

# TEMPORAL AND SPATIAL PATTERNS IN THE SOFT-BOTTOM COMMUNITIES ALONG THE COAST OF CURAÇAO, NETHERLANDS ANTILLES



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**TEMPORAL AND SPATIAL PATTERNS IN THE SOFT-BOTTOM  
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## SAMENVATTING

De macrofauna in de zogeheten soft sediments tussen de koralen langs de zuidkust van Curaçao was bestudeerd op variabiliteit in ruimte en tijd gedurende de periode maart - september 1996. Een negental transecten langs de kust werden geselecteerd, waarbij het rifplateau een drietal keren en de helling éénmaal bemonsterd werd. De samenstelling van de gemeenschappen verschilde tussen de stations. Op alle stations waren de nematoden het meest talrijk. Er bleek een duidelijke gradiënt aanwezig te zijn met afnemende aantallen van oost naar west langs de kust, hoewel op alle stations de biomassa laag was, minder dan  $0.2 \text{ g ADFW.m}^{-2}$ . Dit patroon was aanwezig zowel op het plateau, als op de helling. Een paar stations lieten een afwijkend beeld zien, waarvan aannemelijk gemaakt kon worden dat dit veroorzaakt werd door het effect van menselijk handelen. Variabiliteit in de tijd, zeer waarschijnlijk veroorzaakt door fluctuaties in water temperatuur, was aanwezig, maar de ruimtelijke patronen veranderden hier niet door. Voor een gedetailleerdere analyse is het nodig dat een jaarplaatje beschikbaar is en dat gegevens van meiofauna toegevoegd worden.

## SUMMARY

The spatial and temporal variability of the soft-bottom macrofauna communities along the southern coast of Curaçao was studied throughout the period March - September 1996. Nine stations were selected and the reef flat of these stations was sampled three times and the corresponding reef slope was sampled only once. The composition of the communities differed between the stations. At all stations, nematodes were most abundant, although at all stations only low biomass values were observed of less than  $0.2 \text{ g ADFW.m}^{-2}$ . Their appeared to be a gradient with decreasing number of individuals from the eastern part of the coastline towards the western part, both at the reef flat and at the reef slope. This gradient was interrupted at a few stations, in which case anthropogenic factors might be responsible. Temporal variability appeared to be present, maybe as a consequence of varying temperature conditions, however the gradient observed remained present. For a more detailed analysis year-round information and data on meiofauna are required.



## 1. INTRODUCTION

In the last decades a great deal of attention has been paid to the coral communities on the reefs of Curaçao. Over the years this has resulted in an overwhelming amount of information on the ecology of especially the stony corals (a.o. BAK, 1975; 1977; 1983; BAK *et al.*, 1981). Furthermore, a complete inventory of the coral community along the leeward coast of Curaçao has been made (VAN DUYL, 1985) and a long-term reef monitoring project was started in 1973 by Bak and co-workers.

In a recent paper BAK & NIEUWLAND (1995) analysed the long-term structural changes in the coral communities over the last decades. One of their conclusions was that the number of coral colonies and the coral cover had decreased significantly at the 10 and 20 m deep reefs. BAK & NIEUWLAND (1995) hypothesized about the possible underlying mechanisms and they concluded that the most likely factor in the degradation of the shallow part of the reef might be the 'coastal development'. This coastal development includes the effect of urbanisation and the development of the tourist industry, resulting in the discharge of sewage and the construction of artificial beaches.

Structural changes in coral communities caused by possible disturbances and stress are difficult to analyse due to the low growing rate of corals (BROWN & HOWARD, 1994). On the contrary, soft sediment communities have been useful in reflecting many types of disturbances (WESTON, 1990; PEARSON *et al.*, 1978; AGARD *et al.*, 1993; STEICHEN *et al.*, 1996). The short life-cycles of the soft-bottom inhabitants, make the latter useful for the reflection of disturbances.

In this study the soft-bottom communities within the reefs along the leeward coast of Curaçao has been studied and analysed with the aim:

- [1] to study the spatial and temporal variability in the community structure;
- [2] to try to relate the observed patterns with environmental stress factors, either natural or anthropogenic.

This report presents the data on macrofauna. Information on the meiofauna will be discussed separately.

## 2. MATERIALS AND METHODS

### 2.1 STUDY SITES

All samples were conducted at the reefs of the island Curaçao, Netherlands Antilles. Its geographic location lies between 12°02' and 12°23'N and 68°12' and 69°10'W. Due to a northwesterly tradewind, the southern, south-western and western coasts are sheltered, resulting in little surf and waves (VAN DUYL, 1985).

Nine transects along the southern shoreline were selected, using the Atlas of the Living Reefs of Curaçao and Bonaire (VAN DUYL, 1985). The nine stations were more or less equidistantly spread from each other (Fig. 1). Four series of sampling were completed in six months. During March, May and July the reef flat was sampled at the selected stations and in April the reef slope was sampled. Each sampling series took place within four days.

During the July survey, additional samples were collected to determine the sediment grain size composition. Additional descriptions of the basic morphology and environment of the study sites can be found in the Atlas of the Living Reefs of Curaçao and Bonaire (VAN DUYL, 1985).

### 2.2. SAMPLING METHOD

All samples were collected by scuba diving. At each station twenty samples were collected, with several trials to sample the highest amount of sediment present. At the reef flat all samples were taken approximately equidistant from each other, starting at the beginning of the drop-off zone and continuing till approximately 10 m from the shore. The immense decrease in visibility or the transition of sand to rocks was used as a beacon for this position. The slope sampling started at approximately 20 m depth and continued until the drop-off zone. Hence the slope and reef flat had an overlapping sampling site at the drop-off zone. This sampling method provided a representative reflection of the reef flat and the slope.

The samples were collected using a cylindrical PVC corer with a 5.4 cm internal diameter, after

RIDDLE (1988). They were pushed manually into the sediment, with a maximum penetration depth of 21 cm. After putting a rubber stopper on top, they were taken out of the sediment and subsequently also a rubber stopper was put at the other site. The samples were collected in a plastic bag and taken ashore. Here within an hour, they were washed over a 1 mm square-meshed sieve and preserved in a 6% formaldehyde solution. The organisms were stained by means of Rose Bengal (ELEFThERIOU, 1984; RIDDLE, 1988). After 24 h the organisms were sorted and determined in principle to family level, otherwise to class or subclass-level, using a light microscope at a magnification of 120x.

For the most common and abundant taxonomic groups the mean biomass per individual was determined. Depending on size, a number of individuals were put together, dried for 48 h at 60°C, weighted and subsequently burned at 520°C for 2 h. The weight loss at 520°C was considered to represent the ash free dry weight (AFDW).

Sediment composition was determined at each station by filling five corers, spread equidistantly across the reef flat. The sediment was dried at 100°C for 48 h, then broken up using a glass rod and shaken through a series of sieves (2.6 mm, 1.3 mm, 1.0 mm, 0.6 mm, 0.3 mm, 0.25 mm, 0.15 mm, 0.125 mm, 0.09 mm, 0.063 mm, 0.053 mm). The sediment passing through the smallest (0.053) mm sieve was collected also. The mass of the sediment retained on each sieve (including the <0.053mm sediment) was determined and converted into percentages of the total mass of sediment. The median grain size of each sample was assessed, in addition with the first decile and the 9th decile, to demonstrate the variety of sediment.

### 2.3. STATISTICAL ANALYSIS

For each transect mean number of individuals per taxonomic group was estimated. Based on the average biomass of the various taxonomic groups, the total biomass were assessed with standard error for each station of the July survey at the reef flat. The vertical distribution of the organisms within the corer was determined for the numbers and biomass by correlating sampling depth and the abundance per identified taxa, to find out whether a correctional

multiplication factor should be applied for all undeeep penetrations in relation to deep corer penetrations.

A 'relative abundance ranking' (DAAN *et al.*, 1992) among the identified organisms was used, to indicate for each station the spatial and temporal variability.

