Dynamics and Assessment of Kenyan Mangrove Ecosystems

n° TS2-0240-C (GDF)

Final Report (April 1993)

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FINAL REPORT

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FOREWORD

The aim of this STD-2 project on: "Dynamics and Assessment of Kenyan Mangrove Ecosystems" n° TS2-0240 C (GDF) was double.
First it was meant as a scientific basic research study on mangrove ecology and second, as a real scientific collaboration between African and European scientists.

In general the data output has been considerable, but results still need further integration and interpretation. Further support is therefore required and ideally, such a study should last for 6 to 7 years with careful evaluation of the output every 2 years. The results obtained up to now look very promising and represent the first step towards the understanding of an East African mangrove ecosystem. Such an exercise is essential for a future policy of sustainable management of this fragile and threatened ecosystem which is of great value from both the scientific and the economic points of view.

This project initiated a scientific co-operation between European and African researchers. This co-operation in the fields of both, research and education has in general been perceived very positively by most participants. As a direct or, indirect results of this co-operation, about ten Master Degrees were obtained by African scientists in Europe. Also, ten Belgian students and one Dutch student, wrote a licentiate thesis on the different subjects concerning Gazi Bay ecosystem. However, it is felt that more efforts should be put in providing African scientists with opportunities to complete their scientific formation and this at different levels (technicians, Masters, PhD's). Efforts should also be put in providing our African colleagues with long-term financial, technical and scientific supports in order for the research in Africa, initiated through this project, to continue and to take-off. This should be achieved within the framework of bilateral co-operation agreements between European and African research units. In the future, it might also be useful to elaborate a co-operation system wherein an European scientist or research unit "adopts" an African counterpart.

All participants, in most cases, feel that the present scientific co-operation exercise has been very positive but that in order to achieve its educational, economical and social goals, financial support and follow-up should be pursued during several years.

As general conclusion we will suggest that in the future, National, European and International organisations take into account these remarks and will collaborate to provide opportunities for efficient co-operation in Science and Technology for Development.

Prof. P. Polk[1] and Dr. E. Okemwa[2], general co-ordinators of the project.

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1. GENERAL INTRODUCTION

Mangrove ecosystems are the characteristic littoral plant formation of tropical and subtropical sheltered coastline (Saenger et al., 1983). They play an important role in fishery production, coastal stabilization and in maintenance of critical habitats for many common, threatened and endangered species. Mangrove areas provide numerous commercial products and generate economic opportunities in many countries (Saenger et al., 1983). Mangroves form a buffer zone where the output of continent to the sea undergoes important biogeochemical transformations. For the carbon and nitrogen cycles they form a very important link between continent and ocean.

The association of coastal lagoons and mangrove forests along the Kenyan coast, constitutes unique environments sustaining enhanced biomasses of several commercial fish, shellfish and crustaceans species as compared to coastal and open sea environments. This uniqueness is due to the fact that such lagoons provide natural shelter, characteristic physico-chemical conditions and assumed abundance of nutrients supplied by the mangrove ecosystem.

The lack of appraisal of the status of Kenyan mangrove forest has been a limitation on the formulation of an adequate management and conservation policy (Gang & Agatsiva, 1992). Therefore this project was designed as an interdisciplinary scientific co-operation between Kenya, The Netherlands, and Belgium, to gather basic information on the structure and functioning of a selected Kenyan mangrove ecosystem, Gazi Bay, situated 50 km south of Mombasa. Later on, Italy with the University of Florence received a one year financial support from the CEC, to join this project.

The research work focused on the following: (1) Assessment of the different components of the ecosystem, in terms of biodiversity, biomass and productivity; (2) Estimation of nutrient and energy flows through the ecosystem, and mathematical modelling; (3) Application (oyster culture).

This work was a continuation and a widening of an ongoing scientific co-operation started in 1985, between research units from the Free University of Brussels, the University of Gent, and the Kenya Marine and Fisheries Research Institute, Mombasa under the impulse of Prof. P. Polk.

A complementary research effort was also provided in 1992, by the one year lasting Indian Ocean expedition organised by the Netherlands Marine Research Foundation, both with an offshore research effort in Kenyan coastal waters using the "Tyro" and a coastal research in Gazi Bay.

The research completed during the STD-2 programme will, partly be continued and widened during a 2 year STD-3 project on "Interlinkages between Eastern-African coastal ecosystems".

References

Gang, P.O. & Agatsiva, J.L. (1992). The current status of mangroves along the Kenyan coast: a case study of Mida Creek mangroves based on remote sensing. Hydrobiologia 247: 29-36.

Saenger, P., Hegerl, E.J. & Davie, J.D.S. (1983). Global status of mangrove ecosystems, Working Group on Mangrove Ecosystems of the IUCN Commission on Ecology in co-operation with UNEP and WWF, Commission on Ecology Papers, number 3, 88p.

2. *SITE DESCRIPTION*

2.1. INTRODUCTION TO THE STUDY AREA

Gazi Bay, where the present study was carried out, adopts its name from the nearby village Gazi. The approximately 750 inhabitants of this village depend largely on their natural environment. Besides some small shops, a transport company and a primary school most households find their income out of fisheries (fish, shells, sea cucumber) and the selling of mangrove poles. Except for some small backyard culture of cassava, tomatoes and banana and an old coconut plantation there is no important agriculture in Gazi area.

In Gazi bay (Maftaha bay) the fishermen of Gazi and two nearby villages (Kinondo and Msambweni) find fishing grounds sheltered from the ocean, and a safe landing site for their boats (wooden canoes out of a single mango tree) on a small beach. The most common type of fishing is with a Seine net during low waters on the subtidal seagrass beds. Occasionally, the Seine net is used on the mud flat, at neap tides. Fish traps are widely used in the eastern channel and along the edge of the subtidal seagrass beds. During spring tides weir fishery is used on the mud flat. Only a few of the fishermen use spear and line fishing. The fishermen go out twice a day using the tidal currents to facilitate their travel.

The felling of trees is also done during low waters. The straight poles are piled up along the nearest creek and are collected during high water with a canoe. On the beach the poles are sorted out. Most of the poles are sold outside the village.

Gazi Bay covers an area of 15 km^2 and is protected by Chale peninsula on the west and a coast fringing coral reef on the south from the Indian ocean. The area is covered with seagrass beds and a mangrove swamp with an area of 6.61 km^2.

Two tidal creeks are leading out of the mangrove swamp. The creek on the west side finds its landward continuation in the seasonal river Kidogweni. In upstream direction, the salinity gradient is evident from the decreasing water conductivity (46 mS/cm to 3 mS/cm, at 25 °C and low tide). The creek bottom is bare and sandy with only a scarce cover of seagrass towards the ocean side. The eastern creek is not fed by a river and carries only tidal water (conductivity 49 mS/cm at 25 °C) in and out of the mangrove swamp. This creek has a luxuriant cover with seagrasses and seaweeds. The creek has only a few minor side channels. Both creeks have steep slopes leading to the relative flat mangrove swamp (Figure 2).

3. *PRIMARY PRODUCERS*

3.1. THE MANGROVE VEGETATION

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3.1.1. Survey of the mangrove

3.1.1.1. Methods

An aerial photograph of the whole of Gazi Bay was obtained from the International Institute for Aerial Survey and Earth Science (I.T.C.), Enschede, The Netherlands. Estimation of the scale of the aerial photo was done by measuring recognizable objects in the field. Four roads were measured in the field with a 50 m measuring tape and on the photo with a vernier calliper. It was calculated that the grid on the photo was 498.7 x 498.7 meter. In further use it was assumed that the grid was 500 x 500 m, which is one of the standards.

An Ultra Light aeroplane with pilot (Alexis Peltier, U.L.M. Kenya Ltd.) was hired to make detailed aerial photographs of the mangrove and bay area. With this type of aeroplane it is quite easy to manoeuvre on different heights for overview and for detailed photographs. The photographs were taken with an overlap of at least 15 % between sectors. Photographs, perpendicular to the earth surface were made at 600 and 400 m altitude. A Nikon camera with film winder and a 35 mm lens was used in combination with a colour photo film (Kodakgold 200). Prints of 10x15 cm were made, representing a scale of approximately 1: 6,500. To prevent errors caused by lens aberration at the edges of the photos only the center parts were used for the mapping. The recognizable patterns in vegetation and topography were transferred to transparent paper. Precise scaling of these drawings was done using the aerial photo from I.T.C. and the use of a copier machine with enlargement and shrinking options.

Fieldtrips by foot and boat were made to connect the actual vegetation in the field with the distinctive patterns on the photos. During these fieldtrips also more

detailed study of the vegetation was made along a transect running from the western channel towards the mainland. Estimates of the tree cover (%), tree height (m), abundance and cover of the different mangrove species (ordinal scale of van der Maarel, 1-9) and number of seedlings for the different mangrove species (counts of seedlings) were made every 10 meter in 5 x 5 meter squares along the transect. The relative elevation of the bottom was estimated using a levelling instrument.

3.1.1.2. Results

The following mangrove species were found in the mangrove area of Gazi Bay:

Sonneratiaceae:

Sonneratia alba

Rhizophoracea:

Rhizophora mucronata Lamark

Ceriops tagal [Perr.] Rob.

