RESEARCH ON THE DYNAMICS OF MICROPHYTOBENTHOS IN THE WESTERN SCHELDT 1989-1993

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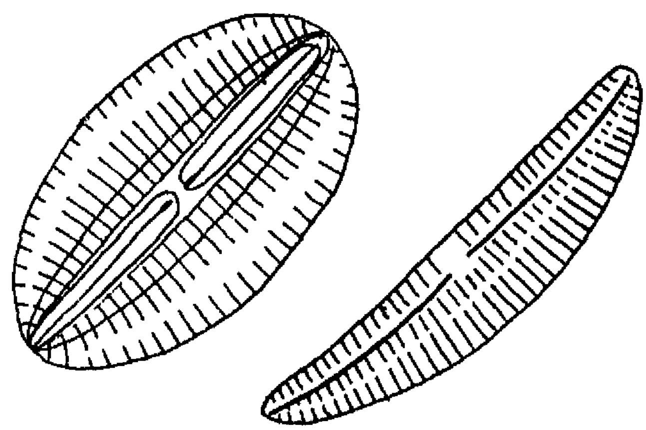

Research done under the supervision of **Drs. D. J. de Jong**
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1. INTRODUCTION

The general purpose of this research is to achieve a better understanding as to the importance of benthic diatoms in the primary production in the Western Scheldt. Although, in general *benthic* primary production is considered as rather insignificant compared to the *pelagic* primary production, comprising only 10-15% of the total primary production, it is an important food source for specific animals like zooplankton, sediment feeders, fish and birds. In the Western Scheldt, due to the very turbid water that may prevent the pelagic algae from having a large primary production, the relative contribution of the microphytobenthos might be higher than usual. Such a larger share of benthic diatoms might benefit certain groups of benthic animals, especially sediment feeders (like worms).

Possible changes in the intensive dredging program in the area might have an influence on ecological systems in the estuary. Such changes may result in a decrease in water turbidity, causing an increase in pelagic primary production as well as benthic primary production (as found in the Eastern Scheldt [de] Jong et al, 1993); This may even result in a change in ratio between both types of primary production. As a consequence, a shift may also occur in the ratio of sedimentfeeders and other benthic animals (like suspensionfeeders as shellfish). Of course alterations at lower levels of the food chain could also have a great influence on levels above.

The following report deals with certain aspects concerning the biomass of microphytobenthos in the Western Scheldt during the years 1989-1993.

The objectives of this research are listed below:

1. To give a description of seasonal and annual changes in the biomass throughout the years 1989-1992.
2. To search for a correlation between the biomass and different abiotic factors, so as to conclude what aspects may influence the distribution of the microphytobenthos in the Western Scheldt.
3. To calculate the average annual primary production of the benthic diatoms in the Western Scheldt during the years 1989-1992.
4. To estimate the contribution of the above to the total primary production (pelagic + benthic) in the Western Scheldt.
5. To compare the results to those of other areas in The Netherlands.

2. METHODS

2.1 AREA

Western Scheldt - The area of research is situated in the Scheldt estuary which lies in the NW of Belgium and SW of the Netherlands. The **Western** Scheldt refers only to the Dutch part of this estuary, stretching from the Belgium-Dutch border to the mouth of the river in Flushing over about 55km (Figures I and II). The total area is approximately 310km^2, of which about 63km^2 is intertidal area and $\pm$32 km^2 salt marsh. The tidal range increases from an average of 3.8 m near Flushing to 4.7 m near the border, and a salinity gradient is present from approx. $6^{\circ}/_{oo}cl^-$ at the border to $18^{\circ}/_{oo}cl^-$ near Flushing.

The intertidal area can be divided into mudflats and sandflats. The mudflats are situated along the dikes while the sandflats are totally surrounded by water. The soil on mudflats usually has a higher clay content, while sandflats are more sandy. However, as a result of constant hydrodynamical changes, sandflats with areas rich in clay and sandy mudflats
can also be found.

Flats examined - The flats examined (shown in figure II) include 6 sandflats and 11 mudflats situated in different locations across the Western Scheldt. The sandflats examined include: Hooge Springer, Molenplaat, Plaat van Ossenisse, Rug van Baarland, Valkenisse, and Hooge Platen. The mudflats: Baalhoek, Saeftinge , Appelzak, Everingen, Platen van Hulst, Bath, Paulina polder, Terneuzen, Rammekens, Staartse Nol and Waarde.

2.2 SAMPLING

The data on the biomass of the benthic diatoms were achieved by taking samples approximately once a month during the years 1989-92 from the different flats mentioned above. (The year of initial sampling varies per area.)
On each flat, 3-6 plots were marked, situated in one or more transects from Mean Low Water upwards. At each plot 5 random samples were taken from the upper first centimetre of the sediment layer, using a perspex corer of 2.3cm in diameter. In this layer one might expect to find a relatively high density of benthic diatoms (see discussion).

In addition, the depth distribution of the diatoms was measured for the layer of 0 to 10cm, in which 5 subsamples were taken from each subsequent cm.
After samples were gathered, they were stored in a refrigerator at -25°C until taken to the laboratory for analysis.

2.3 LAB ANALYSIS

The measurement of the chlorophyll-a content in the samples, is used as a parameter for determining the biomass of benthic diatoms. Therefore, in the period between sampling ,the samples were taken to a laboratory to be analyzed for chlorophyll-a by means of HPLC (High Performance Liquid Chromatography). The extraction and detection of the pigment consist of: use of acetone as an extraction solvent, homogenization, centrifugation and running the resulting supernatant through the HPLC device for chromatographic separation of the pigments (Daemen 1986).

2.4 FILING AND CONVERSIONS

The results of the chlorophyll analysis, from all plots during the years, were filed on the computer and graphs were made.

Since biomass data were originally measured in units of μg chl-a / gr dry sediment, a conversion to mg/m^{-2} was done in order to calculate the average biomass per area. Such a conversion was done by multiplying the biomass by 15.5, based on the average bulk density of the W.S sediment being 1.55 gr/cm^3. (It is assumed that the bulk density of the Western Scheldt is similar to that of the Eastern Scheldt sediment).

The C/chlorophyll-a ratio was chosen as 40, based on Eastern Scheldt data from Daemen & de Leeuw Vereecken (1985).

2.5 ABIOTIC FACTORS

Several distinct abiotic factors were examined: The **height** of the plots in relation to mean sea level, **soil composition***:* clay content and median grain size (D50) and **geomorphology.**

Height:

Actual height measurements according to NAP (Mean Sea Level), were available for years 1989-92 for most areas, while for others (mainly mudflats) the height was estimated using echosounding maps (1991).

Soil composition:

Data on clay content (<44 μm) and D50 were obtained from autumn 1992, and measurements were done in 2 layers: 0-2cm and 0-10cm deep. However, since a clear positive correlation was shown to exist between the clay content in both layers (Fig.12), only data from the 0-2cm layer were used in this report, it being the most important layer concerning the actual biomass of microphytobenthos.

Geomorphology:

Three geomorphological types (or energy classes) were taken into consideration. Areas containing

1. High energy class: were defined as very flat surfaces due to high current velocities, or areas with small mega ripples (2 - 10 meters wide) and bigger ripples, larger than 10m.
2. Medium Energy class: were defined as flat dry areas, poor of clay.
3. Low Energy class: were defined as flat wet areas, rich of clay.

Using geomorphological maps (1988-1990), each of the plots was located and its corresponding energy class filed on the computer. Rough data on energy class were also obtained from field work carried out during 1993.

In addition to searching for correlations between the biomass and abiotic factors, correlations among the abiotic factors themselves were examined.

2.6 PRIMARY PRODUCTION

Primary production was calculated implementing one formula based on two data sets of Cadée & Hegeman (1977) and Colijn & de Jonge (1984) yielding:

$$P=1.13B + 8.23 \quad (R^2=0.92)$$

in which:
P = gross primary production in g C $m^{-2} y^{-1}$
B = average biomass (1989-1992) in mg chlorophyll-a $m^{-2}y^{-1}$ in the 0-1 cm layer.

The two formulas obtained from the separate data sets are:

Cadée & Hegeman: $P=1.22B + 1.77$
Colijn & de Jonge: $P=1.06B + 13.91$

3. RESULTS

Seasonal and annual changes in biomass. (1989-1992)

Fig 1. Changes in diatom biomass 1989-1992.
In figure 1, in all years a peak in biomass can be seen. In general an increase in biomass can be seen towards summertime (months June and July), except for a slight delay in 1989 with maximum levels being reached only in October. In some years more measurements were taken than in others and not for all months data were available.

Fig 2. Changes in diatom biomass 1989-1992 mudflats/sandflats.
When a separation into mudflats and sandflats is made, as depicted in
figure 2, a clear difference can be seen, with mudflats having a higher biomass throughout the entire period.
Biomass levels on mudflats reach a peak during 1991.
Sampling of chl-a from mudflats started only towards the end of 1990.

Fig 3. The relation between average diatom biomass and area (sandflat/ mudflat).
In figure 3, each column represents the average biomass during the years 1989-1992 per plot, on each of the sandflats (Fig 3a) and mudflats (Fig 3b). As in figure 2, here as well, biomass levels can be seen to be higher on the mudflats.
Since generally the plots are situated from high to low in the tidal range (in graph - from left to right), a general correlation can be seen between the biomass and height of the plot per transect. In addition, in some of the areas the different transects are noticeable. (For instance, in Saeftinge 3 transects can be seen).

Correlations between biomass and abiotic factors.

Fig 4. Clay/biomass, Grainsize/biomass relation.
In figure 4, a positive correlation can be seen between clay content and the average biomass per plot, and a negative correlation between grain size (D50) and the average biomass per plot. All data are from 1992. In general, the higher the clay content, or the smaller the grain size in a certain plot, the higher the biomass there. The clear correlation between grain size and clay content in the plots measured can be seen in figure 13.

Fig 5. Height/biomass relation. (1989-1992)
In figure 5, a positive correlation can be seen between the biomass and height of the plots in each of the years 1989-1992. Although there are a few points that show a deviation from the regression line, in general it can be seen that the higher the plot - the variation in biomass levels increases. The results consist only of height data from actual measurements.

Fig 6. Height/biomass relation. Average of 1989-1992.
Figure 6 depicts the relation between the average height and average biomass throughout the years 1989-1992. As the results are derived from those used in fig.5 the same positive correlation can be seen.
Figure 6a, consists only of height data that were established from actual measurements, while in figure 6b all plots were taken into account, including those in which height was estimated according to echosounding maps. From these results one can see that the correlation between biomass and height

is much more clear using only the height data from actual measurements, although these measurements exclude most of the mudflats.

Fig 7. Height/biomass relation on sandflats and mudflats. Average 1989-1992.
In figure 7, heights of all plots were taken into consideration, (measured and estimated), while a division was made into plots situated on mudflats and those located on sandflats. From these graphs the following can be seen:
- There is a clear difference between mudflats and sandflats, with much higher biomass levels on the mudflats.
- On the mudflats the biomass level reaches a peak at 0 mm height, along with a diversity of biomass levels apparent at this level. As the height of the plot drops or rises in relation to mean sea level (0 mm), there is a decrease in the maximum biomass level that can be reached.
- On the sandflats, no clear relation can be seen.

Fig 8. Energy class/biomass relation. 1989-1993
In figure 8, the biomass level per plot was examined in relation to the 3 energy classes. The relation was checked in two methods: Using data on the energy levels according to maps (Fig 8a), and rough estimations from latest observations in the field (Fig 8b). Although no clear relation was evident, in figure 8b biomass levels tend to be somewhat lower in energy class 1 compared to classes 2 and 3.

Fig 9. Depth/biomass relation.
In Figure 9, a negative correlation can be seen between the biomass and the depth of the sediment layer in which the measurement was taken. Some areas show a steep decrease in biomass from the upper-most level to the level below (indicating a high percentage of the total biomass is present at the top most layer), while others show a more gradual decline.

Other relations examined.

Fig 10. Clay/height relation.
Figures 10a and 10b include only those plots in which the height was **measured**, while figure 10c also consists of plots in which the height was **estimated**. Figure 10a refers to data on clay and height solely from 1992. Figures 10b and 10c refer to average measurements of height and biomass during 1989-1992. A positive relation between height and the maximum clay content, can be seen best in figures 10a and 10b. In figure 10c however, the additional plots obscure any relationship.

Fig 11. Clay/Energy class relation.
The above relation was checked using data on the energy levels according to maps (Fig 11a) and according to rough estimations from latest observations in the field (Fig 11b). In figure 11b the relation is more clear with in general a negative correlation between the two factors. The exceptionally high clay content found in plots Bath 12.3 and Waarde 404, situated in a high energy area, can be attributed to the peat layer and stones found on those two plots respectively.

Fig 12. Clay 0-10cm /clay 0-2cm relation. 1992.
Figure 12 shows a clear positive correlation between the clay content in both layers. Points that show a deviation from the regression line include Paulina - plot 7.3 and Waarde - plots 403, 409, all of in which a relatively high clay content can be found in the 0-10 cm layer.

4. DISCUSSION

Following the fluctuations in the benthic diatom biomass throughout the years 1989-1992, a clear seasonal and annual cycle could be seen, generally with maximum levels being reached during summertime. Substantial biomass levels could be seen during the whole period, each year , all year round. Experiments done by Colijn & Van Buurt (1975) and Admiraal (1977) suggest a correlation between the surrounding temperature and the growth rate of benthic diatoms. Whereas, during the summertime high temperatures promote diatom growth, low temperatures are responsible for low production and consequently low biomass during wintertime. In addition, increasing temperatures in spring along with increasing irradiance, are responsible for the increasing production and biomass in spring. The steep decline in biomass in mid July 1992, may be due to: 1) High temperatures that lead to evaporation of water from the sediment, which in turn causes an increase in salinity and therefore a decrease in biomass. 2) A decrease in nutrients (Si).
A decrease in biomass levels during wintertime may be due to waves during stormy weather.

A substantial difference was seen between levels of biomass on mudflats compared to sandflats. The high abundance of diatoms on mudflats is probably due to the fact that as opposed to sandflats, mudflats are not entirely surrounded by water. As a result they are generally more sheltered and therefore less subjected to wave attack and currents. Such a sheltered environment enables the benthic diatoms to burrow themselves in the upper centimetres of the soil and propagate. On sandflats however, the larger exposure to wave attack and high energy levels results in a higher resuspension of the upper layer of the sediment along with the diatoms in it.

