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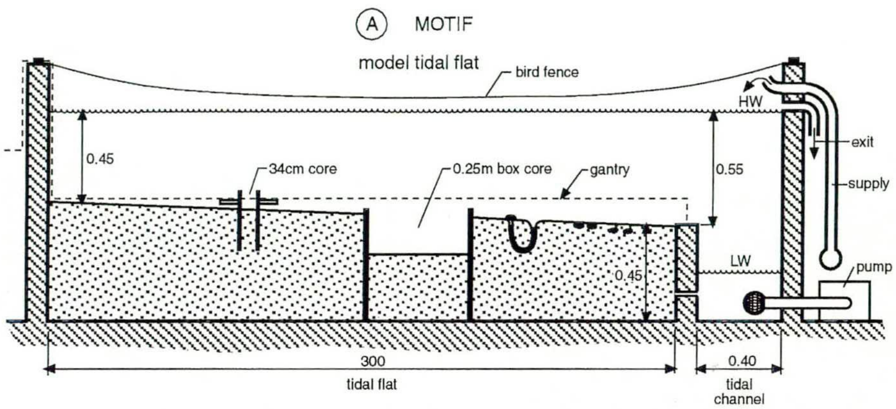
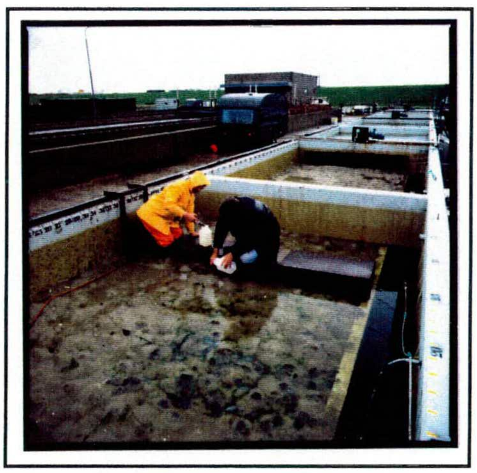
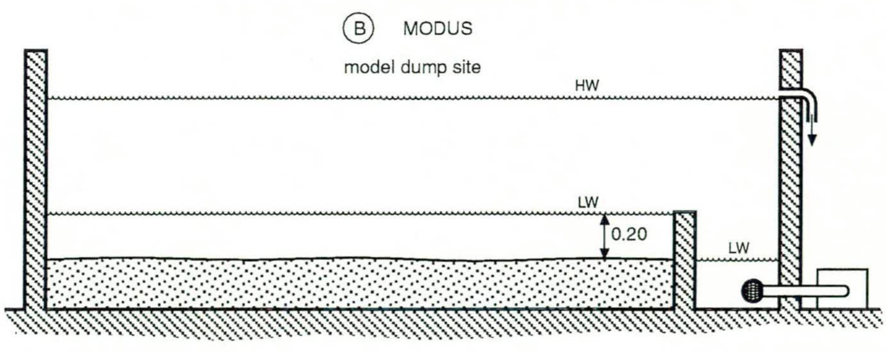
SEDEX

Part 5







TNO Institute of
Environmental Sciences

DLO Institute for Forestry and Nature Management

Netherlands Institute for Sea Research

RWS Tidal Water Division

SEDEX: Intertidal mesocosm studies on the ecological impact of the marine disposal of dredged materials

IMW - R 93/255d

Part 5: Meiobenthos

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Based on the necessity for a sustainable development of society, TNO Environmental and Energy Research aims at contributing, through research and advice, to adequate environmental management, rational energy consumption and the proper management and use of subsurface natural resources.

PREFACE

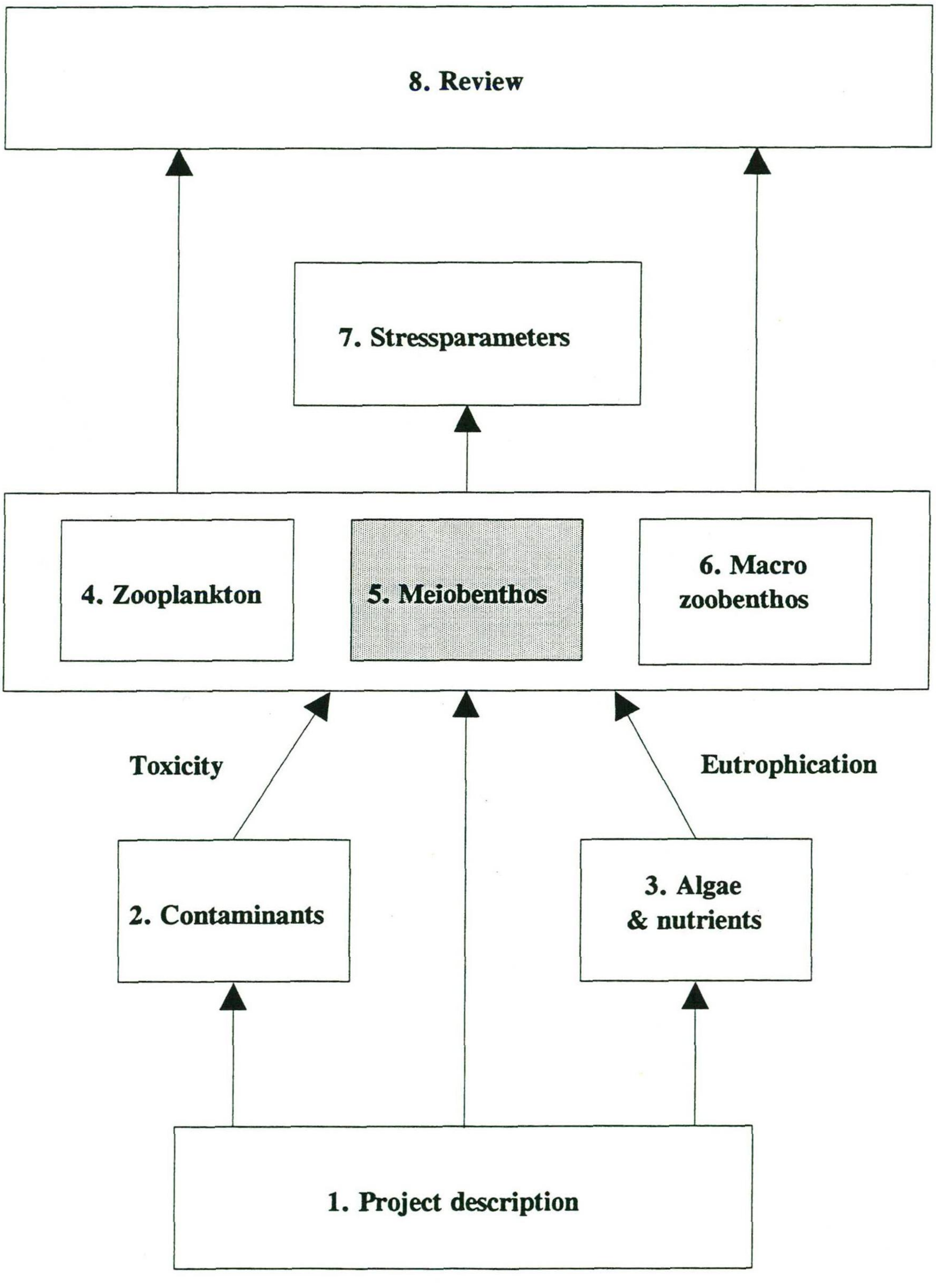
This report forms part of the final report series of SEDEX (sediment experiments), a research project in which the response of marine biota in the intertidal sedimentary environment to the disposal of harbour dredged materials was investigated by making use of experimental tidal flat communities (mesocosms). The experiments were carried out in the period 1987-1989.

The SEDEX project is a joint effort of the DLO Institute for Forestry and Nature Management (Dept. of Estuarine Ecology, Texel); the RWS Tidal Waters Division (Haren), the Netherlands Institute for Sea Research (Depts. of Benthic Systems and Special Projects, Texel) and the TNO Institute of Environmental Sciences (Laboratory of Applied Marien Research, Den Helder) under the co-ordination of Martin Scholten (TNO).

This report is number 5 of a series of 8 reports (see next page), discussing the dynamics of the meiobenthos in relation to contaminant toxicity and eutrophication.

The report series is edited by M.C.Th. Scholten, W.Chr. de Kock and R.G. Jak.

SEDEX REPORT SERIES



CONTENTS

ABSTRACT

A research project (SEDEX) was set up to investigate the response of marine biota from the intertidal sedimentary environment in the Wadden Sea to the marine disposal of harbour dredged materials. The experiments were conducted in mesocosms (MOTIFs = MOdel TIdal Flats, connected to MODUSes = MOdel DUmp Sites). In this report, the meiobenthos development in relation to contaminant exposure and eutrophication is described and discussed.

The meiofauna in the MOTIFs was dominated by nematodes. Harpacticoid copepods and oligochaetes were also present in considerable numbers. Both the composition and the density of the meiobenthos fauna are comparable to the Wadden Sea field situation.

Some meiobenthos (*eg.* the nematode *Monhystera* and oligochaetes) benefit from the enrichment of the sediment with phytoplankton residuals. Others (*eg.* the nematode *Daptonema*, harpacticoid copepods and ostracodes) were negatively affected in systems treated with dredged materials, probably due to an enhanced exposure to sedimented toxicants.

1. INTRODUCTION

1.1 SEDEX

The marine dumping of dredged materials from inland waterways and harbours constitutes an important source of pollution (nutrients, contaminants) in the Dutch sector of the North Sea. The Wadden Sea, is an area of special natural importance lying in the downstream residual tidal current along the Dutch coast and ultimately receives a part of these dredged materials. The SEDEX research project was set up to investigate the response of marine biota from tidal flat communities in the Wadden Sea to the marine disposal of dredged materials. The main goals of SEDEX were: (1) a characterisation of general key processes controlling the response to marine dredged material discharges; (2) an estimation of the impact of reduced water quality on benthic biota and (3) a selection of ecologically relevant stress-indicating parameters for the development of bioassays and monitoring techniques.

An experimental programme (1987-1989) was conducted in MOdel TIdal Flat (MOTIF) systems. MOTIFs are experimental tidal flat communities (mesocosms) consisting of 21 m^2 each and containing the most important biota of a natural tidal flat system (algae, worms, molluscs and crustaceans).
The MOTIFs were exposed to dredged materials in various ways:

- exposure to water which contained substances released from dredged materials disposed in MOdel DUmp Sites (MODUSes) connected to the MOTIFs, and exposure to dredged materials themselves which are mixed through the tidal flat sediments in the MOTIFs;
- exposure to Rotterdam harbour and Delfzijl harbour dredged materials;
- exposure to fresh and weathered (reduced and oxidized respectively) dredged materials.

A general description of the SEDEX project, including some background information on the marine dumping of dredged materials in the Netherlands, is presented in SEDEX report 1 (Scholten, 1993). An introduction of the objectives, experimental set-up and the use of MOTIFs, is also presented.

1.2 Meiobenthos

In this report, the population dynamics of meiobenthic fauna in response to marine disposal of dredged materials will be presented and discussed.

Meiobenthic fauna (meiobenthos) include benthic organisms that pass through sieves with a 1 mm mesh size but are retained by a 30-50 µm sieve. Many phyla have meiobenthic representatives, some even being exclusively meiobenthic. Although diversity is often high the marine meiofauna is usually dominated by only two groups: nematodes and harpacticoid copepods (Crustacea). Juvenile stages of macrofaunal species (temporary meiofauna) may be numerous, particularly in shallow areas.