To assess the state of stress and disturbance of a station, the ABC-curves (abundance-biomass comparison) were applied (WARWICK, 1986; BEUKEMA, 1988), which also made a comparison between the stations possible.

## 3. RESULTS

### 3.1. BENTHOS COMPOSITION

Profiles and physical properties of the nine transects are presented in Table 1. In total 36 taxa, belonging to 7 different phyla were found (Table 2). The most important phyla were the Annelida, the Arthropoda and the Mollusca. The Annelida were identified to subclass level, the Arthropoda to subclass and orde level and the Mollusca mainly to family level. The gastropods were identified using DE JONG & COOMANS (1988). The main characteristic used to determine the family was the shell shape in comparison with the photographs in the book. All the segmented worms, with a dilated part in their body, were classified as oligochaetes. The Loxosoma, Anthozoa and Sipunculida were identified by benthos experts. The Plathyhelminthes were identified as such based on their body shape in comparison with drawings in an identification key, used for educational purposes. All worms that showed the presence of parapodia were classified as polychaetes, based on an identification key used for educational purposes by FAUCHALD (1977). The Chitonidae were identified using the photographs found in GEORGE *et al.* (1979). All the segmented worms without apparent appendages and lacking a clear dilation in their body, were classified as Nematoda.

### 3.2. DENSITY

The number of organisms did not show a significant relationship with depth of the core, neither for the sampling of the reef flat (March data), nor for the reef slope (Table 3). Hence no correction factor was applied to correct for differences in corer depth.

### 3.2.1. SPATIAL VARIABILITY

At the reef flats Nematoda and Copepoda were most abundant at all stations, but especially at Fuik and Jan Thiel (Table 4). Although the Nematoda and Copepoda were retained on a 1 mm square-meshed sieve, the numbers found were considered not to be representative. The third most abundant group was the Polychaeta, which was also found at every station. All other groups were found only in low densities, except for high numbers of isopods at Fuik, Holiday Beach and Carmabi, amphipods at Fuik and Anthozoa at Vaersensbaai. The size of the anthozoans was never larger than 0.5 cm, and therefore it was impossible to determine to any lower taxa level. The annelide 'C-Wis' lived in rocks and empty seashells, whereas the other organisms have been detected among the sediment only, except for several Polychaetes. Crustacean spec4, 5, 6 and 7 were never numerous. 'C-spec6' was only detected once, thus the reason it will be excluded from any analysis. Highest number of individuals was found at Carmabi and Vaersensbaai, up to more than 400 individuals (Table 5). Low numbers were observed in Daaibooibaai and Playa Kalki (Fig. 2). The gastropods, which could be identified to family level, did not show any trends from the eastern to the western stations along the coast (Fig. 3), neither in total number of individuals or in number of families (Table 6).

At the reef slope, also the Nematoda, Copepoda and Polychaeta were the most abundant groups (Table 7). All other groups were found in very low numbers at all stations except for the Amphipoda and the family Tanaidacea at Fuik. No relationship was found between sampling depth (m) and number of polychaetes (Table 8). The total number of individuals showed a clear decreasing trend from the most eastern station (Fuik) towards the western part of the island (Table 9). This general pattern was also present in the polychaetes and in all other individuals (Fig. 2). This trend appeared to be interrupted at Avila, showing lower numbers than expected in both the polychaetes and the other groups. This interruption seemed to be present also in the other groups at Holiday beach and at Carmabi. In the gastropods, a similar pattern was found of a decreasing trend from the easternmost station towards the western part of the coast (Fig. 3;

Table 10). Also in the number of gastropods a dip was observed at Avila.

No significant relationships were present between the total number of individuals found at the reef flat and at the corresponding reef slope (Fig. 4). A relationship was also absent when the polychaetes and the other individuals were examined separately.

### 3.2.2. TEMPORAL VARIABILITY

The temporal variability was determined for the sampling periods, March, May and July. The comparison of the March data with the May and July survey are biased, because Boca Hulu was not sampled in March. Nevertheless, the trends found in the different periods were rather similar to each other (Table 11). However, the actual rank order of the relative abundance's were slightly different. The general trend remained the same. The variability in ranking between the different periods was relatively low.

### 3.3. BIOMASS

Table 12 shows the mean individual AFDW of the various most numerous groups in July at the reef flat. Between the various stations, some variability in the individual AFDW could be observed. The total biomass at each station in July is shown in Fig. 5. The major contributors to the biomass were respectively, Mollusca and Polychaeta. During the biomass determination, several inaccuracies took place and subsequently, the total biomass of Holiday Beach and Vaersensbaai were underestimated.

The pattern in biomass values for the various stations differed from that of the number of individuals (Fig. 5). The lowest biomass was found at Avila, 0.05 g AFDW.m<sup>-2</sup>. Also Jan Thiel and Holiday beach showed biomass values of less than 0.1 g AFDW.m<sup>-2</sup>. Highest values were found at Fuik, Vaersensbaai and Daaibooibaai of more than 0.15 g AFDW.m<sup>-2</sup>. No clear trend could be observed from the easternmost towards the western stations along the coast.

### 3.4. ABC CURVES

The ABC-curves showed two types of predicaments (Fig. 6), as defined by Warwick (1986). Fuik and Jan Thiel revealed a moderately disturbed state of being, in contrast to Avila and Holiday Beach, which demonstrated undisturbed circumstances. Carmabi showed a

moderately disturbed condition as well. The dominance-curve, obtained from Vaersenbaai had a peculiar shape, nonetheless it demonstrated an undisturbed community. Except for the odd dominance-curve, Daaibooibaai revealed a similar state as Vaersenbaai. The condition of the Playa Kalki community was in between moderately disturbed and undisturbed.

#### 4. DISCUSSION

The idea was to find a gradient along the coast, based on the earlier findings of GAST *et al.* (1996). Along the coast of Curaçao, several regions can be distinguished. The eastern side of the island is little perturbed by pollution. The ocean water is considered to be relatively 'clean' since it comes straight out of the ocean and does not pass by a polluting agent. This area includes Fuik and Jan Thiel. The main sewage disposal of Curaçao takes place at Avila. The following station, Holiday Beach, might also be affected by this disposal. However, another aspect enters the picture at this point: production of artificial beaches. Sand is 'sucked' up from the reefs and used to create sandy beaches. This being of unnatural origin, the sea will slowly but distinctively, return the sand where it belongs. The results are among others, unstable soft-sediment communities.

The third disturbing factor at this location is the outflow of the Anna-baai, the harbour entrance. The major polluting component of this outflow is oil. Carmabi, a location further to the west, could also suffer from these stresses. It is thought that the gradient will continue until Vaersenbaai. The last three locations, Daaibooibaai, Boca Hulu and Playa Kalki, are expected to be undisturbed, as Fuik and Jan Thiel.

Another main aspect of this study is the reflection of the structural differences in coral communities found by VAN DUYL (1985), upon the soft-bottom communities. Although other factors could also be responsible for the differences between communities, such as successful larval settlement and adult migration (THISTLE, 1981). Distinctions have been made between disturbances responsible for community differences in Curaçao i.e. discontinuous zonation and patchy distribution:

[1] Tropical storms, western high waves, resulting from the storms south of the island.

[2] Human interference; mainly pollution, such as sewage disposal and the oil industry, but also the construction of artificial beaches.

[3] Disease; the white band disease (Van Duyl, 1985)

Besides these influential factors, community structure might also alter over time (FRANKENBERG, 1977; BEUKEMA, 1974). Even though seasons do not play an great part in the climate of Curaçao, the benthic communities could display changes in their composition over time, i.e. temporal variability.

