period March - September 1993, after which an increase is observed to 1000-1550 N/m² in the period October 1993 - May 1994.

Valkenisse

In Valkenisse the benthic community is numerically dominated by Annelida; Mollusca and Arthropoa form only a minor part of the community. In terms of feeding type, Valkenisse is numerically dominated by surface deposit feeders, in some months together with deposit feeders. Suspension feeders are the third most important group. All species have significantly lower densities in the spring and winter months, except for the amphipod *Bathyporeia pilosa*. *B. pilosa* shows high densities in winter and early spring and nearly disappear in the summer months. This is in contrast to all other species, which show clearly an increase in the summer months. However, the month of increase and the moment of peak densities clearly differ between species. This is well demonstrated with the two *Corophium* species, namely *C. volutator* and *C. arenarium*. Densities of *C. arenarium* increase in June and peak densities are observed in July and August. From September on, *C. arenarium* is nearly disappeared and instead *C. volutator* now reaches peak densities (September-October). Another important feature of the benthic community of Valkenisse is the high and rapid increase in densities of most species. This is best demonstrated with the spionid *Pygospio elegans*. In winter and spring this species is nearly absent, but from May to June an increase from 7500 ind/m2 to 65000 ind/m2 is observed.

Based on these differences the community composition changes from month to month. In April 1993 total density is very low (± 10000 ind/m^2) and the community is numerically dominated by *B. pilosa* (32 %) and *P. elegans* (50 %). In May total density doesn't change but the number *of B. pilosa* decreases and the community is dominated by *P. elegans* (75 %). In June density increases enormously to 80000 ind/m^2, and the community is nearly totally numerically dominated by *P. elegans* (90 %). However, several species like *M. balthica*, *M. arenaria*, , *C. edule*, *P. ligni and C. arenarium*, show an increase in this period as well, but do not contribute numerically to the community. In July and August density stays high (80000-90000 ind/m^2), but the dominance of *P. elegans* drops to 60-70 %, whereas other species reach peak densities in this period and become numerically important like *H. filiformis* (7-14 %), *C. edule* (6-7 %) and *M. balthica* (3-6 %). Other species which reach peak densities in July-August but do not have a substantial contribution to density are *C. arenarium*, *N. diversicolor*, *N. succinea*, *P. ligni*, and *M. areanria*. In September-October total density has dropped (± 55000 ind/m^2) and the community has changed again with the numerically dominant species being now *P. elegans* (35 %), *H. filiformis* (20-30 %) and *Corophium volutator* (16-17 %). Except for *C. volutator*, *H. filiformis* and *Nemertea* all species decreased in this period. In November total density decreases further (35000 ind/m^2) and the community is now dominated by *H. filiformis* (43 %) and *P. elegans* (25 %). In winter density decreased further, in December and January still dominated by *H. filiformis* and *P. elegans* (± 50 %). The amphipod *B. pilosa* appears again and makes 10-15 % of the total density in this period. In this period also *C. edule* disappears, whereas *M. balthica* and *M. arenaria* remains at ± 7 %. In February-April 1994 *H. filiformis* disappears and the only important polychaete left is *P. elegans*, which makes up 30-40 % of the total density observed. The importance of *B. pilosa* increases to ± 32 %, and *M. balthica* and *M. arenaria* are the most important bivalves with ± 20-25 % . In May 1994 *B. pilosa* disappears completely and, like in 1993, the community is dominated by *P. elegans* (60 %).

Groot Buitenschoor Right (GBR)

In GBR the benthic community is numerically dominated by Annelida, in some months forming 100 % of the population. In terms of feeding type, this location is dominated by deposit feeders. Surface deposit feeders and omnivors are less important.

In GBR, *Corophium volutator*, *Macoma balthica*, and *Heteromastus filiformis* show in general a similar pattern as in the other two locations with a sharp increase in the summer months, followed by a sharp decrease towards the winter. It is however striking that the increase in densities is one to two months later as compared to GBL, but is more or less the same as in PVV. *Nereis diversicolor* occurred in the beginning of the study in rather low numbers at GBR, but the numbers increased during the year and now clear decrease is observed. Oligochaeta, which are one of the most important species in this location, show a clear increase in the beginning of the study (March-July), but afterwards no clear trend was observed.

Groot Buitenschoor Left (GBL)

In GBL the benthic community is numerically dominated by Arthropoda, except in some winter and early spring months when Annelida are dominating. In terms of feeding type, surface deposit feeders dominate, in some months together with omnivors.

In GBL, the winter and spring months are numerically dominated by only two species, namely *Nereis diversicolor* and Oligochaeta. These are the only two species which remains in relatively high numbers throughout the year. However, an increase in late spring (Oligochaeta) and early summer (*Nereis diversicolor*) is clearly observed. In the summer and autumn months (June-November) the community is exclusively dominated by *Corophium volutator* (70-80 %). Some other species, like *Macoma balthica*, *Manayunkia aestuarina* and *Pygospio elegans* also enters the community in early summer but they never reach high densities and their numbers decrease rapidly.

3.5. Distribution and seasonal pattern of some important species

Annelida

Pygospio elegans and other Spionids

Pygospio elegans is one of the most common macrobenthic species which occur in high numbers at four locations: Paulina, Baalhoek, Valkenisse and GBL. This species is absent at GBR. Maximum numbers observed are highest in Valkenisse (72000 N/m^2), intermediate at Paulina and Baalhoek (resp. 13000 and 11000 N/M^2), and lowest at GBL (400 N/m^2). At all locations, P. elegans show a clear and relatively similar seasonal pattern: in May (Paulina) and June (Valkenisse, Baalhoek, GBL) numbers increase very rapidly and reach peak densities. At GBL and especially at Baalhoek it concers a very short peak, whereas at Paulina and Valkenisse numbers stay high until July and August respectively. Numbers decrease at all locations to a relatively steady level in winter and spring. This level is highest at Paulina (± 5500 N/m^2), and drops to ± 2000 N/m^2 at Baalhoek and Valkenisse. At GBL the species totally disappear in winter and spring.

Polydora ligni is the second most common Spionid species and it is observed at the same locations as *P. elegans*. But at GBL it only concerns two observations of one individual. Peak densities are much lower as compared to *P. elegans* with maxima of 4100 N/m² at Valkenisse, 1800 N/m² at Baalhoek and 500 N/m² at Paulina. The seasonal pattern is similar as the pattern observed for *P. elegans*: a very short peak of one month at Baalhoek and a longer period of high densities at Paulina and Baalhoek. Whereas *P. elegans* is observed whole yearround at these locations, *P. ligni* completely disappear in winter and spring.

Two other Spionid species are restricted to Paulina. The first one, *Tharyx marioni*, is very common at Paulina and reaches high densities (max. 10000 N/m²). Like the other spionids, T. marioni clearly show a seasonal pattern with an increase in density in May, after which densities stay high (5000-6000 N/m²) until winter and then slowly drop. The peak of 10000 N/m² in November is somewhat aberrant. The second Spionid species which is observed at Paulina concerns *Spio spec.* Maximum densities reached are 400 N/m², but no clear seasonal pattern is observed.

Heteromastus filiformis

Heteromastus filiformis is together with *P. elegans* and *N. diversicolor* the most common Annelid. It is observed at four locations: Paulina, Baalhoek, Valkenisse and GBR. It is absent at GBL.

Nereis diversicolor

N. diversicolor is the only macrobenthic species, together with the bivalve *M. balthica*, which is common on all five locations and it is the only species which is observed yearround at all locations.

Eteone longa

Eteone longa is observed at four locations, but at GBR it concerns one observation of one individual. Maximum densities observed are 2000 N/m² at Paulina, 200 N/m² at Baalhoek and 1250 N/m² at Valkenisse.

Mollusca

Macoma balthica

Macoma balthica is, together with the Annelid *N. diversicolor*, the only species which is common at all five locations. Especially at Paulina and Valkenisse the species reach high densities. Clear seasonal patterns, with an increase (spatfall) in spring/early summer are observed at Paulina, Valkenisse, GBR and GBL.

Scrobicularia plana

Scrobicularia plana is common at the locations Paulina and Baalhoek. At Valkenisse the species is observed almost every month, but only in very low numbers. At GBR and GBL the species is absent. Maximum numbers observed are 2750 N/m² at Paulina and 950 N/m² at Baalhoek.

Cerastoderma edule

Cerastoderma edule is common at Paulina and Valkenisse. At Baalhoek this species is only observed a few times in very low densities. *C. edule* is absent at GBL and GBR. Maximum numbers observed are 1550 N/m^2 at Paulina and 5900 N/m^2 at Valkenisse.

In Paulina numbers vary between 250-375 N/m^2 in the period March-June 1993. In July spatfall occurs and density increase to 1550 N/m^2. However, this peak is very short and in August density drop already to ± 500 N/m^2. Numbers stay then relatively stable until December, after which they slowly decrease to ± 100 N/m^2 in spring 1994.

In Valkenisse a different pattern is observed. *C. edule* is absent until June 1993, after which an explosive increase is noticed in July and August of new spatfall with maxima of 5900 N/m^2. In September and October densities fluctuate around 4000 N/m^2, but from November on a sharp decrease is noticed and from February 1994 *C. edule* is again totally absent at Valkenisse. From this it can be concluded that *C. edule* do not survive winter time at Valkenisse.

The time of increase, and in other words, the moment of spatfall of *C. edule* , is the same in both locations (June 1993).

Mya arenaria

Mya arenaria is only common at Valkenisse with a maximum density observed of 2300 N/m^2. At Paulina and Baalhoek the species is irregularly observed in very low densities. At GBR and GBL the species is absent, except for one observation of one individual at GBR in September 1993.

The seasonal pattern of *M. arenaria* in Valkenisse show some similarity with the pattern observed for C. edule. M. arenaria is also not observed until June 1993, after which a large spatfall occurs in July. Numbers stay high until November 1993 and vary between 1600 and 2300 N/m^2.

Abra tenuis

Abra tenuis is only observed at Paulina in low densities. However, like the other bivalves, this species clearly show a seasonal pattern. *A. tenuis* is absent in winter and spring, but from May on spatfall is observed with a maximum of 250 N/m^2 in June.

Hydrobia ulvae

Hydrobia ulvae is the only commonly seen Gastropod and is observed at all five locations, but at GBR and GBL it concerns only two observations of a few individuals. At the other locations, *H. ulvae* is very common.

Retusa obtusata

Retusa obtusata is only observed at Paulina, but here it is a relatively common species. Densities are very low in winter and spring. In July a very sharp increase is observed with a peak density of 750 N/m^2. From August on, numbers drop steadily towards winter.

Crustacea

Corophium volutator and *C. arenarium*

Corophium volutator is a common species at Paulina, GBL and GBR. Especially at GBL this species dominates the community. At Baalhoek ......

Corophium arenarium is only seen in relatively high numbers at Valkenisse. At all other locations *C. arenarium* is absent. Like *C. volutator*, *C. arenarium* clearly show a seasonal pattern. However, both coexistent species show a clearly seperated pattern at Valkenisse. Densities of *C. arenarium* start to increase in June and reach peak densities in July and August (± 3000 N/m^2). In August, the number *C. volutator* starts to increase and at the time this species reach its peak densities in Septermber-October, *C. arenarium* already disappeared almost completely.

Cyathura carinata

Cyathura carinata is the commonest crustacean at Baalhoek. Except for two observations at Valkenisse, *C. carinata* is absent at the other locations.

Bathyporeia pilosa/sarsi

Bathyporeia pilosa/sarsis is a common species at Valkenisse. At all other locations this species is absent, except for respectively one and three observations of one individual at Baalhoek and GBL. *B. pilosa/sarsi* is the only macrobenthic species which show a complete inverted seasonal pattern. Highest densities are observed during winter, whereas in summer the species nearly disappear.

4. Conclusion

Spatial and seasonal variations in macrobenthic community structure are significantly present in the Schelde estuary. Seasonal variations are more pronounced in the mesohaline zone of the estuary, but diversity is much lower here. At most locations a cyclic seasonal pattern is observed.

5. Literature

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Table 2. List of species found in Paulina (PAU), Baalhoek (BAA), Valkenisse (PVV), Groot Buitenschoor Left (GBL) and Groot Buitenschoor Right (GBR). Feeding guilds are indicated between brackets: sdf=surface deposit feeder; df=deposit feeder; sf=suspension feeder; o=omnivor; p=predator. Rare species observed only 1 to 3 times are indicated with resp. 1, 2 and 3.

	PAU	BAA	PVV	GBR	GBL
Crustacea					
Bathyporeia pilosa (sdf)	1		x		3
Haustorius arenarius (sf)			1		
Corophium arenarium (sdf)			x		
Corophium volutator (sdf)	1	x	x	x	x
Crangon crangon (p)	3	1	3		2
Carcinus maenas (o)	x	1	3		
Eurydice pulchra (p)			1		
Cyathura carinata (o)		x	1		
Mollusca					
Cerastoderma edule (sf)	x	x	x		
Macoma balthica (sdf)	x	x	x	x	x
Mya arenaria (sf)	3	x	x	1	
Scrobicularia plana (sdf)	x	x	x		
Abra tenuis (sdf)	x				
Mysella bidentata (sf)	x				
Petricola pholadiformes (sf)		1			
Ensis spec. (sf)		2			
Bivalve spec.	1	1			
Hydrobia ulvae (sdf)	x	x	x	2	2
Retusa obtusata (sdf)	x				
Annelida					
Anaitides mucosa (p)	x				
Arenicola marina (df)	x		x		
Capitella capitata (df)	x	1			
Etone longa (p)	x	x	x	1	
Heteromastus filiformis (df)	x	x	x	x	
Manayunkia aestuarina (sf)					x
Nephtys spec. (o)			2		
Nephtys hombergii (o)	x		2		
Nereis diversicolor (o)	x	x	x	x	x
Nereis succinea (df)	1		x		
Polydora spec. (sdf)	x	x	x		2
Pygospio elegans (sdf)	x	x	x	2	x
Spio spec. (sdf)	x				
Tharyx marioni (sdf)	x	1			
Oligochaeta (df)	x	1		x	x
Nemertea (p)	1	x	x	1	2
Total number of species	**26**	**21**	**24**	**10**	**11**
(°without rare species)	**20°**	**13°**	**16°**	**5°**	**6°**

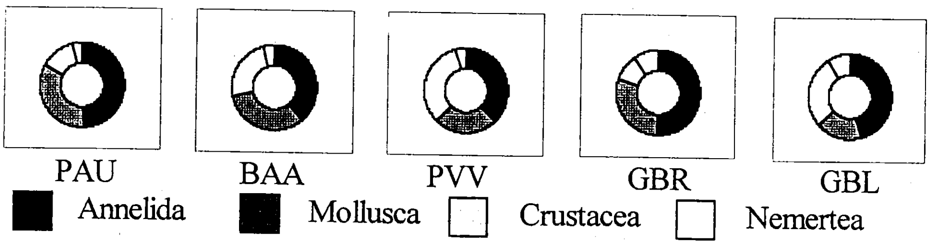


Table 3. Hill's diversity numbers N0, N1 N2 N∞ for each location in each month.

PAU	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	May
N_0	12	15	15	16	18	17	18	16	18	15	16	16	13	13
N_1	6.36	6.87	6.12	7.07	7.89	7.99	7.34	7.56	6.06	6.89	7.57	6.03	5.61	5.2
N_2	5.32	5.29	4.24	4.46	5.01	6.19	6.02	6.21	4.66	5.68	5.75	4.67	4.18	3.74
N_{∞}	3.53	3.03	2.4	2.46	2.58	4.27	4.62	4.53	2.84	3.7	3.58	2.98	2.89	2.61

BAA	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	May
N_0	11	13	12	11	12	13	11	11	14	13	10	9	7	8
N_1	4.28	5.13	4.65	5.06	4.44	4.36	3.59	3.86	4.38	4.29	4	5.32	4.89	5.46
N_2	3.4	4.12	3.73	3.81	3.14	2.94	2.48	2.54	2.81	2.83	2.59	4.35	4.19	4.82
N_{∞}	2.42	3.07	2.72	2.47	1.99	1.89	1.71	1.7	1.78	1.81	1.69	2.66	2.91	3.64

PVV	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
N_0	8	9	11	16	19	14	19	17	15	14	10	8	9	8
N_1	3.44	2.77	1.68	3.6	4.79	6.23	5.98	5.6	7.9	7.8	5.47	4.61	5.8	3.94
N_2	2.63	1.79	1.25	2.07	2.74	4.57	4.19	3.81	5.77	5.81	4.20	3.66	4.8	2.54
N_{∞}	1.91	1.36	1.12	1.46	1.73	2.76	2.83	2.33	3.26	3.37	2.84	2.58	3.37	1.67

GBL	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	May
N_0	4	3	5	8	7	6	6	5	4	5	4	5	5	3
N_1	2.79	2.80	3.33	2.64	1.93	1.98	2.07	2.13	2.13	2.79	2.39	2.42	2.73	1.85
N_2	2.52	2.66	3.06	1.87	1.49	1.51	1.63	1.73	1.75	2.49	2.20	2.06	2.14	1.55
N_{in}	1.95	2.18	2.43	1.41	1.24	1.25	1.32	1.38	1.39	2.17	2.01	1.61	1.56	1.29

GBR	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	May
N_0	3	3	5	4	5	5	8	7	6	5	3	4	2	2
N_1	1.57	1.62	1.54	1.6	2.19	4.02	4.46	4.48	3.81	2.61	1.69	2.24	1.78	1.83
N_2	1.28	1.35	1.23	1.26	1.58	3.38	3.85	3.97	3.19	2.04	1.47	2.1	1.63	1.70
N_{in}	1.14	1.17	1.11	1.13	1.27	2.22	2.77	2.72	2.11	1.51	1.25	1.99	1.36	1.41

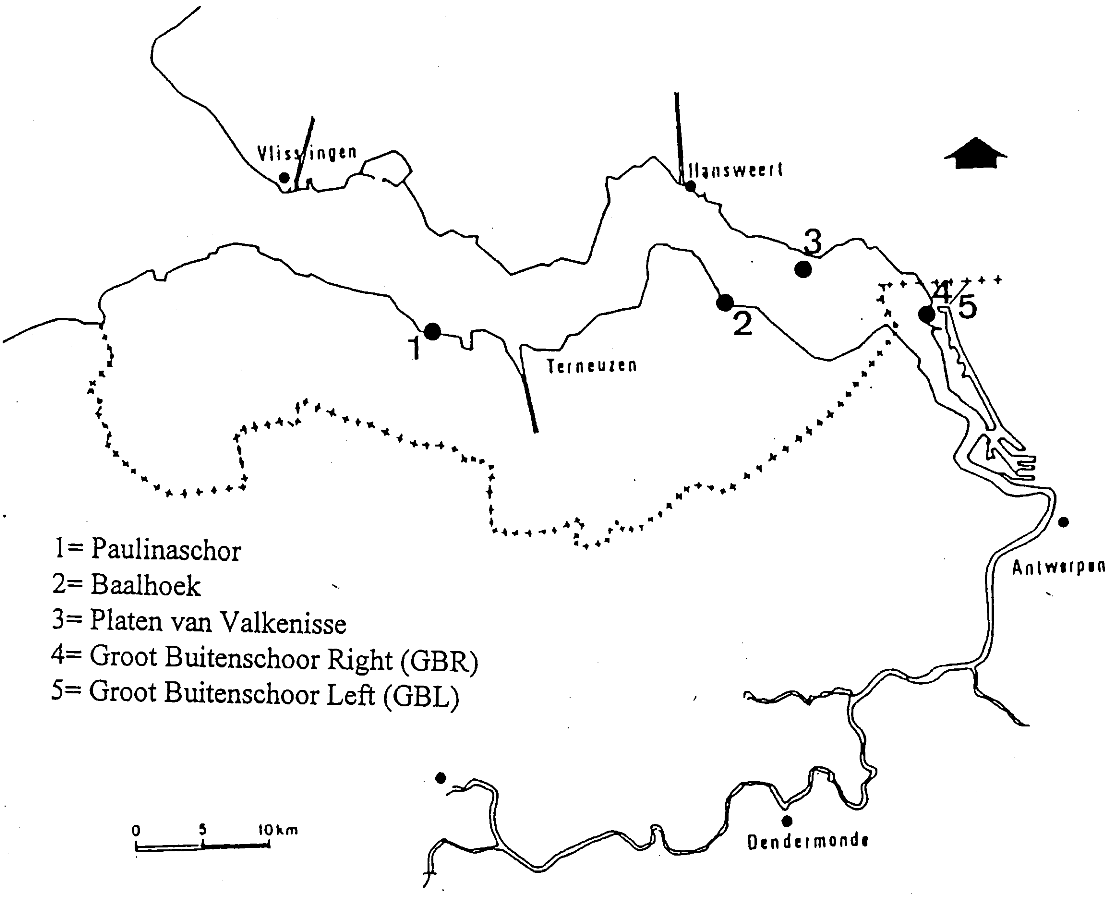


Figure 1. Map of the Schelde estuary with situation of the sampling locations.

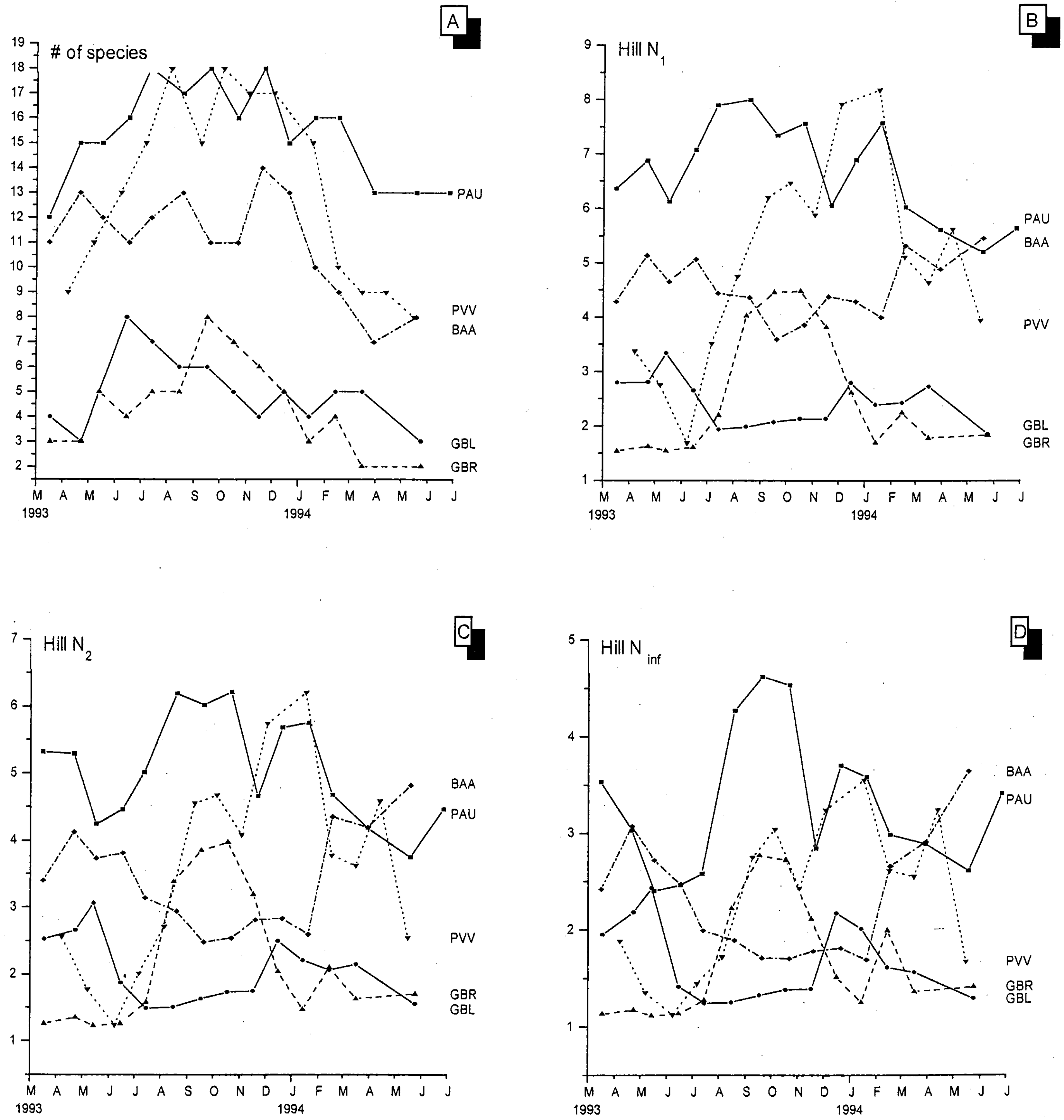


Figure 2. Seasonal variation in Hill diversity indices.

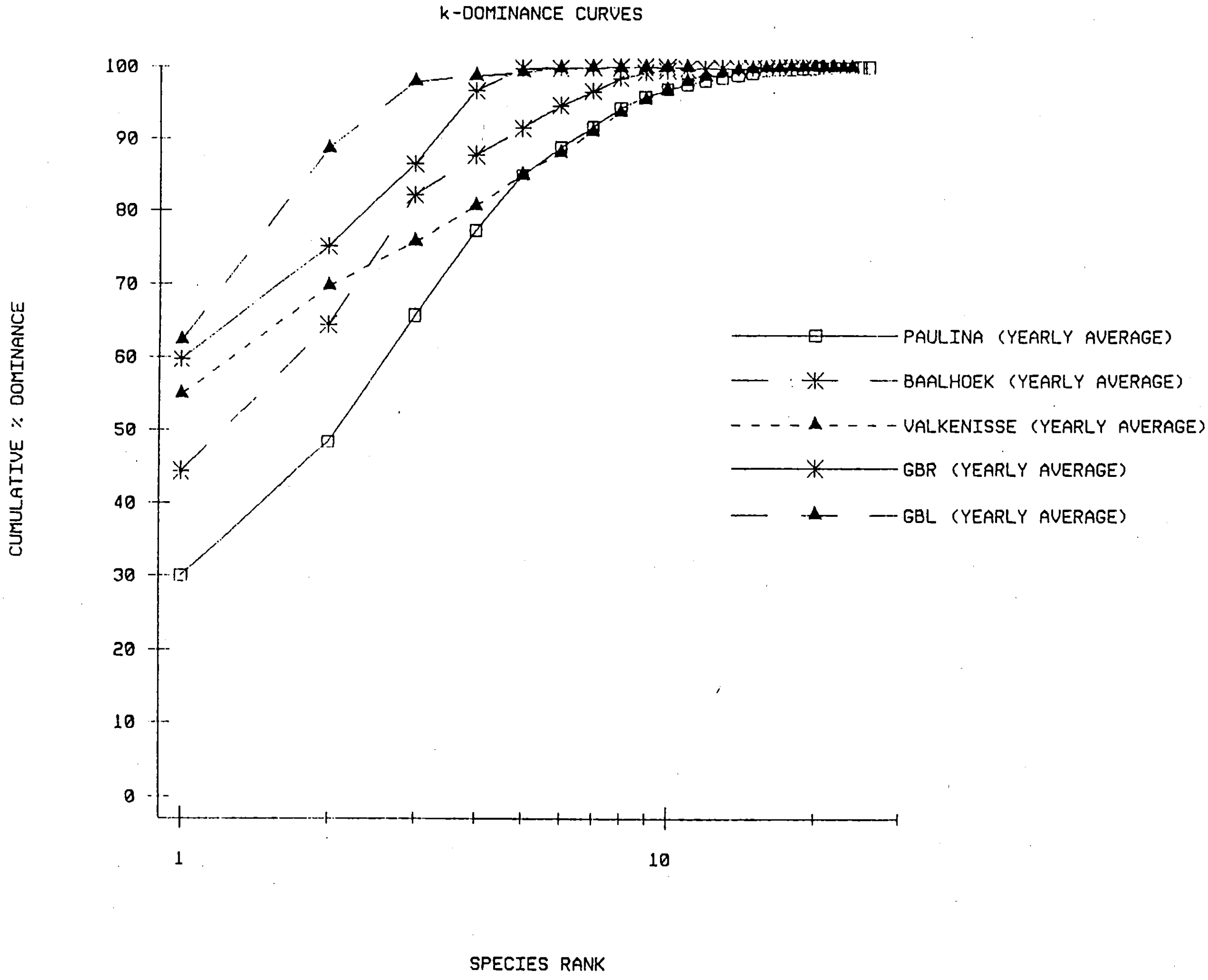


Figure 3. K-dominance curves of the five sampling locations (yearly average).

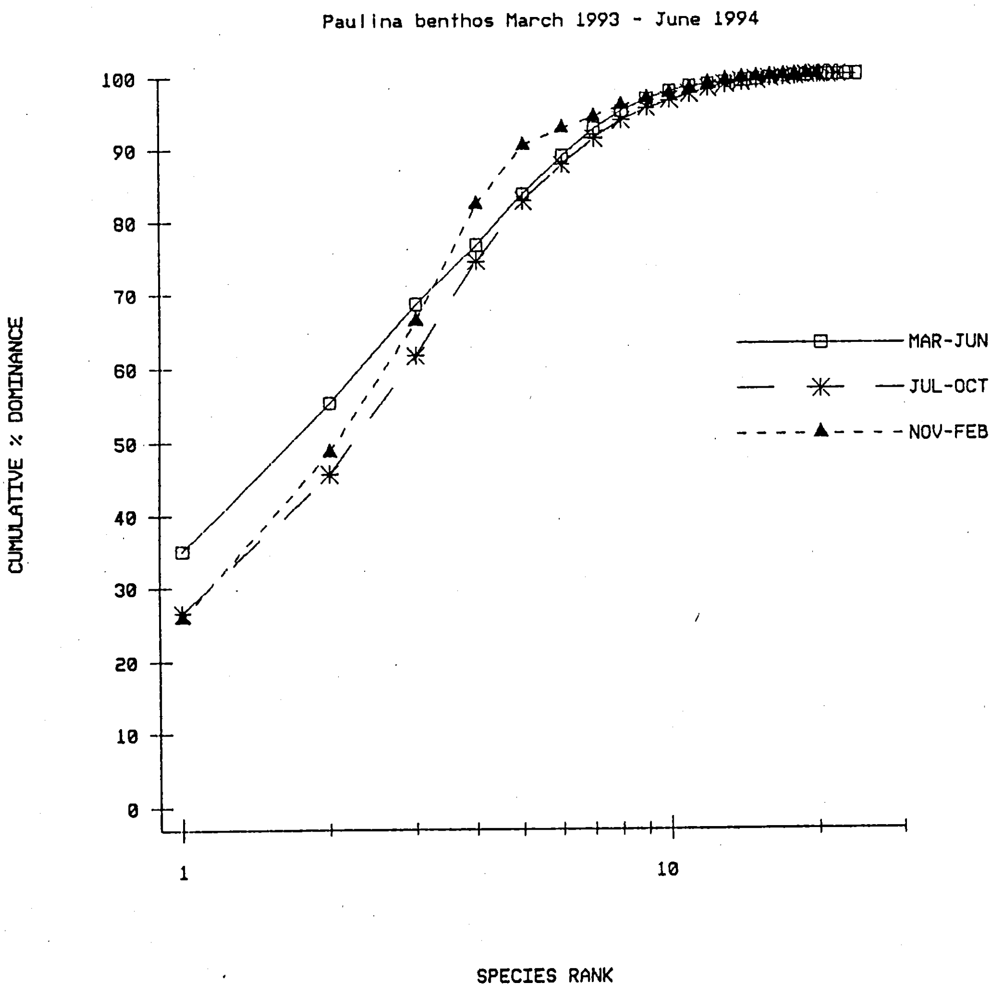


Figure 4. Seasonal variation in k-dominance curves at Paulina.

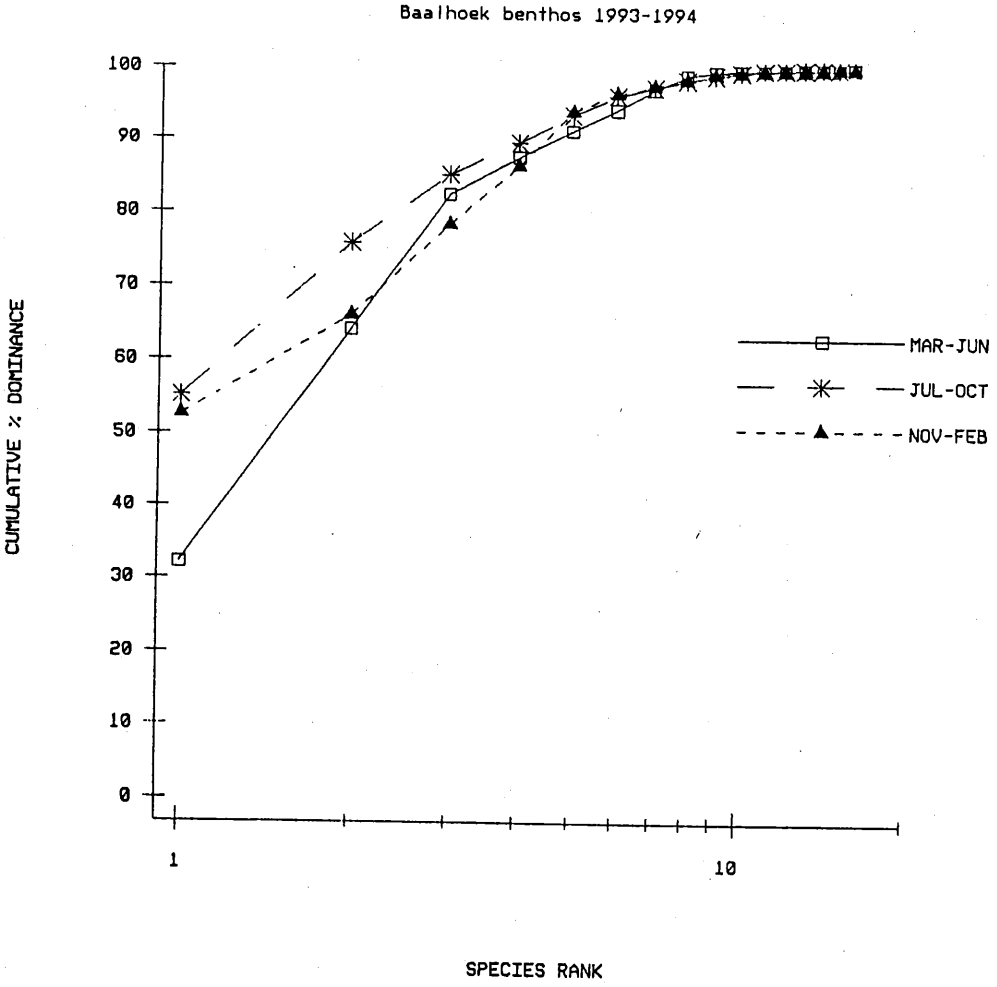


Figure 5. Seasonal variation in k-dominance curves at Baalhoek.

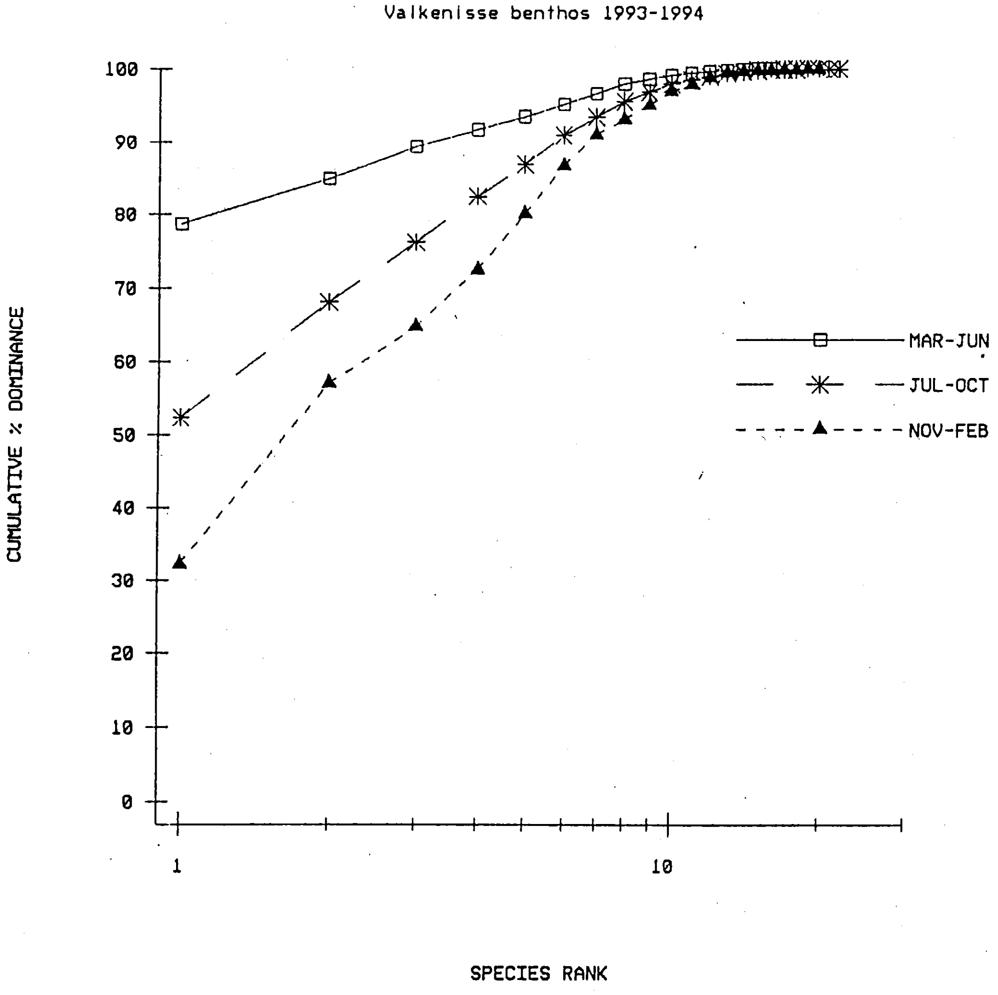


Figure 6. Seasonal variation in k-dominance curves at Valkenisse.

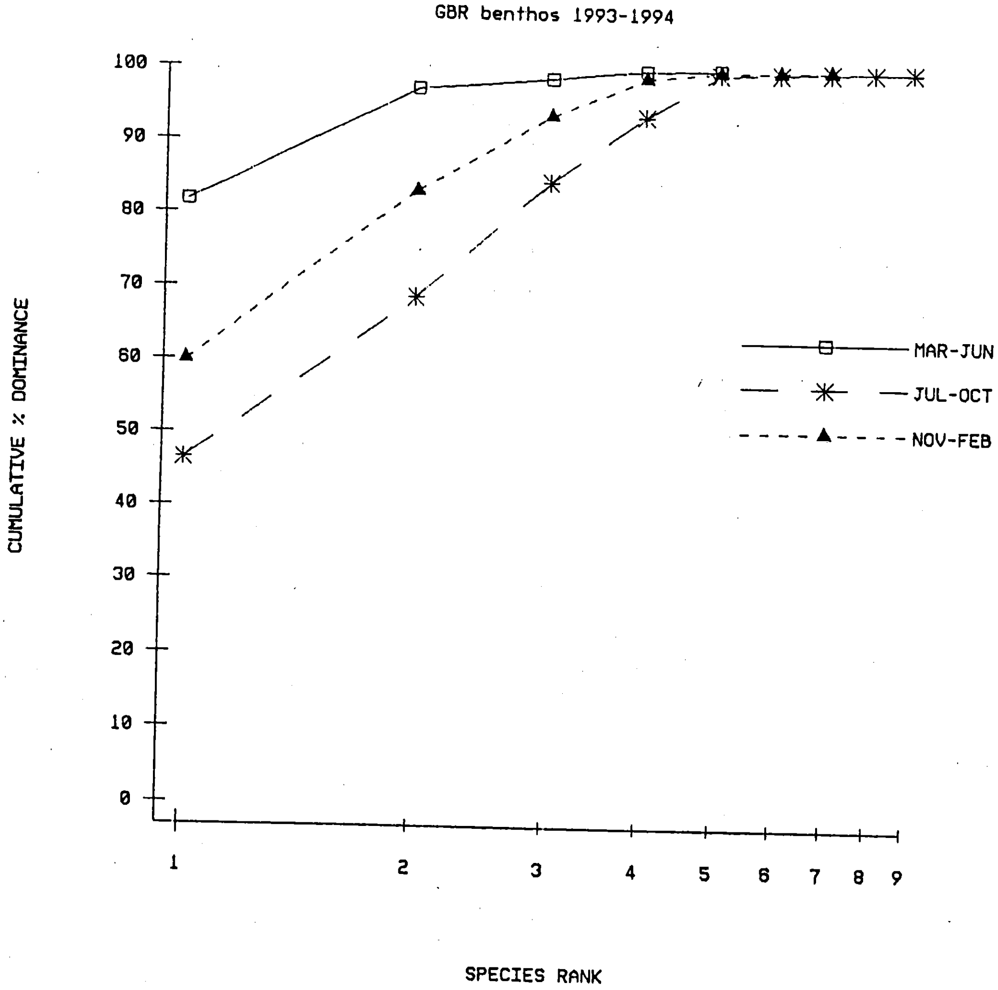


Figure 7. Seasonal variation in k-dominance curves at GBR.

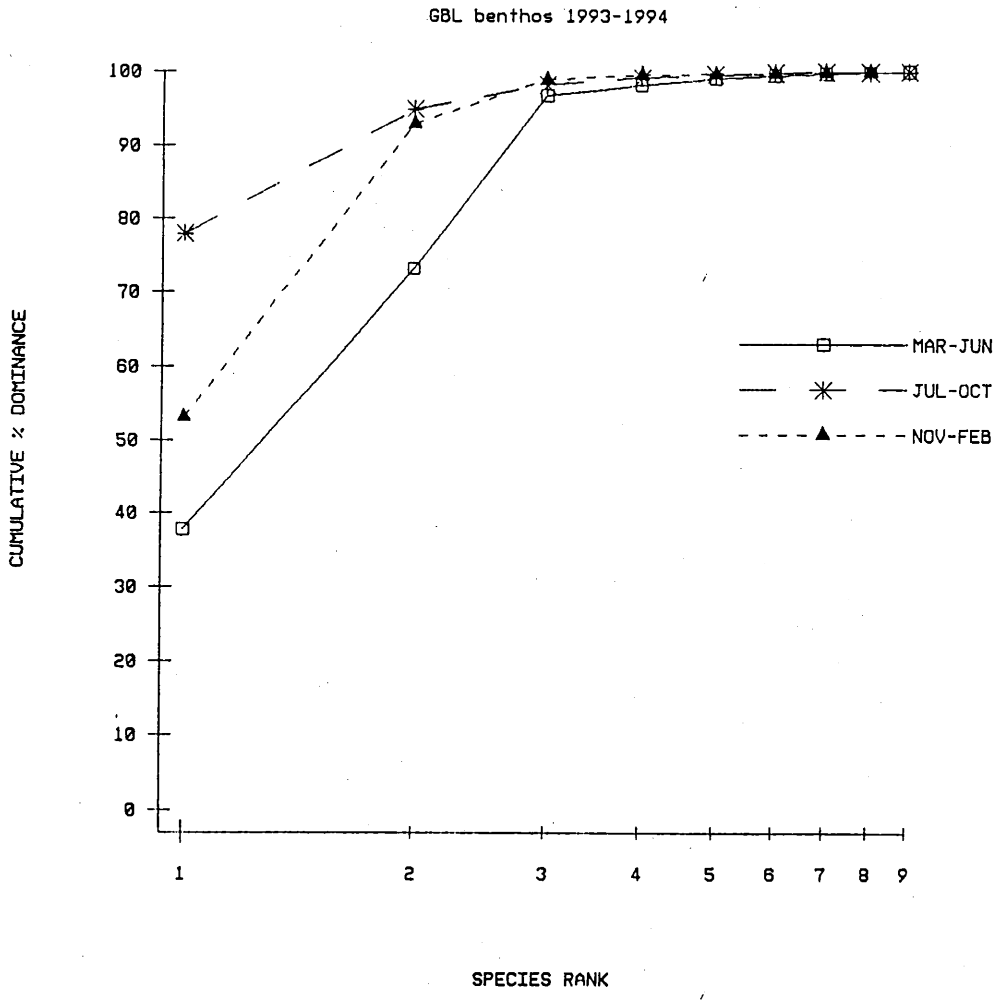


Figure 8. Seasonal variation in k-dominance curves at GBL.

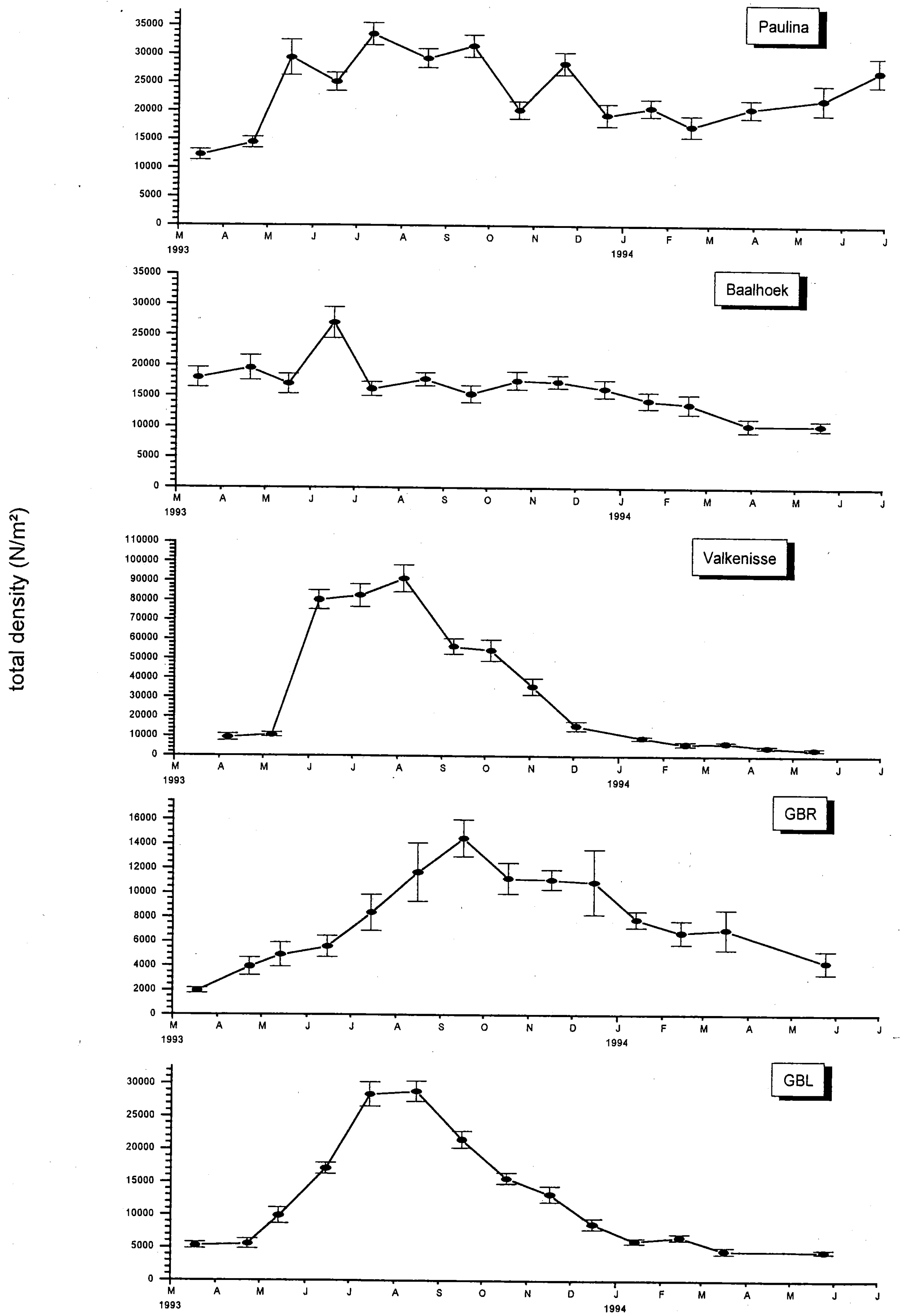


Figure 9. Total density observed at Paulina, Baalhoek, Valkenisse, GBR and GBL.

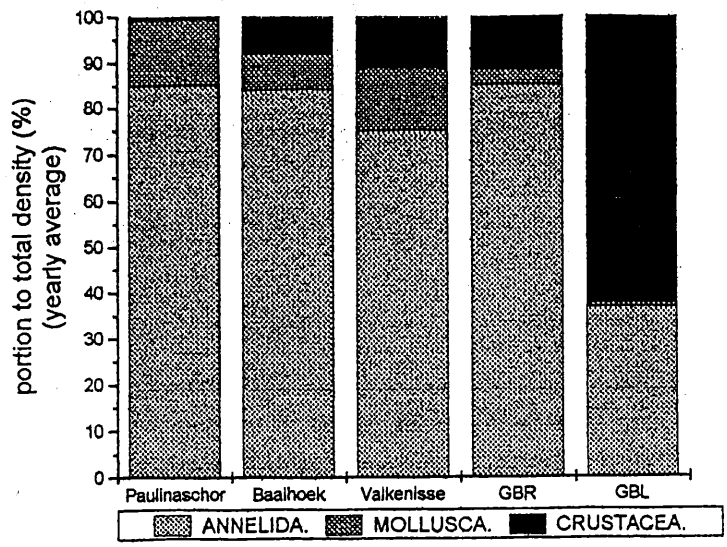


Figure 10. Share of different systematic groups in the total density.

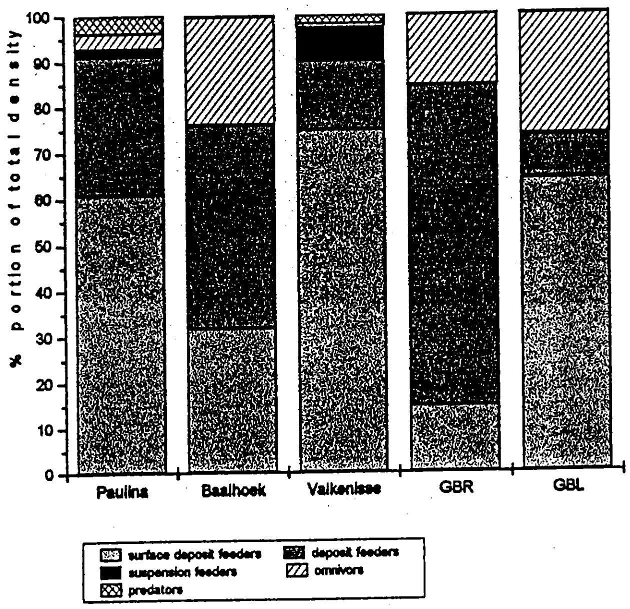


Figure 11. Share of the different feeding guilds in the total density.

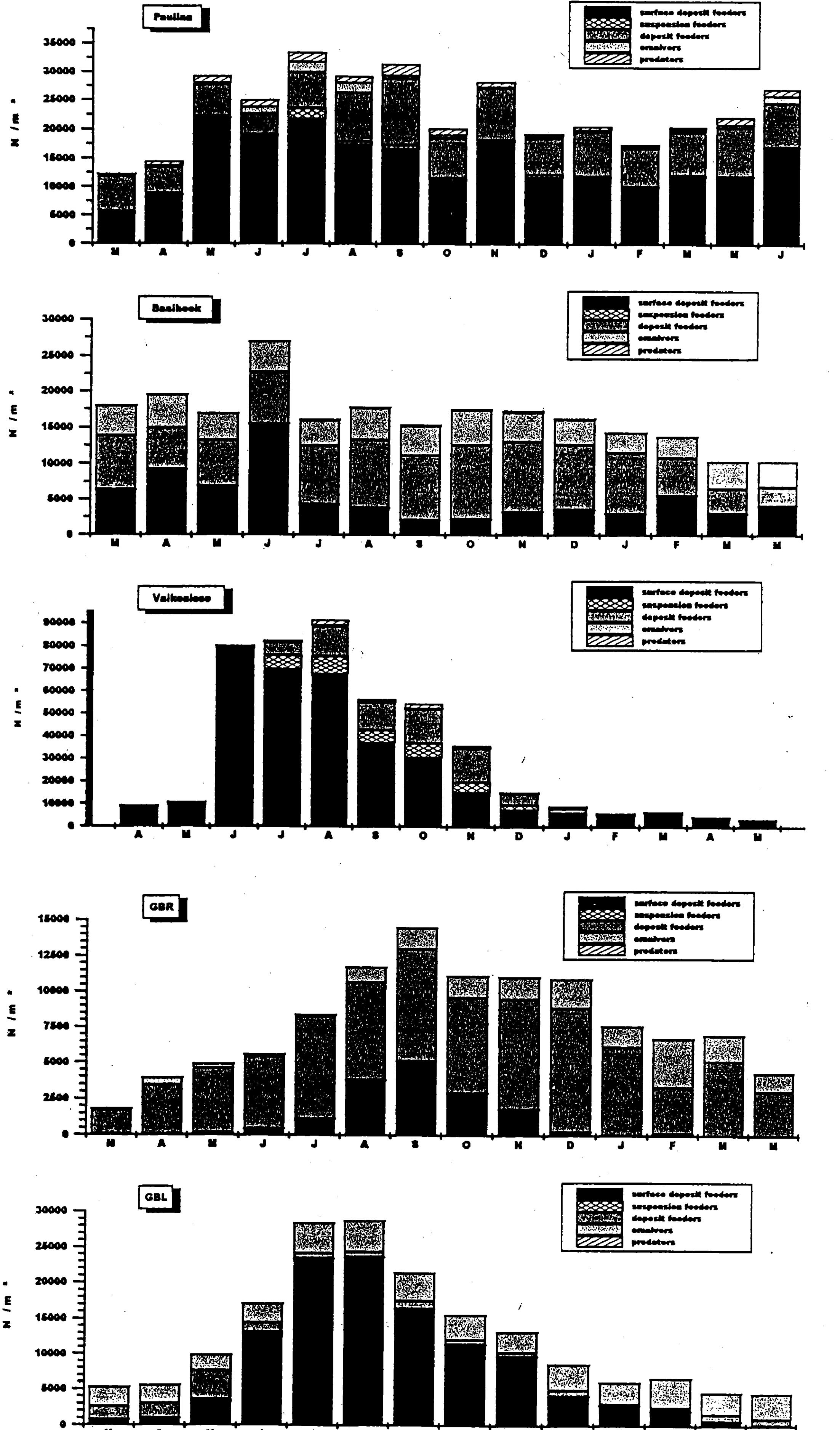
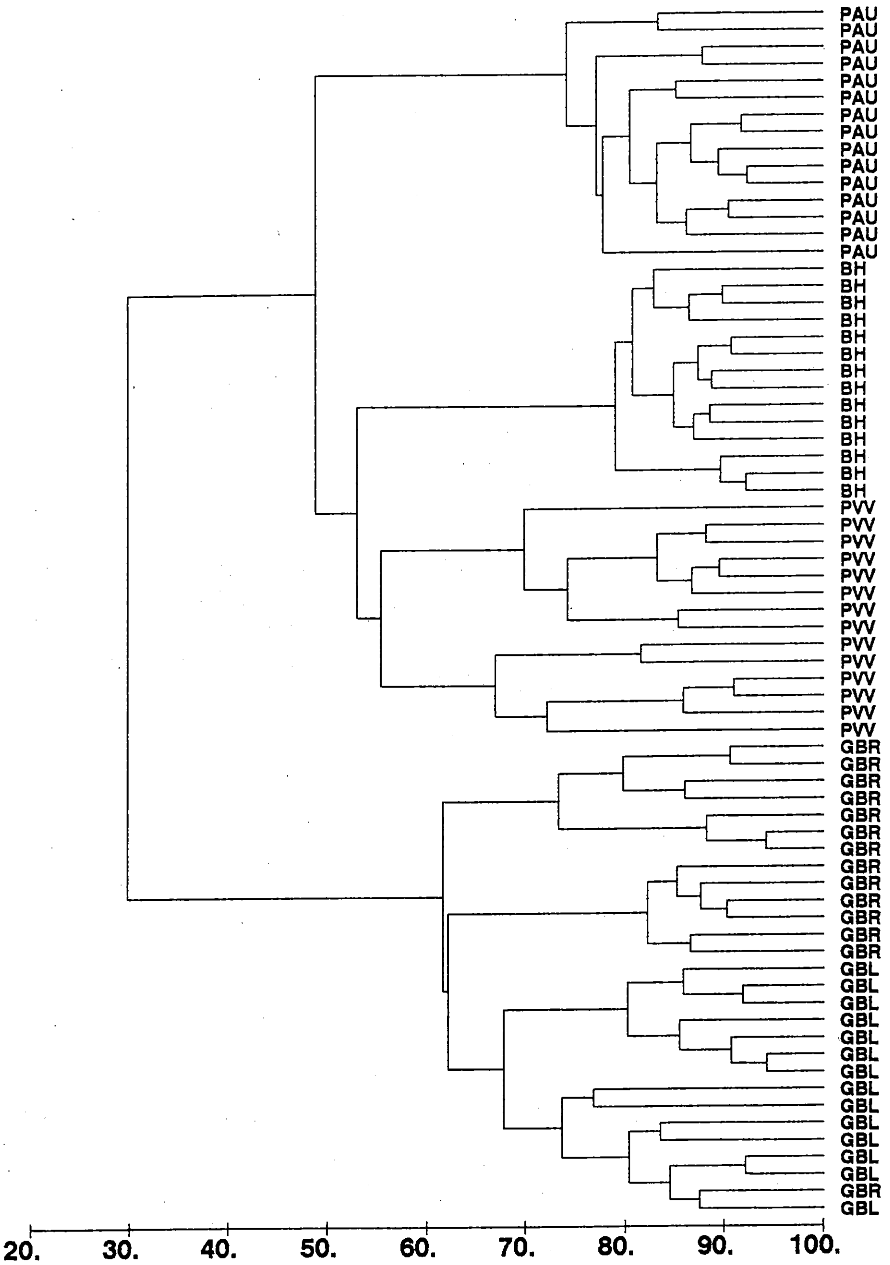


Figure 12. Seasonal variation in the % occurrence of the different feeding guilds (in terms of density) at each location.

Macrobenthos Schelde estuary: 5 locations March 1993 - June 1994



BRAY-CURTIS SIMILARITY

Figure 13

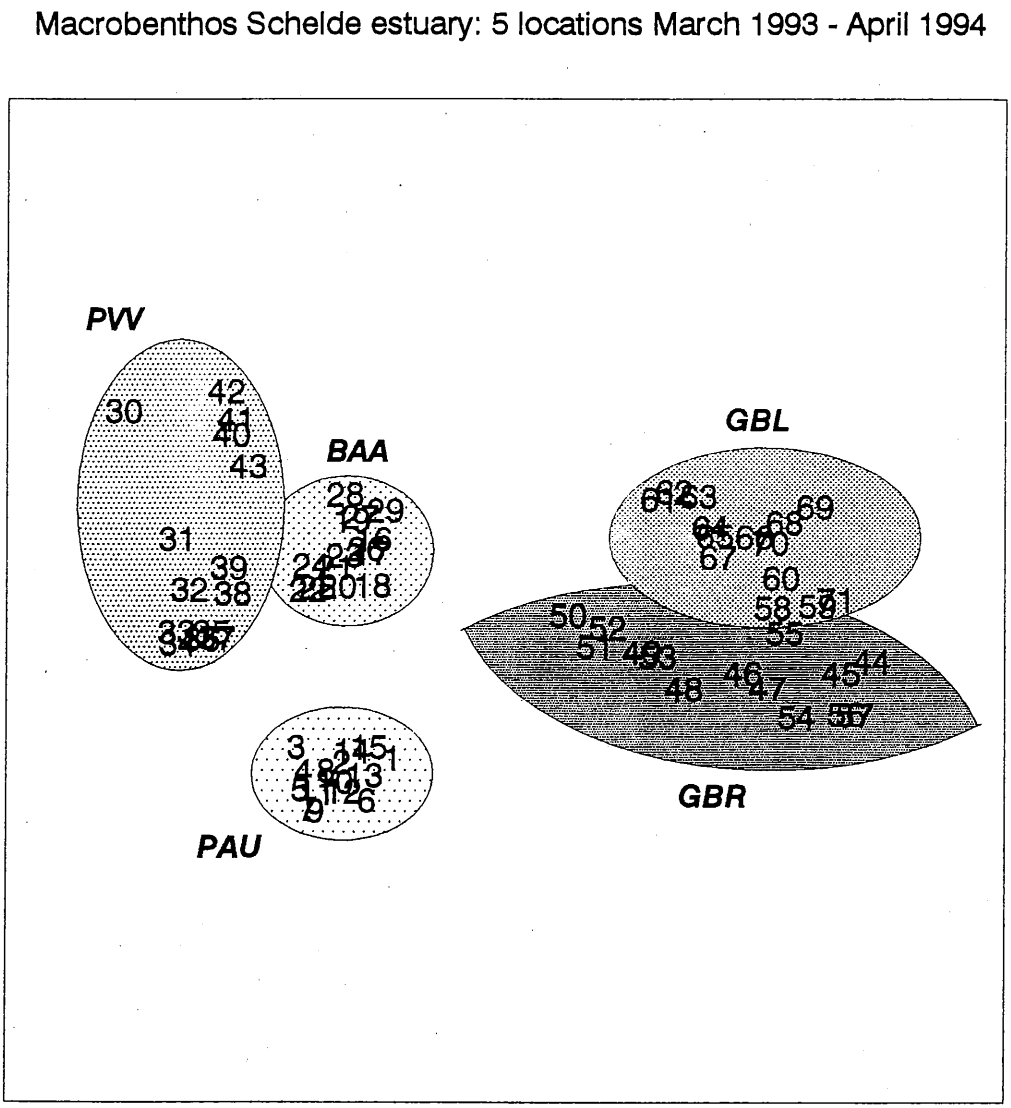
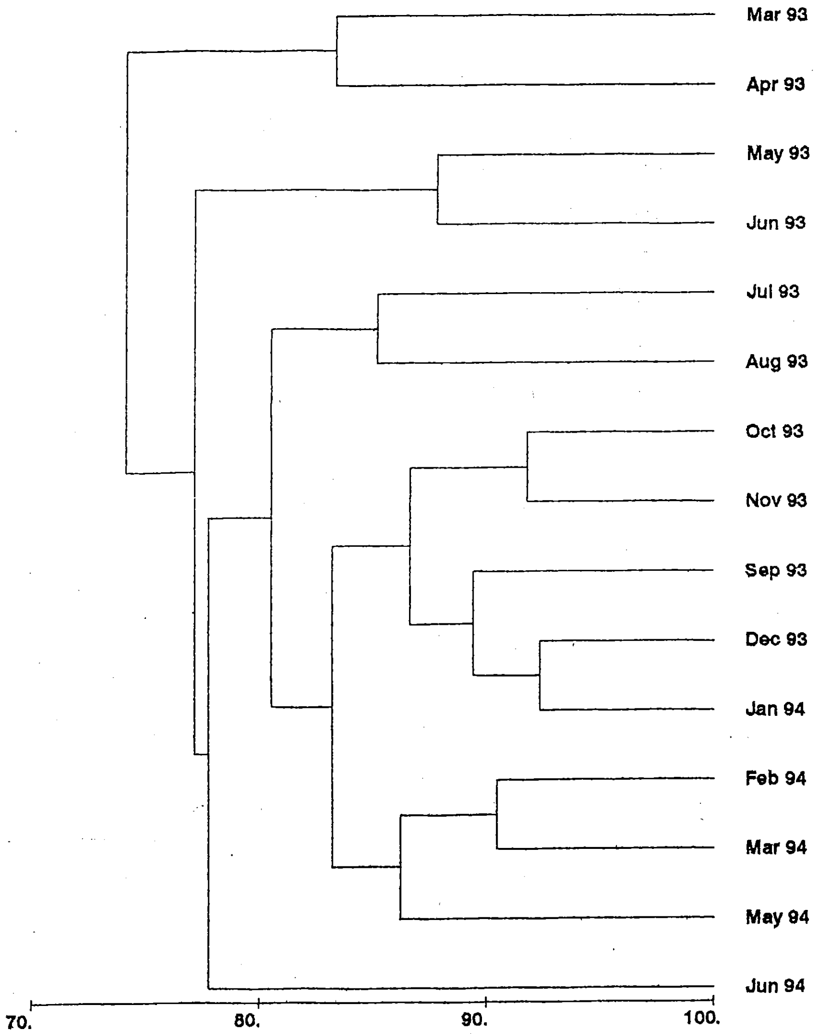


Figure 14. MDS ordination all sampling locations.