In the western Wadden Sea, the meiofauna is dominated by nematodes which contribute up to 90% of the meiobenthos numbers and 50% of the meiobenthic biomass (van Dessel, 1988), followed by annelids and harpacticoid copepods. The meiofauna of the Ems estuary, at the eastern part of the Dutch Wadden Sea, is also dominated by nematodes, while harpacticoid copepods rank second and small polychaetes, olygochaetes, ostracodes and turbellariabs may be numerous incidentally (Bouwman, 1983a). In the North Sea, harpacticoid copepods may be more abundant than nematodes in the Southern Bight, as numbers of the last group are lower than in the central part of the North Sea (Huys et al., 1992). Typically, intertidal muddy estuaries show highest abundance and biomass values, whereas lowest values are recorded from the deep sea (Coull, 1988). Biotic diversity increases from shallow to deeper regions of the seas.

In shallow (sub)tidal areas, benthic diatoms form the major food source for the meiofauna (Admiraal et al., 1983). Harpacticoids may also feed on organic particles which may be enriched (as a source of food) by attached bacteria. Nematode species can be classified to different feeding types. Their diet includes bacteria, protozoa, diatoms and meiofauna organisms, including nematodes (Romeyn & Bouwman, 1983).

Although meiofaunal biomass in a shallow area like the Wadden Sea may be relatively high compared to the North Sea, it is thought to play only a minor role in consumption and mineralisation compared to the macrobenthos, microbenthos and bacteria (van Dessel, 1988).

As consumers of sedimented organic matter, the meiobenthos can benefit from eutrophication related to disposal of dredged materials. Competition for food with the macrobenthos can be of importance in determining under which food conditions the meiobenthos is able to increase in numbers. On the other hand, toxic contaminants bound to the food particles may have adverse effects on meiobenthic organisms. Copepods comprise species that are very sensitive to contaminants.

These simultaneously acting, regative effects that sludges may have on the meiobenthos complicate interpretation of effects found on its development. Toxic effects may be identified if the development of meiobenthos is less than what might be expected on the basis of the amount of the sedimentary organic matter.

1.3 Measurements

The meiofaunal dynamics will be characterized by time series of the numbers of the dominant meiofauna taxa (Figure 5.1) in the MOTIF sediments. The meiofauna were classified in two groups of worms (Nematodes, Oligochaetes) and two groups of crustraceans (Harpacticoid copepods, Ostracods). Nematodes were identified at the genus or species level. To assess the potential inoculation of MOTIFs with meiofauna originating from the MODUSes, samples from the sludges were identified twice per season. The settlement of the meiobenthos from suppletion water into the MOTIFs was followed in plastic trays filled with clean sand and connected with the water supply system.

Nematode composition and densities were examined in spring and autumn at two reference sites in the Mok baai in order to compare the meiobenthic community in the MOTIFs with a field situation.

In 1989, two additional experiments were performed to investigate the effect of the sedimentation of organic material on densities of the meiofaunal groups and the competition for food between the meiofauna and a macrofaunal species (i.e. *Hydrobia ulvae).*

2. MATERIALS AND METHODS

2.1 Experimental set-up

A full description of the experimental set-up, including a description of the MOTIFs (Figure 5.2), is presented in SEDEX Report 1 (Scholten, 1993). The main points are resumed below.

The main experimental variable was the type of sediment deposited in the MODUSes, resulting in an exposure of the adjoining MOTIFs to water contaminated by substances released from the "disposed" dredged materials.
Three classes of sediments where used: sediments from Rotterdam harbour, from Delfzijl harbour and reference ("control") sediments. The nested secondary variable was the treatment of the dredged materials: weathering under reduced or oxidized conditions compared to freshly dredged material.

In **1987**, two MODUSes were filled with fresh Rotterdam harbour sludge, while the other two were filled with reference sediments from Mokbaai (similar to the sediment used in the MOTIFs). In order to study the effects of dredged materials "deposited" in tidal flat sediments, the Rotterdam harbour sludge was mixed (10% v/v) with the sediments of two MOTIFs, one connected to a MODUS filled with sludge and one connected to a MODUS filled with reference sediment. In 1988 and 1989, no further attention was paid to the effects of dredged materials mixed with the MOTIF sediments.

In **1988**, the Rotterdam sludge that was used in one MODUS in 1987 was retained under reduced conditions. The Rotterdam sludge from the other MODUS was air-dried outside the basin for a month during the winter in order to reduce the NH_4^+ content. This oxidized sludge was thereafter re-introduced into the MODUS. Another MODUS was filled with fresh Delfzijl harbour sludge, while the fourth MODUS was filled with new reference sediment from Mokbaai.

In **1989**, the so called "oxidized" Rotterdam sludge from 1988 was again dried, but this time for a longer period (November 1988 - March 1989) and under forced conditions (a heater was used). The resulting "double-oxidized" sediment was put in one MODUS. The Delfzijl sludge from 1988 was treated similarly, resulting in "oxidized" Delfzijl sludge to be disposed in another MODUS. The third MODUS was used for disposal of a fresh amount of Delfzijl sludge. The remaining MOTIF was filled with another, cleaner, type of reference sediment than that used in the previous years, i.e. pure dune sand without substantial amounts of organic matter.

Table 4.1 Synoptic table of MOTIF treatments (Reference = Mokbaai sediment).

Year	Code	MODUS sludge	MOTIF sediment	MODUS/MOTIF
1987	C1	Reference	Reference	1/2
	Rf	Rotterdam, fresh	Reference	3/4
	Rs	Reference	Sludge mixed	5/6
	Rsf	Rotterdam, fresh	Sludge mixed	7/8
1988	C2	Reference	Reference	1/2
	Rr	Rotterdam, reduced	Reference	7/8
	Ro	Rotterdam, oxidized	Reference	5/6
	Df	Delfzijl, fresh	Reference	3/4
1989	C3	Dune sand	Reference	3/4
	Roo	Rotterdam, oxidized	Reference	1/2
	Doo	Delfzijl, oxidized	Reference	5/6
	Dff	Delfzijl, fresh	Reference	7/8

The list of abbreviations used as a code for the various treatments is also given in the Appendix.

The use of freshly collected sediments or re-use of sediments can be illustrated as follows:

Collection		Use		
site	year	1987	1988	1989
Mokbaai	87	C1		
	88		C2	
Dunes	89			C3
Rotterdam	87	Rsf	Rr	
	87	Rf	Ro	Roo
	87	Rs		
Delfzijl	88		Df	Doo
	89			Dff

The three years of experimentation allow for the following comparisons to be performed:

1. Variation between years	C1-C2-C3 Df-Dff
2. Effects of fresh sludges	Rf, Rsf, Rs vs C1 Df and Dff vs C2 resp. C3
3. Effects of treated sludges	Rr and Ro vs C2 Roo and Doo vs C3
4. Effects of "mixed" sludges	Rs and Rsf vs C1 and Rf

2.2 Sampling methods

In 1987, meiobenthic samples were taken from the mixed sediment core samples (ø 2,5 cm) of 0-2 cm depth; a subsample of 25 g sediment per MOTIF was taken which was equivalent to about 15 cm^2 (area of three core samples). In 1988 and 1989, samples were taken at three different places in the MOTIFs, consisting of two core samples with 2.5 cm diameter and a depth of 2 cm. The samples were put in plastic jars and preserved in a 5% formaldehyd solution for further examination.

Samples were taken every two weeks as part of the standard sediment sampling programme, from April 29 to October 22 in 1987, from April 13 to October 12 in 1988 and from April 12 to October 25 in 1989.

2.3 Analytical methods

Preserved meiofaunal samples were extracted from the sandy sediment by means of simple decantation (McIntyre & Warwick 1984) using a sieve with a pore size of 30 μm. Retained samples were washed off in a petridish and were taxonomically identified and counted under a standard light microscope. Numbers at taxonomic group level are completely counted for whole samples. Per sample a maximum of 250 nematodes have been identified at species level. In fresh sediment samples, soft-bodied meiofauna *(Turbellaria)* were counted after decantation. Behaviour and percentage mortality of the different meiofaunal groups were also determined.

2.4 Additional experiment

Two main factors expected to interfere with the development of the meiobenthos are sedimentation of organic matter and competition for food with other benthic organisms. In 1989, experiments were carried out in which the influence of both sedimentation on meiobenthic development and competition for food between the meiobenthos and the macrobenthos were investigated.

Effects of organic enrichment
One of the factors that could influence the development of the meiofauna is organic enrichment of the upper sediment layer resulting from sedimentation of organic matter from the overlying water column. This might increase food levels for the benthic fauna but may also result in negative effects when oxygen becomes depleted and toxic sulphide is produced.
In 1989, an experiment was initiated in which the development of the meibenthos was followed in subplots 4 x 0.25 m^2 in the MOTIFs with and without the extra addition (37.5 $gdw.m^{-2}$) of organic matter (for more details see SEDEX report 6, Dekker *et al.*, 1993).

Competition
A separate, small scale mescosm experiment wes set up to study the development of the meiofauna with and without the presence of macrofauna. Also the effects of the addition of organic matter on competition between the meiofauna and the macrofauna was taken into account resulting in four different treatments with the following codes:

1. meiobenthos and macrobenthos, no addition of organic material (H)
2. meiobenthos, no addition of organic material (-)
3. meiobenthos and macrobenthos, organic material added (OH)
4. meiobenthos, organic material added (O)

Meiobenthos samples were collected from Mok baai at the end of August and equally distributed in 4 trays (35 x 40 cm; 0.14 m^2) filled with azoic sand. In two trays, 400 *Hydrobia* (Mud snail) were introduced in order to serve as a macrobenthic competitor for food. Organic material was collected from the water column of the Dff MOTIF by centrifugation and added at the start of the experiment as a top layer with a thickness of ca. ø 5 mm. The trays were supplied with filtered (35 µm sieve) sea water.
After three weeks, samples were taken weekly from two sites in each tray with a 2.5 cm diameter core. Densities of the dominant meiofaunal groups were counted from each sample. Ash-free dry weights of *Hydrobia* was measured at the start and at the end of the experiment. Numbers of *Hydrobia* present at the end of the experiment were also counted.

2.5 Presentation of results

The time series of densities of the dominant nematode species, oligochates, ostracodes and turbellaria will be presented in graphs. The dominant nematode species were *Monhystera*, Chromadoridae, *Daptonema* (*setosum*) and *Enoplidae* (only in 1988).

Mean percentages of species within the meiofaunal community of each MOTIF sediment and the species diversities of the nematode community were calculated according to Bouwman (1983b) and the Shannon-Wiener diversity index:

Bouwman:

$$D = C\,(100 - \sqrt{(f_{1n}^2 + f_2^2 \ldots + f_n^2)})$$

where D is diversity (values between 0 and 100), C is the correction factor for different sample sizes, f is the frequency percentages of species within a sample and n is the total number of species per sample.

Shannon-Wiener:

$$H' = \sum p_i \log^2 p_i$$

where H' is diversity and p^i is the percentage of individuals of species i of the total number of individuals.

Full statistical analysis of data is postponed until all SEDEX data are analyzed by means of Canonical Correspondence Analysis (CCA). CCA is a multivariate ordination technique that is intended as a support for the interpretation of ecological data sets with simultaneously measured data. The meaningful application of the method in ecotoxicological mesocosm research has been demonstrated by Van der Wal *et al.* (1991) for studies with plankton enclosures.
The method selects environmental variables that contribute substantially to the explanation of variation in observations of target species and it ordinates the state of a system (or development in the case of a time series) to these selected variables.
This enables a direct comparison of differently treated systems with respect to the development of the target species in relation to distinguishing environmental variables and the experimental treatment. The results of the CCA of SEDEX data will be reported separately, in addition to this report series.