Bruguiera gymnorrhiza Lamark

Verbanaceae:

Avicennia marina [Forsk.] Vierh.

Meliaceae:

Xylocarpus granatum Koenig

Combretaceae:

Lumnitzera racemosa Van Steenis

Sterculiaceae:

Heritiera littoralis Drymand ex h. Ait.

Along the creeks high (12-18 m) growing fringing forests of *Avicennia marina* are found, further away from the creeks replaced by a thick bushes (5 - 10 m high) of mainly *Rhizhophora mucronata* and *Bruguiera gymnorrhiza*. The sediments of these lower parts of the mangrove consist of black mud and are daily flooded by high tide. On higher areas inside the bush, *Ceriops tagal* appears in monospecific stands, reaching up to 3 meter height. Most of these areas are only flooded during spring tides. The sediment is more solid and sandy with a grey colour. Especially

on the western mainland side, extensive stands of *Avicennia marina* (2 - 3 m high) are found, with *Lumnitzera racemosa* and *Xylocarpus granatum* on the higher sandy parts. In the transition zone between mainland and mangrove area *Heritrea littoralis* is frequently found. *Sonneratia alba* is commonly found along the borders of the mangrove swamp on the ocean side. Due to regular cutting most of the *R. mucronata* and *B. gymnorrhiza* trees are freakishly formed or truncated. Large areas were only a sparse vegetation is left also exist. The open areas show a scarce settlement of propagules. In an area which was cleaned 5 years ago traces of erosion were visible. The soil was washed away and roots were exposed. This way of cutting, taking out whole trees as fuel for factories, was stopped in the beginning of 1990. Nowadays only selective cutting of straight poles is allowed.

By combining the contours visible on the aerial photographs with "ground truth" observations, nine distinctive types of mangrove sites could be discerned on the photograph. According to this division the vegetation map of the mangrove in Gazi Bay was drawn. A list of the types of mangrove sites is given below; it includes the marker code for each type of site, as was used in the final vegetation map.

1) *Sonneratia alba* fringe:
pattern: dark green; frontier line on ocean side and isolated trees
marker: S
description: boundary vegetation of several (2-10) rows of trees; height 3 to 6 meter; cover 10 to 30 %; sever damage by cutting behind first rows from ocean; most of the older trees are truncated and have regenerating side branches

2) *Avicennia marina* fringe:
pattern: light green/yellow; along creeks
marker: A
description: creek fringing vegetation of several (2 - 5) rows of trees; height 10 to 20 meter; cover 60 to 80 %

3) Mixed forest:
pattern: dark green; texture granulated and rich
marker: Mr, Mb, Mc
description: dense mixed vegetation with *Rhizophora mucronata* (60 %), *Bruguiera gymnorrhiza* (20 %) and *Ceriops tagal* (10 %); height 5 to 10 meter; cover 50 to 100 %; due to cutting *R. mucronata* is often freakishly formed, whereas *B. gymnorrhiza* is truncated; on basin side: monospecific stands of *R. mucronata* [marker = Mr] (cover 80

to 100 %); towards the mainland a mixture with *B. gymnorrhiza* [marker = Mb] and *C. tagal* [marker = Mc] in opener (cover 50 to 80 %) vegetation is found.

4) *Ceriops tagal*:

pattern: light green; fine texture; distinct borders; found as fringing vegetation on the mainland side and in isolated stands

marker: C

description: monospecies stand of *Ceriops tagal*; height 2 to 8 meter; cover 50 to 75 %; thinly tall trees/shrubs

5) *Avicennia marina* shrubs:

pattern: green/brown on grey/yellow; isolated trees and fine texture

marker: A

description: monospecific stand of *Avicennia marina* shrubs; height 2 to 8 meter; cover 10 to 30 %; thinly trees/shrubs with trunks branching on low level above ground

6) Bare grounds:

pattern: yellow/grey; on west mainland side and isolated islands

marker: B

description: bare grounds; scarce settlement of *A. marina* seedlings after flowering season of *A. marina*; after rainy season a thin cover (< 5 %) of *Salicornea spec.* may develop.

7) Main land border:

pattern: light grey and dark grey isolated trees in a fringe on mainland side

marker: H

description: isolated trees of *Xylocarpus granatum* and *Heritiera littoralis* on mainland edge; cover up to 30 %; height 5 to 20 meter

8) Logged area:

pattern: dark green granulated spots on black; isolated trees

marker: L

description: isolated trees of *C. tagal* and *B. gymnorrhiza* in the west and mid area and in the east with mixture of isolated *R. mucronata*; cover < 15 %; height 2 to 8 meter

9) Main land:
pattern: brown/green; rich texture; clear frontier line
marker: -
description: terrestrial vegetation and agriculture; outside study area

The final map of the mangrove vegetation in Gazi bay is shown in Figure 1. The results of the study of a transect through the mangrove, giving an illustration of the zonation of trees and seedlings, is shown in Figure 2. There is a clear separation of species along the transect. *S. alba* and *H. littoralis* are present on the creek and landward side, respectively. The *C. tagal* cover shows a small gap around 70 m from the mainland, filled by *A. marina*. As can be seen on the map (Figure 2a), this is the point where the transect crosses an elongation of a larger *A. marina* site; the area is slightly elevated above its surroundings. Most likely, transport of propagules by tidal water is the cause for this phenomenon.

3.1.2. Biomass estimation in selected field plots

3.1.2.1. Methods

Fieldwork plots

Two fieldwork plots, covered by different vegetation types, were selected for studies on biomass, primary production, litterfall, litter decomposition and benthic decomposers. The plots measured 20 x 20 meter each and were clearly marked with paint and ropes. The co-operation of the local people, to leave the plots undisturbed, was asked for and given. The plots are representative for two vegetation types that are commonly found in Gazi bay. *Rhizophora mucronata* vegetation is dominant in the lower mangrove areas and covers over 50 % of the mangrove area in Gazi Bay. *Ceriops tagal* is common on higher grounds, covering around 15 % of the mangrove swamp. The two plots not only differ in vegetation, elevation (inundation period), soil characteristics and fauna, but are likely also different with respect to nutrient dynamics. The location of the plots is shown in Figure 3.

The *Rhizophora mucronata* plot has a 80 % plant cover. It is situated circa 50 meters inside the mangrove bush seen from the southern border of the mangrove area. The area is flooded with each high tide, and only during low tides it is possible to reach the plot by foot. The soft black sediment of the plot consists of mud and

clay and a minor sand component. Table 1 shows some soil characteristics of this plot.

Table 1. Soil characteristics in the *R. mucronata* plot.

depth cm	C %	N %	P_2O_5 mg/g	$CaCO_3$ %
0 - 5	15.61	0.832	1.70	0.00
5 - 20	10.27	0.498	0.86	0.00
20 - 40	8.10	0.390	0.78	0.00

depth cm	pH KCl	median grain-size µm	NaCl g/l	water[a]
0 - 5	7.00	51	29.5	332.5
5 - 20	6.60	112	29.0	215.4
20 - 40	6.34	216	23.8	168.1

[a]: g water per 100 g dry soil

The *Ceriops tagal* plot has a 60 % cover of small (1 - 4) *Ceriops tagal* trees. The plot was divided in 5 x 5 meter squares for subsampling. Also this plot was marked by paint and a rope. It is situated in the western part of the mangrove (Figure 3). Only during spring tides this relatively high lying plot is flooded. Table 2 shows some soil characteristics of this plot.

Table 2. Soil characteristics in the *C. tagal* plot.

depth cm	C %	N %	P_2O_5 mg/g	$CaCO_3$ %
0 - 5	1.64	0.088	0.14	0.03
5 - 20	5.14	0.142	0.17	0.06
20 - 40	6.93	0.138	0.12	0.00

depth cm	pH KCl	median grain-size µm	NaCl g/l	water[a]
0 - 5	6.86	256	33.8	46.0
5 - 20	4.37	234	33.3	78.8
20 - 40	3.50	205	53.6	86.9

[a]: g water per 100 g dry soil

Development of a non-destructive biomass estimation method

It was attempted to develop a method which could make it possible to estimate the *Ceriops tagal* and *Rhizophora mucronata* biomass in a non-destructive way. To develop such a procedure for *Ceriops*, a series of 26 trees, varying in size, was selected just outside of the *Ceriops* plot. After labelling the individual trees, a series of parameters which were suspected to have a correlation with the total biomass of the tree, were measured (Table 3).

Table 3. Parameters measured on *C. tagal* trees.

Parameter	Precision
circumference of trunk:	
at 30 cm above ground	m m
at 75 cm above ground	m m
height of tree with:	
measuring tape	cm
impro clinometer	cm
diameter of shadow from crown at the ground at noon	cm

Circumference of the trees was measured with a measuring tape. For estimating the height of the trees a line on a pole was used to reach the top of the tree. A sledging marker on the line was used to mark the height of the tree on the line, the marked line was measured with a measuring tape. For large trees a provisional clinometer was used. The diameter of the shadow of the crown could easily be measured on the ground with a measuring tape. An average of two measurements perpendicular to each other was used for the regression calculations. Shortly after taking the measurements the trees were cut down and the separate fresh weights of roots (above ground), trunk, branches and leaves were measured. The leaves were picked from the tree by hand, for separating the branches from the trunk a small saw was used. With a saw the above ground parts of the roots were separated from the trunk at the end of the broadening. Subsamples of the organs were taken for fresh/dry weight relations and C/N/P analyses. Dry weight was determined after drying the samples at 70 °C till constant weight. C and N content was estimated with an element analyzer (Carlo Erba, NA 1500) according to standard procedures at

the NIOO-CEMO laboratories in the Netherlands. For all parameters linear regressions on the logarithmically (LN) transformed data were calculated.