Paulina March 1993 - June 1994



BRAY-CURTIS SIMILARITY

Figure 15

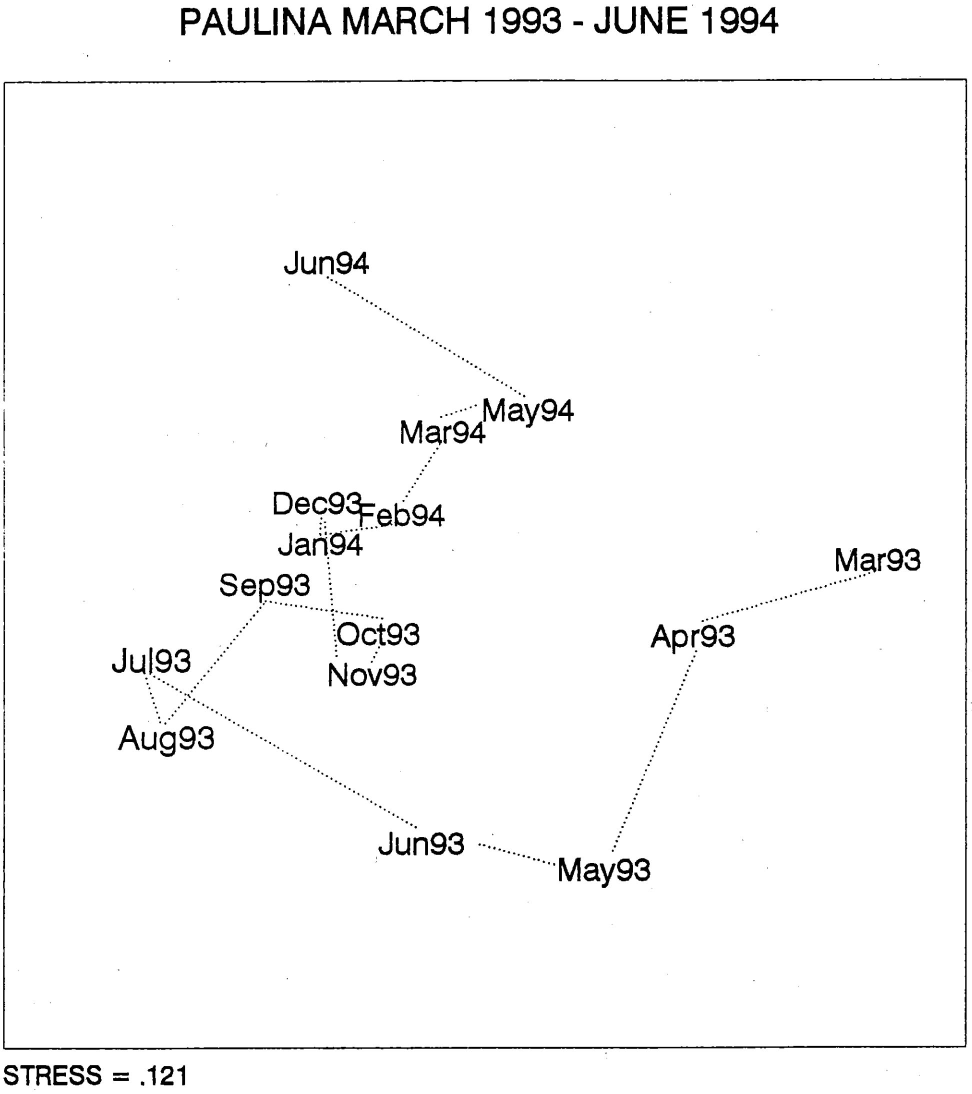


Figure 16. MDS ordination Paulina.

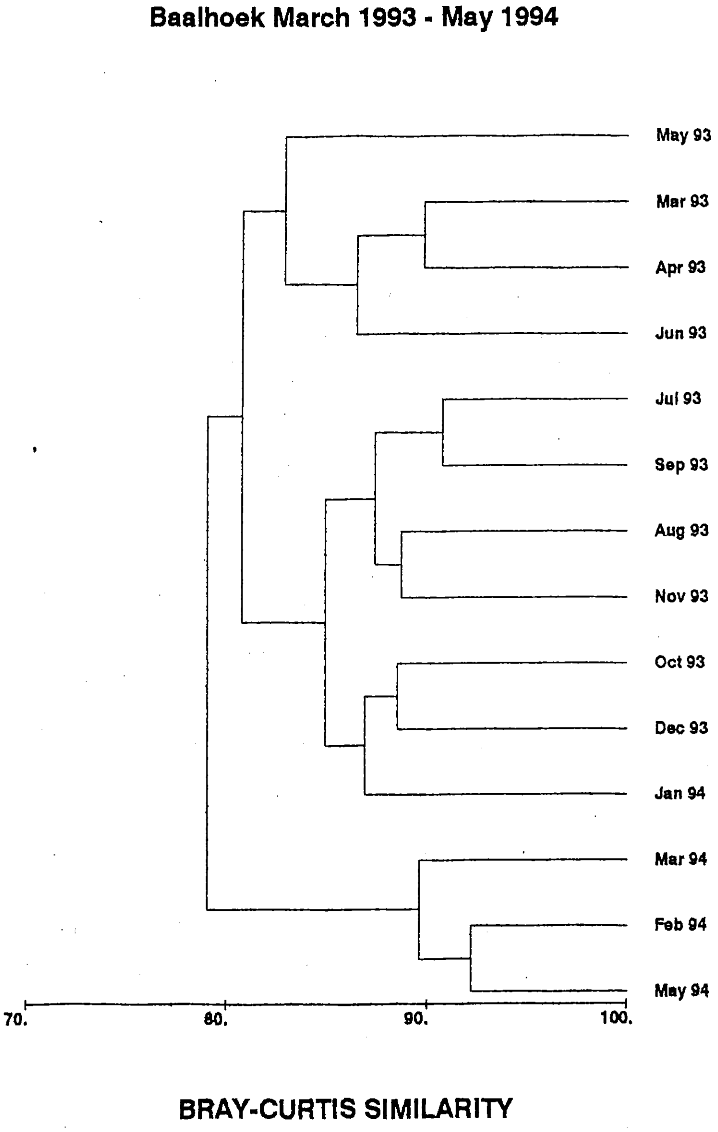

Baalhoek March 1993 - May 1994
May 93
Mar 93
Apr 93
Jun 93
Jul 93
Sep 93
Aug 93
Nov 93
Oct 93
Dec 93
Jan 94
Mar 94
Feb 94
May 94
70.
80.
90.
100.
BRAY-CURTIS SIMILARITY

Figure 17

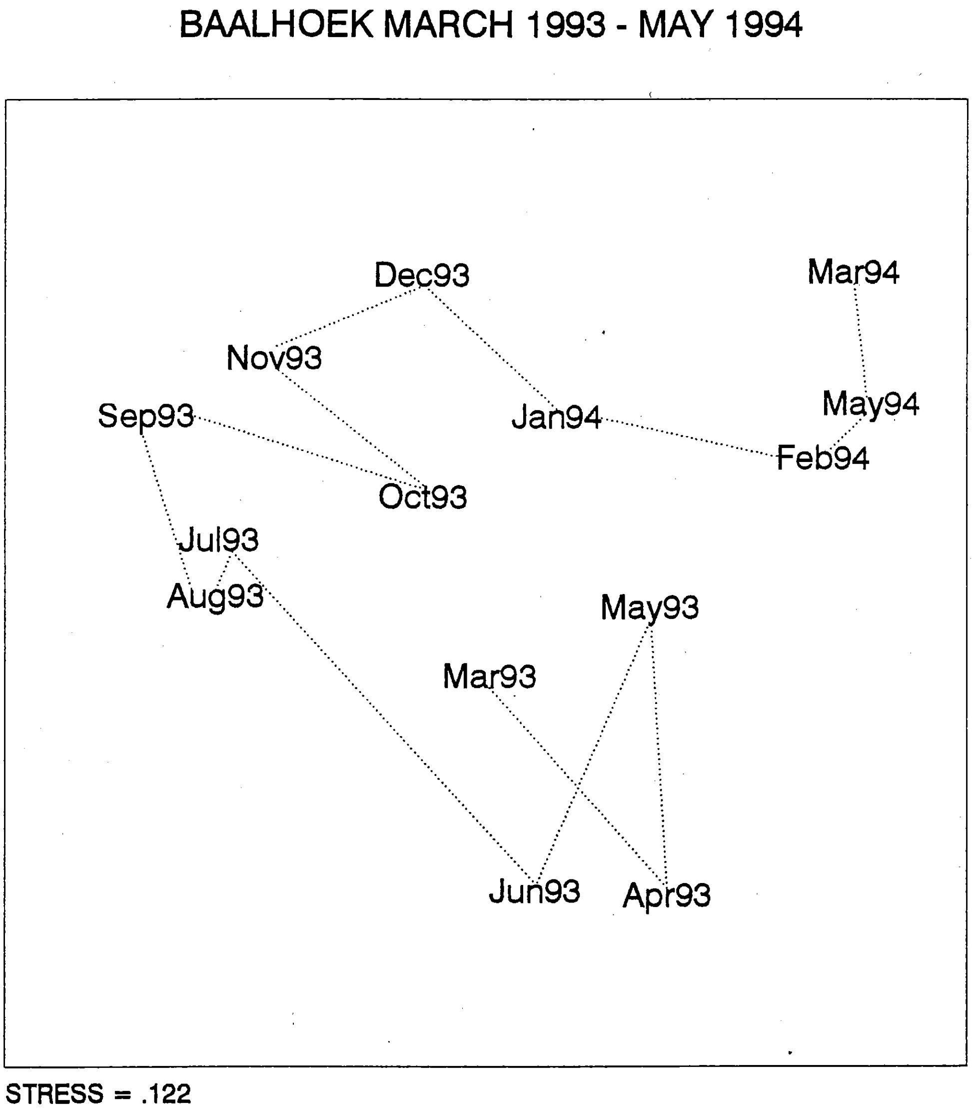


Figure 18. MDS ordination Baalhoek.

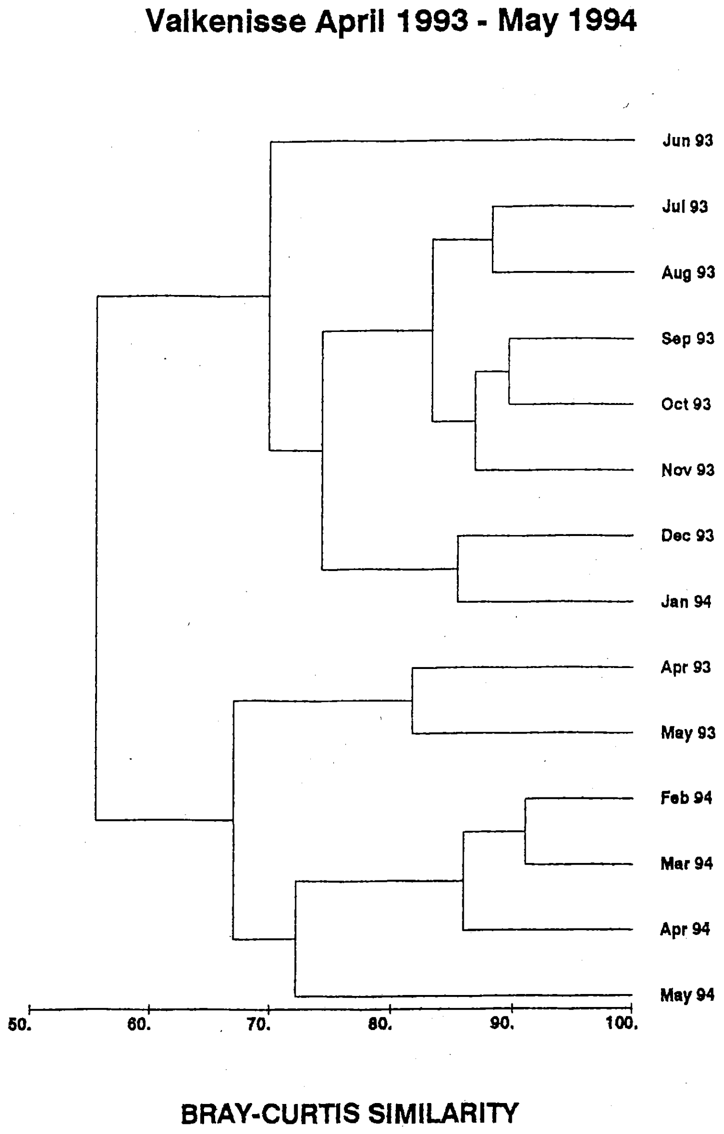

Valkenisse April 1993 - May 1994
Jun 93
Jul 93
Aug 93
Sep 93
Oct 93
Nov 93
Dec 93
Jan 94
Apr 93
May 93
Feb 94
Mar 94
Apr 94
May 94
50.
60.
70.
80.
90.
100.
BRAY-CURTIS SIMILARITY

Figure 19.

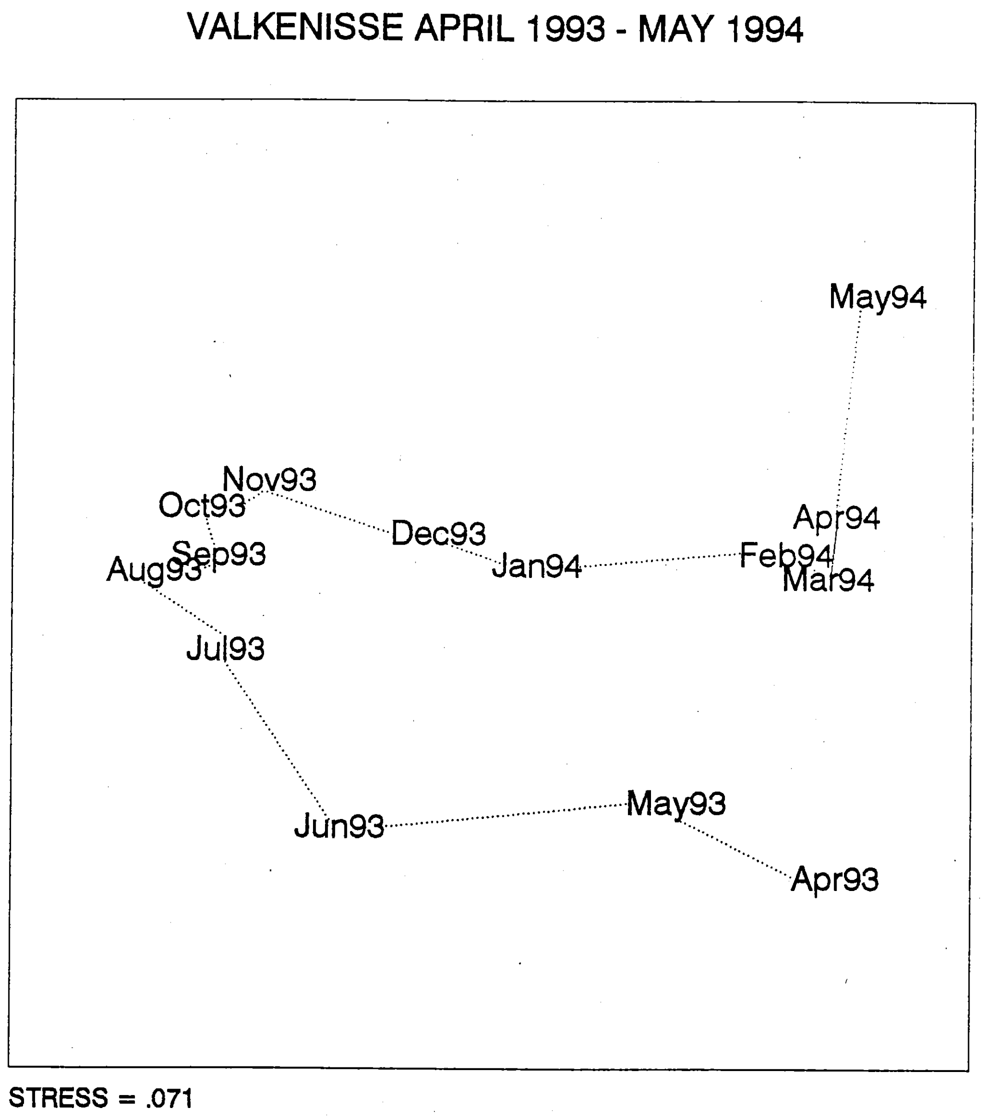


Figure 20. MDS ordination Valkenisse.

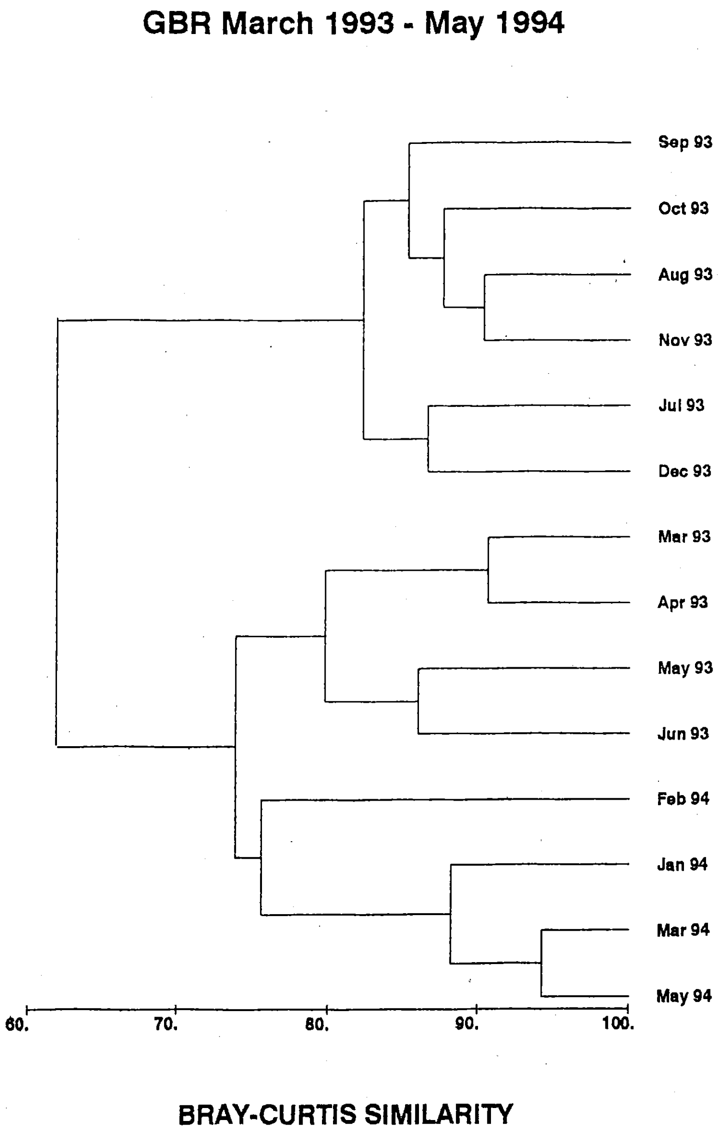
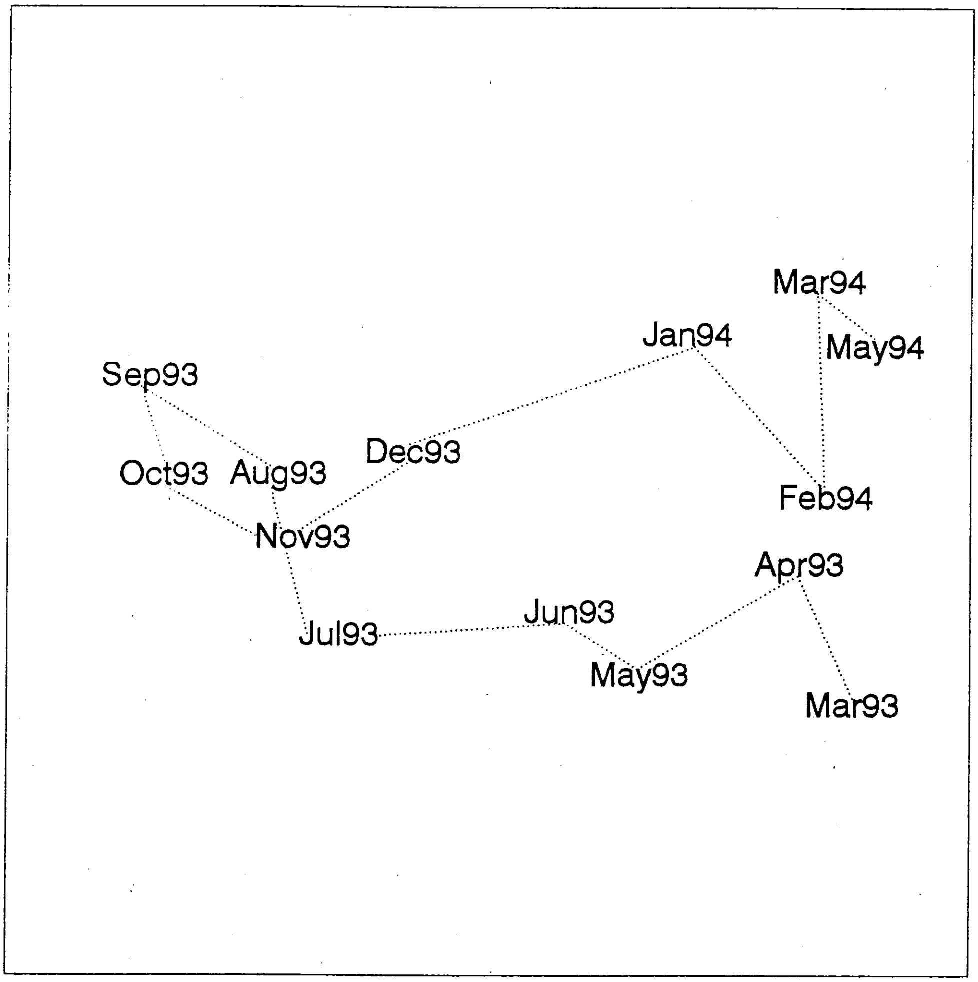

GBR March 1993 - May 1994
Sep 93
Oct 93
Aug 93
Nov 93
Jul 93
Dec 93
Mar 93
Apr 93
May 93
Jun 93
Feb 94
Jan 94
Mar 94
May 94
60.
70.
80.
90.
100.
BRAY-CURTIS SIMILARITY

Figure 21

GBR MARCH 1993 - MAY 1994



STRESS = .086

Figure 22. MDS ordination GBR

GBL March 1993 - May 1994

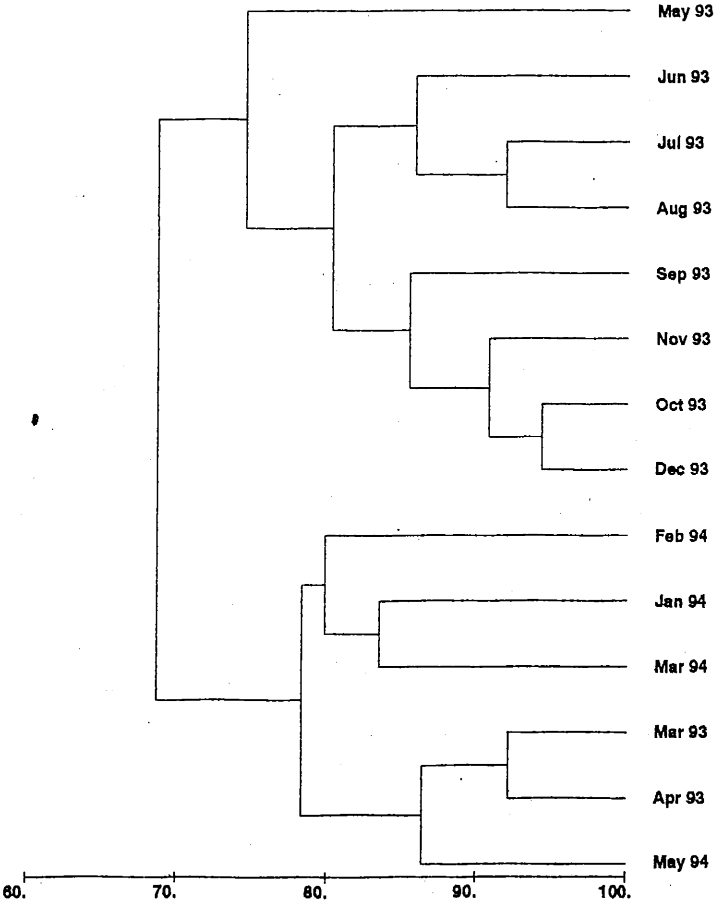


Figure 23

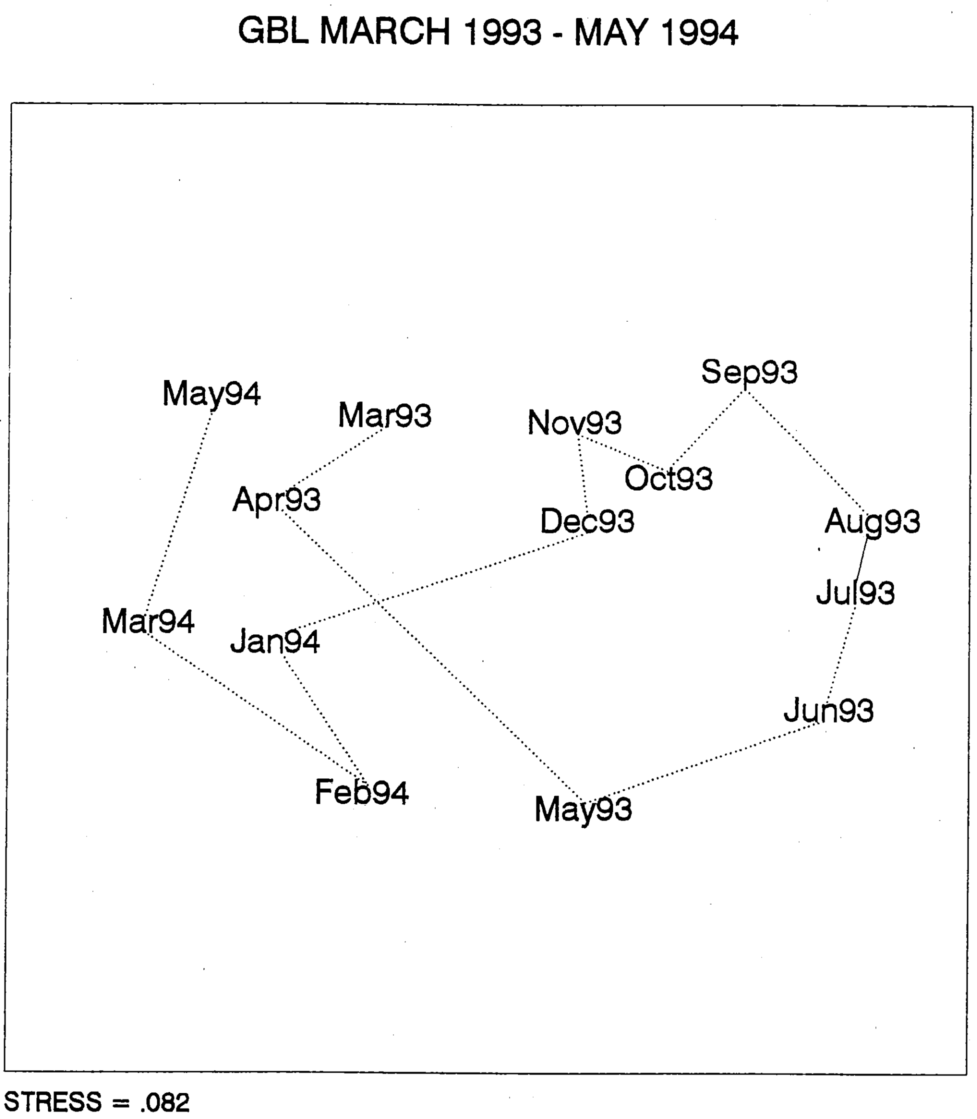


Figure 24. MDS ordination GBL.

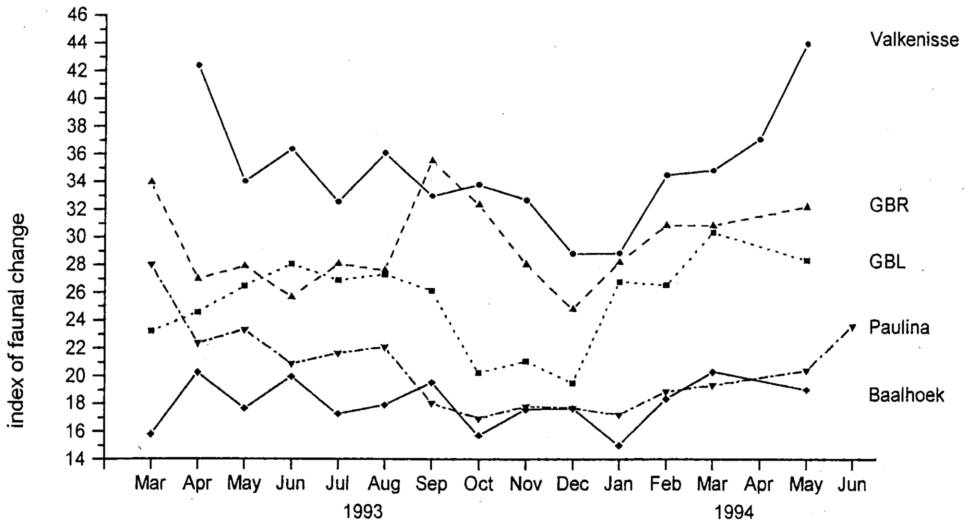


Figure 25. Index of faunal change.

Figure 26

Paulinaschor March 1993 - June 1994
Mollusca (N/m²)

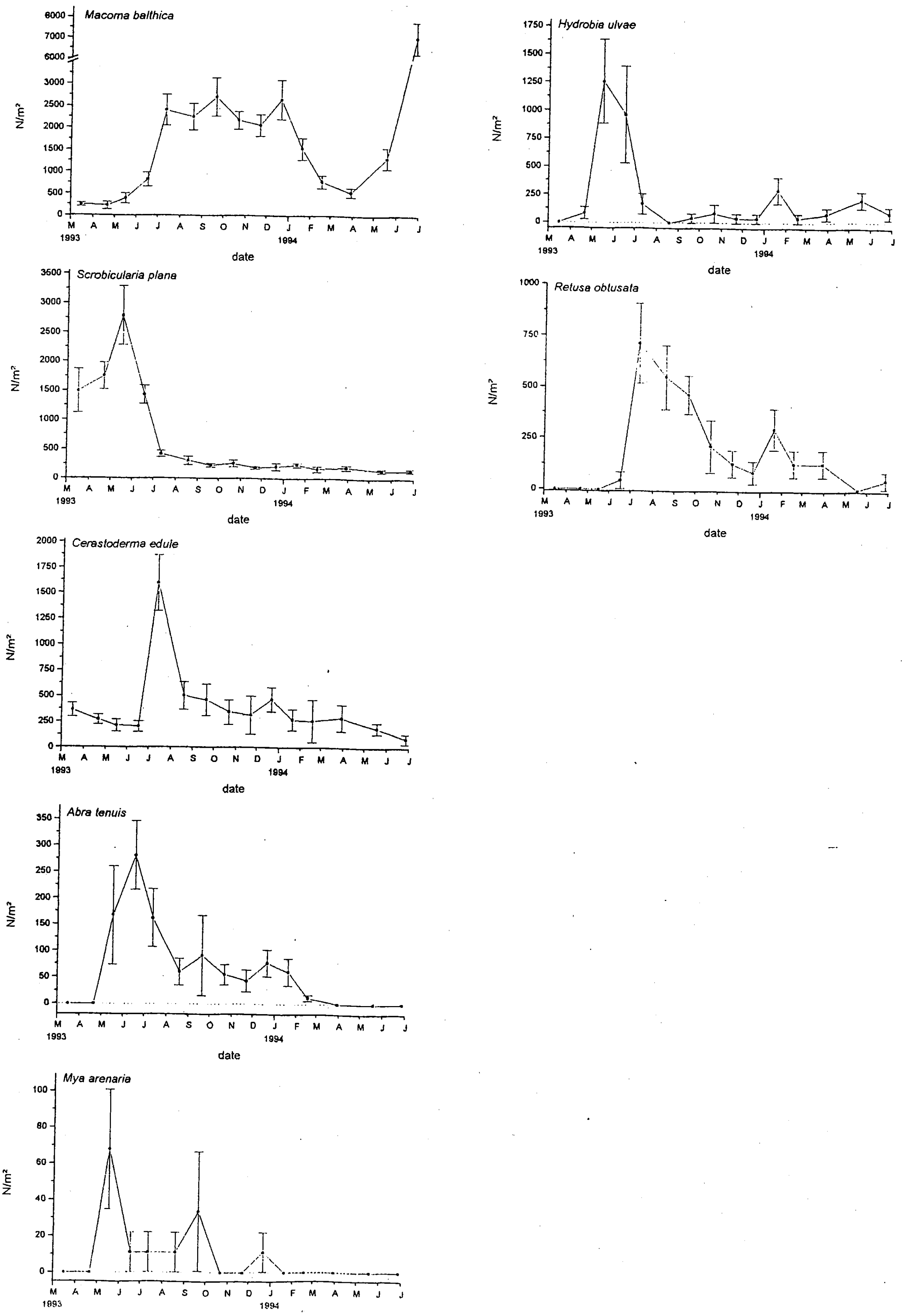


Figure27

Paulinaschor March 1993 - June 1994

Annelida (N/m²)

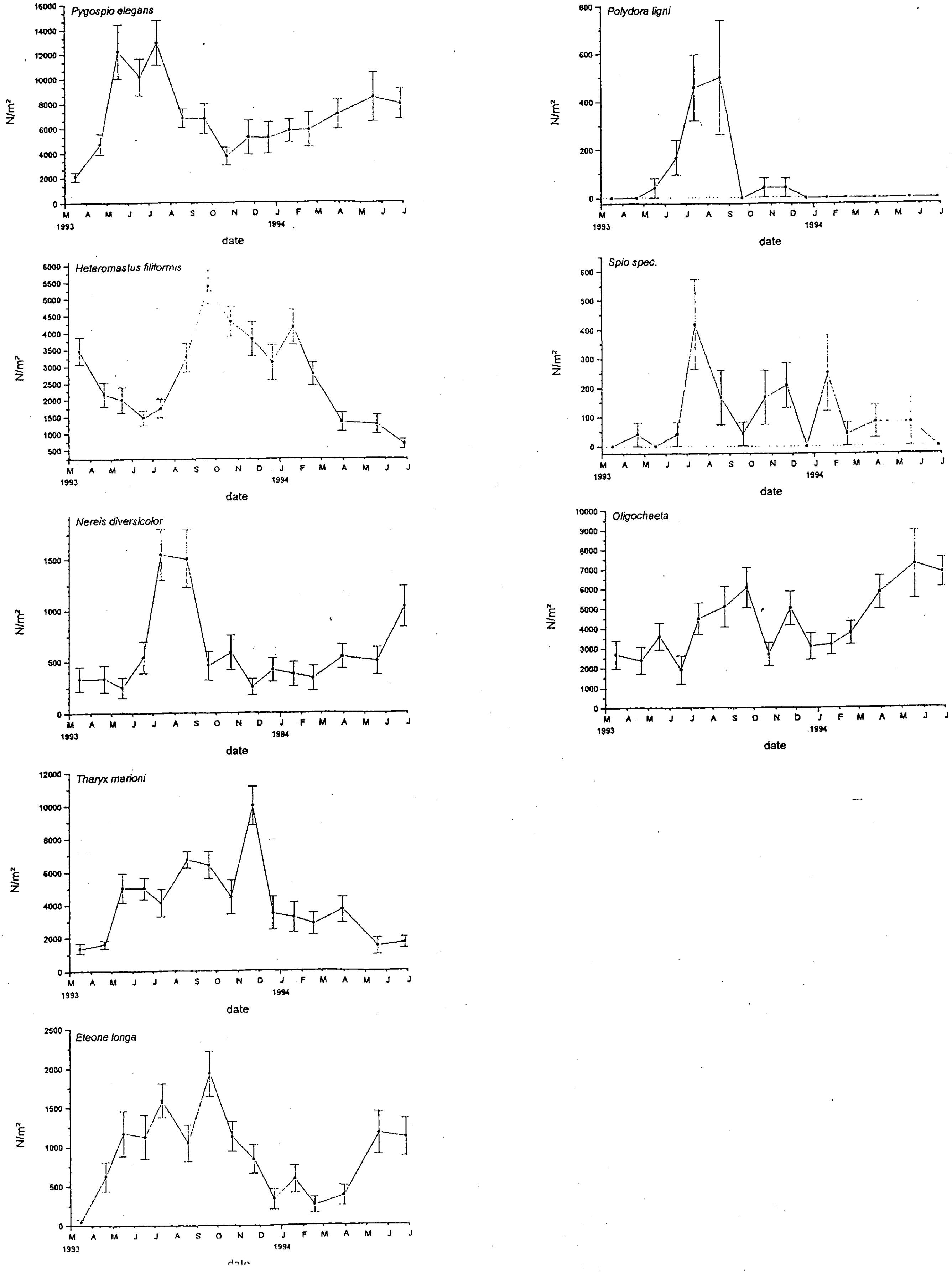


Figure 28

Baalhoek March 1993 - May 1994
Annelida (N/m²)

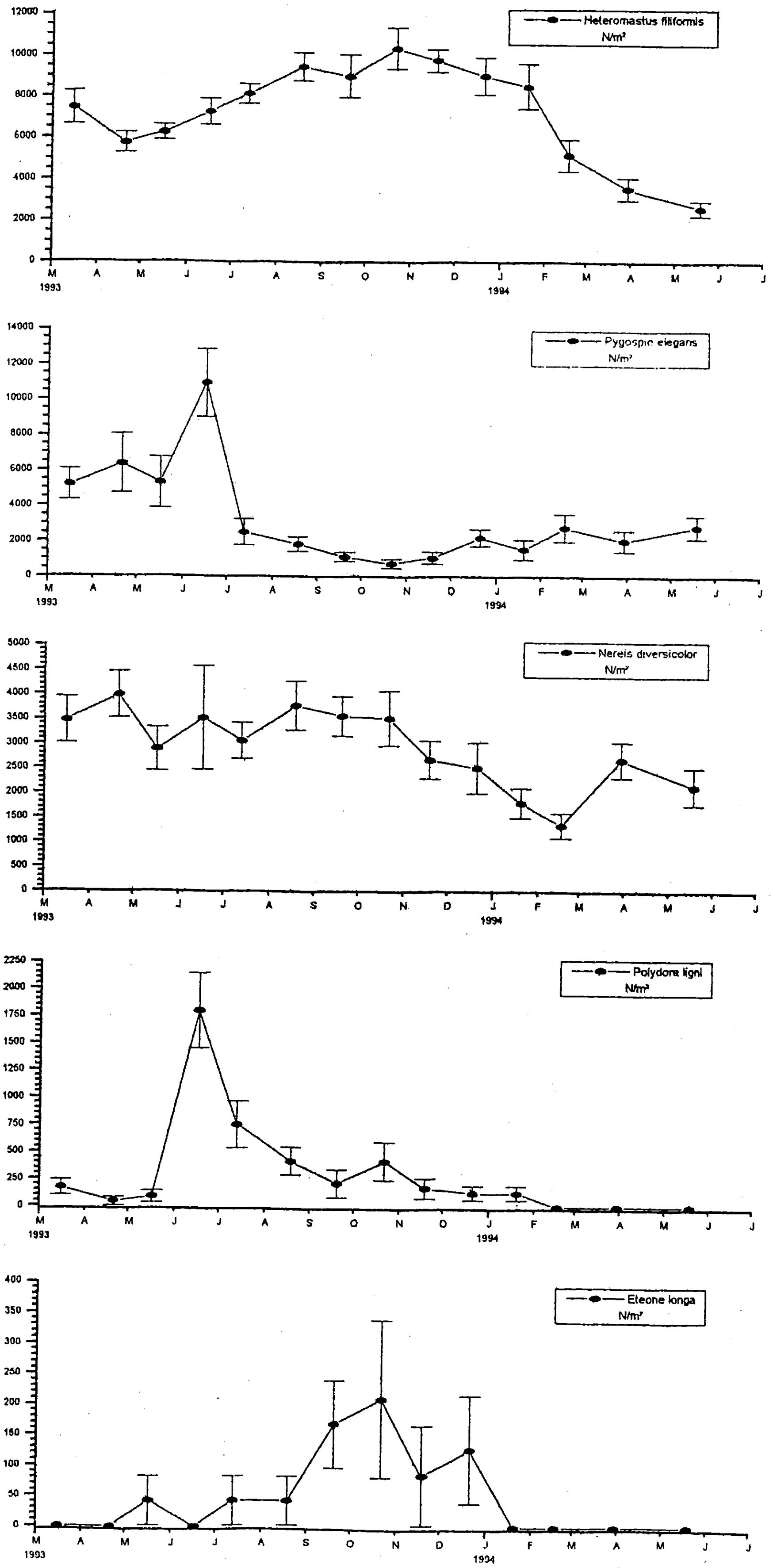
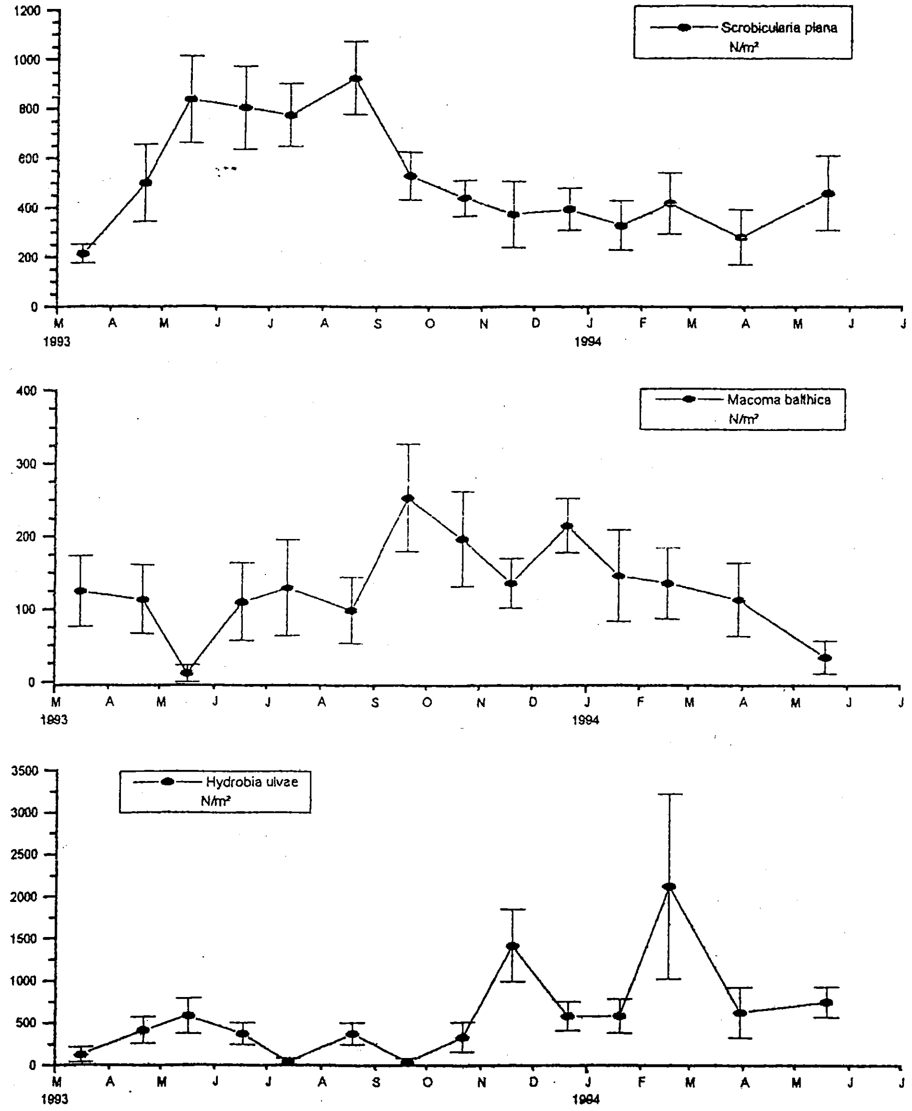


Figure 29

Baalhoek March 1993 - May 1994 *Mollusca* (N/m²)



Baalhoek March 1993 - May 1994 *Crustacea* (N/m²)

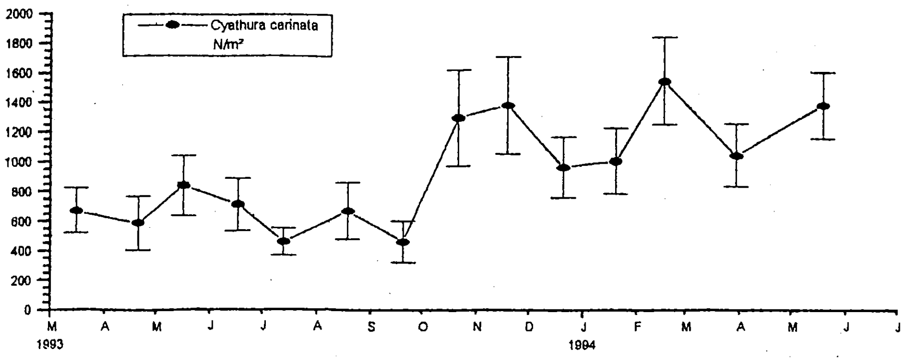


Figure 30

Valkenisse April 1993 - May 1994

Mollusca (N/m²)

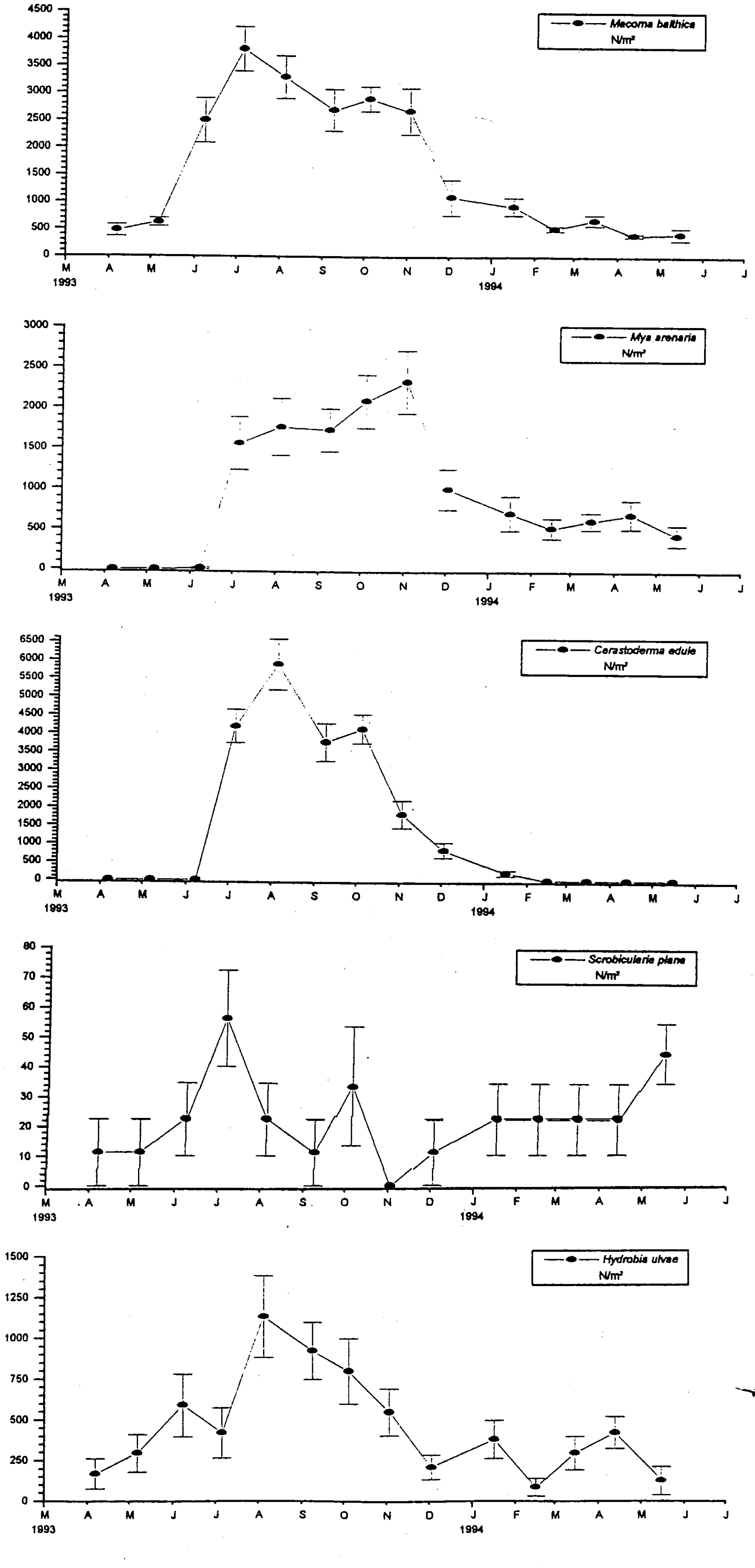


Figure 31

Valkenisse April 1993 - May 1994

Crustacea (N/m²)

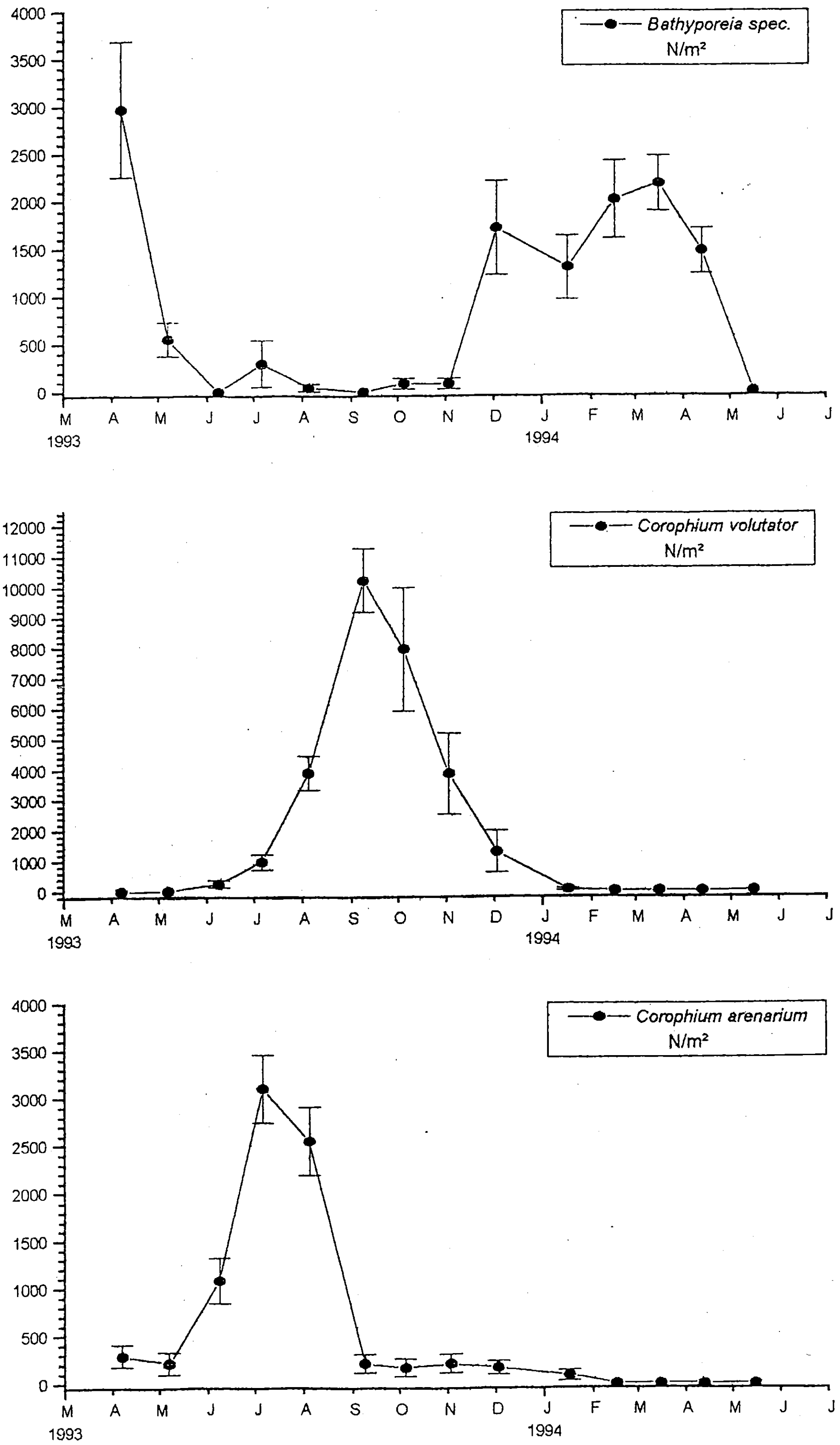


Figure 32

Valkenisse April 1993 - May 1994
Annelida (N/m²) - Part 1

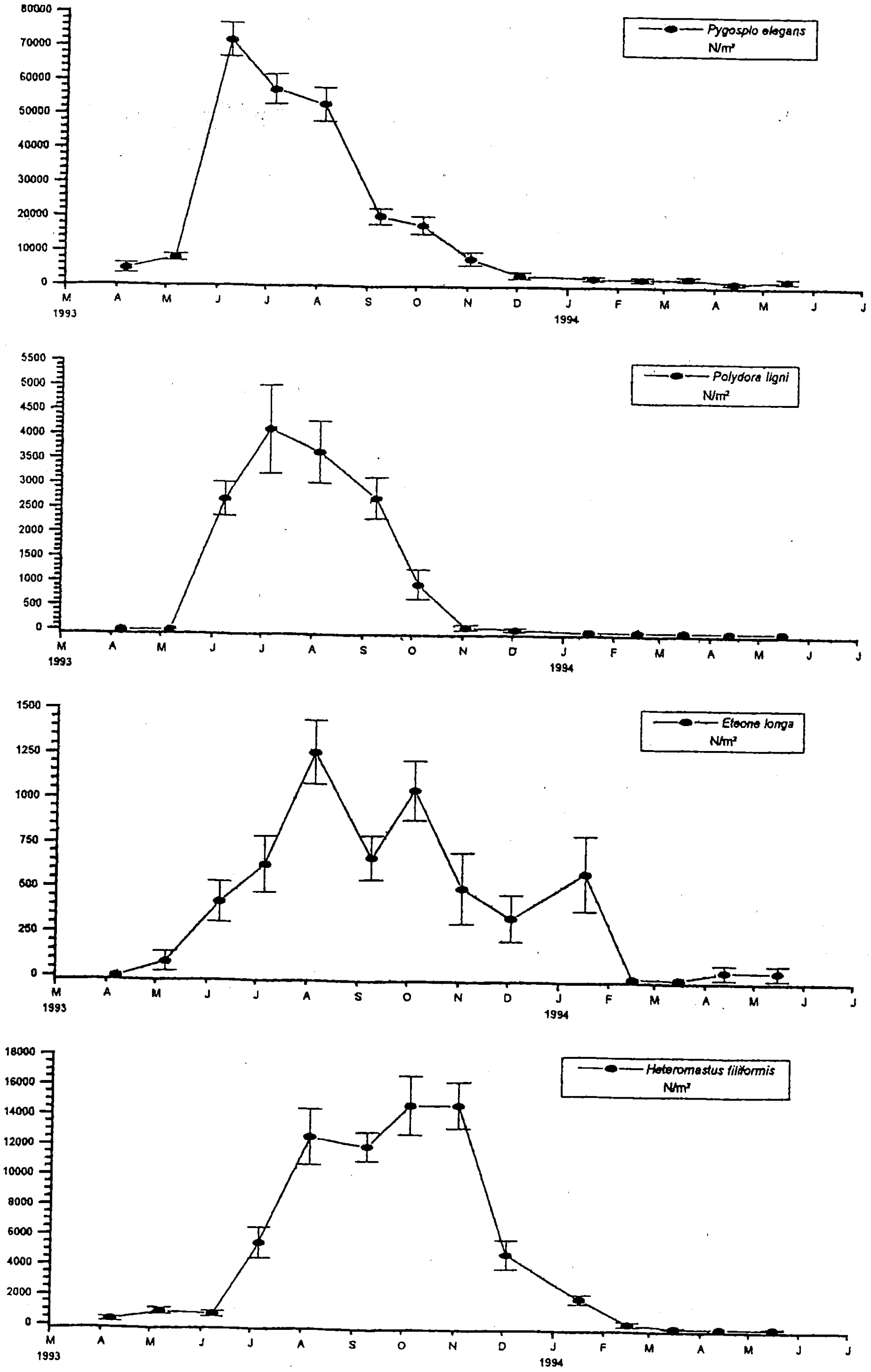


Figure 33

Valkenisse April 1993 - May 1994
Annelida & Nemertea (N/m²) - Part 2

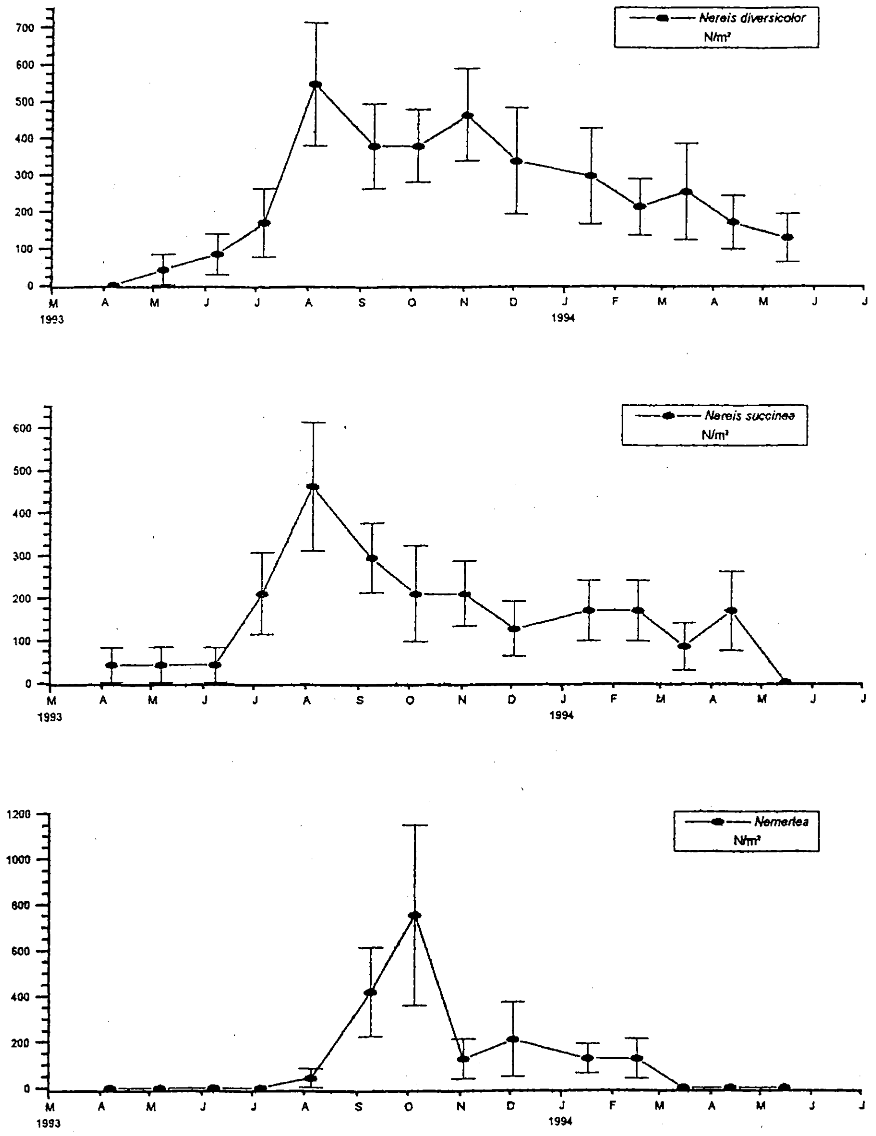
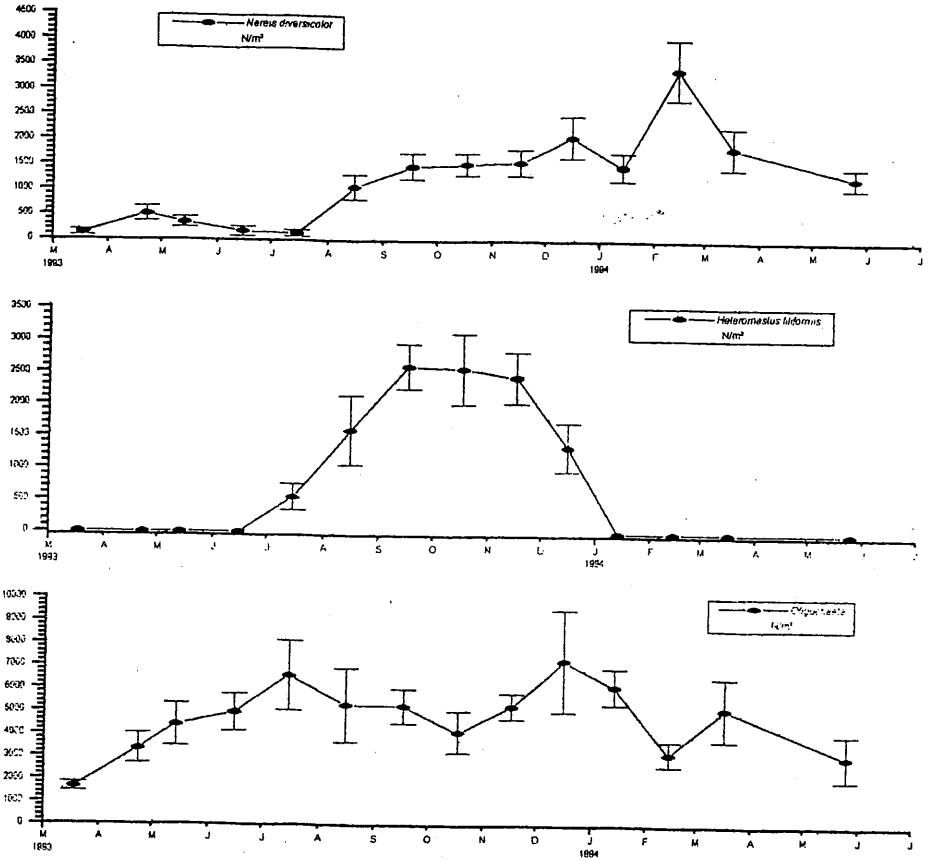
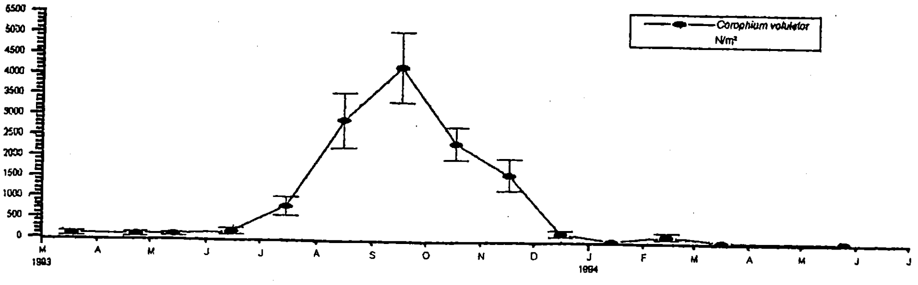


Figure 34

GBR March 1993 - May 1994
Annelida (N/m²)



GBR March 1993 - May 1994
Crustacea (N/m²)



GBR March 1993 - May 1994
Mollusca (N/m²)

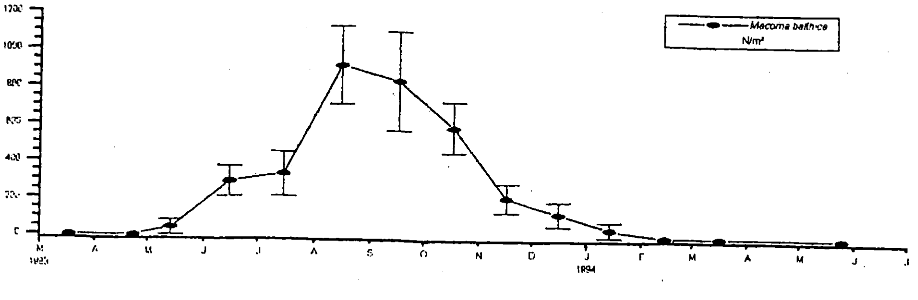
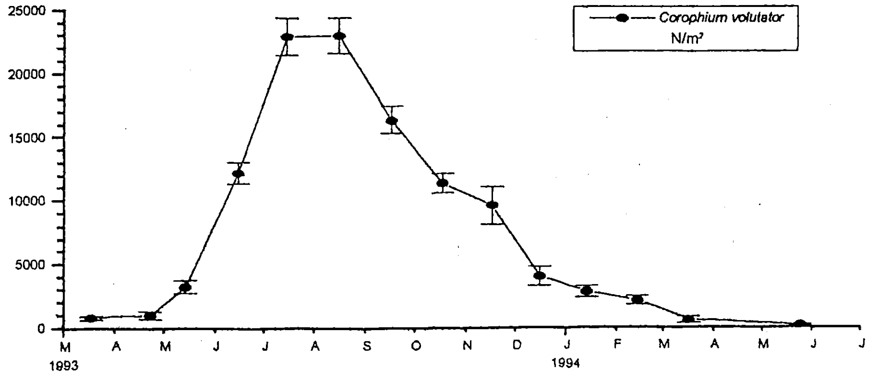
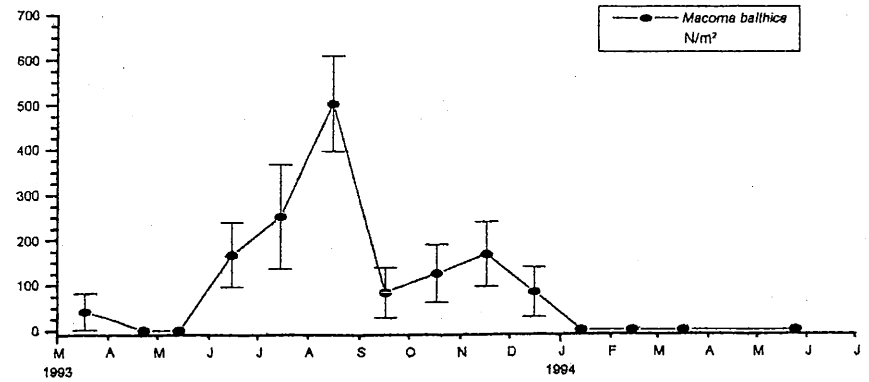


Figure 35

GBL March 1993 - May 1994
Crustacea (N/m²)



GBL March 1993 - May 1994
Mollusca (N/m²)



GBL March 1993 - May 1994
Annelida (N/m²) - Part 1

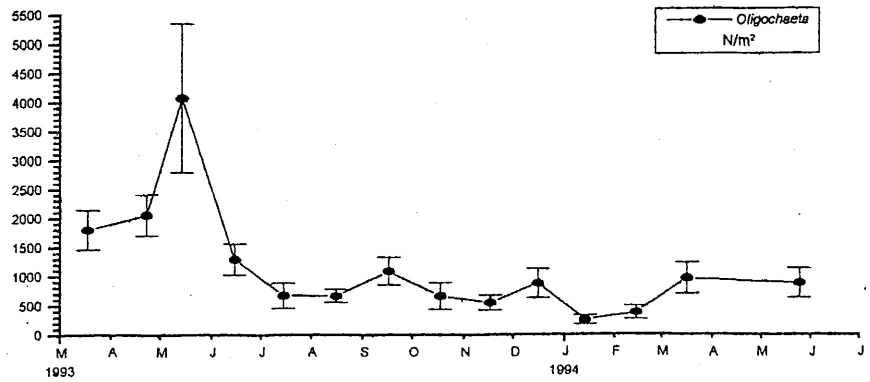
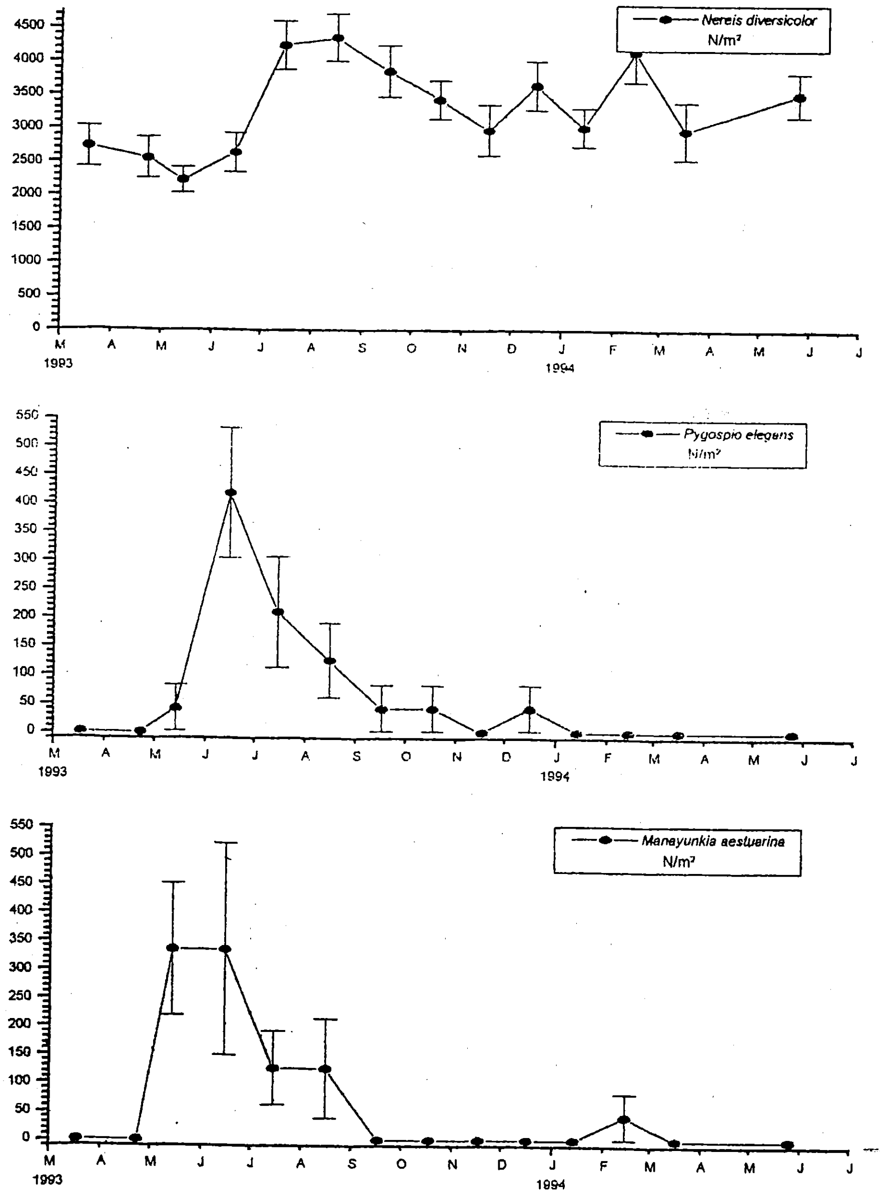


Figure 36

GBL March 1993 - May 1994
Annelida (N/m²) - Part 2



Life history and population dynamics of some indicator species in the Schelde estuary

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1. Introduction

A good and sustainable management of coastal areas and estuaries depends on a thorough understanding of the functioning of these aquatic ecosystems. Knowledge on the life history and estimates of the secondary production of some estuarine indicator species are an essential part of the knowledge one need to understand the ecosystem functioning in estuaries, especially towards a better understanding of natural versus antropogenic induced influences. Indeed, one-off determinations of different *in situ* measures of diversity and community structure of benthic populations will not always reveal totally the functioning of these populations in relation to their abiotic environment. Therefore, in addition population dynamics - studies of some important estuarine key species will provide a better insight in how the abiotic environment interacts with benthic populations. Especially in estuarine environments, typically characterized by highly varying natural environmental variables (e.g. salinity), negative human effects (e.g. pollution) could be masked or misinterpreted, based solely on a snapshot of the benthic community structure.