3. RESULTS

3.1 Nematodes

Nematodes were the dominant meiofauna group in all MOTIFs, reaching maximum densities of about 200 animals per cm^2 in some MOTIFs. Many species were found but only a few species dominated the meiofaunal community.

MODUSes
It is shown in Tables 5.1, 5.2 and 5.3, that for the years 1987, 1988 and 1989 respectively, the number of species found in MOTIF sediments is always higher than that found in the sludges in the MODUSes. *Daptonema setosum* was, in all of those three years, one of the dominant species in the MODUSes. It was almost the only species present in 1987, even in the control MODUS (C1). In 1988 it was the only species found in the oxidized Rotterdam sludge and it was of less importance in the control MOTIF where it was mainly accompanied by other *Daptonema* species, *Chromadora nudicaptata* and *Tripyloides marinus*. The latter species was also found in the MODUS with reduced Rotterdam sludge where it occurred with *Sabatieria pulchra*. In the fresh Delfzijl sludge, *S. pulchra* was the dominant species both in 1988 and 1989. More species were found in the MODUSes in 1989, when *Daptonema* species were most important, except for the fresh Delfzijl sludge.

MOTIFs
The diversity of the nematode communities in the 1987 MOTIFs show a high degree of resemblance with the species settled from suppletion water, indicating that suppletion water is the main source of nematode larvae.
Diversities at the Mok baai sampling sites were higher than in the MOTIFs when calculated with both the Shannon-Wiener and the Bouwman index. In the Mok baai different species to those in the MOTIFs were dominant, although most of these species were present in the MOTIFs. However, diversity tended to increase in the MOTIFs and in the trays where the meiofauna settled from the suppletion water from 1987 to 1989, probably due to improvement in the distribution of the intake water (see SEDEX report 1, Scholten 1992). In 1989, the diversity in the MOTIFs was comparable to the field situation.

The development of nematode densities in the control MOTIFs (C1, C2 and C3) was about the same in the three years (Figure 5.3). In all controls, highest densities were reached in the late summer period (August-September) after a gradual increase throughout the preceeding months. The increase rate was highest in 1987 and lowest in 1989. Therefore, maximum densities were lowered in successive years (ca. 200 cm^{-2} in 1987; ca. 175 cm^{-2} in 1988; ca. 75 cm^{-2} in 1989) and were reached later on in the year (early August in 1987; late August in 1988; late September in 1989). This may have been caused by the increase in species diversity between 1987 and 1989 (Tables 5.1-5.3). A community comprised of fewer species will show a more opportunistic response.

Compared to the development of nematodes in the control MOTIF in 1987, the different treatment of the systems with fresh Rotterdam sludge all showed a similar response. Initially, numbers increased rapidly at the end of May but declined afterwards down to a level of ca. 40 individuals per cm^2 during August and September, which is about three times lower compared to the control MOTIF. Densities increased again in October. Maximum numbers in spring were somewhat higher in the MOTIFs with sludge mixed into the sediments (Rs and Rsf) than in the case where sludge was only added to the MODUSes (Rf). The increase in numbers in the autumn seemed to be somewhat reduced in the MOTIFs with sludge disposed in the MODUSes (Rsf, Rf) compared to the MOTIF with sludge only mixed into the MOTIF sediment (Rs).

The nematode development in MOTIFs treated with fresh Delfzijl sludge, MOTIF (Df), remained substantially behind the development in the control basin (C2, 1988). Only from

August onwards, a substantial increase in numbers was observed. Highest numbers were reached in October. In 1989 no differences could be observed between "Dff" and "C3", except for a strong increase in numbers in the "Df" MOTIF in October.

The disposal of reduced Rotterdam sludge (Rr) to the MODUS shows a similar, but less pronounced development to fresh Rotterdam sludge. Although the initial increase in numbers in the "Rr" MOTIF is high compared to the "C2" MOTIF, it is more gradual compared to the "Rf" MOTIF of the year before. Maximum numbers were reached later on (end of July). Densities from August onwards were low compared to the "C2" MOTIF.
The addition of slightly oxidized Rotterdam (Ro) sludge to the MODUS kept nematode numbers lower than in the control and fresh Rotterdam sludge exposed MOTIFs. To a minor extent, this was also true for oxidized Delfzijl sludge (Doo), except for a large increase in numbers in October, but does not apply to the intensively oxidized Rotterdam sludge, which showed generally higher values even compared to the control.

The nematode community in the MOTIFs is characterized by the subsequent dominance of different species. In Figure 5.4, the dominance of different taxa is shown for the control MOTIF in 1987, but applies to all three experimental years.
Monhystera spec. (Figure 5.5) only appeared in May-July and showed a peak at the beginning of July in all MOTIFs. Highest values were found in 1987, especially in MOTIFs with sludge mixed through the sediments (Rs and Rsf). As *Monhystera* probably feeds on detritus, it might have benefitted from enhanced food levels deposited after the large spring bloom that year, especially in the MOTIFs treated with sludges. Moreover it can feed on organic material present in the sludges which were mixed into the "Rs" and "Rsf" MOTIF sediments. Considerably lower numbers of *Monhystera* were found in 1988 and 1989, with peak values occuring in April, just after the minor *Phaeocystis* bloom periods.

In May, populations of *Daptonema setosum* started to increase and became the dominant species in all systems (Figure 5.6). They almost disappeared in August of 1988, but in the other years it was present in considerable numbers until the end of the sampling period in October. *D. setosum*, which feeds exclusively on benthic diatoms, was negatively effected by all types of exposure to Rotterdam sludges in 1987. However, in 1988 numbers in the Rr system were higher compared to the control system. Oxidated Rotterdam sludges did not show any effect compared to the control system. Fresh Delfzijl sludge lowered summer values in 1988, but resulted in higher numbers in the autumn of 1989. Oxidated Delfzijl sludge lowered their numbers.

Chromadoridae species (eg. *Chromadora nudicapitata* and *Atrochromadora microlaima*) also feed on benthic diatoms. Chromadoridae reached a summer peak in all MOTIFs (Figure 5.7), but were not as obviously affected by the addition of sludges as *D. setosum*. All Delfzijl sludges even seemed to stimulate populations in the late summer and autumn.

Table 5.1 *The species composition of the nematode community in the MOTIFs and MODUSes, in comparison to the settlement from intake water and the field situation (Mokbaai), in 1987. The abundancy of each species is expressed as the percentage of total nematode density. The species composition is summarized as the number of species and by means of diversity indices from Bouwman (D) and Shannon - Wiener (H).*

	Nematodes; mean percentage species; diversity										
	MOTIF				MODUS				Intake	Mokbay	
	2	3	6	7	1	4	5	8	water	mid	lw
Adoncholaimus fuscus		+							1	1	+
Anoplostoma vivipara										+	2
Ascolaimus elongatus	1	+	+	1							2
Atrochromadora microlaima	5	8	6	10		3		4		2	+
Axonolaimus paraspinusus	1	1	2	1					1	3	+
Bathylaimus stenolaimus		+									
Calyptronema maxweberi	+			+						4	2
Chromadora nudicapitata	3	8	4	6		3	2	2	36	+	+
Chromadorita guidoschneideri	1	1	+	+					54		9
Daptonema oxycerca		+	1	+						+	+
Daptonema setosum	53	43	49	45	93	94	92	94	7	4	5
Datonema sp.	1	1	2	1	3		5		1	+	1
Dichromadora sp.	+									3	1
Eleutherolaimus stenosoma	+									22	11
Enoploides labiatus	+										+
Linhomoeus sp.											+
Mesacanthion diplechma	8	9	5	5	1					22	14
Metachromadora vivipara	+										
Metalinhomoeus typicus										2	1
Microlaimus robustidens	21	20	27	26							
Monhystera sp.	+	+	1	+						15	14
Neochromadora poecilosoma	+	+	1	+						3	6
Odontophora rectangula	+	+			1					3	6
Oncholaimus brachycercus	1	1	+	1	1					1	+
Onyx sp.									1	3	3
Oxystomatina elongata	+	+	+								
Paracanthonchus caecus	1	2									
Rhabditis marina	+	+	+	+						1	6
Sabatieria pulchra	+		+							5	10
Sphaerolaimus sp.	+	+	+	1						4	6
Spirina parasitifera	1	3	1	1			1				
Tripyloides marinus											+
Viscosia glabra	+	+									
Viscosia viscosa					1					5	5
	100	100	100	100	100	100	100	100	100	100	100 %
Number of species	25	22	18	17	6	3	4	3	7	24	30
Sampling date					10/8				29/9	21/7	
Density (n/cm^2)					33	8	15	2	13	23	35
Diversity (D)	58	62	56	61	12	14	16	14	56	80	87
(H)	2.09	2.73	2.25	2.37	0.51	0.40	0.53	0.26	1.54	3.29	3.72

$D = C\,(100 - \sqrt{f1^2 + f2^2 + ... + fn^2})$ (Bouwman, 1983)

H = Shannon-Wiener diversity

Table 5.2 *The species composition of the nematode community in the MOTIFs and MODUSes, in comparison to the settlement from intake water and the fieldsituation (Mokbaai), in 1988. The abundancy of each species is expressed as the percentage of total nematode density. The species composition is summarized as the number of species and by means of diversity indices from Bouwman (D) and Shannon - Wiener (H).*

	Nematodes; mean percentage species; diversity										
	MOTIF				MODUS				Intake	Mokbay	
	2	3	6	7	1	4	5	8	water	mid	lw
Adoncholaimus fuscus		+									1
Anoplostoma vivipara											3
Ascolaimus elongatus	+	1		1					6	12	3
Atrochromadora microlaima	15	17	14	9	12				5		16
Axonolaimus paraspinusus	+	+	+							1	+
Bathylaimus stenolaimus				+							
Calyptronema maxweberi										+	1
Chromadora nudicapitata	2	2	2	1	18				39		2
Chromadorita guidoschneideri	2	2	3	1						1	1
Daptonema oxycerca	21	38	32	45	8		100		37	4	7
Daptonema setosum	11	5	7	8	12						1
Datonema sp.	+	+									+
Dichromadora sp.	+	+									
Eleutherolaimus stenosoma		+	+								+
Enoploides labiatus	2	+	2	1						+	
Linhomoeus sp.	+										
Mesacanthion diplechma		+									1
Metachromadora vivipara	3	8	12	4						53	9
Microlaimus robustidens										2	+
Monhystera sp.	35	23	24	17							
Neochromadora poecilosoma	1	1		1						6	+
Odontophora rectangula	+									12	3
Oncholaimus brachycercus	1			3	10					+	1
Onyx sp.	1	+									
Paracanthonchus caecus	+	+	1							3	3
Rhabditis marina	+	+	1	3							
Sabatieria sp.			+								
Sabatieria pulchra		+				70	100				26
Sphaerolaimus sp/.			+							+	1
Spirina parasitifera	+	+		+						5	12
Tripyloides marinus	2	1	1	5	40	30			12		
Viscosia viscosa									5	+	7
	100	100	100	100	100	100	100	100	100	100	100 %
Number of species	21	22	15	15	6	2	1	1	6	15	23
Sampling date					4/10				1/7	13/10	
Density (n/cm^2)					45	7	0.4	11	2	178	56
Diversity (D)	70	65	74	67	87	81	–	–	75	59	81
(H)	2.57	2.38	2.63	2.60	2.36	0.88	–	–	2.11	2.28	3.34

$$D = C\,(100 - \sqrt{f1^2 + f2^2 + \dots + fn^2})$$ (Bouwman, 1983)

H = Shannon-Wiener diversity

Table 5.3 *The species composition of the nematode community in the MOTIFs and MODUSes, in comparison to the settlement from intake water and the field situation (Mokbaai), in 1989. The abundancy of each species is expressed as the percentage of total nematode density. The species composition is summarized as the number of species and by means of diversity indices from Bouwman (D) and Shannon - Wiener (H).*