For seedlings the regression between length and fresh biomass was calculated. Seedlings are defined as: not branching, propagule still recognizable. Their length was measured with a measuring tape (mm) and their weight with an electronic balance (0.1 g). In addition, samples where collected for fresh/dry ratio and C, N and P contents.

Essentially the same measuring, sampling and analysis methods as described for *Ceriops tagal* trees and seedlings, were applied to *Rhizophora mucronata*. Table 4 shows the parameters used to establish a method for non-destructive biomass estimation. These parameters were measured in a series of 25 trees, varying in size, just outside of the fieldwork plot.

Table 4. Parameters measured on *R. mucronata* trees.

Parameter	Precision
circumference of trunk:	
at 20 cm above highest proproot	m m
at 150 cm above ground	m m
at 200 cm above ground	m m
height of tree with:	
measuring tape	cm
number of proproots	1

3.1.2.2. Results

Ceriops tagal

In Table 5 the calculated regressions are summarized.

Table 5. ***Ceriops tagal*****. Results of the linear regressions of different parameters versus total fresh weight (g), after LN transformation of the data. [30, 75 = circumference of trunk at 30 and 75 cm; H = height of tree; C = diameter of crown].**

Parameter	30	75	H	C
Constant	-1.049	-0.053	-3.597	-2.729
Std Err of Y Est	0.724	0.978	1.715	1.120
X Coefficient	1.946	1.872	2.359	2.385
Std Err of Coef	0.138	0.195	0.317	0.225
R squared	0.89	0.82	0.70	0.82
Degr of freedom	24	21	24	24

A LN LN regression between trunk circumference at 30 cm and total fresh weight of the tree showed the best correlation. The regression equation was calculated as:

$$\text{fresh weight in kg} = 48.8 * 10^{-3} * (\text{circumference in mm})^{2.31}$$

This regression is shown in Figure 4.

The determination of fresh weights of various parts shows that most of the biomass of *C. tagal* is found in the aboveground part of the root system (Table 6). The partitioning of dry weights shows a similar pattern as is the fresh weights: roots 30.7 %; trunk 27.4 %; branch 27.6 % leaves 14.0 %.

Table 6. Biomass partitioning in ***C. tagal*** **(on basis of fresh weights).**

Tissue	% of tree biomass			n
root	32,5	±	9.7	22
trunk	22.9	±	6.7	22
branch	24.7	±	8.2	22
leaves	19.9	±	8.3	22

Table 7 shows the percentage water content of the various tissues. Not surprisingly, the leaves are the organs with the highest percentage of water.

Table 7. Water content of different *C. tagal* tissues.

Tissue	% * water			(n)
leaves	63.10	±	9.7	22
branch	22.9	±	6.7	22
trunk	24.7	±	8.2	22
root	19.9	±	8.3	22

Carbon and nitrogen levels in the various parts of the tree are of the same order of magnitude. The percentage nitrogen, however, is conspicuously higher in the leaves than in the other organs (Table 8).

Table 8. C and N content of different dry *C. tagal* tissues.

Sample	% C			% N			n_1
leaves	42.7	±	0.6	1.012	±	0.11	5
branch	45.6	±	0.6	0.342	±	0.07	4
trunk	47.6	±	1.1	0.186	±	0.01	5
root	46.4	±	1.9	0.210	±	0.03	5

[1]: pooled samples.

The linear regression between seedling length and total above ground fresh weight was calculated after LN transformation of the data. The following relation was found (Figure 5):

Fresh weight (gram) = $2.55 * 10^{-3} *$ (length in mm)$^{1.49}$

The water content of the seedlings was 54.7 % ± 1.7 [n=13].

Combination of the data on biomass partitioning by the tree, the water content in the various organs, and the C, N content of these organs, makes it possible to calculate overall conversions from tree fresh weight to dry weight, C weight and N weight Table 9).

Table 9. Overall conversions from fresh weight to dry weight, C and N weight for *C. tagal* trees.

0.522	*	fresh kg = dry kg
0.240	*	fresh kg = kg C
105	* 10^{-3} *	fresh kg = kg N

As mentioned above, measurement of the trunk circumference at 30 cm will give the best estimate of the above ground biomass for *C. tagal*, and this parameter was therefore used for above ground biomass estimations. The *C. tagal* field plot was divided into 16 squares of 5 x 5 meter to describe spatial variance of the biomass. In each of the squares the circumference of all the living trunks at 30 cm above ground level was measured. After correction for LN transformation (Baskerville, 1971) the biomass present in each square was calculated. An estimate of the average biomass per square meter was calculated taking in consideration the variance on the individual tree biomass estimation and the spatial variation. For seedling biomass estimation the length of each seedling in the squares was measured and the same procedure and biomass was determined using the relation shown in Figure 5. Measurements of the trunk circumferences and seedling length were carried out on 4 occasions with intervals of approximately 6 months. The differences in biomass on the various dates (Table 10) are not significant. Thus it appears that the standing crop of the *C. tagal* vegetation is in a steady state or is changing at a rate not detectable with our method.

Table 10. *C. tagal* above ground biomass (fresh weight) for seedlings and trees on different dates.

date	trees kg/m^2			seedling g/m^2			n
January '91	6.75	±	0.59	21.86	±	5.06	9
May '91	7.88	±	1.29	28.61	±	6.38	6
December '91	7.55	±	0.64	24.15	±	3.40	16
August '92	7.56	±	0.65	23.56	±	3.33	16

Rhizophora mucronata

In Table 11 the regressions calculated for *Rhizophora mucronata* are summarized.

Table 11: ***Rhizhophora mucronata.*** **Results of the linear regressions of different parameters versus total fresh weight (g) after LN transformation of the data.**

[+20, 150, 200 = circumference of trunk at 20 cm above highest proproot and at 150 cm and 200 cm above ground in mm; H = height of tree in cm; n prop = number of proproots]

Parameter	+ 20	150	200	H	n prop
Constant	- 4.166	- 1.636	0.761	- 10,071	7.321
Std Err of Y Est	1.177	0.402	0.540	1.523	0.231
X Coefficient	2.851	2.358	1.945	3.273	0.174
Std Err of Coef	0.249	0.090	0.119	0.257	0.018
R squared	0.85	0.95	0.93	0.88	0.80
Degr of freedom	23	33	20	23	23

A LN LN regression between trunk circumference at 150 cm and total fresh weight of the tree showed the best correlation. The regression equation is:

Fresh weight in kg = $404.9 * 10^{-3} *$ (circumference in mm)$^{2.20}$

This regression is shown in Figure 6. As seen in Table 12 the largest part of the biomass (fresh weight) of *R. mucronata* is found in the trunk. This partitioning is essentially the same when the dry biomass is considered: root 24.6 %; trunk 50.5 %; branch 9.6 % leaves 15.1 %.

Table 12: Biomass partitioning in ***R. mucronata*** **(on basis of fresh weights).**

Tissue	% of tree biomass			n
leaves	22.2	±	2.6	55
branch	8.7	±	2.1	55
trunk	43.1	±	3.9	55
root	26.0	±	4.0	55

Table 13 shows the percentage water in the various organs of *R. mucronata*. As was the case for *C. tagal*, the leaves contain the highest percentage of water.

Table 13 : Water content of different *R. mucronata* organs.

Sample	% - water			n
leaves	65.83	±	8.1	122
branch	44.22	±	6.9	14
trunk	41.16	±	6.7	12
root	52.51	±	7.5	14

The percentage carbon in the various organs of *R. mucronata* is rather similar, and of the same order of magnitude as the levels found in *C. tagal* (Table 14). Also in *R. mucronata* the leaves have a higher nitrogen content than other tissues. The percentage nitrogen in the leaves, however, is much lower than in leaves of *C. tagal*.

Table 14 : C and N content of different dry *R. mucronata* tissues, [1]: pooled samples.

sample	% C			% N			n[1]
leaves	46.2	±	0.4	0.610	±	0.02	5
branch	46.9	±	0.5	0.196	±	0.01	5
trunk	47.2	±	0.7	0.110	±	0.03	5
root	48.1	±	0.4	0.248	±	0.10	5

After LN transformation of the data the linear regression between seedling length and total above ground fresh weight was calculated (Figure 7). This equations is as follows:

Fresh weight (gram) = $24.1 * 10^{-3} *$ (length in mm)$^{1.23}$

The water content of the seedlings was 63.5 ± 1.7 (n = 5, pooled samples of 4 individuals). Combination of the various data results in the conversion factors given in Table 15.

Table 15 : Overall conversions from fresh weight to dry weight, C and N weight for *R. mucronata*.