Examining the relation between the flats and biomass, a height gradient was apparent per area (Fig 3). However, within the estuary itself, no overall relation could be found between height and biomass (fig 6b). Hence, other different factors must have an influence on the height-biomass relation: Location - whether on sandflat or mudflat, was seen to have an influence on the maximum biomass that can be reached. Energy level - referring to hydrodynamical forces such as wave attack and tidal currents, should also have an influence on the biomass, although the exact relationship between the 2 factors is not clear (Fig 8). The biomass of the benthic diatoms in the whole estuary is determined therefore, by more than one factor i.e: height, location, energy and clay content (the latter used as an energy parameter, see below). The absence of a correlation between biomass and energy could be due to the fact that the energy class data, which describe a very dynamical area, were taken from out-dated maps (1988-1990), or from very rough estimations by memory.

A rather clear relation was found however, between energy and clay (see fig 11b). Thus, in other comparisons made, the clay content was used as a parameter that defined the energy type: high clay content defining low energy levels and low clay content defining high energy levels. Based on this relation, and analyzing the graph in figure 11b, a division was made into 3 clay groups and 3 height groups to investigate the relation with average biomass. The division was as follows:

height (meters)	**clay** (%)
1. $x<0$	$y<2.5$
2. $0\leq x\leq 1$	$2.5\leq y\leq 5$
3. $x>1$	$y>5$

Since diatoms above mean sea level are more exposed to sunlight and dryer conditions, the height division was made according to those plots situated above, below and at the height of mean sea level. The clay division was decided upon by estimating the average range of clay content per energy type. According to this division, the average biomass (1989-1992) was calculated for each of the 9 possible combinations (clay/height) and results are shown in table 1 and table 2. Table 1 includes all plots,

while in table 2, biomass data from plots Hulst (5.1) and Terneuzen were removed because no clear relation between biomass and clay was found for those areas. The standard deviation and number of plots are mentioned as well. From these tables the following can be seen:
- a clear positive correlation between biomass and clay content exists in each of the 3 height groups, with a larger increase in biomass from column 2 to column 3.
- In Table 1, in each of the clay groups, a peak in biomass is reached at plots situated at a level 0 - 1 meters high (row 2). The decrease in biomass above the height of 1 meter could be caused by one or more of the following factors: a rise in temperature that dries out the sediment, drainage of the sediment during the long period of emersion, a very high light intensity, and/or a decrease in the concentration of carbon dioxide in the thin water film that covers the superficial diatoms during low tide. In Table 2 similar results are seen except for the biomass levels referring to plots with a clay content larger than 5% (column 3).
- It may be that a clay content higher than 5%, compensates for high altitudes (over 1m), and therefore high biomass levels appear in both tables in that corresponding group (i.e row 1 column 3). Such a compensation can be explained by the high degree of moisture that can be contained within the clay. This clay environment not only lowers the degree of water evaporation from the soil, but also reduces the water drainage to lower levels in the sediment. As a result, even at high altitudes the diatoms can still live in a wet environment. Benthic diatoms which inhabit the tidal flats, have a tendency to embed themselves in the interstitial water column. This environment can be kept also during low tide due to the capillary forces exerted. However, with an increase in the amount of water in the soil, the interstitial water column increases as well, and so does the amount of nutrients it contains. In other words, a high clay content can not only add to the moisture in the soil but also allow an increase in nutrients, thus offering good conditions for diatom development.
- In table 2, leaving out plots from Hulst and Terneuzen results in somewhat lower or similar standard deviations.
- In general it can be seen that the final biomass level is a result of 2 (and presumably more) factors that **interact** with each other: height and clay. However, due to the clear division according to clay content as seen in these tables, it may be assumed that the clay content (and therefore the hydrodynamic energy level) has a more significant influence on biomass.
Nonetheless, these results should be checked more thoroughly by applying statistical programs and using more accurate data (i.e height measurements should be taken for all areas).

If infact a clear relation does exist between biomass and energy, it might then be possible to calculate what affects human activities in the estuary might have on microphytobenthos. However, as mentioned, in order to find such a relation, future research has to be done with the help of good sediment and height maps. Perhaps such a division into clay and height groups may provide more accurate data on biomass levels and hence more accurate data on primary production.

Noticing this somewhat complex but existent relation between height/clay and biomass, and concluding the possibly significant influence of energy on biomass levels - the areas of the 3 energy types were calculated . Measurements were made using a planimeter and geomorphological maps of the relevant flats. Doing so, the biomass and primary production of the microphytobenthos could be calculated per energy class. A summation of these results would yield the total biomass and primary production for the whole of the Western Scheldt. Results are presented in Table 3. Also included is a comparison to the Eastern Scheldt (De Jong et al 1993), the western Wadden Sea (Cadèe and Hegeman 1977) and the Ems estuary (Colijn & De Jonge 1984). The average biomass (109 mg Chl/m²) and primary production (131 g C/m²) in the Western Scheldt are similar to those measured in the western Wadden Sea and the Ems estuary, but lower than in the Eastern Scheldt particularly after 1985. This can be ascribed to the increase in biomass and primary production in the Eastern Scheldt after the completion of the storm surge barrier at the entrance of the estuary in 1986. This increase in biomass was apparently a result of a decrease in the dynamic forces, an increase in water transparency and an increase in import of organic carbon from the water column towards the shoals. (De Jong et al 1993).

The negative correlation between biomass and depth revealed 2 types of plots: those that showed a steep decline in biomass with increasing depth and those with a more gradual decline. Examining the average clay content per area both in the layer of 0-2cm and 0-10cm for those areas (table Appendix A), it was found that in general those areas that showed a steep decline, also had a higher clay content. In other words, plots displaying a steep decline, indicating a high biomass percentage in the uppermost level of the soil - were plots that were situated in areas with a high clay content and therefore in a hydrodynamically quiet area enabling the diatoms to remain and live in the topmost level. In all cases highest values were found at the top centimetre of the sediment in which the diatoms can be most active in photosynthesis. Although strong waves may disperse the chlorophyll present at the top of the sediment, the population can adopt to life in such an unstable environment by the presence of deeper living algae (Cadée and Hegeman 1974). The existence of diatoms at the more deeper layers could be a result of hydrodynamic forces like tidal currents and waves or active migration.

Finally, a comparison was made to the primary production of the phytoplankton in the Western Scheldt. Calculations were done according to data on primary production from Kromkamp et al (1993) and multiplying by the area of the Western Scheldt according to Bodkar calculations (Table 4a). Similar results (Table 4b) were obtained using area of Western Scheldt provided by G.I.S, not including salt marsh areas and half the surface of the intertidal areas (since on average only half of the tidal flat is completely submerged). According to these calculations it was found that the microphytobenthos comprise about 16% of the total primary production in the Western Scheldt estuary.

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LIST OF FIGURES AND TABLES

Figure I. The Netherlands

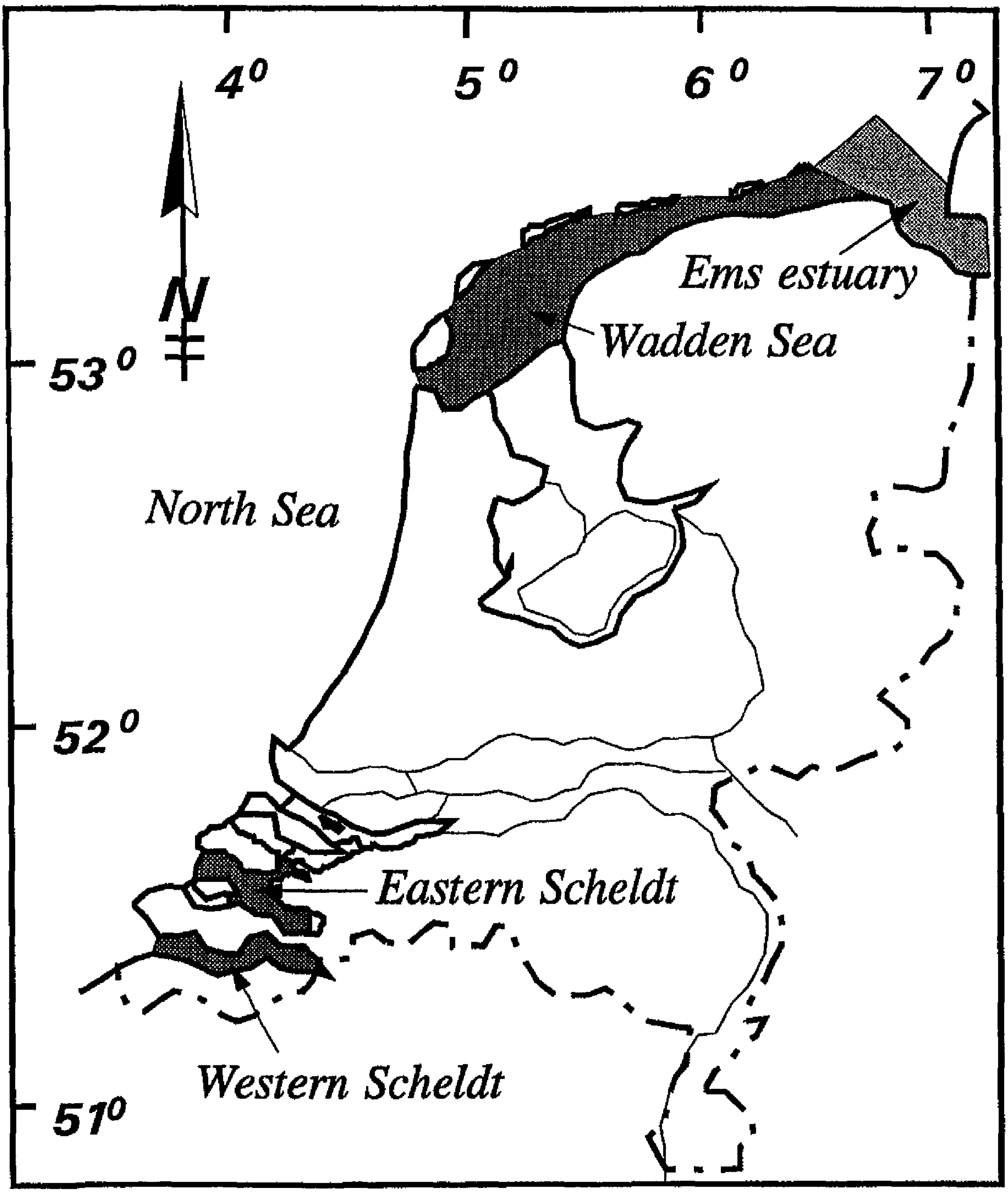
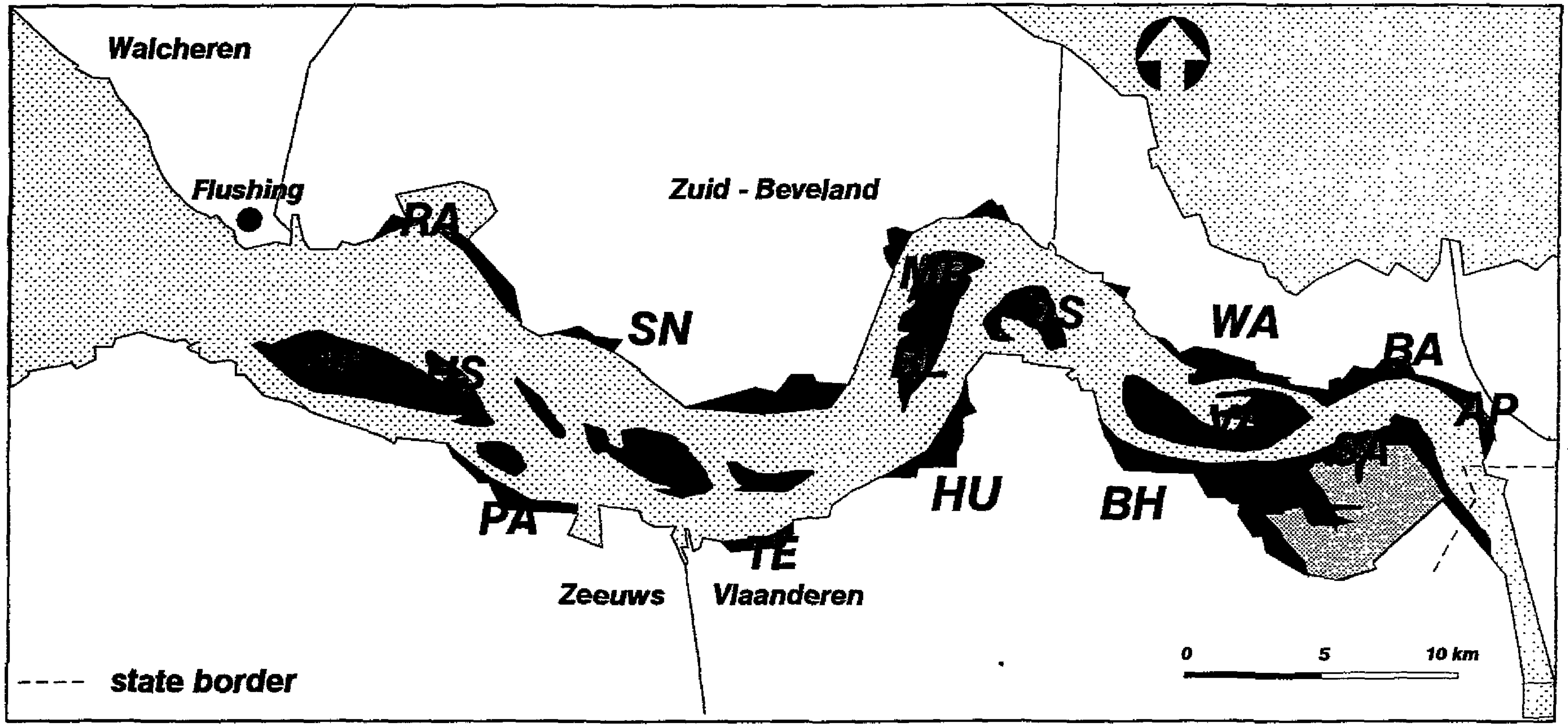


Figure II. Western Scheldt



AP : Appelzak
BA : Bath
BH : Baalhoek
BL : Rug van Baarland
EV : Everingen
HP : Hoge platen
HS : Hoge springer
HU : platen van Hulst
MP : Molenplaat
OS : Ossenisse
PA : Paulina polder
RA : Rammekens
SA : Saeftinge
SN : Staartse nol
TE : Terneuzen
VA : Valkenisse
WA : Waarde