	Nematodes; mean percentage species; diversity										
	MOTIF				MODUS				Intake	Mokbay	
	2	3	6	7	1	4	5	8	water	mid	lw
Adoncholaimus fuscus	13	8	9	8						+	
Anoplostoma vivipara	+	+								2	
Ascolaimus elongatus	2	3	4	3						22	14
Atrochromadora microlaima	18	17	13	14	8	3	4			2	
Axonolaimus paraspinusus		+	1	+					5		
Bathylaimus stenolaimus	2	3	1	+							
Calyptronema maxweberi	+	+	1	1					1		
Chromadora nudicapitata	+		1	+	4	4	22	4	18		
Chromadorita guidoschneideri	2	2	3	3		2	4		16	6	1
Cyarthonema zosterae											+
Daptonema setosum	10	8	5	9	52	17	4		13	3	1
Datonema sp.						55	12	3		+	1
Datonema oxycerca					8						2
Eleutherolaimus stenosoma	+	+				1					
Enoploides labiatus	+	1	1	+	4					+	1
Hypodontolaimus balticus			+								
Metachromadora vivipara	7	8	8	8		1		7		29	20
Microlaimus robustidens	+	+	1	+						+	
Monhystera sp.	3	9	13	15							1
Neochromadora poecilosoma	+			+						1	2
Odontophora rectangula	+	+							2	10	9
Oncholaimus brachycercus	17	15	14	13							1
Onyx sp.	2	+	+	1						+	
Oxystomatina elongata											1
Paracanthonchus caecus	3	2	1	3	4		15	1	6	1	2
Rhabditis marina										+	
Sabatieria pulchra	+			+				87	2	5	2
Sphaerolaimus sp.		+	+	1	4			3		+	1
Spirina parasitifera	2	1	2	1				1	13	13	41
Tripyloides marinus	2	2	2	3	17	17	28			+	
Viscosia viscosa	+	+	+	+			11	1	25	2	1
	100	100	100	100	100	100	100	100	100	100	100 %
Number of species	23	22	22	21	8	8	8	8	9	19	20
Sampling date					24/10				20/10	9/3	29/8
Density (n/cm^2)					3	18	2	7	1	78	57
Diversity (D)	84	83	84	86	68	62	89	20	90	76	65
(H)	2.79	3.27	3.47	3.38	2.23	1.93	2.70	1.12	2.80	2.74	2.85

$D = C\,(100 - \sqrt{f1^2 + f2^2 + ... + fn^2})$ (Bouwman, 1983)

H = Shannon-Wiener diversity

3.2 Harpacticoid copepods

Numbers of harpacticoid copepods were about ten times lower than numbers of nematodes. Highest numbers were found in the period of May-July, and occasionally in late September (Figure 5.8).
In the control systems, high peak values, up to 15 individuals per cm^2, were observed in July 1987. Considerably lower peak values were found in this period in both 1989 and 1988. In 1988, a second peak of up to 15 individuals per cm^2 occurred in the control MOTIF in September.
Except for the "Roo" MOTIF (and "Ro" MOTIF during the peak in June 1988), all Rotterdam sludge treatments lowered densities of harpacticoids. The Delfzijl treatment in 1988 (Df) lowered the densities of copepods too.

3.3 Oligochaetes

Numbers of oligochaetes only occasionally exceeded densities of 5 individuals per cm^2 in 1987 and 1988 (Figure 5.9). In 1989, numbers were higher in all MOTIFs. Seasonal dynamics were hardly recognised, but highest values were found during May-July. Lowest densities were usually found in the control MOTIFs. Higher peak values were especially found in the "Rsf", "Roo" and "Doo" sytems.

3.4 Ostracods

The development of ostracods started in July (1987 and 1989) or in August (1988). Even in the MOTIFs with highest densities, maxima were only about 7 ostracods per cm^2 (Figure 5.10). In 1987, the development of ostracods was strongly inhibited by the mixture of Rotterdam harbour sludge into the MOTIF sediments. Disposal of dredged materials in the MODUSes inhibited ostracod development in 1988. In 1989, no clear adverse effects of dredged materials were observed. The densities of ostracods were even highest in the Roo-MOTIF.

3.5 Turbellaria

Turbellaria were only observed in the MOTIFs in 1988 and 1989, probably as a result of the improvement of the water intake system (see SEDEX report 1, Scholten 1993). Still, the densities (Figure 5.11) were very low (0 - 2 per cm^2). In 1988, the densities were lower in the "Df" and "Rr" MOTIFs compared to the control system, whereas Turbellaria were absent in the "Ro" MOTIF. In 1989, Turbellaria reached higher densities in MOTIFs treated with harbour sludges.

3.6 Effects of organic enrichment

The extra loading of subplots of the control MOTIF with organic matter resulted in somewhat lower densities of nematodes and higher densities of oligochaetes in July, and ended up with lower densities of nematodes and ostracods in August. (Figure 5.12)

3.7 Competition

The effect of competition for food between the meiobenthos with the macrobenthos was studied in a seperate experiment. Food availability was regulated by deposition of organic material, whereas *Hydrobia* was introduced as a macrobenthic competitor for food. Numbers and ash-free dry weight of introduced and sampled *Hydrobia* are presented in Table 5.4.

Table 5.4 Hydrobia *in the competition experiment between the meiobenthos and the macrobenthos at two food levels.*

	Hydrobia addition	Code	*Hydrobia* (number)		AFDW/ind (mg)	
			7 Sept	20 Oct	7 Sept	20 Oct
Without organic material	Yes	H	400	411	0.9	2.4
	No	-		52		
With organic material	Yes	OH	400	290	0.9	2.4
	No	O		4		

Numbers of *Hydrobia* hardly changed during the experiment when no organic material was added. Addition of organic material reduced the number of *Hydrobia.* Although precautions were taken to avoid the introduction of *Hydrobia* in the trays with meiobenthos only, some *Hydrobia* were present in these systems at the end of the experiment. There was a considerable increase in biomass per individual which seemed to be independent of the amount of organic material.

Addition of *Hydrobia* generally reduces the meiofauna density, whereas addition of organic matter generally reduces the densities of copepods and, to minor extent, nematods and increases the densities of oligochaetes (Figure 5.13).

The impact of *Hydrobia* on the meiofauna was most severe when no organic matter was supplied. This is most likely related to a better functioning of *Hydrobia* in sediments without organic matter supply rather than to competition for food.

4. DISCUSSION AND CONCLUSIONS

4.1 MOTIF realism

The meiofauna in the MOTIFs originated from a tidal flat in Mok baai on the island of Texel. An inoculum was dispersed in the MOTIFs each spring in order to guarantee the development of representative meiofaunal species. Additional species may have been introduced with the suppletion water derived from the western Wadden Sea area.
The meiofauna in the MOTIFs was dominated by nematodes. Harpacticoid copepods and oligochaetes were also present in considerable numbers. In Wadden Sea and North Sea sediments, nematodes are the dominant meiofaunal group (van Dessel, 1988; Huys et al., 1992). At four tidal flats in the western Wadden Sea, a mean number of 163.5 per cm^2 was reported during October by van Dessel (1988), which agrees very well with maximum densities found in the control MOTIFs. No clear seasonal pattern was observed in the western Wadden Sea by van Dessel (1988). This can probably be explained by the high number of species, differing in eg. lifetime and lifecycle. In the MOTIFs, however, seasonal patterns were sometimes observed which resulted from the temporary dominance of only a few species. In spring, *Monhystera* spec., which are probably detritus feeders, were dominant, succeeded by Chromadoridae species (like *Chromadora nudicapitata* and *Atrochromadora microlaima*) and *Daptonema setosum* which feeds exclusively on benthic diatoms. All these species are also present in the Wadden Sea.

Harpacticoid copepods in the western Wadden Sea show low densities in April and May (van Dessel, 1988), but no evident seasonal differences were found. Mean density of four tidal stations in October was 7.7 per cm^2 . In the MOTIFs, a clear seasonal pattern was observed with highest densities occuring in June or July and ranging from 5 to 10 individuals per cm^2. Only in 1989 an additional maximum was reached in September. Although numbers of harpacticoid copepods are relatively low compared to nematodes, their contribution to total meiofaunal biomass is substantial because of a higher individual weight (about six times higher than individual nematode biomass).

Oligochaetes, only present in low densities in the MOTIFs, are not an important meiofaunal taxon in the western Wadden Sea but are numerous in more brackish areas of the Ems estuary (Bouwman, 1983). Ostracod densities in the Ems estuary normally do not exceed 0.5 specimens per cm^2 . In the MOTIFs, numbers of 5 per cm^2 were frequently observed. No comparable data are available for Turbellarians which were also of minor importance in the MOTIFs.

It can be concluded that both composition and density of the meiobenthos are comparable to the tidal flats in the Wadden sea.

4.2 Effects of dredged materials

Fresh sludges
The addition of fresh sludges to the MOTIFs generally caused high phytoplankton levels during the summer. Results from 1989 indicate that high phytoplankton densities resulted in an elevated sedimentation of organic material (see SEDEX Report 3, Scholten *et al.*, 1993). In the spring of 1987, settlement of phytoplankton also occurred after a bloom of *Phaeocystis*. This was reflected by the high chlorophyll-a content of the sediment. Some meiobenthos species seemed to benefit from the enrichment of the sediment with organic material. In spring 1987, numbers of *Monhystera*, which feeds on detritus, showed a clear peak in all but the control MOTIFs when the chlorophyll levels in the sediment were high. Also, oligochaetes sometimes showed a positive response to elevated food levels, resulting from settled organic matter or the addition of sludge to the MOTIF sediments. The positive effect of the sedimentation of organic material on oligochaetes was confirmed by an additional

experiment. Other groups in the meiobenthos did not seem to profit from increased organic material levels in the sediment.

The nematode *Daptonema setosum* and ostracods were negatively affected by most fresh sludges except in the "Dff" MOTIF. Drastic effects were observed in 1987 when both the addition of sludge to the MODUSes and the mixing of sludge in MOTIF sediments caused an inhibited development of *D. setosum*. Harpacticoid copepods responded in about the same way. Numbers were lowered in the "Rf", "Rs" and "Rsf" MOTIFs in 1987. Harpacticoid copepod numbers were decreased in the "Df" MOTIF but somewhat increased in the "Dff" MOTIF.

Weathered sludges
Weathering of harbour sludges did not cause large differences in the impact on the meiobenthos, compared to fresh sludges. Reduced weathering of sludges resulted in a somewhat less pronounced response of nematodes to the enrichment of the sediment with organic material, despite the even higher sedimentation rates. Oxidation of sludges resulted in reduced nematode densities, especially where Delfzijl sludge was concerned. Harpacticoid copepods and oligochaetes had a somewhat higher density in systems treated with oxidized sludges compared to fresh sludges. This is also shown for ostracods in the "Roo" system.

4.3 Causes and consequences

The response of the meiobenthos to dredged material disposal is not very clear, but two processes can still be recognized. An increase in the primary production of phytoplankton, due to nutrient release from sludges, leads to an increase in the development of some meiobenthos species as a result of an opportunistic response to the enrichment of the sediment with organic material probably resulting from the sedimentation of phytoplankton and faecal pellets of zooplankton. On the other hand, the development of some meiobenthic species seems to be inhibited by contaminants released from the sludges. The sediments were loaded with these contaminants from settling suspended matter, which is a main food source for the meiobenthos. Therefore, the exposure of the meiobenthos to contaminants released from dredged material might be relatively high, especially in the case of weathered sludges. Crustaceans (eg. copepods and ostracods) seem to be more sensitive to toxicants in comparison to the other groups, although some specific nematode species (eg. *Daptonema setosum)* are sensitive as well. The biology of meiobenthos species is not well known, so that differences in species sensitivity can not be explained by differences in physiology or life history characteristics. Interactions between meiobenthos species or competition with the macrobenthos have not been demonstrated.