0.501	*	fresh kg = dry kg
0.237	*	fresh kg = kg C
69.8	* 10^{-3} *	fresh kg = kg N

As indicated above, measurement of the trunk circumference at 150 cm will give the best estimate of the above ground biomass of *R. mucronata*. This parameter was used for biomass estimations. The *R. mucronata* field plot was divided into 4 squares of 10 x 10 meter to describe spatial variance of the biomass. In each of the squares the circumference of all the living trunks at 150 cm above ground level was measured. After correction for LN transformation the biomass present in each square was calculated. An estimate of the average biomass per square meter was calculated taking in consideration the variance on the individual tree biomass estimation and the spatial variation. For seedling biomass estimation length of seedlings in the squares were measured. Table 16 summarizes the results of the biomass estimations.

Table 16 : *R. mucronata* above ground biomass for trees and seedlings in the fieldplots (September 1992).

	Trees kg/m^2	Seedling g/m^2	n
fresh	51.0 ± 8.2	118 ± 30	4
dry	25.6 ± 41	43 ± 11	

3.1.2.3. Some comments on biomass estimations

In the literature a broad range of biomass estimations for *Rhizophora* forests is available. Putz (1987) summarizes some of these results. With increasing age of the forest the standing biomass increases. From 1.6 - 5 kg DW/m^2 for a 5 years old forest, to 27.0 - 47.4 kg DW/m^2 in forests of 28 years and older. Our estimate of 25.6 kg DW/m^2 thus indicates that the *Rhizophora* plot is part of a full grown forest. Little is known on the standing biomass in *Ceriops tagal* vegetation. Lugo and Snedaker (1974) give a value of 0.79 kg DW/m^2 for shrub mangrove forest in Florida. The *C. tagal* vegetation in our study with its small trees resembles a shrub vegetation, but our estimate of the above ground biomass of 3.95 kg DW/m^2 is far above that of the shrub mangrove studied by Lugo and Snedaker (1974). Woodroffe

(1985) presents a study in which the biomass of an *Avicennia marina* vegetation is calculated. With the structure of *Avicennia* in our study area in mind, a comparison with their results is not unrealistic. Their estimate of 2.3 - 10.4 kg DW/m^2 for trees ranging from 1 to 5 meter is of the same order of magnitude as our estimate.

3.1.3. Measurement of litterfall in the mangrove

3.1.3.1. Methods

Litterfall was determined in two different ways. In the case of *C. tagal* the data were obtained indirectly from a phenological study on new formation and on losses of existing leaves, in combination with the results from the biomass estimation per square meter in the plot and biometric data presented in section 3.2. (e.g.: biomass partitioning in tree, water content of leaves). The phenology study involved observations on 240 branches on a 2 weekly basis over a period of a 2 years. The branches were distributed over 20 trees; per tree 12 branches were followed. These branches were assigned to 3 height levels (1/4, 1/2, 3/4 of relative height of crown; 4 branches per height level). The branches were tagged by plastic labels. At each of the successive observations carried out, the appearance of the branch was checked against a diagram of the branch, showing the amount and position of leaves, flowers, propagules and buds on the previous observation date. From the trunk onwards, each pair of leaves was marked by dots indicating the pair number of the leaves with a marker (Edding 3000). Newly formed leaves were easy to recognize by the lack of a dot whereas the loss of a leaf was noticed by the wrong starting number of the first pair of leaves present. Litterfall subsequently was calculated with the following equations:

lost leaves per leaf present per day =
(total of fallen leaves) + (leaves under observation) + (observation period in days)

leaves present per square meter =
biomass per square meter * 0.199[1] + 0.98[2]

fallen leaves per square meter per day =
(lost leaves per leaf present per day) * (leaves present per square meter)

litterfall (gram dry weight) per square meter per day =
fallen leaves per square meter per day * 0.369[3]

[1]: percentage of biomass present as leaves;
[2]: individual fresh weight of a *C. tagal* leaf;
[3]: dry matter content of a *C. tagal* leaf.

In the case of *R. mucronata*, data on litterfall were obtained directly with the use of littertraps. Twenty of these devices (stainless steel rings ∅ 75 cm, 0.44 m^2, nylon netting # 1 mm) were placed ad random in the field plot. The nets were situated above the high water level to avoid any contact of the tidal water with the litter in the traps, as this would result in material losses due to leaching. Fortnightly the traps were emptied and the litter sorted out into leaves, budscales, flowers, propagules, and wood. Number, fresh and dry weight (70 °C until constant weight) of the samples was determined. The dry samples were taken to the CEMO laboratories for determination of C, N and P content.

3.1.3.2 Results

Litterfall in the Ceriops tagal field plot

The calculated litterfall shows a seasonal pattern that coincides with the rains. As can be seen in Figure 8, the litterfall shows a sudden drop from 1.34 ± 0.26 gram dry/m^2/day in the dry season (August - April) to 0.43 ± 0.12 gram dry/m^2/day in the wet season (April - June). Shortly after the rains, a peak in litterfall occurs. This peak exists only for a short while. During the short rain period of October - November no clear trends in litterfall levels are observed.

Litterfall in the Rhizophora mucronata field plot

Figure 9 shows the data on litterfall in the *R. mucronata* plot.
Although not as obvious as in the *C. tagal* plot, a decrease in litterfall can be observed which coincides with the rainfall. The rise of the litterfall in April is caused by the combined effect of an increase in fallen leaves and the end of the flowering season with high numbers of fallen flowers contributing to the total amount of litter. The contribution of fallen leaves to the total amount of litter is on average 85 % outside the flowering season, and 60 % during the flowering season. Total litterfall drops from 4.66 g dry/m^2/day in October - November to 3.22 g dry/m^2/day in December - March. This drop is followed by a short rise to previous levels. From early April onwards, a gradual decrease in the litterfall in the period

April - June leads to minimum litterfall values in July - September of 1.42 g dry/m^2/day.

Table 17 presents the results on C and N analysis of the trapped litter. The average water content of the trapped leaves was 62.5 % ± 8.3 (n = 336) and their individual fresh weight was 1.97 ± 0.4 (n = 336).

Table 17 : Carbon and nitrogen content of *R. mucronata* litter.

% N	% C	C/N	n
0.267 ± 0.04	45.160 ± 1.53	172.6 ± 26.31	89

The phenology of C. tagal

The same phenology data enabling us to calculate litterfall of *C. tagal*, also yield insight into the reproductive success of this species. Figure 10 presents some of the results on this topic. For further reading we refer to Slim et al. (in prep.). During the hot dry season (December - January) flowerbuds are formed which give in 2 months time flowers in a ratio of 1 bud to 10 flowers. Propagules are formed 5 months after the setting of flowerbuds. Only 2 percent of the flowers will produce a propagule. The flowering season of *C. tagal* is just before the rainy season, and development of the propagules occurs during this season.

3.1.3.3. Some comments on the litterfall data

Twilley (1986) classifies mangrove forests by their tidal activity. In the order of increasing water turnover rates, mangroves are classified as follows: schrub mangroves, basin mangrove monospecies, basin mangroves of mixed character, fringe and overwashed mangroves, riverine mangroves. The schrub mangroves are rarely tidally inundated, basin mangroves are inland or more frequently flooded fringe mangroves, and riverine mangroves are inundated by riverine freshets as well as by tides. Our *R. mucronata* forest fits the description and litterfall (year average 3.06 g DW/m^2/day) values of the fringe and overwash type (1.82 - 3.00 g dry/m^2/day). The *C. tagal* plot is situated higher in the intertidal range and fits both the description and the litterfall values (year average = 1.03 g dry/m^2/day) of the monospecies basin mangroves (0.96 - 1.8 g dry/m^2/day). The general trend that hydrology strongly influences the litter productivity of mangroves is also supported

by our findings. Seasonality is described by other authors (Wium-Andersen, 1978; Christensen, 1977; Duke, 1988; Sasekumar, 1983; Saifullah, 1989; Twilley, 1986) as well. The underlying factors causing seasonality appear to be complex. Few reports focus on the causality of environmental factors and patterns in litterfall. Rainfall (Leach, 1985), soil salinity (Twiley, 1986; Due, 1988), temperature (Saifullah, 1989) have been suggested as underlying environmental factors, but as these factors are coupled it is difficult to distinguish between the effects of each of these factors separately.