Diatom biomass - Western Scheldt

total average per months, 1989-1992

Figure 1

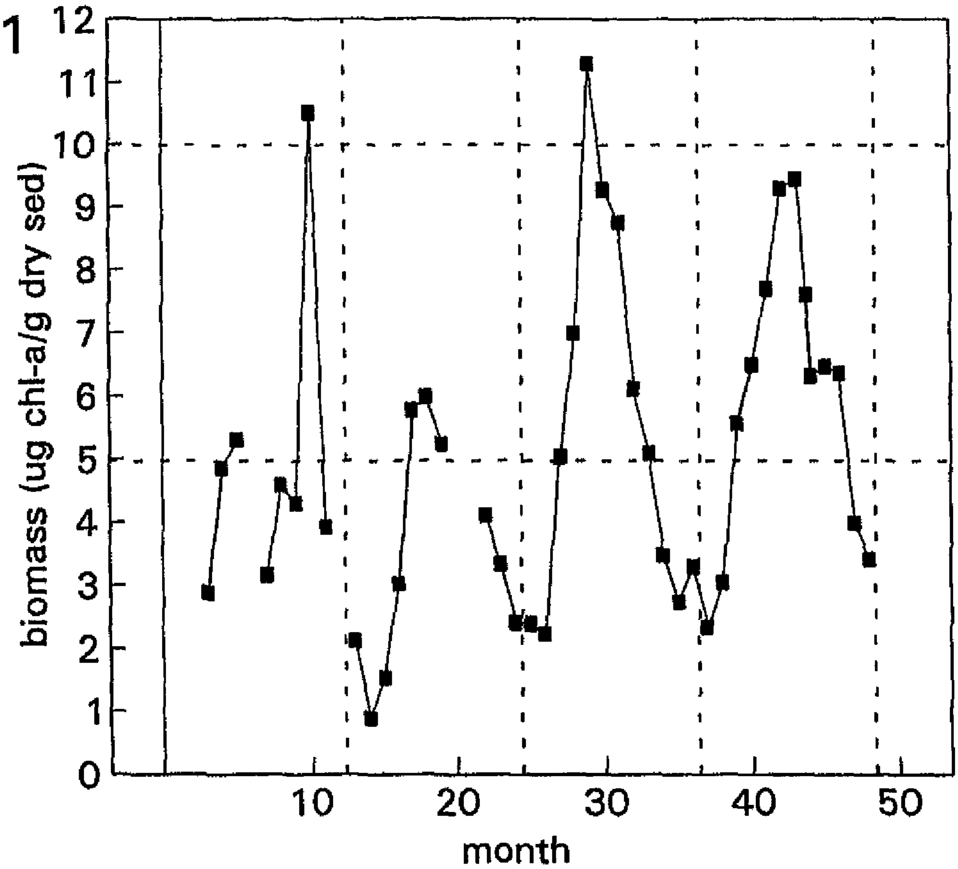


Figure 2

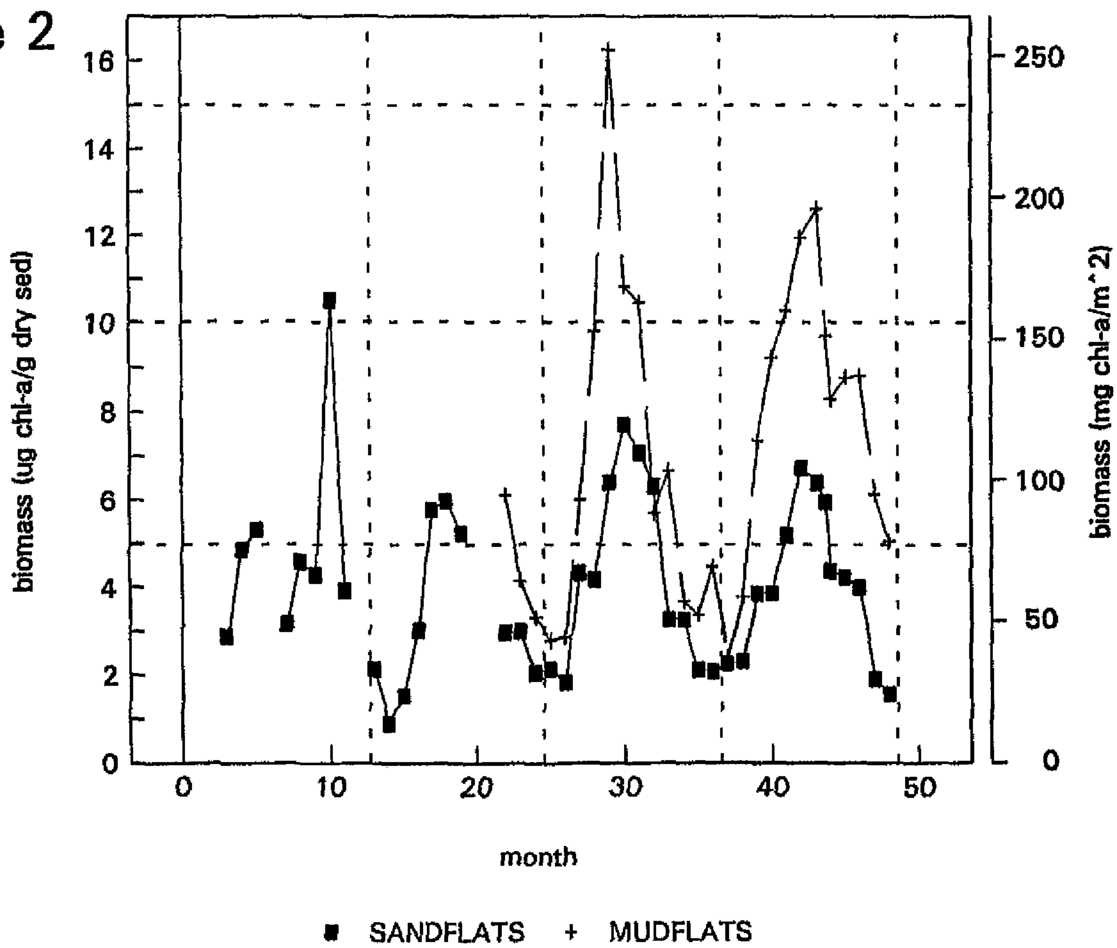


Figure 3a. Diatom biomass - Western Scheldt

total average 1989-1992; sandflats

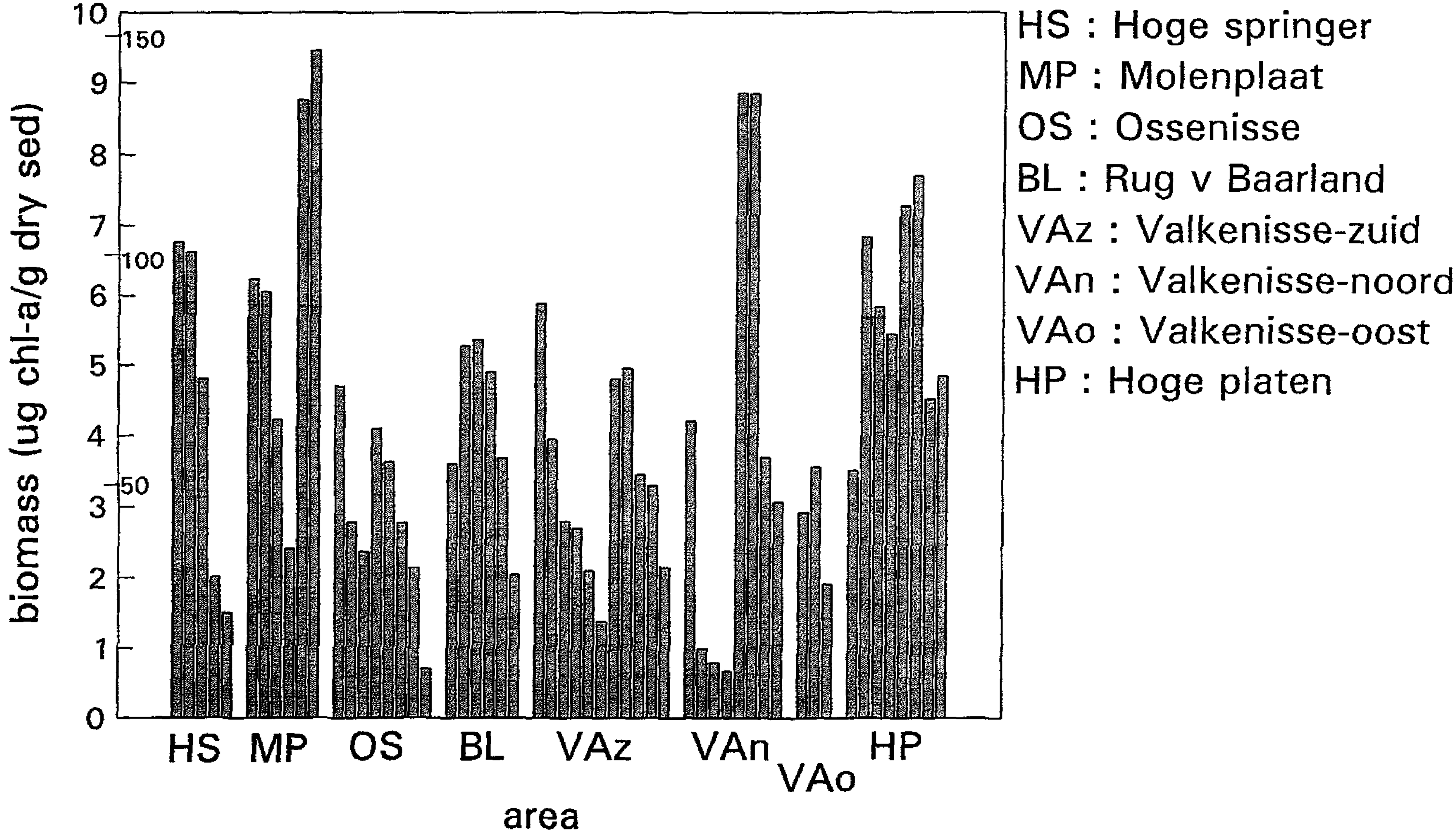
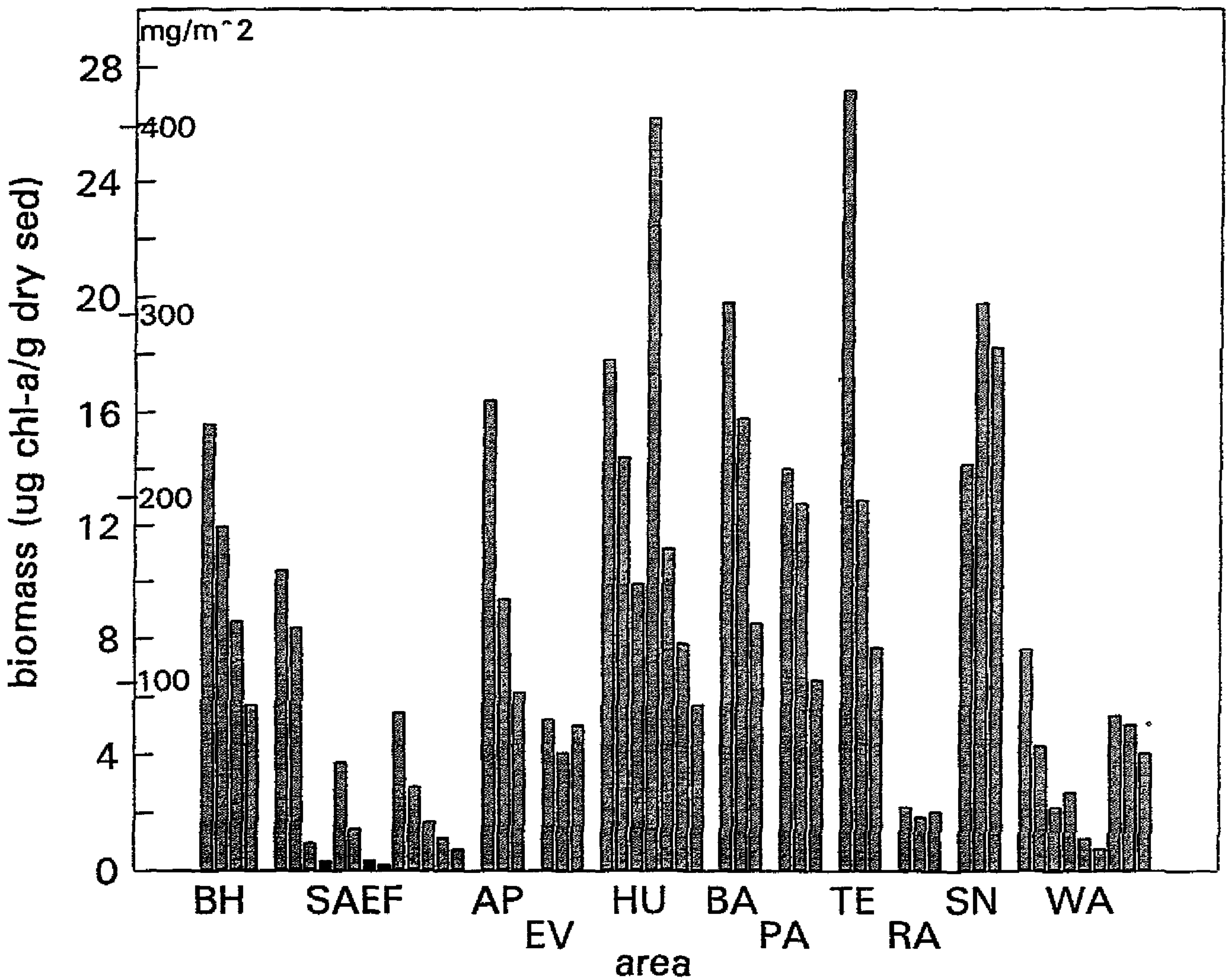