5. ACKNOWLEDGEMENTS

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FIGURES

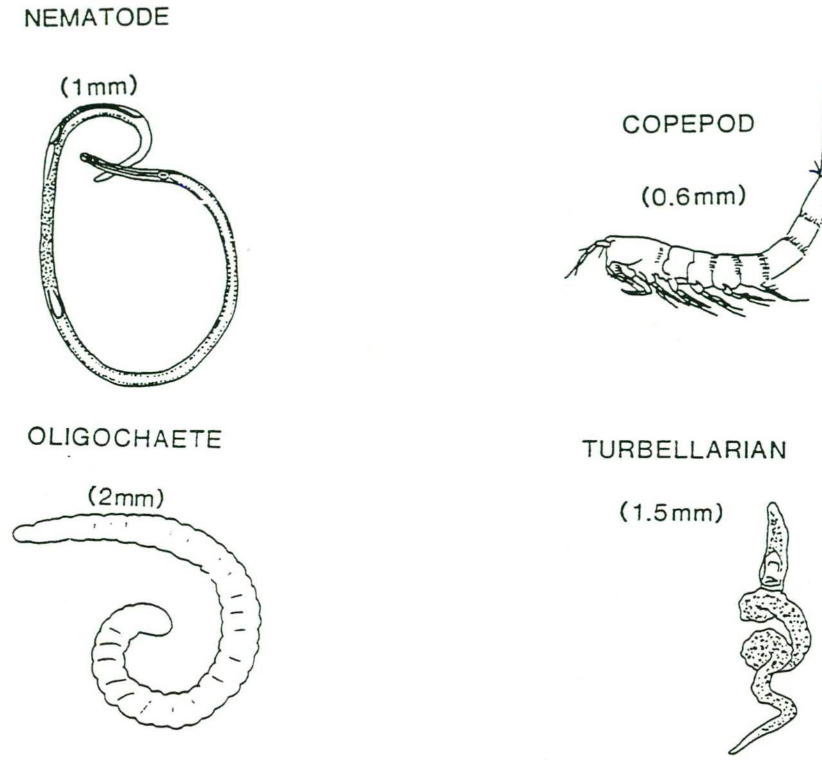


Figure 5.1 *Some dominant meiobenthos taxa present in the MOTIFs: nematodes harpacticoid copepods, oligochaetes and turbellaria.*

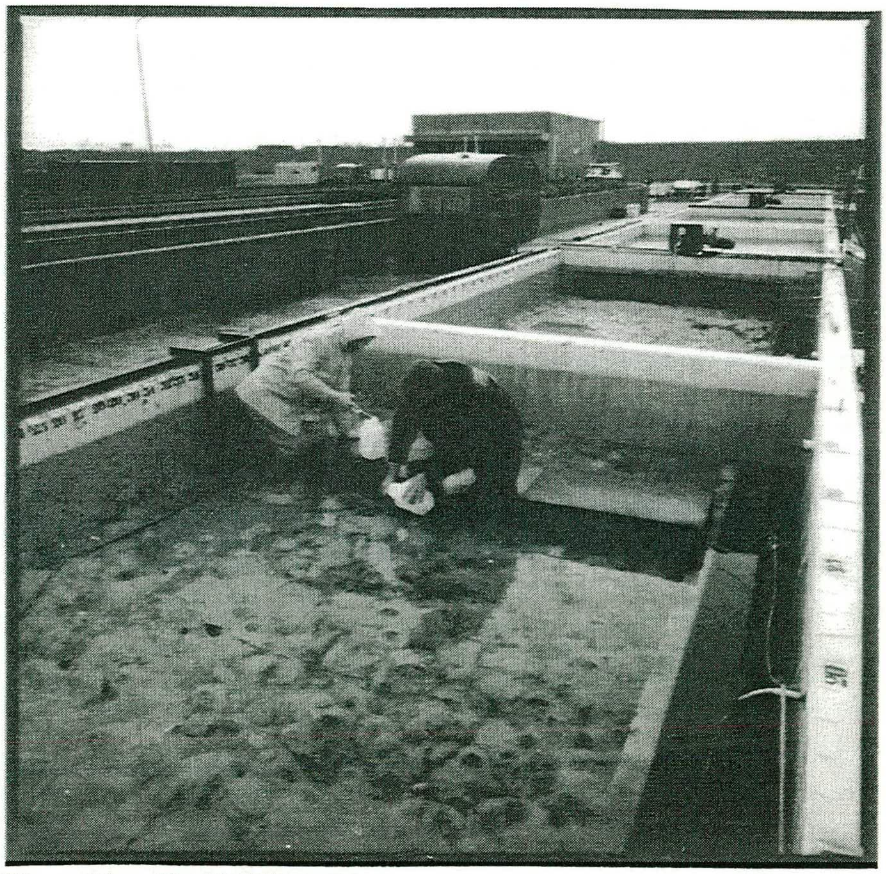


Figure 5.2 *The MOTIF systems.*

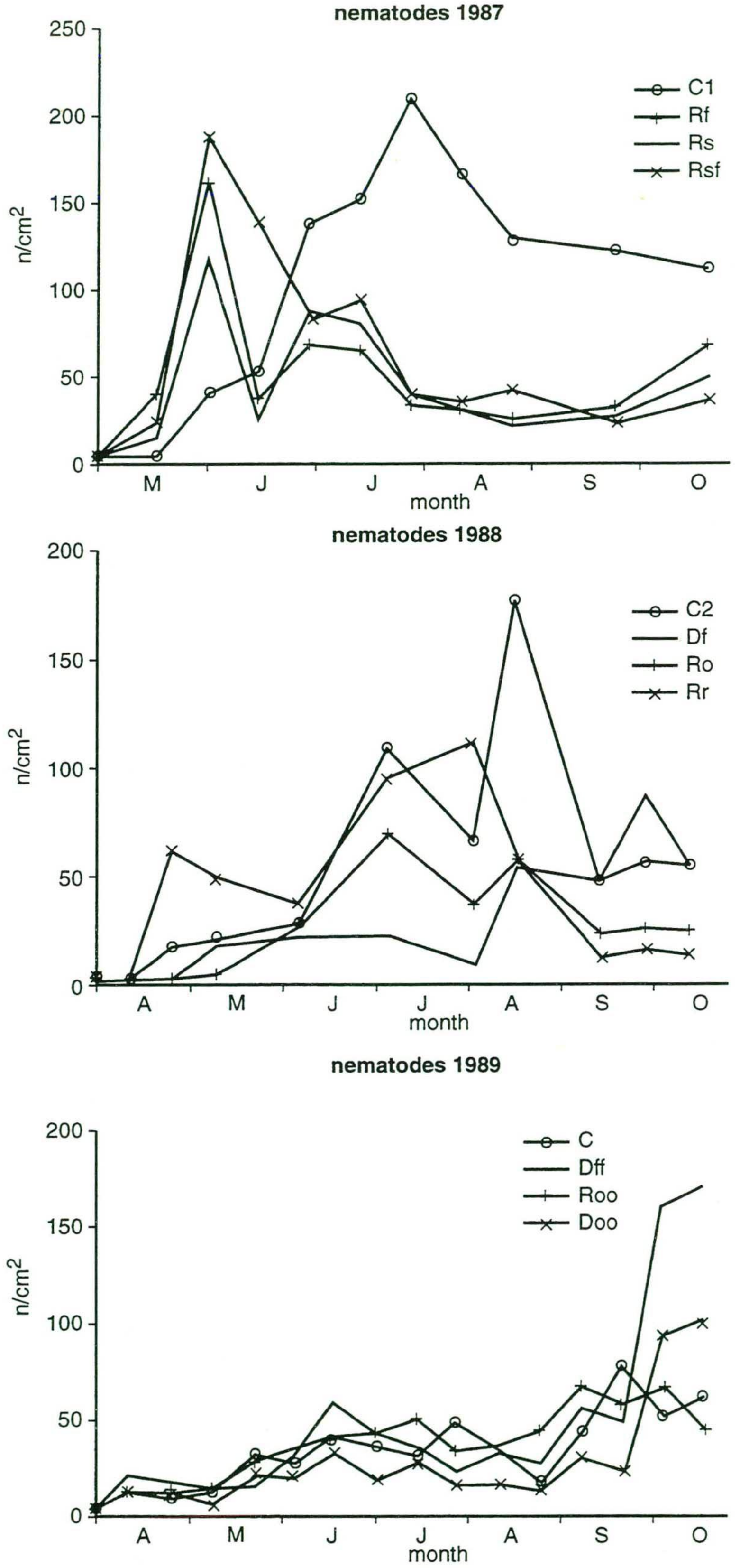


Figure 5.3 *Population densities ($n.cm^{-2}$) of nematodes in the MOTIFs. For abbreviations, see Appendix.*

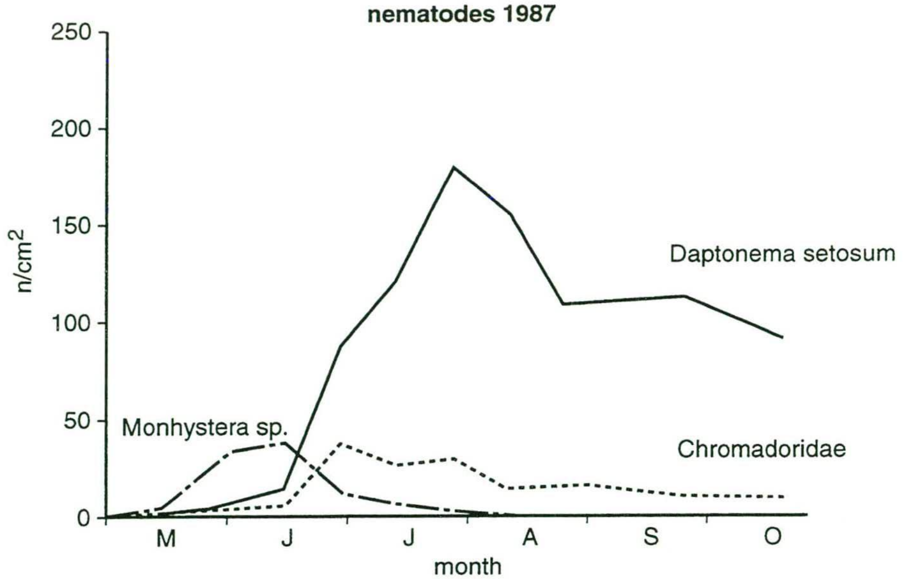


Figure 5.4 *Population densities ($n.cm^{-2}$) of three dominant nematode taxa in the control MOTIF in 1987.*