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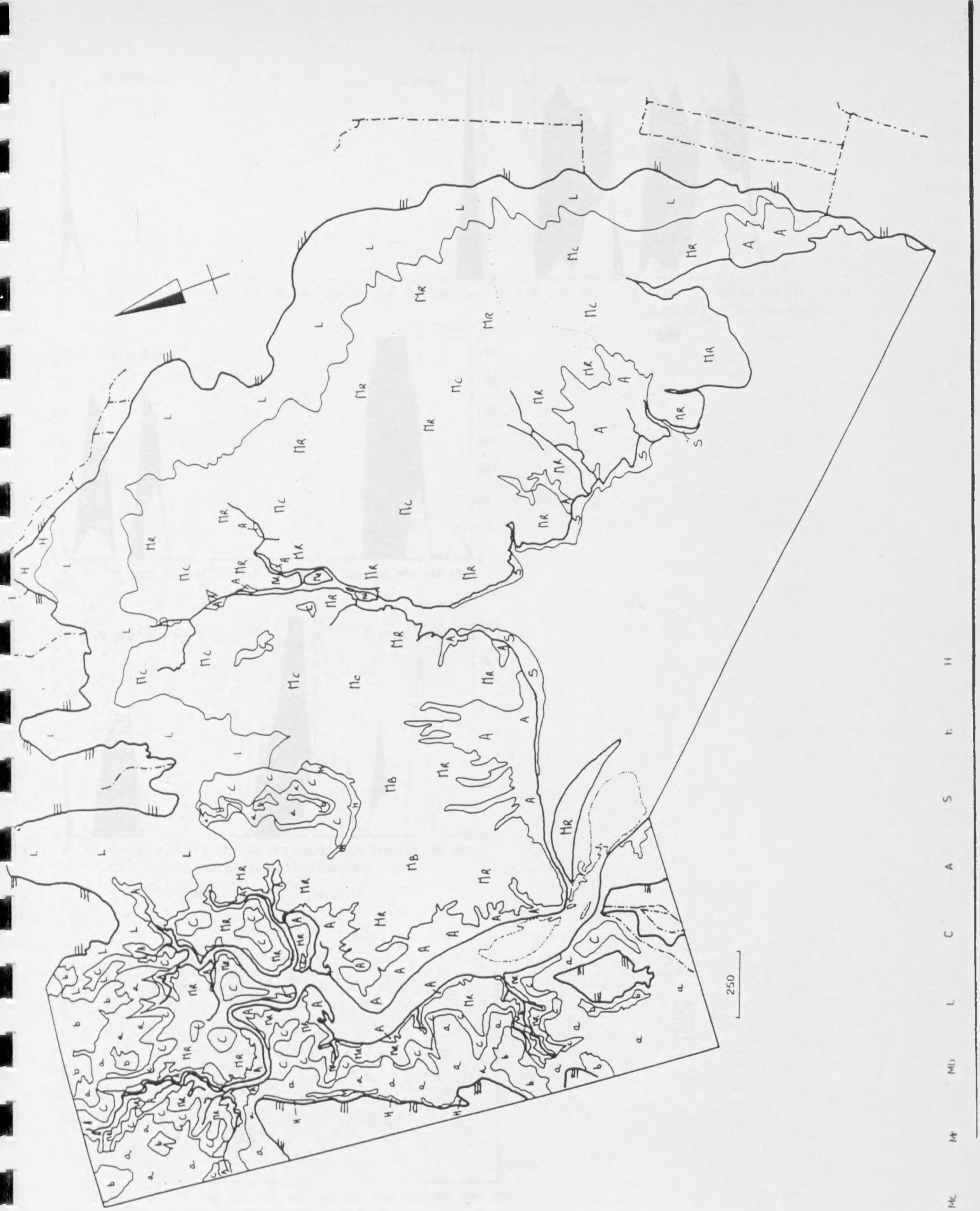

Figure 1 : Vegetation map of the mangrove area in Gazi Bay.

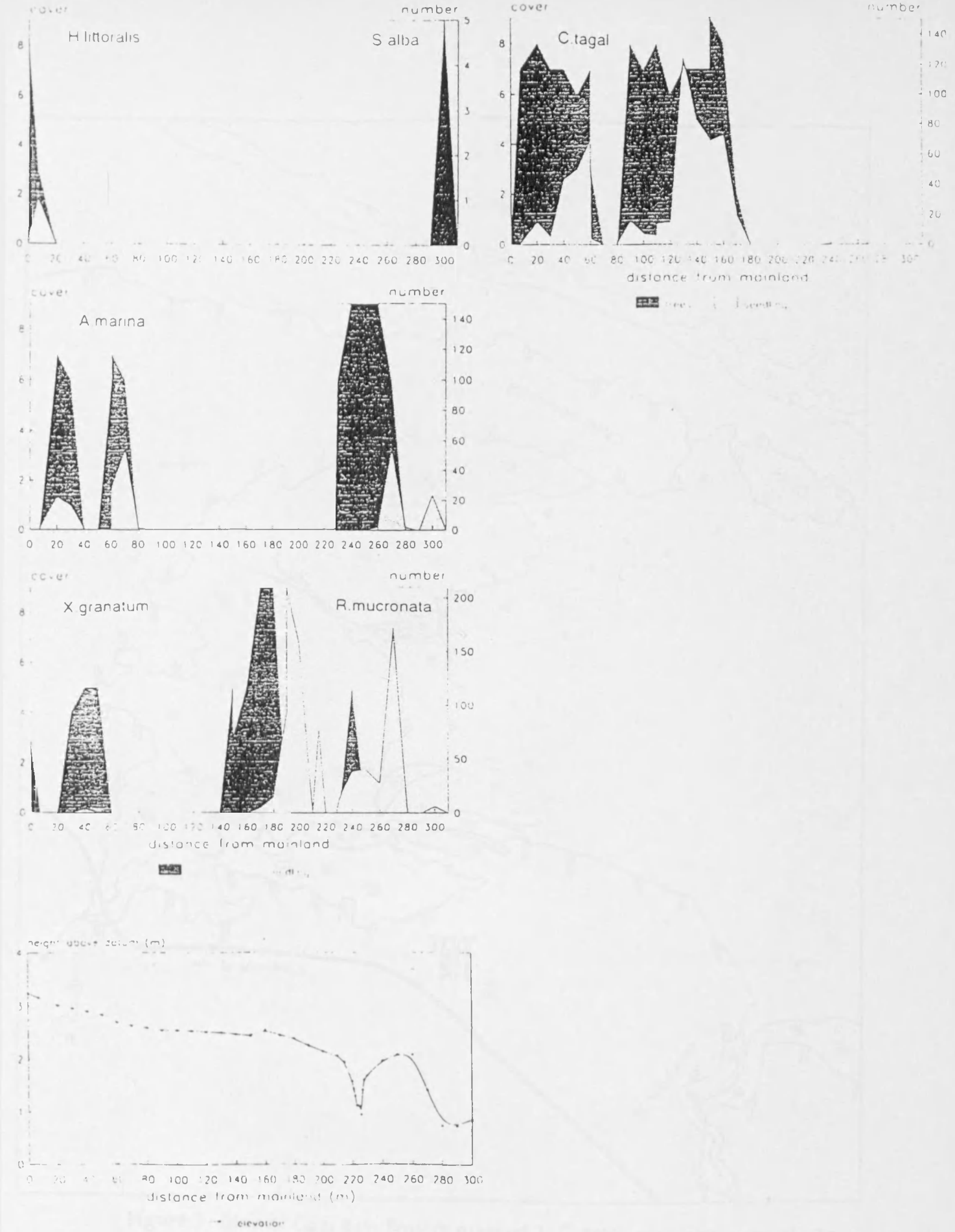

Figure 2 : Abundance and cover for mangrove trees and number of seedlings along a transect from the mainland towards the western creek.