Figure 3b. Diatom biomass - Western Scheldt

total average 1989-1992; mudflats



BH : Baalhoek

SAEF : Saeftinge

AP : Appelzak

EV : Everingen

HU : P v Hulst

BA : Nauw v Bath

PA : Paulinapolder

TE : Pas v Terneuzen

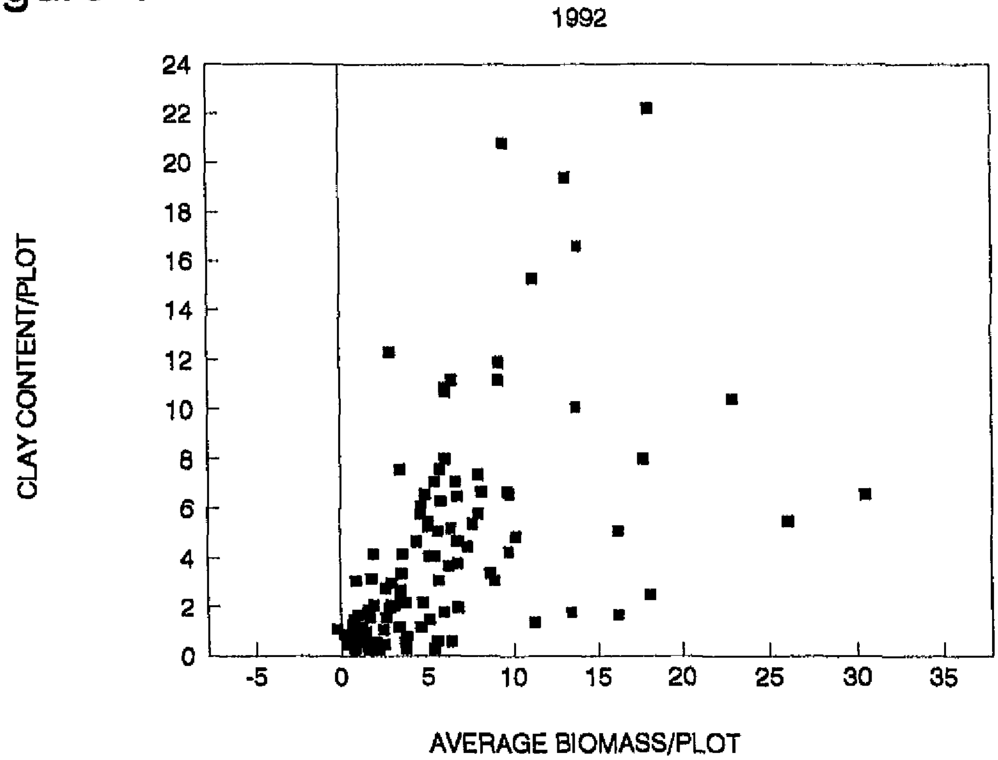
RA : Rammekens

SN : Staartse nol

WA : Slik bij Waarde

Figure 4

CLAY-BIOMASS RELATION



GRAIN SIZE-BIOMASS RELATION

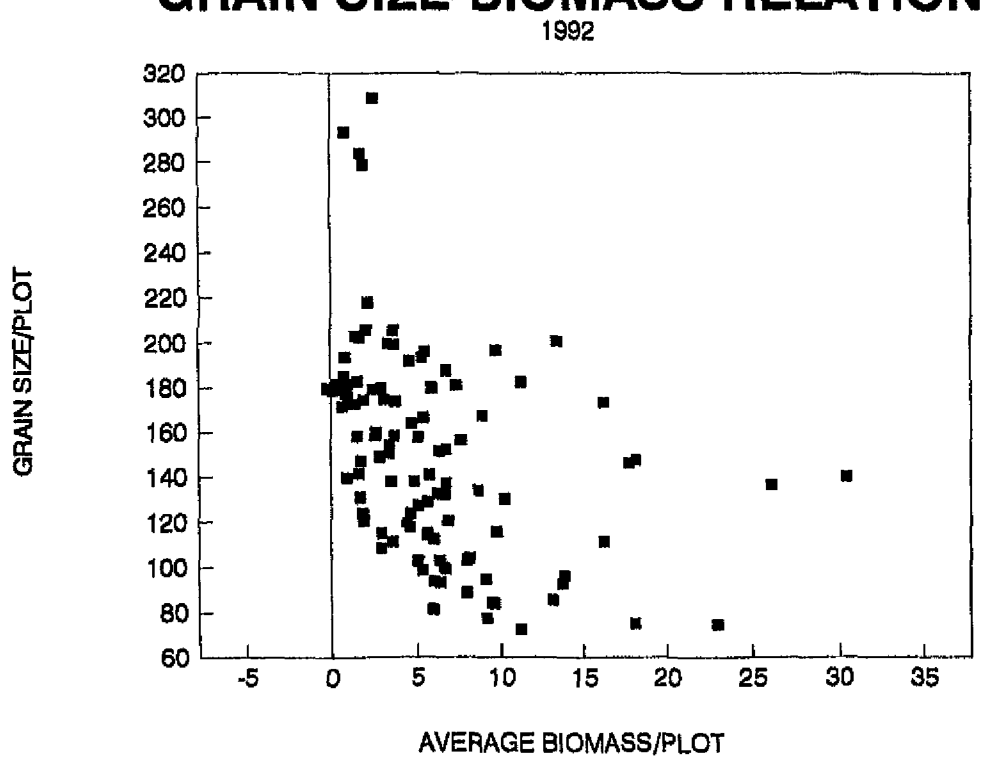


Figure 5. BIOMASS-HEIGHT RELATION 1989-1992