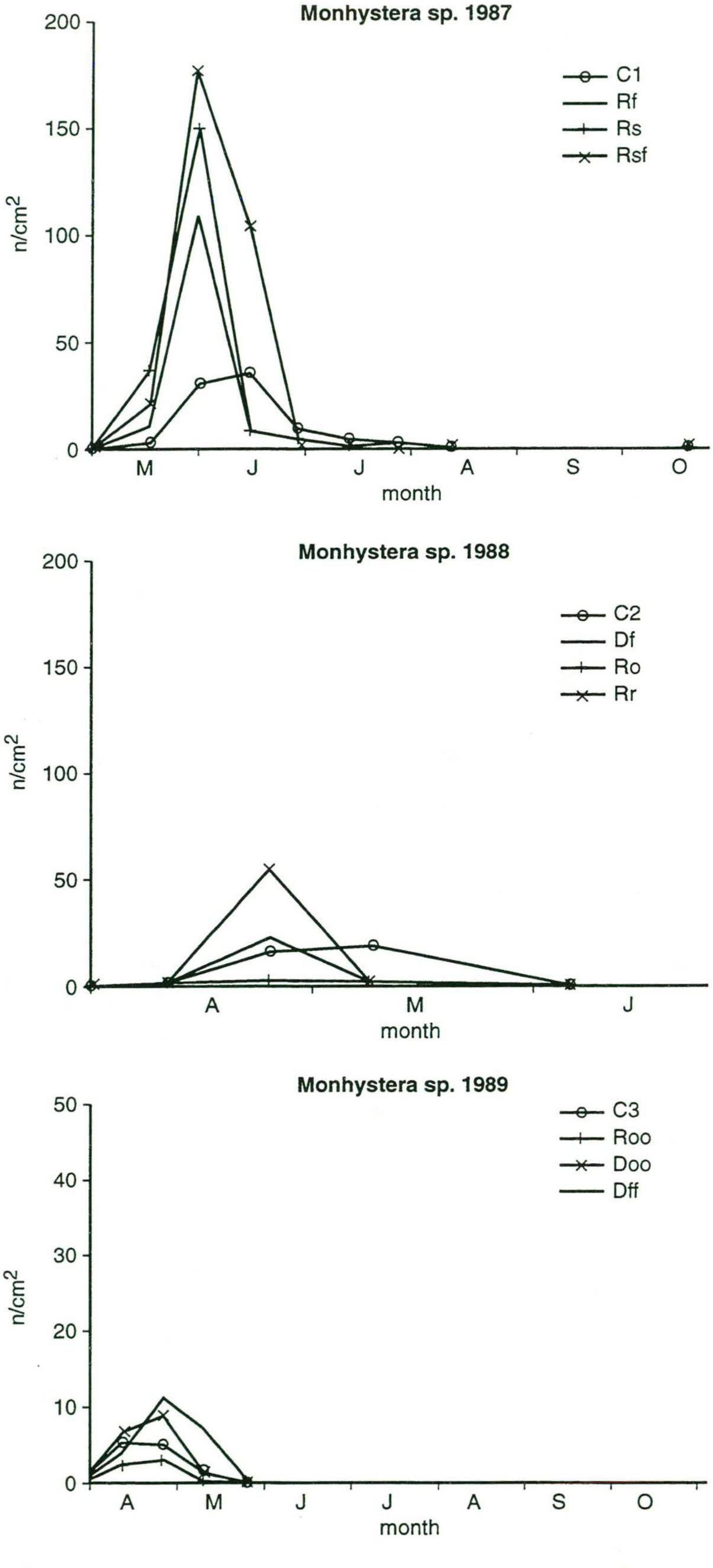


Figure 5.5 *Population densities (n.cm^{-2}) of* ***Monhystera spec*** *in the MOTIFs. For abbreviations, see Appendix.*

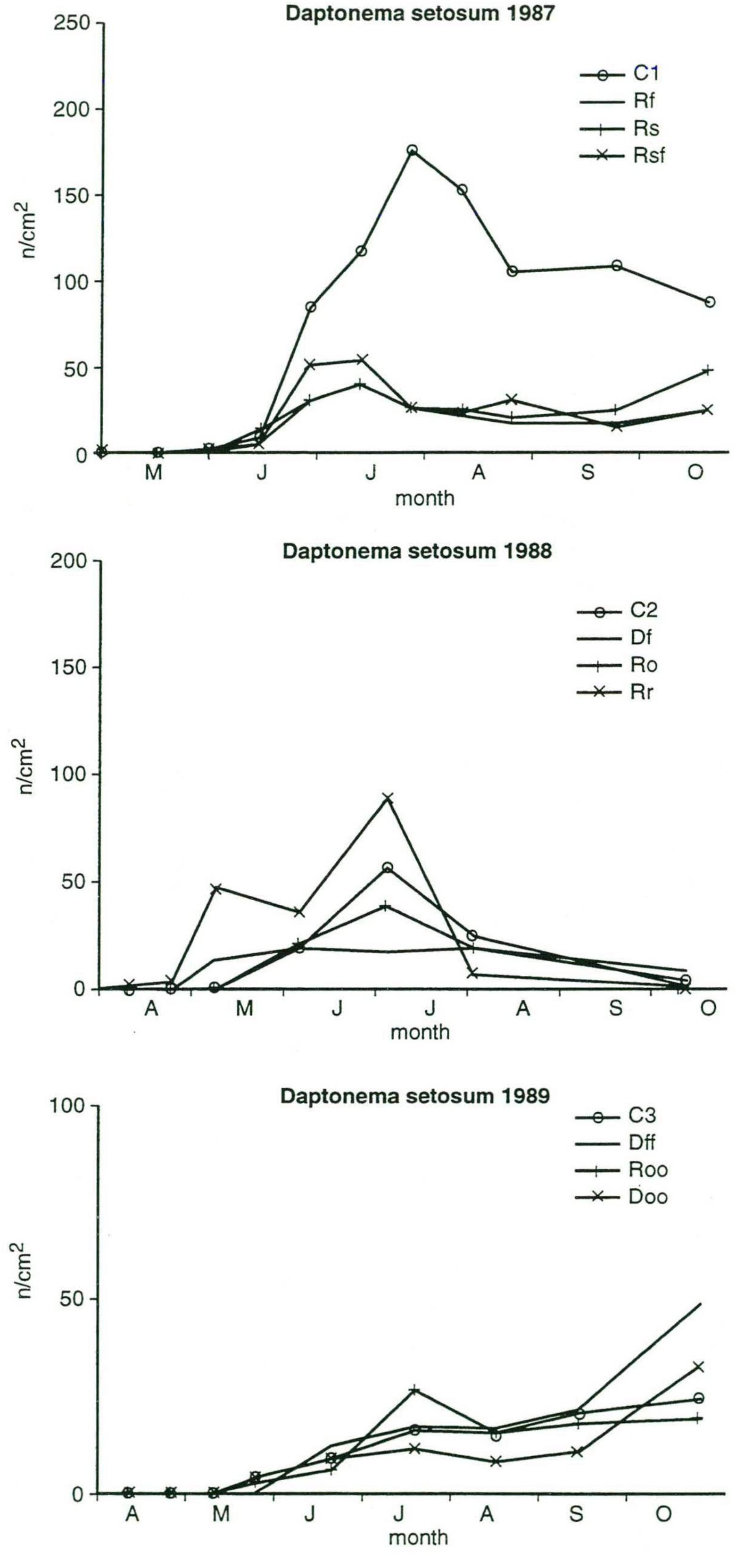


Figure 5.6 *Population densities (n.cm^{-2}) of* ***Daptonema setosum*** *in the MOTIFs. For abbreviations, see Appendix.*

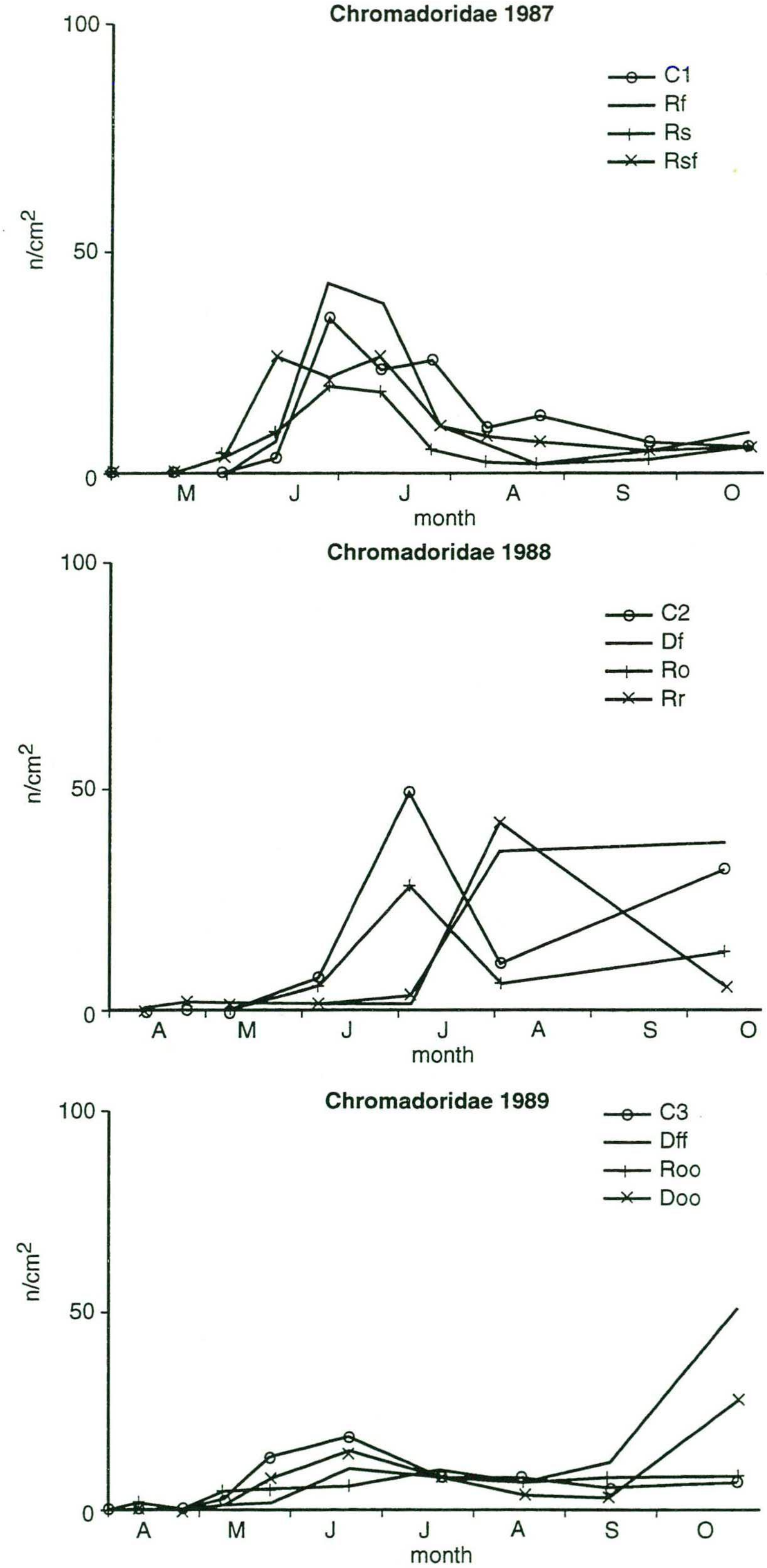


Figure 5.7 *Population densities (n.cm^{-2}) of* ***Chromadoridae*** *in the MOTIFs. For abbreviations, see Appendix.*