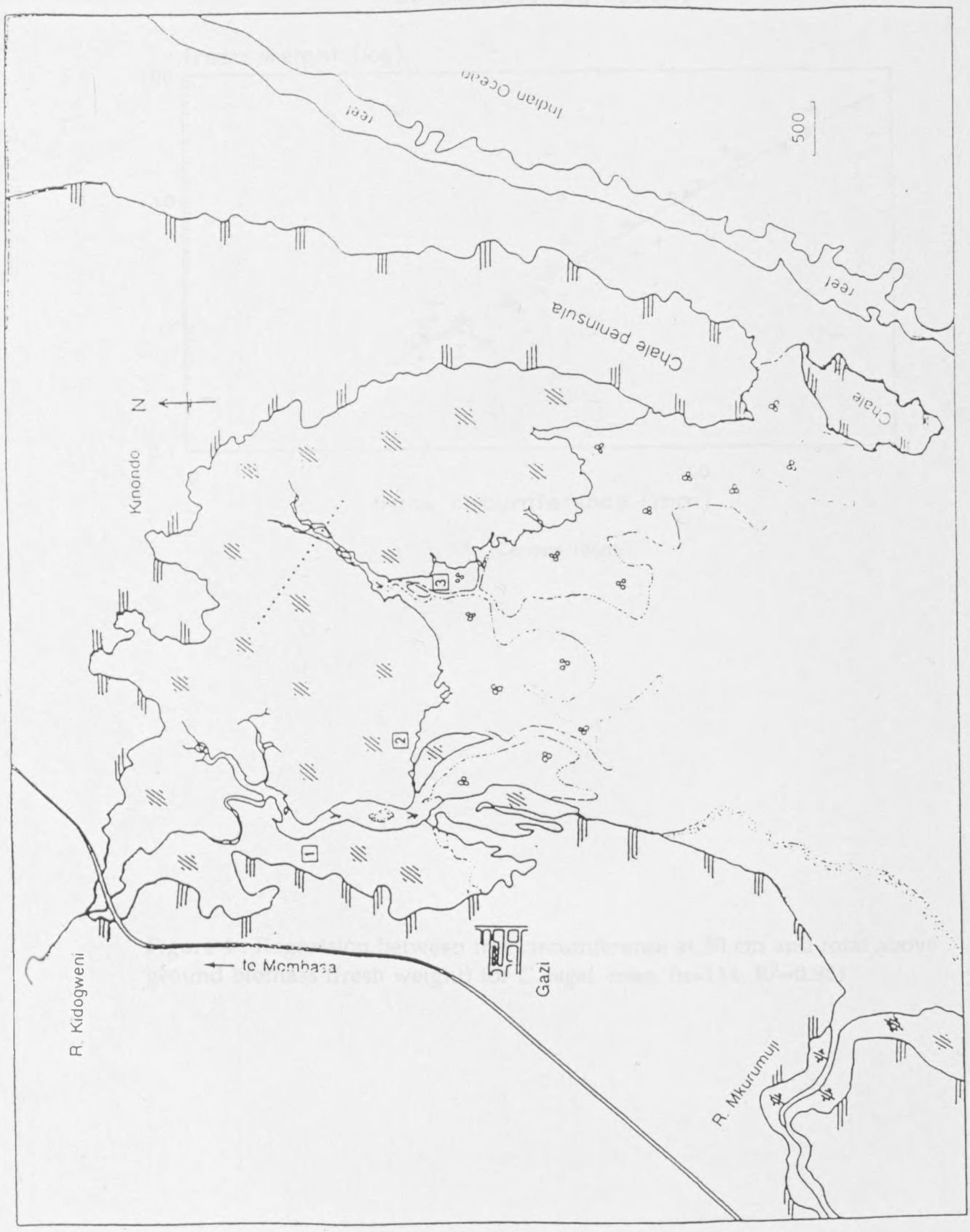

Figure 3 : Map of Gazi Bay. Square marked 1: *C. tagal* plot; square marked 2: *R. mucronata* plot; square marked 3: workplatform. Dotted line: transect used for measurement of elevations (see Figure 2).

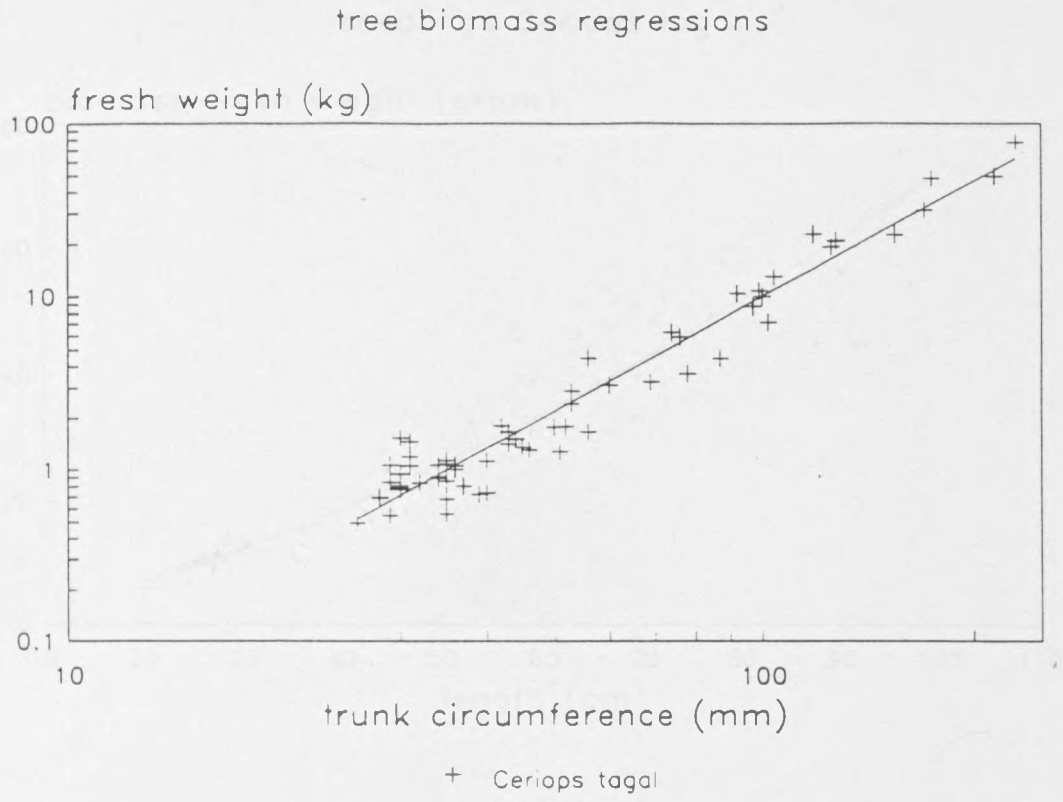

Figure 4 : Regression between tree circumference at 30 cm and total above ground biomass (fresh weight) for *C. tagal* trees. (n=114; R^2=0.98)

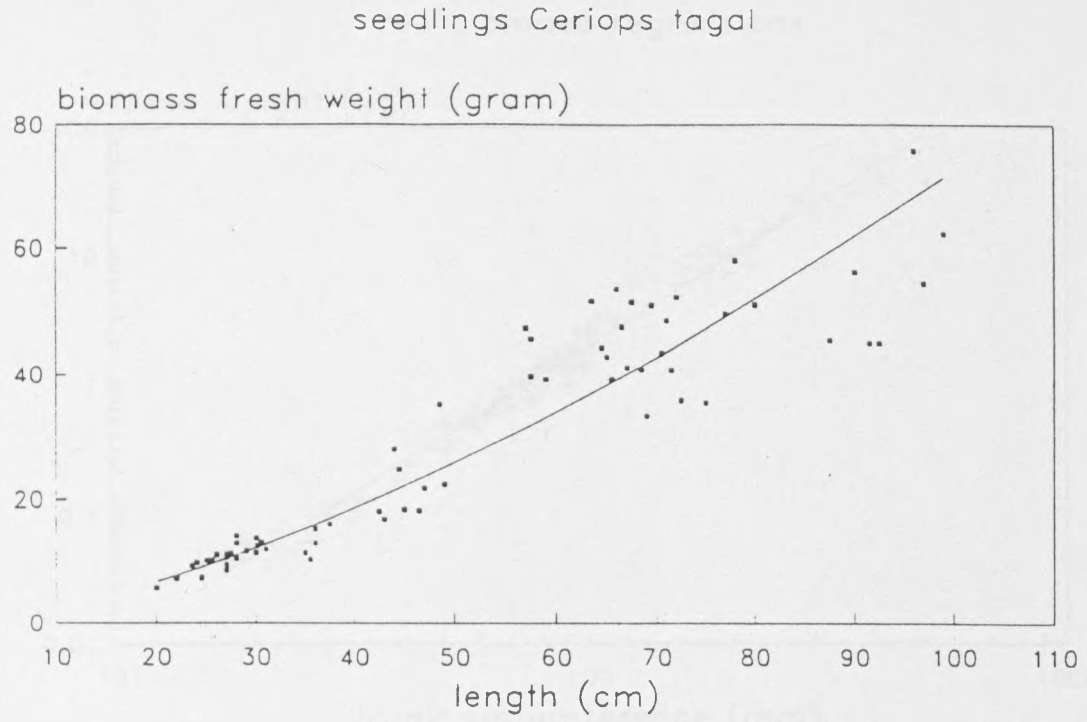

Figure 5 : Regression between seedling fresh weight and its length for *C. tagal*. (R^2=0.93; n=67)

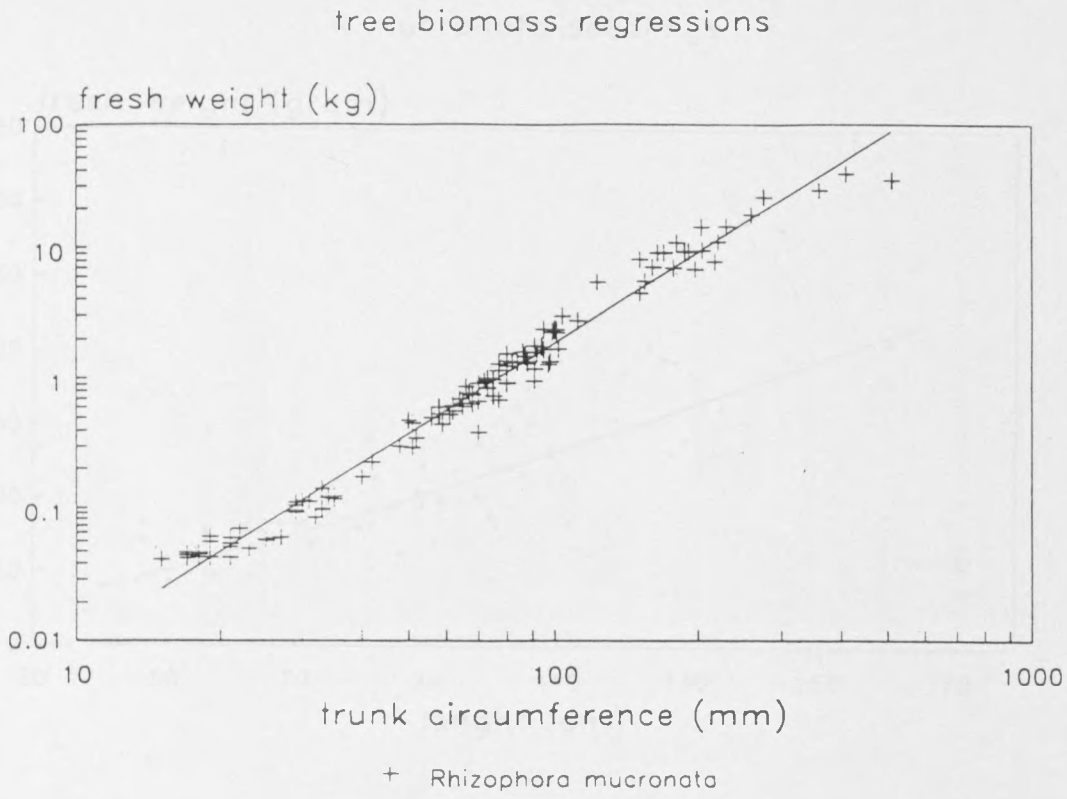

Figure 6 : Regression between tree circumference at 150 cm and total above ground biomass in kg (fresh weight) for *R. mucronata* trees. (n=62; R^2=0.95)