2. Key species in this study

The spatial and seasonal analysis of the benthic community structure (see previous chapter), already revealed clearly the importance of the seasonal factor. Indeed, large fluctuations in diversity, density and biomass were observed within one year at the same location. These fluctuations can be attributed to a certain extent to changes in the abiotic environment. However, these fluctuations, based solely on numbers and biomass, give only partial answer to how these populations are structured. Supplementary data on age structure, reproduction, growth, and condition are necessary to better understand the role of underlying processes.

Based on previous studies (e.g. Meire et al., 1991,Ysebaert et al., 1993, Ysebaert et al., in prep.), on the ecology of the species itself and its role in the estuarine foodweb, and on the possibility of determining age structure, sex, growth, etc., six representative key species were chosen. These species were at least at one location common, out of the five locations investigated (see previous chapter).

Bivalves

Bivalve species (4) dominate because of the ease of determining age structure (counting yearrings). But also in terms of biomass and production, these species often dominate the benthic community structure. The following species were chosen:

- *Macoma balthica*: this species is by far the most common bivalve species in NW-European estuaries. It is a typically euryhaline species, which is clearly reflected in our study where this species is observed at all five locations situated in the polyhaline and mesohaline zone of the estuary.

- *Scrobicularia plana*: this species is also a typical estuarine species, which shows an increasing occurrence in the Schelde estuary. At two locations in our study the species is present in high numbers and it takes an important part of the total biomass in these locations.

- *Cerastoderma edule*: this species is a typical marine species, which penetrates the estuary as far as the mesohaline zone. It is the most important suspension feeder in the Schelde estuary. At the polyhaline location Paulina an important cockle population was found, consisting of different year classes, whereas at the mesohaline location Valkenisse only spatfall occurred. Both locations are analysed in detail.

- *Mya arenaria*: this species is also a typical estuarine species. However, this species is not very common in the Schelde estuary. The reasons for its absence are not very clear. At Valkenisse an important spatfall occurred, and this spatfall was followed in the course of the year. Irregular observations on older individuals are also available.

Polychaeta

- *Nereis diversicolor*: this species is one of the most common estuarine polychaete species in NW-European estuaries. This is clearly reflected in our study where this species is observed at all five locations situated in the polyhaline and mesohaline zone of the estuary. The species is important in structuring the benthic community and it takes a considerable part of the total biomass observed.

Crustacea

- *Corophium volutator*: this species is also one of the most common estuarine species, and by far the most common crustacean in the intertidal zone. Especially in the mesohaline zone it is one of the determining species and it was observed at Valkenisse, GBL and GBR.

The next chapters gives for each species a detailed auto-ecological profile based on literature, and a first analysis on distribution, density and biomass, age and population structure, and growth at the different locations were the species were observed. These analyses are not yet complete, but will be extended with profound analyses on growth (growth models), condition and production estimates.

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Life history and population dynamics of Macoma balthica (Linnaeus, 1758) in the Schelde estuary

1. Introduction

A good and sustainable management of coastal areas and estuaries depends on a thorough understanding of the functioning of these aquatic ecosystems. Knowledge on the life history and estimates of the secondary production of some estuarine indicator species are an essential part of the knowledge one need to understand the ecosystem functioning in estuaries, especially towards a better understanding of natural versus antropogenic induced influences. Indeed, one-off determinations of different *in situ* measures of diversity and community structure of benthic populations will not always reveal totally the functioning of these populations in relation to their abiotic environment. Therefore, in addition population dynamics - studies of some important estuarine key species will provide a better insight in how the abiotic environment interacts with benthic populations. Especially in estuarine environments, typically characterized by highly varying natural environmental variables (e.g. salinity), negative human effects (e.g. pollution) could be masked or misinterpreted, based solely on a snapshot of the benthic community structure.

This study, which is part of an integrated study on macrobenthic populations in the Schelde estuary in relation to the abiotic environment with special attention for pollution effects, focuses on the life history and population dynamics of *Macoma balthica*.

Aut-ecology of *Macoma balthica* (Linnaeus, 1758)

The Baltic Tellin *Macoma Balthica* shows a wide arctic-boreal distribution along the coasts of the Norhtern Ice Sea and both sides of the Northern Atlantic. However, there is some doubt about the conspecifity of European and American Baltic Tellins.

It is a very common species along the coasts and estuaries of northern Europe and its distribution extends from the White Sea and other parts of northern Russia (Beukema & Meehan, 1985) to the Gironde estuary (Bachelet, 1980) in SW France where the species reaches its southern limit of its geographical range. In North America the species is found from the Hudson Bay (Green, 1973) in North America to as far south as Cheaspeake and San Francisco Bays (Nichols & Thompson, 1982). The Baltic Tellin *Macoma balthica* has been subject of numerous papers because of its common occurrence and its role as an important link between primary producers and fish and shorebirds.

The occurrence of *Macoma balthica* is limited to shallow coastal areas (up to about 25 m depth) and intertidal areas. In the Baltic Sea the species is observed to a depth of 150 m. M. balthica is a typical euryhaline species with a large salinity tolerance (from full sea water to less 3 ‰ S) but shows reduced growth rates and thin shells at low salinities.

Macoma balthica lives horizontally (for migrating individuals) or vertically in the sediments. The inhalant siphon is long and can be extended above the surface (at low tide) where it moves round and round. The exhalant siphon is much shorter and does not come out of the substrate (Reise, 1985). The siphons keep on growing (Reading & McGrorty, 1978), which means that older animals will live deeper than juveniles (Vassallo, 1977; Zwarts & Wanink, 1989). Depth distribution is seasonally determined (Reading & McGrorty, 1978; Zwarts & Wanink, 1989), with *Macoma balthica* living deeper in autumn and winter than in spring and summer. However, at high summer temperatures *Macoma balthica* reacts also by burrowing deeper into the sediment.

Macoma balthica is in the first place a selective deposit feeder (Gilbert, 1977; Reise, 1983), which is able to switch to filter feeding in sandy sediments (Olafsson, 1986; Hummel, 1985). When deposit feeding, also suspended algae can be taken up (Hummel, 1985; Beukema & Cadée, 1991; Thompson & Nichols, 1988).

Also in the course of the year *Macoma balthica* is able to switch between feeding techniques. In spring and early summer, when phytoplankton blooms occur, food uptake occurs mainly through the water column by filter feeding. In summer and autum, *Macoma balthica* shifts more towards deposit feeding and in winter it is almost inactive. Also the presence of large densities of congeners and/or other species can cause shifts in feeding techniques used (Lin & Hines, 1994; Kamermans, 1994).

Food exists both of benthic and planktonic microalgae, but also detritus with bacteria and protozoa (Reise, 1985).

Macoma balthica is a gonochoristic species with comparable numbers of male and females. Duration, timing and number of spawning periods varies from year to year (Gilbert, 1978; Bachelet, 1980, 1986; Harvey & Vincent, 1989) and differ from place to place (Warwick & Price, 1975; Chambers & Milne, 1975; Bachelet, 1980, ...) and depends on water temperatue and age. Main reproduction period is situated in spring (March-May) when water temperature rise above 10 °C. In the more southern areas of its geographical range a second reproduction period can occur in autumn. Macoma balthica has pelagic larvae (Jorgensen, 1946), which settle down at a size of 270-310 µm (Bachelet, 1986). Settling takes place all over the intertidal flats (Boyden & Little, 1973; Ratcliffe et al., 1981). By passive transport through tidal currents a redistribution takes place and the juveniles colonize mainly the areas high in the intertidal zone and near the marsh edge (Beukema, 1981). However, this can be hampered by the activity of sediment reworking invertebrates, such as *Arenicola marina* (Flach, 1992). During their first winter the juveniles actively migrate by thread-drifting to the lower parts of the intertidal area and to the subtidal zone. The reason for this second (winter)migration is probably the very low wintertemperatures and the possibility of ice cover on the mudflats. However, this winter migration is not seen in all areas, but specifically it is already often observed in the Wadden Sea (Armonies & Hellwig-Armonies, 1992; Beukema & de Vlas, 1989; Günther, 1991).

The start and length of the growing season depends on the geographical position. In northern areas growth start later and the duration is shorter. In the Netherlands animals start growing in spring with a duration of approximately four months (March-June). Year to year variations can be very high, depending e.g. on the presence of diatoms (Beukema & Cadée, 1991).

Production estimates are given by e.g. Ankar (1980), Bergh (1974) and Cranford et al. (1985).

Populations of Macoma balthica are characterized by a relatively low variability in time and space, compared to other estuarine species (Beukema et al., 1983). This relative constancy is the result of a long life span, the large tolerance towards different environmental variables, and the use of different feeding mechanisms (McLusky & Elliot, 1981). It also has an opportunistic reproductive strategy (Harvey & Vincent, 1989).

Macoma balthica is an important prey-item of many shorebirds like Knot *Calidris canutus*, Dunlin *Calidris alpina*, Redshank *Tringa totanus*, Bar-tailed Godwit and Oystercather *Haematopus ostralegus*. Other important predators are flatfish, gobiids and epibenthic species like shrimps and crabs. Benthic organisms such as *Retusa obtusa* and *Nereis diversicolor* are important predators of young *Macoma balthica* (Ratcliffe et al., 1981).

2. Material & Methods

2.1. Study area

The Schelde estuary, a macrotidal coastal plain estuary, is situated at the border between the Netherlands and Belgium. It measures 160 km with a surface area of approximately 350 km^2. The lower and middle estuary, the so-called Westerschelde between the Dutch-Belgian border and Vlissingen (55 km), is a well mixed region characterized by a complex network of flood and ebb channels surrounded by several large intertidal mud- and sandflats. The general environmental conditions of the Schelde estuary have been summarized in Part 3 of this report.

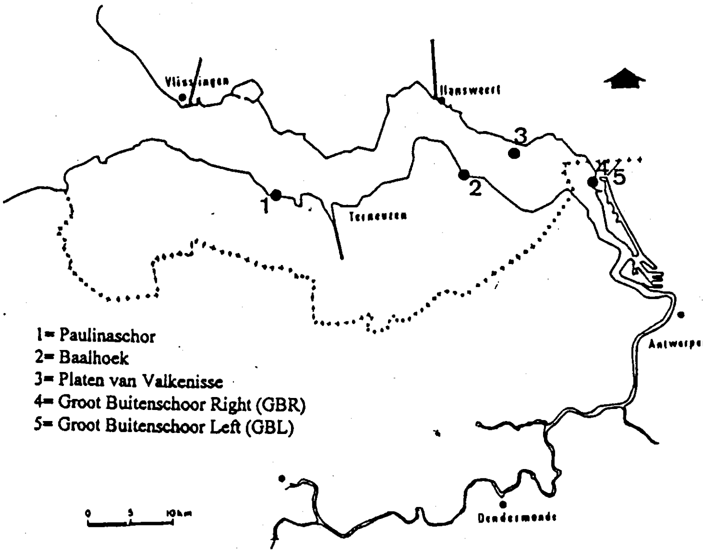

Figure 1. The Schelde estuary with the position of the sampling locations.

2.2. Sampling

The macrozoobenthos was sampled on a monthly basis in the period March 1993 - June 1994 at five locations along a salinity and sediment gradient of the Schelde estuary (Figure 1 and Table 1). The location Paulinaschor (PAU) is situated in the polyhaline zone of the estuary, the locations Baalhoek (BH) and Valkenisse (PVV) in the poly-mesohaline transit zone, and the locations Groot Buitenschoor Left (GBL) and Groot Buitenschoor Right (GBR) in the mesohaline zone. All locations are situated in the intertidal zone. More details on the abiotic environment of the locations are given in Part 3 of this report.

All macrobenthos was sampled by means of sediment cores. The methods used for the samping and subsequent treatment of the samples follow Ysebaert et al. *in prep.* (see chapter on benthic community structure).

Table 1. Names and codes of the sampling locations. Distance (from the mouth of the estuary) and estuarine division is given.

Location	**Code**	**Distance (km)**	**Estuarine division**
Paulina	PAU	15	polyhaline zone
Baalhoek	BH	40	poly/mesohaline transit
Valkenisse	VAL	43	poly/mesohaline transit
Groot Buitenschoor R	GBR	60	mesohaline zone
Groot Buitenschoor L	GBL	60	mesohaline zone

2.3. Labo analysis

Samples were sorted and the number of *Macoma balthica* per sample was counted. Individual shell length of *M. balthica* along the anterio-posterior axis was measured to the nearest 0.1 mm under a binocular with an ocular micrometer. Shell width was also measured of all collected bivalves. Width was taken as the greatest distance between the outsides of the two valves when the clam was closed. Shells were aged by counting and measuring distinct growth cessation rings, formed in winter. Based on these rings, shells were placed into year classes (0+: spat of 1993 to 4+: spat of 1989).

The flesh and shell of a subset of specimens > 5 mm were analysed seperately for weight determination. Both flesh as shell were dried at 105 °C for 12 hours, to obtain the dry weight DW, and then incinerated for 2 h at 550 °C to determine the ash-free dry weight (AFDW). Measurements were done either seperately in each specimen or in group samples from particular mm-classes. Flesh and shell were not seperated in specimens < 5 mm, so that DW and AFDW here refer to the soft as well as hard parts.

2.4. Data analysis

Density and biomass of the population is expressed as number of individuals per m² (N/m²) and g AFDW/m² respectively.

Length-frequency distributions were analysed by pooling all individuals into mm classes.

Data on density are shown with standard error.

3. Results

3.1. Distribution

Macoma balthica was present at all five locations studied. At the two mesohaline locations GBL and GBR, *M. balthica* was not present all year round, but was only observed in summer and autumn. In winter and spring the species was absent here.

Densities of *M. balthica* show a clear seasonal pattern at all locations, but is less pronounced at Baalhoek. At Paulina, densities are low in spring 1993 (± 250 N/m²) but start to increase in June (± 750 N/m²) and reach peak densities of 2500 N/M² in July. Densities stay more or less at the same high level until December. From January 1994 on densities decrease and reach a minimum of ± 500 N/m² in March 1994. Already in May 1994 numbers start to increase again and in June 1994 a density of 7000 N/m² is reached.

At Valkenisse a similar pattern is observed (Figure 2). Densities are low in spring 1993 (± 500 N/m²). In June alreday a steep increase in density is observed (2500 N/m²) and peak densities are reached in July 1993 (3750 N/m²). Densities stay high (> 2500 N/m²) until November 1993, after which a steep decrease is observed to 400-500 N/m² in spring 1994. In May 199 densities are still low.

At Baalhoek, *M. balthica* was observed every month, but only in relatively low densities (10-250 N/m²). The variation in density is low and now clear seasonal pattern is observed.

At GBL and GBR *M. balthica* is absent in spring 1993 (Figures 3-4). From May-June, the first individuals are seen and density increases further in June-July to reach maximum density in August 1993. Maximum density is 500 N/M² and 1000 N/m² at GBL and GBR respectively. At GBL densities drop already steep in September to ± 100 N/m² and in January 1994 *M. balthcia* disappear again. In GBR density decreases at a slower rate as compared to GBL, but in December 1993 it already dropped to 150 N/m² and in February 1994 *M. balthica* totally disappeared.

Biomass patterns follows the observed density patterns (Figures 2-4), but peak biomasses are mostly seen one or two months later as compared to peak densities.

3.2. Age structure

The age structure of all *Macoma* populations studied is characterized by a relatively low number of generations. This is further described for Valkenisse, GBL and GBR.

At Valkenisse 0+ individuals are most abundant during most of the year (Figure 2). Individuals of the 1+ and 2+ generations are also present in relative high numbers (Figure 2). Numbers of all generations decrease in the course of the year. A few individuals belonging to the 3+ and 4+ generations are observed irregularly.

At the locations GBL and GBR only 0+ individuals are observed. One individual belonging to the 1+ generation was observed once at GBL. *M. balthica* seems not to be able to survive at these locations, since the observed spatfall totally disappear during the course of the year.

3. *Growth curves*

Growth curves are presented for Valkenisse, GBR and GBL.

At Valkenisse, growth curves were calculated for the 0+, 1+ and 2+ generations (Figure 5). For older generations this was not possible, because too few individuals were available. Distinct growth was observed for all three (0+,1+,2+) generations considered (Figure 5). The first 0+ individuals appear in the population with a mean length of 3-3.5 mm. Between the beginning of June and the beginning of July growth rate is fastest and a mean length of ± 5 m is reached. In August growth rate decreases (mean length 5.5 mm) and from September on no growth is observed until October. In the winter months mean length increases again to 6.0-6.5 mm, but this increase could be due to other factors than growth (e.g. mortality or migration). In May 1994 a new growing season starts.

Growth rate of 1+ individuals is even more pronounced. IN March 1993 the 1+ individuals have a mean length of ± 4.5 mm. In May they have already reached a length of 6 mm. Growth rate is fastest between May and June, one month earlier than observed for the 0+ individuals. In that period an increase of more than 3 mm is observed and mean length exceed 9 mm. Between June and July mean length increases further with another 2 mm to ± 11.0 - 11.5 mm. Growth is no longer observed from August on.

Growth rate of 2+ individuals is significantly slower as compared to the 0+ and 1+ individuals. A distinct increase is observed between May and June (from 11.75 mm to 13.25 mm). From July on, no clear growth is observed anymore until December 1993. A small increase in mean length is observed from January 1994 on, but this is supported by a limited number of observations.

At GBL and GBR no growth at all is observed (Figure 6). Individuals of the 0+ generation appear in May/June in the population with a length of 2-3 mm and this length stay more or less the same during the rest of year, until they disappear totally. From October on, mean lengths are based on only a few individuals. The increase at GBL in that period should therefore not be considered as real growth (falling outside normal growing season), but is caused by the presence of one larger individual.

3.4. *Allometric relationships*

A highly significant relationship is observed between length and width of *Macoma balthica* at all locations (Figures 7-8). Slopes are very similar for all locations.

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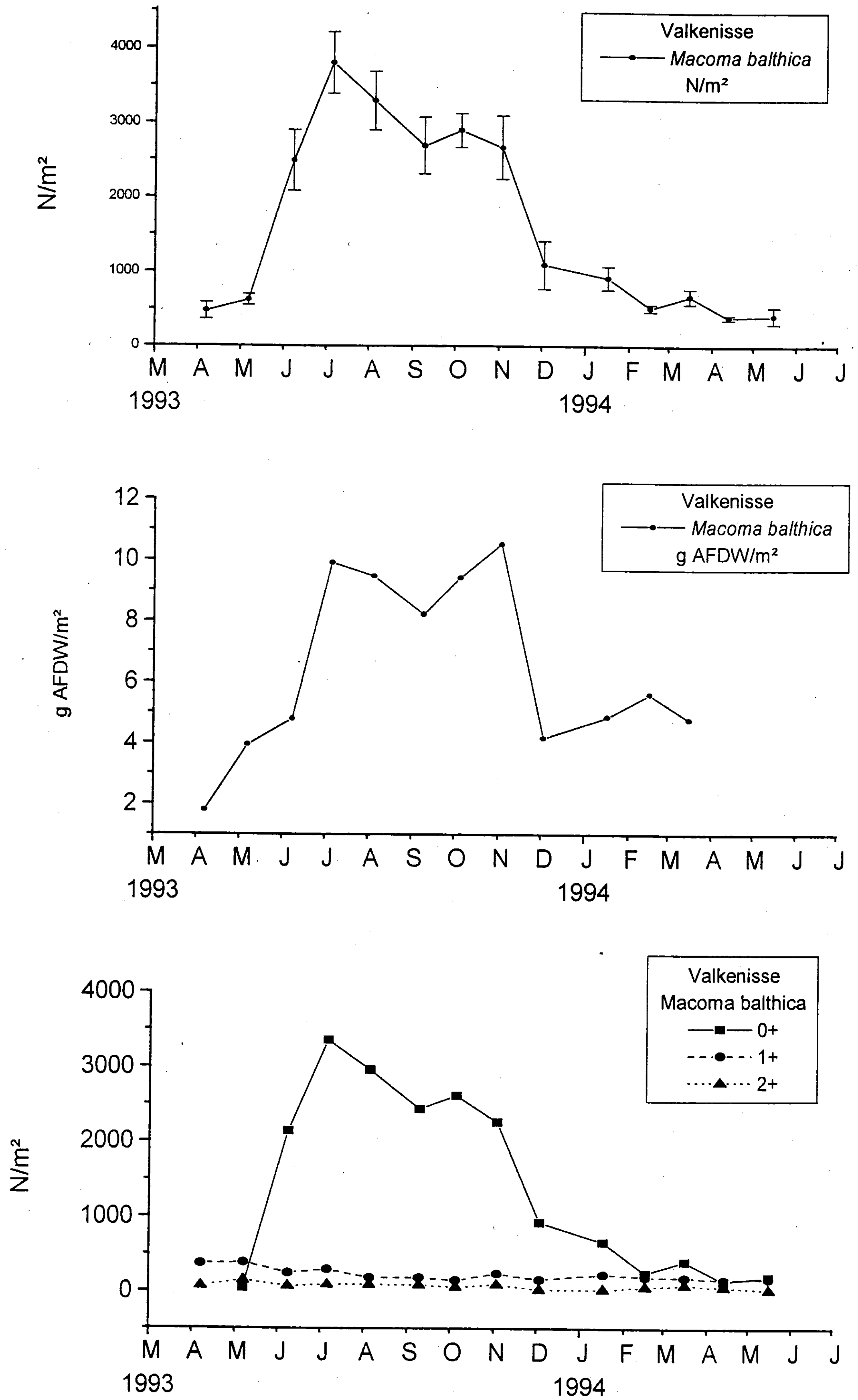
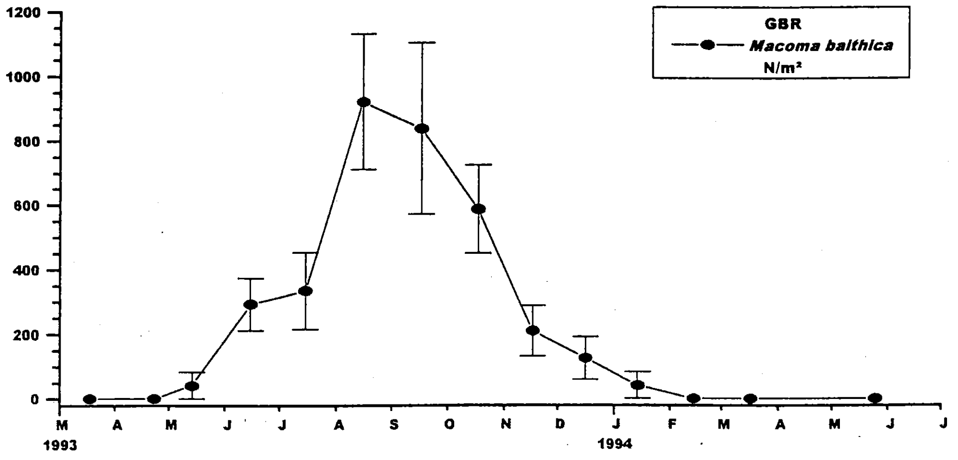


Figure 2. Density, biomass and age structure of *Macoma balthica* at Valkenisse.



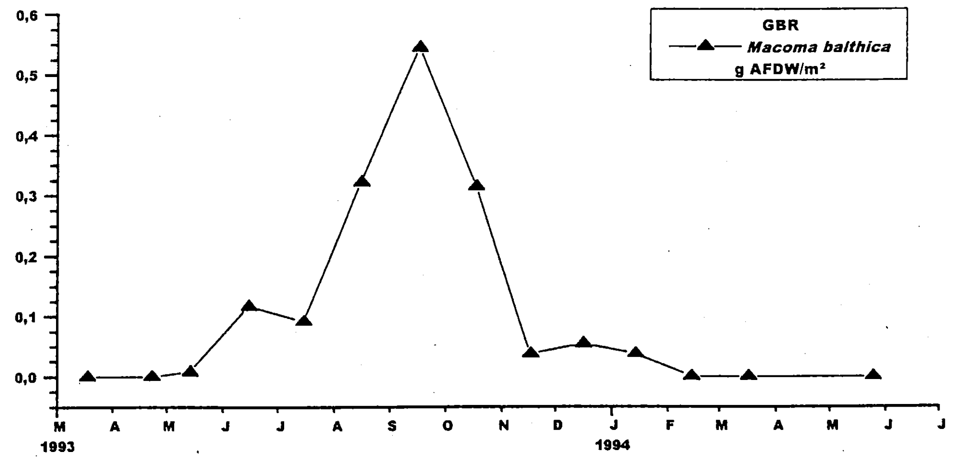
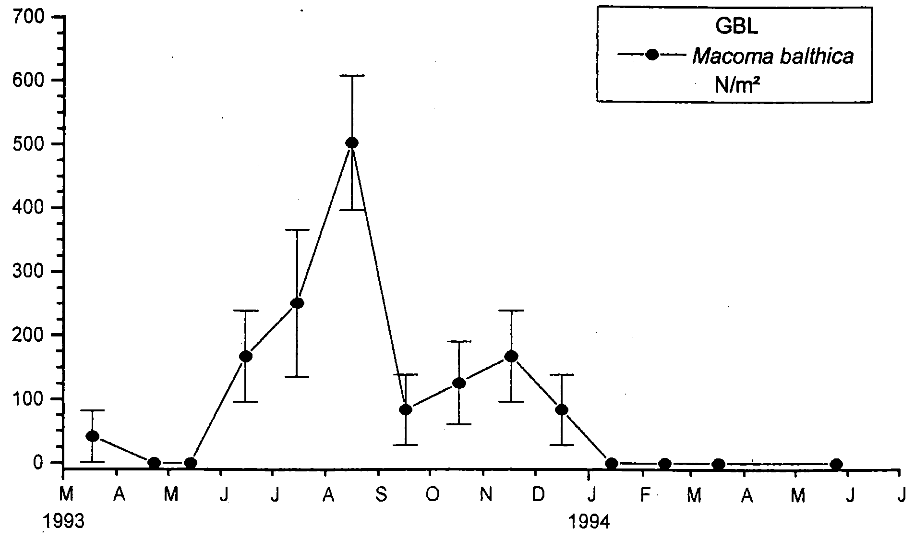


Figure 3. Density and biomass of *Macoma balthica* at GBR.



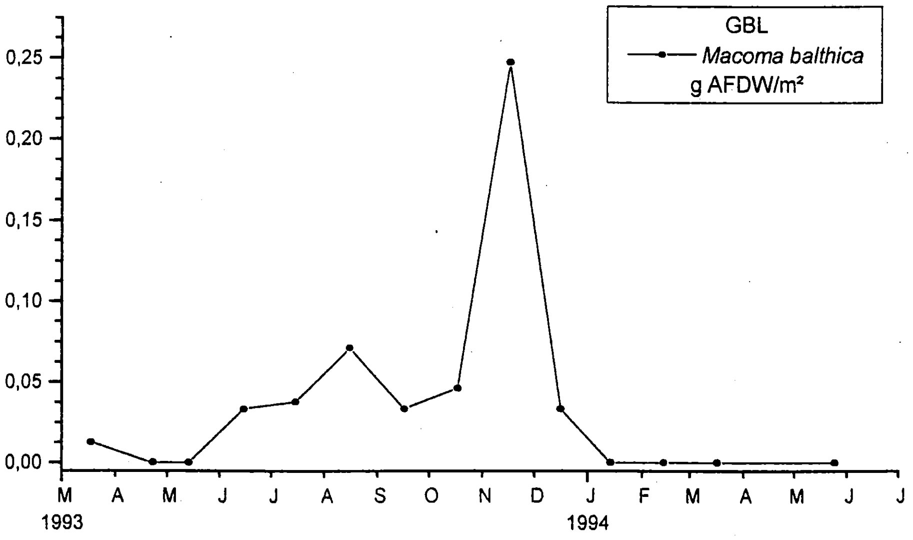


Figure 4. Density and biomass of *Macoma balthica* at GBL.

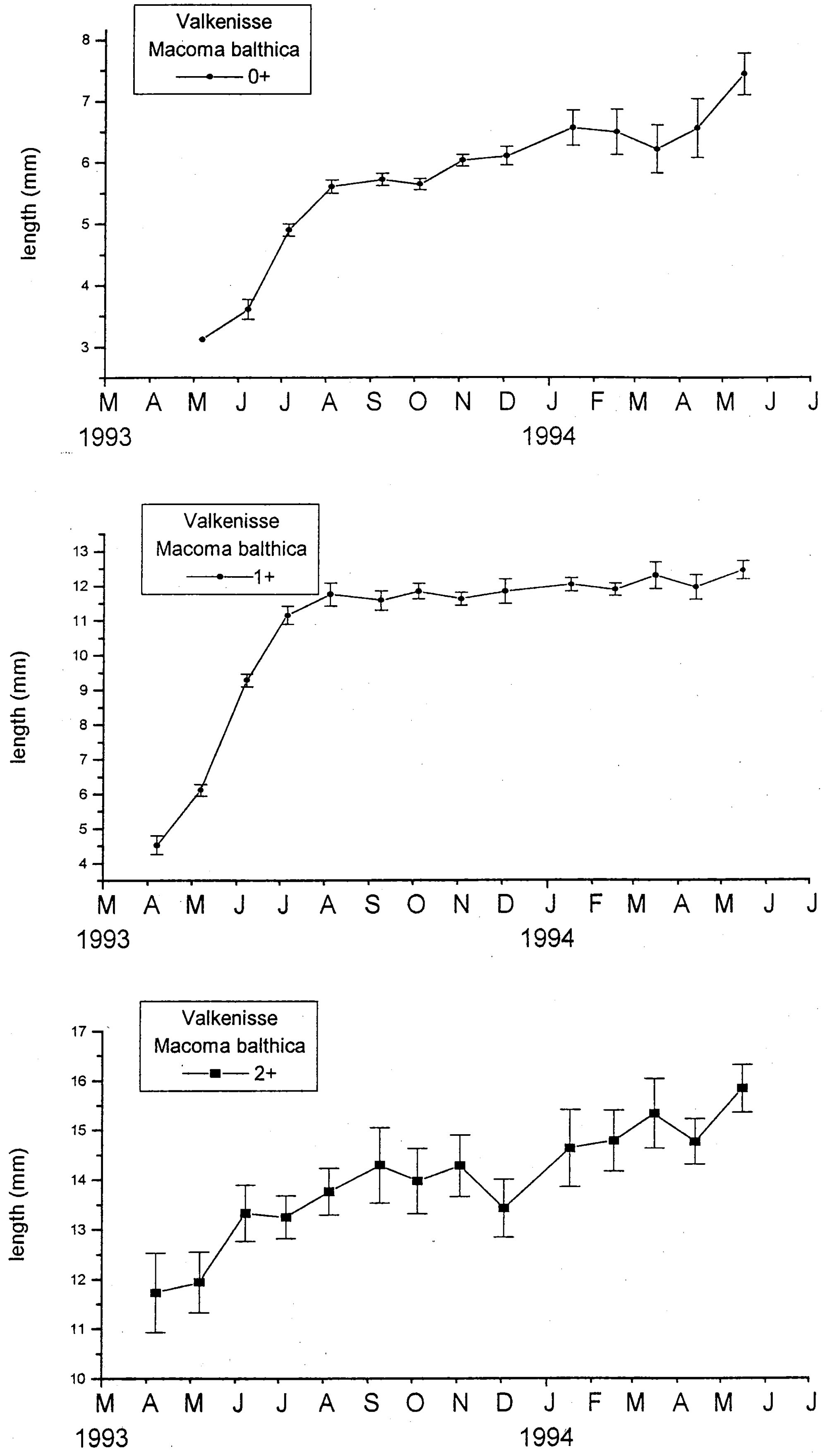


Figure 5. Growth rate of 0+, 1+ and 2+ *Macoma balthica* at Valkenisse.

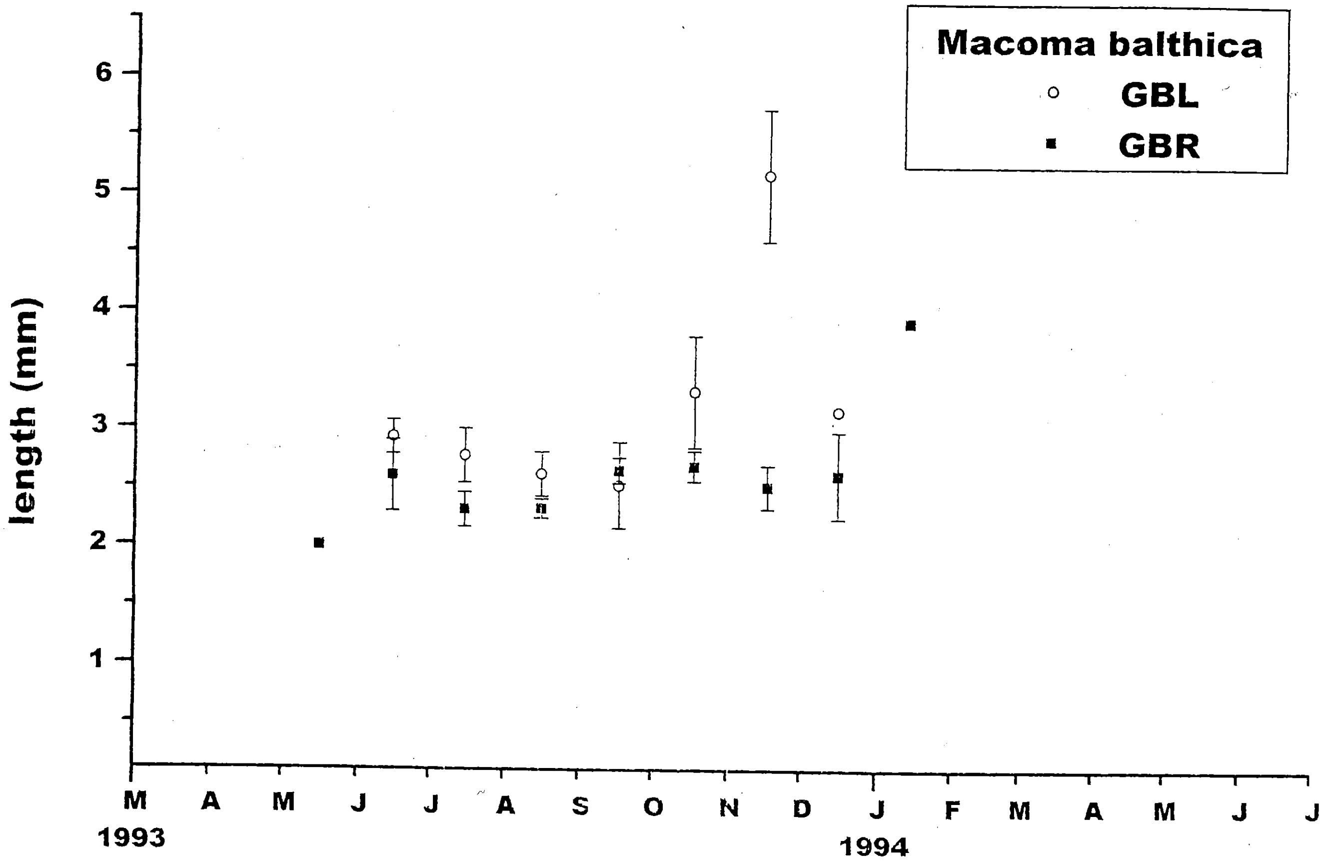


Figure 6. Growth rate of 0+ individuals at GBR and GBL.

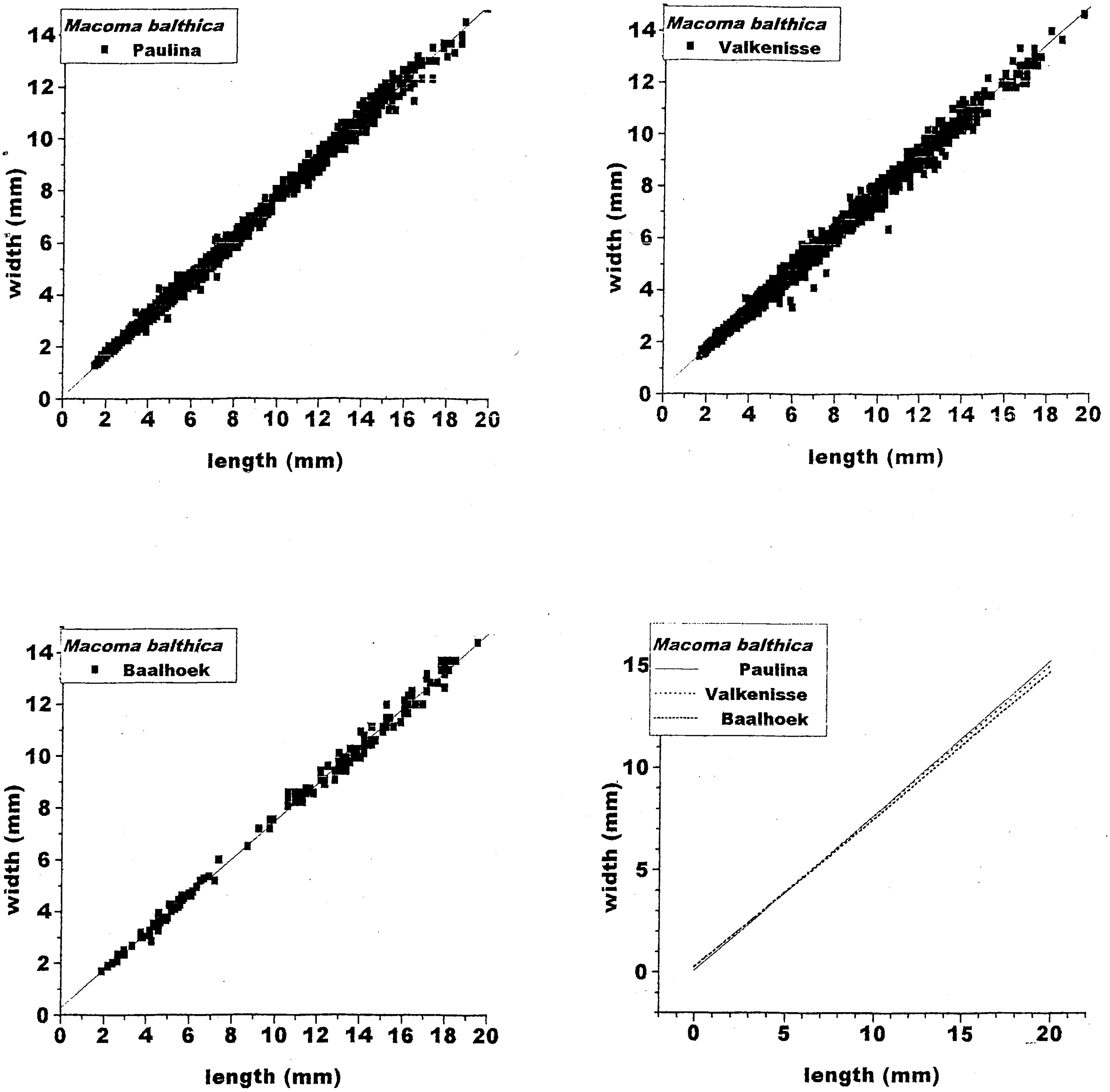


Figure 7. Length-width relationships of Macoma balthica, originating from Paulina, Baalhoek and Valkenisse.

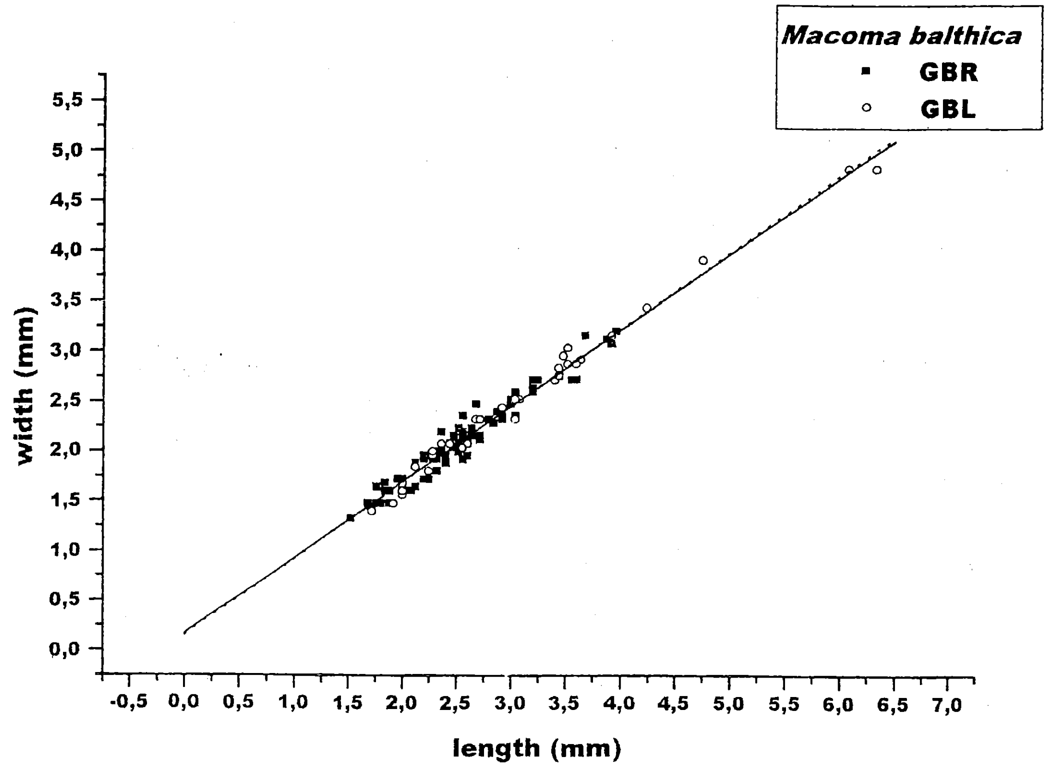


Figure 8. Length-width relationships of *Macoma balthica* originating from GBR and GBL.

Life history and population dynamics of Scrobicularia plana (Da Costa, 1778) in the Schelde estuary

1. Introduction

A good and sustainable management of coastal areas and estuaries depends on a thorough understanding of the functioning of these aquatic ecosystems. Knowledge on the life history and estimates of the secondary production of some estuarine indicator species are an essential part of the knowledge one need to understand the ecosystem functioning in estuaries, especially towards a better understanding of natural versus antropogenic induced influences. Indeed, one-off determinations of different *in situ* measures of diversity and community structure of benthic populations will not always reveal totally the functioning of these populations in relation to their abiotic environment. Therefore, in addition population dynamics - studies of some important estuarine key species will provide a better insight in how the abiotic environment interacts with benthic populations. Especially in estuarine environments, typically characterized by highly varying natural environmental variables (e.g. salinity), negative human effects (e.g. pollution) could be masked or misinterpreted, based solely on a snapshot of the benthic community structure.

This study, which is part of an integrated study on macrobenthic populations in the Schelde estuary in relation to the abiotic environment with special attention for pollution effects, focuses on the life history and population dynamics of *Scrobicularia plana*.

Aut-ecology of Scrobicularia plana (Da Costa, 1778)

Scrobicularia plana is a euryhaline species. With large fresh water influx shells are closed. It is most abundant in fine sediments high in the intertidal area (Dankers & Beukema, 1981; Spooner & More, 1940; Wolff, 1973); subtidally the species is confined to the upper part (Rasmussen, 1973; Wolff, 1973). More important than sediment type and height as distribution determining factors is the presence of a waterfilm on the flat during the whole low water period (Guérin, 1961; Reichert & Dörjes, 1980).

S. plana is living in a vertical position in the substrate, to a maximal depth of 20 cm (Hughes, 1969) to 30 cm (Green, 1968) for adults. Smaller individuals live less deep as compared to larger ones (Zwarts & Wanink, 1989). An inhalating siphon is held vertically and reaches the surface, whereas the exhalating one is much shorter and curved (Hughes, 1969). Burrowing capacity is dependent on sedimenttype (Guérin, 1961) and favoured by its big foot. According to Hodgson (1982), vertical migration occurs during winter. Horizontal migration is very rare, unlike the other Tellinids.

S. plana is primarily a non-selective deposit feeder during the whole low water period. However, the presence of a waterfilm is necessary for the intake of food particles (Hughes, 1969; Reichert & Dörjes, 1980). The inhalating siphon is held 5-8 cm out of the sediment, where it moves round and round. Since *S. plana* is most abundant in anaerobic sediments, sulphur bacteria (4-40 µm) are an important food source. The availability of food is an important factor which determines growth in a significant way (Worrall & Widows, 1983; Worrall et al., 1983). Besides deposit feeding, *S. plana* can also behave as a filter feeder: when the sediment is inundated, the siphon is retracted to protect it against predators and to take up particles from the water column. Deposit feeding activities decreases in November and remains low until bottom temperatures rises above 7° C.

S. plana is a gonochoristic species with comparable numbers of male and females (Hughes, 1971). Hermaphrodites are scarce (Paes-da-Franca, 1956). *S. plana* becomes sexually mature in their second summer, at a size of approximately 20 mm. Maturation of gametes starts in April when bottom temperature exceeds 10° C, and ends up in the second half of June. Spawning takes place in July-August. In bays and estuaries along the English Channel and North Sea recruitment is irregular and has only one cohort per year. In the latter areas, especially in the Wadden Sea, recruitment may be absent for several years (Essink et al., 1990). In southern populations along the Atlantic ocean (south of Brittany), ripe gametes are found the whole year round, resulting in two or three distinct spawning periods (Paes-da Franca, 1956; Essink, et al., 1990). Spermatozoids are released through the exhalating siphon, to disperse into the watercolumn. Spawning in males is synchronised and takes about 15 minutes. It does not induce egg deposition by females. After spawning, there is a resting period of several months. *S. plana* can become old (18 years) and as big as 54 mm (Green 1968).

S. plana is an important prey-item for several birds. Hughes (1971) found a mortality rate of 5-6 % due to predation by Oystercatchers (*Haematopus ostralegus*). Siphon retraction - after changes in pressure on the substrate - forms the visual stimulus for these birds (Hughes, 1970). Other predators of *S. plana* are fishes (*Pleuronectes platessa*, *Gadus morhua*, *Anguilla anguilla*, ...) and crabs. Very often, they can only take parts of the siphon ('cropping') which regenerates quickly (Hodgson, 1981). However, siphon predation has several negative consequences (Hodgson, 1982; Zwarts, 1986).

2. Material & Methods

2.1. Study area

The Schelde estuary, a macrotidal coastal plain estuary, is situated at the border between the Netherlands and Belgium. It measures 160 km with a surface area of approximately 350 km^2. The lower and middle estuary, the so-called Westerschelde between the Dutch-Belgian border and Vlissingen (55 km), is a well mixed region characterized by a complex network of flood and ebb channels surrounded by several large intertidal mud- and sandflats. The general environmental conditions of the Schelde estuary are been summarized in Part Three of this Report.

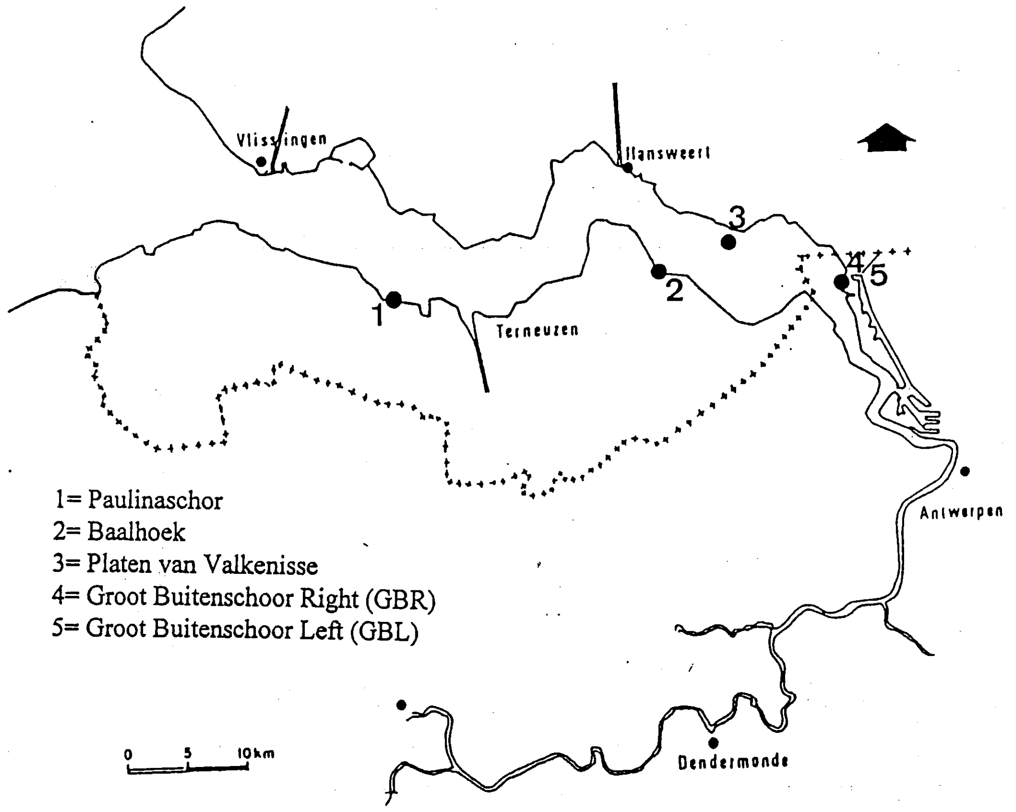


Figure 1. The Schelde estuary with situation of the sampling locations.

2.2. Sampling

The macrozoobenthos was sampled on a monthly basis in the period March 1993 - June 1994 at five locations along a salinity and sediment gradient of the Schelde estuary (Figure 1 and Table 1). The location Paulinaschor (PAU) is situated in the polyhaline zone of the estuary, the locations Baalhoek (BH) and Valkenisse (PVV) in the poly-mesohaline transit zone, and the locations Groot Buitenschoor Left (GBL) and Groot Buitenschoor Right (GBR) in the mesohaline zone. All locations are situated in the intertidal zone. More details on the abiotic environment of the locations are given in Part Three of this report.

All macrobenthos was sampled by means of sediment cores. The methods used for the samping and subsequent treatment of the samples follow Ysebaert et al., *in prep* (see chapter on benthic community structure).

Table 1. Names and codes of the sampling locations. Distance (from the mouth of the estuary) and estuarine division is given.

Location	**Code**	**Distance (km)**	**Estuarine division**
Paulina	PAU	15	polyhaline zone
Baalhoek	BH	40	poly/mesohaline transit
Valkenisse	VAL	43	poly/mesohaline transit
Groot Buitenschoor R	GBR	60	mesohaline zone
Groot Buitenschoor L	GBL	60	mesohaline zone

2.3. Labo analysis

Samples were sorted and the number of *Scrobicularia plana* per sample was counted. Individual shell length of *S. plana* along the anterio-posterior axis was measured to nearest mm with vernier callipers along. Shell width was also measured in a subsample of the collected bivalves. Width was taken as the greatest distance between the outsides of the two valves when the clam was closed. Shells were aged by counting and measuring distinct growth cessation rings, formed in winter. Based on these rings, shells were placed into year classes (0+: spat of 1993 to 4+: spat of 1989).

The flesh and shell of a subset of specimens > 10 mm were analysed seperately for weight determination. Both flesh as shell were dried at 105 °C for 12 hours, to obtain the dry weight DW, and then incinerated for 2 h at 550 °C to determine the ash-free dry weight (AFDW). Measurements were done either seperately in each specimen or in group samples from particular mm-classes. Flesh and shell were not seperated in specimens < 10 mm, so that DW and AFDW here refer to the soft as well as hard parts.

2.4. Data analysis

Density and biomass of the population is expressed as number of individuals per m^2 (N/m^2) and g $AFDW/m^2$ respectively.

Length-frequency distributions were analysed by pooling all individuals into mm classes.

The morphometric condition index was calculated as follows (see Beukema & Cadée, 1991; Bonsdorff & Wenne, 1989; Wenne & Styczynska-Jurewicz, 1985):

$CI = AFDW*L^{-3}$ (L= shell length, mm)

3. Results

3.1. Distribution

Scrobicularia plana was present at three locations, namely Paulina, Baalhoek and Valkenisse. At the two mesohaline locations GBL and GBR, *S. plana* was lacking. At Valkenisse, *S. plana* was observed every month, but only in very low densities (10-50 N/m^2) (Figure 2). The population structure at this location is not further discussed in this paper.

Densities of *S. plana* observed at the two locations Paulina and Baalhoek show a clear seasonal pattern (Figure 3). At Paulina, densities are relatively high at the beginning of the study (± 1500 N/m^2 in March 1993). Towards May, maximum density is reached with 2800 N/m^2, after which a sharp decline is observed. From July on, densities vary between 200 and 400 N/m^2 during the rest of the year. At Baalhoek, an increase is observed from 200 N/m^2 to ± 850 N/m^2 in the period March-May 1993. Between May and August densities stay relatively stable, after which densities decrease to 500-600 N/m^2 the rest of the year. Variations in densities are less pronounced at Baalhoek as compared to Paulina.

The biomass of *S. plana* varies between 10 and 20 g AFDW/m^2 at Paulina and between 4 and 13 g AFDW/m^2 at Baalhoek (Figure 4). At both locations a clear seasonal pattern is observed with high values in summer and lower values in winter and spring.

2. Age structure

The age structure of the two studied populations is characterized by only a limited number of generations. At Baalhoek the population exists almost exclusive of 0+ and 1+ individuals (Figure 3). In March and April also one individual with age 2+ is observed and in June one individual with age 3+. Spatfall (0+) is observed from April on and densities of 0+ individuals increase towards August when a maximum of reached of 850 ind/m^2. In September densities of 0+ individuals drop to 500 N/m^2. In winter numbers slowly decrease further to ± 300 N/m^2. The 1+ individuals are found in densities of ± 200 N/m^2 in the period March-May 1993, but from June on numbers start to decrease to around 50 N/m^2.

At Paulina a same age structure within the *S. plana* population is observed with 0+ individuals dominating the population (Figure 3). In March 1993 already a high density of 0+ individuals (spatfall) is observed. In May peak densities of 0+ individuals are reached, after which a steep decrease is observed; from July on densities vary between 115 and 250 N/m^2. The 1+ individuals are observed yearround with densities of 50-100 N/m^2 in the period March-December, after which numbers decrease further to 10-50 N/m^2. In comparison to Baalhoek, 2+ individuals are observed more regularly at Paulina, but still in very low densities (10-30 N/m^2). Individuals of 3+ and 4+ are observed at respectively 5 and 1 occassions.

3. *Seasonal changes in length composition and growth curves*

The length class - frequency distributions by date show for both locations clearly seperated age classes with almost no overlap (Figures 5 and 6). A clear seasonal increase in shell length is observed in both locations for the 0+ and 1+ individuals. Data on bivalves > 1+ are not sufficient enough to detect increase in total shell length. The data clearly show that the 0+ individuals consists of only one cohorte. The time of spatfall clearly differ between the two locations. At Paulina spatfall is already present at the beginning of our study (March 1993). However, since the length at that time is very small (mainly 1 and 2 mm), it can be concluded that spatfall took place in the period February-March 1993. At Baalhoek spatfall appeared later with the first individuals observed in April 1993. In 1994, still no spatfall appeared at Paulina in June, whereas in Baalhoek the first new recruits were observed in May 1994.

Figure 7 clearly show the distinct shell growth of both 0+ and 1+ individuals at Paulina and Baalhoek. At Paulina a constant growth of 0+ individuals is observed between March and Augustus-September in which the mean length increases from 2 mm to 20 mm. From September on no clear growth is observed anymore. A similar pattern is observed at Baalhoek but here the growth rate of 0+ individuals is less as compared to Paulina: between April and August an increase of the mean length from 2 mm to 12 mm is observed. The growth rate of the 1+ individuals, measured by the increase in total shell length, is less pronounced as for the 0+ individuals. At Paulina the mean shell length of 1+ individuals amounts 23-24 mm in spring 1993. In summer an increase is observed to 28-30 mm, indicating an increase in growth of ± 5-7 mm. At Baalhoek 1+ individuals are significantly smaller as compared to Paulina, with a mean shell length of 15 mm in spring 1993. However, the increase in growth of the 1+ individuals is larger in Baalhoek as compared to Paulina and amounts ± 9 cm. The increase in length for individuals > 1+ can not be shown based on the total shell length since too few individuals are available.

4. *Allometric relationships*

A very strong and linear relationship is observed between length and width of *Scrobicularia plana* (Figure 8).

The contribution of the shell itself to the total AFDW of the shell and flesh together varied between 10 and 30 %, with a mean of 17.15 ± 0.27 % at Baalhoek and 17.95 ± 0.28 % at Paulina. No significant difference was found for size (Figure 9).

The condition of the bivalves show a significant negative relationship with length at Baalhoek, whereas at Paulina no effect of length on condition is observed (Figure 10).

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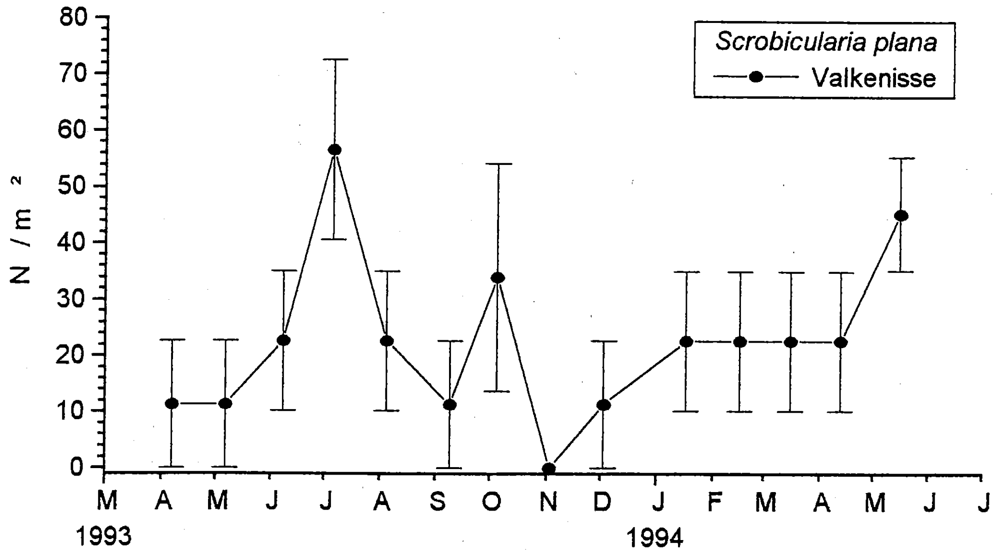


Figure 2. Seasonal variation of the density of Scrobicularia plana at Valkenisse.