##### 4.1. BENTHOS COMPOSITION AND DISTRIBUTION

The physical environmental aspects of the communities already indicate differences between the stations. Hence the soft-bottom communities are expected to be unlike each other. A first glimpse at the taxa found and the numerical data supports this view. Differences in number of individuals per station was not the result of a bias in sampling. The absence of a clear relationship between sampling depth of a corer and number of individuals found, suggests that most animals live in the uppermost centimeters of the sediment, supporting earlier results. WESTON (1990) found that 90% of the organisms were living in the upper 5 cm of the sediment. RHOADS (1982) found a similar outcome: most organisms live in the upper 10 cm or higher. STEICHEN *et al.* (1996) found 92% of the organisms living in the first 4 cm. At Playa Kalki the distribution of the organisms shows an almost linear relationship to the corer depth. Strangely enough, the biomass outcome at Playa Kalki agrees with WESTON' (1990) results: 40-90% of the biomass is situated below the first 5 cm. In order to assess a more precise insight in the vertical distribution, it is recommended to cut a sample into slices of a centimeter and to determine the presence of organisms and biomass. This procedure would provide more accurate results, which might indicate trends not identified by these data.

The most important factor affecting distribution and abundance of the various organisms might be the physical environment. AGARD *et al.* (1993) found that sediment type and water depth are the major factors responsible for community composition. Daaibooi baai, Avila,

Vaersenbaai and Fuik consist of relatively fine sand, in comparison to the other stations and the bivalves seem to show a distinct tendency towards these stations, although STEICHEN *et al.* (1996) found that bivalves were predominately living in coarser sediments. However, STEPHEN *et al.* (1996) does not document the grain size of this 'larger sediment'. It might therefore be possible that the same grain size is in question. The reason for the low number of bivalves at Fuik is unclear at the moment. The Isopods are particularly numerous at Holiday Beach and Carmabi. Both these stations have quite a coarse sediment structure. Besides this, the stations have no other specific parameter in common. This might indicate that Isopods prefer a habitat consisting of coarse sediment. The locations, considered to be relatively unexposed, show a high number of Amphipods. PARKER (1975) found that Amphipods occurred everywhere except on wave-influenced sand flats.

#### 4.2. SPATIAL AND TEMPORAL VARIABILITY

The spatial variability in benthos composition varied considerably between stations, however the patterns in numbers differed from the pattern in biomass. Both at the reef slope and reef flat a trend of decreasing numbers towards the eastern part of the coast was suggested. At the reef flat this trend was interrupted at Carmabi and Vaersenbaai. The range between the lowest and the highest total number found was 4.7 at the reef flat and 3.0 at the reef slope, and expressed as coefficient of variation the variability amounted respectively 43 and 38 %. The range in biomass at the reef flat was larger than that in number of individuals, about 6.5, which is also reflected in a higher coefficient of variation of about 70%. Considering the differences within a station over time, one might conclude on the one hand that the spatial variability between these stations is quite constant and on the other hand that temporal variability is rather low. Although the ranking of the groups differs somewhat between May and July, the relative abundance along the coast is similar.

A possible answer for the relative increase throughout the six months, could be the increase in temperature. Even though the temperature measured (using a diving computer) in May still showed 27°C, a more

sensitive and accurate temperature registration might indicate subtle temperature fluctuations. A clarification for the decrease in relative abundance during May might be a local perturbation. The assumptions above could explain, to some extent, the difference in rank order between May and July. Nonetheless, July also displays a maximum temperature for all stations. Again, the temperature could be, and most probably will be responsible. Supporting evidence is given by GRAY (1984), who shows an increase in the total sum of organisms as a result of a 1°C increase in temperature per year.

FRANKENBERG *et al.* (1977) found a great variety in temporal variations between the species. Causal relationships were used to elucidate the fluctuations of several species, instead of seasonality. In order to establish such explanations for the variability found in Curaçao, further research would be required. In addition, the taxa would need to be determined to species level, to gain information on the ecological relationships. However, the similarity in trends found in Curaçao are bound to be a result from seasonal changes. They are a collective representation of the community changes. In South Africa (FRANKENBERG *et al.*, 1977), indications of seasonality have also been detected. Therefore it would be highly probable that the increase in temperature, as a result of seasonality, is responsible for the trends in Curaçao.

#### 4.3. ABC ANALYSIS

Several stations, which were expected to show a clearly disturbed community, showed exactly the opposite ABC curve. Fuik and Jan Thiel, characterised to be non-stressed and clean areas, both display a curve which WARWICK (1986) classified as 'moderately disturbed' state. In fact all the stations displayed the 'moderate disturbed' curve by the ABC criteria, except for Avila, Holiday Beach, Vaersenbaai and Daaiboosbaai. Little attention should be paid to the outcome of Avila, since the curve is based upon 3 taxa, which is not considered sufficient to be representative. WESTON (1990) found similar odd outcomes, when using the ABC-curves. According to WESTON (1990) two factors could account for this phenomenon:

- [1] a misclassification of the method or
- [2] a puzzling and undetected faunal gradient exists.

Considering the fact that BEUKEMA (1988) has demonstrated that the ABC-method is of limited value in tidal flat areas, conclusions from these ABC-curves should be drawn carefully. To integrate the results and generate a complete illustration of the communities, each station will be discussed separately.

Fuik has a low relative species abundance. The physical environment, particularly the exposure, is probably the main determinant responsible. The community suffers more wave energy and thus is perturbed more frequent than those with a lower wave energy environment. This is supported by the general concept of a stable community. This concept outlines a community to be stable when the species number is high, the biomass is high also and the number of organisms is moderate (PEARSON, 1978; GRAY, 1984). Fuik has quite a high number of organisms in comparison to the other stations. The low number of bivalves, compared to other stations with similar sediment composition, also supports the assumption of Fuik being an unstable community.

Jan Thiel represents the undisturbed station that was expected. Although the ABC-curve shows differently, the community lives up to the 'definition' of a stable community, given above. The relative abundance of organisms is high, but the actual number of organisms found is lower than the maximum found (Fuik). The biomass is also higher than the minimum found. Hence, no extremes are detected in biomass or number. The exposure supports the assumption that Jan Thiel is a relatively undisturbed community as well. The moderate sediment composition provides a possible high number of niches, consequently a diverse and complex community can be founded.

Avila can be classified as a disturbed area beyond any doubt. The extreme low number of organisms and biomass indicate that this area is stressed (PEARSON, 1978; STEPHEN, 1996, WESSON, 1990). Polychaetes represent 99% of the biomass. If the Polychaetes had been determined to species level, they would have been indicative for the level of pollution: WESSON (1990) showed a composition of the Polychaetes populations at different locations along an organic gradient. The organisms were divided into tropic groups and the composition of these groups changed clearly along this

gradient. Using this information, the level of pollution could have been determined. Nonetheless, it has become obvious that Avila is a heavily disturbed location.

Holiday Beach appears to be in a similar condition as Jan Thiel. This assumption is supported by the similar exposure and coherence with the concept of a stable community. Although the total number of organisms is higher than at Jan Thiel, the ABC-curves also agree with the former assumption. This outcome is quite surprising as three types of perturbations were expected to influence the community greatly were: the outflow of the Anna baai, the sewage disposal and the production of artificial beaches. One possibility, applying a positive approach, would be to assume the disturbances are having a smaller impact on its environment than was expected. Or the data obtained in this study do not uncover the actual situation. As this research is being continued at the moment, an answer might be provided in the near future.

Carmabi showed the highest average rank number for the relative abundance between the stations. Due to the coarseness of the sediment, more potential niches could be present (GRAY, 1974). Due to the fact that the taxa have not been determined to lower levels, diversity indices cannot be applied to support the above presumption. It would seem probable though that a higher diversity could result in a high relative abundance also. There is, however, another factor that could cause perturbations; the outflow of the Piscaderabaai. Taking the general current into account, and the fact that this bay has an outflow every day, it would be conceivable to suggest that it might cause some type of stress. On the contrary, instead of classifying this event as a stress factor, it could also act as an enrichment agent (PEARSON, 1978; WESTON, 1990). Thus resulting in high numbers of organisms.