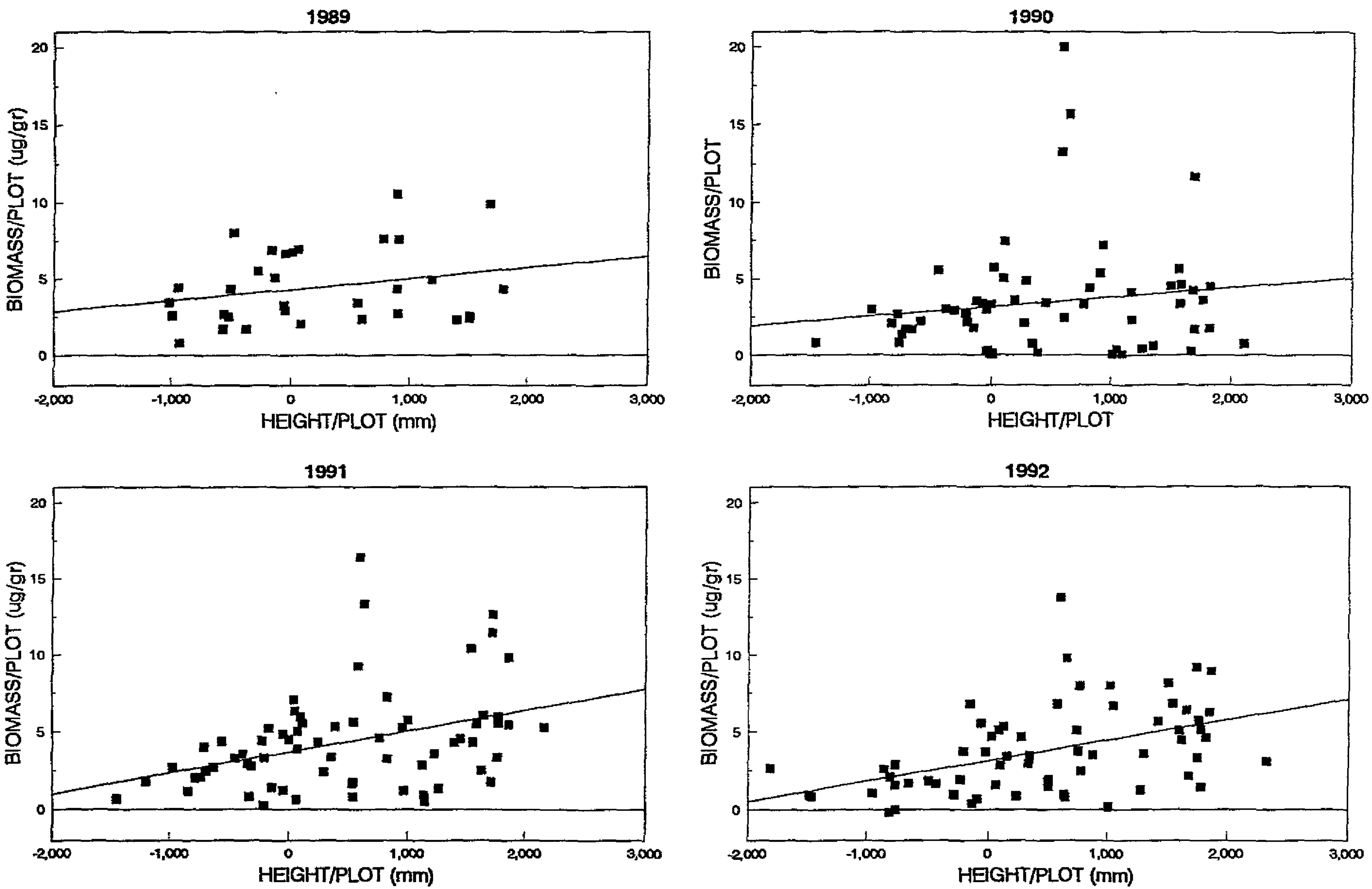


Figure 6a. BIOMASS-HEIGHT RELATION

average 1989-1992

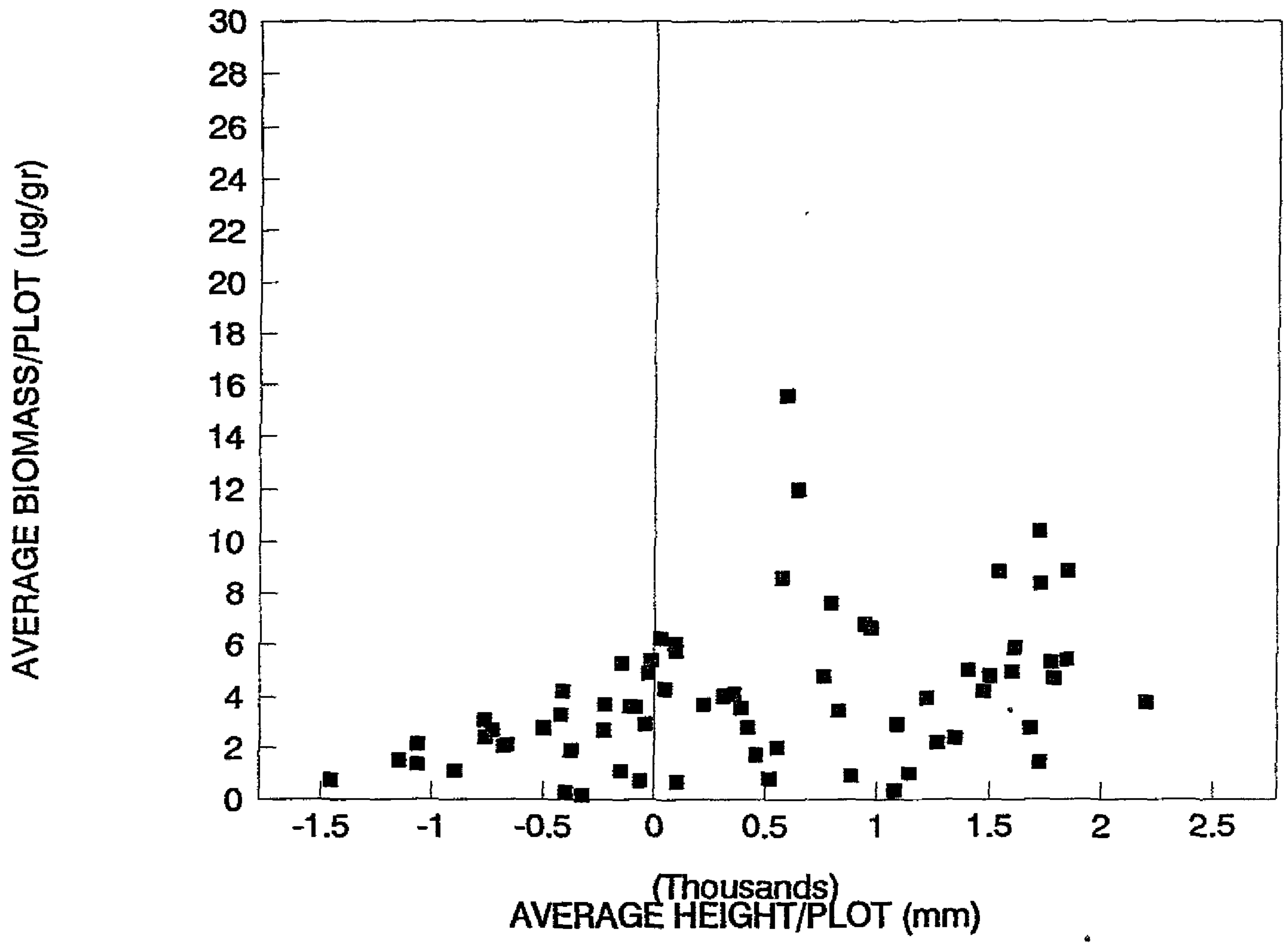


Figure 6b. BIOMASS-HEIGHT RELATION

average 1989-1992

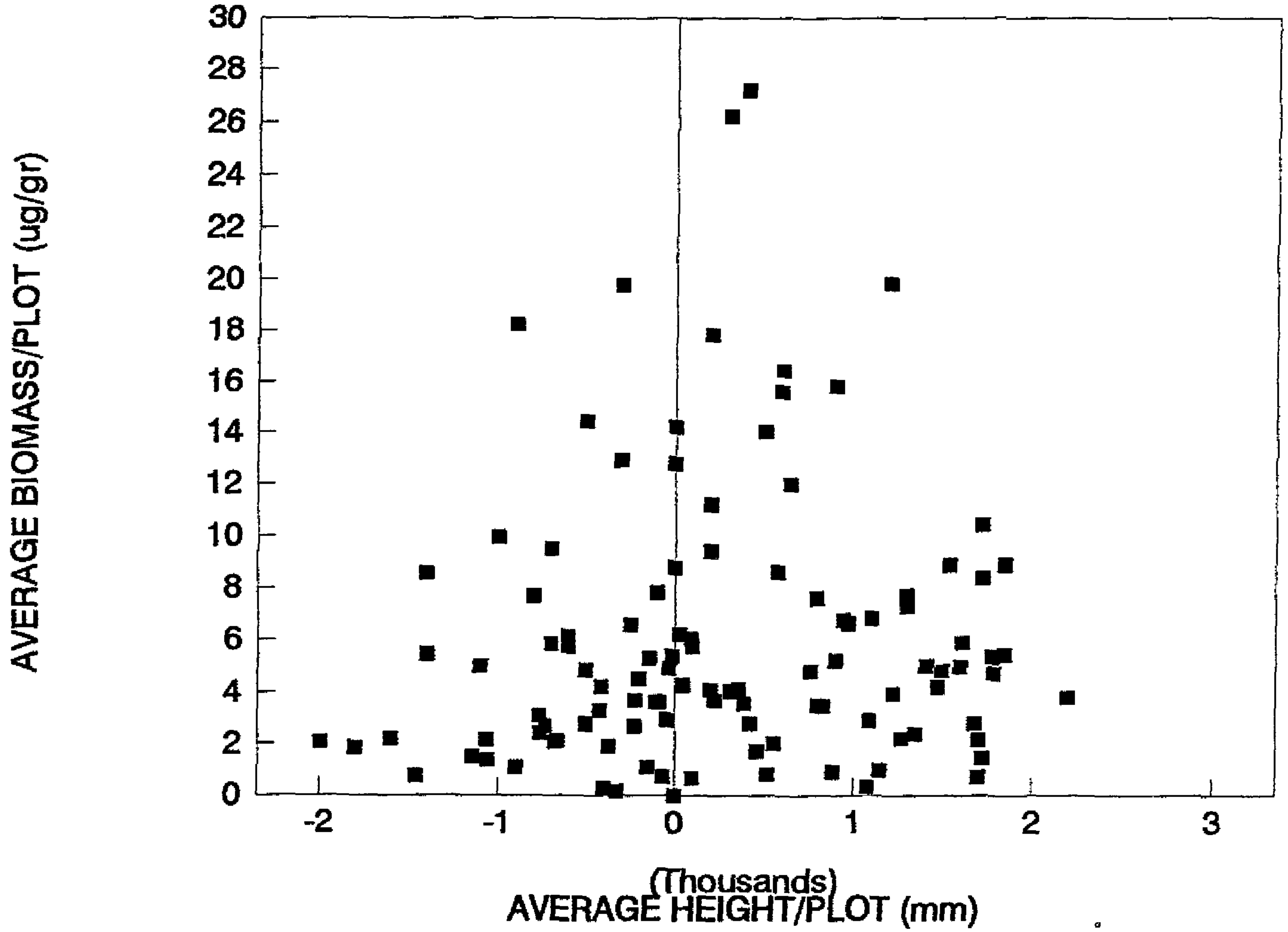


Figure 7. BIOMASS/HEIGHT RELATION ON SANDFLATS AND MUDFLATS 1989-1992

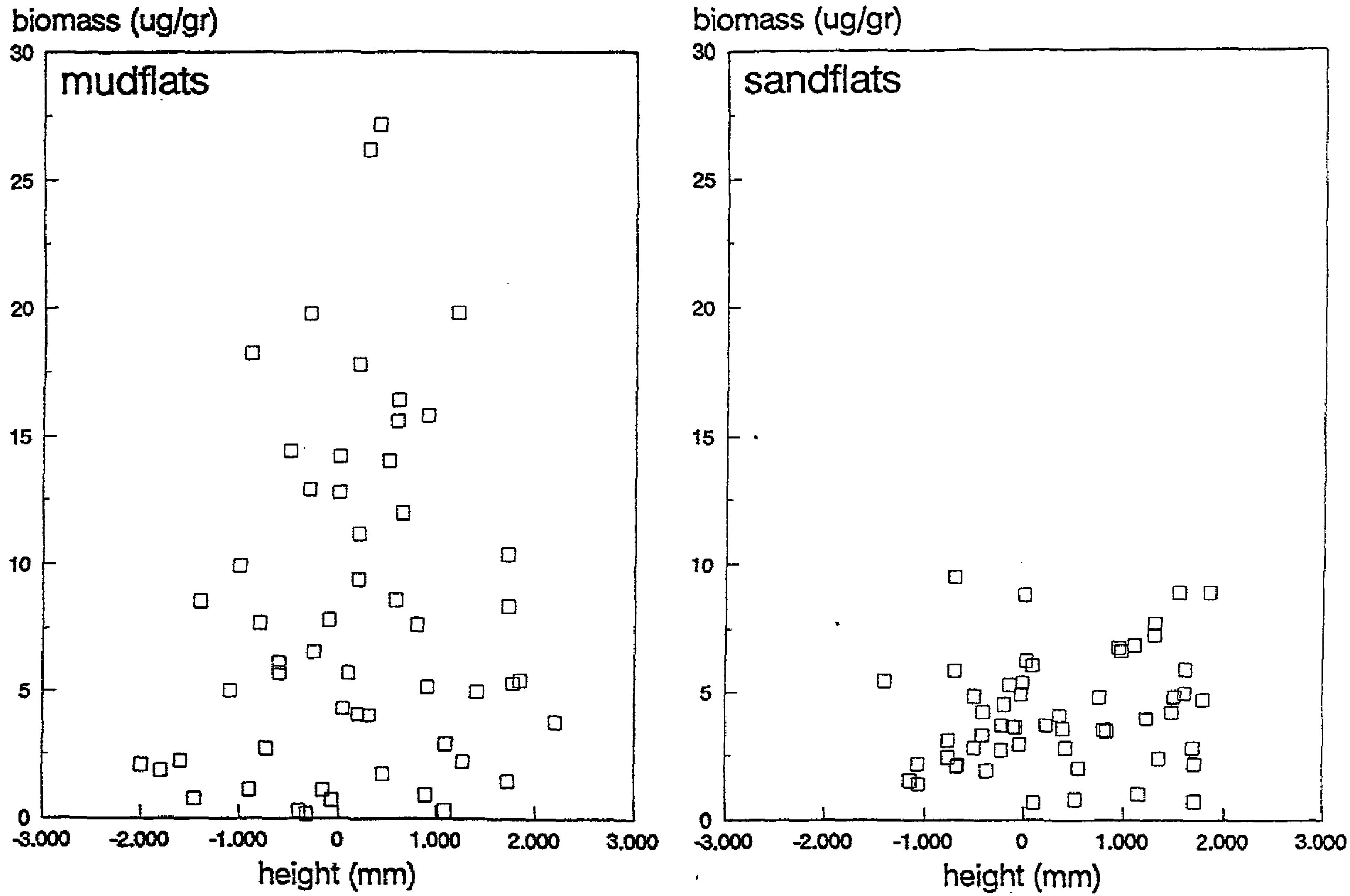


Figure 8a. BIOMASS/ENERGY RELATION

1988-1992

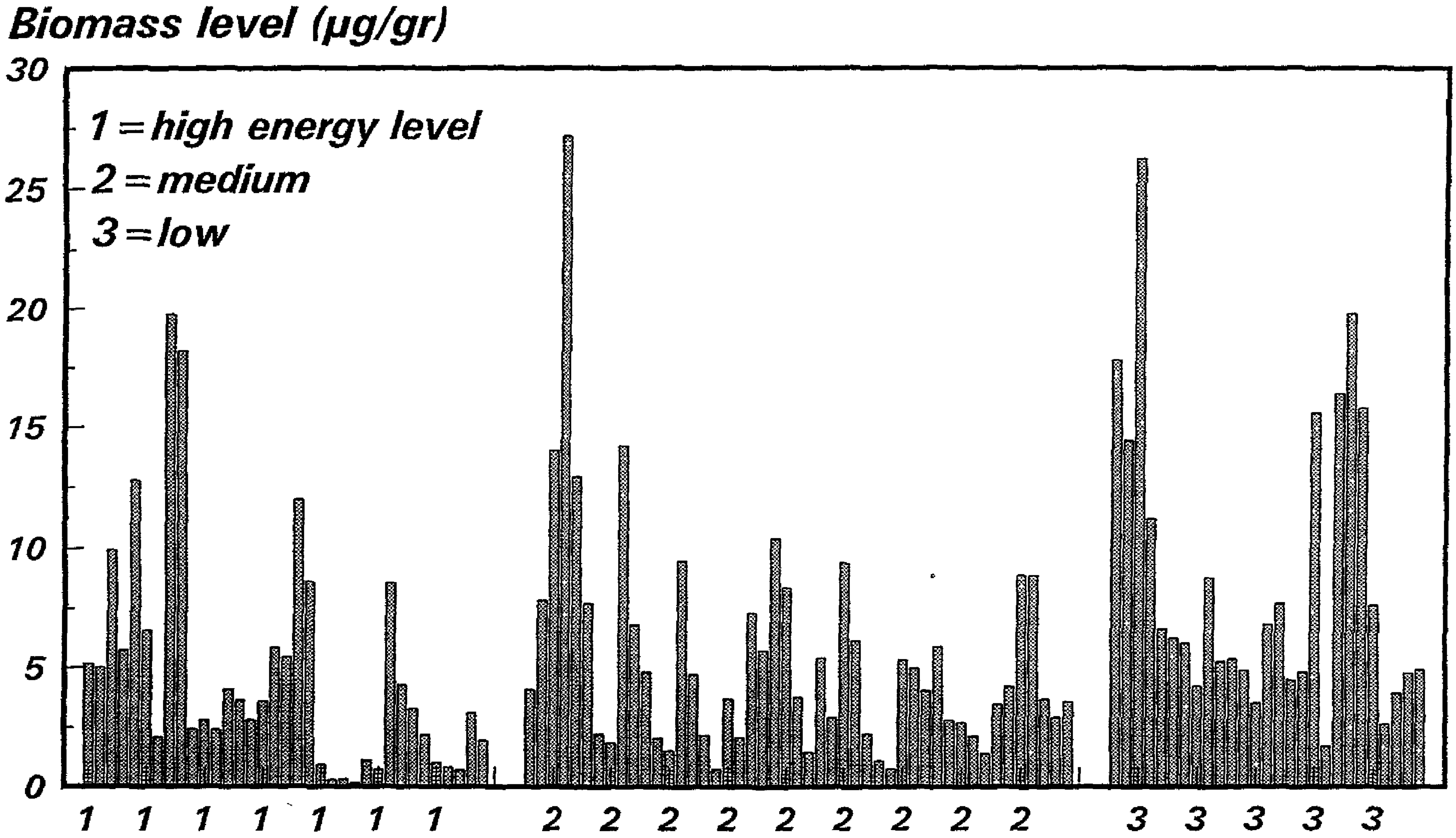


Figure 8b. BIOMASS/ENERGY RELATION

1989-1993