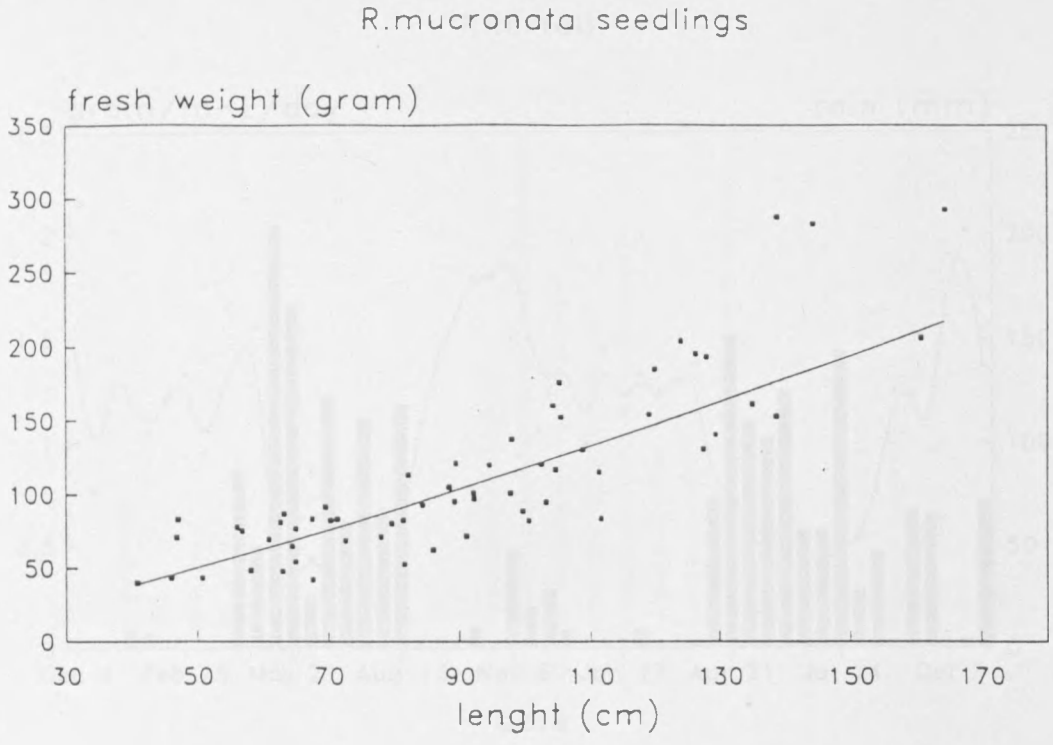

Figure 7 : Regression between seedling fresh weight and its length for *R. mucronata*. (R^2=0.72; n=59)

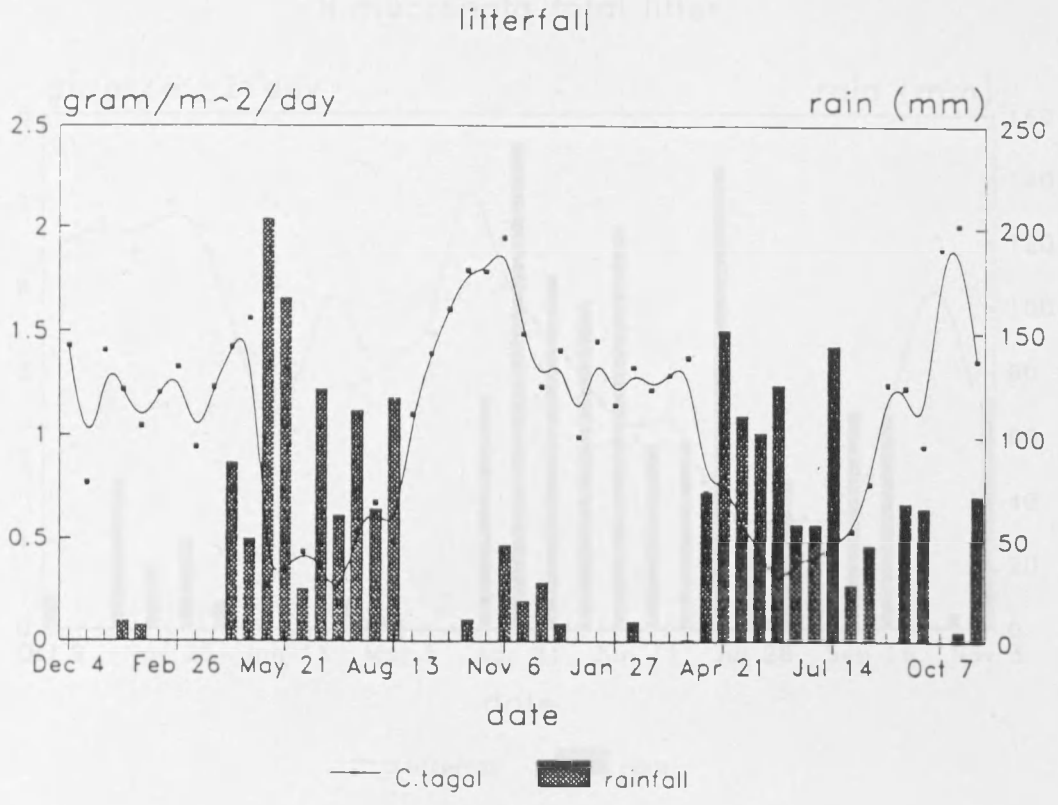

Figure 8 : *C. tagal*: : calculated litter fall (g DW) in field plot, as related to rainfall periods in Gazi. (rainfall data from Kenya Meteorological Department; Dist. Agr. Off. Msambweni)

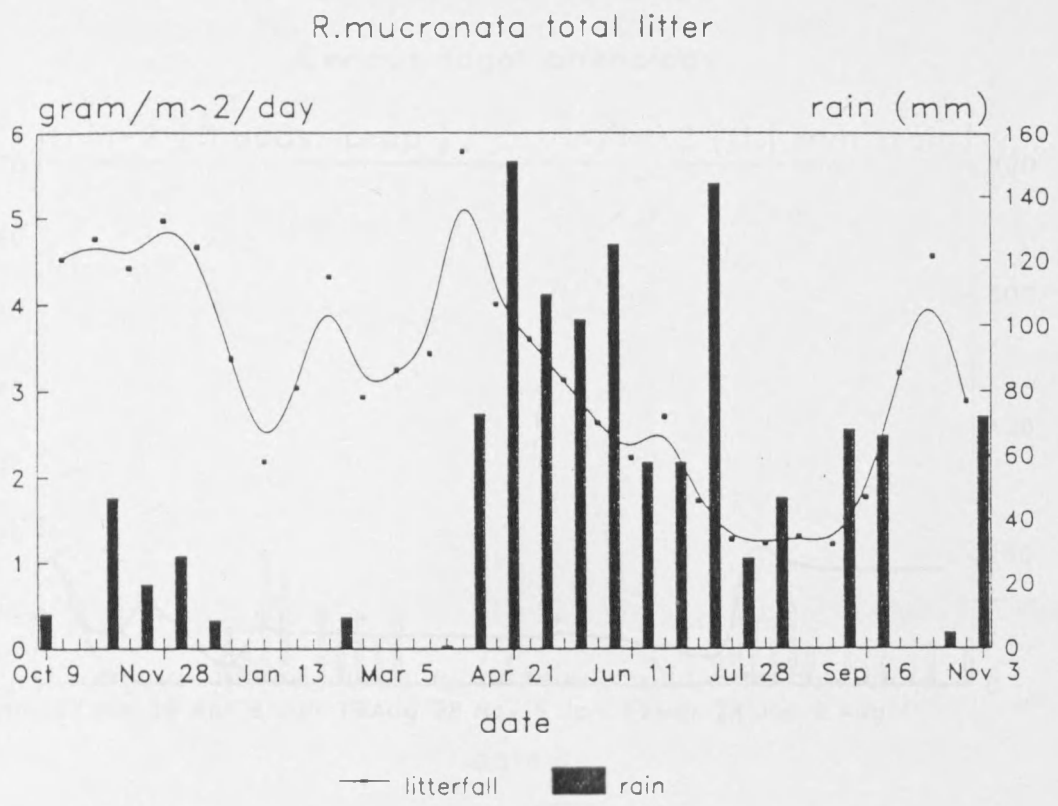

Figure 9 : *R. mucronata.* : litterfall in the field plot (g DW) as related to rainfall periods in Gazi. (rainfall data from Kenya Meteorological Department; Dist. Agr. Off., Msambweni)