Vaersenbaai endures little disturbance from its exposure. This could partly be responsible for the high relative abundance. The sediment composition is fine, hence the diversity is presumably lower. This does not necessarily result in lower abundances of organisms. With such little exposure, a stable community could develop. The ABC-curve, although somewhat peculiar in shape, also indicates Vaersenbaai to be a non-stressed community. This environment

seems to be the preference of the anthozoans. None of the other stations disclosed similar sums of anthozoans. PARKER (1975) found that the anemone *Edwardsia elegans* preferred sandy bottoms as well, but only in combination with eel grass beds. The anthozoans in Curaçao might also favour serene and sandy locations.

Daaibooi baai has physical properties similar to Vaersenbaai. The exposure is low and the sediment consists of fine sand. However, the relative abundance rank is quite low in comparison and the anthozoans are also absent. The major difference between the stations lies in their geographic location. Daaibooi baai is enclosed within two rock walls. Both reaching far into the ocean. Consequently this community could experience less exposure than suggested by VAN DUYL (1985). The influx of nutrients from the ocean could be lower, due to the longer distance it must travel to reach halfway the reef flat. Besides this, the water does not pass by any nutrient source, such as coral colonies. The entire reef flat consists of sand only. However, these are mere assumptions, and further research is required for confirmation.

Boca Hulu endures a moderate exposure. As all the other locations with moderate exposure, with the exception of Avila, the relative abundance is high. It is assumed that exposure factor 4, does not cause stress onto the community. The moderate sediment composition probably also favours a high abundance, due to a higher amount of potential niches. The high amounts of amphipods, adds to the indication for the undisturbed condition of Boca Hulu.

Playa Kalki surprisingly reveals a low relative abundance, which is contrary to the expectations. The moderate sediment composition could provide a higher number of organisms, as is assumed for several other stations. The exposure factor is unlikely to be responsible. In opposition to Daaibooi baai, Playa Kalki is not enclosed by rock walls. The lack of influx cannot be applied to the condition found in Playa Kalki. Aside from July, the number of amphipods was never high in Playa Kalki. On the basis of the data obtained throughout this study, an elucidation for the relative abundance found cannot be given.

At the beginning of this study, it was presumed that a gradient in nutrient concentration and organic matter exists along the coast of Curaçao. So far, only 'disturbed' areas have been discussed. Until what degree can these disturbances be interpreted as pollution? In the case of Avila, regarding the earlier findings of GAST (1996), it is almost certain that this station is polluted. However, providing an answer to the question whether a pollution gradient runs along the coast of Curaçao, is rather difficult, based on the data obtained from this study. In case the organisms could have been identified to lower taxa levels it would have been possible to identify 'indicator'-species, as have been done in earlier studies (PEARSON, 1978). Such indicator organisms would provide more conclusive answers as to the condition of the reefs of Curaçao. It is therefore strongly recommended to do so in following studies.

Most literature covers species and families since the feeding strategies differ greatly, even between families and genera (JUMARS, 1977). The feeding strategies are often used to regroup the organisms found. Many distinctions are made between the feeding strategies (GRAY, 1974; GRAY, 1984; JUMARS, 1997; MCCALL, 1982). A vast amount of information is available on the changes in communities, due to organic pollution, through natural or anthropogenic causes (AGARD *et al.*, 1993; GRAY, 1984; PEARSON *et al.*, 1978; STEICHEN *et al.*, 1996; WARWICK, 1986; WESTON, 1990). Several of these articles discuss an organic gradient and its effect on the benthic communities. Contrary to the distance between the stations in Curaçao, the studies mentioned above used a maximum of 50 m in between the stations. Hence, if a gradient is present along the coast of Curaçao, it would presumably not be detected by this type of study. On the other hand, if the effects of the pollution are not traceable, or indicated by the data gathered throughout this study, then the pollution might cause a smaller impact on the reef communities, than was expected.

Unfortunately, such an approach seems highly improbable and unbecoming in times as these. Scuba-diving in Curaçao will convince anybody that the reefs are enduring stress. It would be more than appropriate to continue this research, until it becomes clear what the actual stress agents and their impacts are.

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TABLE 1

Physical properties of the stations, in combination with sediment composition. The profiles of the slope were constructed based on VAN DUYL (1985). The coarse sand (>2.8mm) mainly consisted of rubble and the calcified leaves of the algae *Halimeda* (HUMANN, 1993). The temperature range varied between 27°C in March, April and May and 29°C in July 1996. Level of exposure after VAN DUYL (1985): 3 : high-moderate wave energy environment (waves 1-1.5 m high); 4 : moderate wave energy environment (waves 0.5-1 m high); 5 : moderate-low wave energy environment (waves 30-50 cm high); 6 : low wave energy environment (waves 0-30 cm high). The sediment composition was classified as 'fine' for Fuik, Avila, Vaersenbaai and Daaibooi baai; 'moderate' for Jan Thiel, Boca Hulu and Playa Kalki; and 'coarse' for Holiday Beach and Carmabi.

Code	Location	Exposure	Coral cover		Characteristics
			Plateau	Slope	
1	Fuik	3	high	high	Small sand patches (not connected).
2	Jan Thiel	4	high	high	Low penetration depth, small sand patches (not connected).
3	Avila	4	low	low	Merely sand on both flat and slope
4	Holiday Beach	4	moderate	high	A great amount of rubble. Moderately great sand patches spread across the reef flat, although not connected.
5	Carmabi	4	moderate	high	A great amount of rubble. Moderately great sand patches spread across the reef flat, although not connected.
6	Vaersenbaai	6	low	high	The reef flat mainly consists of sand, resulting in high penetration depths.
7	Daaibooi baai	6	low	high	The reef flat mainly consists of sand.
8	Boca Hulu	4	moderate	high	A vast amount of rubble, coral colonies and a scarcity of sand patches
9	Playa Kalki	5	moderate	high	A vast amount of rubble, coral colonies and a scarcity of sand patches

TABLE 2

Systematic overview of the various groups found in the soft sediments along the coast of Curaçao, together with their code of abbreviation. After Eales (1952), Parker & Haswell (1956) and De Jong & Coomans (1988)

Code	Phylum	Class	Subclass	Order	Sub-order	Family	Genus
C-Ant	Coelenterata	Anthozoa					
N-Nem	Nematoda						
A-Pol	Annelida	Chaetopoda	Polychaeta				
A-Oli			Oligochaeta				
A-Wis							Spec 1
G-Sip	Gephyrea	Sipunculidae					
C-Ost	Arthropoda	Crustacea	Ostracoda				
C-Cop			Copepoda				
C-Bra			Branchiura				
C-Tan			Malacostraca	Tanaidacea			
C-Iso				Isopoda			
C-Amp				Amphipoda			
C-Ano				Decapoda	Anomura		
C-Car					Natantia	Caridea	
C-Sp4							Spec 4
C-Sp5							Spec 5
C-Sp6							Spec 6
C-Sp7							Spec 7
M-Chi	Mollusca	Placophora				Chitonidae	
M-Tro		Gastropoda	Prosobranchia	Archeagastropoda		Trochidae	
M-Vit				Mesogastropoda		Vitrinellidae	
M-Ris						Rissoidae	
M-Mel						Melanellidae	
M-Cyc						Cyclostematidae	
M-Col				Neogastropoda		Columbellidae	
M-Nas						Nassariidae	
M-Oli						Olividae	
M-Mar						Marginellidae	
M-Ter						Terebridae	
M-Tur						Turridae	
M-Pyr			Opisthobranchia	Pyramidelloida		Pyramidellidae	
M-Ham				Cephalaspidae		Haminoeidae	
M-Sp10							Spec 10
M-Biv		Bivalvia					
Plat	Platyhelminthes						
E-Lox	Entoprocta						Loxosoma

TABLE 3

Relationship between core depth and total number of individuals found, for the sampling in March 1996 at the reef flat and in April 1996 at the reef slope, according to  $Y = aX + b$ , in which Y is number of individuals and X is depth of core in cm. Number of samples per transect: 20.