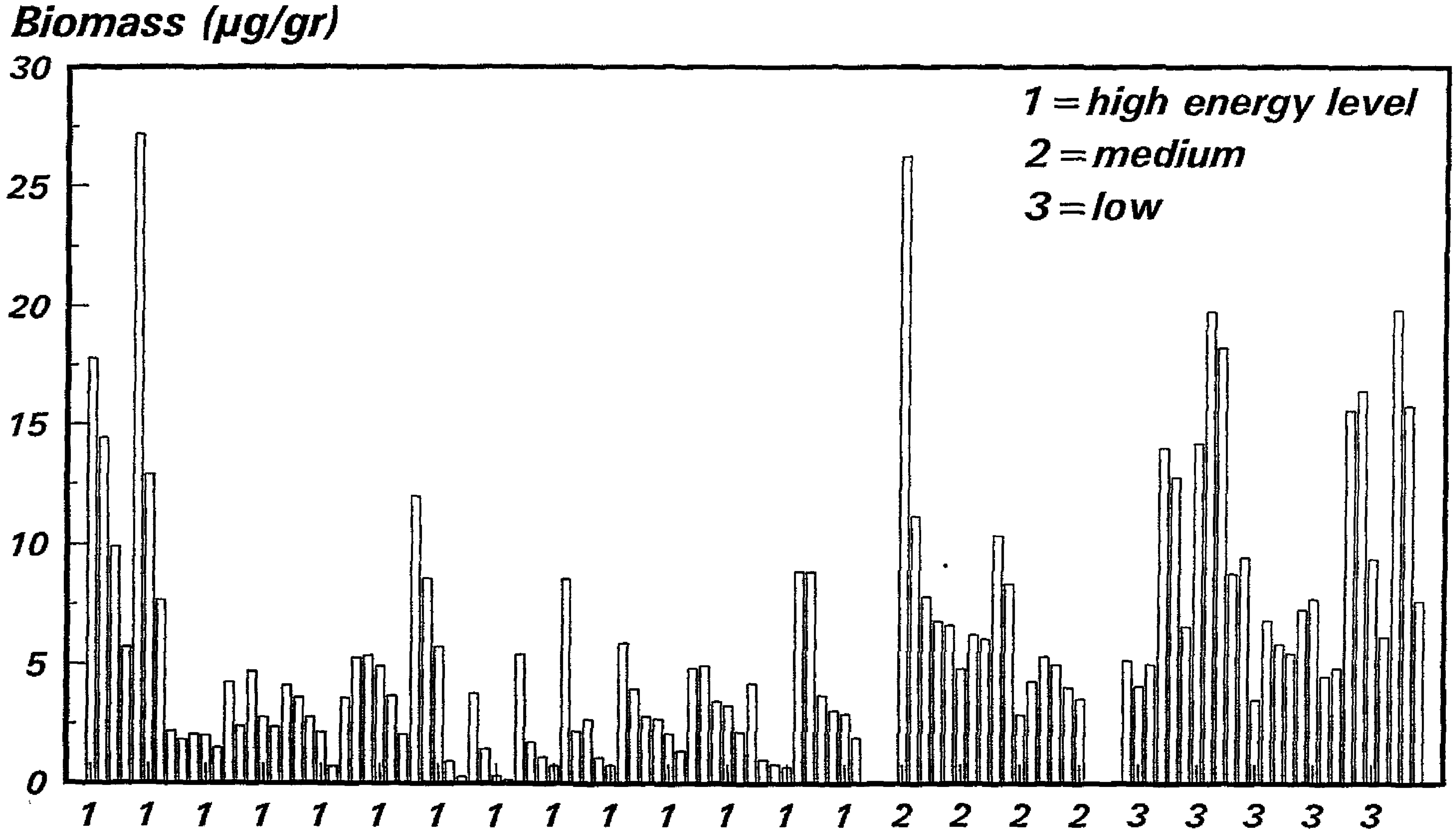
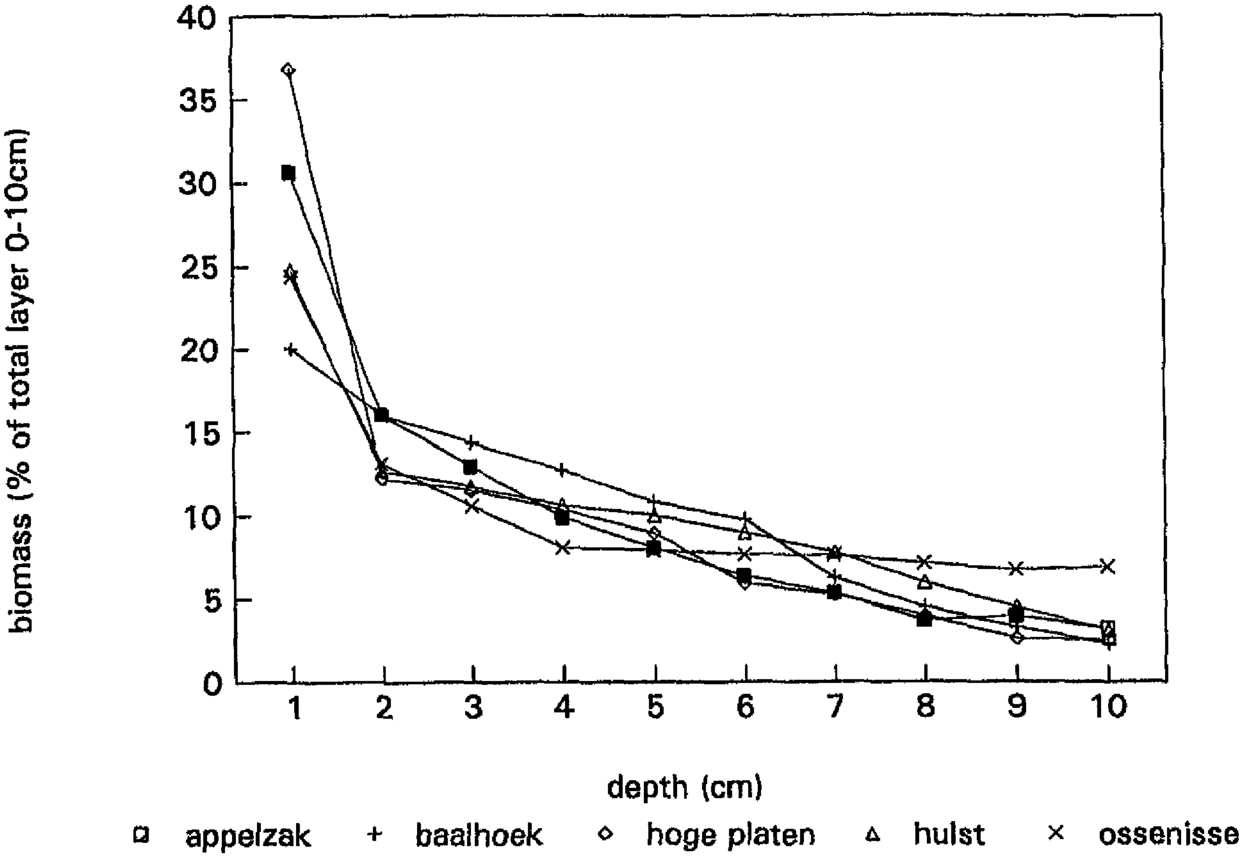
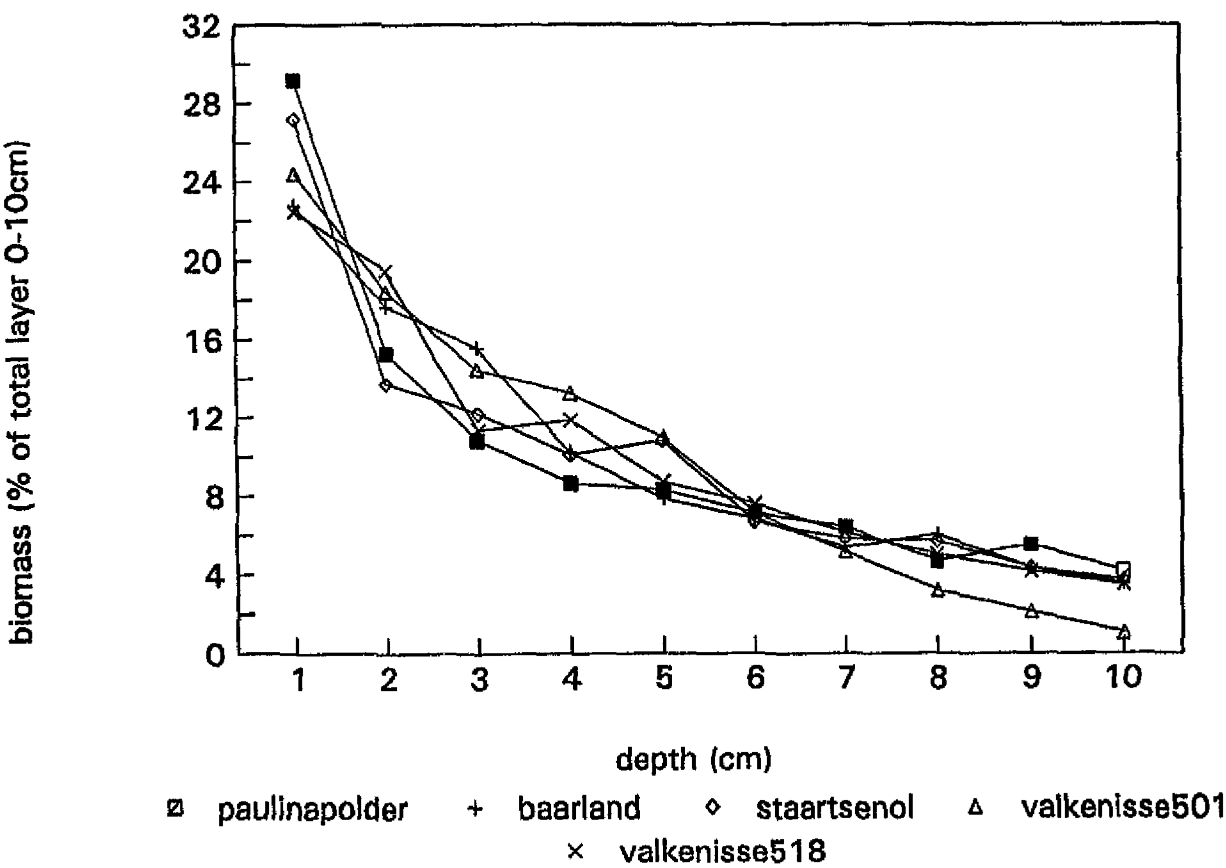
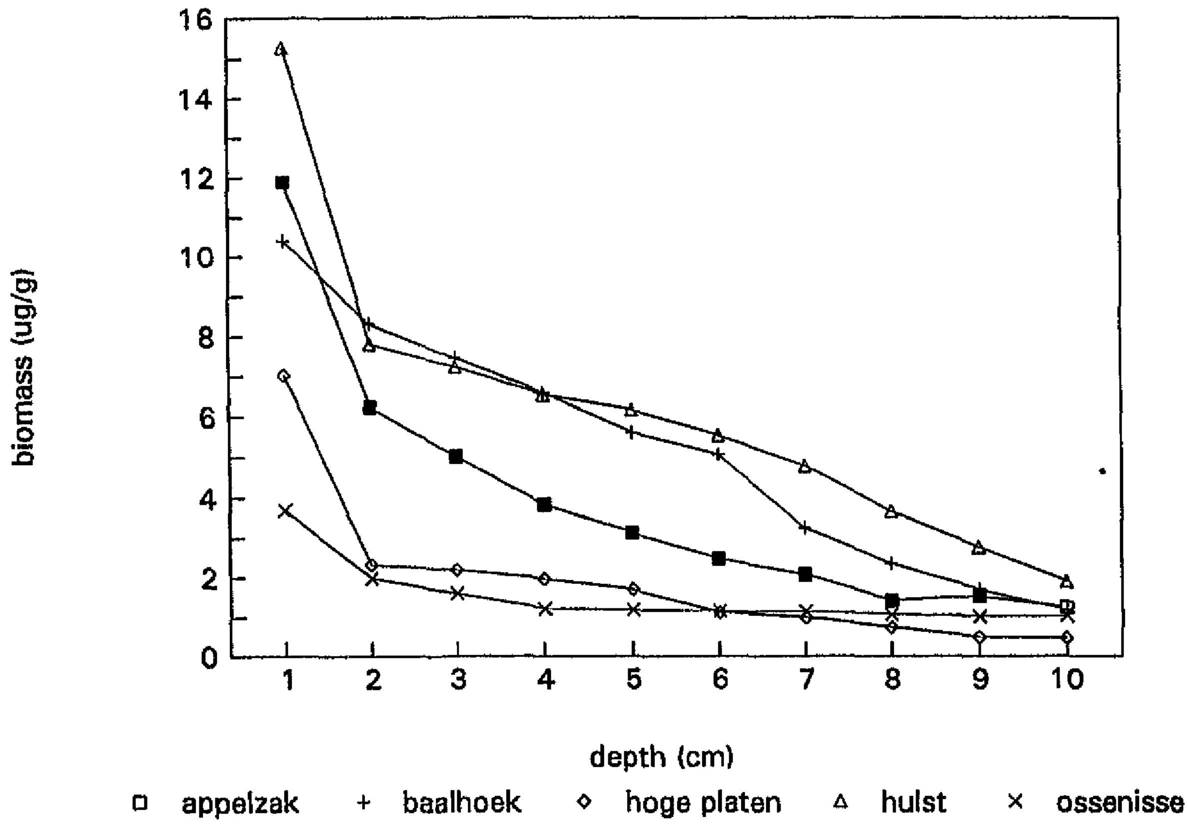


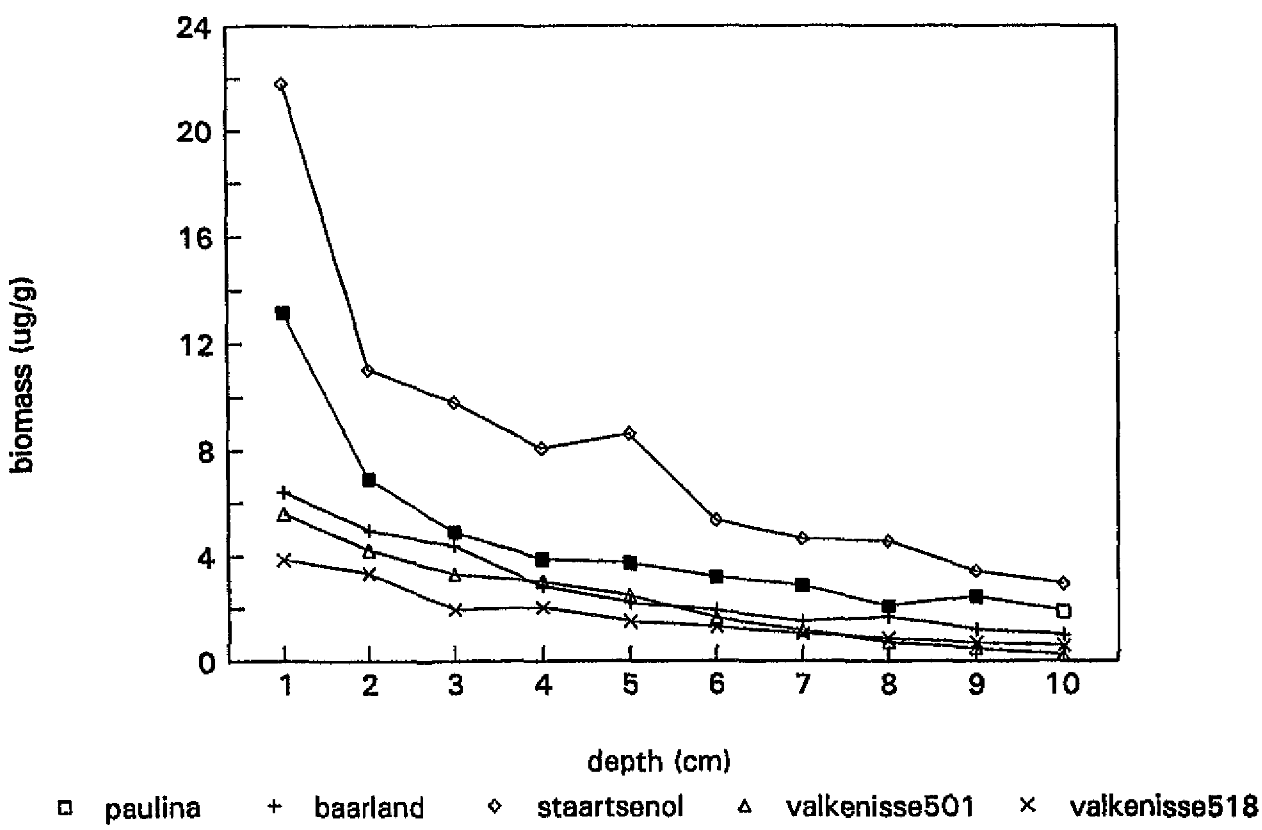
Figure 9. DEPTH/BIOMASS RELATION







biomass (ug/g)
0
2
4
6
8
10
12
14
16
1
2
3
4
5
6
7
8
9
10
depth (cm)
appelzak
baalhoek
hoge platen
hulst
ossenisse



biomass (ug/g)
0
4
8
12
16
20
24
1
2
3
4
5
6
7
8
9
10
depth (cm)
paulina
baarland
staartsenol
valkenisse501
valkenisse518