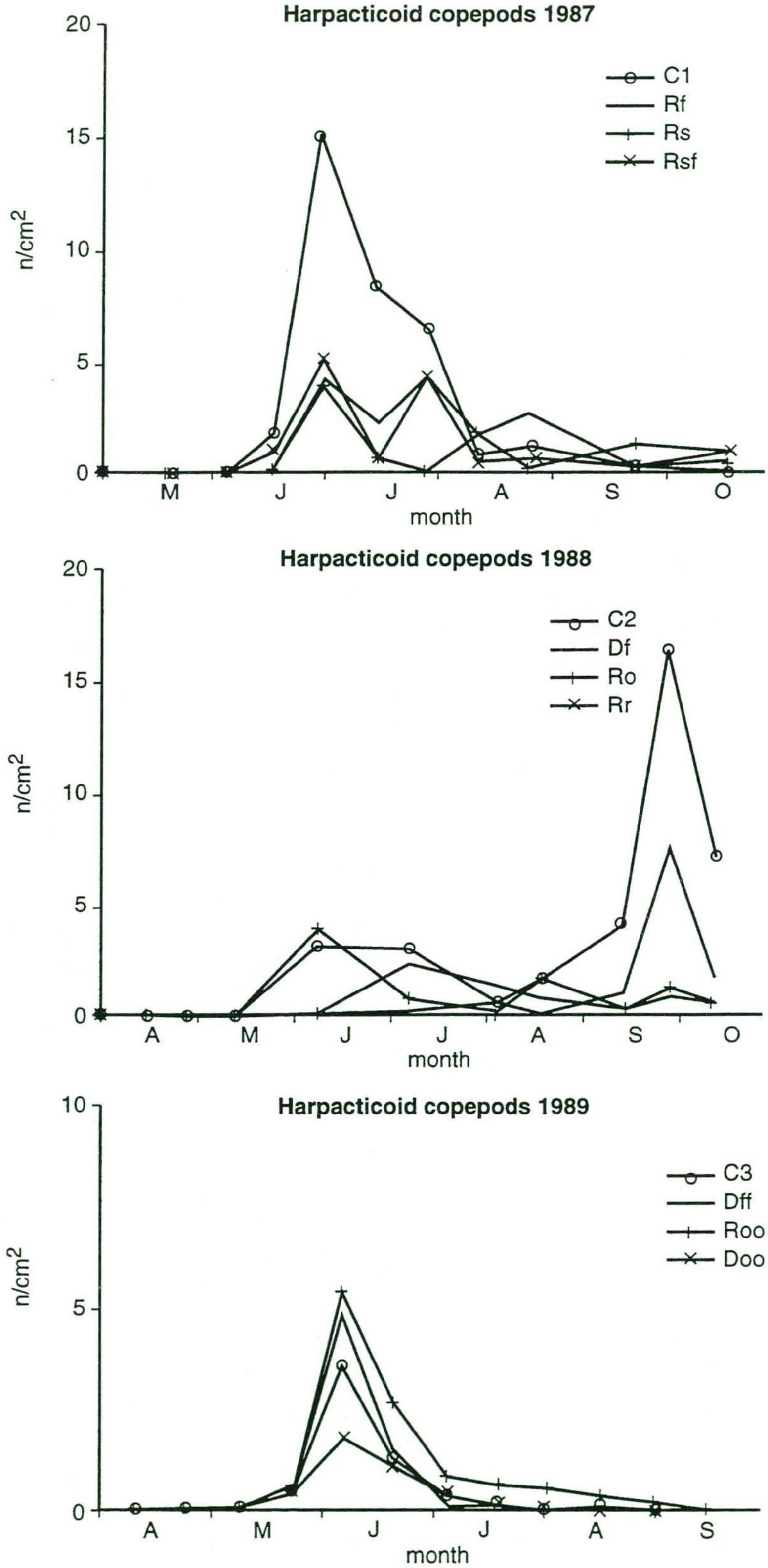


Figure 5.8 *Population densities ($n.cm^{-2}$) of harpacticoid copepods in the MOTIFs. For abbreviations, see Appendix.*

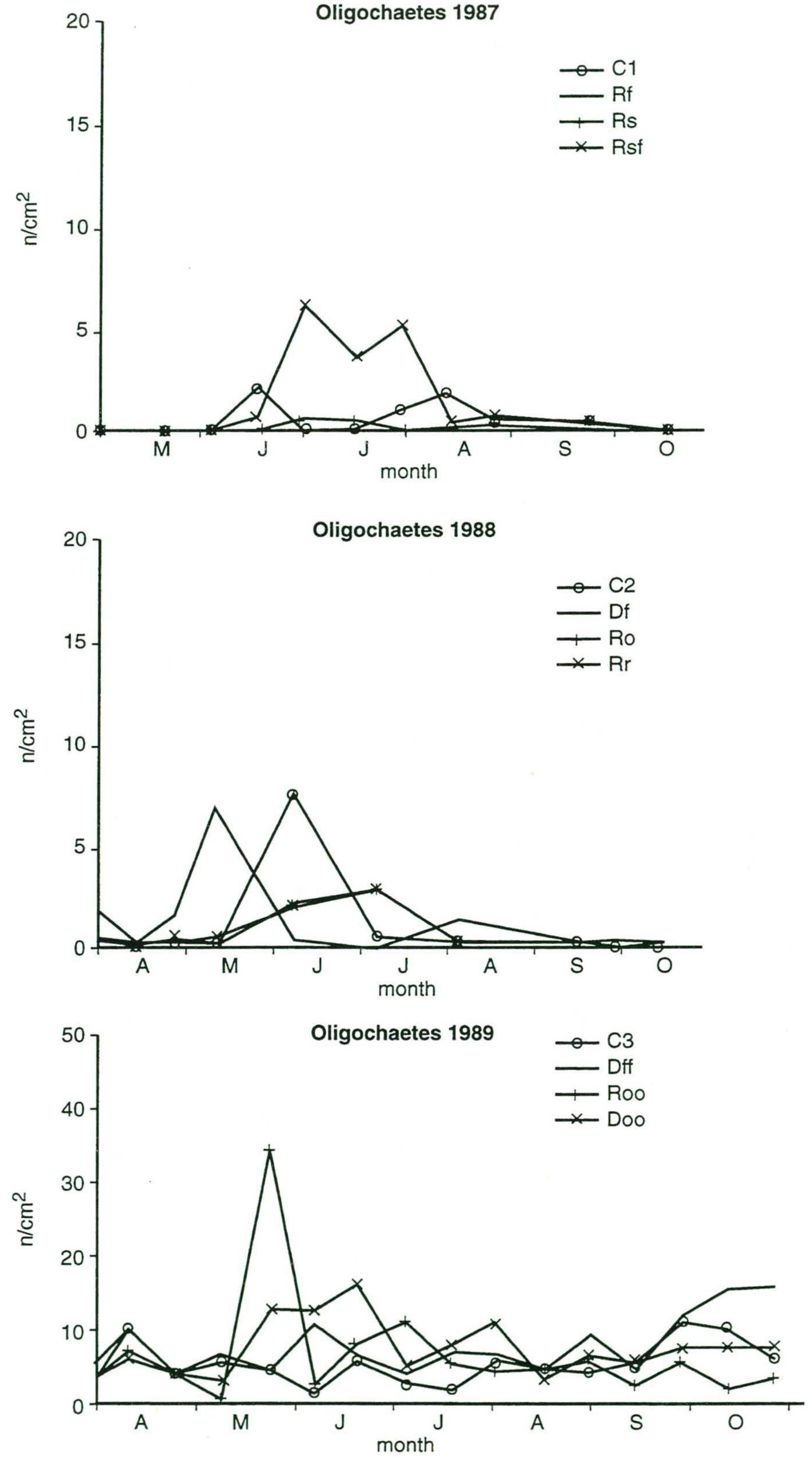
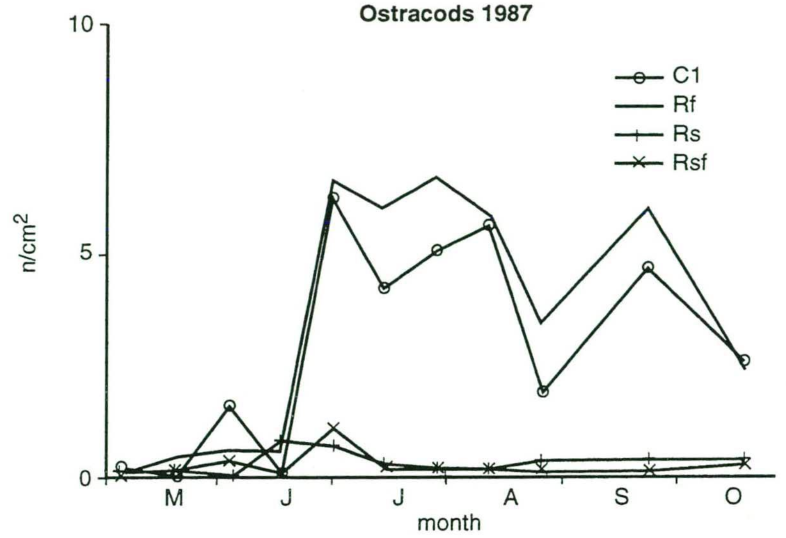
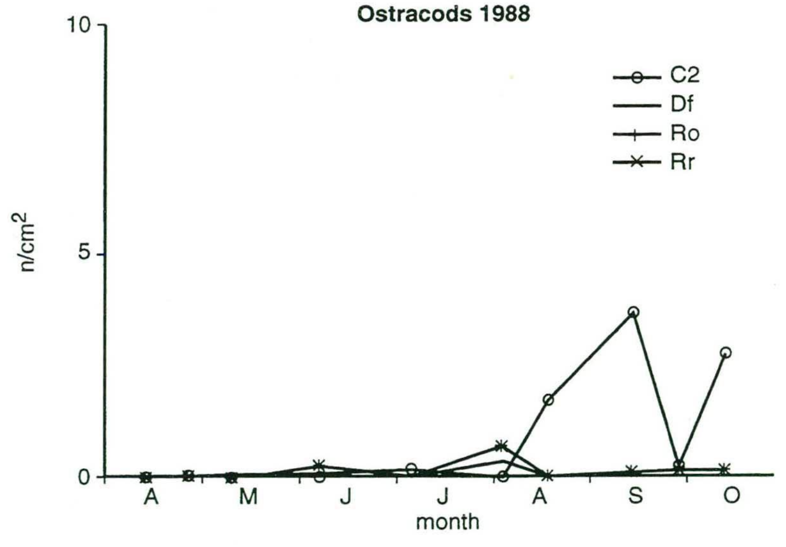


Figure 5.9 *Population densities (n.cm^{-2}) of oligochaetes in the MOTIFs. For abbreviations, see Appendix.*





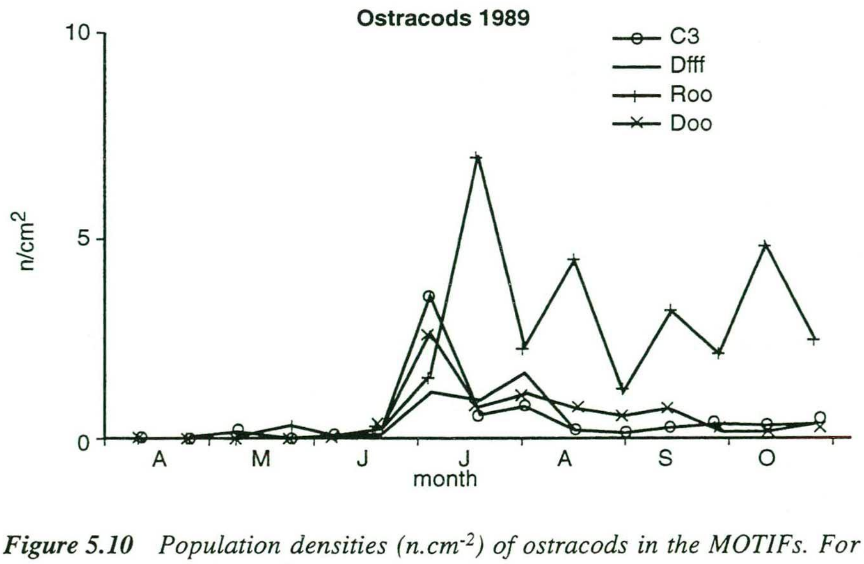
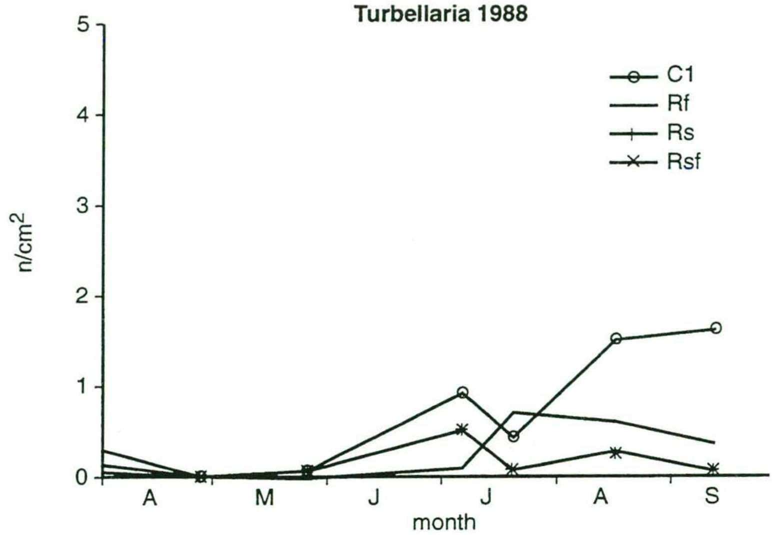