Code	Location	Reef flat			Reef slope		
		a	b	r <sup>2</sup>	a	b	r <sup>2</sup>
1	Fuik	2.43	75.65	0.006	2.57	48.29	0.063
2	Jan Thiel	2.33	135.19	0.008	4.10	32.01	0.166
3	Avila				1.04	11.68	0.147
4	Holiday beach	-1.98	78.78	0.025	1.75	10.27	0.384
5	Carmabi	2.46	22.74	0.010	0.02	17.91	0.000
6	Vaersenbaai	0.07	25.56	0.000	-0.14	26.47	0.001
7	Daaibootbaai	0.33	9.40	0.006	-0.25	20.54	0.014
8	Boca Hulu				0.31	18.02	0.005
9	Playa Kalki	0.62	3.42	0.072	-0.26	16.70	0.009

TABLE 4

Number of individuals found per group in 20 cores at the sampling of the reef flat in March 1996 at the various sampling stations.  
For abbreviations see Table 2

Code	Fuik 1	Jan Thiel 2	Avila 3	Holiday beach 4	Carmabi 5	Vaersenbaai 6	Daaibooibaai 7	Playa Kalki 9
C-Ant		4	3	1	4	36		3
N-Nem	1122	1983	267	31	231	93	85	50
A-Pol	191	277	201	90	313	302	41	101
A-Oli					7	3		2
A-Wis	39	20	11	26	59	7	24	3
G-Sip		2						1
C-Ost						1	1	
C-Cop	736	1071	308	93	199	54	122	49
C-Bra	1	1		1				
C-Tan			2		2	3	1	3
C-Iso	57	7	9	185	48	1	2	1
C-Amp	85	4	11		7	18	5	6
C-Car							1	1
C-Sp4		1	2					
C-Sp5						1		
C-Sp6				1				
M-Tro			1					
M-Vit				2				
M-Mel							1	
M-Cyc				1				1
M-Col					1			
M-Nas			1				1	2
M-Oli	4	2	3		1		3	
M-Mar		4	3		5		3	1
M-Ter			1					
M-Tur								1
M-Pyr						1		
M-Biv	3	1	1		6	1	15	2
Plat					1			
E-Lox		12			4	7		

TABLE 5

Number of polychaetes, number of other individuals and total number of individuals found in 20 cores at the sampling of the reef flat in March 1996 and at the reef slope in April 1996 at the various sampling stations.

Code	Location	Total	Reef flat		Total	Reef slope	
			Polychaetes	Others		Polychaetes	Others
1	Fuik	341	191	150	277	142	135
2	Jan Thiel	339	277	52	194	137	57
3	Avila	250	201	49	108	69	39
4	Holiday beach	303	90	219	133	109	24
5	Carmabi	460	313	147	149	119	30
6	Vaersenbaai	381	302	79	146	94	52
7	Daaibootbaai	98	41	57	133	106	27
8	Boca Hulu				104	62	42
9	Playa Kalki	130	101	29	93	59	34

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TABLE 6

Number of individuals of the families of the Gastropoda found in 20 cores at the reef flat in March 1996 of the various sampling stations, together with total number of individuals and total number of species (between parenthesis). For abbreviations see Table 2.

Code	Location	M-Tro	M-Vit	M-Mel	M-Cyc	M-Col	M-Nas	M-Oli	M-Mar	M-Tur	M-Pyr	Total
1	Fuik							4				4(1)
2	Jan Thiel							2	4			6(2)
3	Avila	1					1	3	3			8(4)
4	Holiday beach		2		1							3(2)
5	Carmabi					1		1	5			7(3)
6	Vaersenbaai										1	1(1)
7	Daaibootbaai			1			1	3	3			7(3)
8	Boca Hulu											
9	Playa Kalki				1		2	1		1		5(4)

TABLE 7

Number of individuals found per group in 20 cores at the sampling of the reef slope in April 1996 at the various sampling stations. For abbreviations see Table 2

Code	Fuik 1	Jan Thiel 2	Avila 3	Holiday beach 4	Carmabi 5	Vaersenbaai 6	Daaibooibaa 7	Boca Hulu 8	Playa Kalki 9
C-Ant	1	2	2	1					
N-Nem	540	347	167	209	143	181	109	178	86
A-Pol	142	137	69	109	119	94	106	62	59
A-Oli					5			5	
A-Wis		3	14	1				1	
C-Ost	3	1							
C-Cop	632	725	176	240	71	165	110	150	93
C-Tan	79	19		2		1	3	3	8
C-Iso		1	1	1			1		
C-Amp	30	15	8	6	6	10	2	15	9
C-Ano						2	1		2
C-Car		4	4		2	1	4	6	8
C-Sp4		1		4			1		
C-Sp5	1						1		
M-Vit	2								
M-Cyc			1	1					
M-Nas	5	1				1			
M-Oli	1	3	2	1	4	3	2	1	1
M-Mar	11	5		6	4	6	4	6	2
M-Ham			1				1		
M-Sp10									1
M-Biv	2	1	2	1	2	1	6	1	3
E-Lox					7	26	2		

TABLE 8

Relationship between sampling depth and total number of polychaetes found for the sampling at the reef slope, according to  $Y = aX + b$ , in which Y is number of individuals and X is depth of corer in cm. Number of samples per transect: 20.

Code	Location	Reef slope		
		a	b	r <sup>2</sup>
1	Fuik	-0.970	21.75	0.235
2	Jan Thiel	0.043	6.578	0.003
3	Avila	-0.221	6.390	0.030
4	Holiday beach	0.208	2.480	0.033
5	Carmabi	0.400	1.917	0.054
6	Vaersenbaai	-0.359	9.485	0.098
7	Daaibootbaai	-0.271	9.563	0.031
8	Boca Hulu	-0.345	8.764	0.077
9	Playa Kalki	0.129	1.087	0.061

TABLE 9

Number of polychaetes number of other individuals and total number of individuals found in 20 cores at the reef slope at the various sampling stations.

Code	Location	Total	Reef slope	
			Polychaetes	Others
1	Fuik	277	142	135
2	Jan Thiel	194	137	57
3	Avila	108	69	39
4	Holiday beach	133	109	24
5	Carmabi	149	119	30
6	Vaersenbaai	146	94	52
7	Daaibootbaai	133	106	27
8	Boca Hulu	104	62	42
9	Playa Kalki	93	59	34

TABLE 10

Number of individuals of the families of the Gastropoda found in 20 cores at the reef slope in April 1996 of the various sampling stations, together with total number of individuals and total number of species (between parenthesis). For abbreviations see Table 2.

Code	Location	M-Vit	M-Cyc	M-Nas	M-Oli	M-Mar	M-Ham	Total
1	Fuik	2		5	1	11		19(4)
2	Jan Thiel			1	3	5		9(3)
3	Avila		1		2		1	4(3)
4	Holiday beach		1		1	6		8(3)
5	Carmabi				4	4		8(2)
6	Vaersenbaai			1	3	6		10(3)
7	Daaibooibaii				2	4	1	7(3)
8	Boca Hulu				1	6		7(2)
9	Playa Kalki				1	2		3(2)

TABLE 11

The rank order of abundance for May and July. The lowest rank represents the lowest abundance. The Nematoda and Copepoda have been excluded.