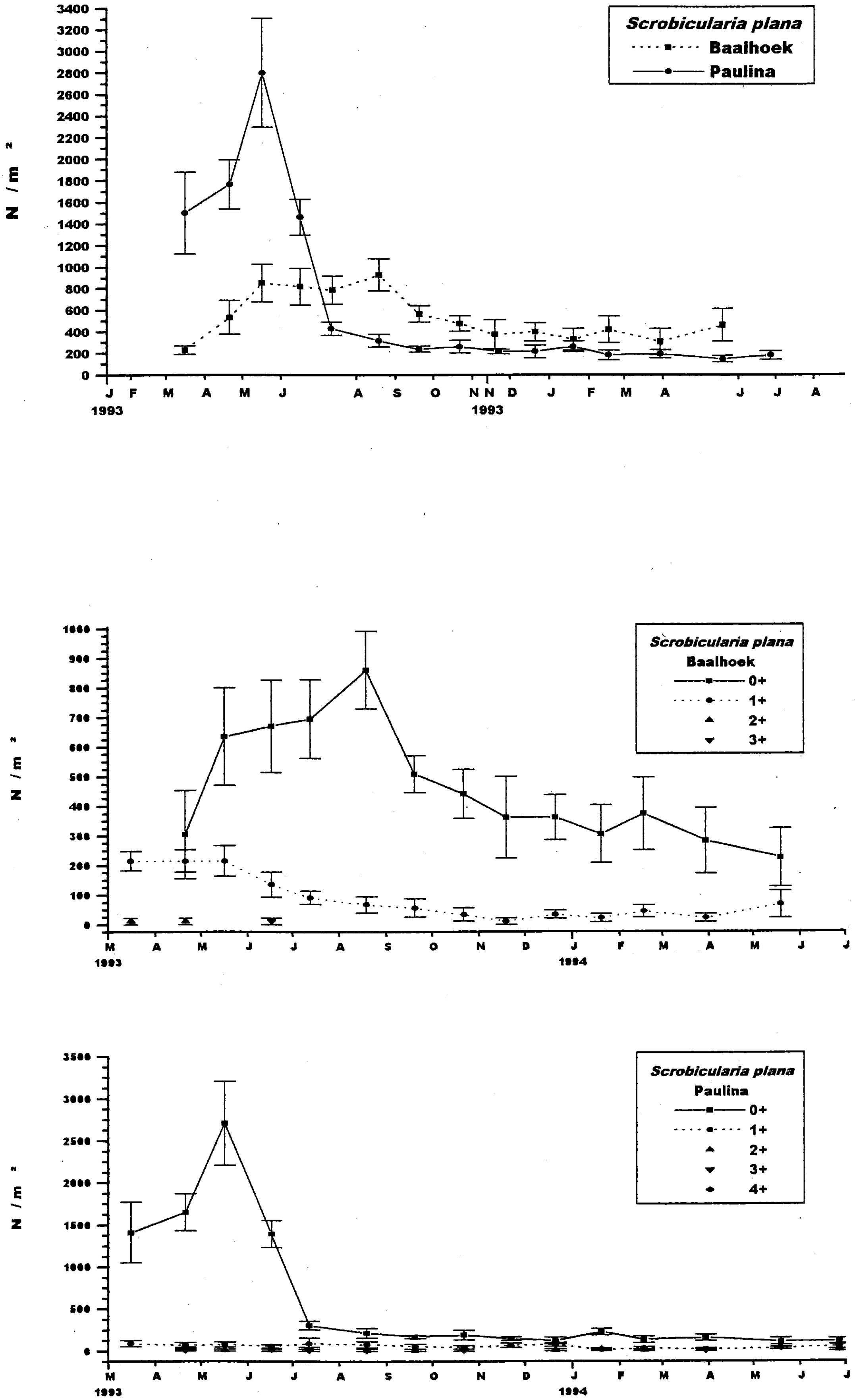


Figure 3. Seasonal variation in density and age structure at Paulina & Baalhoek.

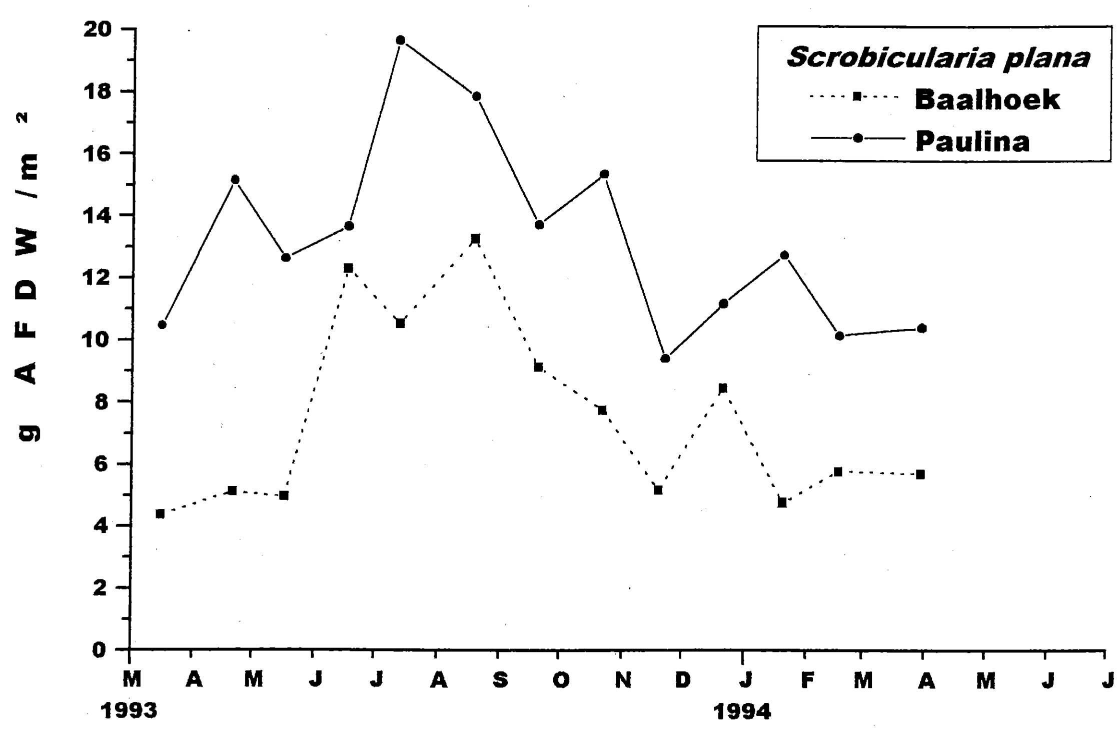


Figure 4. Seasonal variation in biomass of *Scrobicularia plana* at Paulina and Baalhoek.

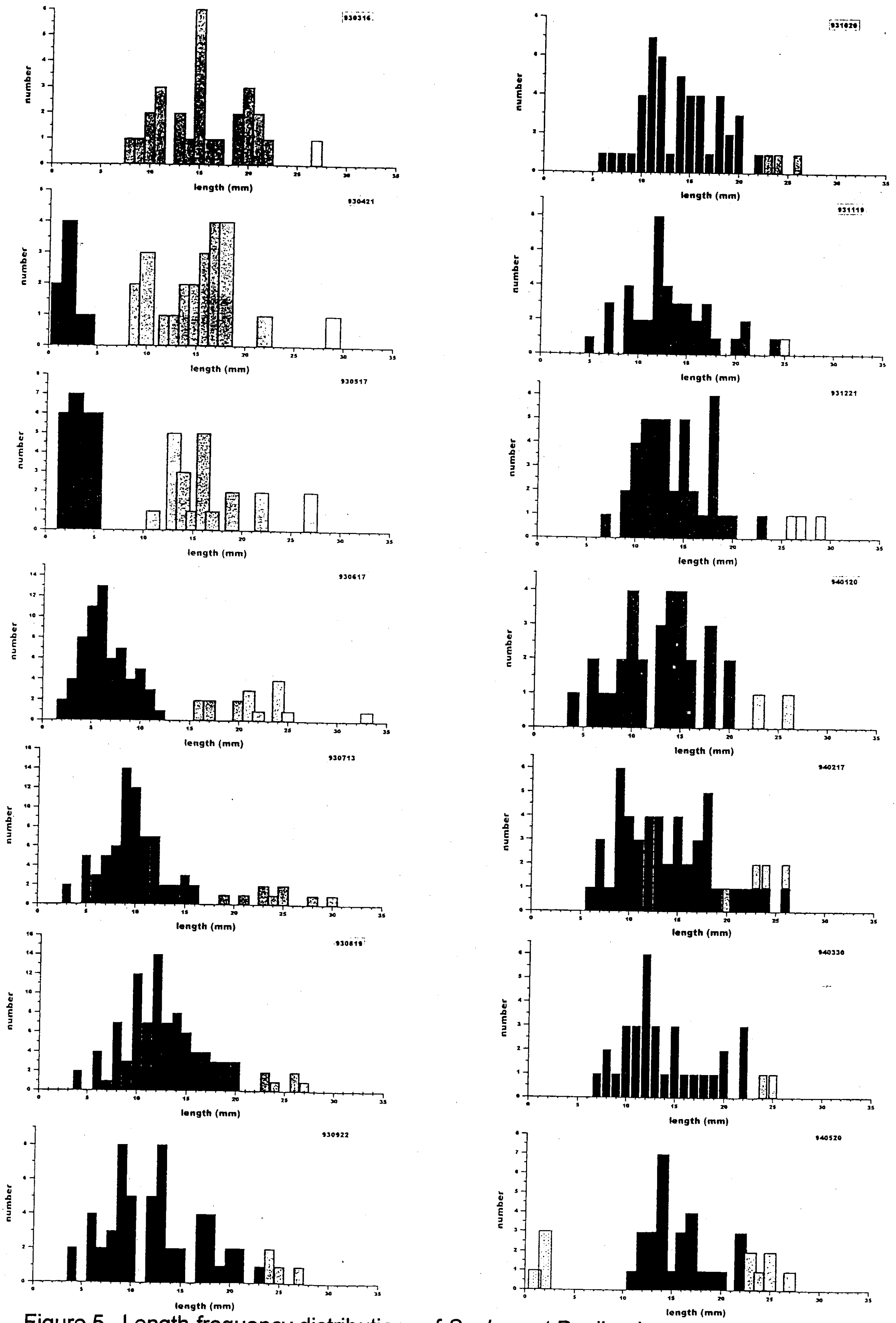


Figure 5. Length-frequency distributions of *S. plana* at Baalhoek.

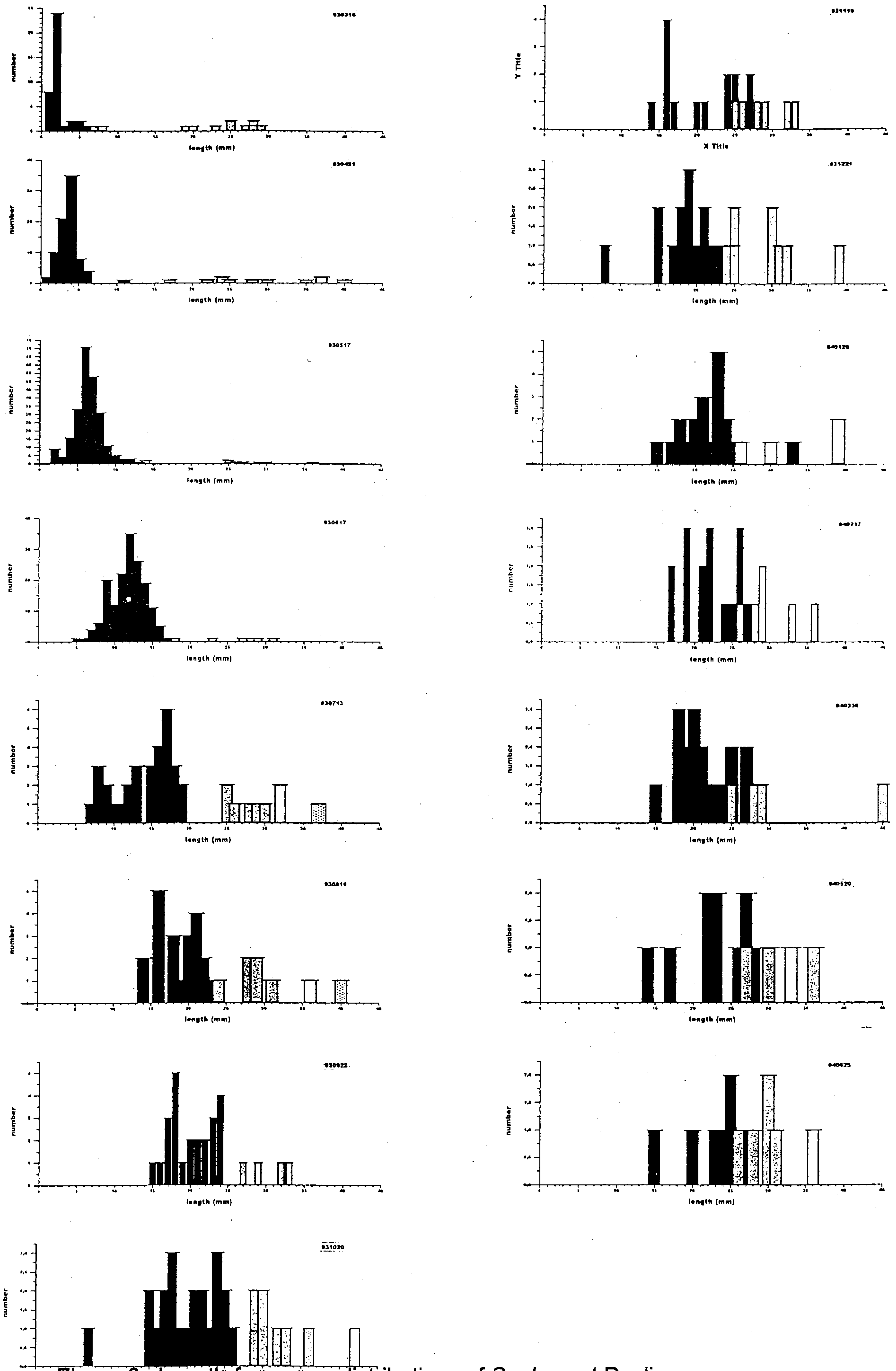


Figure 6. Length-frequency distributions of *S. plana* at Paulina.

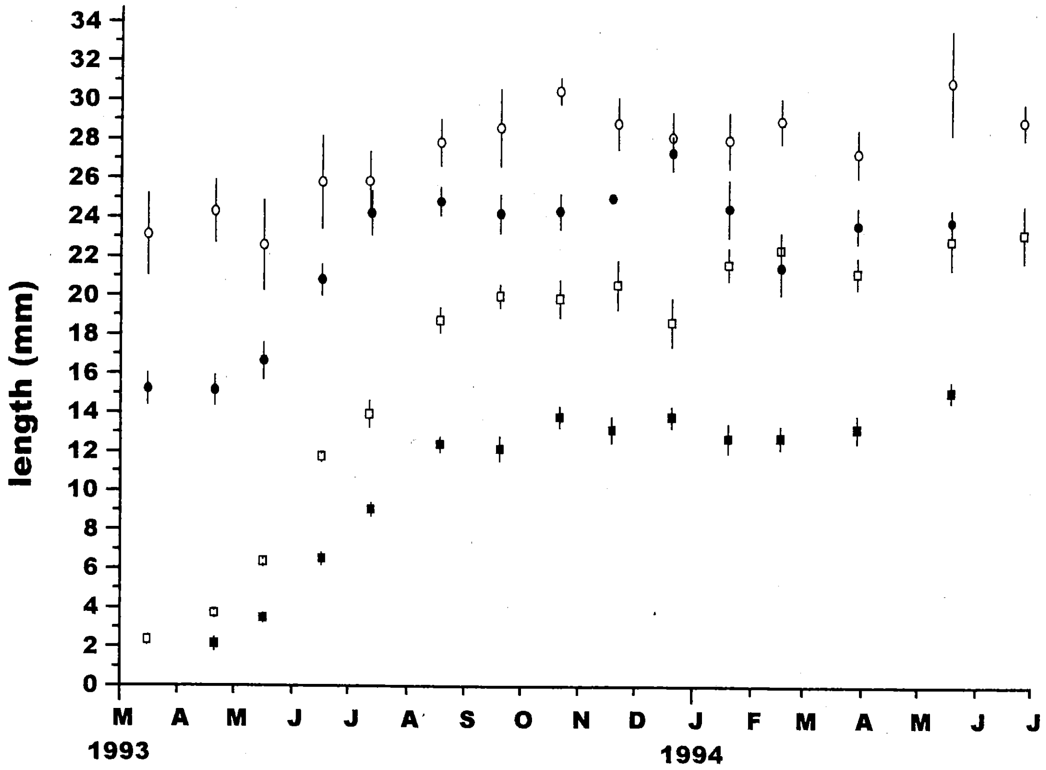


Figure 7. Growth rate of 0+ and 1+ *Scrobicularia plana* at Paulina and Baalhoek.
Open squares: 0+ Paulina Solid squares: 0+ Baalhoek
Open circles: 1+ Paulina Solid circles: 1+ Baalhoek

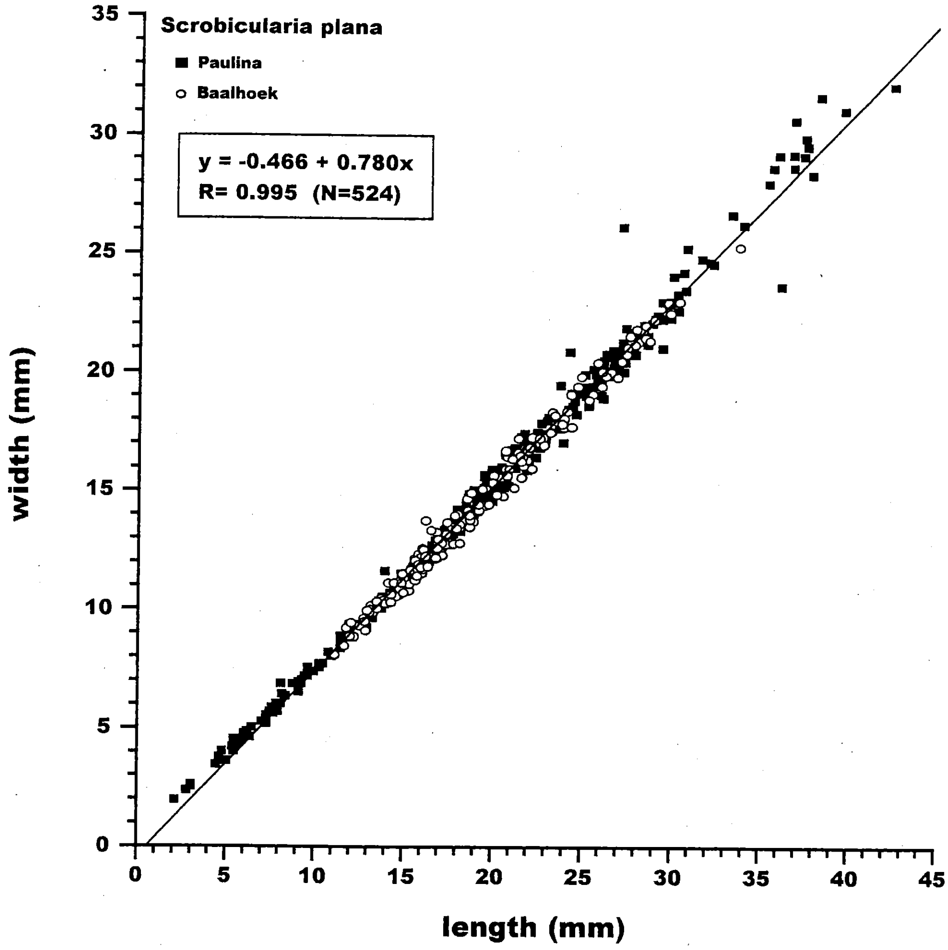


Figure 8. Length-width relationship of Scrobicularia plana, originating from Baalhoek and Paulina.

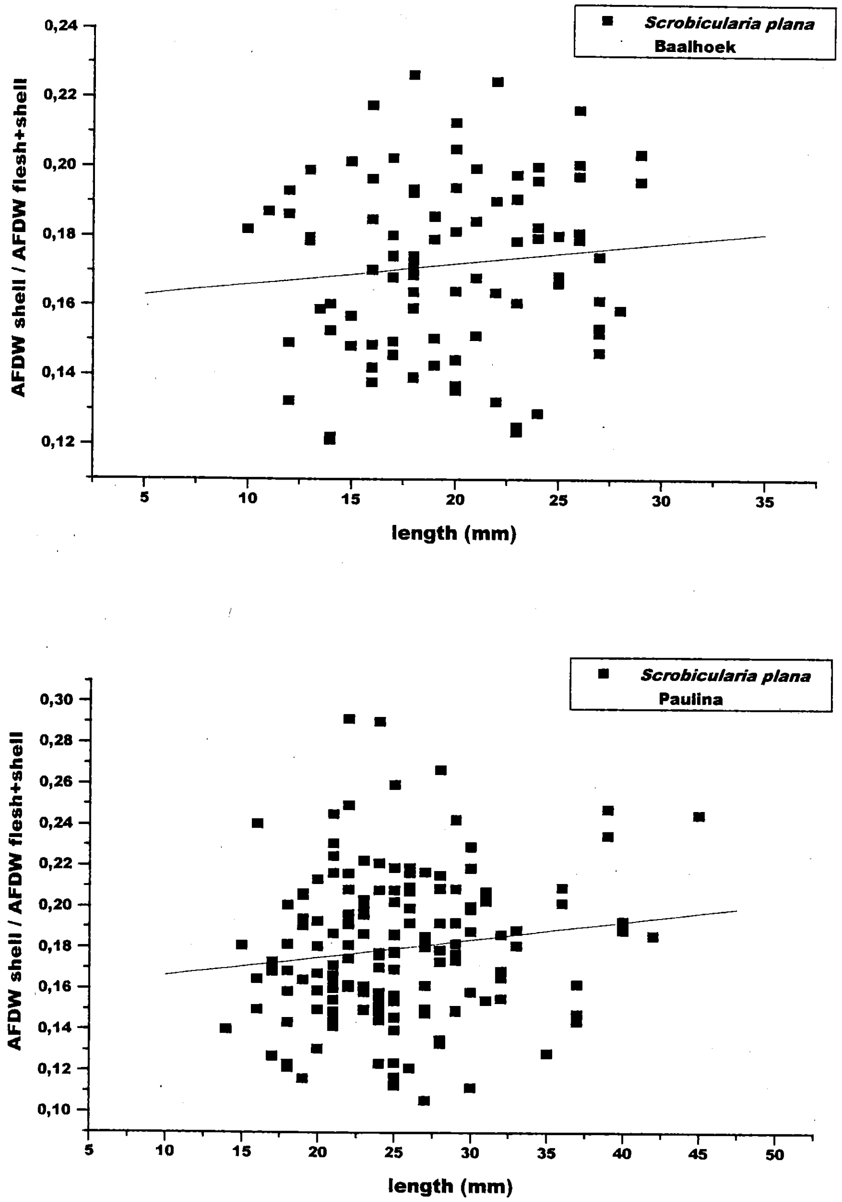
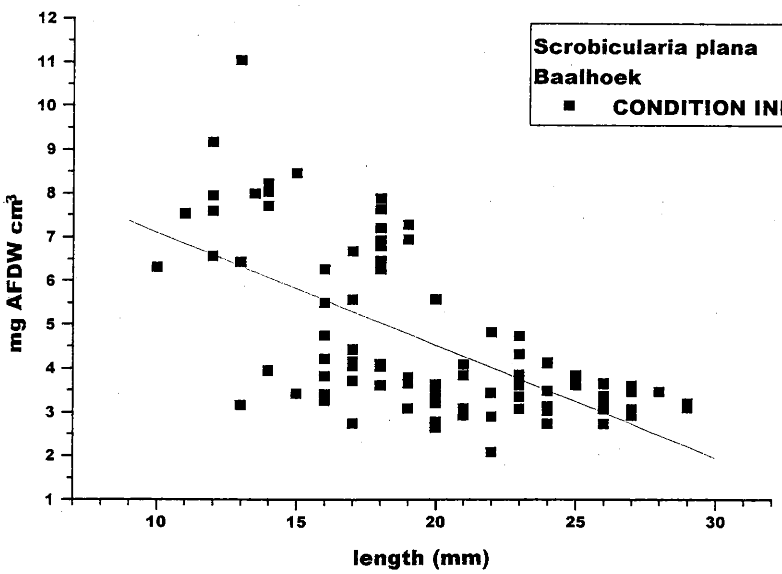


Figure 9. Contribution of the shell to the total AFDW of shell and flesh.



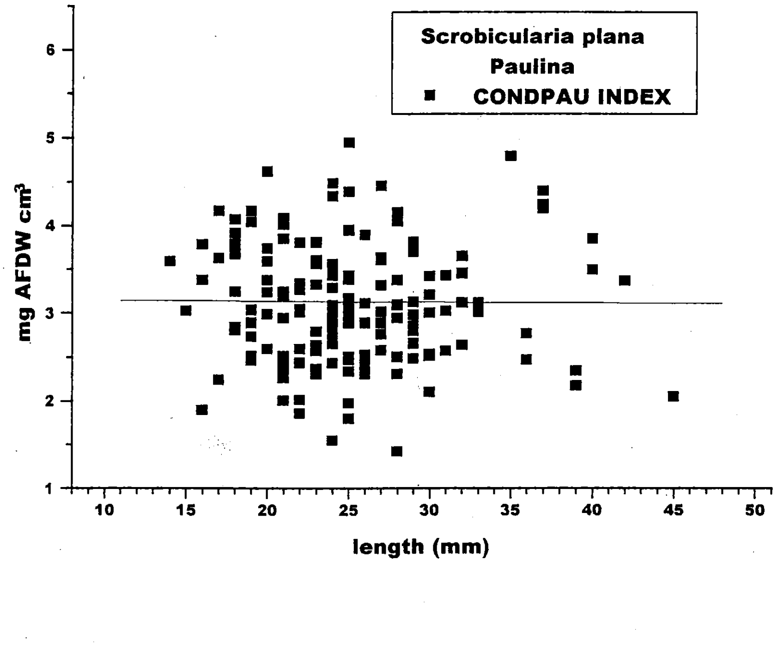


Figure 10. Condition index of *Scrobicularia plana* in function of shell length.

Life history and population dynamics of Mya arenaria (Linnaeus, 1758) in the Schelde estuary

1. Introduction

A good and sustainable management of coastal areas and estuaries depends on a thorough understanding of the functioning of these aquatic ecosystems. Knowledge on the life history and estimates of the secondary production of some estuarine indicator species are an essential part of the knowledge one need to understand the ecosystem functioning in estuaries, especially towards a better understanding of natural versus antropogenic induced influences. Indeed, one-off determinations of different *in situ* measures of diversity and community structure of benthic populations will not always reveal totally the functioning of these populations in relation to their abiotic environment. Therefore, in addition population dynamics - studies of some important estuarine key species will provide a better insight in how the abiotic environment interacts with benthic populations. Especially in estuarine environments, typically characterized by highly varying natural environmental variables (e.g. salinity), negative human effects (e.g. pollution) could be masked or misinterpreted, based solely on a snapshot of the benthic community structure.

This study, which is part of an integrated study on macrobenthic populations in the Schelde estuary in relation to the abiotic environment with special attention for pollution effects, focuses on the life history and population dynamics of *Mya arenaria*. The population dynamic of other indicator species *Macoma balthica*, *Cerastoderma edule*, *Scrobicularia plana*, *Nereis diversicolor* and *Corophium volutator* are reported elsewhere.

Aut-ecology of *Mya arenaria* (Linnaeus, 1758)

The Sandgaper *Mya arenaria* has a boreal amphi-atlantic distribution, which at present also occurs in the Pacific (Japan, Alaska). This American species was introduced in Europe in the 16-17th century. *M. arenaria* is a typical euryhaline species, which penetrates estuaries to the low salinity zones. In the Delta area (SW Netherlands) small specimens reach nearly the isohaline of 2 g Cl^-/l during high tide at normal river discharge, but larger individuals only occur at higher salinities (Wolff, 1973). In the Baltic *M. arenaria* occurs down to salinities of 2.5-3 g Cl^-/l (Muus, 1967). In the Loire estuary Robineau (1987) classifies the species as typically brackish. The seaward extension is not restricted by salinity, but by other factors, such as its slow pumping rate resulting in shortage of food in offshore waters (Wolff, 1973).

M. arenaria lives in a vertical position in the sediment to a depth of 40 cm, depending on the age and the length of the two siphons (Zwarts & Wanink, 1989). Through these siphons the species is in contact with the overlying water. The burrowing capacity diminishes with age (Kühl, 1983). To a size of 5 cm *M.*

arenaria is able to burrow again after being washed out, whereas older and bigger *M. arenaria* loose this burrowing capacity because the relative shorter foot is no longer able to get the shell in a vertical position, which is necessary for burrowing.

M. arenaria is found in almost all sediment types (Kühl, 1983), except in anaerobic mud and very coarse sand (Muus, 1967; Dankers & Beukema, 1983). However, this species mainly prefer fine and muddy sediments (Wolff, 1973). Newell & Hidu (1982) experimentally demonstrated that juvenile *M. arenaria* grew fasted in fine and muddy sediments. *M. arenaria* is relatively resistent to oxygen deficiency, long exposure times and severe winter weather (Muus, 1967). *M. arenaria* has an aggegrated distribution pattern. It is suggested that, as in the case of sediment particles, hydrodynamic forces are primarily responsible for the zonation of *Mya* populations in intertidal areas (Matthiessen, 1960).

M. arenaria is a suspension feeder which feeds on small plankton (flagellates) and detritus (Wolff, 1973; Kühl, 1983). The pumping rate is lower than in many other suspension feeders. Deposit feeding has been observed in Mya, particularly when there is only a thin waterfilm on the substrate.

M. arenaria has separate sexes. The species reproduces and spawns in summer from May/June until September (Wolff, 1973; Kühlm, 1983; Warwick & Price, 1975). The eggs (70-80 µm) are fertilised in the exhalant siphon or in the mantle cavity of the female. The larvae (150-225 µm) swim freely in the water column for about two weeks and undergo a metamorphosis at a size of 240-300 µm. These veliconcha larvae settle by means of byssus threads which they anchor to sand grains and algae (Green, 1968). In a later phase the animals burrow into the sediment. Growth rate can reach 10 to 15 mm in the first year (Thamdrup, 1935; Warwick & Price, 1975). *M. arenaria* can become very large (> 10 cm) and very old (> 15 years). As in *Cerastoderma edule*, *M. arenaria* often have a good spatfall after severe winters (Beukema, 1982).

The growing season of *M. arenaria* is situated betwen April and August.

2. Material & Methods

2.1. Study area

The Schelde estuary, a macrotidal coastal plain estuary, is situated at the border between the Netherlands and Belgium. It measures 160 km with a surface area of approximately 350 km^2. The lower and middle estuary, the so-called Westerschelde between the Dutch-Belgian border and Vlissingen (55 km), is a well mixed region characterized by a complex network of flood and ebb channels surrounded by several large intertidal mud- and sandflats. The general environmental conditions of the Schelde estuary are summarized in Part three of this report.

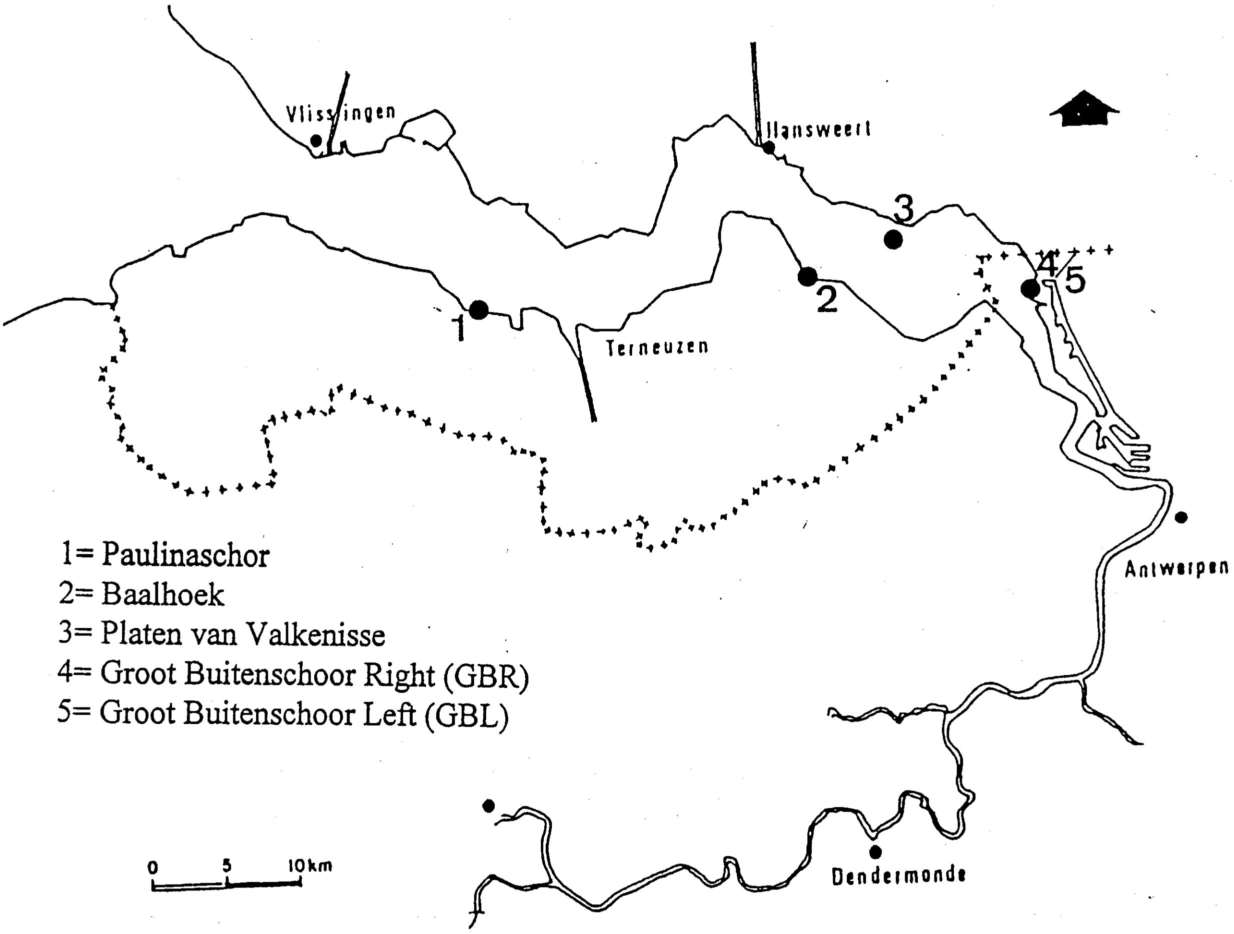


Figure 1. Schelde estuary with situation of the sampling locations.

2.2. Sampling

The macrozoobenthos was sampled on a monthly basis in the period March 1993 - June 1994 at five locations along a salinity and sediment gradient of the Schelde estuary (Figure 1 and Table 1). The location Paulinaschor (PAU) is situated in the polyhaline zone of the estuary, the locations Baalhoek (BH) and Valkenisse (PVV) in the poly-mesohaline transit zone, and the locations Groot Buitenschoor Left (GBL) and Groot Buitenschoor Right (GBR) in the mesohaline zone. All locations are situated in the intertidal zone. More details on the abiotic environment of the locations are given in Part three of this report.

All macrobenthos was sampled by means of sediment cores. The methods used for the samping and subsequent treatment of the samples follow Ysebaert et al., *in prep* (see chapter on benthic community structure).

Table 1. Names and codes of the sampling locations. Distance (from the mouth of the estuary) and estuarine division is given.

Location	**Code**	**Distance (km)**	**Estuarine division**
Paulina	PAU	15	polyhaline zone
Baalhoek	BH	40	poly/mesohaline transit
Valkenisse	VAL	43	poly/mesohaline transit
Groot Buitenschoor R	GBR	60	mesohaline zone
Groot Buitenschoor L	GBL	60	mesohaline zone

2.3. Labo analysis

Samples were sorted and the number of *Mya arenaria* per sample was counted. Individual shell length of *M. arenaria* along the anterio-posterior axis was measured to the nearest 0.1 mm under a binocular with an ocular micrometer for individuals < 15 mm. Larger individuals were measured with venier callipers to the nearest mm. Shell width was also measured of all collected bivalves. Width was taken as the greatest distance between the outsides of the two valves when the clam was closed. Shells were aged by counting and measuring distinct growth cessation rings, formed in winter. Based on these rings, shells were placed into year classes (0+: spat of 1993 to 5+: spat of 1988).

The flesh and shell of a subset of specimens > 5 mm were analysed seperately for weight determination. Both flesh as shell were dried at 105 °C for 12 hours, to obtain the dry weight DW, and then incinerated for 2 h at 550 °C to determine the ash-free dry weight (AFDW). Measurements were done either seperately in each specimen or in group samples from particular mm-classes. Flesh and shell were not seperated in specimens < 5 mm, so that DW and AFDW here refer to the soft as well as hard parts.

2.4. Data analysis

Density and biomass of the population is expressed as number of individuals per m^2 (N/m^2) and g AFDW/m^2 respectively.

Length-frequency distributions were analysed by pooling all individuals into mm classes.

3. Results

3.1. Distribution

Mya arenaria was present at four locations. However, only at Valkenisse high densities were observed. At GBR only one observation of one individual was seen in September 1993. At Paulina and Baalhoek *M. arenaria* was observed irregularly in very low densities. Only at Valkenisse the *M. arenaria* was observed in high densiteis and population dynamics are further only discussed for this location.

2. Age structure

The age structure of the Mya population at Valkenisse is characterized by only a limited number of generations. The population exists almost entirely of 0+ individuals. These 0+ individuals appear in July when a density of 1500 N/m² is reached (Figure 2). Densities increase until September (± 2100 N/m²). In October, densities drop to 1250 N/m², and a further decrease is observed in January. From January 1994 until May 1994 densities stay relatively stable at ± 750 N/m².

The biomass of these 0+ individuals shows also a clear seasonal pattern but peak values are observed later in the season as compared to the density, namely in October-November (Figure 2).

Individuals belonging to older generations are scarce at Valkenisse. Only 1+ individuals are seen regularly, but not every month. Maximum densities of 35 N/m² are observed for these 1+ individuals. A few individual observations of 2+, 3+, and 4+ individuals were done. A 4+ individual of 46 mm was observed in April 1993.

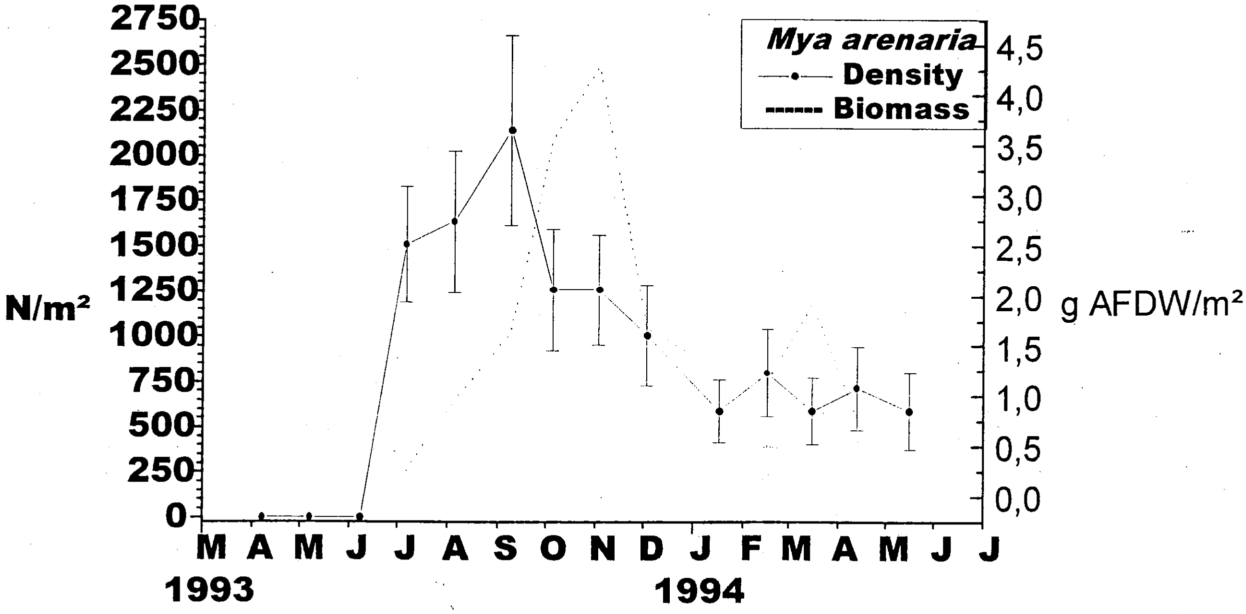


Figure 2. Seasonal variation in density and biomass of *Mya arenaria* at Valkenisse.

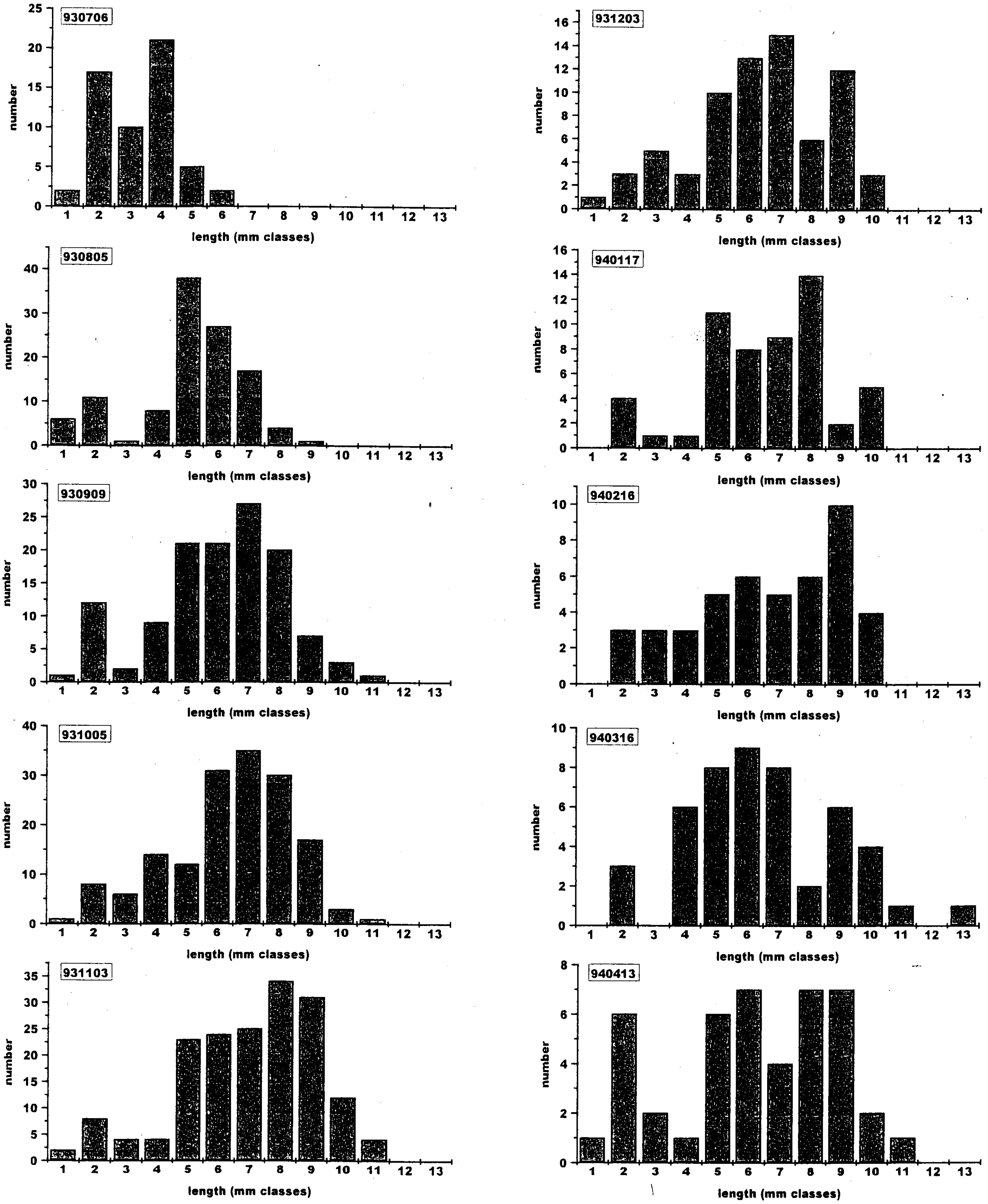


Figure 3. Length frequency distributions of 0+ Mya arenaria at Valkenisse.

3. Seasonal changes in length composition and growth curves

The length class - frequency distributions by date show for the 0+ individuals of *M. arenaria* at Valkenisse a clear seasonal increase in shell length (Figure 3). In July 1993 the first individuals are observed, belonging mainly to the size class 2-4 mm. Maximum length reached at that time is 6 mm. In August, the 0+ individuals did grow substantially with the size class 5-6 mm being dominant. Maximum length reached in August is 9 mm. In September and October further growth is observed with the size classes 7-8 mm dominating. Maximum length reached in September-October is 11 mm. For the rest of the year larger individuals were not observed, except in March 1994 when one individual of 13 mm was observed.

The increase in growth is better shown in Figure 4 where the mean length of the 0+ individuals is plotted against time. The spatfall appears at Valkenisse at a mean size of 3.5 mm. The first month a very steep growth curve is observed, and the length of the animals almost double in that first month (5.6 mm). In September and October animals still grow but at a considerably slower rate. From October on the mean length stay relatively stable for the rest of the year and amounts 6.5-7 mm.

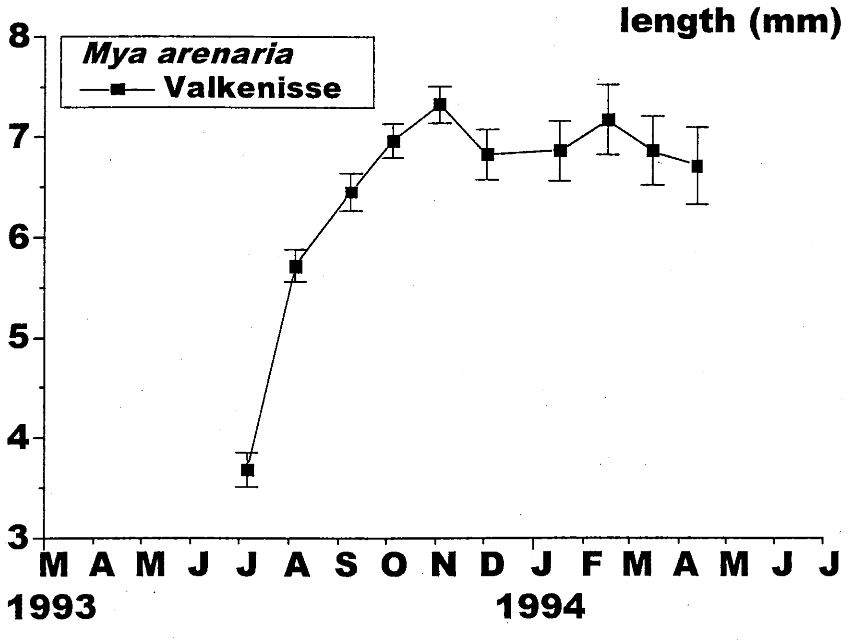


Figure 4. Growth rate of 0+ *Mya arenaria* at Valkenisse.

4. Allometric relationships

A highly significant and linear relationship is observed between length and width of *Mya arenaria* (Figure 5).

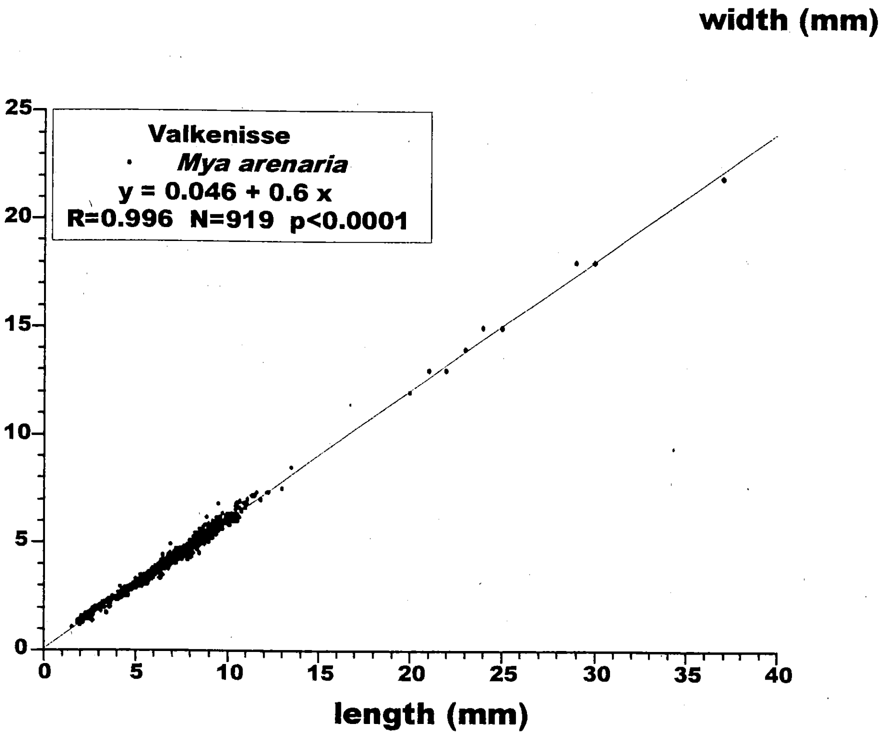


Figure 5. Length - width relationship for Mya arenaria.

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Life history and population dynamics of Corophium volutator: a literature review

1. Introduction

Corophium volutator is one of the most common macrobenthic amphipods in the intertidal zone of the Schelde estuary. Especially in the mesohaline part this species is one of the most dominant macrobenthic species.

In Ysebaert et al. (1993, 1994) already the first results were presented on the population dynamics of *Corophium volutator* at Groot Buitenschoor Left.

Besides a detailed study on the population dynamics of this species in the Schelde estuary, a comparison will be made with the literature. Therefore an extensive review of the available literature on this species is being made. Presented here is a first draft of this review, with emphasis on the population dynamics of this species.

2. General

The gammaridean Amphipoda are one of the most common taxa in the class Crustacea. A well known family within the Amphipoda are Corophiidae, with representatives like *Corophium volutator*, *C. arenarium*, and *C. lacustre*.

C. volutator is a benthic amphipod, widely distributed in the North Temperate Zone. The species inhabits U-shaped burrows in estuarine sediments and lives upto six cm deep, mainly in muddy or muddy-sandy sediments.

C. volutator is frequently found in conditions from marine to almost fresh water (see further) and is relatively resistent to anaerobic conditions (Gamble, 1970).

As a component in the food web of an estuary, *C. volutator* is an important link, feeding on mud and organic detritus, and in turn forming a major constituent in the diet of fish (e.g. Flounder) and waders (e.g. Redshank, Dunlin).

3. Feeding

C. volutator is a selective deposit feeder, feeding mainly on bacteria and to a lesser extent on diatoms. Food is collected by filtering particles from the current generated through the U-shaped burrow by the beating pleopods, or by using the antennae to scrape material into this current (Meadows & Reid, 1966). For more detailed studies on the food selection by *C. volutator* see Fenchel et al. (1975), Nielsen & Kofoed (1982), Miller (1984), Murdoch et al. (1986).

4. Salinity preference and tolerance

C. volutator has been most frequently reported in estuarine waters, or seas such as the Baltic, that have a reduced salinity. Some authors have mentioned a lower limit of salinity below which *C. volutator* was not found and ranges between 2 and 6 psu (see McLusky, 1967). These variations in the lower limits observed may reflect the varying distribution of suitable substrates in the areas studied.

A salinity preference of 10-30 psu was found experimentally by McLusky (1970). This preference has been shown to be stable, despite acclimation to either low or high salinities. However, below 20 psu and especially below 10 psu the animals are under increasing osmotic stress (McLusky, 1967; 1968b). Below 5 psu they are scarce in the field, and below 2 psu *C. volutator* is absent (McLusky, 1968a). *C. volutator* is able to tolerate salinities up to 50 psu for long periods, and are essentially isosmotic to the medium, being only limited by tissue tolerance (McLusky, 1967).

5. Life history

5.1. Density and biomass

All studies show low densities and biomasses in winter and spring, followed by a rapid increase in the summer period. Later in the year, densities and biomasses drop again to a winter level.

In winter, density observed varies between studies and between study sites. McLusky (1968a) found in the Ythan estuary (UK) an overwintering population, characterized by low to very low densities, depending on the salinity (Table 1). Highest density was observed at the study site with a winter salinity > 10 psu (8000 ind/m^2), whereas at a winter salinity < 1 psu, *C. volutator* was absent. Peer et al. (1986) found in the Bay of Fundy (Canada) maximum overwintering densities of " 3500 ind/m^2. However, in some stations *C. volutator* was totally absent during the winter. These low densities were attributed to severe ice scouring. M`ller & Rosenberg (1982) found on the west coast of Sweden a high variation in winter density, ranging from 0 to 12000 ind/m^2. Also here ice formation was the main cause for the absence of *C. volutator.* Omori & Tanaka (1984) observed relatively high densities during the winter months (23000-35000 ind/m^2). This is probably due to the relatively high winter temperatures.

Olafsson & Persson (1986) studied a shallow area on the south coast of Sweden. The area was divided into two sites: between 0-400 m from the shore and between 400-500 m from the shore. During 1980 and 1981, *C. volutator* population in the outermost part of the site studied (400-500 m) showed typical seasonal fluctuations in densities with the lowest numbers being during winter and spring and peaks of 25000-30000 ind/m^2 in July. In 1982, the population crashed and low densities were recorded through the entire area. At the innermost part (0-400 m), only very low densities were observed of *C. volutator*, being almost absent in winter and increasing to 2000-4000 ind/m^2 in summer. At this site, *Nereis diversicolor* is the most important species.

Population crashes of *C. volutator* is reported more than once. Parasite infestation is often mentioned as being the main cause for a suddenly dramatical decimation of the population in the summer period (Muus, 1967; Olafsson & Persson, 1986; Lauckner, 1987; Jensen & Mouritsen, 1992). Also predation by waders can cause a tempory decrease of the numbers of *C. volutator* (Peer et al., 1986). Raffaelli et al. (1991) observed a dramatical decline of *C. volutator* in the Ythan estuary throughout those parts of the estuary affected by macroalgal mats. Under a high biomass of weed, *C. volutator* disappeared almost completely from the mudflat.

5.2. Egg development and brood size

C. volutator has, like all amphipods, no larval stage. Small amphipods hatch from eggs retained in a ventral thoracic brood pouch. Within the brood pouch four clearly defined stages can be recognized (Peer et al., 1986):

Stage A: Eggs small, white to cream coloured; no differentiation of cells; eggs held in a pair of transparent sacs.

Stage B: Eggs case transparent; appendage rudiments discernible; optic rudiments present; transparent sacs, if present, broken.

Stage C: Egg case transparent; all appendages fully developed; transparent sacs absent.

Stage D: Newly hatched juveniles.

Fish & Mills (1979) and Peer et al. (1986) recorded a 25-30 % mortalility between stage A and stage C eggs. For gravid females of all size classes the mean brood size observed varies between different studies: 23.6 (Fish & Mills, 1979), 29 (Hart, 1930) and 37.5 (Peer et al., 1986). The number of eggs of stage A observed in the brood pouch shows a large variation: between 10 and 172 for the Bay of Fundy (Peer et al., 1986), 10 to over 70 for Danish estuaries (Muus, 1967), and a maximum of 48 on the south coast of England (Hart, 1930). Peer et al. (1986) demonstrated a clear positive correlation between length of gravid females and numbers of stage A eggs in the brood pouch.

The newly hatched amphipods remained in the brood pouch for 1-3 days according to Hughes (1988) and up to five days according to Fish & Mills (1979), but are able to move in or out at will.

Fish & Mills (1979) estimated the time from copulation to the release of young being " 14 days, while Peer et al. (1986) recorded 19 days between the observation of the first gravid females and the first young. M`ller & Rosenberg (1982) gives a hatching time of " 2 weeks for the first generation (see further).

C. volutator is known to have a semi-lunar rhythm of release of young (Fish & Mills, 1979). Also Peer et al. (1986) observed the release of young occurring during the time of the highest tides associated with the full moon at perigree.

Afther the escape from the brood pouch by the young, they remaine in the parental burrow for a few hours before constructing their own burrow (Hughes, 1988). Based on these short laboratory observations, Hughes (1988) concluded that there was no direct evidence that juveniles swim or crawl from the parental burrow immediately after release from the brood pouch.

5.3. Population structure and life history

Most gammarid species in the North Temperate Zone are inferred to be uni- or bivoltine, with a long-lived overwintering generation and a short-lived spring-summer generation. However, like Omori & Tanaka (1984) state, the majority of these studies determined the number of generations per year by seasonal changes of size distribution, data being obtained by successive field sampling. Especially for species with an extended reproductive season and overlapping generations, this method can give rise to erroneous interpretation of population dynamics and number of generations due to the non-recognition of overlapping generations. Omori & Tanaka (1984) therefore applied a more detailed study, including growth and survivorship of the different seasonal generations by combining detailed field studies, rearing experiments and a simulation model (see further).

C. volutator is generally believed to be bivoltine, although some studies record one to four generations per year. The different studies are summarized in detail below.

SeggerstrDle (1940) found for a Baltic population of *C. volutator* one generation annually, with a overwintering population of 7.5-8.0 mm.

Watkin (1941) noted two generations per year for Dovey estuary (Scotland).

Muus (1967) investigated at Niva Bay (north of Copenhagen, Denmark), a shallow, mesohaline, sheltered bay, the population dynamics of *C. volutator* in the period April-August 1957. In april, Muus (1967) observed a small overwintering generation, mainly including 7-9 mm long individuals. Already gravid females were present at that time. In the second half of May, a bimodal pattern was observed, with a first new generation of 2.5-3.0 mm. On Mid-june, this generation had grown to 5-6 mm long, with most of the females carrying eggs in the brood pouch. A second new generation was already occurring. At the beginning of July, both the first and the second new generation produced a third generation, while the overwintering generation totally disappeared at that time. At the end of July, the second and third generation gave rise to a fourth generation. At the end of August, the numbers had already decreased dramatically, and only the third and fourth generation were still present (Muus, 1967). But this decrease was probably due to a malignant cercaria infection. Muus (1967) concluded that four generations of *C. volutator* per year were present.

McLusky (1968a) studied the effects of salinity on the distribution and abundance of the amphipod *C. volutator* in the estuary of the River Ythan (Aberdeenshire, UK) between October 1966 and November 1967 at four locations. Throughout the winter (Oct.-Mar.) the mean size of the animals fluctuated between 3.0 and 3.6 mm, with little growth from December to March. In May, the mean size increased to 5.61 mm and first egg-bearing females were observed. Comparing the four study areas, it can be seen that although they all experienced the same temperature conditions, breeding began first at the area with the highest salinity. It appears that breeding occurred only as the salinity increased above 7.5 psu. The sequence of breeding reflected the successive increase of salinity up to and above this level. McLusky (1968a) concluded that only one single breeding season occurred per year in this population of *C. volutator*, extending from May to August. Animals born in the summer of one year grew to a maximum size, bred when over 5 mm, and subsequently died in the summer of the next year. The onset of the reproductive season was correlated with increased temperature and salinity conditions.

Gratto (1979) recorded two generations annually at Minas Basin, Bay of Fundy (Canada).

Fish & Mills (1979) also recorded two generations annually for the Dovey estuary (Scotland), the same result as found by Watkin (1941) for this estuary.

M`ller & Rosenberg (1982) investigated the production and abundance of *C. volutator* in three shallow coastal areas in Sweden. In winter these areas were complety covered by ice for several months. Samples taken just after ice disappeared in March- April showed an overwintering population of *C. volutator* which consisted of animals between 2 and 8 mm in length. This overwintering generation was breeding from May to June, which gave rise to a subsequent summer-breeding generation which reproduced between the beginning of July and September. So two generations per year were distinguished. However, within these two generations, M`ller & Rosenberg (1982) observed two distinct cohortes (bimodal generations). Omori & Tanaka (1984) recorded in Tomioka Bay (Amakusa Shimosima Island, West Kyushu, Japan), based on successive field sampling, two types of generation in a year, one a long-lived, overwintering generation, and the other a short-lived, spring-summer generation. Furthermore, detailed analysis revealed that both the short-lived and long-lived generations were each composed of two partially overlapping generations. In stead of two generations a year, Omori & Tanaka (1984) showed four generations of different duration per year.

Peer et al. (1986) recorded in the Bay of Fundy (Canada) both a summer and overwintering generation. In May, the population was dominated by adults of the overwintering generation having a mean length of approximately 5.0 mm. By June the population became bimodal representing the remaining larger overwintering animals and their progeny. Near the end of July a new cohort entered the population. In August the overwintering population and the May-June cohort were gone and mainly juveniles remained with a unimodal frequency distribution.

5.4. Ovigorous females

Peer et al. (1986) recorded ovigorous females between May and July 1978, and May and August 1979. In 1979, Peer et al. (1986) recorded a first peak of ovigorous females (> 50 % of the female population) between 23 May and 20 June. This was followed by a sharp decline. The next peak in frequency coincided with the maturity of the May-June cohort. Peer et al. (1986) also showed that the mean length of gravid females from the overwintering generation was larger at maturity (7.8 mm) than that of the May-June cohort (6.4 mm).

Smallest size of gravid females observed varies between different studies: 5.4 mm in the Bay of Fundy (Peer et al., 1986), 4.5 mm in the Baltic (Segerstrale, 1959), 4.0-4.5 mm in Denmark (Muus, 1967) and 5.0 mm in Wales (Fish & Mills, 1979).

6. Pelagic occurrence

C. volutator seemingly have little need to leave their burrow, except to find a mate, and in laboratory studies this has rarely been seen (Hughes, 1988). Fish & Mills (1979) found that as the tide ebbs, adult males emerge from the sediment and crawl across the mud surface, probably searching for burrows occupied by adult, receptive females. This behaviour was especially evident at the spring tides just before the time when gravid females were carrying Stage A embryos.

C. volutator has been found in plankton samples, and the pelagic occurrence has been demonstrated under laboratory conditions. Holmstr`m & Morgan (1979, 1983a,b,c) studied a Welsh population of *C. volutator* and demonstrated a rhythm of swimming activity with three components: a circa-tidal rhythm of 12-13 h, with the maximum occurring on the ebb tide; a semi-lunar rhythm, where swimming was more pronounced at the time of spring tides; and a seasonal rhythm with swimming throughout the year but more pronounced in the summer. However, the relevance of these observations to the in situ behaviour of *C. volutator* are subject to doubt because the observations were made on animals with no natural substrata in which to burrow (see further). The same results were found by Harris & Morgan (1986).

Only few studies have been undertaken to study the in situ swimming behaviour of *C. volutator*. Most detailed observations are made by Hughes (1988) in the estuary of the River Stour (Suffolk, East Anglia, UK), making use of traps, emergence traps and plankton nets. Hughes (1988) found a swimming behaviour of C. volutator which has a rhythmicity with circadian, semi-lunar and seasonal components. C. volutator swim only at night, on both the flood and ebb tide, around times of spring tides, and between May and August.

Because of the differences found between the in situ observations of Hughes (1988) and the laboratory observations of Holmstr`m & Morgan (1983a), Hughes & Horsfall (1990) examined both areas in situ and under simulated tidal conditions. Swimming *C. volutator* were caught in the Welsh estuary in the summer, but only rarely in the autumn and winter, and in both daylight and darkness. In simulated tidal conditions in the laboratory *C. volutator* from two sites in East Anglia never swam, while those from Wales swam whenever the substratum was immersed, in daylight and darkness, mostly on the ebb tide and in winter. The tidal swimming rhythm is different to east coast *C. volutator* which only swam at night (see above). There is, therefore, a difference in the behaviour of these geographically seperated *C. volutator* (Hughes & Horsfall, 1990). This has probably to do with the time of the successive spring tides (Hughes & Horsfall, 1990).

Gidney (1971) also mentions large numbers of swimming *C. volutator* occurring on the ebb tide at night, while only few animals were observed above the mud during the day.

Essink et al. (1989) studied the pelagic occurrence of *C. volutator* in tidal channels of the Dollard, the inner part of the Ems estuary (The Netherlands). The mean concentration of *C. volutator* was almost always higher during flood than during ebb, resulting in a net landward (=southward) transport. This transport was believed to be the result of a passive accumulation mechanism, and apparently the swimming ability of *C. volutator* is of no significance in this process (Essink et al., 1989). No indications for a seasonal migration were observed. Essink et al. (1989) estimated the pelagic population as only " 0.06 % of the total benthic population at any time.

Few studies report on the pelagic occurrence as a possible way of immigration into an area. McLusky (1968) observed changes in the distribution of *C. volutator* within an estuary, depending on changing salinities, which indicate the possible use of tidal currents for dispersal and thus pelagic occurrence of the species.

7. Role of *C. volutator* in stabilization of sediments

The presence/absence of C. volutator may have significant impact on sediment topography, sediment stability and erosion/sedimentation processes (Reise, 1978; Meadows et al., 1990; Jensen & Mouritsen, 1992).