Figure 5.10 *Population densities (n.cm^{-2}) of ostracods in the MOTIFs. For abbreviations, see Appendix.*



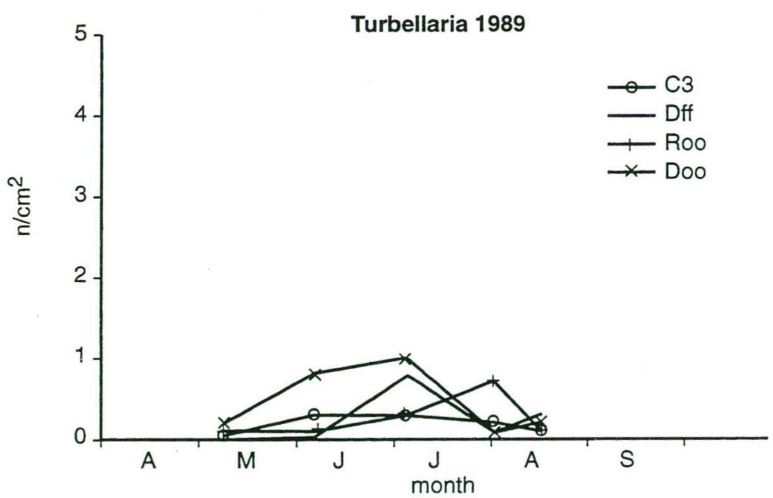


Figure 5.11 *Population densities (n.cm^{-2}) of Turbellaria in the MOTIFs. For abbreviations, see Appendix.*

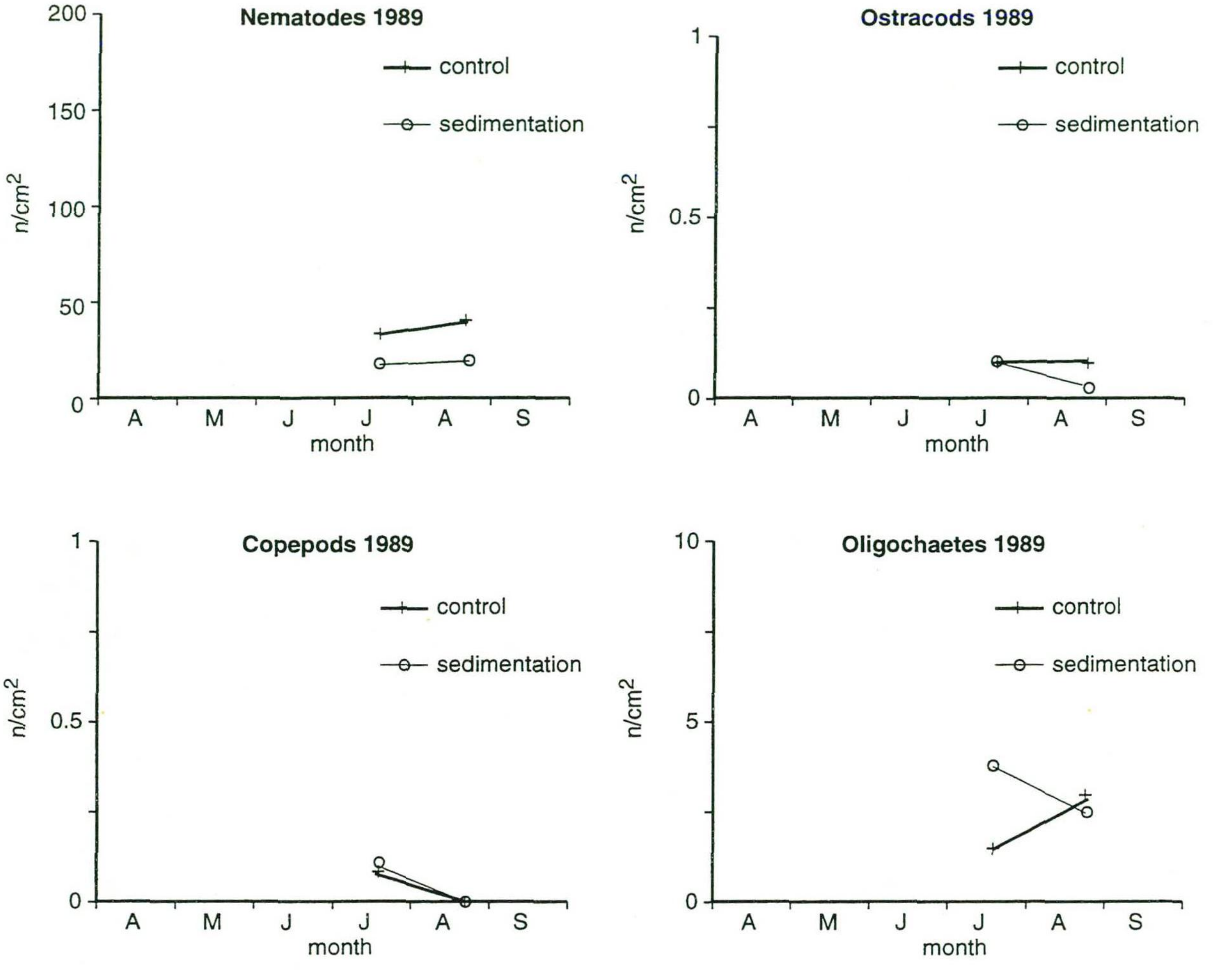


Figure 5.12 *Population densities ($n.cm^{-2}$) of the meiobenthos taxa in the subplots in the control MOTIF, with or without organic material addition.*

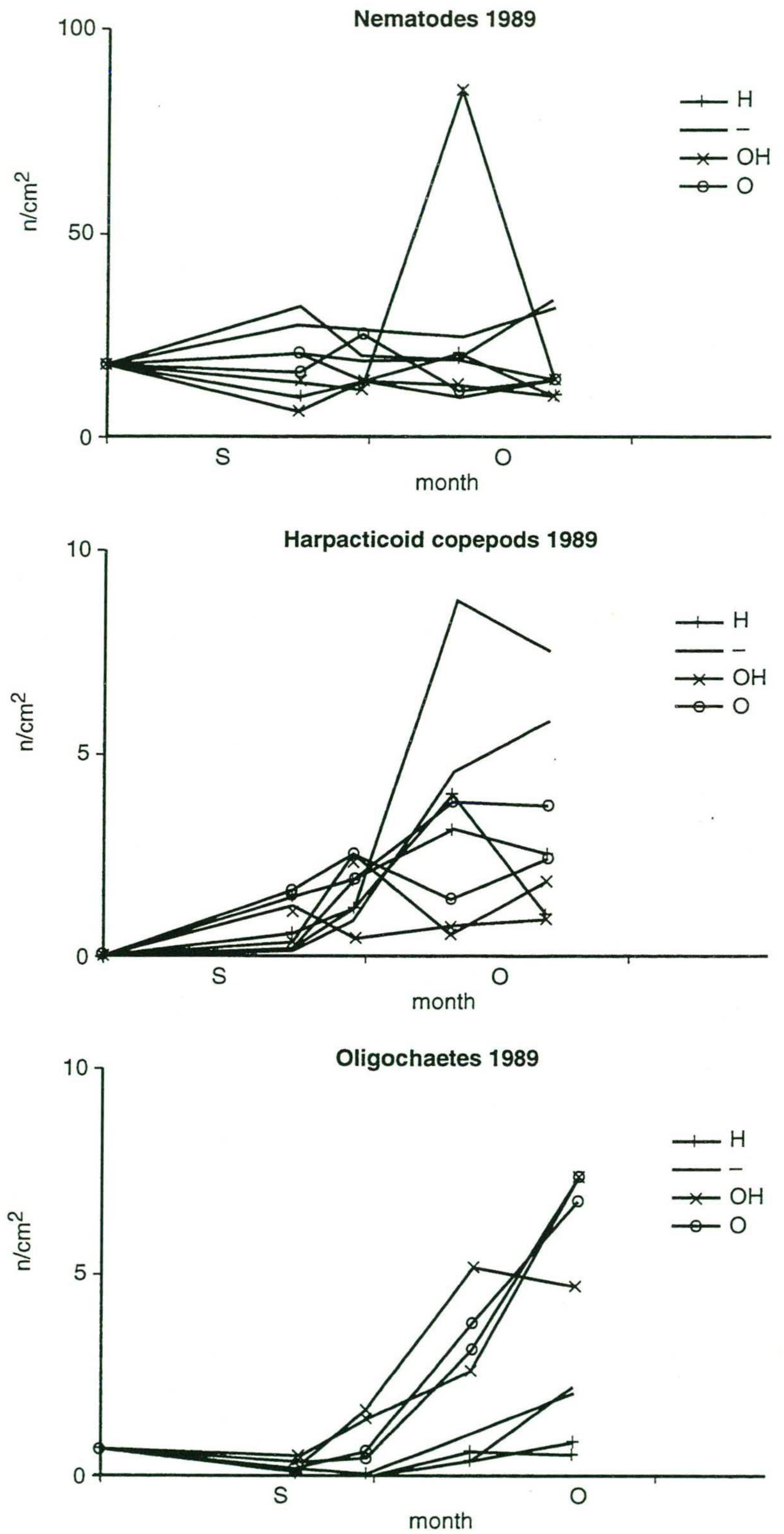


Figure 5.13 *Population densities (n.cm^{-2}) of the meiobenthos taxa in the additional experiment with or without organic material (O) and Hydriobia (H) addition.*

APPENDIX Abberviations used a as code for the various treatments of the MOTIF systems

MOTIF code	Year	Treatment
C1	1987	Control (Mokbaai sediment)
C2	1988	Control (Mokbaai sediment)
C3	1989	Control (Dune sand)
Df	1988	Delfzijl sludge (fresh) in MODUS
Dff	1989	Delfzijl sludge (fresh) in MODUS
Doo	1989	Delfzijl sludge (oxidized) in MODUS
Rf	1987	Rotterdam sludge (fresh) in MODUS
Ro	1988	Rotterdam sludge (oxidized) in MODUS
Roo	1989	Rotterdam sludge (double-oxidized) in MODUS
Rr	1988	Rotterdam sludge (reduced) in MODUS
Rs	1987	Rotterdam sludge (fresh) mixed with sediment of MOTIF
Rsf	1987	Rotterdam sludge (fresh) in MODUS and mixed with sediment of MOTIF