Code	Location	March	May	July	Mean
1	Fuik	7	2	3	4.0
2	Jan Thiel	5	5	7	5.7
3	Avila	3	1	1	1.7
4	Holiday beach	4	6	4	4.7
5	Carmabi	8	9	9	8.7
6	Vaersenbaai	6	8	6	6.7
7	Daaibootbaai	1	4	2	2.3
8	Boca Hulu		7	8	7.5
9	Playa Kalki	2	3	5	3.3

TABLE 12

Mean individual ash free dry weight (AFDW;  $g \cdot 10^{-6}$ ) of individuals of the most numerous groups at the various sampling stations, together with mean (Mean) and standard deviation (Stdev). For abbreviations see Table 2

	Fuik	Jan Thiel	Avila	Holliday Beach	Carmabi	Vaesen- baai	Daaibooi- baai	Playa Kalki	Mean	Stdev
Code	1	2	3	4	5	6	7	9		
C-Ant		1400		3600	570	229	250	320	1061	1319
A-Pol	133		393		85	1099	368	337	402	364
A-Wis	700	4900			3157	569	610		1987	1963
C-Bra						5750				
C-Tan	33				17			2400	816	1371
C-Iso	23				4			100	42	50
C-Amp	23	49	200	71	22	22	40	35	58	59
C-Ano				300	833	250		400	445	265
C-Sp-5							200			
C-Sp-7	700						250		475	318
M-Cyc					4200					
M-Nas	3550			7400		2600			4516	2541
M-Oli	3575	2860		4950	1000	900			2657	1730
M-Mar	1000		1700	200	433			1600	986	672
M-Biv	17			800			4658	3244	2179	2149
Plat						650				
E-Lox				30				75	52	32

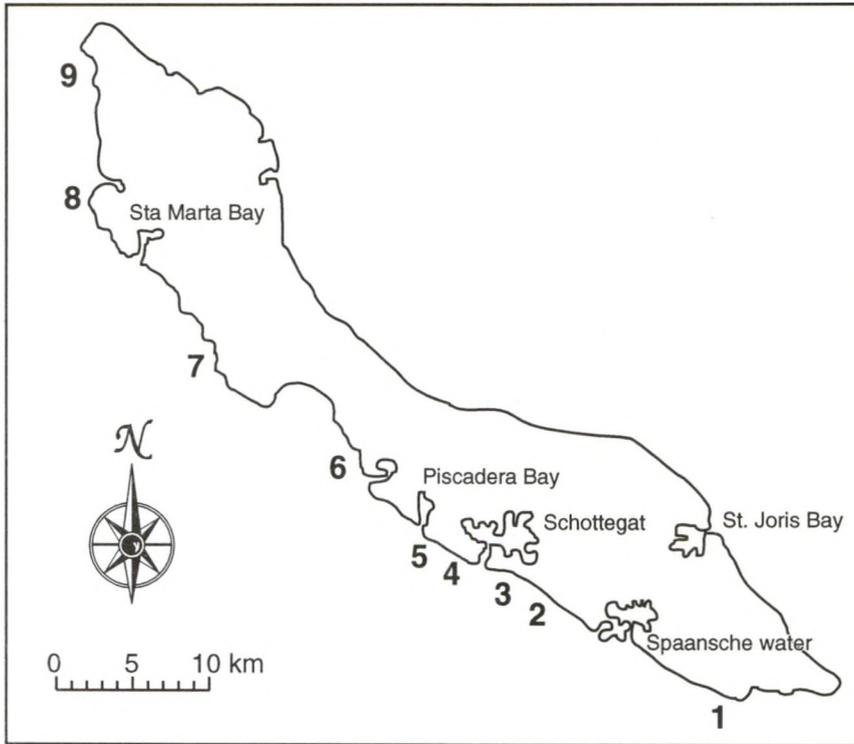


Figure 1. Location of sampling sites along the coast of Curaçao. 1= Fuik; 2= Jan Thiel; 3= Avila; 4= Holiday beach; 5= Carmabi; 6= Vaersenbaai; 7= Daaibooi baai; 8= Boca Hulu; 9= Playa Kalki. For more information see Table 1

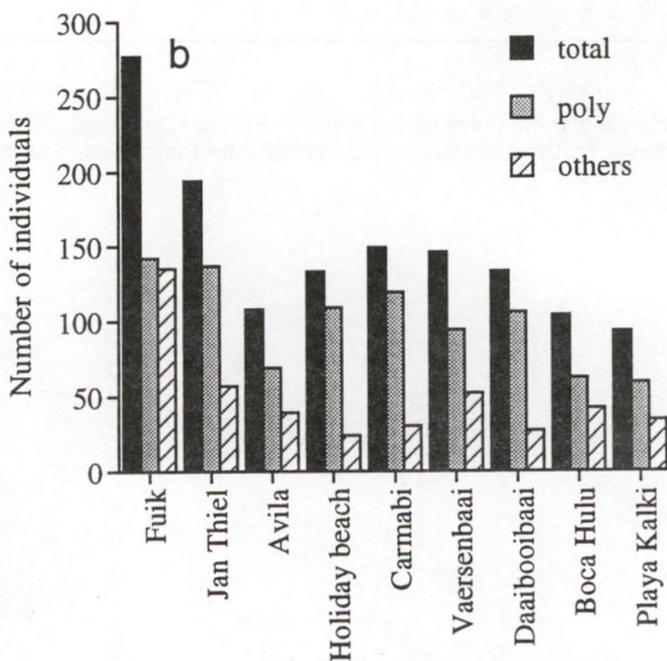
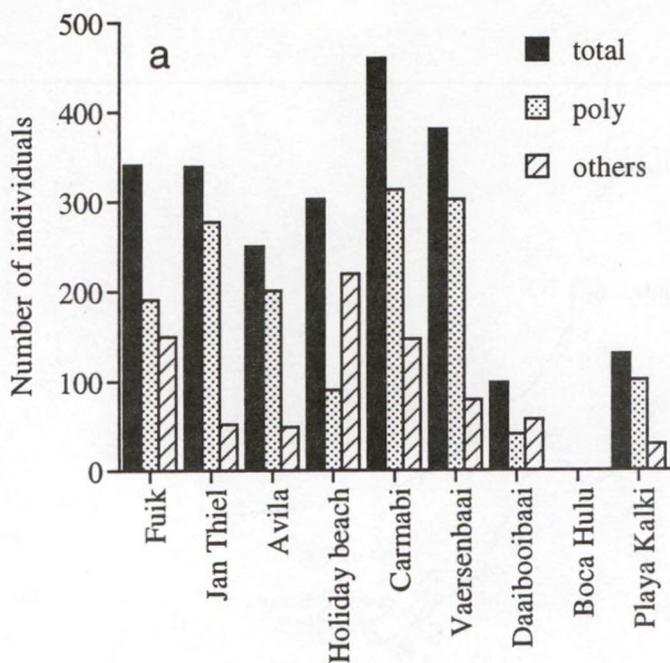


Figure 2. Number of polychaetes, number of other individuals and total number of individuals found in 20 cores at the various sampling stations. a; at the sampling of the reef flat in March 1996; b: at the sampling of the reef slope in April 1996.