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Short note on the macrobenthos observed in the oligohaline and freshwater tidal zone of the Schelde estuary

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1. Introduction

In most estuaries, the oligohaline and freshwater tidalt areas have been strongly manipulated in the past by land-claim, diking, dredging, industrial activities, etc. The oligohaline and freshwater tidal zone of the Schelde estuary (the Zeeschelde) is one of the largest left in NW-Europe, making it a very rare but valuable habitat on a European scale. However, also here direct and indirect losses due to human activities affected the area in a serious way. Nowadays, pollution is one of the main areas of concern (Van Eck et al., 1991; Van Damme et al., 1995).

Recently, people become more aware of the ecological importance of the freshwater tidal and oligohaline zone of the Schelde estuary and of the fact that these areas should be managed in a sustainable and integrative way. However, a good management needs a thorough understanding of the functioning of these aquatic ecosystems. But until recently, hardly no ecological data were existing for these areas. This is a more widespread phenomenon which Odum (1988) attributed to the fact that limnologists ignored tidal freshwater environments because of the presence of oceanic tidal influence, and marine ecologists neglected these areas because they contain freshwater and are inhabited primarily by freshwater organisms. Therefore, the Institute of Nature Conservation has set up a multidisciplinary research project (OMES), which aims at setting up an ecosystem model for this area. An important part of this research is the study of macrobenthic populations in these areas. The first quantitative data, collected in the autumn 1991 (Ysebaert et al., 1993) showed that the intertidal zone of these oligohaline and freshwater tidal areas where only inhabited by an impoverished fauna of Oligochaeta. More recently, this research was extended to a profound study on the macrobenthos of these areas, including a stratified random sampling of the whole Zeeschelde and study of the population dynamics of Oligochaeta at several locations.

This short note presents the first data on the seasonal distribution of the macrobenthos at two locations, Boereschans and Ballooi, respectively situated in the oligohaline and freshwater tidal zone. Data presented here deal only with the fraction sieved through a 1 mm mesh sieve. The smaller fractions (250 and 500 µm) are not described here.

2. Material & Methods

2.1. Study area

The Schelde estuary, a macrotidal coastal plain estuary, is situated at the border between the Netherlands and Belgium. It measures 160 km with a surface area of approximately 350 km^2. The inner and upper estuary, the so-called Zeeschelde between the Dutch-Belgian border and Gent (105 km), is characterized by a single channel, bordered with mudflats and marshes (28 % of total surface). Besides a brackish zone (mesohaline and oligohaline) between the border and the tributary Rupel, it has a freshwater tidal area of app. 60 km lenght. It forms an unique ecosystem, being one of the latest freshwater tidal areas of North-western Europe. However, this section is heavily polluted by domestic, industrial and agricultural waste loads. For more details on the estuary see Part three of this report.

2.2. Sampling and laboratory analysis

The macrozoobenthos was sampled on a monthly basis in the period March 1993 - June 1994 at two locations (Figure 1). Boereschans is situated in the oligohaline zone of the estuary, whereas Ballooi is a freshwater tidal location. Both locations are respectively 81 and 100 km situated from the mouth of the estuary. More details on the abiotic environment of the two locations are given in Part three of this report.

All macrobenthos was sampled by means of sediment cores. Three to five small sediment cores (0 4.5 cm) were taken to a depth of ± 25 cm. In the laboratory the samples of the small cores were sieved successively through a 250 µm, a 500 µm and a 1 mm mesh sieve, and sorted after staining with 0.02 % Rose Bengal. The organisms of all samples were identified to species level, except *Oligochaeta*, and counted. Since Annelids are often broken due to handling, only parts with a head structure were counted and used in determining density.

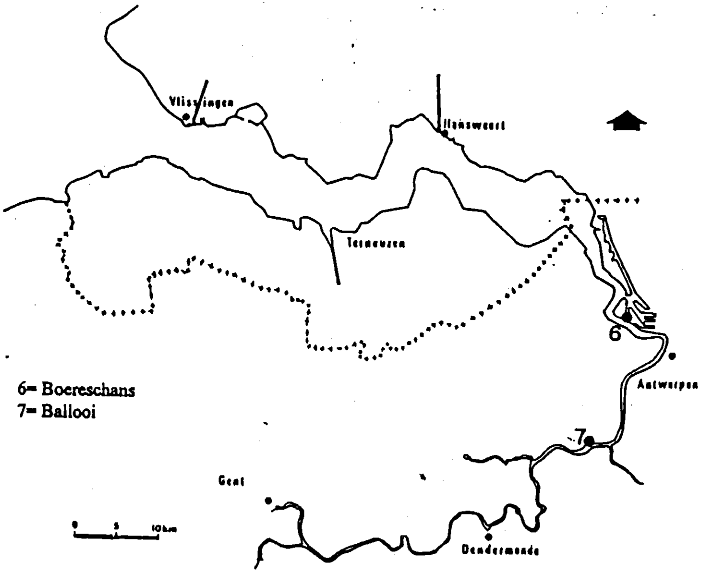

Figure 1. Sampling locations in the Schelde estuary.

3. Results

Boereschans

At Boereschans the macrobenthos found on the 1 mm mesh sieve contained only Oligochaeta. Most individuals are most probably *Tubifex costatus*. No other macrobenthic species were observed.

Figure 2 shows the monthly variation in density (± SE) of Oligochaeta observed at Boereschans. A slight increase in density is observed in spring 1993 (April), after which density stay relatively high (12000-15000 N/m², except August) untill September. In autumn and further in winter densities decrease slightly again. In spring 1994 density is again at the same level as in 1993 (7000-8000 N/m²).

In general, it can be concluded that Oligochaeta are not very abundant at Boereschans and the seasonal variation in density is relatively low.

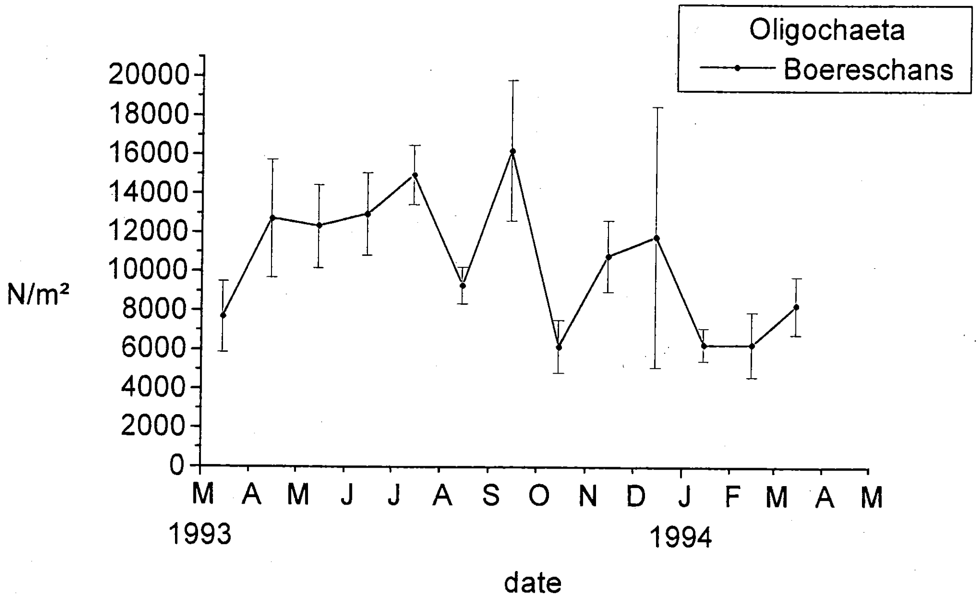

Figure 2. Montly variation in density of Oligochaeta at Boereschans.

Ballooi

At Ballooi the macrobenthos found on the 1 mm mesh sieve contained almost only Oligochaeta. Most individuals are most likely *Limnodrilus hoffmeistrii*. Besides a few irregular observations of Ceratopogonidae-larvae, no other macrobenthic species were observed.

Figure 2 shows the monthly variation in density of Oligochaeta observed at Ballooi. In comparison to the oligohaline location Boereschans, density is much higher at Ballooi and the Oligochaeta show a very clear seasonal pattern.

Densities stay relatively low in spring (March-May) 1993 (± 25000 N/m²). In June a first small peak is observed with 75000 N/m², but in July density decrease again to ± 30000 N/m². A second and much higher peak is observed in August, and especially September, when a maximum density is reached of 225000 N/m². From October on, a steep decrease in density is observed (100000 N/m²), and in winter and spring 1994 numbers drop further to 15000-25000 N/m².

In general, it can be concluded that Oligochaeta are very abundant at Ballooi with a clear seasonal pattern with peak densities of 225000 N/m² observed in September 1993.

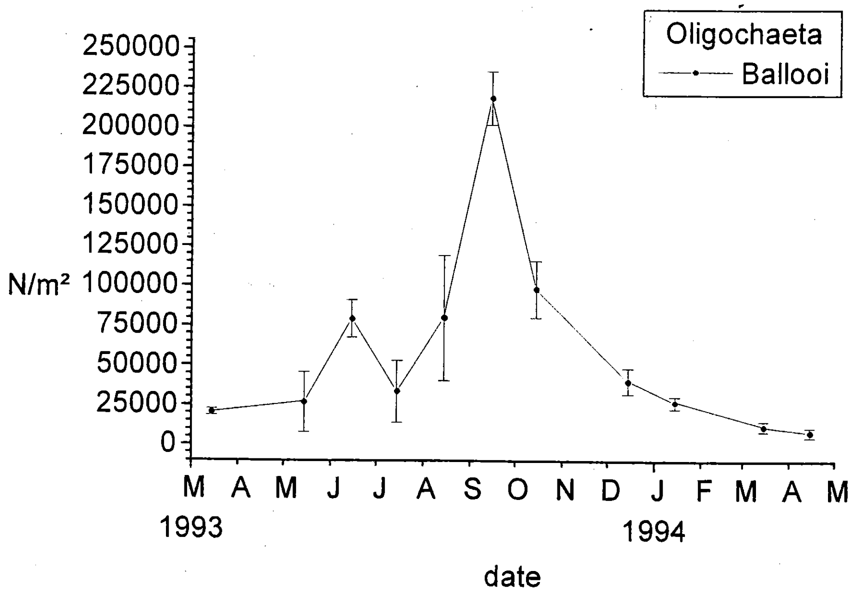

Figure 3. Montly variation in density of Oligochaeta at Ballooi.

4. Discussion and conclusions

The first results presented here on two locations situated in the oligohaline and freshwater tidal part confirm the earlier findings of Ysebaert et al. (1993) that these areas are numerically dominated by Oligochaeta.

Based on Wolff (1973) and Caspers (1948), resp. for the former Biesbosch (The Netherlands) and the Elbe estuary (Germany), the benthic community of the freshwater tidal area potentially contains more than 30 species, of which 8 Oligochaeta, larvae of 10 Chironomidae, 8 molluscs and 4 crustaceans. Therefore, the benthic fauna of the oligohaline and freshwater tidal zone of the Schelde estuary can be characterized as an impoverished community. The cause of this impoverished fauna in the Schelde estuary is almost certainly the high pollution degree of this part of the estuary. In other estuaries, this almost exclusive dominance of Oligochaetes in the upper parts is also often observed and mostly contributed to organic enrichment causing severe oxygen depletion (McLusky et al., 1980; McLusky, 1987; Shillabeer & Tapp, 1989).

Mees et al. (1995), who studied the hyperbenthos in the Schelde, Ems and Gironde estuary, found the low salinity hyperbenthic community being completely absent in the Schelde estuary, whereas in the other two estuaries maximum density and biomass were observed in these low salinity zone. Mees et al. (1995) also contributed this absence in the Schelde estuary to the oxygen deficiency in this zone. They also noted a shift towards higher salinity zones for several brackish species like *Neomysis integer*, *Mesopodopsis slabberi*, *Pomatoschistus microps* and *Gammarus salinus*.

An improvement in water and sediment quality in the Schelde estuary will probably re-establish a freshwater community and will allow euryhaline species to penetrate further upstream in the estuary. This was already observed in the upper Forth estuary (Scotland) where a reduction in the organic inflow resulted in a reduction in oligochaete numbers and a further penetration intertidally of some euryhaline and brackish water species like *Nereis diversicolor*, *Corophium volutator* and *Manayunkia aestuarina* (McLusky et al., 1993). Also in the Tees estuary (north east England) an increase in diversity and abundance with a penetration of marine fauna into the estuary was observed after water quality improvements (Shillabeer & Tapp, 1989). It must be stressed that a recovery of benthic and fish communities in these reaches of the estuary not only depend on a good water quality but also on the presence of sufficient natural habitats. Due to the direct loss of habitats by channelization and reclamation this is hampered in several estuaries (e.g. Weser estuary, Schuchardt et al., 1993).

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Waterbirds along the estuarine gradient of the Schelde estuary

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Keywords: Schelde estuary, waterbirds, estuarine zonation, freshwater tidal area

ABSTRACT

The zonation of non-breeding waterbirds along the whole estuarine gradient of the Schelde estuary, including the freshwater tidal area, is described. Therefore, the Schelde estuary was divided in six large areas of which three where situated in the Westerschelde (Dutch part) and three in the Zeeschelde (Belgian part).

Due to the much larger available intertidal surface in the Westerschelde, higher numbers are observed here in comparison with the Zeeschelde. However, the freshwater tidal zone is characterized by relatively high densities of waterbirds.

The results clearly indicate different, successive waterbird communities along the estuarine gradient. The outer areas 1 and 2 of the estuary (polyhaline zone) are typically wader dominated areas. The dominating species are Dunlin and Oystercatcher, which resp. accounts for ± 29 and 27 % of the observed numbers during winter. Other characteristic (indicator) species for the areas 1 and 2 are Knot, Sanderling, Turnstone, and Bar-tailed Godwit. The waterbird community of area 3 (mesohaline zone) is totally different from the other two Westerschelde areas 1 and 2. The reason is clearly the presence of the very large brackish marsh 'Verdronken Land van Saeftinghe' (2800 ha). The marsh community is numerically dominated by Wigeon and Greylag Goose, which resp. accounts for 35 % and 29 % of the total numbers observed during winter in this area. Despite the also large available mudflat surface, number of waders are much less compared to area 1 and 2. .

Area 4 can be regarded as a transition area between the brackish area 3 and the freshwater tidal area 5. Dominance of certain species is less pronounced and consists of species found in both area 3 and 5. During winter Teal (25 %), Mallard (14 %), Greylag Goose (14 %), and Wigeon (13 %) are the most important species. A characteristic (indicator) species for this area is the Gadwall. Also a lot of wader species are still observed in this area, such as Dunlin, Avocet and Ringed Plover. The waterbird community in area 5 is mainly characterized by several duck species. The two numerically dominating species are Teal and Mallard, with resp. 38 % and 28 % of the total numbers observed during winter. Other characteristic (indicator) species of this area are Gadwall and Pochard. Waders are not common, besides Lapwing (15 %). Area 6 clearly differ from the other areas. Numbers are very low and only two species dominate here: Mallard (44 %) and Moorhen (40 %). The seasonal and spatial distributions of the most important waterbird species are discussed in detail.

The Schelde estuary is of national and international importance for waterbirds. With a maximum of 140000 waterbirds present, this estuary is one of the most important NW-European estuaries for waterbirds. The 1% level is exceeded in all months of the year and for 18 species the estuary is of international importance during the considered observation period. Most internationally significant bird populations are observed in the Westerschelde (15 species) with Greylag Goose, Wigeon and Pintail being the most important. The Zeeschelde area contains internationally significant bird populations of Teal and Gadwall, two species which are characteristic for this part of the estuary. During the winter period the 1 % level is exceeded for these two species every month Also Greylag Goose exceeds the 1 % level during several winter months.

1. Introduction

Estuaries and coastal marine ecosystems are cited among the most productive biomes of the world (Odum, 1983; Day et al., 1989; Costanza et al., 1993). The high biological productivity in estuaries results in their economic importance for shellfish fisheries and as nursery grounds for important seafood species (e.g. shrimps, fish). But also birds benefit from this high estuarine production and for many species (especially waders and waterfowl) estuaries are of vital importance in one or several stages of their life cycle (Piersma, 1987; Smit & Piersma, 1989; Davidson et al., 1991). Many papers in Europe deal with the distribution and feeding ecology of waterbirds in the marine and/or brackish part of estuaries or the adjacent coastal zones (e.g. Oosterschelde, Wadden Sea, British estuaries) (Davidson et al., 1991; Meire, 1993; Meltofte et al., 1994). However, very few papers deal with the zonation of waterbirds along the whole estuarine gradient, including the freshwater tidal area. Not only freshwater tidal areas are nowadays relatively rare habitats, also the knowledge on these freshwater tidal areas is very poor (see also Odum, 1988). Furthermore, uses and abuses of this zone by humans are becoming so critical that the unique features of (whole gradient) estuaries must become widely understood to develop an integrated and sustainable water management. Waterbirds are from a management point of view interesting species, not only because they are situated high in the estuarine foodweb and therefore being important consumers which will react on changes or human interventions in the water system (sensitive indicators), but also because the general public is sensitive to birds.

The aim of this paper is to describe the zonation of waterbirds along the estuarine gradient of the Schelde estuary, including the marine, brackish and freshwater tidal area. The paper emphasis on the spatial and seasonal distribution of the most important non breeding waterbirds and on the (international) importance of this estuary as wetland for water bird species.

2. Material & Methods

2.1. Study area

The Schelde estuary measures 160 km from the mouth in Vlissingen (The Netherlands) to Gent (Flanders) (Figure 1). Between the mouth in Vlissingen and the Dutch/Flemish border the estuary is called Westerschelde; between the border and Gent the estuary is called Zeeschelde. The width is about 50 m at Dendermonde, ± 250 m at Temse, ± 500 m at Antwerpen, ± 1.5 km near the border, and ± 4.5 km at Vlissingen. The maximal width is 7.8 km. The mean tidal range increases from 3.8 m at Vlissingen to > 5 m near Antwerpen. At Gent the tidal range is still 2 m.

The lower and middle estuary, the so-called Westerschelde (55 km), is a well mixed region characterized by a complex morphology with flood and ebb channels surrounding several large intertidal mud- and sandflats. The surface of the Westerschelde amounts 310 km^2. Tidal flats and marshes cover 34 % of the Westerschelde. The average depth amounts ± 10 m.

The inner and upper estuary, together with the freshwater tidal part, the so-called Zeeschelde (105 km), is characterized by a single channel, bordered with relatively small mudflats and marshes (28 % of total surface). Despite its length, the surface of the Zeeschelde amounts only 42 km². Human activities are much more concentrated in this zone, with industries and agglomerations located closely along the river banks. Therefore, the intertidal zone is often absent (e.g. quais, wharfs) or very narrow, consisting only of a steep hard substrate of rubbles. Especially upstream Dendermonde, the estuary gets a more canalized view.

The Schelde estuary is one of the longest estuaries in NW-Europe with still a complete estuarine gradient: at the mouth and in the lower reaches a marine (polyhaline) zone, in the middle and inner reaches a brackish (mesohaline) zone and in the upper reaches a oligohaline and freshwater tidal zone (Figure 1 and Table 1). Especially the freshwater tidal part is nowadays a very rare habitat in Europe.

Despite this complete estuarine gradient, the Schelde estuary suffers from severe human impacts. In the past 200 years, 15000 ha of tidal area were lost due to land reclamation. Nowadays, dredging activities for shipping and pollution are the major anthropogenic stressors. Especially the Zeeschelde is heavily polluted by domestic, industrial and agricultural waste loads. One of the most striking features of this area is the presence of a nearly anoxic water column, especially during summer time. However, in recent years a slow recovery was noticed (Van Damme et al., 1995). More details on the morphology, hydrology, ecology are found in several papers in Meire & Vinckx (1993) and in this volume.

2.2. Methods

Birdcounts

In the Westerschelde, the National Institute for Coastal and Marine Management/RIKZ coordinates monthly waterbird cencuses already since 1975 (Meininger & van Haperen, 1988; Meininger et al., 1984, 1985, 1994). These counts are part of systematic waterbird counts in the whole Delta region of SW-Netherlands. In the Zeeschelde the Institute of Nature Conservation started systematic waterbird counts in 1991. However, the counting methods used differ between the two parts. In the Westerschelde monthly counts are performed during high tide when birds concentrate at roosts. Birds counted on these roosts can spatially be attributed to a certain known intertidal area. The Westerschelde counts are mainly performed by amateur ornithologists and concentrate towards one weekend which coincides during winter with the international and national IWRB-counts. In the Zeeschelde monthly counts are done by low tide from a ship. The counts are divided into three days: one day from the Dutch/Belgian border to Antwerpen, another day from Antwerpen to Dendermonde, and a last day from Dendermonde to Gent. These counts are performed during the week proceeding or following the international and regional IWRB counting weekends in winter.

Results shown deal with counts performed in the period July 1991 through June 1993 in the Westerschelde and October 1991 through April 1994 in the Zeeschelde. No severe winters were encountered during this period.

Waterbirds include divers, grebes, cormorants, herons, geese, swans, ducks, coots, and waders. Gulls and terns are not included in this study.

Analysis of data

The Schelde estuary was divided into six large areas (three in the Westerschelde, three in the Zeeschelde) in order to get insight into the large spatial distribution of waterbirds along the estuarine gradient (Figure 1). These areas clearly differ in surface area of available subtidal and intertidal area. In general, the Westerschelde (area 1-3) is characterized by large mud and sandflats, whereas in the Zeeschelde (area 4-6) this surface decrease clearly towards the freshwater tidal zone (Table 1). Marsh surface is more or less evenly distributed along the estuary, except in the brackish zone (area 3) where a very large marsh area exists, the 'Verdronken Land van Saeftinghe' (3000 ha) (Table 1). In the most upstream area 6 hardly any mudflats are present, and also marsh surface is very small.

Mean numbers per month and monthly maxima for the period considered were calculated for each species and for each area. Only species of which the number exceeded more than 1000 individuals in a certain month or which numbers are of (inter)national importance are discussed in detail in this paper. Year-to-year fluctuations are not discussed.

Winter average is considered as the period October through March.

The number of bird-days for each species was calculated by summing the monthly counts and multiplying by 30.5.

Bird species were divided into trophic groups. All waders and Shelduck were considered as benthivores and geese and most of the ducks as herbivores. Grebes, divers and sawbills were considered as piscivores, whereas diving ducks and Coot were considered as diving benthivores.

The following multivariate analyses were applied: agglomerative clustering method (group average sorting GAS of Bray-Curtis dissimilarities) and ordination by non-metric multi-dimensional scaling (MDS). Plotting of the GAS clusters on the 2-D ordination planes aided in evaluating the divisions imposed. Data were subjected to fourth root transformation prior to analysis. Analysis were performed on the six areas distinghuished, based on the numbers observed in the six winter months (October through March) of all waterbird species. All data were ÖÖ transformed.

Criteria for the international importance of wetlands for waterbird populations are worked out within the Ramsar Convention (Convention of Wetlands of International Importance Especially as Waterfowl Habitat). Within this Ramsar Convention numerical criteria were formulated to assign and protect wetlands of international importance. A wetland is of international importance when (a) more than 20000 waterbirds are regularly present, and (b) 1% of the total geographical population of a certain species uses the area regularly (Boyd & Pirot, 1989; Rooth, 1989). In this paper the 1% level is used as an objective standard to evaluate the importance of the Schelde estuary. Besides observed maxima, also winter average or yearly average (depending on species considered) was used to compare with the 1% levels. Population estimates are used according to Rose & Scott (1994) and Meininger et al. (1995).

3. Results

3.1. Number of species and total numbers of waterbirds

In total 80 species were observed in the Schelde estuary during the considered counting period. For 30 species less than 10 individuals were observed, and from another 15 species less than 100 individuals were observed. For 22 species the number exceeded 1000 individuals at a certain month.

In general, the number of species observed is higher in the Westerschelde as compared to the Zeeschelde with 67, 57 and 63 species observed in resp. area 1, 2 and 3 (Westerschelde areas) and 49, 41 and 26 species in resp. area 4, 5 and 6 (Zeeschelde areas). Especially in the most upstream area 6 less species were observed.

Along the estuarine gradient, total numbers of waterbirds clearly differ between areas (Figure 2). In winter numbers are clearly higher in the three Westerschelde areas (1-3) as compared to the three Zeeschelde areas (4-6). Especially in area 3 high numbers are observed. In the Zeeschelde highest numbers were observed in area 5, whereas area 6 is clearly characterized by the lowest numbers. Different systematic groups dominate in the six areas (Figure 2): waders dominate in area 1 and 2, whereas area 3 is dominated by ducks and geese. In the Zeeschelde areas ducks form the major part of the water bird community. In terms of trophic structure, the trends observed mainly follows these of the systematic groups, since waders are considered as benthivores and geese and most of the ducks as herbivores. Benthivores clearly dominate the two most outer areas 1 and 2, whereas all other areas are dominated by herbivores (Figure 3). In areas 4 and 5, a small portion of diving benthivores is observed, whereas piscivores are nearly absent in all areas. Therefore, the main habitats used by waterbirds are the intertidal areas (mud- and sandflats and marshes). The subtidal area is of minor importance in the Schelde estuary.

Total numbers observed in the Schelde estuary show a clear seasonal pattern (Figure 4). In summer numbers are relatively low (20000-25000) but numbers double in early autumn (Aug-Sep) to 50000-60000. In October numbers double again to 120000 and they stay high until January with a peak in November of 140000 birds occurring in the Schelde estuary. In February numbers drop steadily but decreases sharply in March (52500), April (20000) and May (27500). Figure 4 also shows that the most important systematic groups are ducks and waders. In winter geese also play an important role. Other systematic groups are of no significant importance in the Schelde estuary.

Seasonal distribution of waterbirds also clearly differ between areas (Figure 5). The wader dominated areas 1 and 2 show highest numbers in the winter period, but also during spring and especially during autumn migration (August-September) high numbers are reached. This is most pronounced in the most outer area 1. In the Saeftinghe area 3 only high numbers are observed between October and February. In the Zeeschelde numbers increase in September with highest numbers in the period December trough February. Also a small peak in June-July is observerd, caused by moulting birds.

3.2. Estuarine zonation of waterbird communities in the Schelde estuary

Due to the larger available surface area of marshes and especially mudflats in the Westerschelde (Table 1), higher numbers were expected here in comparison to the Zeeschelde. However, if numbers are expressed as number of birddays per hectare intertidal surface (mudflats + marshes) the freshwater tidal area 5 clearly have the highest densities (Figure 6), assuming birds are spread uniformly over the intertidal area. The other areas have on average the same densities per hectare intertidal surface.

To get insight into the difference and/or structure of the bird communities of the different areas, a multivariate analysis was performed based on the six winter months of each area. Figure 7 shows the results of the GAS-classification. In a first division all winter months of area 6, the most upstream area, are separated from the other areas. In a second division, the two remaining Zeeschelde areas 4 and 5 are separated from the three Westerschelde areas. In a third division the two Zeeschelde areas are further clearly separated from each other, and Westerschelde area 3 is divided from the two most outer areas 1 and 2. In other words, the classification clearly show a separation of each area along the estuarine gradient. This is also shown in the MDS ordination (Figure 8). Areas 1 and 2 are found to cluster closely. The othter areas are clearly divided, following the estuarine gradient. Area 6 is clearly separated from the other areas. The results clearly indicate different, successive waterbird communities along the estuarine gradient.

Areas 1 and 2 are typically wader dominated areas. The dominating species are Dunlin and Oystercatcher, which resp. accounts for ± 29 and 27 % of the observed numbers during winter. However, these two species are not restricted to these areas, but are seen along the whole estuary. Characteristic (indicator) species for the areas 1 and 2 are Knot, Sanderling, Turnstone, and Bar-tailed Godwit, but none of these species take more than 5 % of the total observed numbers.

The waterbird community of area 3 is totally different from the other two Westerschelde areas 1 and 2. The reason is clearly the presence of the very large brackish marsh 'Verdronken Land van Saeftinghe' (2800 ha). The marsh community is numerically dominated by Wigeon and Greylag Goose, which resp. accounts for 35 % and 29 % of the total numbers observed during winter in this area. Despite the also large available mudflat surface, number of waders are much less compared to area 1 and 2. However, during certain migration periods this area has also large numbers of e.g. Grey Plover and Bar-tailed Godwit, and the area is typically suitable for Spotted Redshank, a species which is only seen in this area in relatively large numbers.

Area 4 can be regarded as a transition area between the brackish area 3 and the freshwater tidal area 5. Dominance of certain species is less pronounced and consists of species found in both area 3 and 5. During winter Teal (25 %), Mallard (14 %), Greylag Goose (14 %), and Wigeon (13 %) are the most important species. A characteristic (indicator) species for this area is the Gadwall. Also a lot of wader species are still observed in this area, such as Dunlin, Avocet and Ringed Plover.

The waterbird community in area 5 is mainly characterized by several duck species. The two numerically dominating species are Teal and Mallard, with resp. 38 % and 28 % of the total numbers observed during winter. Other characteristic (indicator) species of this area are Gadwall and Pochard. Waders are not common, besides Lapwing (15 %).

Area 6 clearly differ from the other areas. Numbers are very low and only two species dominate here: Mallard (44 %) and Moorhen (40 %).

3.3. Temporal and spatial distribution of most important species

Geese

Geese only occur in large numbers in area 3, where they totally rely upon the presence of the large brackish marsh Saeftinghe. White-fronted geese use the marsh mainly as resting and sleeping area, and reach maximum numbers of 12710 (Table 2). Their feeding areas are mainly situated in the surrounding farming land.

Saeftinghe is especially important for Greylag geese. Greylag geese arrive in large numbers in October with maximum numbers up to 28000 ind. (Figure 9, Table 2). In February numbers decrease rapidly. This species is only from 1990 onwards present in large numbers in the Saefthinge area. Before 1990 only a few thousand were wintering in the area. In the Saeftinghe area the Greylag Goose mainly feed on *Scirpus* roots. *Scirpus maritimus* is one of the dominating marsh plants here.

Ducks

Ducks typically (1) inhabit the inner parts of the estuary (area 3-6) where they are the dominating systematic group and (2) reach highest numbers during late autumn and winter. Two species differ from this general pattern, the Shelduck and the Mallard.

The Shelduck is the only duck species which reach highest numbers in the summer months (Figure 10, Table 2), when they are mainly present in the Westerschelde (area 1 and 3). This phenomenon is related to the pre-moulting and moulting sites in the estuary which are situated in the mouth of the estuary (Hooge Platen) and near the Dutch/Flemish border (Meininger & Snoek, 1992). Numbers of moulting birds varies between 2000 and 3000. A small number also moult on the Flemish side (area 4). In winter numbers of Shelduck are lower but the relative importance of the freshwater tidal area (area 5) increases during this period (Figure 10). In the whole estuary the Shelduck is typically found on soft bottom mudflats where they probably feed on a wide range of food items: bivalves and crustaceans in the marine part; diatoms, copepods and crustaceans (*Corophium volutator*) in the brackish part and probably Oligochaetes and organic debris in the freshwater tidal part (Meininger & Snoek, 1992; pers. observ.)

The Mallard reaches highest numbers in winter and is present in large numbers both in the marine zone, as in the brackish and the freshwater tidal zone (Figure 11, Table 2). In late spring/early summer the freshwater tidal area (area 5) becomes the most important area. Here a lot of them breed and use the area as a moulting site.

Some duck species are restricted to area 3, and more specifically to the Saeftinghe area. A good example is the Wigeon, which arrive in Saeftinghe in large numbers in October (maximum 46000) (Table 2). From December on, numbers drop steadily (Figure 12). The Pintail also concentrates in the Saefthinghe area, but is not that restricted to this area as the Greylag Goose and the Wigeon. Regularly more than 1000 ind. stay in the Saeftinghe area with a maximum of 3450 in October 1992 (Table 2). Smaller numbers are seen in the downstream areas, as well as in the freshwater tidal area (Table 2).

Other duck species are typically found in the oligohaline/freshwater tidal zone (area 4 and especially area 5). The Gadwall is very common in both area 4 and 5, where it is mainly observed on rubbles (Figure 13). From October until February, on average 650 ind. are observed in these areas, with a maximum of 1082 ind. in the Zeeschelde in November 1993 (Table 2). It is the only duck species which almost exclusively feed along these rubbles, probably on algae and seeds. Other duck species, such as Teal and Mallard are also seen on these rubbles, but they mainly use these as a resting place.

The Teal is a characteristic species of the freshwater tidal area (area 5) (Figure 14). Smaller numbers are also observed in the brackish area (area 3 and 4). In summer, numbers of Teal are very low. From September on, Teals arrive in the area and between October and March 6000-10000 ind. are observed. A maximum of 10716 was observed in the Zeeschelde in February 1992. Teals are mainly seen on mudflats were they feed along the low water line. Probably their diet consist of both plant seeds and Oligochaetes. Another characteristic species of the freshwater tidal area 5 is the Pochard (Figure 15). The Pochard is the only common diving duck here, together with the Tufted Duck, but numbers of the latter are much less (Table 2). Like most ducks, the Pochard is a typical winter bird, which arrive in the area in October, and reaches highest numbers in the period December-February with a maximum of 1829 in January 1994 (Table 2). Pochards are mainly observed in large groups and most of the time on the same spots in the area where they are often seen actively diving. The food preference is not yet clear, but probably they feed on Oligochaetes and organic debris.

Waders

Waders dominate the outer areas of the Schelde estuary (area 1 and 2) and both the number of wader species and densities decrease going up the estuary. For most species, the Schelde estuary acts both as a migration and wintering area. However, some species are only seen in high numbers during short migration periods (see further).

The most common wader species is the Dunlin (Figure 16). This species concentrates mainly in the marine areas 1 and 2, but is also frequently observed in the other areas. During migration periods they are mainly seen in the most outer area 1, but numbers are relatively low at that time. Highest numbers are observed between November and January, when approximately 20000 Dunlins are observed, with a maximum of 22882 in January 1992 (Table 2). In the marine and brackish part they feed mainly on Annelids, Amphipods (*Corophium spec.*) and small Molluscs (*Hydrobia ulvae*, *Macoma balthica*). In the freshwater tidal area they feed on Oligochaetes.

The second most common wader in the Schelde estuary is the Oystercatcher (Figure 17). Like most waders, Oystercatchers dominate in the areas 1 and 2 (Table 2). In contrast with the Dunlin, Oystercatchers are seen year-round in relatively high numbers. Numbers are lowest during the breeding season (4000-5000). Between August and February numbers are highest (12500-16000) with an observed maximum in the Schelde estuary of 18019 Oystercatchers in October 1992. Oystercatchers feed on large Molluscs (mainly *Cerastoderma edule*), but also large Annelids (e.g. *Nereis diversicolor*) are eaten, especially in the brackish part of the estuary.

Another important wader is the Grey Plover. This species is mainly restricted to the most outer area 1 (Figure 18, Table 2). In area 2 also high numbers are regularly seen but more upstream numbers decrease rapidly. Only during spring migration, when highest numbers are reached, the species also uses area 3. Another species showing the same spatial pattern is the Bar-tailed Godwit (Table 2). During spring migration this species also uses area 3. On the other hand, Sanderling and Turnstone are two species which are completely restricted to the areas 1 and 2 (Table 2).

The Knot is a wader species which is almost exclusively seen in the outer area 1, feeding on small molluscs (Figure 19, Table 2). Highest numbers are reached during autumn migration (max. 1445 Augustus 1992). Remarkable are the great fluctuations between successive months, which partly can be explained by counting problems (Meininger et al., 1994).

Some wader species do not concentrate in the outer areas 1 and 2 but uses other areas as well. A good example is the Avocet, which reach high numbers also in the areas 3 and 4 (Figure 20, Table 2). During late summer/begin autumn area 4 is the most important area for this species, and during late autumn migration the Avocet reaches its maximum with highest numbers in area 3 (Figure 21). Curlew is also a species which winter distribution is more evenly spread along the Westerschelde (Table 2). In the Zeeschelde this species is only seen in low numbers in area 4. During autumn migration the outer areas 1 and 2 are more important.

The Redshank reaches its highest numbers in the period July-August, short after the breeding season. From September on, numbers drop and stay relatively constant during the rest of the year (Figure 22). Redshank is mainly seen in the outer areas 1 and 2, especially in winter. In other periods, also area 3 and 4 are used.

The Ringed plover is typically seen during migration, with highest numbers in the period August-September (Table 2). Highest numbers are observed in area 1, but high numbers are seen up to area 4.

A species restricted almost exclusively to area 3 is the Spotted Redshank, of which 500-1000 are seen in the period June-September (Figure 21, Table 2). The Spotted Redshank is only seen in high numbers in summer and autumn, whereas in winter and spring it is nearly absent.

The Lapwing is a common wader along the whole Schelde estuary but is mainly seen resting on the mudflats or in the freshwater tidal part also on hard substrates. Numbers are fluctuating heavily under the influence of changing weather conditions. Numbers inside the dikes are much higher for this species.

Most of the wader species concentrate on the soft bottom mudflats, where macrobenthic biomass is highest (see discussion). Wader species feeding mainly on bivalves and larger polychaetes (e.g. Oystercatcher, Curlew, Knot) will be mainly observed in the polyhaline zone (area 1 and 2), whereas species which typically feed on smaller crustaceans and polychaetes (e.g. Avocet) will also be present in the brackish area (area 3 and 4).

Other waterbirds

Other waterbirds are of no numerical importance in the different areas of the Schelde estuary, besides the Moorhen which is one of the dominating species in the most upstream area 6 (Figure 22). This area with only a very small amount of mudflat surface only contains Moorhen and Mallard in substantial numbers. Moorhens are mostly seen on the rubbles, where they are searching for food. During disturbance or high tide they withdraw in the small marshes or on the dikes.

3.4. National and international importance

The Schelde estuary is of national importance both in the Netherlands and in Flanders. Especially in Flanders the Zeeschelde area is one of the most important wetland areas. In the Netherlands the Westerschelde is, together with the Oosterschelde, numerically the most important area of the Delta region and together with the Wadden Sea the Delta region is the most important wetland area.

The international importance is clearly demonstrated by Table 2. The 1% level is exceeded in the Schelde estuary in all months of the year and for 18 species the estuary is of international importance during the considered observation period.

Most internationally significant bird populations are observed in the Westerschelde. The Westerschelde is of international importance for 15 species during the considered observation period (Table 2). A species not included in Table 2 is the Spoonbill, which in recent years exceeds the 1% level in the Saeftinghe area in late summer. Some species exceeds the 1 % level many times and on a regular base. Most important species are Greylag Goose, Wigeon and Pintail, which maximally exceeds the 1% level resp. 14, 6 and 5 times. These three species are characteristic for the area 3, which clearly demonstrates the extremely high importance of the marsh of Saeftinghe. Other important species for the Westerschelde are Grey Plover and Shelduck, with exceeds the 1% level resp. 5.5 and 2.5 times at the maximum. Considering the whole Schelde estuary, the importance of the Shelduck is even greater, because also important numbers are observed in the Zeeschelde (see above). Some species show only short peaks exceeding the 1 % level, especially during migration (e.g. Ringed Plover, Bar-Tailed Godwit, Spotted Redshank).

Based on a longer study between 1987 and 1991, Meininger et al. (1994) observed, besides the species mentioned here, also international important numbers of Sanderling and Kentish Plover in the Westerschelde.

The Zeeschelde area contains internationally significant bird populations of Teal and Gadwall, two species which are characteristic for this part of the estuary. During the winter period the 1 % level is exceeded for these two species every month, with a maximum of 2.5% and 4% for Teal and Gadwall respectively.

Especially area 5 is of importance for the Teal. Also Greylag Goose exceeds the 1 % level in area 4 during several winter months. The exchange with the Saeftinghe area 3 is however clear for this species. In area 6 no important waterbird populations were observed (Table 2).

The Mallard is the only species for which the whole Schelde estuary has to be considered to exceed the 1% level.

4. Discussion

Estuarine zonation and habitat suitability

The occurrence and distribution of waterbirds along an estuarine gradient depends on several factors, of which habitat suitability and available habitat surface are the most important. The Schelde estuary gets its importance from the occurrence of large intertidal areas. The subtidal area of the Schelde estuary is of minor importance for waterfowl, because of its highly dynamic nature (e.g. high current velocities, high turbidity). Also available food for waterfowl is very low in the subtidal. Most of the ducks, geese and waders depend on the occurrence of suitable intertidal areas (mudflats and marshes). In this paper no detailed analysis based on habitat types was made. However, in the lower and middle part of the Schelde estuary (Westerschelde areas 1-3), not only the available intertidal surface is much higher as compared to the inner and upper estuary (Zeeschelde areas 4-6), also the structure of the mud- and sandflats is more diverse with a whole range of sediment types ranging from very sandy to very silty sediments, whereas in the Zeeschelde the mudflats are more uniformly silty. This has consequences for the available prey items (see further). Both a larger and a more diverse habitat surface cause the higher number of waterfowl species and the higher total numbers observed in the Westerschelde as compared to the Zeeschelde.

One of the major factors determining habitat suitability for wintering and migrating waterfowl is the available food present. The benthivores depend on the available benthos on the mud- and sandflats. In general terms, a significant decrease of both diversity and biomass of macrobenthic species is observed in upstream direction (Ysebaert et al., 1993; in prep.). In the polyhaline zone dominant macrobenthic species are the polychaetes *Heteromastus filiformis*, *Nereis sps.*, *Pygospio elegans*, *Tharyx marioni* and *Arenicola marina*, and the molluscs *Macoma balthica*, *Cerastoderma edule* and *Hydrobia ulvae*. Mean biomass observed in this zone amounts 35 g AFDW/m^2, but ranges are very high with up to 150 g AFDW/m^2 in cockle beds. The Cockle *C. edule* takes a large part of the biomass in the polyhaline zone (Ysebaert et al., 1993). In the mesohaline zone diversity of macrobenthos drops with the polychaetes *Heteromastus filiformis*, *Nereis diversicolor* and *Pygospio elegans*, the mollusc *Macoma balthica* and the crustacean *Corophium volutator* being the most important species here. Mean biomass observed in this zone amounts 10 g AFDW/m^2. Towards the Dutch-Belgian border, only *N. diversicolor* and *C. volutator* are observed in large numbers, and the dominance of Oligochaeta becomes more and more pronounced. In the oligohaline and freshwater tidal area, only an impoverished fauna is observed here (because of the poor water quality), existing almost exclusively of Oligochaeta (Ysebaert et al., 1993). However, these Oligochaeta can be very numereous, with locally biomasses of more than 50 g AFDW/m². This gradient in macrobenthic fauna is reflected in the benthivorous waterfowl (which are often specialistic feeders) present in the Schelde estuary. Both the higher diversity and higher biomass of macrobenthos is responsible for the higher numbers observed in the more outer areas 1 and 2. Especially wader species feeding mainly on bivalves and large polychaetes will be present here (e.g. Oystercatcher, Curlew, Knot). Species which depends on soft and silty sediments to forage in, feeding on small crustaceans and polychaetes (e.g. Avocet, Spotted Redshank), will however be more concentrated in the mesohaline zone, since this habitat is more present here. The uniformly Oligochaeta dominated freshwater tidal area seems not attractive for wader species. The question rise if more waders would be present in the freshwater tidal area if water quality was better and the macrofauna more divers, existing of freshwater gastropods, insect larvae, amphipods, etc. A lot of wader species, such as Knot and Sanderling, are restricted in their distribution to the coastal zone, and will not migrate that far landinwards. In the Biesbosch, the former freshwater tidal area in the northern part of the Delta region, some wader species were present in relatively high numbers. Especially during migration, high numbers of Black-tailed Godwitt (> 1000), Ruff (> 250) and Common Snipe (many hundreds) were observed (Wolff, 1969; Lebret, 1979). In autumn and winter large numbers of Lapwing (10000) were observed, feeding on the mudflats (Lebret, 1979). The absence of wader species, such as Black-tailed Godwitt, Ruff, and Common Snipe in the freshwater tidal area of the Schelde estuary probably has a lot to do with the available habitat types itself, besides the available food. These species not only feed on mudflats, but also uses often flooded marshes (rushes) and grasslands. Both inside and outside the estuary these habitats are nearly absent in the freshwater tidal area. Also suitable breeding places are nearly absent. For the Common Snipe it also needs to be mentioned that the counting method (from a ship at low tide), is not very suitable because of their more secretive habits (availability of cover vegetation). However, other observations made in the marshes itself indicate low numbers of the Common Snipe.

The occurrence of marshes also determines directly or indirectly the occurrence of waterbirds along the Schelde estuary. Not only there is a large difference in available surface along the estuarine gradient, also the vegetion structure changes. Generally spoken, the height of the vegetation in the polyhaline and mesohaline of the estuary is relatively low and the dominating species are *Halimione portulacoides*, *Aster trifolium*, *Elymus athericus*, *Limonium vulgare* and *Spartina anglica* (polyhaline zone) and *Phragmites australis*, *Elymus athericus* and *Scirpus maritimus* (mesohaline zone). The relatively low vegetation structure and the suitable plant species (including seeds) allows herbivorous waterfowl to feed directly in the marshes or marsh creeks. Especially the very large Saeftinghe area (3000 ha), situated in area 3, is very attractive for herbivores such as Wigeon, Greylag Goose, and Pintail. In the freshwater tidal area the vegetation structure clearly change with a much more pronounced vertical structure, with Reed beds and willow scrubs being the most important vegetation types. Also a lot of large competitive herbs are present (e.g. *Urtica dioica*, *Rumex obtusifolius var. transiens*, *Lythrum salicaria*). Marshes situated low in the tidal zone, mainly consisting of rushes, are nearly absent today. The relatively high vegetation structure is not suitable for waterfowl to feed directly in/on it. However, these freshwater tidal marshes are characterized by a high production of both plant tissues and seeds and large amounts are transported to the water column (e.g. at spring tides or storms) and enrich the mudflats with organic material (seeds, decomposed plant tissues, etc.). This is probably an important food source for the dominating waterfowl species in this area, togehter with the locally abundant Oligochaeta. This high productivity, together with a suitable feeding habitat, explains the high numbers and high densities of relatively opportunistic feeders, such as the Teal. These species are known to have a basically herbivorous diet, but due to the way they are feeding, often have a more omnivorous diet. In the freshwater tidal part of the Schelde estuary, Teals are feeding most of their time along the low water line, where they dabble in the soft muds. Also Shelduck shows a similar way of feeding, and has probably also a more omnivorous diet in this part of the estuary, whereas in the Westerschelde a more benthivorous diet will be eaten.

The observation that the freshwater tidal area is a very suitable habitat for Teals, was proven in the Biesbosch. This large freshwater tidal area in the northern part of the Delta region was closed in 1970. Before 1970, more than 10000 Teals were regularly seen in autumn and winter, foraging mainly on soft bottom substrates. After the fall off of the tide in November 1970, the Teal disappeared within a few weeks and the following years only a few hundreds were seen (Lebret, 1979). Along the 'Oude Maas', another freshwater tidal area in the northern part of the Delta, the same decrease in Teal numbers was observed, after the tide reduced dramatically in 1970 (Strucker, 1992; Strucker et al., 1994). Loss of suitable foraging habitat (soft mud) is given as the main reason for this decrease.

Marshes not only function as direct or indirect feeding habitat, but also serve as resting and refuge area. At high tide a lot of the waders and waterfowl roost in the marshes, both in the Westerschelde as in the Zeeschelde. However, also areas outside the estuary are used at high tide as roosts (e.g. farmland, creeks) (Mostert et al., 1990).

Besides the Teal, the most characteristic waterbird species in the Zeeschelde is the Gadwall. The Gadwall showed a clear increase in recent years in the whole Delta region (Meininger et al., 1994). Besides the Zeeschelde, the Gadwall is mainly observed in the 'closed' basins Volkerakmeer, Markiezaat en Zoommeer. The Gadwall is a very characteristic species which shows a clearly different feeding behaviour as the other duck species. Its preference for mainly hard substrates (rubbles, breakwaters) is a phenomenon which is also observed in other areas of the Delta region (Meininger et al., 1994).

Besides estuarine ecosystem factors, also external factors will influence the occurrence of a certain waterbird species in the Schelde estuary. A good example is the Greylag Goose which is only since 1990 present in large numbers in the Saefthinge area (area 3). Before 1990 only a few thousand were wintering in the area. The spectacular increase was caused by a combination of factors: a general increase in the northwest-European population, a shift from traditional wintering grounds in southern Spain towards northwestern Europe, and an abandonment of hunting in the Saefthinge area. This indicates that certain areas are still potentially suitable for an increase of certain waterbird species. E.g., hunting is still allowed in certain marshes in the freshwater tidal area. Abandonment of hunting here can have a positive effect on the waterbird community present here.

International importance of the Schelde estuary and estuarine management

The Schelde estuary is both in Belgium and The Netherlands of great national importance. With a maximum of 140000 waterbirds present in the Schelde estuary, this estuary is one of the most important NW-European estuaries for waterbirds. Other estuaries which contains high numbers of waterfowl in midwinter are the Oosterschelde (190000) in the Netherlands (Meininger et al., 1994), The Wash (180000) and Morecambe Bay (140000) in Great Britain (Davidson et al., 1991). Five other British estuaries support in excess of 50000 waterfowl: the Severn estuary, the Dee estuary and North Wirral, the Ribble estuary, the Solway Firth and the Humber estuary (Davidson et al., 1991). (Eems-Dollard estuary ?, other estuaries ?)

The 1% level provides an effective tool in the assessment of the importance of a wetland, and clearly demonstrates the international importance of the Schelde estuary. The 1 % level has become widely accepted as a basis of the site selection component of bird conservation and it forms an important element of both national and international site selection criteria (Davison et al., 1991; Meininger et al., 1995). However, other factors also needs to be taken into account in considering the importance of a wetland for waterbirds (see also Davidson et al., 1991). Also the Schelde estuary can not be considered as an area on its own. On a local scale a clear exchange with other areas is observed (e.g. Oosterschelde, non-tidal ponds, harbour docks, etc.). On a larger scale the Schelde estuary is one of the chains of the East-Pacific Flyway. It is one of the necessary sites of the network on which estuarine birds depends. Their use of estuaries emphasis the importance of conserving networks of such sites on both a national and international scale

The importance of the Schelde estuary for waterbirds have led to the protection of several parts of this estuary. In the Zeeschelde, 420 ha situated near the Dutch/Belgian border are designated as RAMSAR site, and recently large parts of the freshwater tidal area were also proposed to be put under the RAMSAR convention. Also large parts, both in the brackish zone near the Dutch/Belgian border as in the freshwater tidal zone (between Rupel and Dendermonde) were designated as special protection site within the EEC Wild Birds Directive. In the Westerschelde (aanvullen ......). Several intertidal areas (mostly marshes) along the estuary are also nationally protected and/or managed as nature reserve (e.g. Hooge Platen, Paulinaschor and Verdronken Land van Saeftinghe in the Westerschelde (5208 ha in total) ; e.g. Groot Buitenschoor, Schor Oude Doel, Notelaar, Schorren van de Durme in the Zeeschelde (650 ha in total).

In recent years also the governments of both The Netherlands and Belgium are incorporating more and more the ecological features of the estuarine system within management and policy goals. Togehter with other important ecological features of the Schelde estuary, the international importance for waterbirds clearly justify the need for an integrated management, considering both economical and ecological features. Estuarine management should not only consider improvement of the water quality, but also the optimalisation of the physical structure of the habitats. It is essential that existing habitats are safeguarded and new losses are avoided. Also the creation of new habitats and the restoration of the exchange with the areas lying on the landside of the dikes is essential The distribution and occurrence of waterbirds clearly demonstrates the links between habitats within the estuarine system. This interdependence highlights the need to conserve the entire Schelde estuary since loss of an area of habitat can have substantially greater consequences for the birds which depend on it as part of their mosaic than appears from the size of the area.

Table 1. Surface area of mud- and sandflats, marshes and subtidal zone in the different areas along the Schelde estuary.

Area	*Classification*	*Mudflat*	*Marshes*	*Subtidal*	*TOTAL*
1	marine (polyhaline)	4310	224		
2	marine (poly/meso)	2927	70		
3	brackish (mesohaline)	3344	2485		
4	brackish (meso/oligohaline)	505	185	2005	2695
5	tidal fresh (oligo/limnetic)	147	292	948	1387
6	tidal fresh (limnetic)	3	30	250	282
TOTAL	whole estuary	11236	3276	20598	35110

Table 2. List of most important waterbird species in the Schelde estuary. Winter average (W), yearly average (Y) or a specific period is given for each area, depending on the seasonal pattern of each species. Maximum numbers for each area and for the whole estuary are also given, together with the 1% level of each species (see text). Numbers exceeding the 1% level are dotted.

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List of Figures

Figure 16. Mean number of Dunlin *Calidris alpina* unted per month in the six subareas of the Schelde estuary.

Figure 17. Mean number of Oystercatcher *Haematopus ostralegus* counted per month in the six subareas of the Schelde estuary.

Figure 18. Mean number of Grey Plover *Pluvialis squatorala* counted per month in the six subareas of the Schelde estuary.

Figure 19. Mean number of Knot *Calidris canutus* counted per month in the six subareas of the Schelde estuary.

Figure 20. Mean number of Avocet *Recurvirostra avosetta* counted per month in the six subareas of the Schelde estuary.

Figure 21. Mean number of Curlew *Numenius arquatus* counted per month in the six subareas of the Schelde estuary.

Figure 22. Mean number of Redshank *Tringa totanus* counted per month in the six subareas of the Schelde estuary.

Figure 23. Mean number of Spotted Redshank *Tringa erythropus* counted per month in the six subareas of the Schelde estuary.

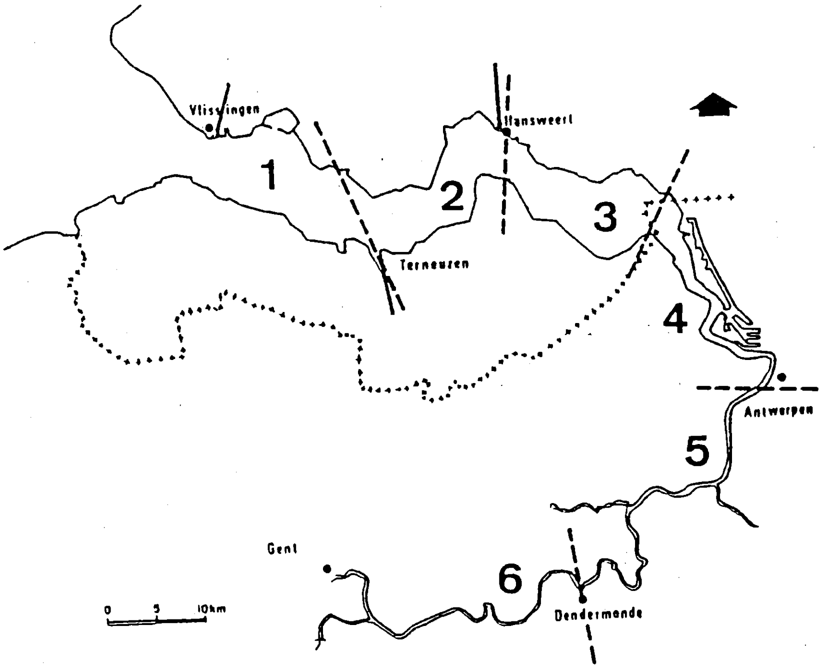
Figure 24. Mean number of Moorhen *Gallinula chloropus* counted per month in the six subareas of the Schelde estuary.

TABLE 2

Species	Area 1	Area 2	Area 3	Area 4	Area 5	Area 6	Maximum whole estuary	1% level
White-fronted Goose W	3 ± 2 *(29 Jan92)*	390 ± 208 *(1600 Jan92)*	2763 ± 1045 *(12710 Feb92)*	15 ± 8 *(78 Feb94)*	- -	- -	*13253 Feb92*	4500
Greylag goose W	29 ± 16 *(121 Nov92)*	12 ± 5 *(40 Nov91)*	14244 ± 3478 *(27704 Jan92)*	799 ± 244 *(2927 Jan94)*	- -	- -	*28225 Jan92*	1200
Shelduck Y	1212 ± 350 *(4877 Sep91)*	572 ± 165 *(1738 Jul92)*	845 ± 244 *(2989 Jul92)*	693 ± 200 *(1821 Jun93)*	546 ± 126 *(1821 Dec93)*	17 ± 6 *(78 Mar92)*	*7422 Jun93*	2500
Wigeon W	970 ± 213 *(1840 Jan91)*	385 ± 67 *(612 Jan93)*	16890 ± 3955 *(46079 Oct92)*	766 ± 56 *(1872 Jan94)*	3 ± 1 *(24 Oct91)*	0.2 ± 0.1 *(2 Mar92)*	*48178 Oct92*	7500
Gadwall W	2 ± 1 *(5 Feb93)*	0.5 ± 0.3 *(4 Oct92)*	38 ± 12 *(144 Nov92)*	300 ± 27 *(558 Nov93)*	250 ± 33 *(374 Nov93)*	0.5 ± 0.2 *(3 Jan92)*	*934 Nov93*	250
Teal W	37 ± 9 *(120 Oct91)*	29 ± 5 *(68 Jan92)*	1038 ± 364 *(4011 Oct91)*	1446 ± 173 *(3473 Dec92)*	5117 ± 363 *(9367 Feb94)*	44 ± 15 *(152 Mar94)*	*10716 Feb94*	4000
Mallard Y	1814 ± 476 *(4893 Dec92)*	1793 ± 372 *(3955 Jan92)*	3558 ± 848 *(9651 Jan92)*	689 ± 96 *(1760 Sep92)*	3623 ± 417 *(7118 Feb94)*	346 ± 52 *(862 Nov93)*	*21454 Jan92*	20000
Pintail W	24 ± 7 *(58 Feb93)*	47 ± 15 *(142 Feb93)*	1434 ± 454 *(3443 Oct92)*	55 ± 11 *(207 Jan94)*	39 ± 9 *(130 Mar93)*	0.5 ± 0.2 *(3 Mar94)*	*3571 Oct92*	700
Pochard W	8 ± 2 *(24 Feb93)*	1 ± 0.4 *(5 Feb93)*	68 ± 22 *(195 Nov91)*	127 ± 41 *(649 Feb94)*	523 ± 144 *(1767 Jan94)*	2 ± 1 *(20 Feb93)*	*1829 Jun94*	3500
Tufted duck W	23 ± 5 *(48 Oct92)*	9 ± 3 *(26 Jan93)*	448 ± 67 *(1272 Jan93)*	183 ± 110 *(2099 Feb94)*	93 ± 25 *(270 Dec93)*	1 ± 0.5 *(9 Dec93)*	*2243 Feb94*	7500
Moorhen W	1 ± 0.8 *(10 Feb92)*	36 ± 4 *(59 Mar91)*	1 ± 0.7 *(9 Feb93)*	7 ± 0.8 *(18 Feb94)*	210 ± 15 *(460 Sep93)*	346 ± 86 *(721 Oct92)*	*1073 Oct91*	10000
Oystercatcher Y	5049 ± 753 *(10555 Sep91)*	3952 ± 659 *(9410 Oct92)*	626 ± 95 *(1815 Feb93)*	69 ± 18 *(216 Jul93)*	1 ± 0.2 *(4 Feb93)*	1 ± 0.3 *(3 Mar94)*	*18019 Oct92*	9000
Avocet Y	96 ± 24 *(505 Nov92)*	173 ± 23 *(372 Oct92)*	144 ± 63 *(809 Nov91)*	119 ± 18 *(336 Sep92)*	- *(2 Mar93)*	1 ± 0.1 *(7 Mar94)*	*1478 Oct92*	700
Ringed Plover Aug-Sep	1050 ± 267 *(1333 Sep92)*	471 ± 209 *(910 Sep91)*	54 ± 46 *(162 Aug91)*	169 ± 13 *(271 Sep92)*	- *(1 Jul93)*	- -	*2223 Sep91*	500
Grey Plover Y	1504 ± 370 *(8021 Mar92)*	557 ± 99 *(1494 May93)*	282 ± 173 *(2148 May92)*	20 ± 12 *(112 May93)*	- *(1 Aug93)*	- -	*8388 Mar92*	1500
Lapwing W	457 ± 155 *(1038 Dec92)*	1247 ± 470 *(4240 Nov92)*	1376 ± 682 *(4730 Nov92)*	273 ± 52 *(780 Jan92)*	1939 ± 412 *(5781 Jan92)*	19 ± 16 *(200 Oct92)*	*11692 Nov92*	20000
Knot Y	265 ± 92 *(1180 Aug91)*	22 ± 21 *(502 Aug92)*	2 ± 1 *(25 Oct91)*	- *(1 Sep93)*	- -	- -	*1445 Aug92*	3500
Sanderling	(787 Aug91)	*(546 Apr93)*	0	0	- -	- -	*864 May93*	1000
Dunlin W	6702 ± 1495 *(14412 Nov92)*	5541 ± 1350 *(12020 Jan92)*	1127 ± 382 *(4125 Nov91)*	172 ± 76 *(1390 Jan92)*	381 ± 100 *(873 Feb92)*	0.2 ± 0.1 *(1 Oct91)*	*22882 Jan92*	14000
Bar-tailed Godwit Y	635 ± 139 *(2604 May92)*	326 ± 68 *(871 Aug92)*	187 ± 95 *(1251 May92)*	8 ± 5 *(77 May93)*	- -	- -	*4837 May 92*	1000
Curlew Y	876 ± 199 *(3216 Aug91)*	869 ± 157 *(1839 Sep92)*	483 ± 104 *(1480 Feb93)*	54 ± 10 *(158 Jan92)*	- *(1 Jul93)*	- -	*5491 Aug 91*	3500
Redshank Y	305 ± 38 *(683 Jul92)*	280 ± 70 *(1204 Jul91)*	106 ± 31 *(463 Jul91)*	34 ± 15 *(196 Jul93)*	- *(1 May94)*	- *(1 Apr94)*	*2076 Jul91*	1500
Spotted Redshank Jun-Oct	13 ± 3 49 (Jun92)	119 ± 35 431 (Aug92)	514 ± 100 1102 (Jul 93)	- 1 (May94)	- -	- -	*1307 Aug92*	1200

SCHELDE ESTUARY

AREA	INTERTIDAL ZONE	MUDFLAT	MARSHES
1	4534	4310	224
2	2997	2927	70
3	5829	3344	2485
4	690	505	185
5	439	147	292
6	33	3	30



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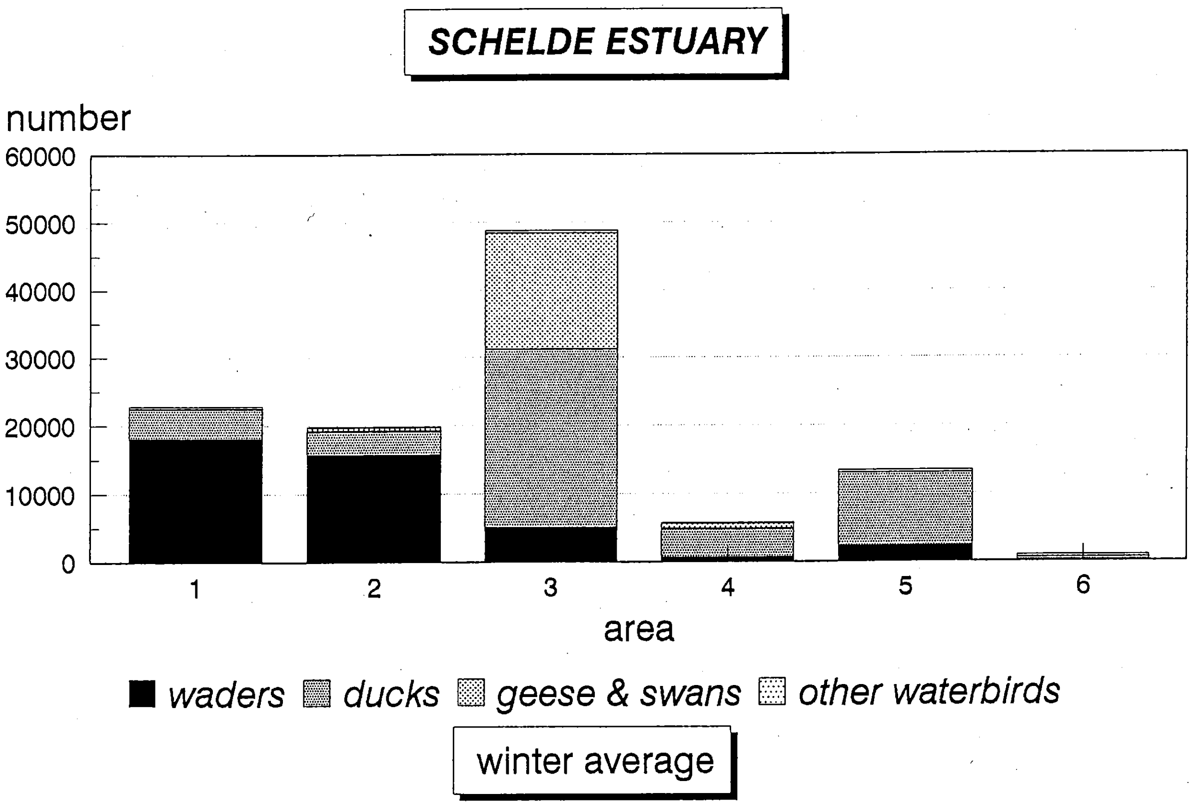
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30000
20000
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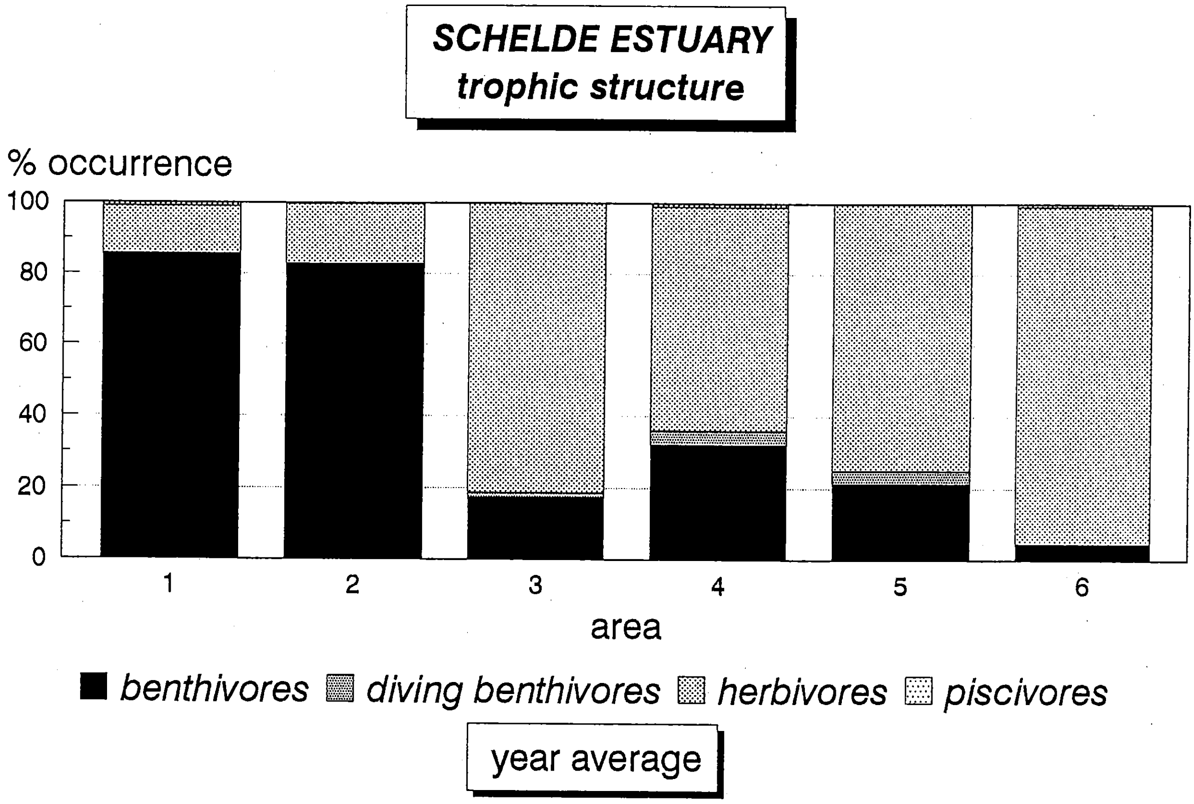
3
4
5
6
area
waders
ducks
geese & swans
other waterbirds
winter average