Figure 10a. CLAY-HEIGHT RELATION

1992

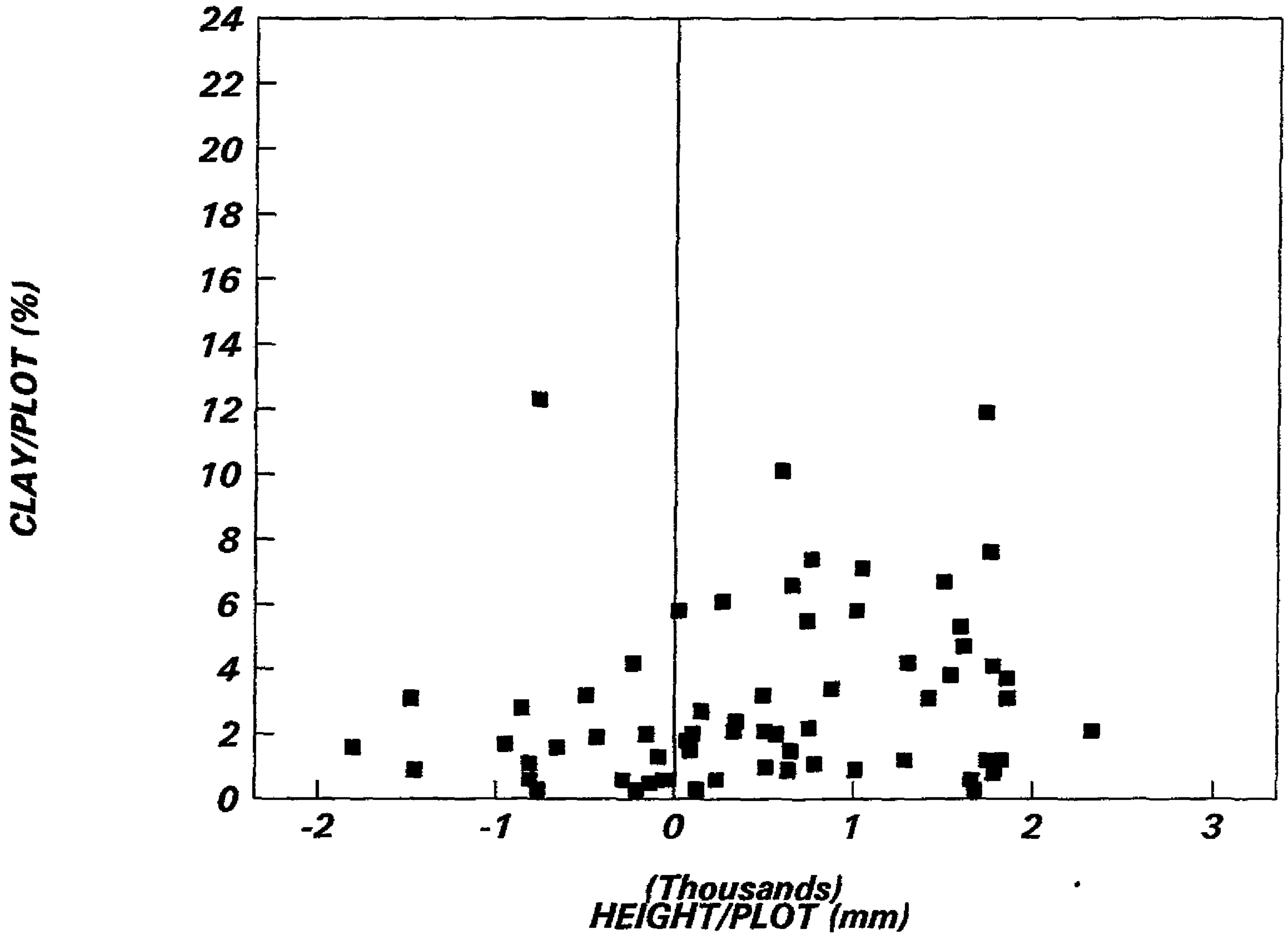


Figure 10b. CLAY-HEIGHT RELATION

1989-1992

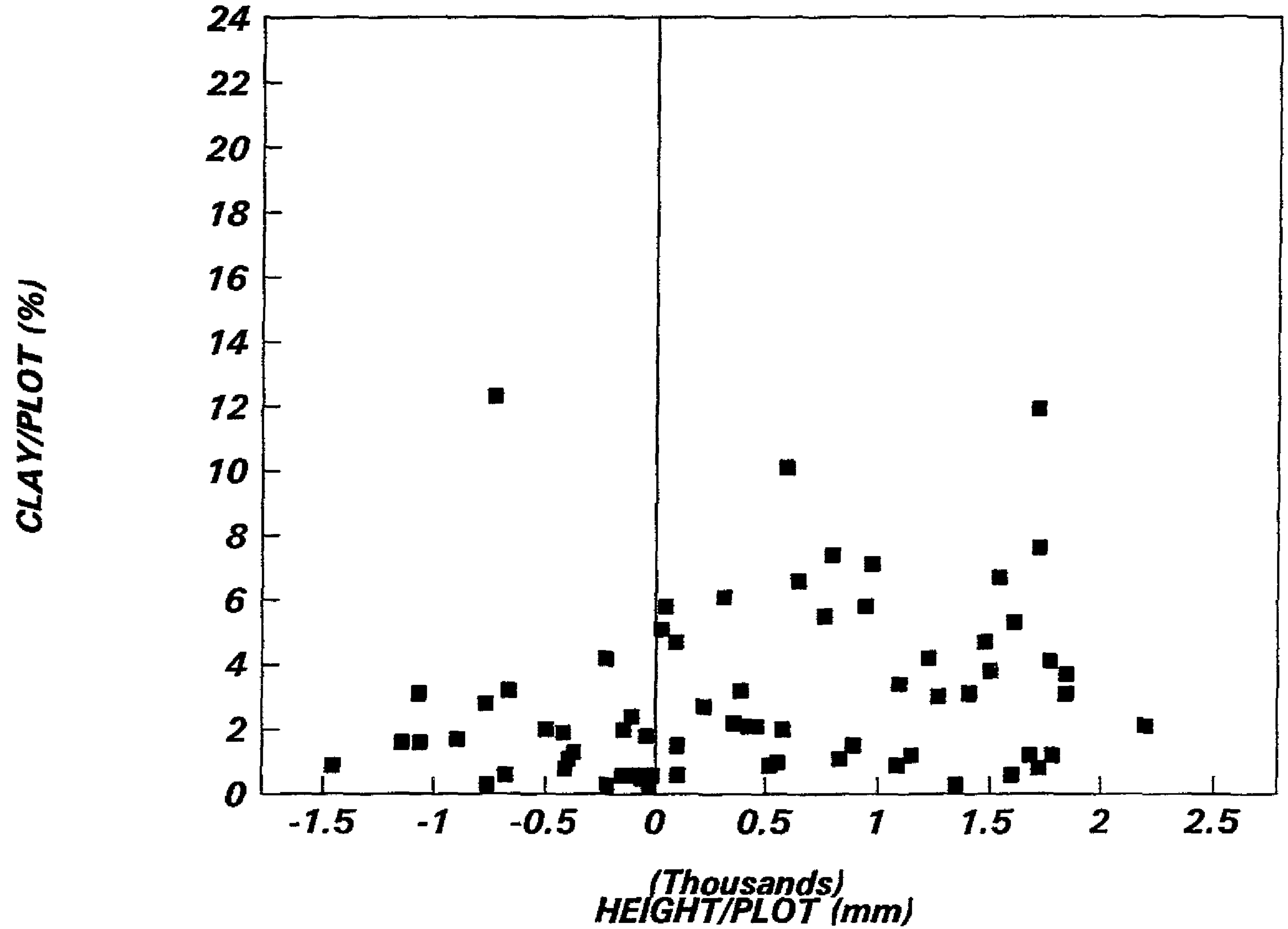


Figure 10c. CLAY-HEIGHT RELATION

1989-1992

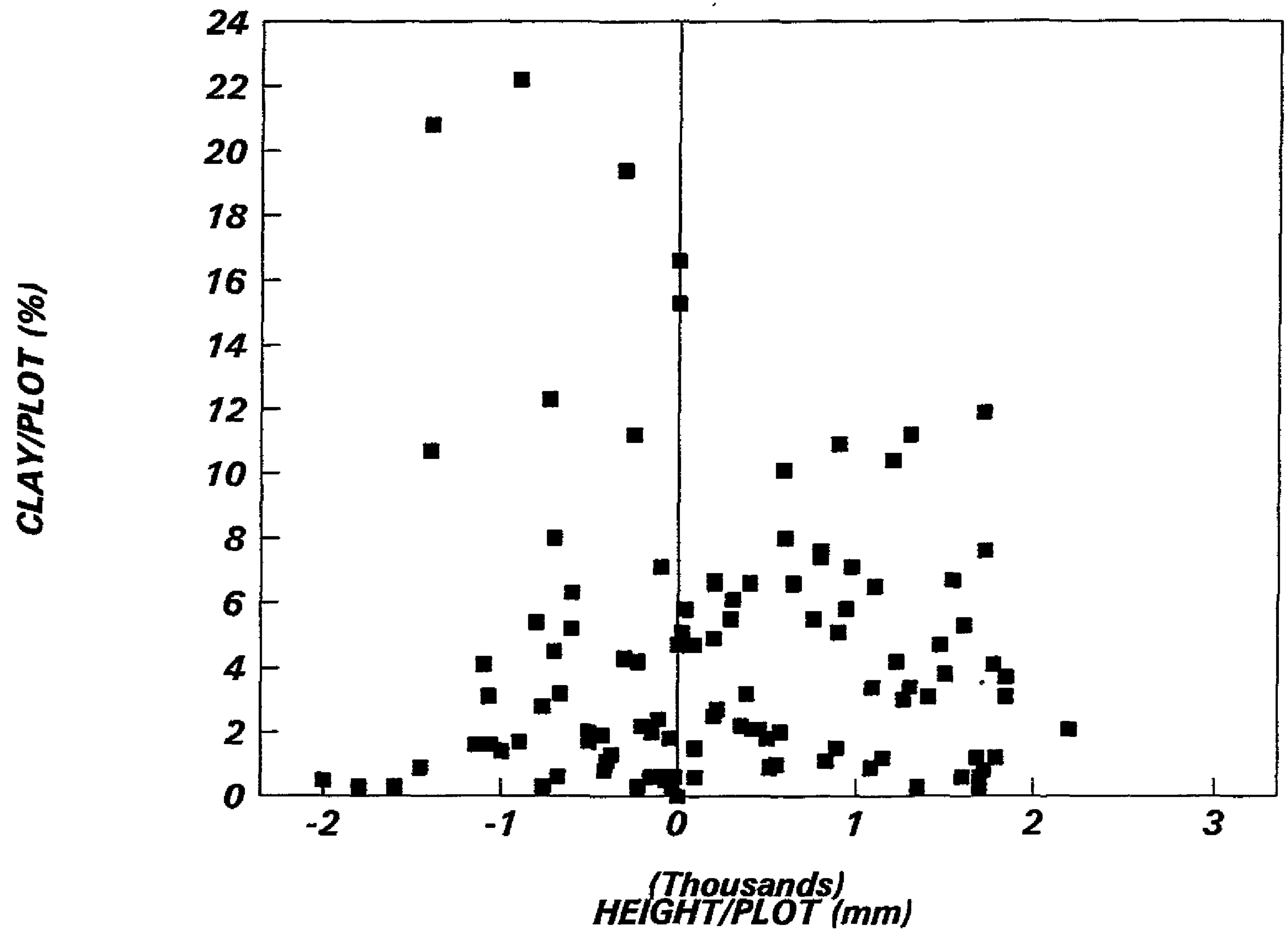


Figure 11a. CLAY/ENERGY RELATION

1988-1992

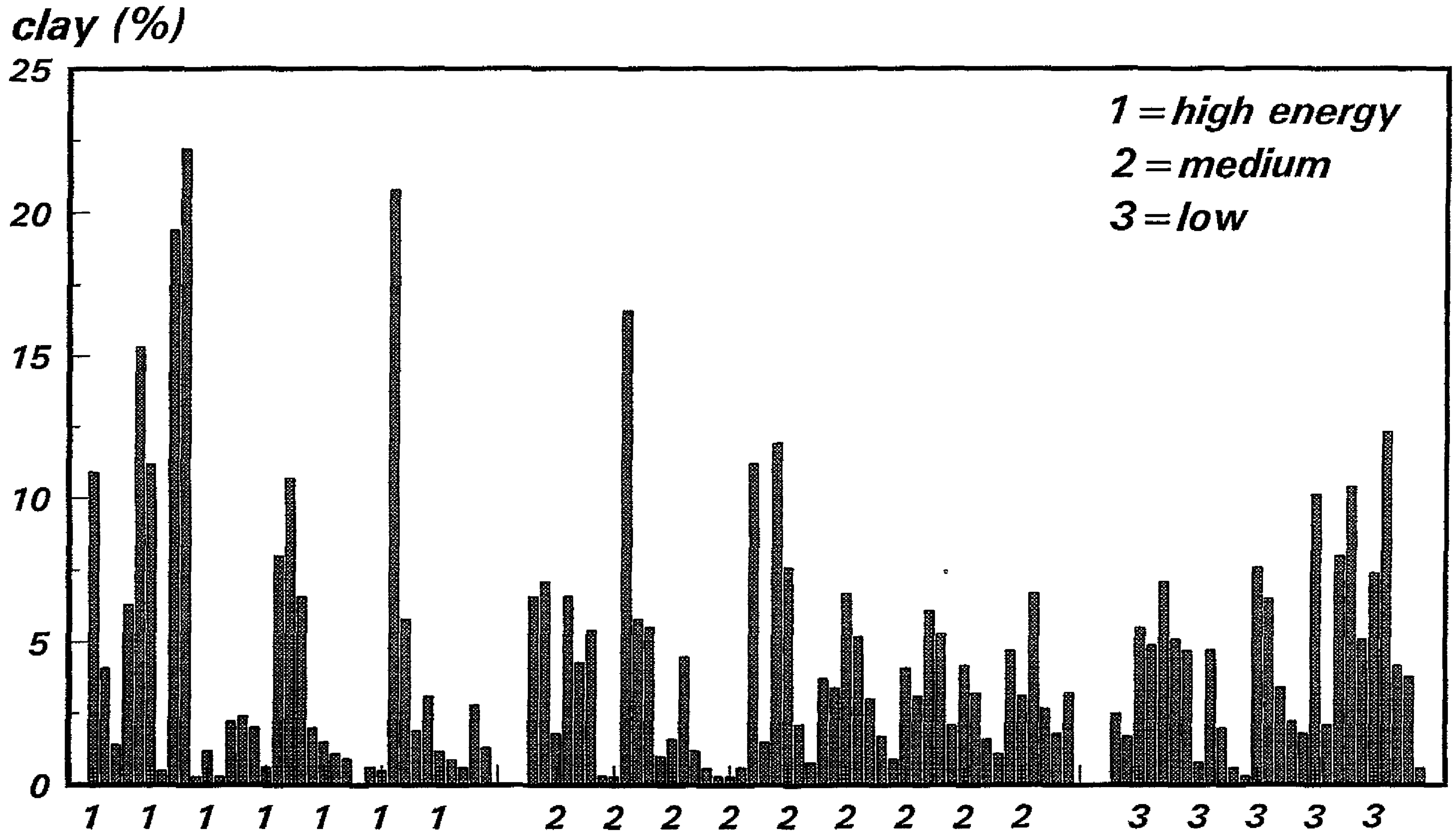


Figure 11b. CLAY/ENERGY RELATION

1989-1993

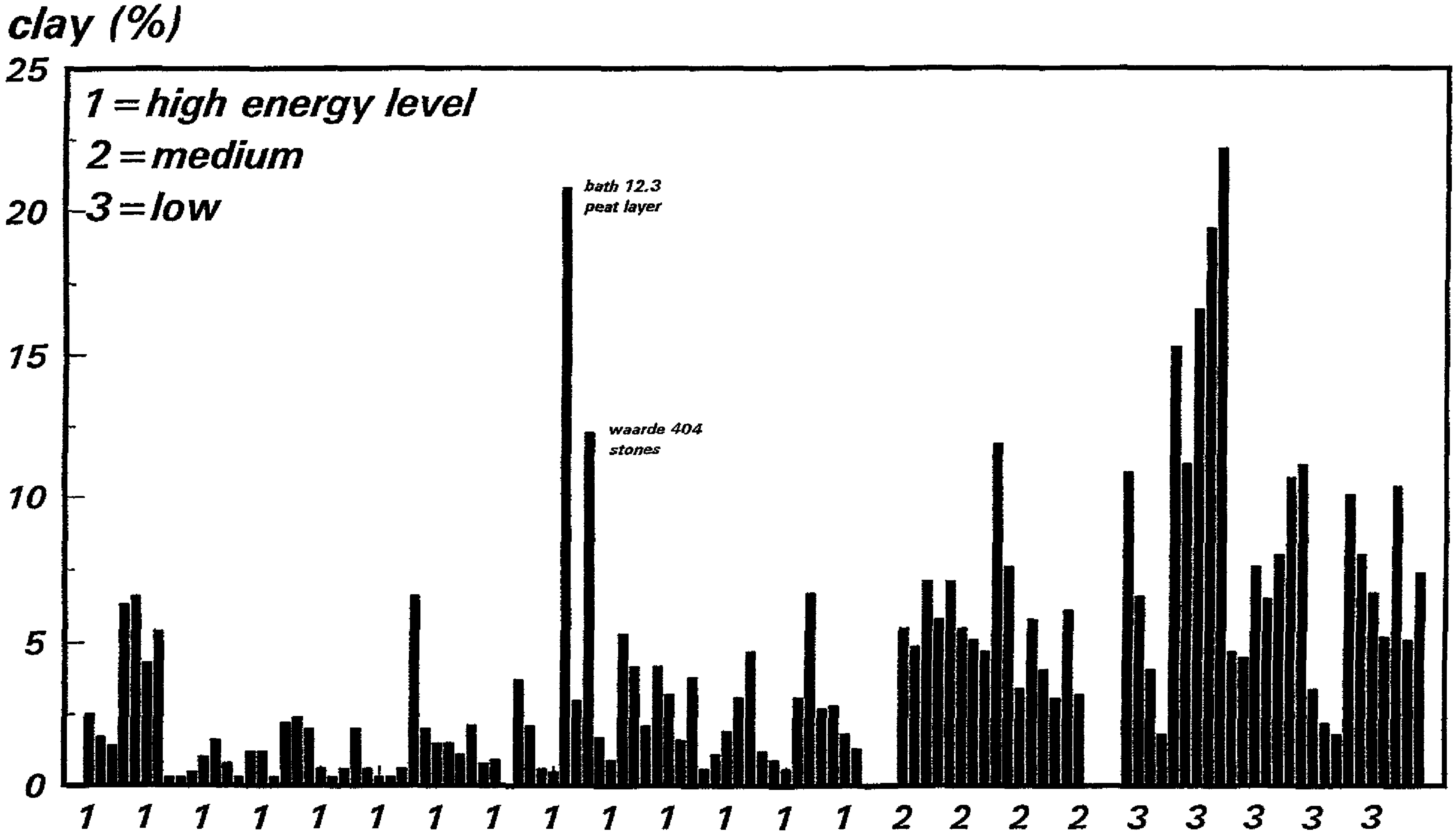


Figure 12. Relation between clay measurments

0-10cm / 0-2cm deep.

1992

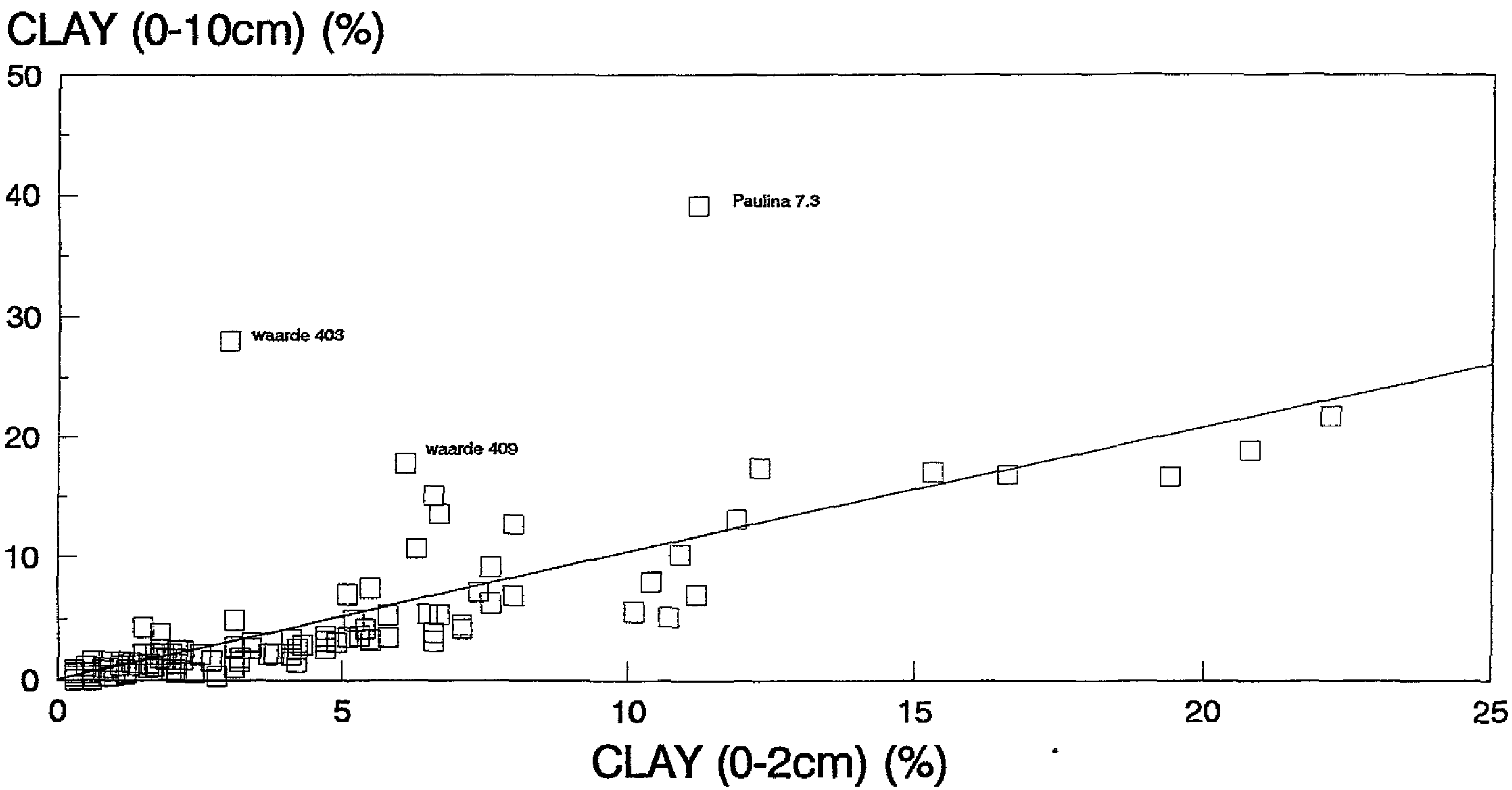


Figure 13. Clay content - grain size relation (1992)

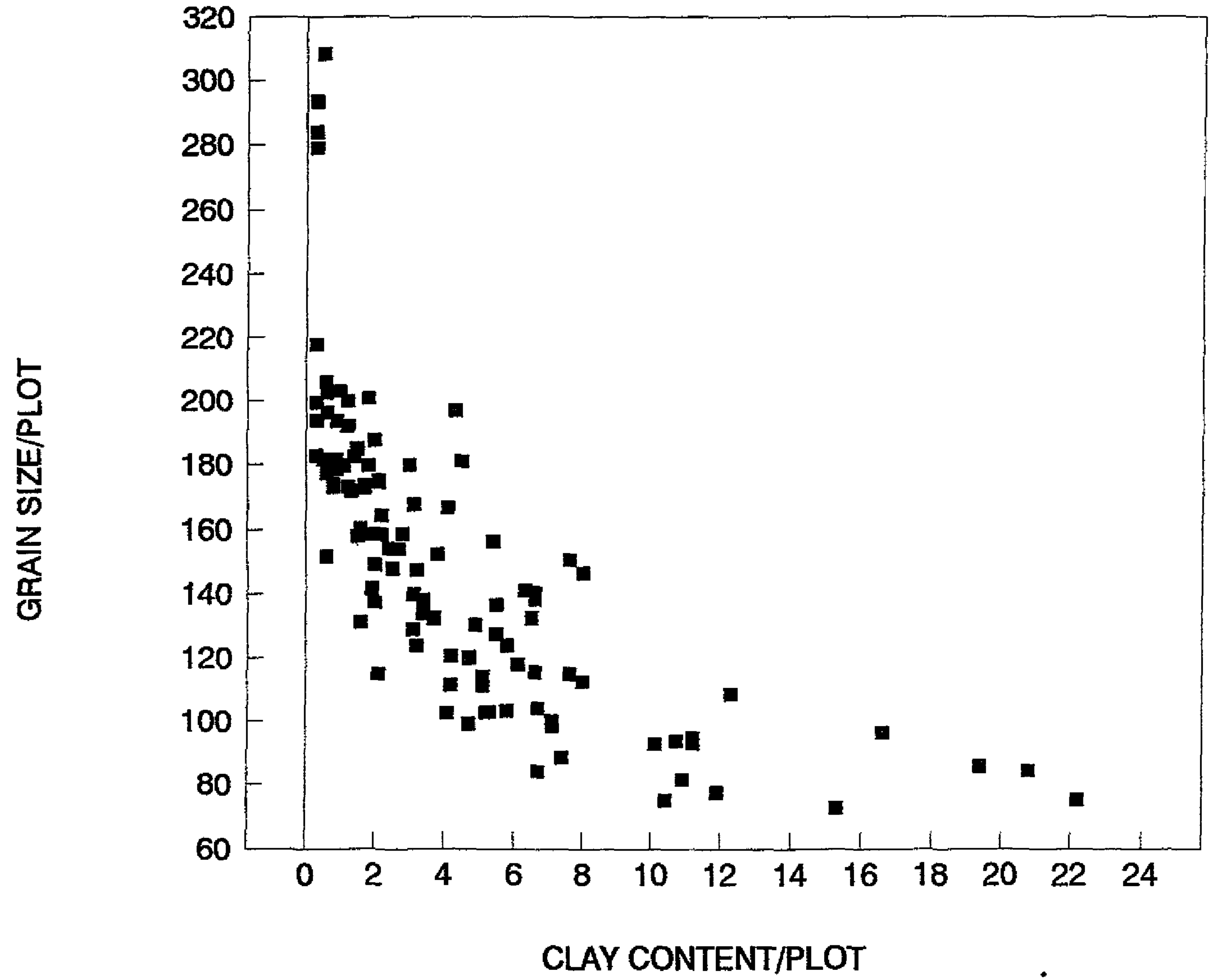


TABLE 1
Average biomass (μg chl-a/ gr dry sediment), standard deviation and number of plots per clay/height combination. All plots included.

height (m)	CLAY (%) <2.5	2.5≤ - ≤5	>5	average biomass per plot
>1	biomass 2.9 STD 2.1 plots 11	4.7 1.8 9	9.6 4.4 7	≥5.2
0≤ - ≤1	biomass 4.1 STD 3.8 plots 11	8.5 4.9 6	10.6 7 19	8.3
<0	biomass 3.4 STD 2.9 plots 27	5.3 3.9 7	8.6 5.1 11	4.9
average bio.- per plot	3.4	5.9	9.8	

TABLE 2
Average biomass (μg chl-a/ gr dry sediment) standard deviation and number of plots per clay/height combination. Not including Hulst and Terneuzen.

height (m)	CLAY (%) <2.5	2.5≤ - ≤5	>5	average biomass per plot
>1	biomass 2.9 STD 2.1 plots 11	4.7 1.8 9	9.6 4.4 7	≥5.2
0≤ - ≤1	biomass 4.1 STD 3.9 plots 11	5.5 2.1 4	8.7 4.5 17	6.7
<0	biomass 2.7 STD 1.5 plots 25	4.1 2.6 6	9.0 5.6 9	4.3
average bio.- per plot	3.1	4.7	9	

TABLE 3
Average biomass and primary production of microphytobenthos in Western Scheldt, Eastern Scheldt (De Jong et al 1993), west Wadden Sea (Cadée & Hegeman 1977) and Ems estuary (Colijn & De Jonge 1984).