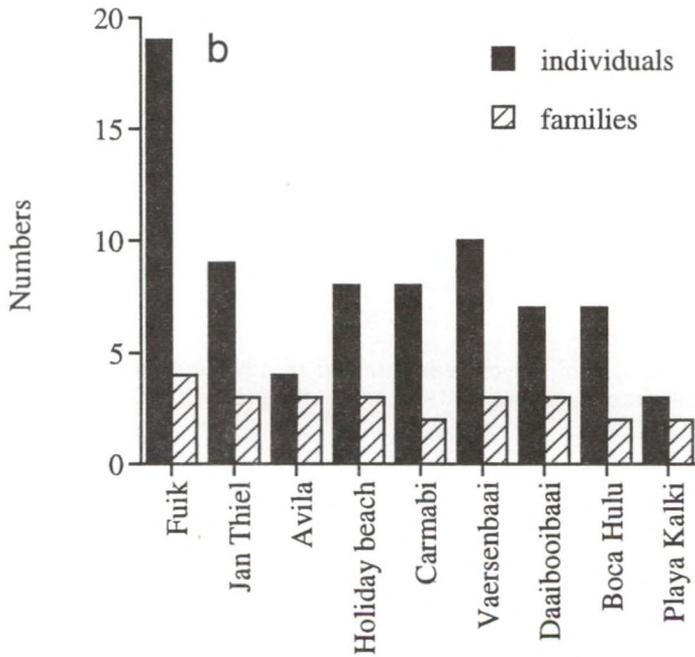
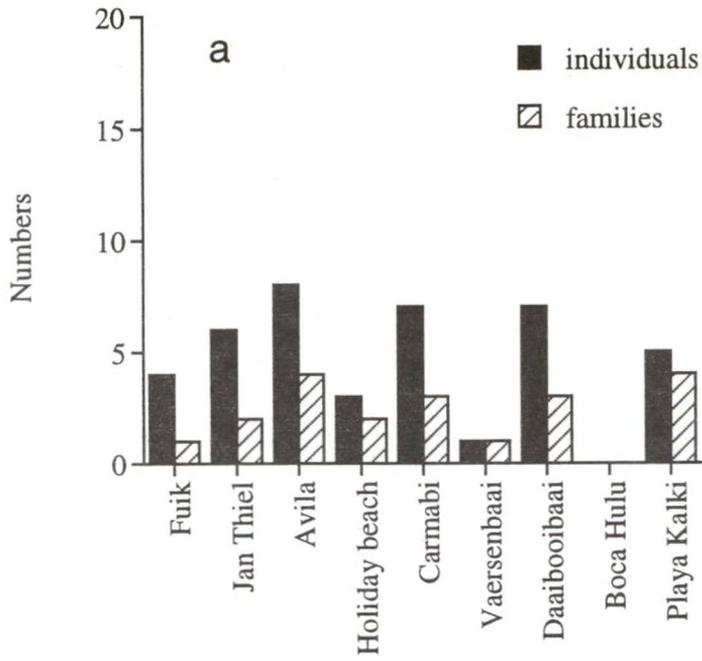


Figure 3. Number of gastropod individuals and gastropod found in 20 cores at the various sampling stations. a; at the sampling of the reef flat in March 1996; b: at the sampling of the reef slope in April 1996.

$$y = 0.207x + 94.570 \quad r^2 = 0.194$$

$$y = 0.086x + 88.164 \quad r^2 = 0.090$$

$$y = 0.081x + 41.822 \quad r^2 = 0.022$$

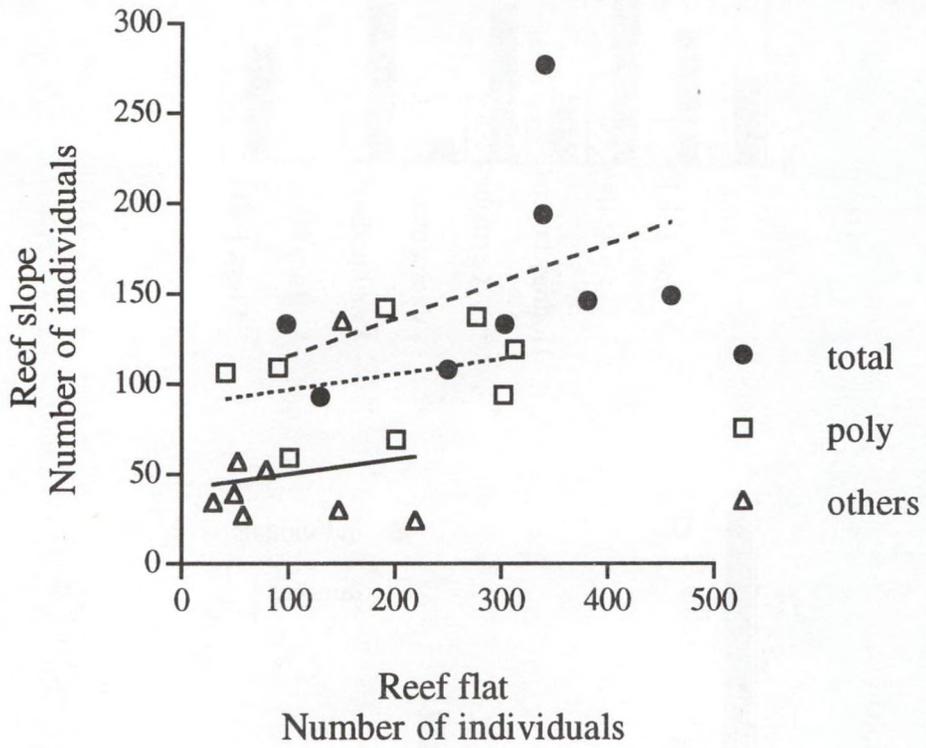


Figure 4. Relationship between number of polychaetes, number of other individuals and total number of individuals found in 20 cores at the reef flat in March 1996 and at the reef slope in April 1996 at the various sampling stations

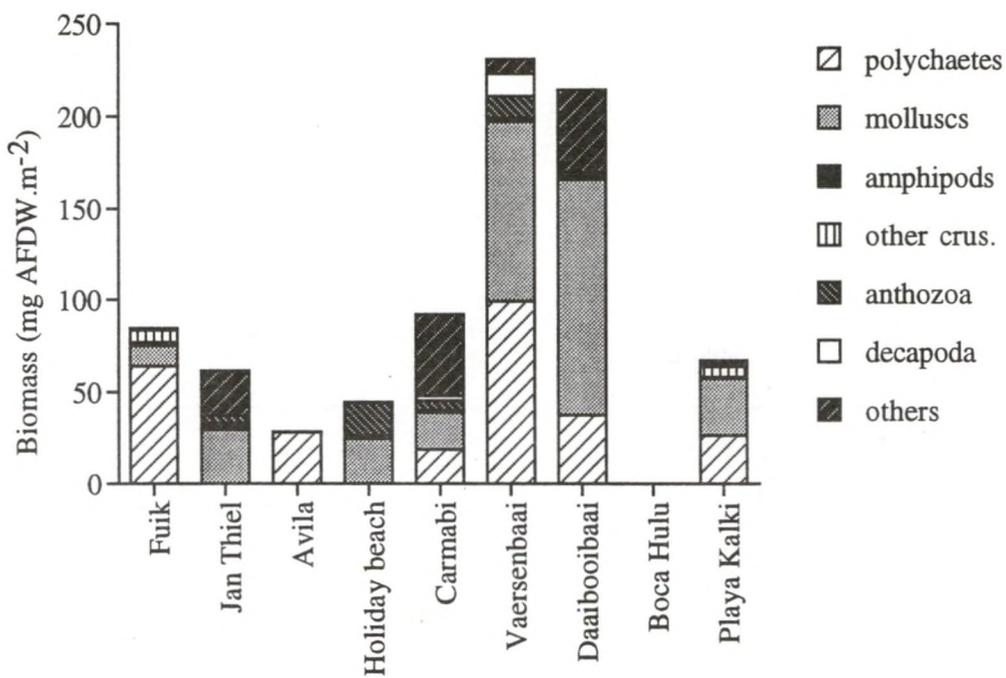


Figure 5. Biomass values (mg AFDW.m<sup>-2</sup>) and biomass composition at the reef flat during the sampling of July 1996. Boca Hulu is missing due to inaccuracies during the biomass procedure. Nematoda and Copepoda have been excluded.