Figure 2


SCHELDE ESTUARY
trophic structure
% occurrence
100
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60
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3
4
5
6
area
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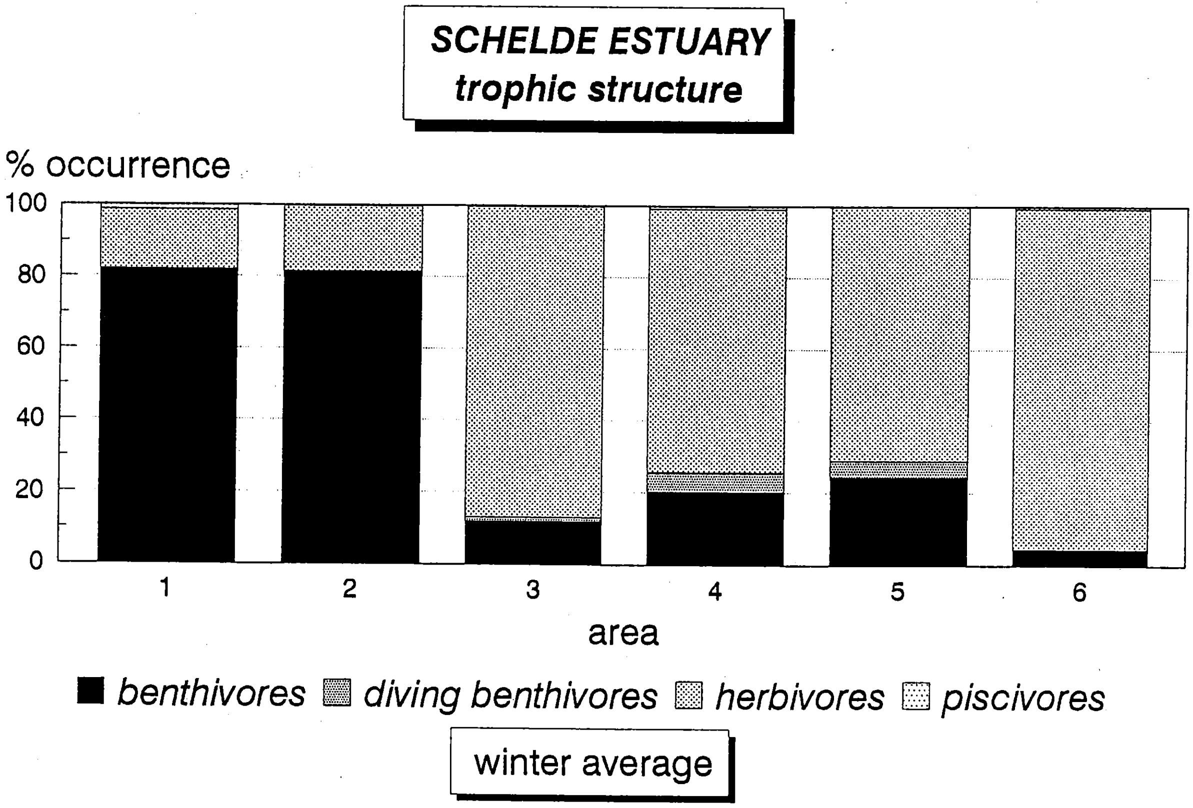
year average


SCHELDE ESTUARY
trophic structure
% occurrence
100
80
60
40
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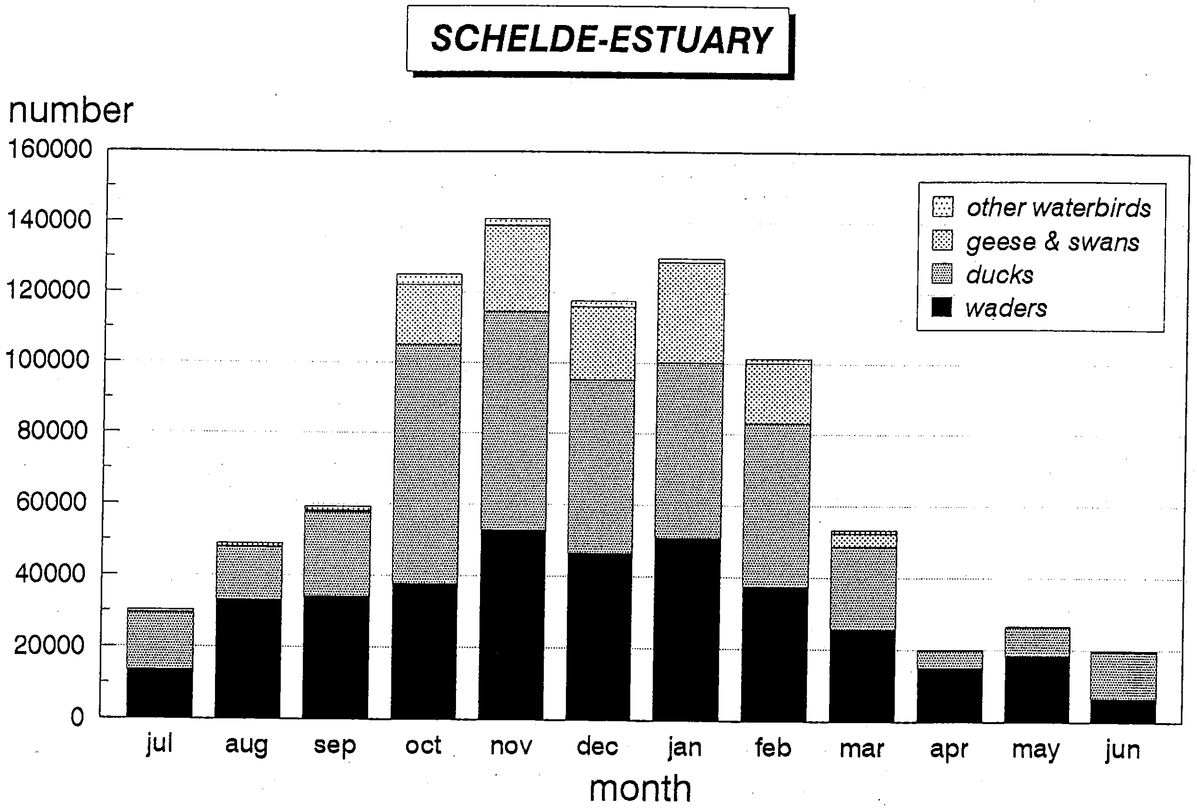
5
6
area
■ benthivores ▨ diving benthivores ▨ herbivores ▨ piscivores
winter average

Figure 3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ducks
waders
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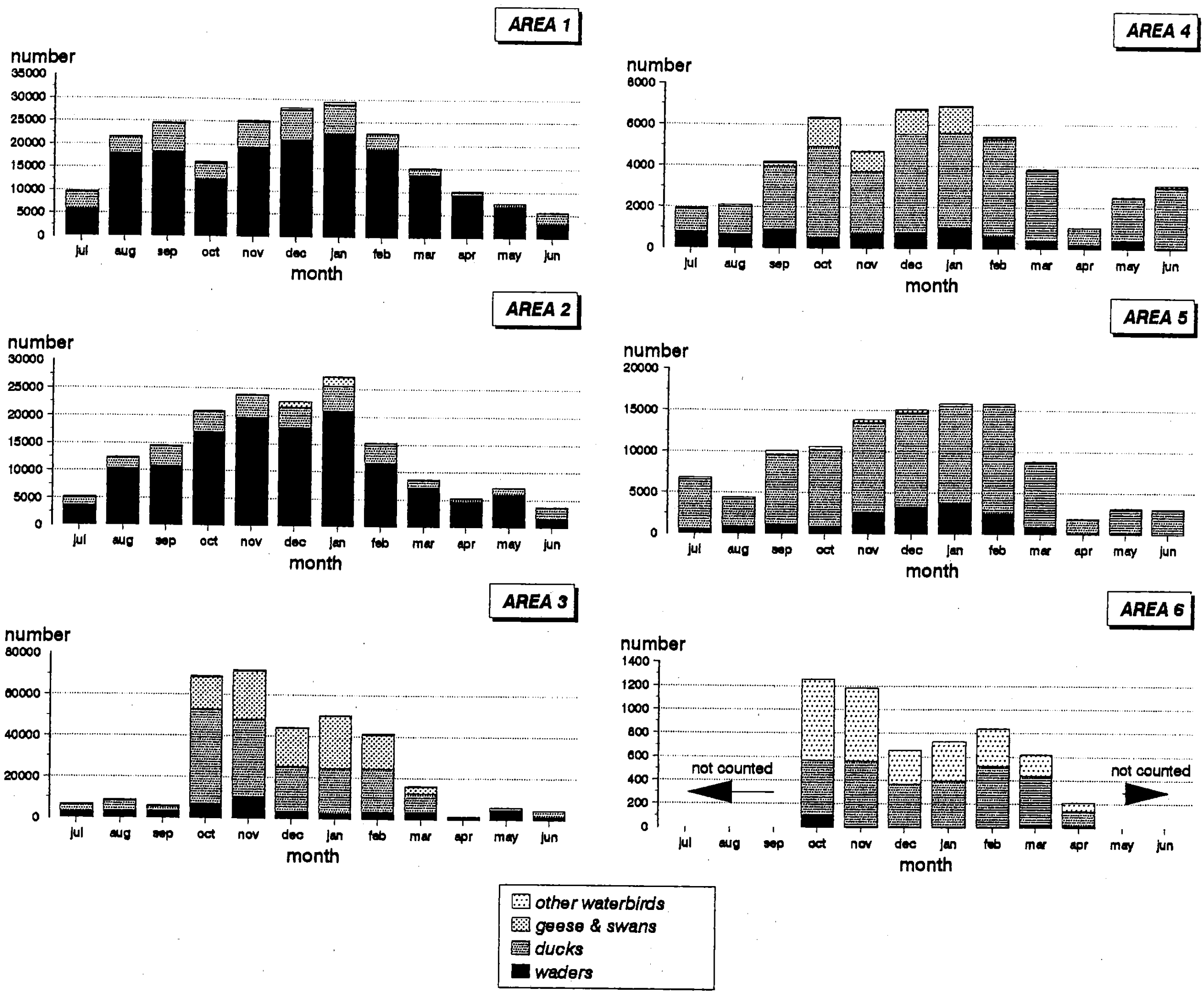
nov
dec
jan
feb
mar
apr
may
jun
month

Figure 4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month
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30000
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20000
15000
10000
5000
0
jul aug sep oct nov dec jan feb mar apr may jun
month
AREA 3
number
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20000
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month
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number
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month
AREA 5
number
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15000
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month
AREA 6
number
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1200
1000
800
600
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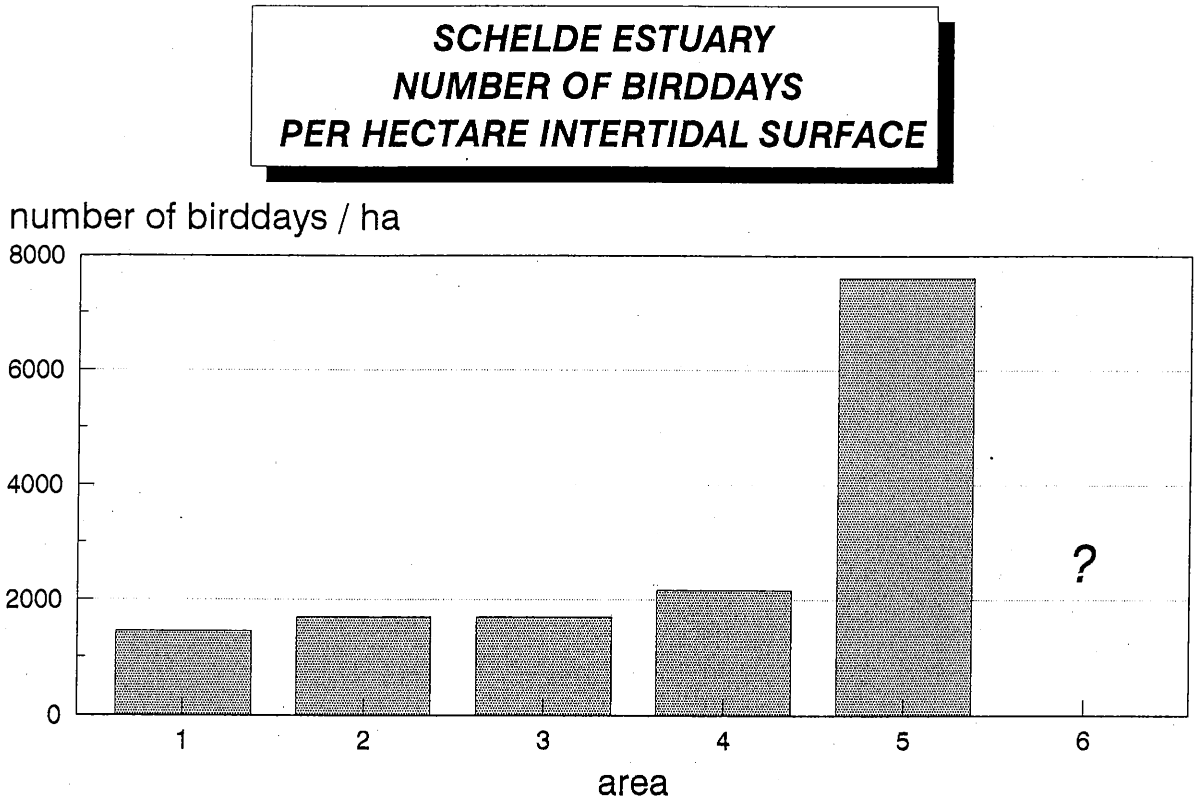
month
other waterbirds
geese & swans
ducks
waders

Figure 5


SCHELDE ESTUARY
NUMBER OF BIRDDAYS
PER HECTARE INTERTIDAL SURFACE
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6000
4000
2000
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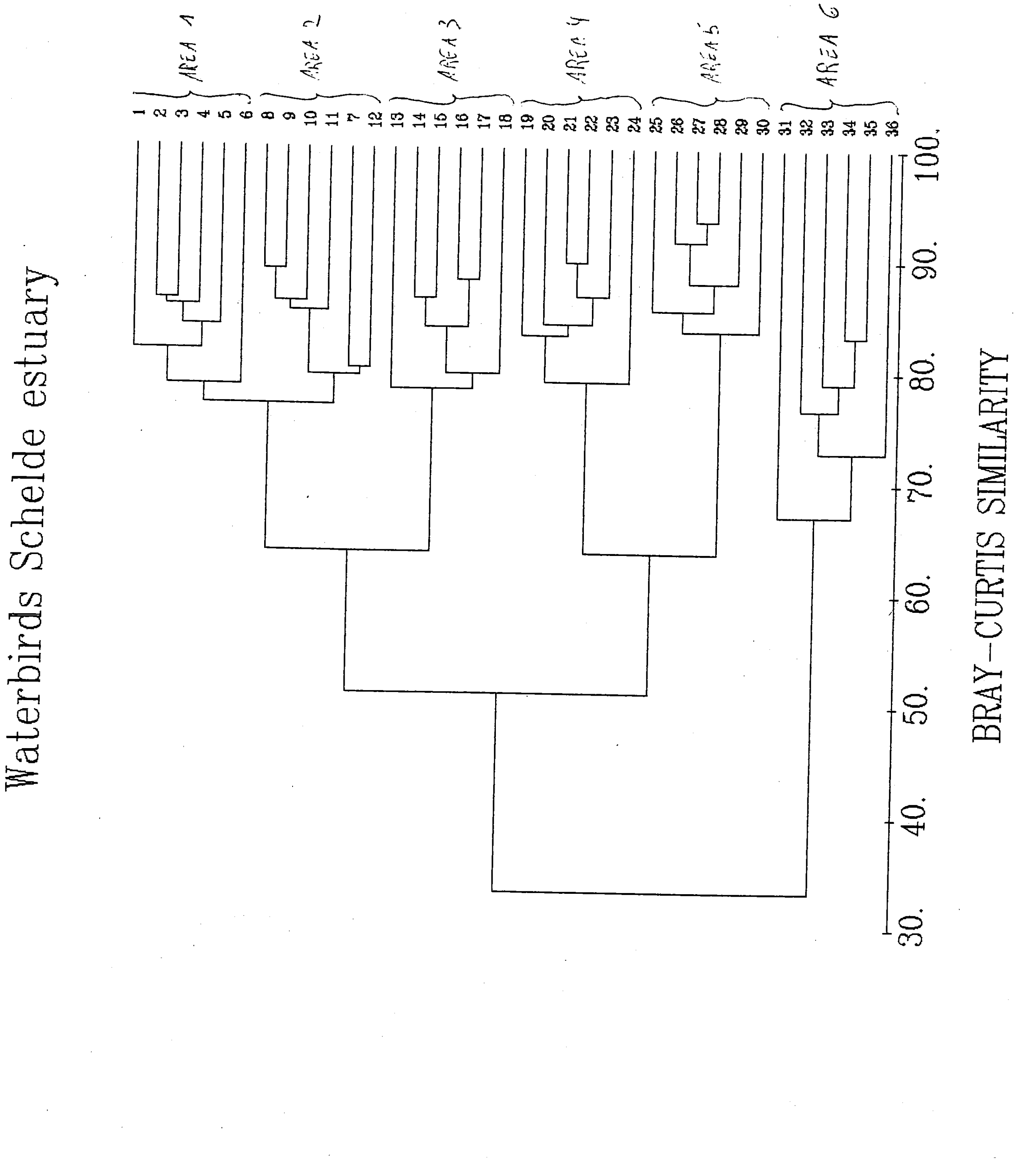
?
1
2
3
4
5
6
area

Figure 6


Waterbirds Schelde estuary
BRAY-CURTIS SIMILARITY
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40.
50.
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70.
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90.
100.
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8 9 10 11 7 12
13 14 15 16 17 18
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31 32 33 34 35 36
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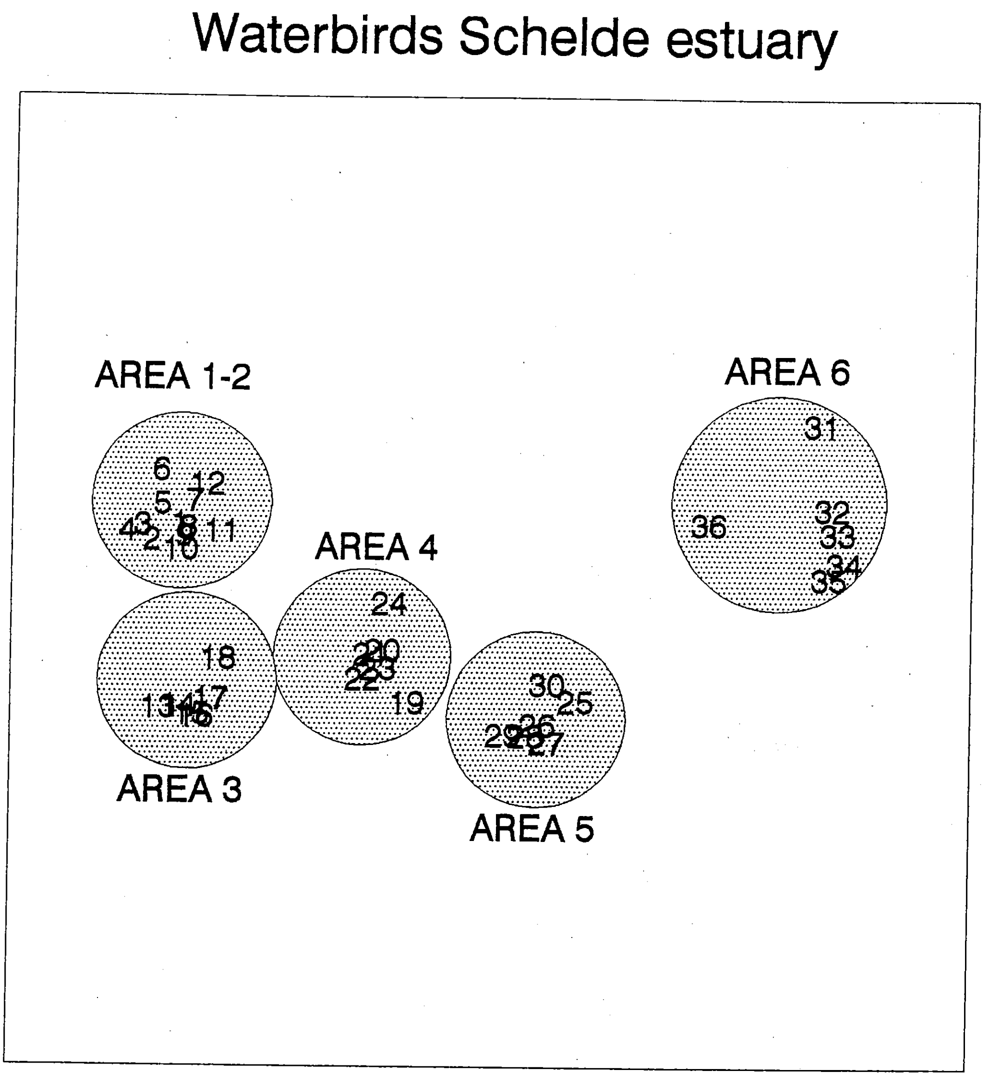
AREA 2
AREA 3
AREA 4
AREA 5
AREA 6

Figure 7


Waterbirds Schelde estuary
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AREA 4
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AREA 6
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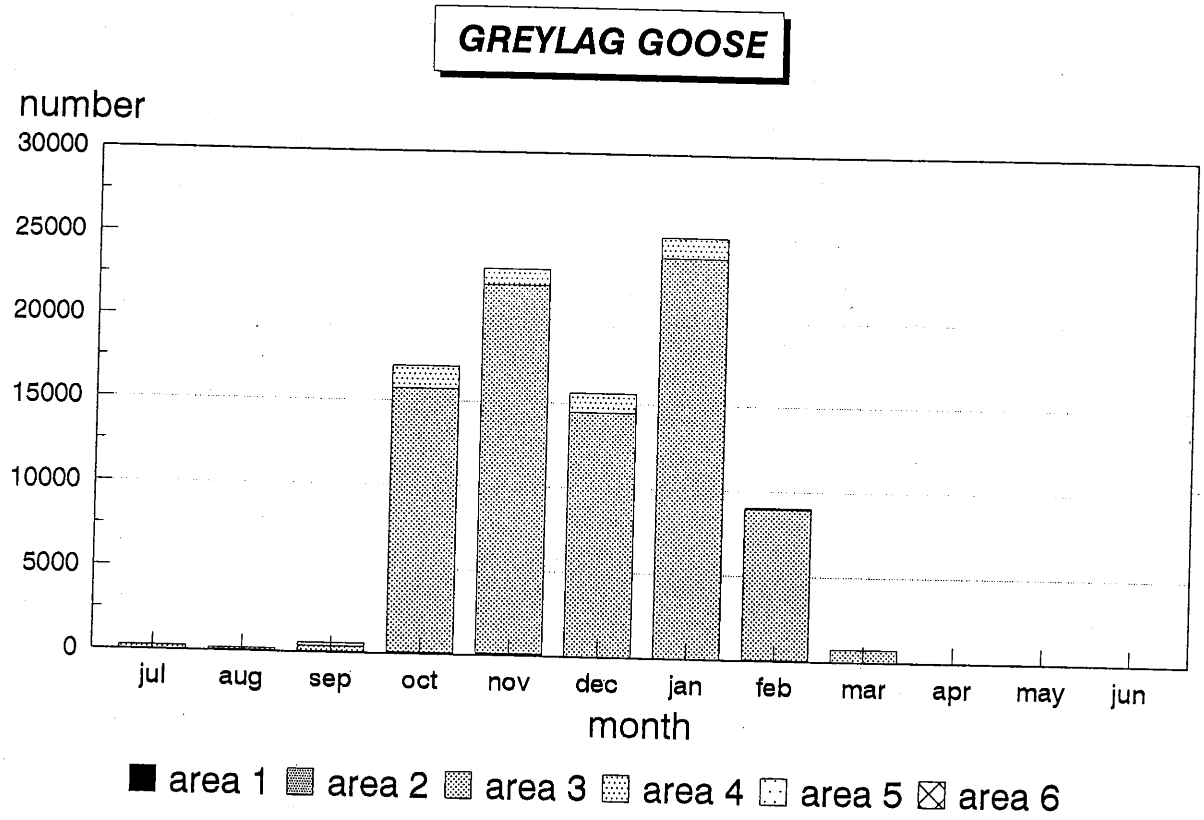
Figure 8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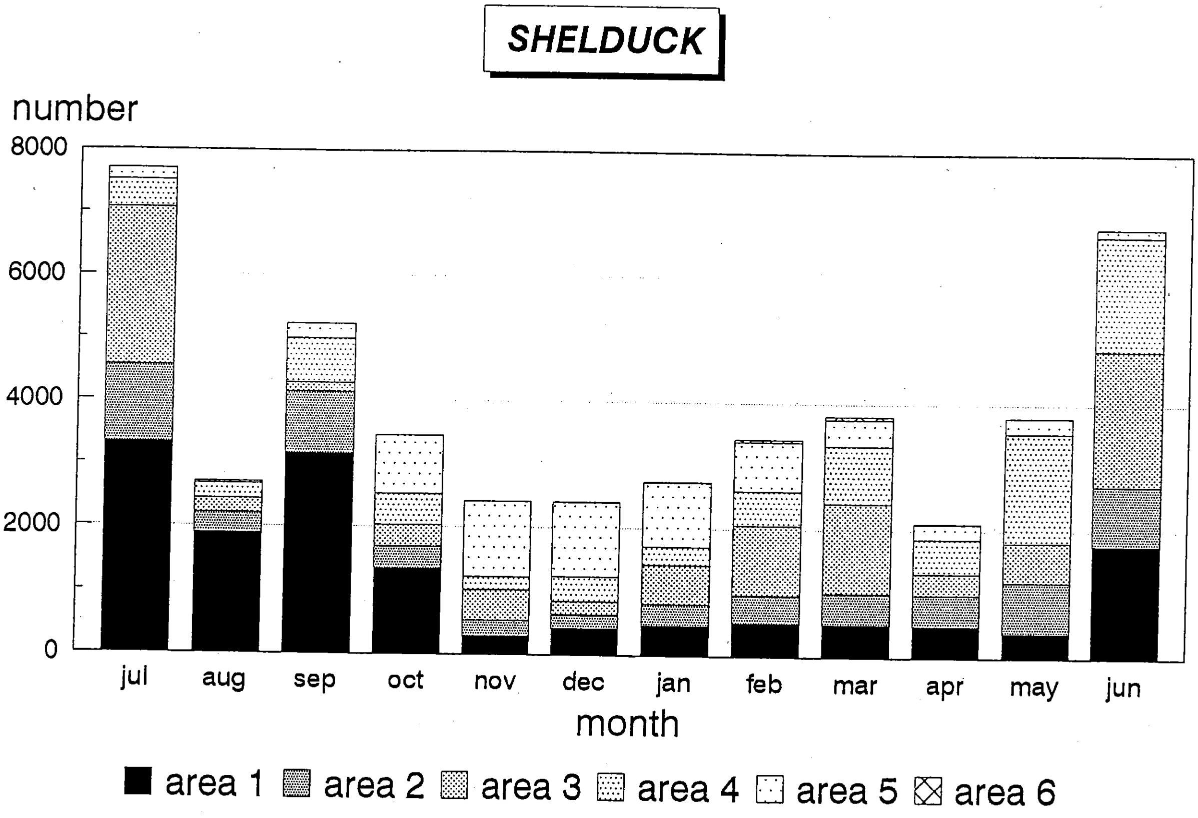
area 4
area 5
area 6

Figure 9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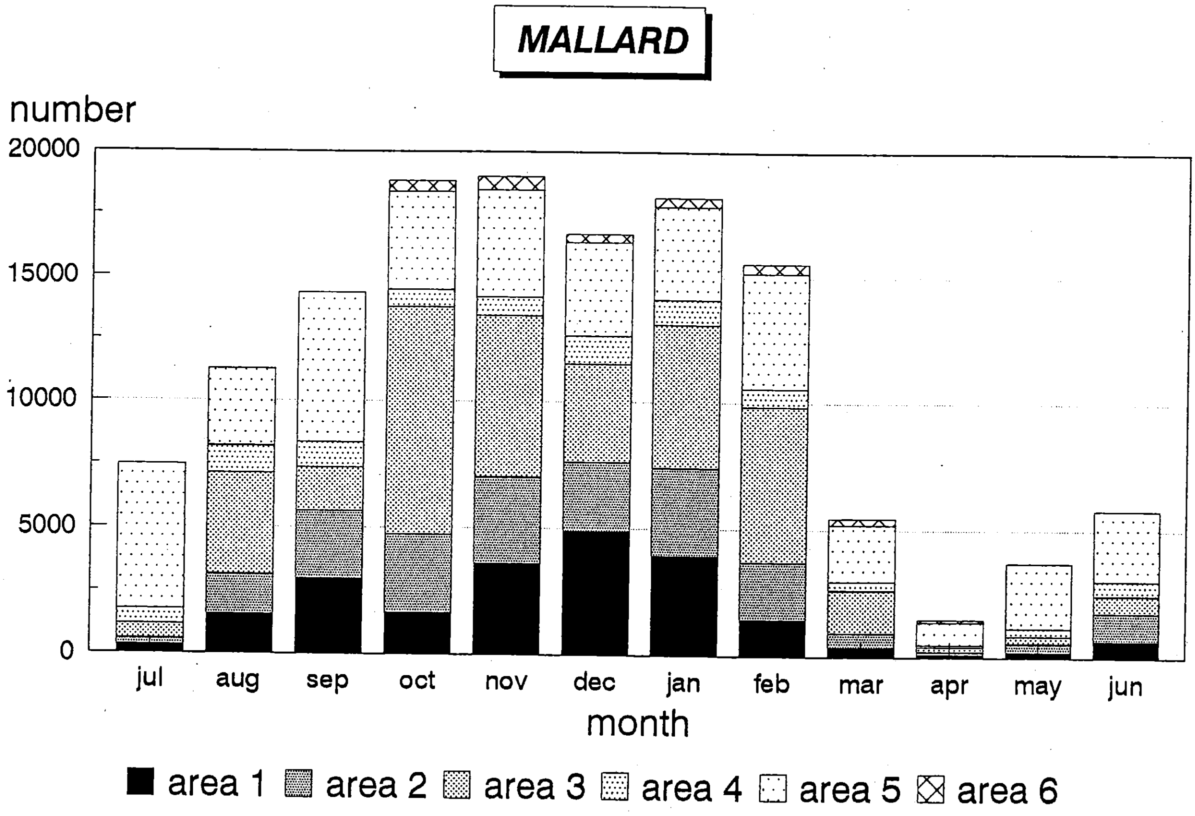
area 6

Figure 10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▨ area 2
▨ area 3
▨ area 4
☐ area 5
☒ area 6

Figure 11

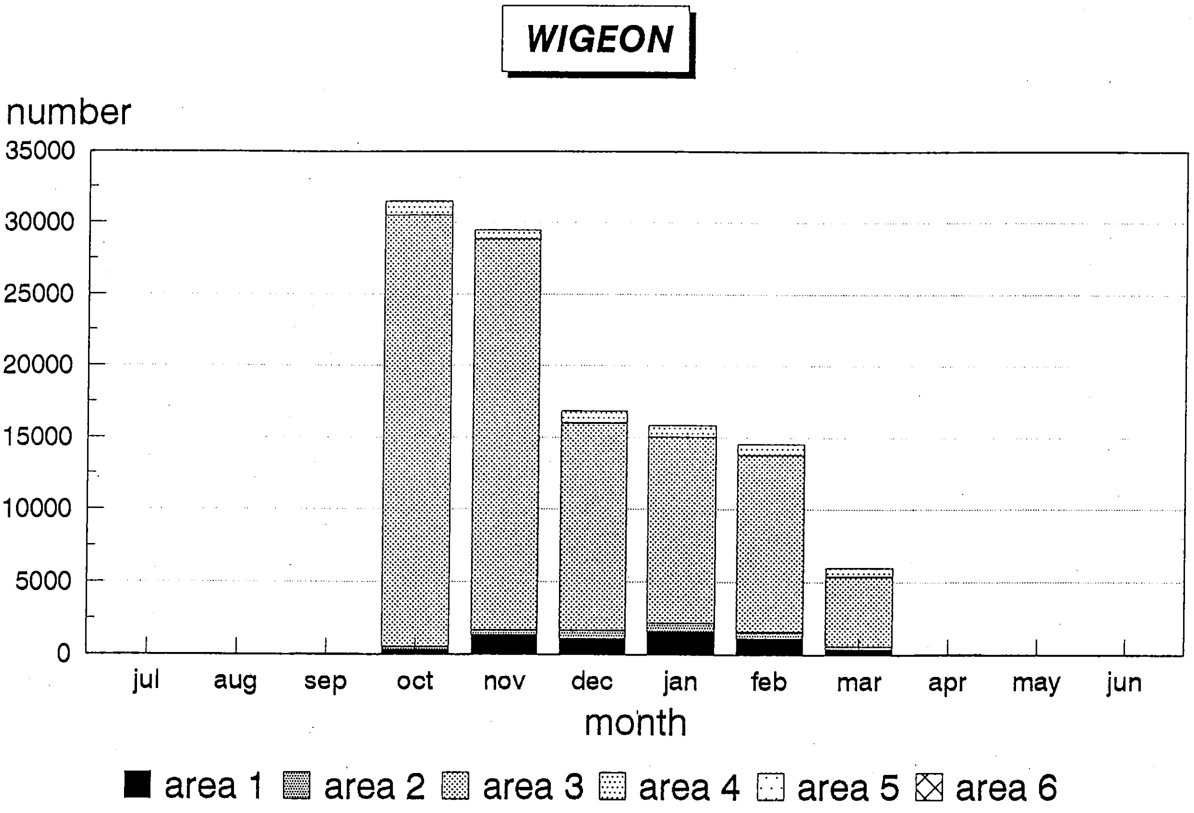
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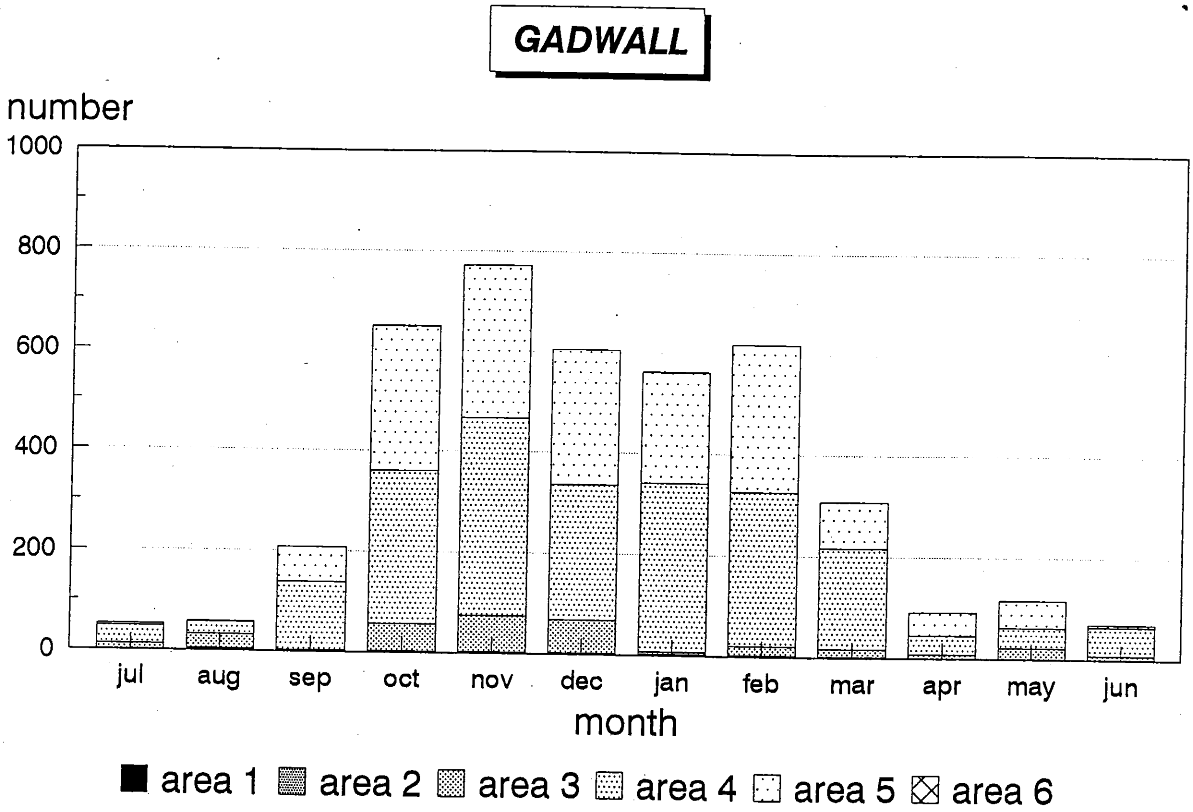
Figure 12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may
jun
month
area 1
area 2
area 3
area 4
area 5
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Figure 13

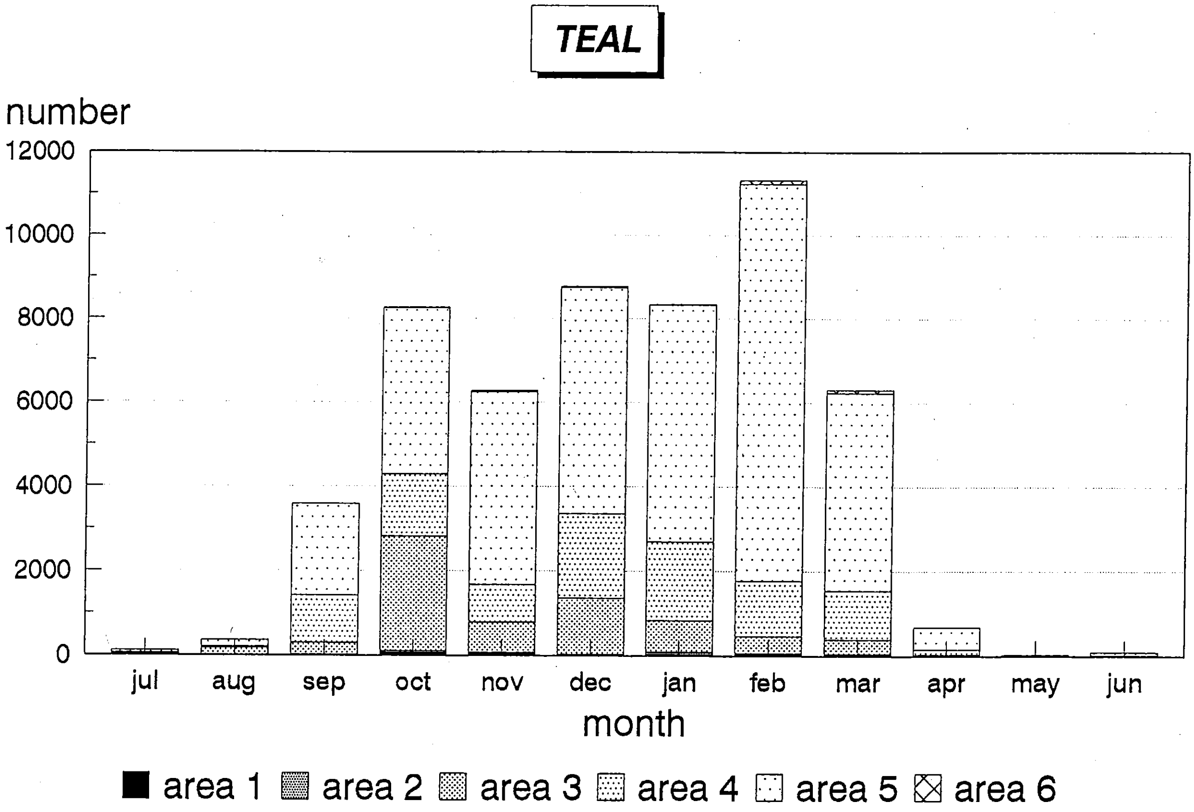
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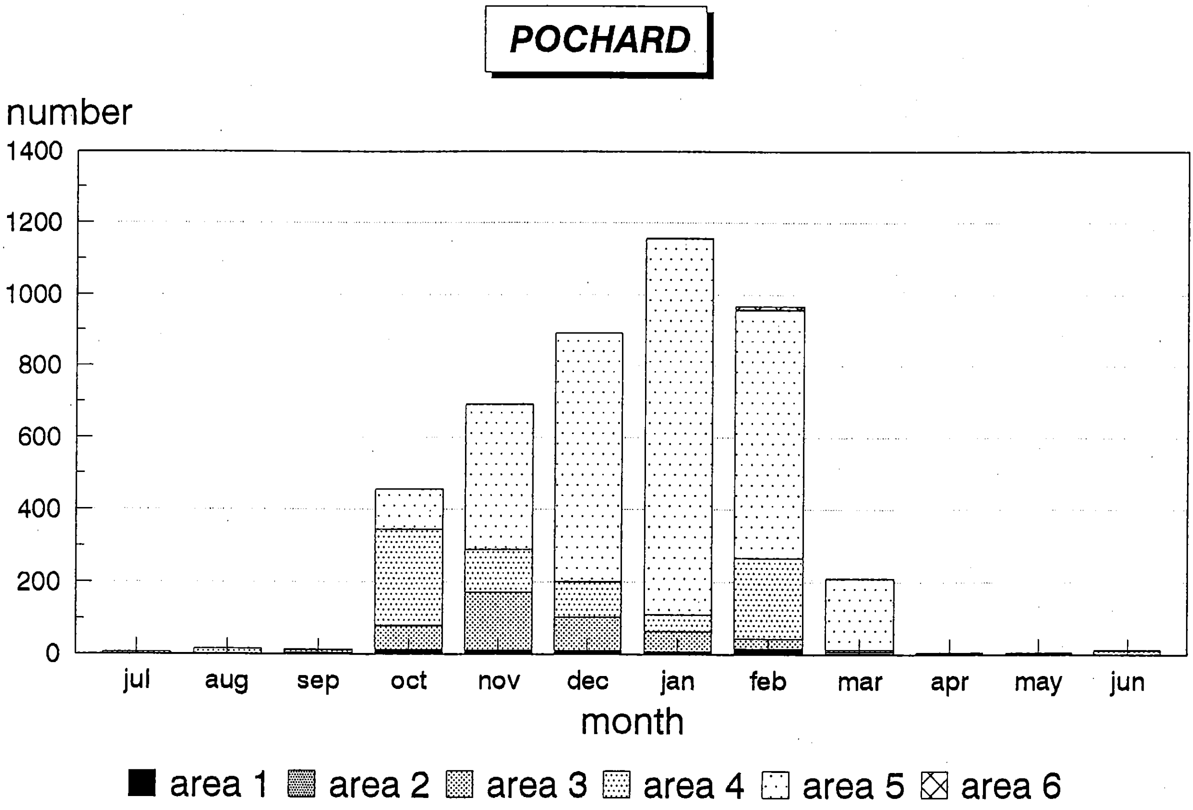
Figure 14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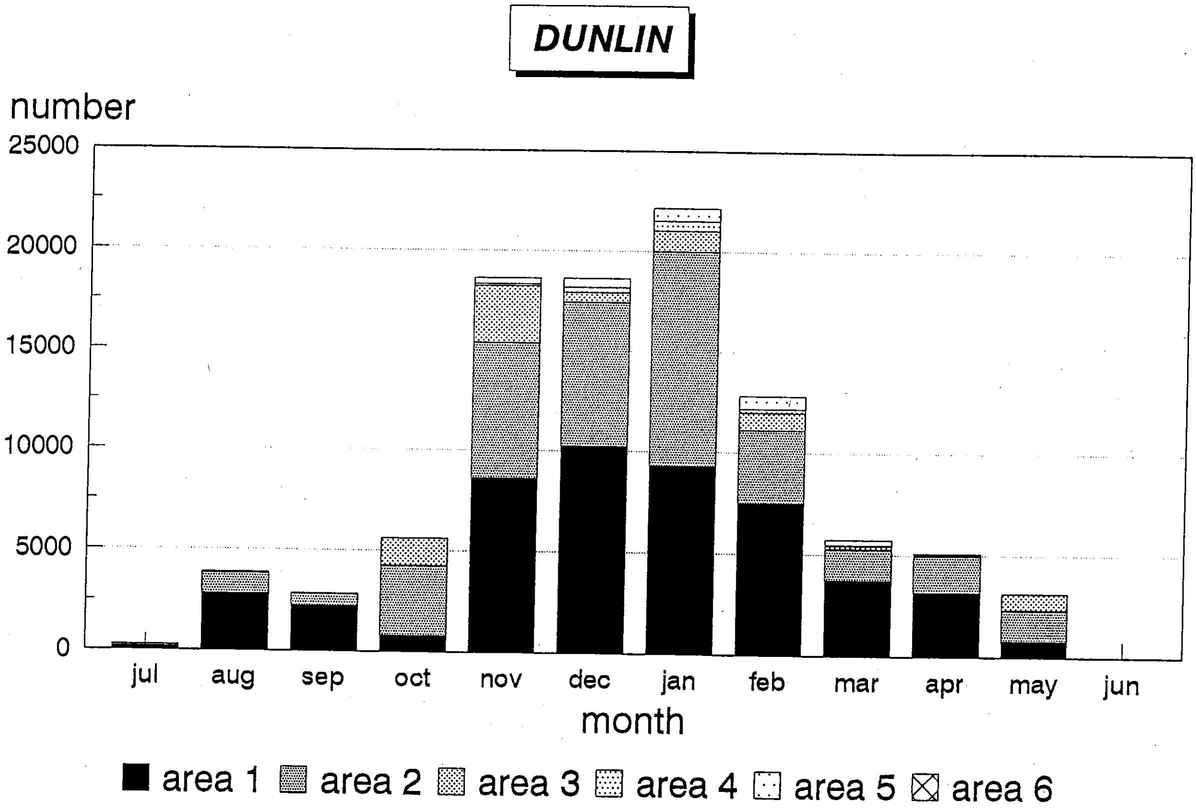
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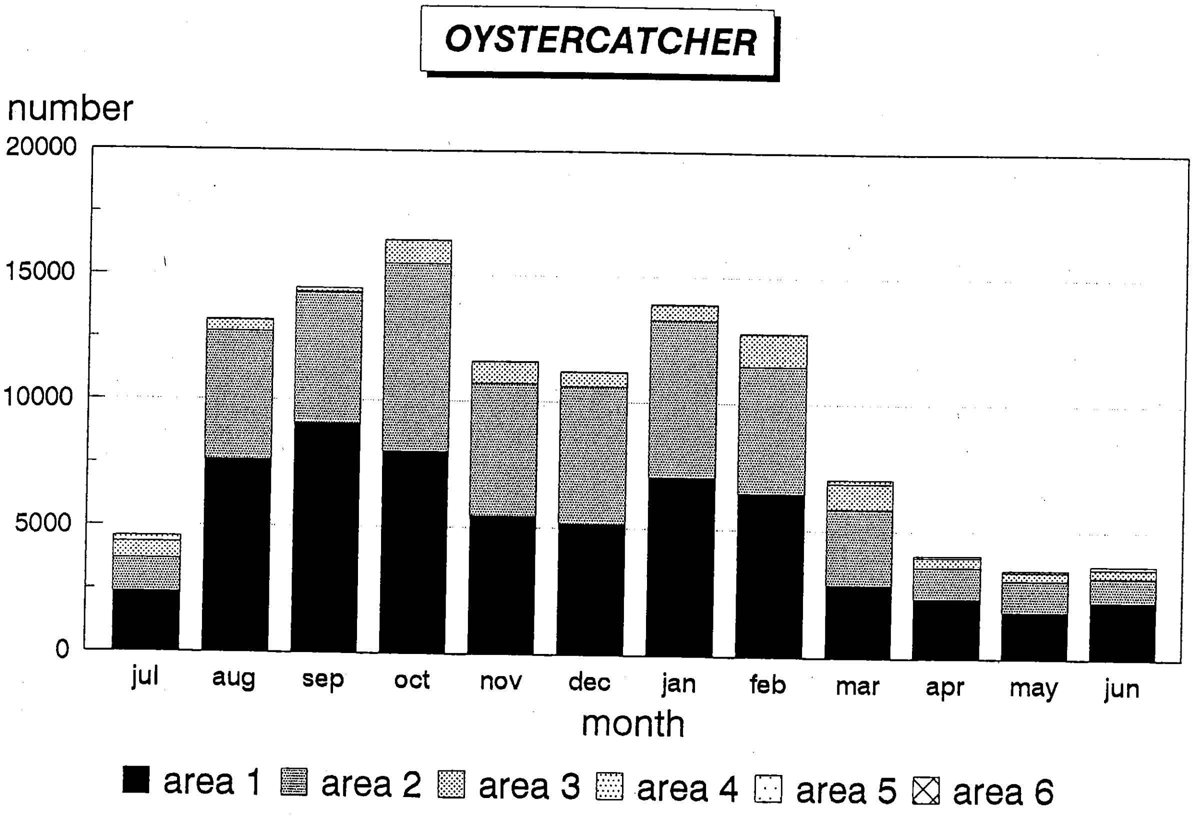
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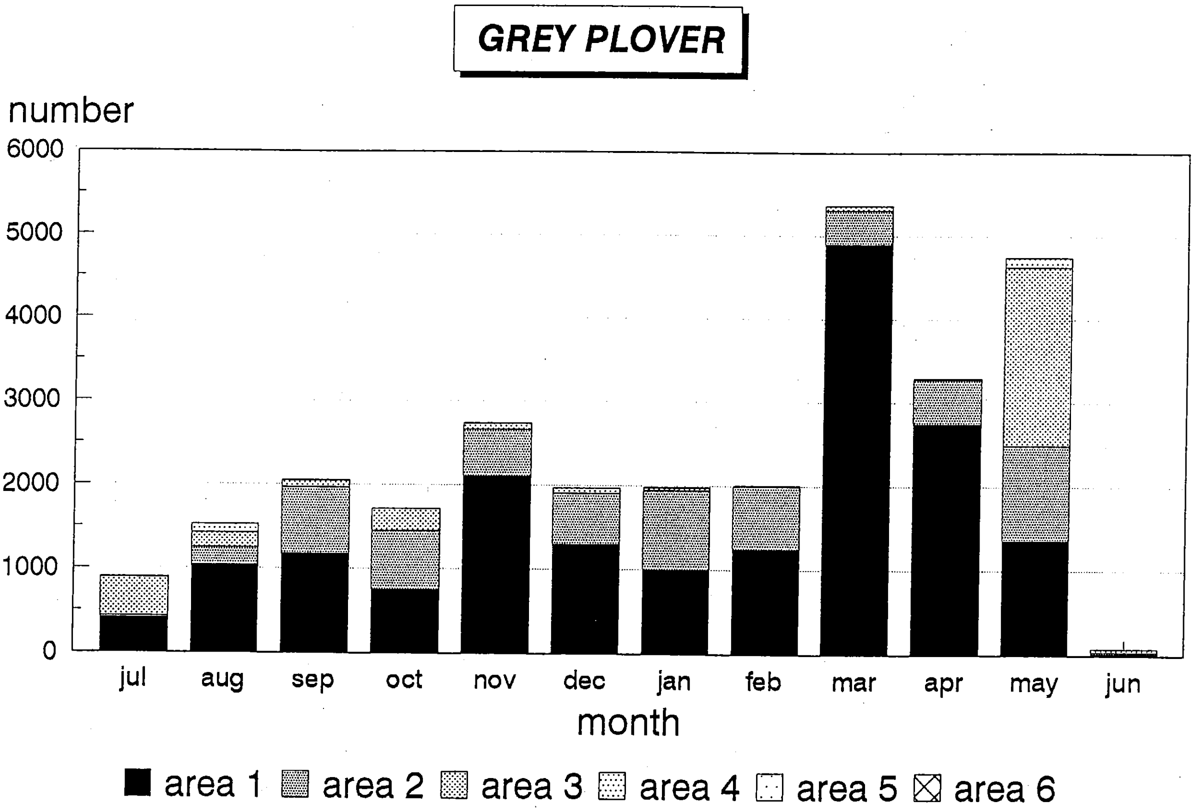
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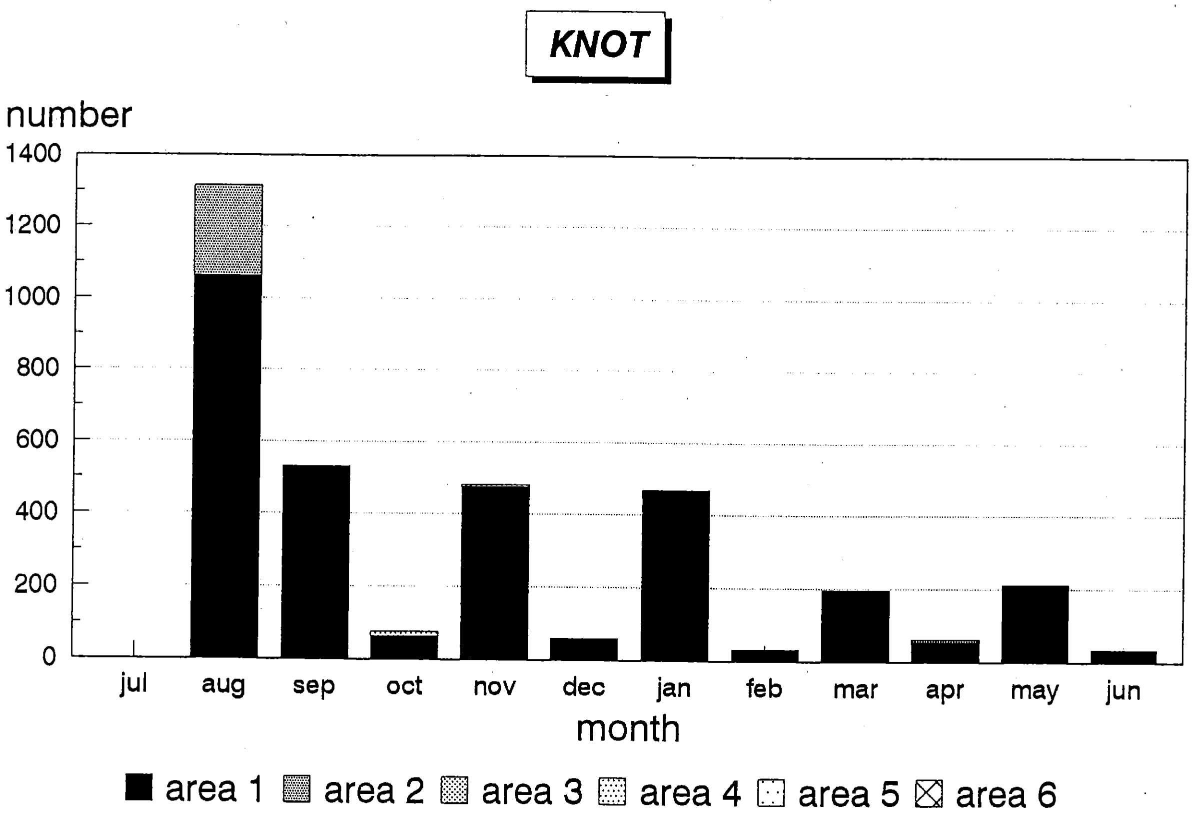
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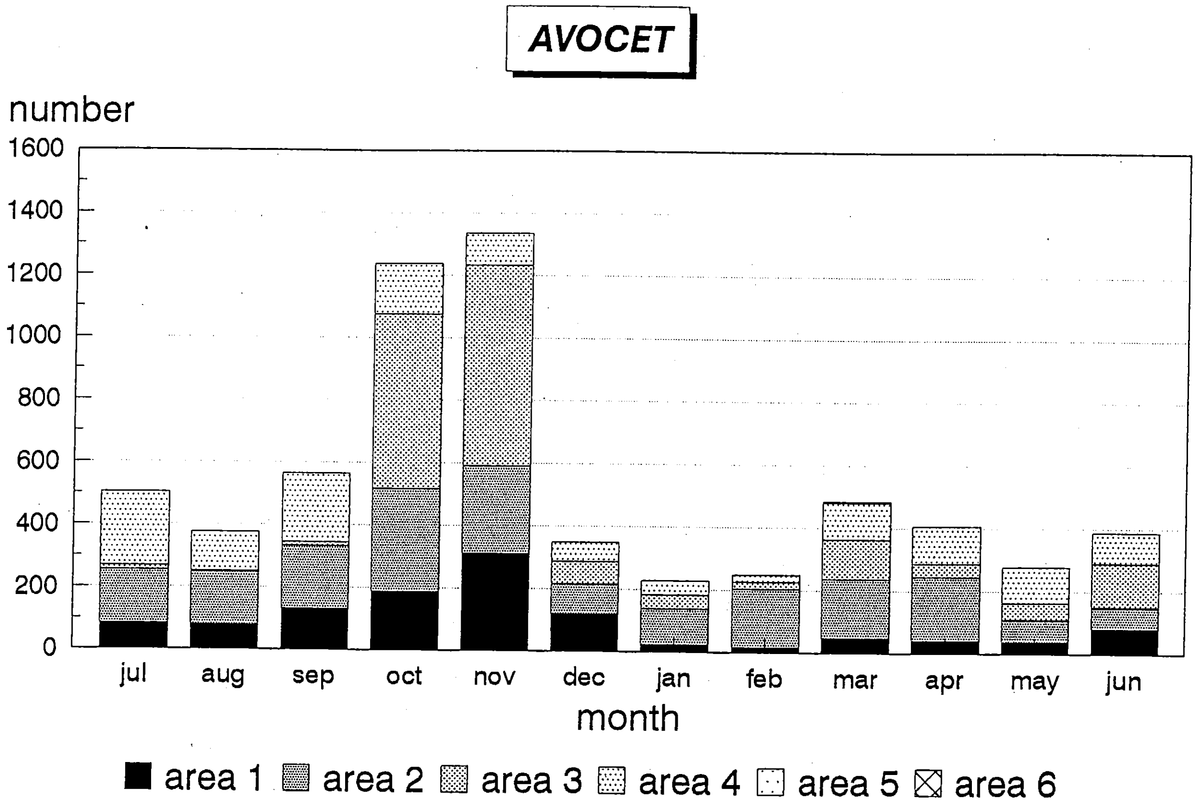
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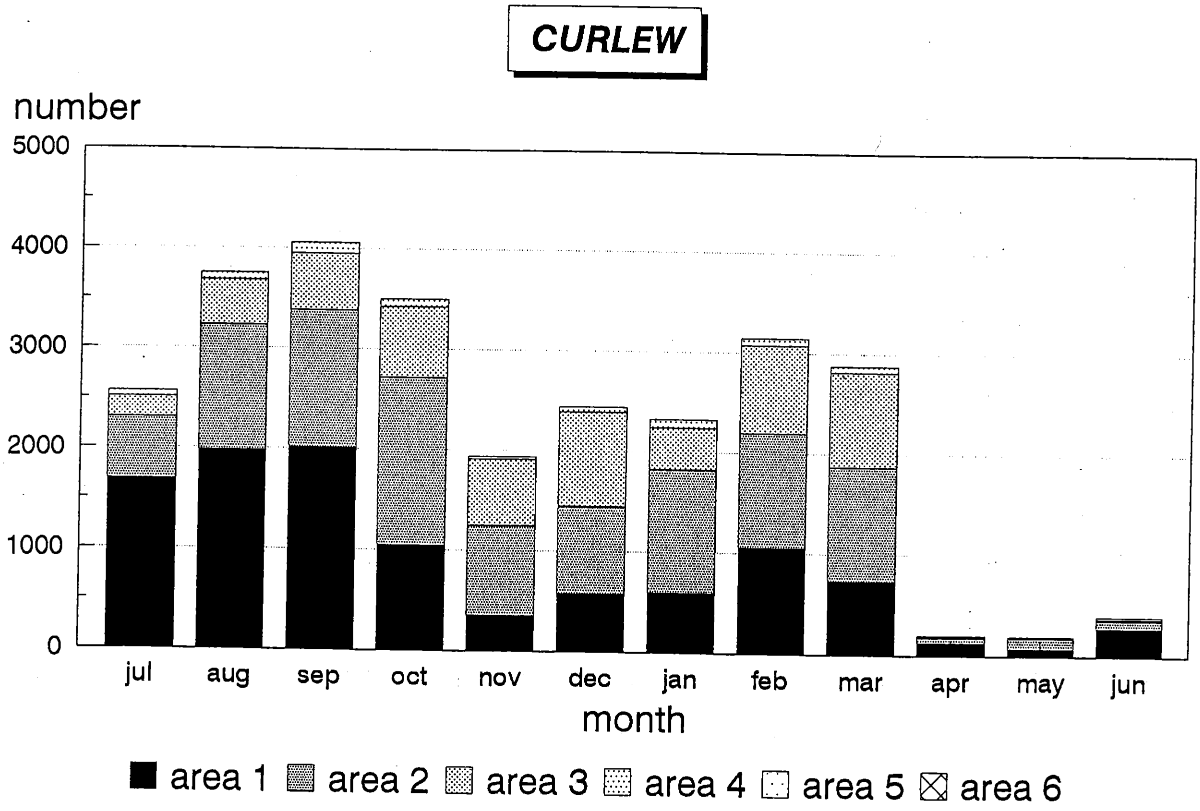
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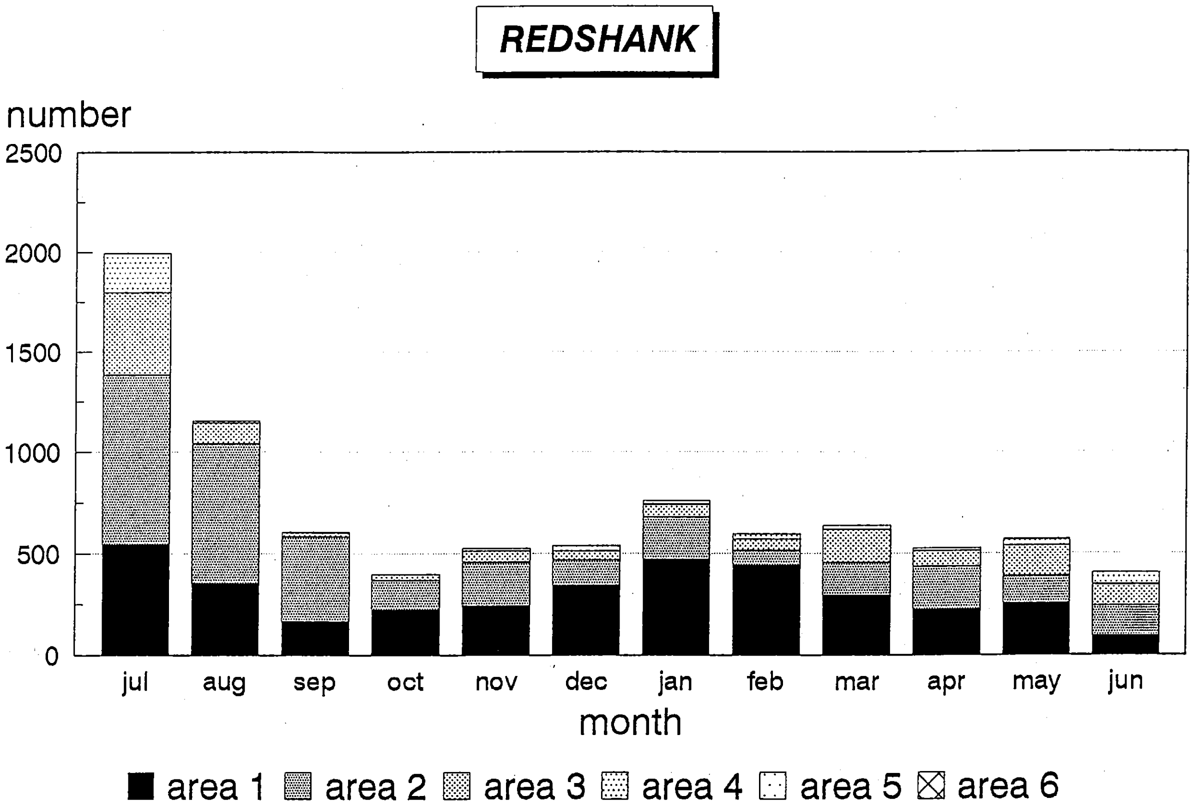
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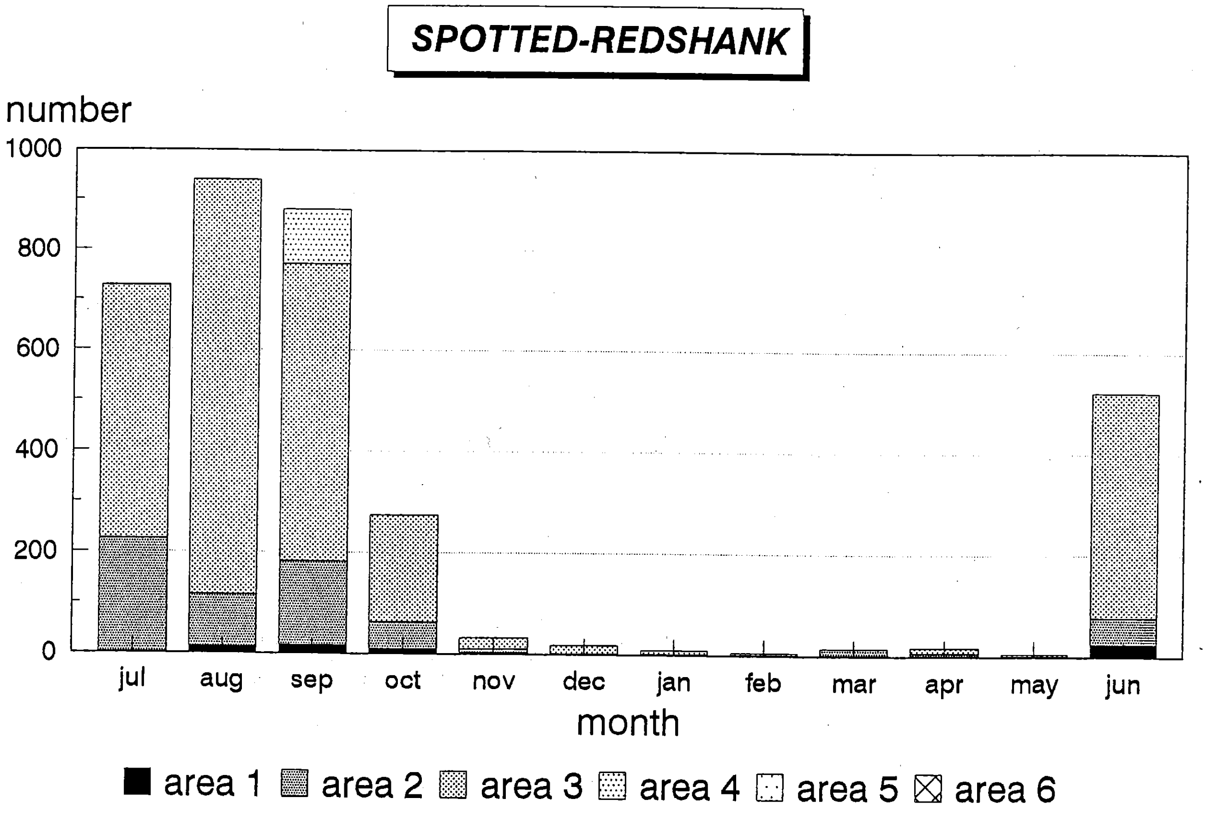
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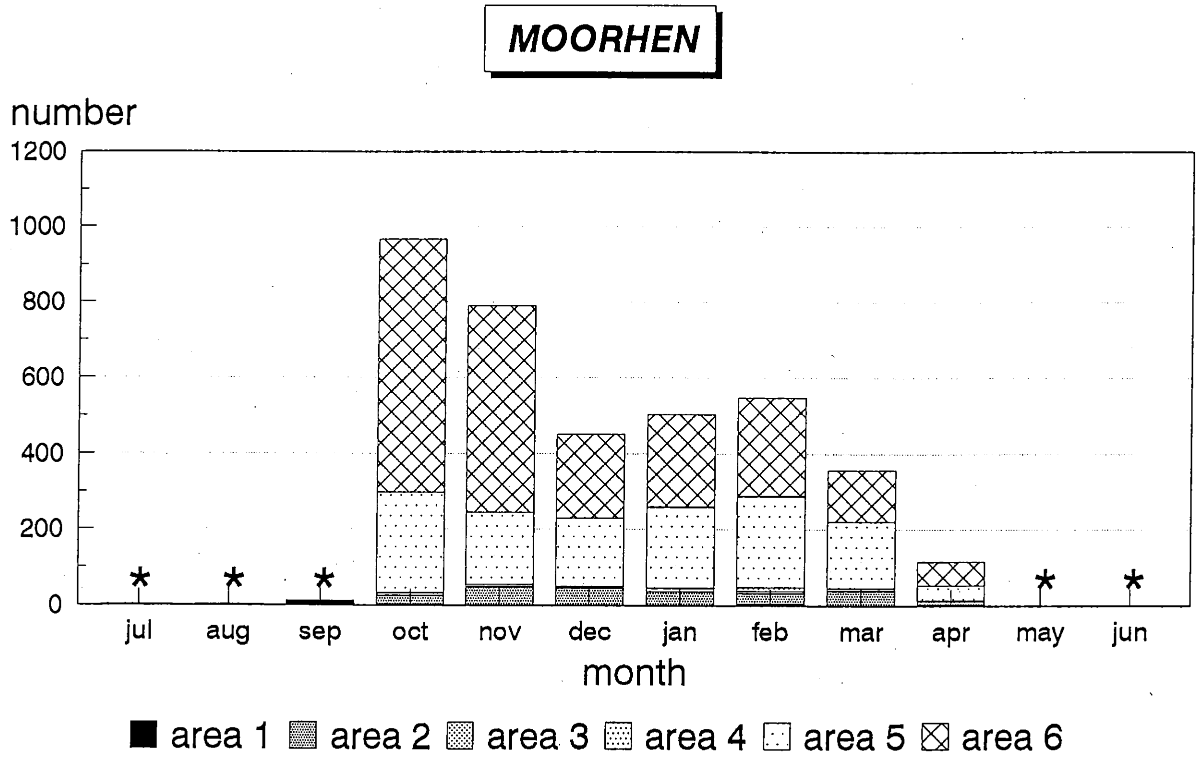
Figure 23



* = not completely counted

Figure 24

Abiotic characterization of intertidal mud- and sandflats situated along a salinity gradient of the Schelde estuary

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1. Introduction

The distinctive feature of estuarine ecosystems is the nature and variability (high-amplitude and unpredictable) of the physical and chemical forces acting on these ecosystems. These forces will determine and structure in an important way the occurrence and distribution of populations and communities inhabiting the estuarine ecosystems. In other words, estuarine populations and communities tend to be dynamic and ever changing, as is the estuarine environment itself. Changes will happen both on a short and a long term basis, and can be predictable (e.g. tidal cycle) or non predictable (e.g. storms, freshwater runoff).