(Eastern Scheldt: <1985 = before construction of storm surge barrier. >1985 = present situation with barrier).

	WESTERN SCHELDT			W.Scheldt Total	EASTERN SCHELDT		WADDEN SEA	EMS ESTUARY
	high energy	med. energy	low energy		<1985	>1985		
area (ha)	2586	1456	2288	6330	9300	9300		
average biomass								
(μg/gr)	4.34	7.47	9.79	7.03				
(mg/m^2)	67.3	115.8	151.7	109.0	125	207.5	35 - 120	23 - 120
total biomass								
(ton chl-a)	1.74	1.68	3.5	6.89	11.7	19		
(ton Carbon)	69.6	67.2	138.8	275.9	469	760		
primary production								
(gC/m^{2}y)	84.2	139.1	179.7	131.4	149.5	242.5	40 - 80	60-100(250)
(ton C/y)	2178	2025	4111	8314	14045	22265		

TABLE 4a
Calculation of phytoplankton primary production in Western Scheldt.
Data on area taken from Bodkar calculations and own measurements with planimeter.
Data on primary production taken from Kromkamp et al (1993).

	Flushing ---> Hansweert	Hansweert ---> border	
Primary production ($gC/m^2/y$) (Krompkamp et al)	210	85	
Water area at level NAP (ha) (Bodkar) (planimeter)	 17788 19020.5	 5854 6145.5	
Primary production (tonC/y) (Bodkar) (planimeter)	 37354.8 39943	 4975.9 6145.5	Flushing ---> border 42330.7 45166.7

Contribution of microphytobenthos to primary production:
Bodkar: 16.4%
planimeter: 15.5%

TABLE 4b
Calculation of water area (ha) according to G.I.S and own measurements with planimeter.

	Flushing ---> Hansweert	Hansweert ---> border
Total area G.I.S	21400	10100
Salt marsh area	235	3000
Intertidal area planimeter	4289	1909
Water area at level NAP	19020.5	6145.5