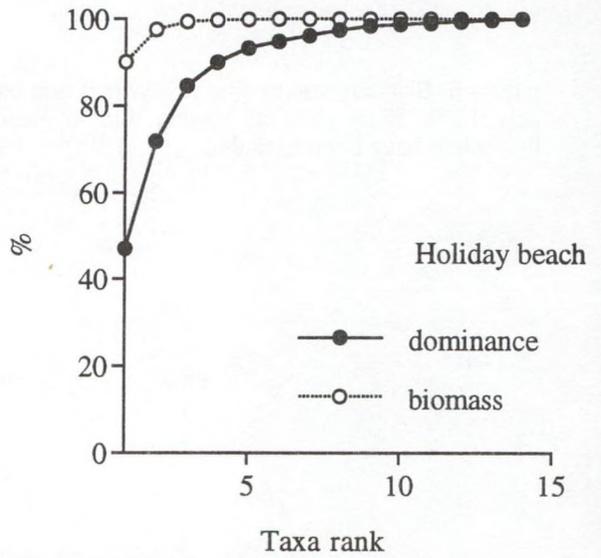
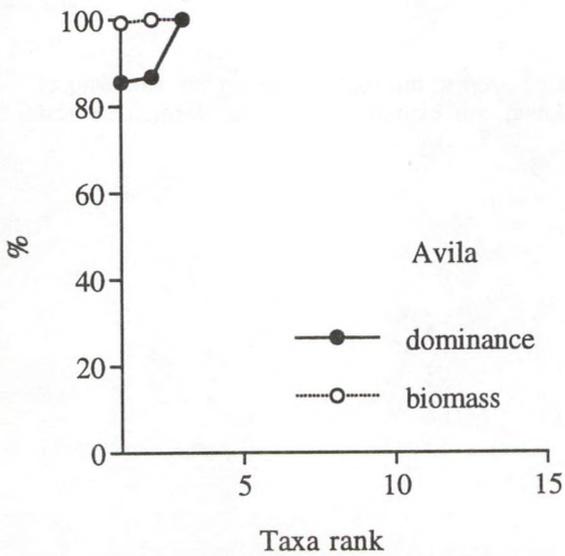
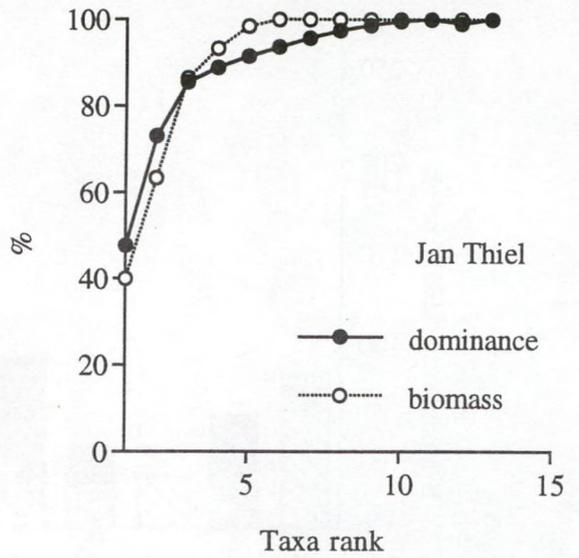
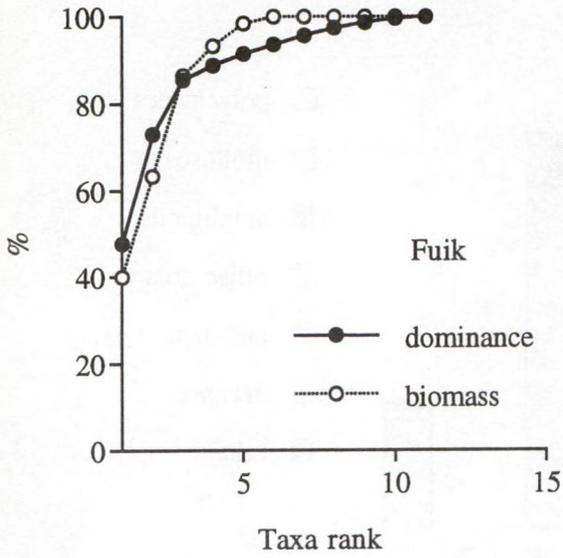


Figure 6. The ABC-curves (WARWICK, 1986) for all stations, except for Boca Hulu, based on the data from the May series. Nematoda and Copepoda have been excluded. For more information see text.

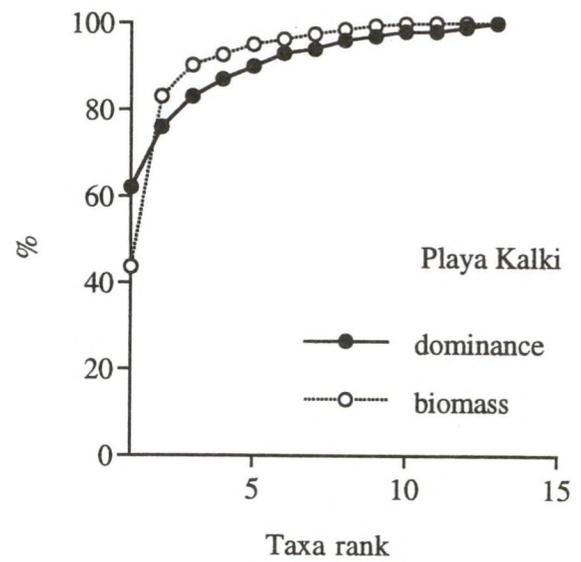
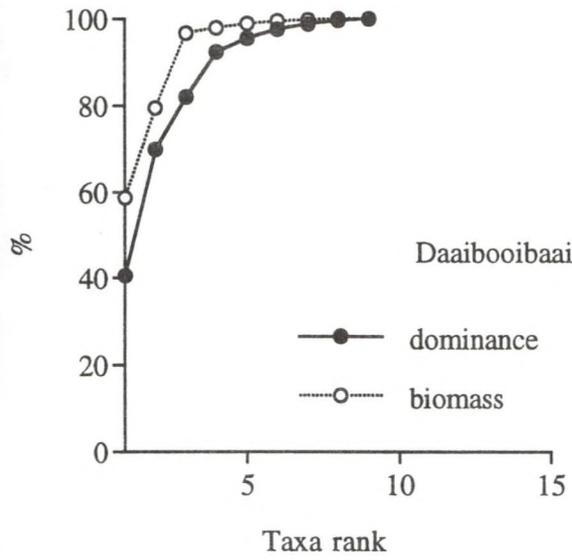
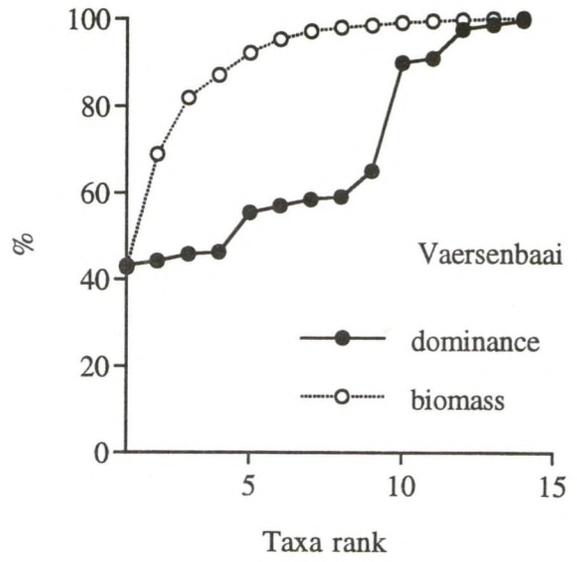
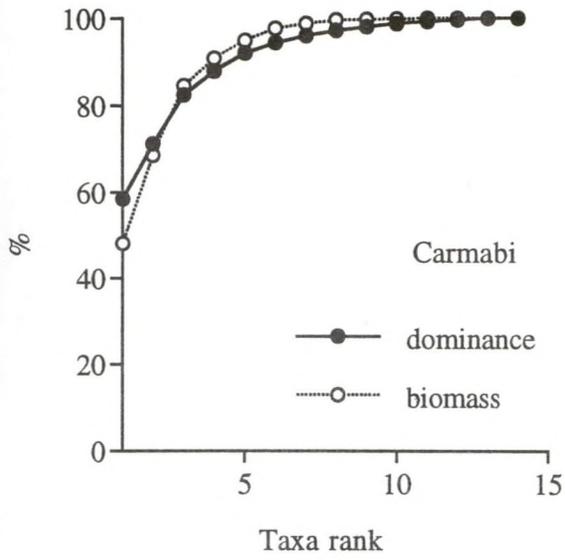


Figure 6. Continued.

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