Therefore, when studying estuarine macroinvertebrate populations and communities, it is necessary to have a thorough understanding of the abiotic environment acting on them. The abiotic environment will also influence the occurrence and distribution/behaviour of possible chemical stressors (contaminants).

This paper gives a detailed description of the abiotic environment of the seven locations where also the macrobenthic communities, as well as the contaminants are followed.

The aim of this paper is (1) to describe the abiotic environment of the seven locations and (2) to study the relationships between hydrology, morphology and other abiotic variables.

2. Material & Methods

2.1. Study area

The Schelde estuary, a macrotidal coastal plain estuary, is situated at the border between the Netherlands and Belgium. It measures 160 km between the mouth in Vlissingen and Gent, where it is artificially stemmed by a weir (Fig. 1). The surface area of the estuary (excluding the tidal tributaries) is approximately 350 km^2, including a freshwater tidal area of about 17 km^2. The mean tidal amplitude increases from 3.8 m at Vlissingen to a max. of 5.2 m at Kruibeke. It diminishes more upstream to " 2 m near Gent. The river discharge varies from 20 m^{3}s^{-1} during summer to 400 m^{3}s^{-1} during winter, with a mean yearly average of 105 m^{3}s^{-1}. The total volume of the estuary (2.5*10^9 m^3) is large in comparison with the volume of the water that enters each day from the river (9*10^6 m^3). The residence time of the water in the estuary is rather high, ranging from one to three months, depending on the river discharge. The mean annual chlorinity decreases from " 16.6 g Cl^-/l near Vlissingen to " 4.5 g Cl^-/l at the Belgian-Dutch border, and near the tributary Rupel the water becomes fresh (< 0.3 g Cl^-/l).

The lower and middle estuary, the so-called Westerschelde between the Dutch-Belgian border and Vlissingen (55 km), is a well mixed region characterized by a complex network of flood and ebb channels surrounded by several large intertidal mud- and sandflats. Tidal flats and marshes cover 34 % of the Westerschelde. The water column is moderately to well oxygenated, with oxygen saturation increasing from 20-60 % at the border to 90-100 % at the mouth of the estuary. Especially the middle and inner estuary is subject to extensive dredging and dumping.

The upper estuary, the so-called Zeeschelde between the Dutch-Belgian border and Gent (105 km), is characterized by a single channel, bordered with mudflats and marshes (28 % of total surface). Besides a brackish zone (mesohaline and oligohaline) between the border and the tributary Rupel, it has a freshwater tidal area of app. 60 km lenght. It forms an unique ecosystem, being one of the latest freshwater tidal areas of North-western Europe. However, this section is heavily polluted by domestic, industrial and agricultural waste loads. An important feature of a large part of this section is the presence of an anoxic water column during most of the year.

The chemical, physcial and biological properties of the Schelde estuary have been documented in detail by Heip (1988, 1989), Van Eck et al. (1991), Meire et al. (1992), Van Damme et al. (1995) and several papers in Meire and Vincx (1993).

2.2. Sampling and labo analysis

Samples were taken in the period March 1993 - June 1994 at seven locations along a salinity and sediment gradient of the Schelde estuary (Figure 1 and Table 1). Paulina is a mudflat situated in the polyhaline zone of the estuary, a few km downstream of the city of Terneuzen. The mudflat Baalhoek is situated in the poly/mesohaline transit zone, bordering at the very large marsh area 'Saeftinghe'. Valkenisse is a large sandflat, also situated in the poly-mesohaline transit zone. The mudflat Groot Buitenschoor is situated at the Dutch/Belgian border (mesohaline zone). Two locations (GBR and GBL) were chosen here, only a few hundred meters apart, but with a totally different sediment (see further). The mudflat of Boereschans in the oligohaline zone is lying in the middle of the harbour region of Antwerpen. The mudflat Ballooi is the most upstream chosen location, situated in the freshwater tidal zone. All locations were situated in the intertidal zone.

Table 1. Names and codes of the sampling locations. Distance (from the mouth of the estuary) and estuarine division is given.

Location	**Code**	**Distance (km)**	**Estuarine division**
Paulina	PAU	15	polyhaline zone
Baalhoek	BH	40	poly/mesohaline transit
Valkenisse	VAL	43	poly/mesohaline transit
Groot Buitenschoor R	GBR	60	mesohaline zone
Groot Buitenschoor L	GBL	60	mesohaline zone
Boereschans	BOE	81	oligohaline zone
Ballooi	BAL	100	freshwater tidal zone

Waterquality parameters were derived from monthly monitoring campaigns, conducted by different by different institutions. For each intertidal location the nearest monitoring point was chosen to get an idea of the water quality in that part of the estuary. Data for Paulina, Baalhoek, Valkenisse and GBL and GBR were derived from RIKZ, for Boereschans and Ballooi from VMM. Since GBL and GBR are very near to each other (a few hundred meters), the same monitoring point was chosen for these two locations. Parameters chosen for this study are temperature, pH, salinity, oxygen, SPM and chla.

For sediment granulometry, monthly samples of five replicate sediment cores (2.5 cm diameter) were taken to a depth of 10 cm at each location. In the laboratory each replica was stored in the deep freezer until being analysed. Conductometric analysis by means of laser diffraction was done by means of a

Coulter Particle Size Analyser. The five replicates were analysed seperately to get a better idea of the variation of the sediment granulometry on each sampling. Median grain size, silt, mud and sand fraction were determined.

Organic matter (OM) in sediment was estimated by percentage ignition loss. Wet sediment samples were weighted in clean crucibles. They were then oven-dried in two steps at 105 EC and 500 EC for 24 hours. After each step the sediment was weighted and ignition loss was calculated by sediment weight loss.

TOC was measured by 'non-dispersive infrared measurement' with Dohrman-DC 180 Carbon Analyser. TOC measurements were analysed by PIH (Antwerpen).

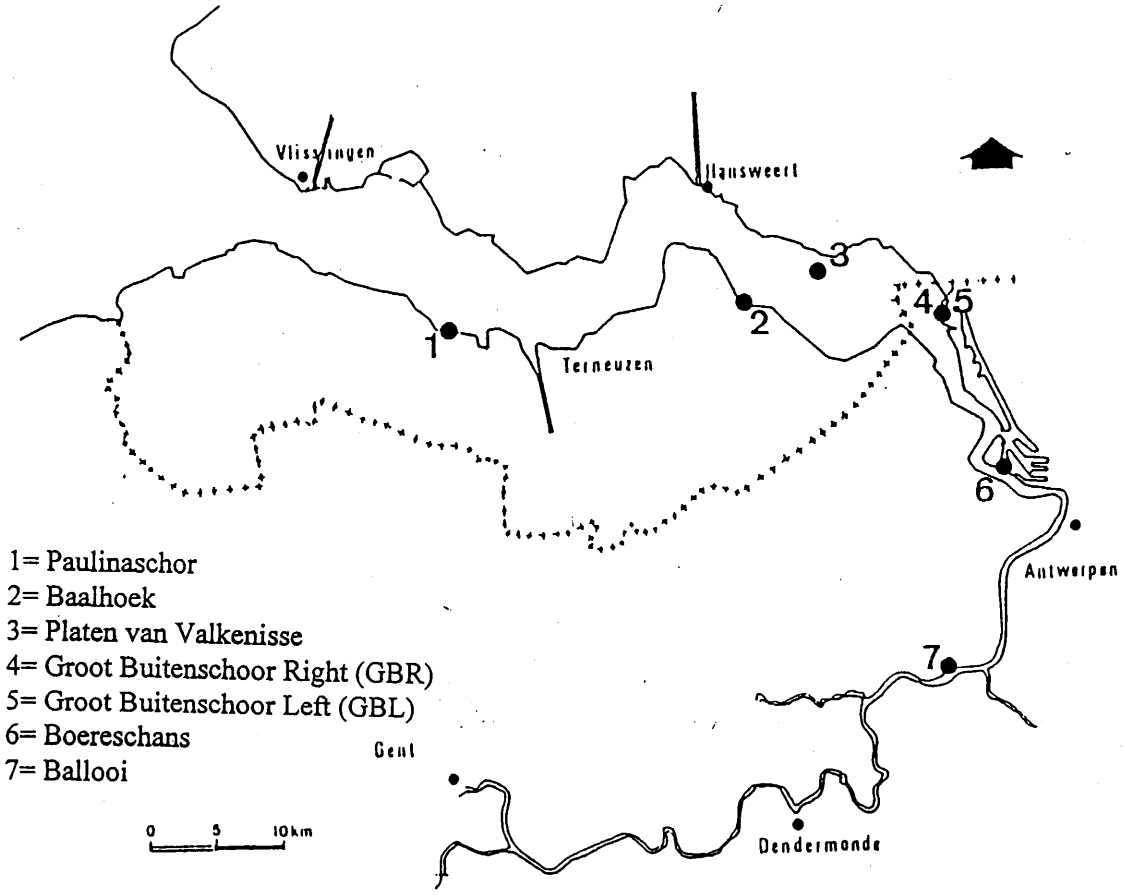


Figure 1. Schelde estuary with situation of the sampling locations.

3. Results

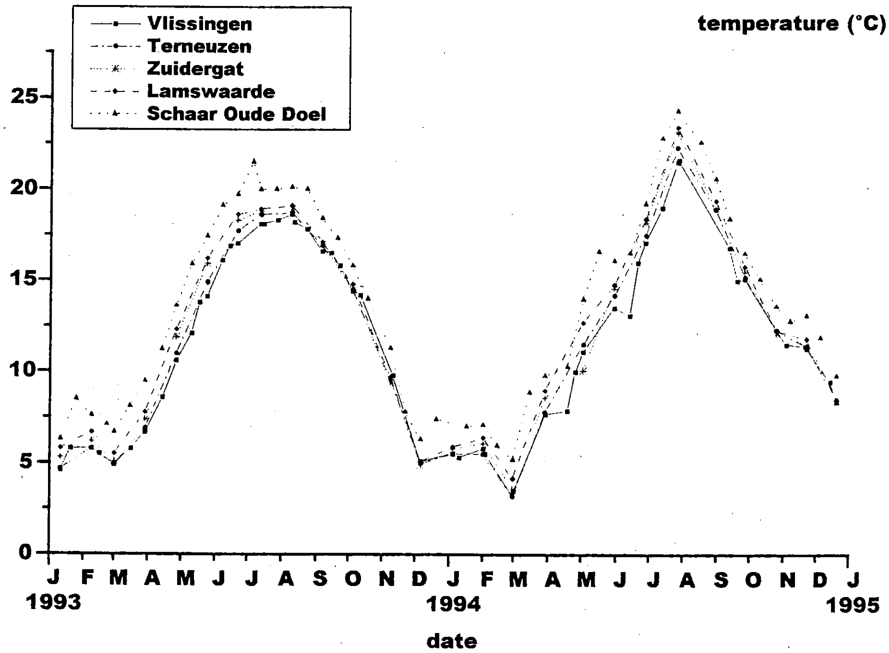
3.1. *Water quality*

Data shown deal with the following monitoring points: 'Vlissingen' is situated near the mouth of the estuary and represents the seaward conditions of the estuary; 'Terneuzen' is situated in the middle of the polyhaline zone and represents mostly the conditions at the sampling location Paulina; 'Zuidergat' and 'Lamswaarde' are situated in the poly-/mesohaline zone and represents mostly the conditions at the Baalhoek and Valkenisse respectively; the monitoring point 'Schaar van Ouden Doel' is situated near the Dutch/Belgian border and represents the two locations GBR and GBL.

Data on waterquality are presented for the period January 1993-December 1994.

Water temperature

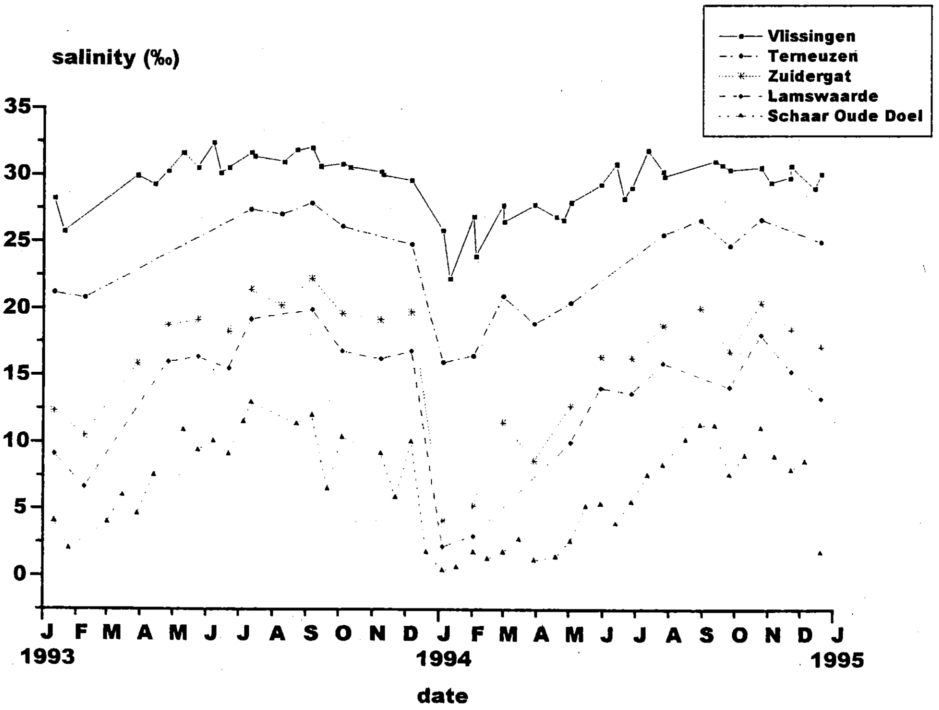
The temperature is one of the most essential environmental variables, determining a lot of ecological processes (e.g. metabolic activities). The evolution of the water temperature during 1993-1994 is shown in Figure 3. All locations show a similar seasonal pattern. Only at 'Schaar Oude Doel' slightly higher temperatures are observed the whole year round. Temperatures are low until March 1993, after which temperatures start increasing to a maximum of 18 °C (20 °C at 'Schaar Oude Doel') in summer period (June-August 1993). From September on, temperatures decrease and from December 1993 until March 1994 temperature are below 5 °C. In April 1994 temperature increase, and in July temperature exceed 20 °C.



Salinity

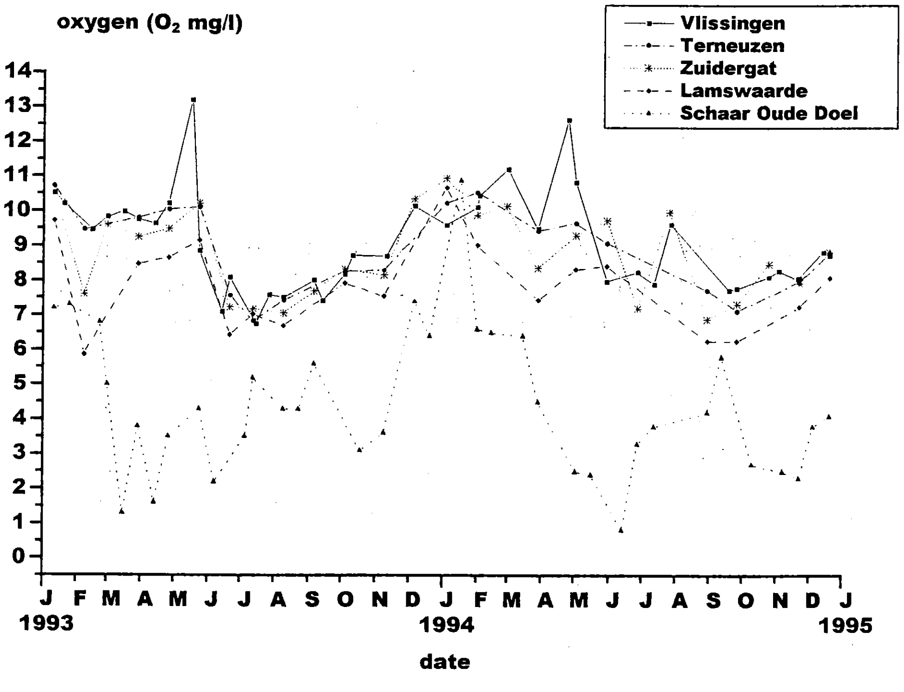
As temperature, salinity is one of the most essential environmental variable in estuaries, determining to a great extent the occurrence and distribution of most of the estuarine species. The salinity in the Schelde estuary is determined to a great extent by the freshwater runoff of the Schelde basin. The evolution of the salinity for the period 1993-194 is shown in Figure 4. Obviously, salinity is higher in the more downstream situated locations. A clear seasonal pattern is observed at all locations with high salinities in summer and lower salinities in winter and spring. These variations are much more pronounced in the mesohaline locations and diminish towards the mouth of the estuary. From December 1993 until February-March 1994, extremely low salinities were observed due to a very high river runoff in that period. Especially in the, under normal conditions called mesohaline zone, salinities dropped very low. At 'Schaar Oude Doel', salinities dropped in that period to 0.5-2.5 ‰, turning the conditions to almost freshwater. At 'Lamswaarde' and 'Zuidergat' salinity dropped from respectively 17 and 20 ‰ in December 1993 to 2.5 and 4 ‰ in January 1994. This drop in salinity is to a lesser extent also observed in 'Terneuzen' and 'Vlissingen'.

Normal mean summer salinities amount at GBR and GBL ± 10 ‰, at Valkenisse 15-17 ‰, at Baalhoek 17-20 ‰, and at Paulina ± 25 ‰.



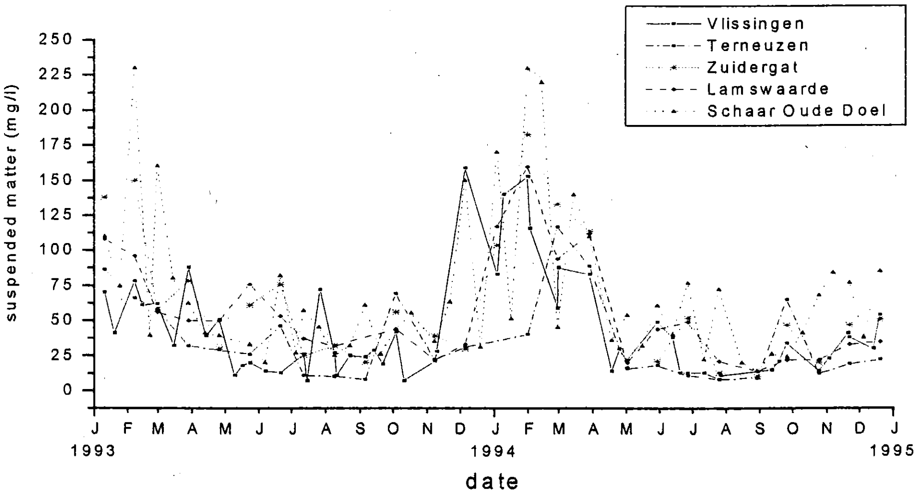
Oxygen concentration

The oxygen concentration, both in the water column as in the sediment, will determine in an important way the functioning of the estuary. Because of the high loadings of oxygen demanding waste water (industrial, agricultural, domestic) coming into the Schelde estuary, oxygen concentrations can drop severely in certain regions and at certain times (e.g. summer). The evolution of the dissolved oxygen for the period 1993-194 is shown in Figure 5. In general, higher dissolved oxygen concentrations are observed during winter, whereas in summer oxygen concentrations decreases. Concentrations are significantly lower at 'Schaar Oude Doel' and show the highest seasonal variation. In winter concentrations are > 5 mg/l, whereas in late spring and during most of the summer period concentrations drop below 5 mg/l. At certain moments concentrations of no more than 1 mg/l are observed. Five mg/l has been set as a minimum concentration for basic water quality.



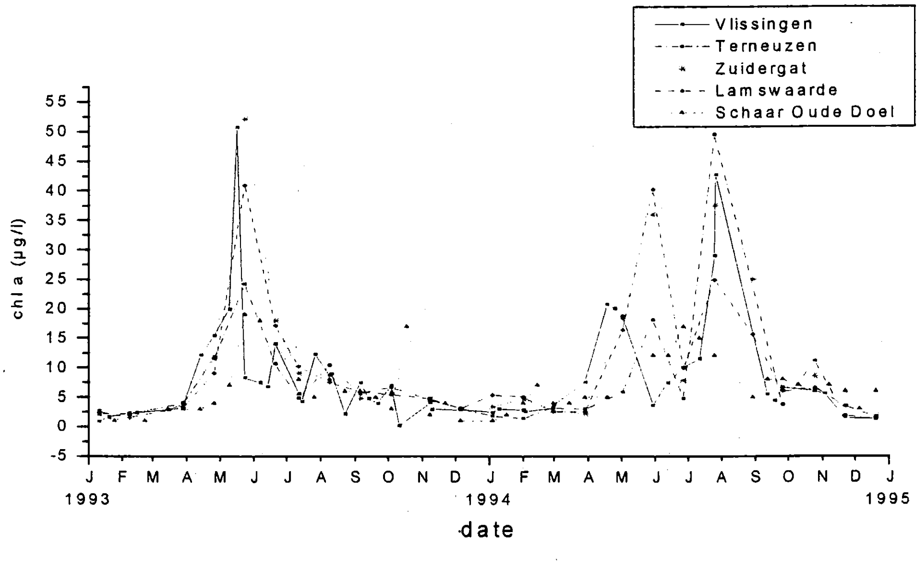
Suspended matter

Suspended matter in the water column is of great importance for several biological processes (e.g. food for suspension feeders) and also for physico-chemical processes (e.g. sorption of contaminants). The evolution of the suspended matter for the period 1993-1994 is shown in Figure 6. Relatively high month to month variations are observed, masking clear seasonal patterns or differences between locations. Slightly higher values are observed for 'Schaar Oude Doel'. During the high freshwater runoff in December 1993 - March 1994 (see salinity) increased suspended matter concentrations are observed.



Chlorophyl a

The chlorophyll a concentration is a measure of phytoplankton production. The evolution of the *chl a* concentration for the period 1993-194 is shown in Figure 7. Typically, *chl a* is observed in distinct and short peaks, coinciding with phytoplantkton production. One peak was observed in 1993 (May), whereas in 1994 two peaks were observed at all locations (except 'Schaar Oude Doel' one peak): a first peak in April (Vlissingen)-May (other locations) and a second peak in July-August. In general, concentrations are higher in the polyaline zone as compared to the mesohaline zone.



3.2. Sediment characteristics

Figures 8 and 9 shows for each location the seasonal variation in median grain size and the fraction < 63 µm respectively. In general, the following rank order can be made, with from finest to more coarse sediments: GBR > Boereschans > Baalhoek > Paulina > Paulina > GBL > Valkenisse. Especially GBL and Valkenisse are characterized by relatively coarser sediments.

Variations from month to month are relatively high, but no clear seasonal patterns are observed at most locations. However, their is a tendency to a decrease in mudcontent (and an increase in median grain size) in winter and spring period of 1994, coinciding with the high water runoff in that period (see above).

Finer sediments are observed at Valkenisse during summer (August-September). A similar phenomenon is observed at Ballooi (Figures 8-9).

Water content of the sediment was highest at locations characterized by muddy sediments. The highest water content was found at Ballooi and GBR (17-33 %), followed by Baalhoek, Boereschans and Paulina (13-24%). The water content of GBL (8.4-15.4 %) and Valkenisse (8.9-15.4 %) were very low (Table).

TOC values are highest at GBR, varying in most months between 30000-40000 mgC/dm (dm=dry matter). Second highest TOC values are found in Ballooi with values above 30000 mgC/dm. At Boereschans TOC values vary between 10000-20000 mgC/dm. Paulina and Baalhoek has TOC values similar to Boereschans (7500-20000 mgC/dm). Lowest TOC values are observed at GBL (3500-10000 mgC/dm) and at Valkenisse (< 3000 mgC/dm).

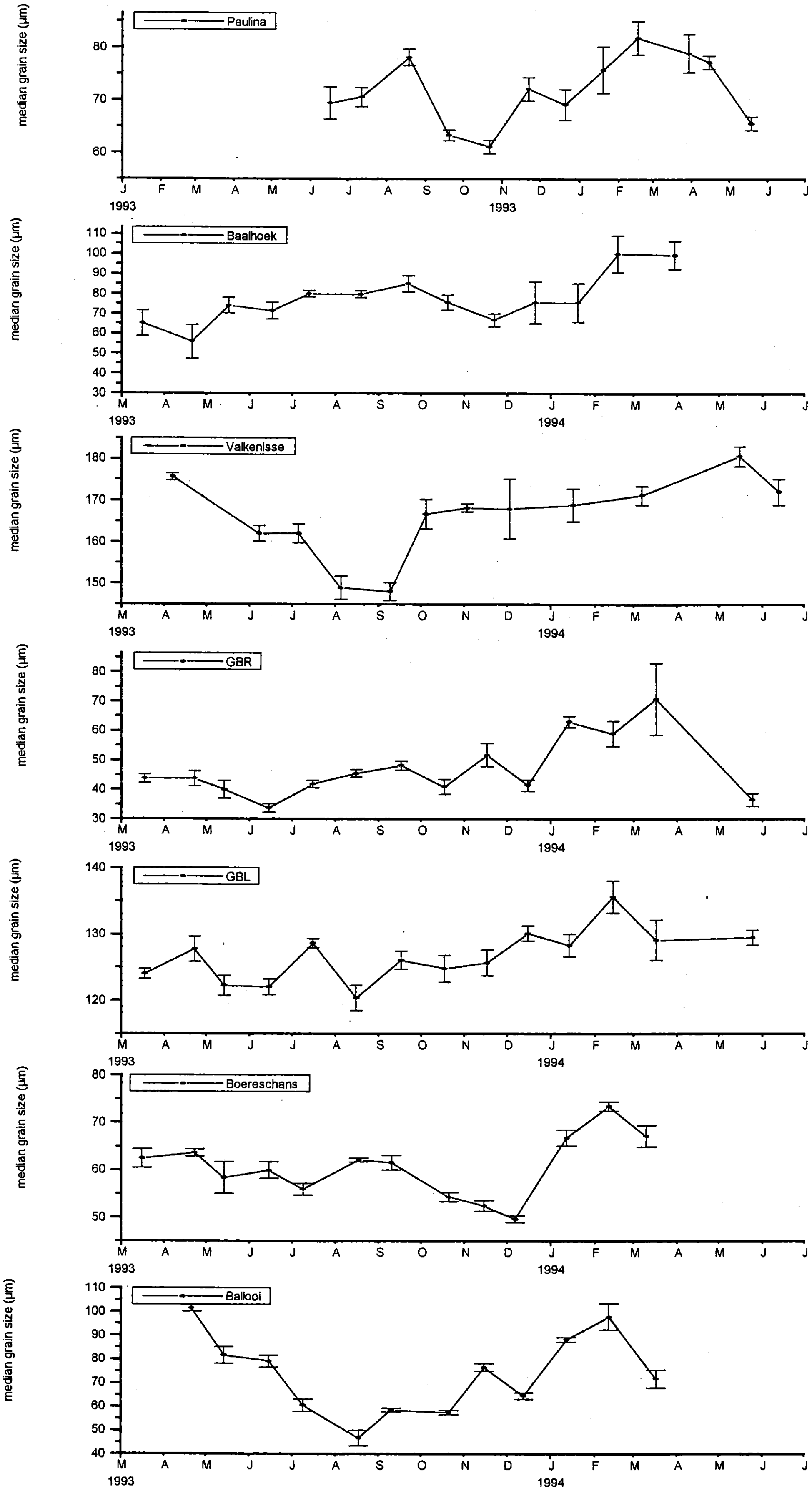


Figure 8. Seasonal variation in median grain size at all locations.

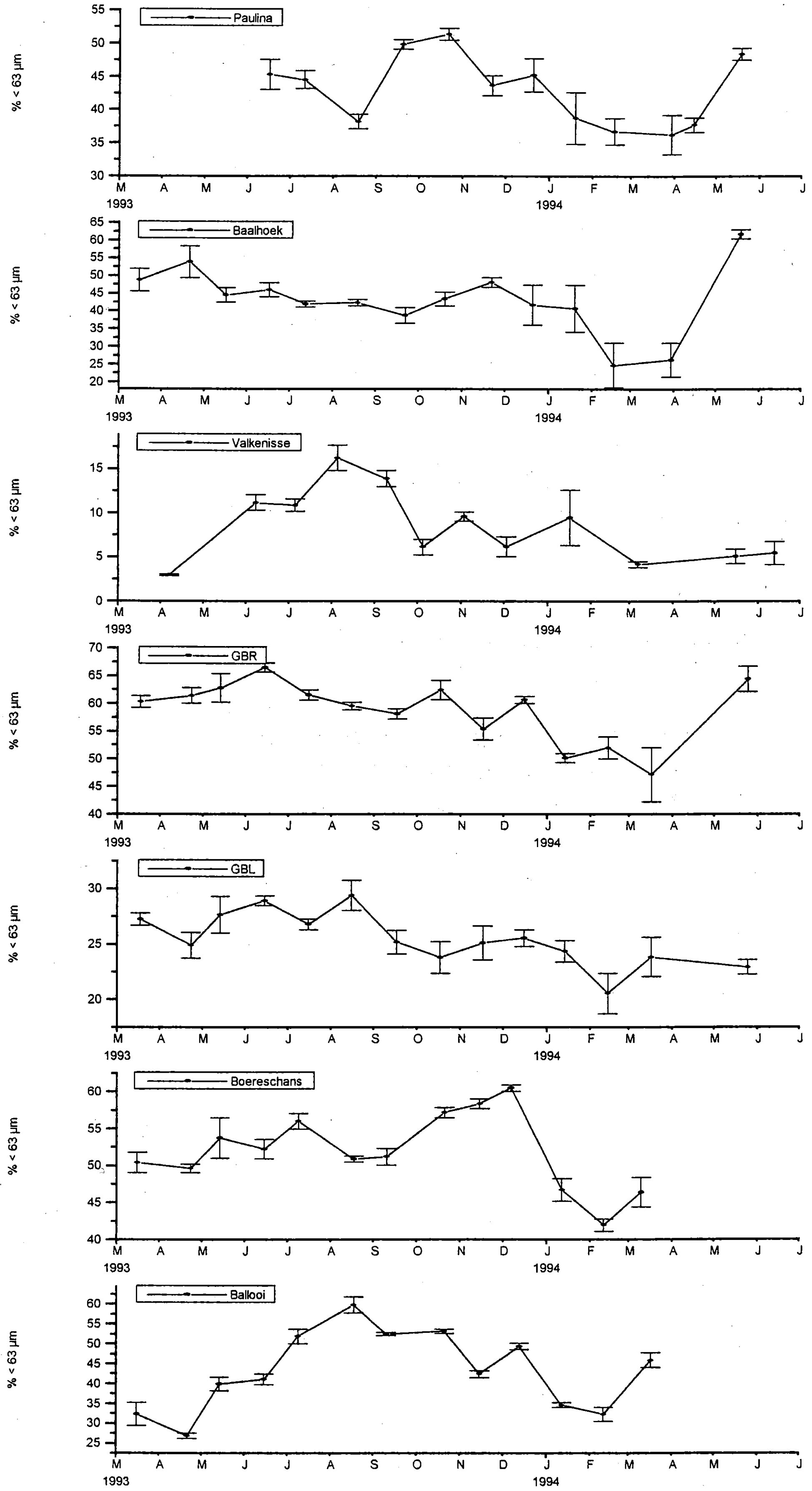


Figure 9. Seasonal variation in mud content (% < 63 µm) at all locations.

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Bioavailability of sediment-associated metals to macrobenthic communities in the Schelde estuary: a conceptual framework

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Introduction

In this chapter the framework and outline of the research concerning the metal chemistry is reported. Scientific backgrounds and aims of the study are dealt with. Results and discussion are presented in the dissertation of Vithet Srinetr. This dissertation* was completed in March 1997.

*Shrinetr, V. 1997. Metal bioavailability to macrobenthic species of the Western Scheldt : adverse effect, source and exposure. Phd. Thesis, Vrije Universiteit Brussel.

1. Definitions of Bioavailability

Bioavailability is a relatively new term which was introduced by many branches of environmental studies: chemistry, toxicology, ecotoxicology, pharmacokinetics, thermodynamics. This term was first proposed at a National Science Foundation Workshop on Ecosystem Processes and Organic Contaminants, held at Washington D.C. in 1975. It was defined as "the extent to which a toxic contaminant is available for biologically mediated transformations and/or biological actions in an aquatic environment" (Dickson et al, 1994). Later, different disciplines defined this term varying on their own perspectives. Therefore, bioavailability can be defined in many ways; in relative or absolute terms, and in either chemical or biological terms. It is always operationally-defined. Some definitions of bioavailability (regarding sediment-associated contaminants) are as follows;

- The fraction of total contaminants in the interstitial water and on the sediment particles that is available for bioaccumulation (Landrum and Robbins, 1990).
- The total concentration of a sediment-released toxicant to which aquatic organisms are exposed (Anderson et al, 1987).
- The external availability of a chemical to an organism (Schrap, 1991).
- The portion of dissolved, biologically-, or sediment-associated chemical constituents that are readily accessible to biota either through physical contact or by ingestion (Horowitz, 1991).
- The degree to which a contaminant in a potential source is free for uptake ;movement into or onto an organism (Newman and Jagoe, 1994).
- A contaminant in a biological available state when it is taken up by the organism and can react with its metabolic machinery (Campbell et al, 1988 cited in Newman and Jagoe, 1994).

There is no single definition for all conditions and perspectives. The variety of definitions of bioavailability implies that there are many approaches which are used to understand this operationally-defined term; from kinetical, chemical, to biological aspects. In fact, these different approaches of bioavailability studies have increased and broadened our understanding more and more. A main theme of this research is to demonstrate a collaborate work between environmental chemists and biologists. The idea is "Chemist should understand more in biology and biologist should understand more in chemistry" . Therefore, bioavailability is defined from both a chemical and a biological perspective. The concept idea of bioavailability study here is to try to understand it from two points of view; biology and geochemistry simaltaneously.

In summary, the term "Bioavailability in a sediment environment" in this thesis is defined as:

"The portion of metals in both sediment and porewater, which is exposed to macrobenthos and to which the macrobenthos responses at different levels of biological organization (species, population and community level)".

A better understanding of bioavailability of contaminants needs a multidisciplinary approach. For example, how can we understand why cadmium is potentially more bioavailable in oxic conditions than in anoxic conditions if we do not understand underlying geochemical processes. How can we understand why a bivalve species take up more metals than a polychaete species if we do not understand the life history of the animals. In this study, biological and chemical studies will support each other to explain metal bioavailabilty.

2. Importance of bioavailability

Pollution studies aim at assessing contaminant effects to human and ecosystems in general. Recently, the term bioavailability becomes more and more mentioned and its importance has been confirmed. In the past, bulk measures of contaminants often were limiting to point out their effects to biota. In many cases, although sediments contained high concentrations of contaminants, they didn't necesarily lead to adverse effects to biota. It has been accepted and recognized that only a portion of contaminants will react with biota. A total measure of contaminants in the surrounding environment (e.g. sediment, water) is not sufficient to define the contaminant concentration to which organisms are exposed.

Environmental quality criteria, e.g. sediment quality criteria, for regulatory purposes need to consider the bioavailable fraction of contaminants, otherwise they will over- or underestimate the *in-situ* impact of contaminants to organisms, populations, or whole ecosystems. Understanding bioavailability will help us to better protect our ecosystem. In fact, by understanding bioavailability better we will be closer to what is really happening in nature: how biota encounter and cope with the contaminated environment.

3. Objectives

1. General Objectives

1.1 To better define "Bioavailability of sediment-associated metal to macrobenthic species" in the study area, the Schelde estuary.

1.2 To assess possible metal contaminant adverse effects on the benthic environment of the Schelde Estuary at a species, population and community level.

2. Specific Objectives

A set of questions below aims to support estuarine managers for further decision on estuarine management.

2.1 Do metals contaminate in benthic communities of the Schelde estuary ?

2.2 If so, to what extent do metals contaminate in different macrobenthic key species ?

2.3 Which are metal exposure routes and sources to macrobenthic species ?

2.4 What is the most appropriate method to understand and predict metal distribution in macrobenthic species: sediment, porewater or biota monitoring?

2.5 What are the key factors and processes which influence on the metal bioavailability in the benthic environment: physical, chemical or biological factors ?

4. Conceptual framework with the outline of thesis

This research focuses on the metal bioavailability in the benthic environment of the Schelde estuary. Bioavailability of sediment-associated contaminants is complex because the sediment bed is a heterogeneous mixture of numereous phases. Also benthic organisms range from microbes to macrobenthos. At the onset, the system is conceptualized as the most simple case. The hypothesis is "**Metals are partitioned among three compartments of the benthic environment: sediment, porewater and biota**". The conceptual framework of the research is shown in Figure 1.

The biotic compartment will be presented in Part A. Part A devotes to possible adverse metal effects to macrobenthos. Part B presents results on the abiotic compartments sediment and porewater, which are the metal exposure and route to the macrobenthos. The simple conceptual model of Figure 1 will be gradually filled in by knowledge we gained from in-depth studies of each compartment. Processes and patterns involved in modifying the conceptual model will be illustrated and revealed by each chapter.

Following chapters are included in the dissertation :

Material and Methods

The study include three main compartments: biota, porewater and sediment. Seven macrobenthic species and nine metal elements were studied in seven intertidal flats over monthly sampling periods from 1993 through 1995. The thesis is structured as a step-to-step study from one compartment to another. Several following chapters shared in material, methods and data analysis. This chapter aims to give a clear overview of sampling scheme, sampling frequency, animal description, site description, methodology for sampling and chemical analysis, data analysis, statistical application, quality insurance analysis.

Metal Effects at an organism level

Species level is the lowest biological organisation considered in this study. If metals have an adverse effect on biota, they will firstly manifest at a species level by bioaccumulation.. Each species will response to metals to a different extent. Several macrobenthic species of the Schelde estuary are chosen for this study, each representing a different life style, feeding type, habitat preference and distribution. Metals are quantified by metal body burdens in seven macrobenthic species: the polychaete *Nereis diversicolor*, the amphipod *Corophium volutator*, the four bivalves *Macoma balthica*, *Scrobicularia plana*, *Cerastodema edule*, and *Mya arenaria* and oligochaetes. Spatial and temporal variations in metal tissue concentrations are quantified. An average and range of tissue concentrations are compared with previous studies conducted in the Schelde estuary and with other geographical regions. Tissue concentrations are also compared with numerical quality guidelines in order to preliminary assess how far metal effects extend at an organism level.

In fact, this chapter is a first essential step to assess the situation of metal contamination in macrobenthic species of the Schelde estuary. It will answer and clearify some basic questions; for example whether metals contaminate in macrobenthic species, and to what extend metal bioaccumulation exists by using tissue metal concentrations as a criteria. If bioaccumulation occurs at a species level, the question rise if these metals have also an adverse effect at the population level (of that species).

Metal effects at a population level

The bioindicator concept is accepted worldwide as an effective tool to assess metal contamination. However, large spatial and temporal variations in metal concentrations are often observed, making sound conclusions very difficult. In this chapter biological factors are investigated which can influence the observed metal tissue concentration: body size, growth, age, sex and maturity. Among individuals in a population, those biological factors will vary over space (locations) and time (sampling months). We use these factors to find out whether metal effects extend to a population level (of each species).

Multispecies biomonitoring is a very labor-extensive work. The study design included several species for two main reasons. Firstly, we expect that each species will reflect a different behaviour to metal bioavailability due to their different bioaccumulation strategies and metal responses. Secondly, we aim to investigate a possible ultimate metal effect at the community level. Do metal effects give rise to benthic community change ?

Metal Effects at a community level

If metal effects at a population level occur, metal sensitive species will disappear from that community and opportunistic species will invade. Consequently, species composition, species richness, species biomass will change to a less healthy condition. This chapter tries to compare metal tissue concentrations with some community structure indices across habitats of the Schelde estuary. The difficultly to assess metal effects at a community level will be pointed out.

Through the previous chapters the biotic compartment (macrobenthos) is emphasized (see Figure 1). Metal bioavailability is investigated by applying a multispecies bioindicator concept and benthic ecology studies. The advantages and disadvantages of using biota are indicated. Pattern of metal tissue concentrations are revealed. A significance of biological factors in metal bioavailability is pointed out. Possible metal effects through different levels of biological organization will be demonstrated. But, how do the surrounding environments, sediment and porewater, contribute to this uptake of metals by benthic species ?

Porewater as an exposure and source of metals

Porewater geochemistry is emphasized and introduced as an important uptake route for metal pollution assessment in the benthic environment. Spatial and temporal variations of porewater concentration are studied by sediment depth profiles and fluxes in/out of the surface sediment. Environmental factors which influence on porewater concentrations are identified. This is a pioneer extensive work based on field observation, not a laboratory experiment, which try to identify a relationship between metal tissue and porewater concentrations /porewater fluxes across several macrobenthic species and several elements in function of time. The results are a further step to link benthic ecology and geochemistry study for metal pollution assessment.

Sediment analysis to assess metal bioavailability is questionable. Sediment is, however, a food source and habitat for macrobenthic species. In fact, the dynamic distribution of metals among the three compartments biota, porewater and sediment brings the need to complete and add sediment analysis in this study. Also, a new methodology to use sediment analysis is introduced.

Sediment as an exposure and source of metals

Spatial and temporal metal concentrations in sediment solid phase are quantified together with those in macrobenthos and porewater. Partitioning and distribution of metals among these three compartments will be further assessed. This chapter tries to point out the relative importance between sediment and porewater in metal bioaccumulation by several macrobenthic species. Some key factors which influence the spatial and temporal variation and further bioavaialbility of sediment metal concentrations are identified.

Concluding Remarks

The main findings of the thesis are summarized. The conceptual model which is set up in chapter 1 is refined. The strength and weakness of the whole approach will be evaluated and a new monitoring plan will be presented.

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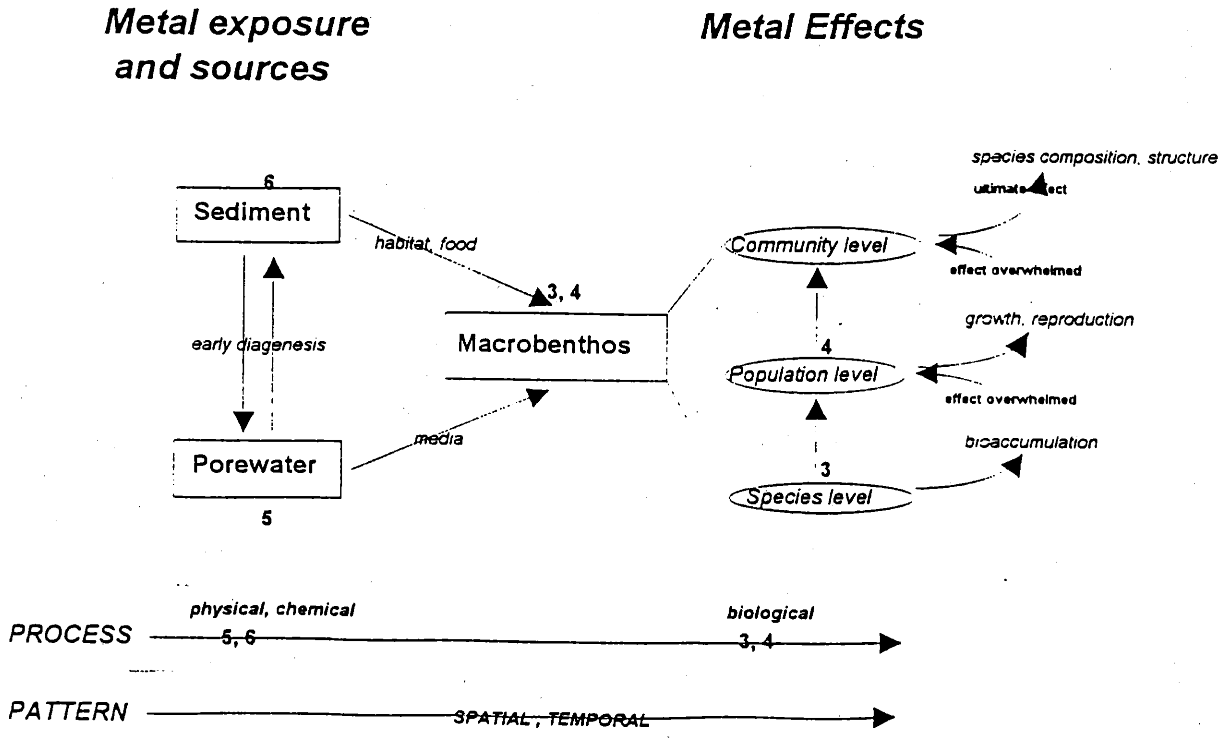

Figure 1 : A conceptual framework of the thesis. Numbers indicate chapter for that compartment or process.

Spatial and temporal variation of Acid Volatile Sulfide (AVS) and Simultaneous Extracted Metals (SEM) in intertidal sediments of the Schelde estuary

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1. Introduction

1.1 General

The bioavailability and/or toxicity of many nonionic organic chemicals and metals in sediments are correlated with interstitial (pore)water concentrations of the chemicals (equilibrium partitioning concept). For organic micropollutants it has been demonstrated through both toxicological and bioaccumulation studies that organic carbon is the primary factor that influences the partitioning of these chemicals (Di Toro et al., 1991). Recently, Acid-Volatile Sulfide (AVS) was proposed as important in regulating the partitioning of metals in anoxic sediments (Di Toro et al., 1990, 1992). It shows promise as a tool for predicting the potential for metal toxicity to sediment-dwelling organisms. Nowadays, despite a lot of criticism, this approach is proposed as the normalizing factor in sediment quality criteria.

Within the framework of the Impuls Programme Marine Sciences (1993-1996) the Institute of Nature Conservation conducted a field-orientated study on macrobenthic populations in the Schelde estuary with emphasis on the role of the abiotic environment (natural and human) in structuring the benthic communities. One of the main research topics within this study was the investigation on metal chemistry in the Schelde estuary, which was performed by the Laboratory for Analytical Chemistry (Free University of Brussel). The aim was to conduct a field research on the temporal and spatial variation in metal concentrations in the three different compartments within the equilibrium partitioning model: pore water, sediment and biota (macrobenthos). In the sediment itself, only bulk concentrations were measured. In cooperation with VITO, an important addition to the study of the bioavailability of metals was achieved with the analysis of Acid Volatile Sulfide (AVS) and Simultaneously Extracted Metals (SEM). It will give more understanding on the metal distribution in the sediment solid phase and it will provide important baseline data on sulfur geochemistry for metal pollution studies in the Schelde estuary.

This report only gives the results on the AVS/SEM analysis, and do not relate to other parts of the whole research (pore water chemistry, benthos, ...). This will be reported elsewhere.

1.2. The AVS/SEM - principle

The toxicity of a contaminated sediment depends on the extent to which chemicals are bound in the sediment. The available chemical fraction, not the total chemical fraction, will determine sediment's toxicity to benthic organisms. Because bioavailability of many nonionic organic chemicals and metals is correlated to their concentration in the interstitial (pore)water, the controlling factors in sediment toxicity are those that influence the distribution of a chemical between the solid phase and the interstitial water.

In an oxic environment Fe-oxides and Mn-oxides form an important binding place for metals. However, it has been suggested that the subsurface anoxic region is the main reservoir for metals once within the sediment. Of the many sediment components that influence metal behavior, the primary controller of many trace metals in anoxic sediments may be sulfide present in the form of mainly FeS. These iron sulfides are formed by the reaction between hydrogen sulfide (H_2S) and ferrous iron. H_2S is produced primarily by the oxidation of organic matter by sulfate-reducing bacteria (Morse & Cornwell, 1987). Ferrous iron is generated by the reduction of iron oxides.

Sulfides in sediment play an important role in the metal binding capacity of that sediment. The chemical base is that, at equilibrium, the sulfide ion successfully competes with any other commonly present either dissolved or particle-associated ligand to form insoluble metal sulfides which are removed from the interstitial water by precipitation (see inset), presumably rendering them unavailable to sediment-dwelling organisms. In other words, the bioavailability of metals in sediments may be controlled by formation of insoluble metal sulfide solids, because porewater in equilibrium with these sulfide phases will contain extremely low concentrations of free metal ions.

Measurements of sulfide and metals released by weak acid extraction, termed acid volatile sulfide (AVS) and simultaneous extracted metals (SEM), have been used to estimate the relative abundance of amorphous sulfides and metals in sediments. The AVS originates primarily from soluble sulfides and iron monosulfides (Morse et al., 1987).

The AVS-concept is based on the formation of poorly soluble metal sulfides. In an anoxic environment Fe^{2+} and HS^- form iron monosulfides:

$$Fe^{2+} + HS^- \rightarrow FeS + H^+ \quad (\log K \approx 3)$$

In the presence of the divalent metals Ni^{2+}, Zn^{2+}, Pb^{2+}, Cd^{2+}, and Cu^{2+} (in decreasing order of metalsulfide solubility) more insoluble metal sulfides (MeS) than iron monosulfides are formed:

$$Me^{2+} + HS^- \rightarrow MeS + H^+ \quad (\log K > 3)$$

These metal ions will replace the iron ion in the iron sulfides:

$$Me^{2+} + FeS \rightarrow MeS + Fe^{2+}$$

At equilibrium, the divalent metal (Me^{2+}) displaces the iron in FeS to form the insoluble metal sulfide (MeS) and soluble ferrous iron Fe^{2+}.

The molar ratio of the sum of concentrations of Cd, Cu, Pb, Ni and Zn in SEM extracts to AVS (SEM:AVS ratio) has been proposed as a predictor of metal bioavailability (Di Toro et al., 1990, 1992). On a molar basis, if SEM is less than AVS, all of the metal should be precipitated as metal sulfide and no metal should be dedected in the pore water. At molar metal/AVS ratios greater than 1.0, excess metal may be released to the interstitial water where it may be potentially bioavailable or it may be bound again in the presence of other binding compounds, like for instance organic matter. Toxic metals that are expected to fit this model (in decreasing order of metal-sulfide solubility) include: Ni - Zn - Cd - Pb - Cu - Hg (Di Toro et al., 1990; Casas & Crecelius, 1994).

1.3. The SEM/AVS ratio and toxic effects

To date, the role of AVS in regulating the acute toxicity of metals in marine sediments has mainly been investigated in laboratory spiking experiments with cadmium, nickel, zinc, and copper, as well as mixtures of these metals (Casas & Crecelius, 1994; Di Toro et al., 1990, 1992; Pesch, 1995). Comparable experiments utilizing freshwater sediments have been conducted (Ankely et al., 1991; 1993; Carlson et al., 1991). In most studies AVS and SEM/AVS ratio proved useful as predictors of toxicity. In most cases, mortalities occurred as predicted. However, there are still some constraints to this approach and it cannot be generalized to all sediment environments (e.g. Ankley et al., 1993; Hare et al., 1994). The formation and stability of sulfides in sediments are affected by many biotic and abiotic factors (e.g. sulfate concentrations, loadings of labile organic matter, redox conditions, temperature,...). Interactions of these factors can produce substantial spatio-temporal variation in AVS concentrations (Besser et al., 1996; Brumbaugh et al., 1994; Leonard et al., 1993).

2. Material and Methods

2.1. Sediment sampling

Seven intertidal locations, situated along a salinity gradient of the Schelde estuary were investigated between March 1993 and May/June 1994 (Table 1, Figure 1). On a regular interval samples were taken for macrobenthos analysis (monthly), metal analysis in pore water, sediment and biota ((bi)monthly), and organic micropollutant analysis in sediment and biota (4x). Sediment samples for AVS and SEM determination were taken on the same time as pore water samples: July, September and November 1993 and January, March and May 1994. After collecting the sediment samples from the field, the samples were immediately frozen.

Table 1. Names and codes of the sampling locations. Distance (from the mouth of the estuary) and estuarine division is given.

Location	**Code**	**Distance (km)**	**Estuarine division**
Paulina	PAU	15	polyhaline zone
Baalhoek	BH	40	poly/mesohaline transit
Valkenisse	VAL	43	poly/mesohaline transit
Groot Buitenschoor R	GBR	60	mesohaline zone
Groot Buitenschoor L	GBL	60	mesohaline zone
Boereschans	BOE	81	oligohaline zone
Ballooi	BAL	100	freshwater tidal zone

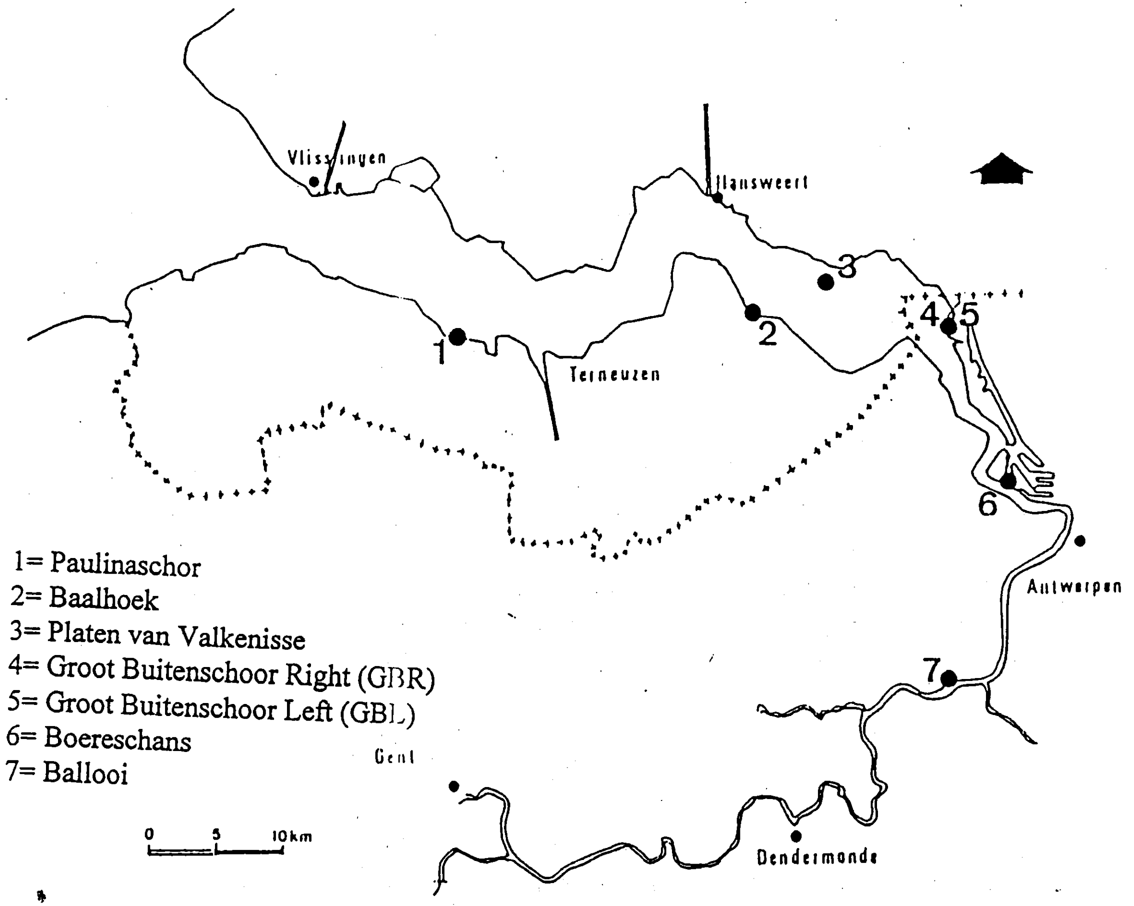

Figure 1. The Schelde estuary with the seven study sites situated along the whole salinity gradient of the estuary.

2.2. Chemical analyses

The methods used at VITO (VITO, 1995) to determine SEM/AVS is based on the method described by EPA (Environmental Protection Agency) (Allen et al., 1991, 1993) and RIVM (den Hollander, 1994). The method set up by VITO was subjected to an analytical validation and is reproducable, operational and can be used routineously.

Acid volatile sulfide was extracted from the sediment sample by ..-min extractions with cold hydrochloric acid (1N HCl). The H_2S-gas formed is then removed from the suspension under nitrogen atmosphere and trapped in a NaOH-solution to form NA_2S. The sulfide S^{2-} is then spectrofotometrical determined.

For the determination of SEM (Pb^{2+}, Cd^{2+}, Mn^{2+}, Fe^{2+}, Cu^{2+}, Hg^{2+}) the suspension is centrifugated after removal of the sulfides. Metals are then determined in the acid supernatans by ICP-AES analysis (Inductive Coupled Plasma - Atomic Emmision Spectrometry).

For more details see VITO (1995).

3. Results

3.1. Spatio-temporal variation in SEM and AVS concentrations

Table 2 gives the simultaneously extracted metals (mmol/kg dry), AVS, SEM (sum of Ni, Zn, Pb, Cd, Cu and Hg) and ratio SEM/AVS in sediment samples of seven intertidal locations along the Schelde estuary.

Acid Volatile Sulfide vary considerably between sites. AVS is highest at the mesohaline location GBR (max. 31.5 µmol/g), followed by the oligohaline site Boereschans and the freshwater tidal site Ballooi (maw. 11.5 µmol/g) (Table 2 and Figure 2). At the polyhaline sites Paulina and Baalhoek maximum AVS values of 2-3 µmol/g are observed. At Valkenisse and GBL AVS was not dedectable (Table 2 and Figure 2). The within-site variation of AVS appeared to be very high, almost as high as the between-site variation. The seasonal pattern observed is similar for most locations. Highest AVS concentrations were observed in July 1993 (September 1993 for Boereschans), after which a decrease is observed in AVS concentration. At all locations lowest concentrations were observed in January 1994. In March and May 1994 again an increase is observed (Table 2 and Figure 2).

The sum of the six Simultaneously Extracted Metal concentrations (Ni, Zn, Pb, Cd, Cu and Hg) differ between sites, but the variation is less as compared to AVS. Lowest SEM concentrations are measured in the sandy locations Valkenisse (0.2-0.4 µmol/g) and GBL (0.8-1.1 µmol/g) (Table 2 and Figure 2). Slightly higher values were found in the polyhaline locations Paulina (0.7-3.0 µmol/g) and Baalhoek (1.1-2.0 µmol/g). Highest concentrations were observed at Boereschans (2.6-4.9 µmol/g), Ballooi (3.8-6.2 µmol/g) and GBR (3.4-7.2 µmol/g). The within-site variation is relatively low, indicating no clear seasonal patterns (Table 2 and Figure 2). At most locations the variation is less than 2x, except at Paulina where a 5x variation was observed with highest values in winter.

At all locations SEM-Zn has by far the greatest share in total SEM concentrations (> 75 %). In the poly/mesohaline locations Paulina, Baalhoek, and Valkenisse SEM-Pb concentration is the second highest with a share of 7-15 %, followed than by SEM-Cu and SEM-Ni. In the meso-oligohaline and freshwater tidal locations SEM-Cu and SEM-Pb concentrations take an equal proportion of ± 7-12 %. At all locations the share of SEM-Cd and SEM-Hg in total SEM concentrations is very low and takes less than one percent of the total SEM concentration.

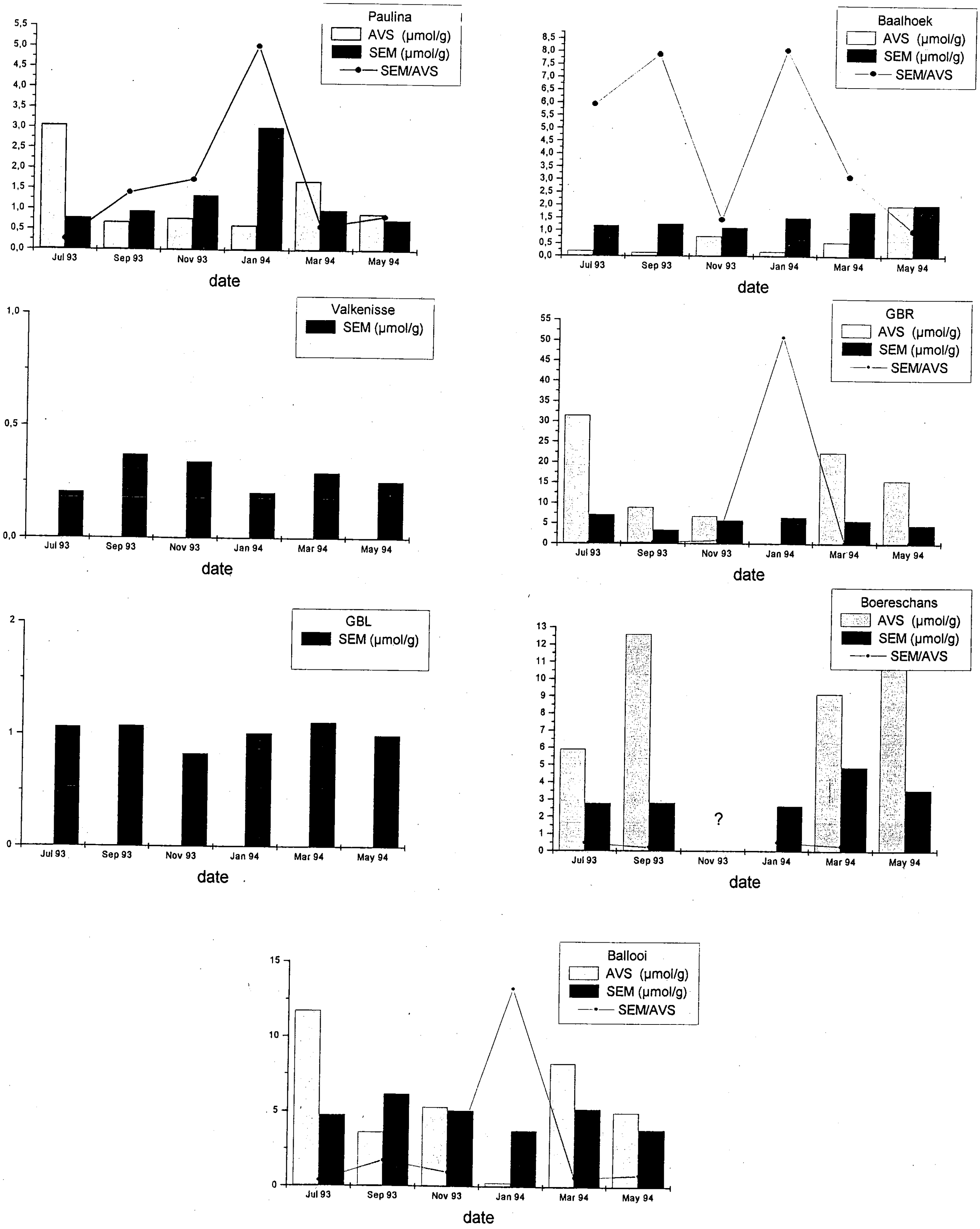

Figure 2. Seasonal AVS, SEM and SEM/AVS ratio variations in seven intertidal locations along the Schelde estuary

3.2. Spatio-temporal variation in SEM/AVS ratio

Because of the relatively high variation in AVS concentrations within and between sites, the SEM/AVS ratios observed vary between 0.2 and 50. At most locations the SEM/AVS ratio is < 1 during most part of the year. This is clearly shown at GBR, where only in January 1994 the SEM/AVS ratio is exceded 50 times (Figure 2). The very high value in January is totally due to a steep decrease in AVS concentration, whereas SEM concentration didn't change. The same pattern of a steep decrease in AVS concentration in January 1994, coupled with an increase in SEM/AVS ratio was observed at Ballooi, Boereschans and Paulina.

Baalhoek is the only location where the SEM/AVS ratio is > 1 the whole year round, but also here highest value is observed in January.

Other studies have also demonstrated that AVS concentrations in aquatic sediments show a seasonally determined variation. An important part of AVS is formed by sulfate reducing bacteria. In summer, due to increased production of organic matter and increased activity of sulfate-reducing bacteria (Herlihy & Mills, 1985), AVS concentration show an optimum, whereas in winter, due to a decrease in biological activity and oxidation of the sediment, the AVS concentration decreases (Howard & Evans, 193; Leonard et al., 1993) and metals can become mobilised (Zhuang, 1994).

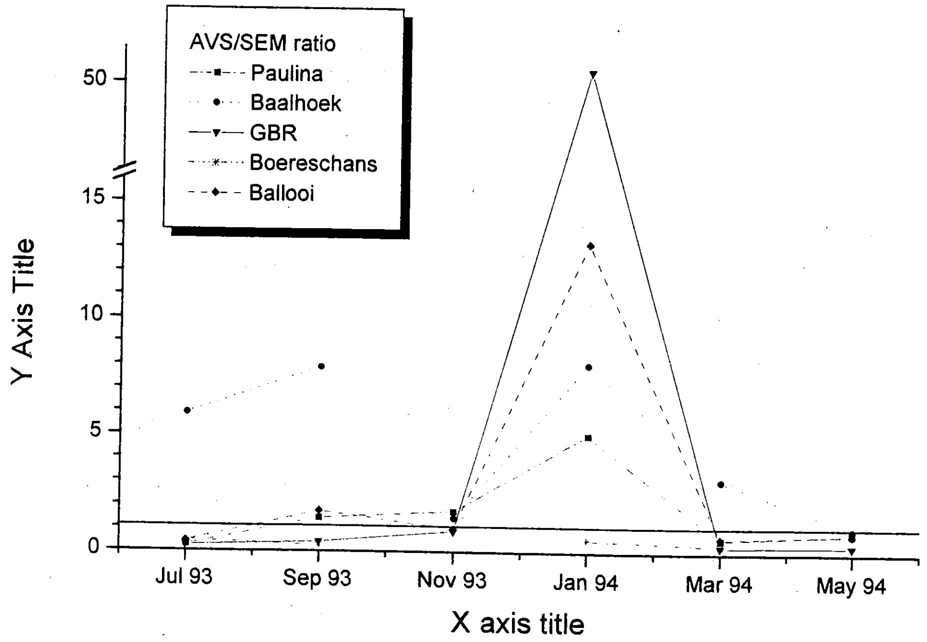

Figure 3. Seasonal variation in SEM/AVS ratio at five intertidal locations in the Schelde estuary.

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Table 2. Simultaneously extracted metals (mmol/kg dry), AVS, SEM (sum of Ni, Zn, Pb, Cd, Cu and Hg) and ratio SEM/AVS in sediment samples of seven intertidal locations along the Schelde estuary.

Location	*Date*	*Cr*	*Fe*	*Mn*	*Ni*	*Zn*	*Pb*	*Cd*	*Cu*	*Hg*	*AVS*	*SEM*	*SEM/AVS*
PAU	930712	0,061	48,823	2,504	0,031	0,589	0,088	0,001	0,062	0,002	3,049	0,773	0,255
	930920	0,072	65,192	2,970	0,034	0,717	0,103	0,001	0,087	0	0,673	0,943	1,405
	931122	0,052	43,834	2,035	0,041	1,141	0,09	0	0,062	0,001	0,773	1,336	1,734
	940120	0,08	56,052	2,370	0,038	2,799	0,099	0	0,087	0,002	0,608	3,025	5,021
	940330	0,085	55,549	2,900	0,037	0,781	0,088	0,001	0,082	0	1,700	0,990	0,583
	940519	0,091	50,913	2,562	0,033	0,567	0,079	0	0,07	0,001	0,897	0,749	0,843

Location	*Date*	*Cr*	*Fe*	*Mn*	*Ni*	*Zn*	*Pb*	*Cd*	*Cu*	*Hg*	*AVS*	*SEM*	*SEM/AVS*
BAA	930713	0,117	70,850	2,920	0,033	0,930	0,097	0,012	0,123	0,002	0,202	1,197	5,923
	930922	0,129	71,370	3,086	0,032	0,941	0,142	0,008	0,135	0,002	0,163	1,260	7,871
	931119	0,101	55,100	1,880	0,045	0,798	0,153	0,01	0,114	0,001	0,787	1,120	1,426
	940120	0,129	51,630	1,893	0,039	0,730	0,626	0,007	0,105	0,003	0,191	1,511	8,045
	940330	0,172	88,890	4,682	0,05	1,381	0,128	0,01	0,19	1E-04	0,567	1,759	3,106
	940519	0,197	111,200	7,555	0,058	1,597	0,169	0,012	0,196	1E-04	2,008	2,031	1,011

Location	*Date*	*Cr*	*Fe*	*Mn*	*Ni*	*Zn*	*Pb*	*Cd*	*Cu*	*Hg*	*AVS*	*SEM*	*SEM/AVS*
PVV	930706	0,024	22,848	0,786	0,008	0,143	0,034	0	0,015	0,003	<20	0,205	
	930909	0,051	31,389	1,837	0,018	0,255	0,06	0,001	0,033	0,004	<20	0,372	
	931103	0,047	27,432	1,494	0,023	0,233	0,05	0,003	0,03	0,002	<20	0,341	
	940117	<0.05	20,601	0,937	0,009	0,138	0,03	0,003	0,017	0,006	<20	0,204	
	940316	<0.05	28,974	1,657	0,017	0,207	0,035	0,001	0,032	0,002	<20	0,295	
	940516	<0.05	26,784	1,090	0,017	0,197	0,031	0,002	0,024	0,002	<20	0,256	

Table 2. ..continuation

Location	Date	Cr	Fe	Mn	Ni	Zn	Pb	Cd	Cu	Hg	AVS	SEM	SEM/AVS
GBR	930715	0,497	231,700	14,850	0,151	6,278	0,329	0,041	0,429	1E-04	31,520	7,228	0,230
	930917	0,312	185,320	7,093	0,075	2,705	0,25	0,025	0,387	0	8,942	3,442	0,385
	931117	0,491	235,840	10,835	0,143	4,537	0,403	0,06	0,671	0	6,817	5,814	0,853
	940114	0,605	204,570	8,312	0,189	5,064	0,447	0,091	0,787	0	0,130	6,577	50,798
	940317	0,616	202,420	8,799	0,11	4,761	0,416	0,09	0,431	0	22,454	5,809	0,283
	940525	0,437	230,470	11,210	0,112	3,792	0,334	0,035	0,456	0	15,670	4,728	0,302

Location	Date	Cr	Fe	Mn	Ni	Zn	Pb	Cd	Cu	Hg	AVS	SEM	SEM/AVS
GBL	930715	0,095	56,439	3,194	0,034	0,817	0,103	0,001	0,106	0,001	<20	1,063	
	930917	0,087	57,639	2,957	0,039	0,811	0,11	0,001	0,112	0,005	<20	1,077	
	931117	0,066	43,033	2,041	0,031	0,621	0,087	0	0,086	0,003	<20	0,830	
	940114	0,09	55,883	2,917	0,04	0,764	0,089	0,003	0,11	0,008	<20	1,013	
	940317	0,085	54,702	2,534	0,033	0,854	0,093	0,001	0,128	0,003	<20	1,112	
	940525	0,092	52,243	2,655	0,037	0,756	0,105	0	0,096	0,003	<20	0,997	

Location	Date	Cr	Fe	Mn	Ni	Zn	Pb	Cd	Cu	Hg	AVS	SEM	SEM/AVS
BOE	930709	0,267	134,600	5,484	0,08	2,271	0,21	0,005	0,226	0,001	5,925	2,793	0,472
	930910	0,247	143,900	6,451	0,058	2,375	0,206	0,002	0,187	0	12,615	2,829	0,225
	940112	0,198	122,890	5,155	0,083	2,075	0,207	0,017	0,279	0,002	<20	2,663	
	940310	0,354	158,980	7,084	0,099	4,200	0,259	0,027	0,334	0	9,168	4,919	0,533
	940530	0,275	179,500	5,906	0,09	2,906	0,237	0,003	0,34	0,001	11,267	3,577	0,318

Location	Date	Cr	Fe	Mn	Ni	Zn	Pb	Cd	Cu	Hg	AVS	SEM	SEM/AVS
BAL	930709	0,385	168,900	7,293	0,107	3,963	0,316	0,035	0,325	0	11,740	4,746	0,404
	930910	0,446	192,500	8,174	0,151	4,994	0,361	0,036	0,626	1E-04	3,600	6,168	1,720
	931115	0,365	165,200	6,733	0,112	4,188	0,349	0,031	0,422	1E-04	5,315	5,102	0,963
	940112	0,263	116,600	5,166	0,104	2,986	0,248	0,022	0,415	4E-04	0,285	3,774	13,263
	940317	0,384	163,100	6,866	0,095	4,382	0,31	0,028	0,437	1E-04	8,288	5,252	0,635
	940530	0,293	129,630	5,289	0,081	3,242	0,214	0,02	0,311	1E-04	5,000	3,868	0,800

Spatial and temporal variation of organic microcontaminants in intertidal sediments along the Schelde estuary

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1. Introduction

Within estuaries, the occurrence, distribution and behaviour of organic microcontaminants such as polycyclic aromatic hydrocarbons, polychlorinated biphenyls and organochlorine pesticides, received much attention (Duinker, 1986; Readman et al., 1982; Klamer & Laane, 1990; Van Zoest & Van Eck,1993) because of their often mutagene and toxic character.

In this report results are presented of organic microcontaminants in intertidal sediments along the salinity gradient of the Schelde estuary.

2. Material and Methods

2.1. Sediment sampling

Seven intertidal locations, situated along a salinity gradient of the Schelde estuary were investigated between March 1993 and May/June 1994 (Table 1, Figure 1). On a regular interval samples were taken for macrobenthos analysis (monthly), and metal analysis in pore water, sediment and biota ((bi)monthly). Sediment samples for the determination of organic contaminants were taken in following months:

- July 1993
- September 1993
- December 1993
- April 1994
- (June 1995)

After collecting the sediment samples from the field, the samples were immediately frozen.

Table 1. Names and codes of the sampling locations. Distance (from the mouth of the estuary) and estuarine division is given.

Location	**Code**	**Distance (km)**	**Estuarine division**
Paulina	PAU	15	polyhaline zone
Baalhoek	BH	40	poly/mesohaline transit
Valkenisse	VAL	43	poly/mesohaline transit
Groot Buitenschoor R	GBR	60	mesohaline zone
Groot Buitenschoor L	GBL	60	mesohaline zone
Boereschans	BOE	81	oligohaline zone
Ballooi	BAL	100	freshwater tidal zone

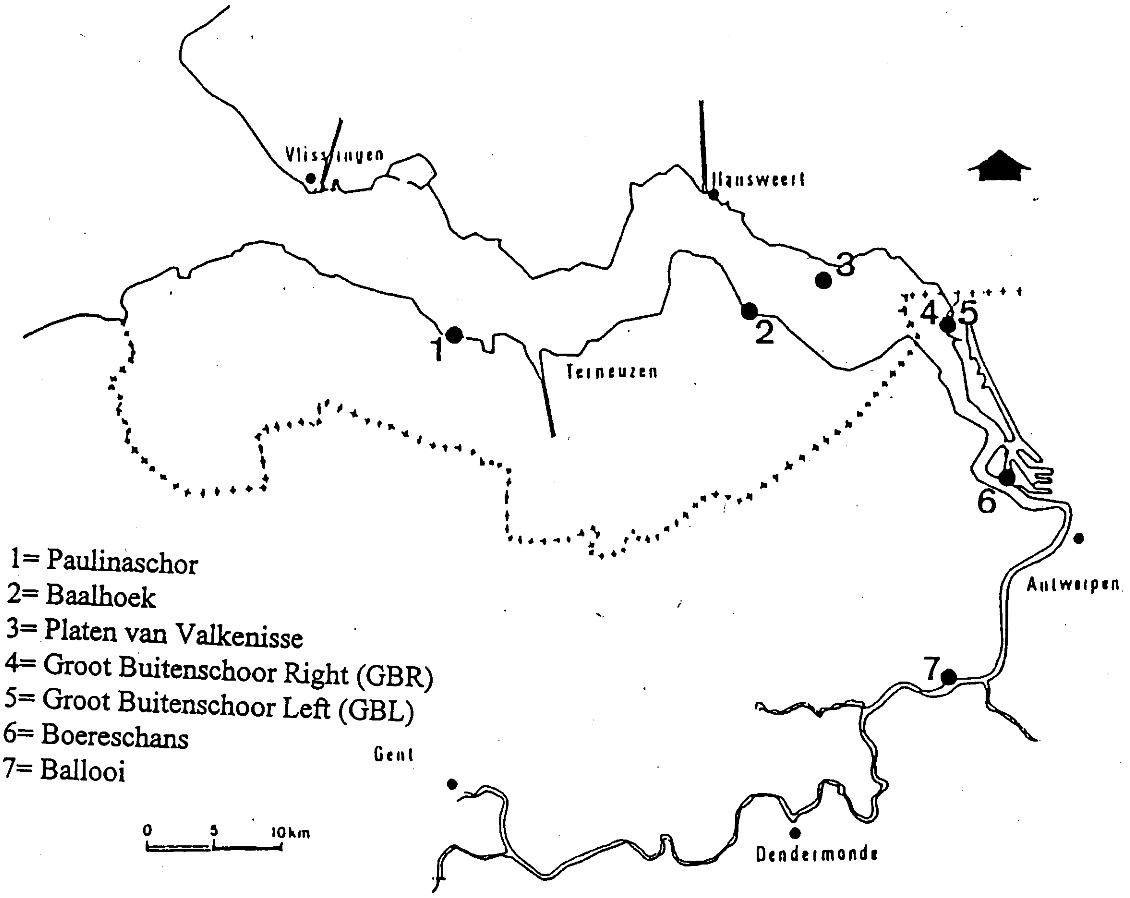


Figure 1. The Schelde estuary with the seven study sites situated along the whole salinity gradient of the estuary.

2.3. *Chemical analyses (see inset)*

Preparation of sediment for analysis of organic contaminants

Sediment samples were homogenized and freeze dried.

For organochlorine pesticides and polychlorinated biphenyls 5 g of freeze dried sediment was soxhlet-extracted with 100 ml 'petroleumether' during four hours. Extracts were in a first step with Kuderna-Danish and in a second step under mild nitrogenpressure reduced to 2 ml. Afterwards elemental sulfur was removed with TBA-sulfite. The extract was further purified with aluminium oxide, and fractioned on silica gel. In this way two fractions were obtained which were analysed seperately. As internal standards PCB29 and Mirex were added.

For polycyclid hydrocarbons 5 g of freeze dried sediment was soxhlel-extracted with 100 ml 'dichloormethaan' during four hours. The volume of the extract was reduced in a first step with Kuderna-Danish and in a second step under mild nitrogenpressure reduced to 1 ml. The extract was purified on a silica gel SPE cartridge and transformed to actonitrile. As internal standard a 6-methylchryseen was added.

Analysis of sediment for organic contaminants

Two separate subsamples were analyzed for (a) organochlorine pesticides (OCPs) and polychlorinated biphenyls (PCBs) and (b) polycyclic aromatic hydrocarbons (PAHs).

Organochlorine pesticides (OCPs) and polychlorinated biphenyls (PCBs) were performed with GC-ECD equipped with two, temperature-programmed, fused silica capillary columns (DB5/DB1701). Polycyclic aromatic hydrocarbons (PAHs) were analysed using HPLC with fluorescence- and UV-detection. Appendix 1 gives a list of the measured contaminants with their detection limit.

Setup for analysis of sediment for organic contaminants

Organochlorine pesticides (OCPs) and polychlorinated biphenyls (PCBs)

based on VPR C 88-16 / NEN 5734

- freeze dried sediment
- soxhlet extraction with petroleumether
- elemental sulfur removal with TBA-sulfite
- clean-up with aluminiumoxide
- fractioned on silica gel
- double column gc analysis with electron capture detection

Polycyclic aromatic hydrocarbons (PAHs)

based on VPR C 88-11 and method DBW/RIZA B352

- freeze dried sediment
- soxhlet extraction with dichloormethaan
- clean-up on silica gel
- HPLC with fluorescence and UV detection

3. Results

A summary of the concentrations observed (combined in a group paramater) is presented in Table 2. Concentrations of the individual contaminants is given for each location in Appendix 2. In Table 1 PAHs are presented as the six from Borneff, PCBs as the sum of the seven PCBs measured, OCPs as the sum of all organochlorine pesticides.

In general, the following ranking of locations can be distinguished considering all contaminants (from lowest to highest contaminated): Valkenisse < GBL < Paulina < Baalhoek < Boereschans < GBR < Ballooi.

Table 2. Summary of the concentrations of organic microcontaminants in sediments of the Schelde estuary (TOC in mgC/kg dm; others in µg/kg dm).

		jul-93	sep-93	dec-93	apr-94	jun-95
TOC	Valkenisse	2400	2600	2510	655	8440
	Boereschans	20200	12500	16400	10400	14200
	Ballooi	32200	38200	32700		
	GBR	41200	32000	34500	14800	29800
	GBL	6200	6000	6100	3850	10100
	Baalhoek	15600	8500	20400	8600	
	Paulina	16100	19800	15900	7200	
ΣPAHs 6	Valkenisse	12	107	79	24	0
	Boereschans	1731	1943	1938	2898	1455
	Ballooi	1992	1857	3040		
	GBR	2165	2027	2427	2772	1905
	GBL	432	328	351	429	581
	Baalhoek	346	377	461	1122	
	Paulina	535	509	651	605	
ΣOCPs	Valkenisse	0	0	0	0	0
	Boereschans	9	13	2	4	1
	Ballooi	11	16	9		
	GBR	13	16	7	10	11
	GBL	0	1	0	0	1
	Baalhoek	0	0	0	2	
	Paulina	0	0	1	0	
Σ PCB 7	Valkenisse	0	0	0	0	0
	Boereschans	32	33	21	37	21
	Ballooi	45	62	48		
	GBR	52	41	54	72	73
	GBL	8	10	7	6	15
	Baalhoek	7	5	4	14	
	Paulina	2	1	8	8	

Concentrations of polycyclic aromatic hydrocarbons are highest at the mesohaline location GBR, the oligohaline location Boereschans and the freshwatertidal location Ballooi (Figure 2). Paulina, Baalhoek and GBL have intermediate levels, whereas at Valkenisse very low concentrations were observed. No clear seasonal or temperal pattern is observed.

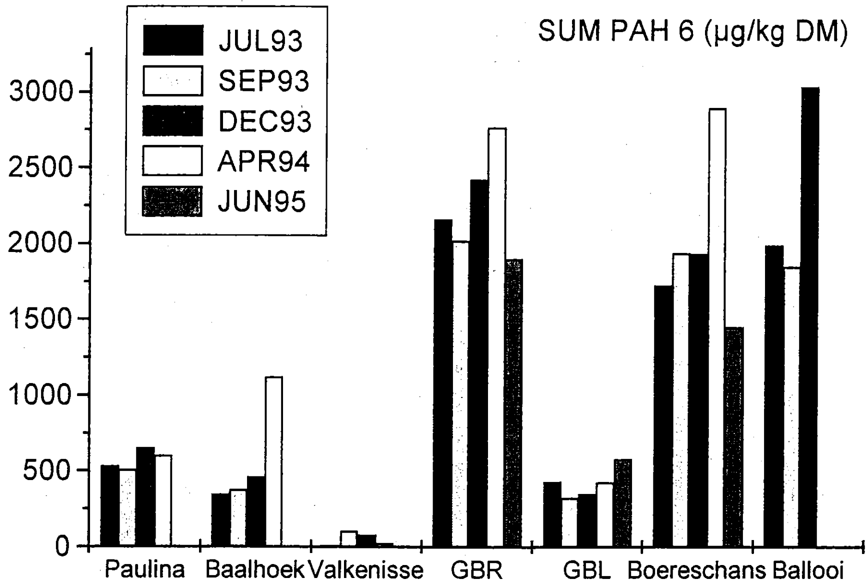


Figure 2. Concentrations of polycyclic aromatic hydrocarbons (PAHs) in sediments of the Schelde estuary.

Concentrations of polychlorinated biphenyls (PCBs) show a similar pattern as observed for the PAHs (Figure 3). Highest concentrations are observed at GBR, followed by the freshwater tidal location Ballooi and the oligohaline location Boereschans. Other locations have much lower concentrations, and at Valkenisse concentrations were even not detectable.

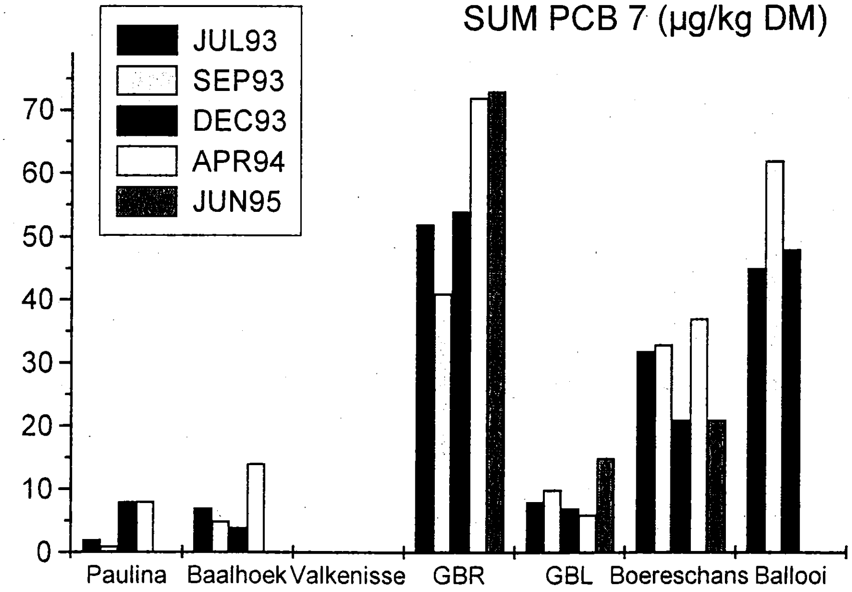
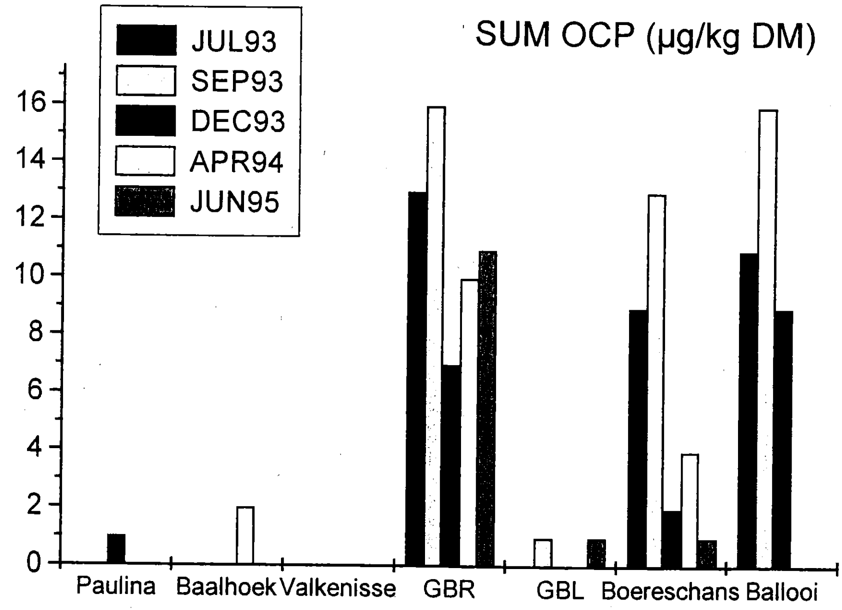


Figure 3. Concentrations of polychlorinated biphenyls (PCBs) in sediments of the Schelde estuary.

Concentrations of organochlorine pesticides (OCPs) show a similar but even more pronounced pattern (Figure 4): relatively high values in GBR, Ballooi and Boereschans, whereas at the other locations very low to undetectable concentrations.



In conclusion we can say that organic microcontaminants are present in the Schelde estuary in concentrations ranging from non detectable to maximum 3050 µg/kd dm ($\sum$ 6 Borneff PAHs), 75 µg/kg dm ($\sum$ 7 PCBs) and 16 µg/kg dm ($\sum$ OCPs). The nature of the sediment clearly plays an important role in the observed concentrations. Indeed, the hydrophobic nature leads to significant sorption onto particulates, especially onto particulate organic matter (Karickhoff et al., 1979). This is clearly demonstrated with the two locations GBR and GBL, which are only a few hunderd meters seperated from each other. GBL sediment with relatively low TOC values has much lower concentrations of organic contaminants, whereas GBR sediment with very high TOC values as the highest concentrations of organic contaminants (Table 2). Valkenisse, with the lowest values of TOC has very low to non detectable concentrations of organic contaminants. However, TOC values only partly explain the observed differences. Clearly also a spatial factor is involved, with clearly higher concentrations in the inner and upper regions (meso/oligo/freshwater tidal) of the estuary, as compared to the middle and outer regions (poly/mesohaline). This is in agreement with the findings of Van Zoest & Van Eck (1993), which found an essentially conservative behaviour of PCBs and PAHs in particulate matter and sediment of the Schelde estuary as a result of the mixing of riverine particulates with high, and marine particulates with low organic microcontaminants contents.

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Appendix 1. Measured contaminants with detection limit

Contaminant	**detection limit**
alfa hch	1 µg/kgds
beta hch	1 µg/kgds
gamma hch	1 µg/kgds
hexachloorbenzeen	1 µg/kgds
heptachloor	1 µg/kgds
heptachloorepoxide	1 µg/kgds
hexachloorbutadieen	1 µg/kgds
opDDD (2,4-dichloordifenyldichloorethaan)	1 µg/kgds
ppDDD (4,4-dichloordifenyldichloorethaan)	1 µg/kgds
opDDE (2,4-dichloordifenyldichlooretheen)	1 µg/kgds
ppDDE (4,4-dichloordifenyldichlooretheen)	1 µg/kgds
opDDT (2,4-dichloordifenyltrichloorethaan)	1 µg/kgds
ppDDT (4,4-dichloordifenyltrichloorethaan)	1 µg/kgds
aldrin	1 µg/kgds
dieldrin	1 µg/kgds
isodrin	1 µg/kgds
endrin	1 µg/kgds
endosulfan (alfa)	1 µg/kgds
trifluraline	1 µg/kgds
pcb28 (2,4,4-trichloorbifenyl)	1 µg/kgds
pcb52 (2,2,5,5-tetrachloorbifenyl)	1 µg/kgds
pcb101 (2,2,4,5,5-pentachloorbifenyl)	1 µg/kgds
pcb118 (2,3,4,4,5-pentachloorbifenyl)	1 µg/kgds
pcb138 (2,2,3,4,4,5-hexachloorbifenyl)	1 µg/kgds
pcb153 (2,2,4,4,5,5-hexachloorbifenyl)	1 µg/kgds
pcb180 (2,2,3,4,4,5,5-heptachloorbifenyl)	1 µg/kgds
naftaleen	50 µg/kgds
acenafthyleen	50 µg/kgds
acenaftheen	50 µg/kgds
fluoreen	10 µg/kgds
fenanthreen	10 µg/kgds
anthraceen	10 µg/kgds
fluorantheen	10 µg /kgds
pyreen	10 µg/kgds
benzoanthraceen	10 µg/kgds
chryseen	10 µg/kgds
benzo(b)fluorantheen	10 µg/kgds
benzo(k)fluorantheen	10 µg/kgds
benzo(a)pyreen	10 µg/kgds
dibenzo(a,h)anthraceen	10 µg/kgds
benzo(g,h,I)peryleen	10 µg/kgds
indeno(1,2,3,c,d)pyreen	10 µg/kgds

Appendix 2. Concentrations of organic contaminants in sediments in seven intertidal locations situated along a salinity gradient of the Schelde estuary.

Location: VALKENISSE

Ref. nr PIH		11535	14085	3912	19932	12773	
sampling date	**sediment**	**juli 93**	**sept 93**	**dec 93**	**apr 94**	**juni95**	
					(1995)		
TOC	mg C/kgds	**2400**	**2600**	**2510**	**655**	**8440**	
EOX	mg oCL/kgds				**8.5**	**6.5**	
APKWS	mg/kgds				**12**	**44**	
alfa hch	µg/kgds	< 1	< 1	< 1	< 1	< 1	
beta hch	µg/kgds	< 1	< 1	< 1	< 1	< 1	
gamma hch	µg/kgds	< 1	< 1	< 1	< 1	< 1	
hexachloorbenzeen	µg/kgds	< 1	< 1	< 1	< 1	< 1	
heptachloor	µg/kgds	< 1	< 1	< 1	< 1	< 1	
heptachloorepoxide	µg/kgds	< 1	< 1	< 1	< 1	< 1	
hexachloorbutadieen	µg/kgds	< 1	< 1	< 1	**n.g.**	**n.g.**	
opDDD	µg/kgds	< 1	< 1	< 1	< 1	< 1	
ppDDD	µg/kgds	< 1	< 1	< 1	< 1	< 1	
opDDE	µg/kgds	< 1	< 1	< 1	< 1	< 1	
ppDDE	µg/kgds	< 1	< 1	< 1	< 1	< 1	
opDDT	µg/kgds	< 1	< 1	< 1	< 1	< 1	
ppDDT	µg/kgds	< 1	< 1	< 1	< 1	< 1	
aldrin	µg/kgds	< 1	< 1	< 1	< 1	< 1	
dieldrin	µg/kgds	< 1	< 1	< 1	< 1	< 1	
isodrin	µg/kgds	**n.g.**	**n.g.**	**n.g.**	< 1	< 1	
endrin	µg/kgds	< 1	< 1	< 1	< 1	< 1	
endosulfan (alfa)	µg/kgds	< 1	< 1	< 1	< 1	< 1	
trifluraline	µg/kgds	< 1	< 1	< 1	< 1	< 1	
pcb28	µg/kgds	< 1	< 1	< 1	< 1	< 1	
pcb52	µg/kgds	< 1	< 1	< 1	< 1	< 1	
pcb101	µg/kgds	< 1	< 1	< 1	< 1	< 1	
pcb118	µg/kgds	< 0.4	< 0.4	< 0.4	< 0.4	< 0.4	
pcb138	µg/kgds	< 0.4	< 0.4	< 0.4	< 0.4	< 0.4	
pcb153	µg/kgds	< 0.4	< 0.4	< 0.4	< 0.4	< 0.4	
pcb180	µg/kgds	< 0.4	< 0.4	< 0.4	< 0.4	< 0.4	
naftaleen	µg/kgds	< 50	< 50	< 50	< 50	< 50	
acenafthyleen	µg/kgds	< 50	< 50	< 50	< 50	< 50	
acenaftheen	µg/kgds	< 50	< 50	< 50	< 50	< 50	
fluoreen	µg/kgds	< 10	< 10	< 10	< 10	< 10	
fenanthreen	µg/kgds	< 10	27	10	< 10	< 10	
anthraceen	µg/kgds	< 10	< 10	< 10	< 10	< 10	
fluorantheen	µg/kgds	12	47	37	< 10	< 10	
pyreen	µg/kgds	11	20	22	< 10	< 10	
benzoanthraceen	µg/kgds	< 10	12	13	< 10	< 10	
chryseen	µg/kgds	< 10	11	12	11	< 10	
benzobfluorantheen	µg/kgds	< 10	23	17	12	< 10	
benzokfluorantheen	µg/kgds	< 10	< 10	< 10	< 10	< 10	
benzo(a)pyreen	µg/kgds	< 10	13	13	12	< 10	
dibenzoanthraceen	µg/kgds	< 10	< 10	< 10	< 10	< 10	
benzoperyleen	µg/kgds	< 10	10	< 10	< 10	< 10	
indenopyreen	µg/kgds	< 10	14	12	< 10	< 10	

Location : BOERESCHANS

Ref. nr PIH		11536	14088	3915	19935	12776	
sampling date	sediment	juli 93	sept 93	dec 93	apr. 94	juni 95	
					(1995)		
TOC	mg C/kgds	20200	12500	16400	10400	14200	
EOX	mg oCL/kgds				33.5	21.5	
APKWS	mg/kgds				324	150	
alfa hch	µg/kgds	< 1	< 1	< 1	< 1	< 1	
beta hch	µg/kgds	< 1	< 1	< 1	< 1	< 1	
gamma hch	µg/kgds	< 1	1.4	< 1	< 1	< 1	
hexachloorbenzeen	µg/kgds	< 1	1.0	< 1	< 1	< 1	
heptachloor	µg/kgds	< 1	1.4	< 1	< 1	< 1	
heptachloorepoxide	µg/kgds	< 1	< 1	< 1	< 1	< 1	
hexachloorbutadieen	µg/kgds	< 1	< 1	< 1	n.g.	n.g.	
opDDD	µg/kgds	< 1	< 1	< 1	< 1	< 1	
ppDDD	µg/kgds	3.0	< 1	1.3	2.1	< 1	
opDDE	µg/kgds	1.2	2.1	1.1	< 1	< 1	
ppDDE	µg/kgds	< 1	2.6	1.1	1.7	1.3	
opDDT	µg/kgds	< 1	< 1	< 1	< 1	< 1	
ppDDT	µg/kgds	1.0	2.1	< 1	< 1	< 1	
aldrin	µg/kgds	< 1	< 1	< 1	< 1	< 1	
dieldrin	µg/kgds	< 1	1.0	< 1	< 1	< 1	
isodrin	µg/kgds	n.g.	n.g.	n.g.	< 1	< 1	
endrin	µg/kgds	3.6	1.5	< 1	< 1	< 1	
endosulfan (alfa)	µg/kgds	< 1	< 1	< 1	< 1	< 1	
trifluraline	µg/kgds	< 1	< 1	< 1	< 1	< 1	
pcb28	µg/kgds	1.5	2.2	< 1	1.7	< 1	
pcb52	µg/kgds	2.2	1.1	< 1	2.4	1.4	
pcb101	µg/kgds	4.8	4.1	3.2	5.3	3.7	
pcb118	µg/kgds	2.3	2.0	2.1	4.1	2.0	
pcb138	µg/kgds	10.6	10.2	6.6	8.6	4.6	
pcb153	µg/kgds	6.4	8.1	5.4	8.9	5.3	
pcb180	µg/kgds	4.1	5.5	3.3	6.1	3.6	
naftaleen	µg/kgds	234	172	188	< 50	< 50	
acenafthyleen	µg/kgds	51	< 50	< 50	< 50	< 50	
acenaftheen	µg/kgds	< 50	< 50	< 50	< 50	< 50	
fluoreen	µg/kgds	< 10	< 10	< 10	< 10	< 10	
fenanthreen	µg/kgds	164	174	167	352	65	
anthraceen	µg/kgds	71	60	53	114	62	
fluorantheen	µg/kgds	590	768	759	1027	381	
pyreen	µg/kgds	429	430	437	756	407	
benzoanthraceen	µg/kgds	245	249	234	439	259	
chryseen	µg/kgds	228	234	209	395	245	
benzobfluorantheen	µg/kgds	324	301	311	504	329	
benzokfluorantheen	µg/kgds	149	150	164	223	143	
benzo(a)pyreen	µg/kgds	270	276	263	455	273	
dibenzoanthraceen	µg/kgds	83	183	64	71	45	
benzoperyleen	µg/kgds	190	211	204	334	158	
indenopyreen	µg/kgds	208	237	237	355	171	

Location : PAULINA

Ref. nr PIH		11537	14083	3910	19930		
sampling date	sediment	juli 93	sept 93	dec 93	apr 94		
TOC	mg C/kgds	16100	19800	15900	7200		
EOX	mg oCL/kgds				22.0		
APKWS	mg/kgds				23		
alfa hch	µg/kgds	< 1	< 1	< 1	< 1		
beta hch	µg/kgds	< 1	< 1	< 1	< 1		
gamma hch	µg/kgds	< 1	< 1	1.2	< 1		
hexachloorbenzeen	µg/kgds	< 1	< 1	< 1	< 1		
heptachloor	µg/kgds	< 1	< 1	< 1	< 1		
heptachloorepoxide	µg/kgds	< 1	< 1	< 1	< 1		
hexachloorbutadieen	µg/kgds	< 1	< 1	< 1	n.g.		
opDDD	µg/kgds	< 1	< 1	< 1	< 1		
ppDDD	µg/kgds	< 1	< 1	< 1	< 1		
opDDE	µg/kgds	< 1	< 1	< 1	< 1		
ppDDE	µg/kgds	< 1	< 1	< 1	< 1		
opDDT	µg/kgds	< 1	< 1	< 1	< 1		
ppDDT	µg/kgds	< 1	< 1	< 1	< 1		
aldrin	µg/kgds	< 1	< 1	< 1	< 1		
dieldrin	µg/kgds	< 1	< 1	< 1	< 1		
isodrin		n.g.	n.g.	n.g.	< 1		
endrin	µg/kgds	< 1	< 1	< 1	< 1		
endosulfan (alfa)	µg/kgds	< 1	< 1	< 1	< 1		
trifluraline	µg/kgds	< 1	< 1	< 1	< 1		
pcb28	µg/kgds	< 1	< 1	< 1	< 1		
pcb52	µg/kgds	< 1	< 1	< 1	1.4		
pcb101	µg/kgds	< 1	< 1	< 1	1.3		
pcb118	µg/kgds	< 0.4	< 0.4	1.0	1.5		
pcb138	µg/kgds	1.0	1.1	2.7	1.6		
pcb153	µg/kgds	1.0	< 0.4	2.1	1.6		
pcb180	µg/kgds	< 0.4	< 0.4	1.8	0.7		
naftaleen	µg/kgds	91	69	65	< 50		
acenafthyleen	µg/kgds	< 50	< 50	< 50	81		
acenaftheen	µg/kgds	< 50	< 50	< 50	< 50		
fluoreen	µg/kgds	< 10	< 10	<10	< 10		
fenanthreen	µg/kgds	96	84	111	68		
anthraceen	µg/kgds	24	21	17	30		
fluorantheen	µg/kgds	172	226	265	195		
pyreen	µg/kgds	133	112	132	129		
benzoanthraceen	µg/kgds	68	79	69	92		
chryseen	µg/kgds	73	63	62	81		
benzobfluorantheen	µg/kgds	83	77	107	117		
benzokfluorantheen	µg/kgds	51	42	50	50		
benzo(a)pyreen	µg/kgds	87	66	82	98		
dibenzoanthraceen	µg/kgds	55	28	24	< 10		
benzoperyleen	µg/kgds	56	48	71	68		
indenopyreen	µg/kgds	86	50	76	77		

Location : BAALHOEK

Ref. nr PIH		11538	14084	3911	19931		
sampling date	sediment	juli 93	sept 93	dec 93	apr 94		
					(1995)		
TOC	mg C/kgds	15600	8500	20400	8600		
EOX	mg oCL/kgds				29.0		
APKWS	mg/kgds				68		
alfa hch	µg/kgds	< 1	< 1	< 1	< 1		
beta hch	µg/kgds	< 1	< 1	< 1	< 1		
gamma hch	µg/kgds	< 1	< 1	< 1	< 1		
hexachloorbenzeen	µg/kgds	< 1	< 1	< 1	< 1		
heptachloor	µg/kgds	< 1	< 1	< 1	< 1		
heptachloorepoxide	µg/kgds	< 1	< 1	< 1	< 1		
hexachloorbutadieen	µg/kgds	< 1	< 1	< 1	n.g.		
opDDD	µg/kgds	< 1	< 1	< 1	< 1		
ppDDD	µg/kgds	< 1	< 1	< 1	1.5		
opDDE	µg/kgds	< 1	< 1	< 1	< 1		
ppDDE	µg/kgds	< 1	< 1	< 1	< 1		
opDDT	µg/kgds	< 1	< 1	< 1	< 1		
ppDDT	µg/kgds	< 1	< 1	< 1	< 1		
aldrin	µg/kgds	< 1	< 1	< 1	< 1		
dieldrin	µg/kgds	< 1	< 1	< 1	< 1		
isodrin	µg/kgds	n.g.	n.g.	n.g.	< 1		
endrin	µg/kgds	< 1	< 1	< 1	< 1		
endosulfan (alfa)	µg/kgds	< 1	< 1	< 1	< 1		
trifluraline	µg/kgds	< 1	< 1	< 1	< 1		
pcb28	µg/kgds	< 1	< 1	< 1	< 1		
pcb52	µg/kgds	< 1	< 1	< 1	< 1		
pcb101	µg/kgds	1.0	< 1	< 1	2.2		
pcb118	µg/kgds	0.7	< 0.4	0.5	2.0		
pcb138	µg/kgds	2.5	1.9	1.5	3.7		
pcb153	µg/kgds	1.9	2.3	1.2	3.7		
pcb180	µg/kgds	0.8	0.8	0.7	2.1		
naftaleen	µg/kgds	74	< 50	72	< 50		
acenafthyleen	µg/kgds	< 50	< 50	< 50	< 50		
acenaftheen	µg/kgds	< 50	< 50	< 50	< 50		
fluoreen	µg/kgds	< 10	< 10	< 10	< 10		
fenanthreen	µg/kgds	71	68	61	178		
anthraceen	µg/kgds	13	29	15	52		
fluorantheen	µg/kgds	127	151	148	299		
pyreen	µg/kgds	76	64	96	285		
benzoanthraceen	µg/kgds	42	40	54	172		
chryseen	µg/kgds	39	51	47	166		
benzobfluorantheen	µg/kgds	66	69	82	242		
benzokfluorantheen	µg/kgds	30	31	41	106		
benzo(a)pyreen	µg/kgds	49	48	72	211		
dibenzoanthraceen	µg/kgds	31	33	19	< 10		
benzoperyleen	µg/kgds	33	32	57	136		
indenopyreen	µg/kgds	41	46	61	128		

Location : **GROOT BUITENSCHOR RIGHT**

Ref. nr PIH		11539	14086	3913	19933	12775	
sampling date	sediment	juli 93	sept 93	dec 93	apr 94	juni 95	
					(1995)		
TOC	mg C/kgds	41200	32000	34500	14800	29800	
EOX	mg oCL/kgds				41.0	18.0	
APKWS	mg/kgds				527	480	
alfa hch	µg/kgds	< 1	< 1	< 1	< 1	< 1	
beta hch	µg/kgds	< 1	< 1	< 1	< 1	< 1	
gamma hch	µg/kgds	< 1	1.5	< 1	< 1	< 1	
hexachloorbenzeen	µg/kgds	< 1	< 1	< 1	< 1	< 1	
heptachloor	µg/kgds	< 1	< 1	< 1	< 1	< 1	
heptachloorepoxide	µg/kgds	< 1	< 1	< 1	< 1	< 1	
hexachloorbutadieen	µg/kgds	< 1	< 1	< 1	n.g.	n.g.	
opDDD	µg/kgds	< 1	< 1	< 1	2.1	1.1	
ppDDD	µg/kgds	4.8	3.2	1.4	3.7	3.7	
opDDE	µg/kgds	< 1	3.2	3.5	1.5	3.2	
ppDDE	µg/kgds	2.4	3.0	1.2	2.8	3.2	
opDDT	µg/kgds	< 1	< 1	< 1	< 1	< 1	
ppDDT	µg/kgds	1.9	2.2	1.3	< 1	< 1	
aldrin	µg/kgds	< 1	< 1	< 1	< 1	< 1	
dieldrin	µg/kgds	< 1	1.2	< 1	< 1	< 1	
isodrin	µg/kgds	n.g.	n.g.	n.g.	< 1	< 1	
endrin	µg/kgds	3.4	1.5	< 1	< 1	< 1	
endosulfan (alfa)	µg/kgds	< 1	< 1	< 1	< 1	< 1	
trifluraline	µg/kgds	< 1	< 1	< 1	< 1	< 1	
pcb28	µg/kgds	< 1	1.4	1.4	3.4	1.5	
pcb52	µg/kgds	2.2	< 1	2.7	6.3	4.1	
pcb101	µg/kgds	7.3	6.0	7.9	11.4	9.4	
pcb118	µg/kgds	4.0	2.6	5.3	8.5	7.1	
pcb138	µg/kgds	15.2	12.6	15.5	14.0	15.8	
pcb153	µg/kgds	13.7	10.7	12.8	17.2	17.8	
pcb180	µg/kgds	9.3	8.0	8.8	11.1	17.6	
naftaleen	µg/kgds	366	243	253	< 50	119	
acenafthyleen	µg/kgds	191	90	94	< 50	66	
acenaftheen	µg/kgds	< 50	< 50	< 50	< 50	< 50	
fluoreen	µg/kgds	< 10	< 10	< 10	< 10	82	
fenanthreen	µg/kgds	240	238	281	326	255	
anthraceen	µg/kgds	86	72	83	149	97	
fluorantheen	µg/kgds	675	745	946	854	286	
pyreen	µg/kgds	500	379	594	799	584	
benzoanthraceen	µg/kgds	313	247	296	455	328	
chryseen	µg/kgds	276	228	225	405	284	
benzobfluorantheen	µg/kgds	415	350	417	563	491	
benzokfluorantheen	µg/kgds	186	176	149	241	200	
benzo(a)pyreen	µg/kgds	347	292	344	476	422	
dibenzoanthraceen	µg/kgds	187	174	62	85	54	
benzoperyleen	µg/kgds	260	198	257	301	253	
indenopyreen	µg/kgds	282	266	314	337	253	

Monstername : GROOT BUITENSCHOOR LEFT

Ref. nr PIH		11540	14087	3914	19934	12774	
sampling date	sediment	juli 93	sept 93	dec 93	apr 94	juni 95	
					(1995)		
TOC	mg C/kgds	6200	6000	6100	3850	10100	
EOX	mg oCL/kgds				22.0	17.0	
APKWS	mg/kgds				60	62	
alfa hch	µg/kgds	< 1	< 1	< 1	< 1	< 1	
beta hch	µg/kgds	< 1	< 1	< 1	< 1	< 1	
gamma hch	µg/kgds	< 1	< 1	< 1	< 1	< 1	
hexachloorbenzeen	µg/kgds	< 1	< 1	< 1	< 1	< 1	
heptachloor	µg/kgds	< 1	< 1	< 1	< 1	< 1	
heptachloorepoxide	µg/kgds	< 1	< 1	< 1	< 1	< 1	
hexachloorbutadieen	µg/kgds	< 1	< 1	< 1	n.g.	n.g.	
opDDD	µg/kgds	< 1	< 1	< 1	< 1	< 1	
ppDDD	µg/kgds	< 1	< 1	< 1	< 1	1	
opDDE	µg/kgds	< 1	< 1	< 1	< 1	< 1	
ppDDE	µg/kgds	< 1	< 1	< 1	< 1	< 1	
opDDT	µg/kgds	< 1	< 1	< 1	< 1	< 1	
ppDDT	µg/kgds	< 1	1.0	< 1	< 1	< 1	
aldrin	µg/kgds	< 1	< 1	< 1	< 1	< 1	
dieldrin	µg/kgds	< 1	< 1	< 1	< 1	< 1	
isodrin	µg/kgds	n.g.	n.g.	n.g.	< 1	< 1	
endrin	µg/kgds	< 1	< 1	< 1	< 1	< 1	
endosulfan (alfa)	µg/kgds	< 1	< 1	< 1	< 1	< 1	
trifluraline	µg/kgds	< 1	< 1	< 1	< 1	< 1	
pcb28	µg/kgds	< 1	< 1	< 1	< 1	< 1	
pcb52	µg/kgds	< 1	< 1	< 1	< 1	< 1	
pcb101	µg/kgds	1.4	1.2	1.0	< 1	2.1	
pcb118	µg/kgds	0.6	0.7	0.9	0.7	1.8	
pcb138	µg/kgds	2.0	3.2	2.1	1.7	3.9	
pcb153	µg/kgds	2.5	2.7	2.0	2.0	4.2	
pcb180	µg/kgds	1.4	1.8	1.2	1.3	2.6	
naftaleen	µg/kgds	< 50	< 50	< 50	< 50	< 50	
acenafthyleen	µg/kgds	< 50	< 50	< 50	< 50	< 50	
acenaftheen	µg/kgds	< 50	< 50	< 50	< 50	< 50	
fluoreen	µg/kgds	< 10	< 10	< 10	< 10	< 10	
fenanthreen	µg/kgds	39	47	40	31	51	
anthraceen	µg/kgds	12	11	10	< 10	18	
fluorantheen	µg/kgds	110	94	132	63	111	
pyreen	µg/kgds	91	64	85	55	127	
benzoanthraceen	µg/kgds	50	40	32	33	89	
chryseen	µg/kgds	40	29	26	44	89	
benzobfluorantheen	µg/kgds	93	76	65	108	146	
benzokfluorantheen	µg/kgds	43	30	29	35	68	
benzo(a)pyreen	µg/kgds	67	47	49	86	107	
dibenzoanthraceen	µg/kgds	40	36	26	36	< 10	
benzoperyleen	µg/kgds	35	29	29	61	70	
indenopyreen	µg/kgds	84	52	47	76	79	

Location : **BALLOOI**

Ref. nr PIH		11541	14089	3916			
sampling date	sediment	juli 93	sept 93	dec 93			
TOC	mg C/kgds	32200	38200	32700			
EOX	mg oCL/kgds						
APKWS	mg/kgds						
alfa hch	µg/kgds	< 1	< 1	< 1			
beta hch	µg/kgds	< 1	1.1	< 1			
gamma hch	µg/kgds	< 1	1.5	1.2			
hexachloorbenzeen	µg/kgds	< 1	< 1	< 1			
heptachloor	µg/kgds	< 1	< 1	< 1			
heptachloorepoxide	µg/kgds	< 1	< 1	< 1			
hexachloorbutadieen	µg/kgds	< 1	< 1	< 1			
opDDD	µg/kgds	< 1	< 1	< 1			
ppDDD	µg/kgds	4.7	< 1	2.3			
opDDE	µg/kgds	3.4	3.1	1.9			
ppDDE	µg/kgds	1.2	3.8	1.2			
opDDT	µg/kgds	< 1	< 1	< 1			
ppDDT	µg/kgds	1.8	2.8	2.8			
aldrin	µg/kgds	< 1	< 1	< 1			
isodrin	µg/kgds	n.g.	n.g.	n.g.			
dieldrin	µg/kgds	< 1	1.4	< 1			
endrin	µg/kgds	< 1	2.6	< 1			
endosulfan (alfa)	µg/kgds	< 1	< 1	< 1			
trifluraline	µg/kgds	< 1	< 1	< 1			
pcb28	µg/kgds	1.8	2.4	2.1			
pcb52	µg/kgds	2.9	3.9	1.7			
pcb101	µg/kgds	6.7	9.4	6.7			
pcb118	µg/kgds	3.4	3.9	4.7			
pcb138	µg/kgds	13.0	18.3	14.2			
pcb153	µg/kgds	10.3	15.0	11.2			
pcb180	µg/kgds	7.0	9.3	7.7			
naftaleen	µg/kgds	221	178	300			
acenafthyleen	µg/kgds	123	75	93			
acenaftheen	µg/kgds	< 50	< 50	< 50			
fluoreen	µg/kgds	< 10	< 10	< 10			
fenanthreen	µg/kgds	204	248	358			
anthraceen	µg/kgds	66	75	90			
fluorantheen	µg/kgds	724	637	1379			
pyreen	µg/kgds	603	424	828			
benzoanthraceen	µg/kgds	269	268	349			
chryseen	µg/kgds	259	244	330			
benzobfluorantheen	µg/kgds	367	344	439			
benzokfluorantheen	µg/kgds	173	170	235			
benzo(a)pyreen	µg/kgds	298	281	380			
dibenzoanthraceen	µg/kgds	173	168	184			
benzoperyleen	µg/kgds	209	184	275			
indenopyreen	µg/kgds	221	241	332			

ECOTOXICOLOGICAL EVALUATION OF INTERTIDAL SEDIMENTS ALONG A SALINITY GRADIENT OF THE SCHELDE ESTUARY

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1. Introduction

The results presented here are the summary of two theses made at the Laboratory for Biological Research in Aquatic Pollution in cooperation with the Institute of Nature Conservation. The first thesis was set up as a first ecotoxicological screening, based on short running acute bioassays on pore water, of some intertidal sediments in the Schelde estuary.
The second thesis then focused more on the development and evalution of chronic sediment toxicity tests with ecologically relevant test species.

Summary of These 1

'Evaluatie van de ecotoxiciteit van de waterbodems langsheen een saliniteitsgradiënt in het Schelde estuarium'
by Jeroen Van Waeyenberge

An ecotoxicological screening of seven intertidal locations, situated along a salinity gradient in the Schelde estuary, was conducted with a few short-term pore water bioassays. The seven locations are:
(1) Paulina (polyhaline zone)
(2) Baalhoek (poly/mesohaline zone)
(3) Valkenisse (poly/mesohaline zone)
(4) Groot Buitenschoor Right (mesohaline zone)
(5) Groot Buitenschoor Left (mesohaline zone)
(6) Boereschans (oligohaline zone)
(7) Ballooi (freshwater tidal zone).

Sediment cores were sampled in the field and brought to the laboratory where, based on measurements of the redox profile, the cores were sectioned into (a) an oxidated top layer, (b) a transition layer, and (c) a reduced layer. Of each fraction the pore water was extracted by centrifugation, followed by filtration.

On the pore water following toxicity tests were conducted:

- a test with bacteria (Microtox®): all locations
- a test with rotifera (Rotoxkit M): locations 1-6

- an acute bioassya with the marine copepod *Acartia tonsa*: location 1-6
- a test with crustacean *Thamnocephalus platyurus* (Thamnotoxkit F): location 7

As endpoints were chosen mortality (LC_{50}) for the tests with the crustaceans and rotifera and bioluminiscence (EC_{50}) for the test with the bacteria. The effect levels were afterwards recalculated to toxic units T.U. For all pore waters the individual contribution and the expected toxic strength of each metal was calculated with the concentration-addition model. Next to it the individual contribution of ammonium was determined for those samples which gave an acute toxic signal.

Chemical analysis of heavy metals (Mn, Ni, Cu, Zn, As, Se, Cd and Pb) (Laboratory for Analytical Chemistry) were conducted on both centrifugated as filtrated samples. In general, higher metal concentrations were dedected by centrifugating the sediment. DOC was determined by PIH (Antwerpen).

Two out of the four toxicity tests conducted gave no acute toxic signal at all (bacteria and rotifera test). Only with the marine copepod *Acartia tonsa* and the crustacean *Thamnocephalus platyurus* (T.U.=1.2) an acute toxic signal was detected. For *Acartia tonsa* only the oxic layer of Baalhoek and the anoxic layer of Boereschans gave a clear toxic signal (T.U. ≥ 1). The oxic layer of Boereschans, the transition layer of Valkenisse and Boereschans and the anoxic layer of Baalhoek, Valkenisse, and Groot Buitenschoor Left gave only a weak signal (0.1<T.U.<1).

In most cases the observed toxicity did not agree with the expected toxicity based on the concentration-addition model. In cases where the highest toxic strength was expected, this was not reflected in an acute toxic signal. Based on the calculations of the individual metal contributions, cadmium and lead were found to have a neglectable contribution to the toxic strength of all pore waters studied. Nickle and zinc were found respectively 5 and 4 times in concentrations higher than its LC_{50}. However, no acute toxic signal was observed for these metals. A possible explanation is that the metals were not bioavailable to the organisms studied.

Summary of These 2

'Evaluatie van de toxiciteit van waterbodems in het Schelde-estuarium: ontwikkeling van chronische testen met indigene soorten'

by Ilse Vandemoortel

The first part of the thesis focused on the possibility to use indigenous species for ecotoxicological research on sediments of the Schelde estuary. A second part deals with the sediment quality of intertidal sediments along the Schelde estuary based on an integration of ecotoxicological, chemical and biological data.

Five locations were investigated, namely four locations situated in the brackish zone (Valkenisse, Groot Buitenschoor Right, Groot Buitenschoor Left, Boereschans) and one location situated in the freshwater tidal zone (Ballooi). As a reference sediment two marine locations were chosen in the Oosterschelde (Yacobahaven and Oesterput), and one freshwater location in the Grote Nete.

The locations in the Oosterschelde are used as a standard reference by researchers in The Netherlands.

For the development of chronic sediment contact tests with brackish water sediments the following indigenous macrobenthis species were chosen:

- the amphipod *Corophium volutator*
- the mysid *Neomysis integer*
- the bivalve *Macoma balthica*
- the bivalve *Mya arenaria*

These indigenous species were preferred above standard test species, because indigenous species are more ecologically relevant, and therefore a more complete and realistic estimation of the possible effects of toxic contaminants can be made. Due to the shortage of indigenous species in the freshwater tidal part, the freshwater test was conducted with the standard test amphipod *Hyalella azteca*.

All tests were conducted in a flow through system and the animals were fed during the tests with approriate food, depending on the species. Endpoints chosen were mortality, growth (increase in bodylength or dry weight). Following conclusions could be made concerning the development of the different tests:

- the test development with the amphipod Corophium volutator demonstrated that the most suitable size at the beginning of a test is 500-600 µm. Smaller (350-500 µm) were to sensitive during handling, whereas bigger (600-710 µm) animals didn't survive well until the end of the chronic test.
- For *Neomysis integer* the best endpoint appeared to be growth, measured as dry weight. However, a relatively high control mortalitiy was observed, making the test not acceptable.
- For the bivalves growth was considered as a good and sensitive endpoint. Mortality was very low.
- For the chronic test with *Hyalella azteca* growth, measured as dry weight, was the most promising endpoint.

The ecotoxicological evaluation of the different locations was performed following the method of Kreis. Only the tests with *Neomysis*, *Macoma* and *Mya* were used for the evaluation. With the TRIAD-method then a first attempt to evaluate the quality of the area was performed. From this, clearly the limitations in the application of the TRIAD-approach in estuaries came forward. These limitations can mainly be attributed to highly dynamic nature of estuaries (e.g. salinity and sediment gradients), which makes it very difficult to find suitable reference points. Therefore, the results should be considered as a first and rough attempt, but clearly show some trends:

- in general higher levels of microcontaminants are observed in the meso/oligo/freshwatertidal zone near Antwerpen, but also sediment characteristics do determine the observed concentrations.
- in the brackish zone a trend to toxicological degradation is noticable
- in the freshwater tidal zone the negative effect on the macro fauna is probably not due to pollution of microcontaminants, but rather through oxygen deficiency, caused by the very high organic load coming into this part of the estuary.

Remarkable was the bad ecotoxicological score of the reference location Oesterput, since this location is used as a standard reference in the Netherlands.