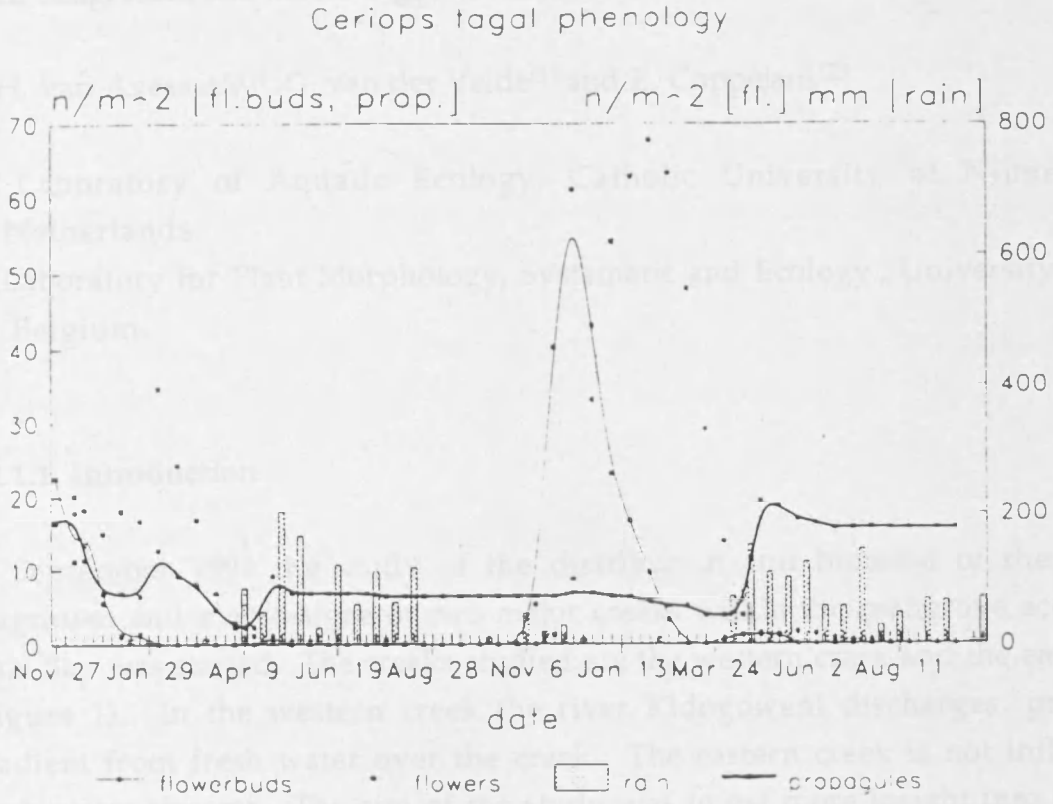

Figure 10 : *C. tagal*: : time course of development of flowerbuds, flowers and propagules.

3.2. THE SUBMERGED VEGETATION OF THE TIDAL CREEKS

3.2.1. Seagrasses and Macro-algae of eastern and western creeks

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3.2.1.1. Introduction

In September 1991 the study of the distribution and biomass of the abundant seagrasses and macro-algae of two major creeks within the mangrove ecosystem of Gazi Bay was started. The creeks studied are the western creek and the eastern creek (Figure 1). In the western creek the river Kidogoweni discharges, producing a gradient from fresh water over the creek. The eastern creek is not influenced by fresh water streams. The aim of the study was to get more insight into the species composition, distribution patterns and biomass of the dominant seagrass and macro-algae communities of the two creeks.

3.2.1.2. Materials and Methods

The survey took place from September until December 1991 and was organized in such a way that at the same time data could be collected for the description of the distribution as well as of the biomass of the vegetation of seagrasses and macro-algae.

For these purposes, an adapted line intercept method (Orth & Moore, 1985) was used. At fixed intervals transects were made perpendicular to the creek. Along the transect, each 5 m a quadrate (area 0.04 m^2) was placed on the bottom and the above ground parts of the vegetation within the quadrate was sampled by hand using snorkelling gear. At each sampling site the composition of the sediment was described. In the eastern creek, transects were made at 50 m intervals. In the western creek transects were at 100 m intervals. The composition of the vegetation within a quadrate was considered representative for an area of approximately 5 by 50

metres in the eastern creek and 5 by 100 metres in the western creek, which are the smallest units of the grid cells of the GIS maps.

In the laboratory samples were split into the various species. The following keys were used for the identification: Moorjani & Simpson (1988), Jaasunel (1976) and Den Hartog (1970). The number of shoots and leaves of the seagrasses were counted. The dry weight of the above ground parts of the vegetation was used as a biomass measure. The dry weight of the samples was determined by weighing the subsamples after being dried to a constant weight at 70 °C.

A cluster analysis (twinspan) was used to distinguish the several vegetation types using species composition and abundance. Aboveground biomass was used as a measure for the abundance of the species.

The data were collected in such a way that they could be analysed with a Geographical Information System (GIS) computer model. This programme (IDRISI) was used to calculate the total biomass of the vegetation. Furthermore it was used to visualize the distribution of the vegetation types within the creeks. As a base for the GIS map of the eastern creek Figure 2a was used. Processing using GIS produced a schematic map shown in Figure 2b. As a base for the GIS map of the Figure 3a was used. Processing using GIS produced a schematic map shown in Figure 3b.

3.2.1.3. Results and discussion

The sampled area of the eastern creek is about 2.7 ha. It consists of two main channels which are locally connected, thus forming islands in-between. The channels are rather small (mean width approximately 18 m) and therefore the influence of shading by the mangrove trees is relatively strong. The mean depth is approximately 1.2 m at spring tide low water; the maximum depth is approximately 3 m. The entire area of the creek which has been studied is situated in the subtidal zone: apart from some large coral blocks at the end of the western channel, no area is exposed to air during low tide. The composition of the substrate varies from stone (coral blocks) to silt. Silt was always found at the sheltered sites of the creek.

The western creek differs in some ways from the eastern creek. The creek is fed by a small river which results in salinity and nutrient gradients. Also the dimensions differ. The total area of the studied part of the creek is 18 ha which is almost seven times bigger than the eastern creek. The main part of the creek is also much wider. The mean width is approximately 92 m. The influence of shading by the

surrounding trees of the mangrove forest is therefore relatively small in this creek. The western creek is also much deeper: 1.9 m deep at spring tide low water. An extensive sandbank near the beach of the fishermen is exposed to the air at low water: no vegetation was found at this site. The substrate consists mainly of sand. Very rarely a coral block or a small area with a silt bottom can be found.

As shown in Table 1, the species composition of the eastern creek differs greatly from that of the western creek. The vegetation of the eastern creek is more diverse. Apart from a few seagrass species in common (*Cymodocea rotundata, Cymodocea serrulata, Halodule uninervis* and *Thalassia hemprichii*), in the western creek some pioneers were found which lack in the eastern creek (*Halophila ovalis* and *Halophila stipulacea*). The eastern creek, in contrast, is dominated by *Thalassodendron ciliatum* and occasionally by *Enhalus acoroides*. *T. ciliatum* often contains epiphytic macro-algae such as *Gracilaria corticata* and *Dictyota spec.* In the eastern creek also more epilythic algae were found (such as *Sargassum spec.* and *Hormophysa triquetra*). The dominant algae are listed in Table 1.

Table 1. Species composition of the creeks.

Species	W. Creek	E. Creek
Macro-algae:		
Acanthophora specifera		+
Amphiroa fragilissima		+
Avrainvillea spec.	+	
Caulerpa racemosa	+	+
Caulerpa scalpelliformis	+	
Caulerpa sertularioides	+	+
Chaetomorpha crassa		+
Cystoseira myrica		+
Dictyota spec.		+
Gracilaria corticata		+
Gracilaria foliifera		+
Gracilaria millardeti		+
Gracilaria salicornia		+
Halimeda macroloba	+	
Halimeda opuntia		+
Hypnea cornuta		+
Janea adherens		+

Species	W. Creek	E. Creek
Padina boreana		+
Sargassum spec. 1		+
Sargassum spec. 2		+
Seagrasses:		
Cymodocea rotundata	+	+
Cymodocea serrulata	+	+
Enhalus acoroides		+
Halodule uninervis	+	
Halophila ovalis	+	
Halophila stipulacea	+	
Thalassia hemprichii	+	+
Thalassodendron ciliatum		+

The multivariate analysis technique (twinspan) resulted in eight vegetation types (appendix Table 2). This programme forms groups of samples based on their similarity using presence or species absence, and abundance (aboveground biomass). In the following, a description of the vegetation types in the eastern creek is given, based on the twinspan analysis.

Group 1

Species:
Gracilaria salicornia
Acanthophora specifera
Cystoseira myrica
Padina boreana
Hormophysa triquetra
Ulva cf lactuca
Dictyota spec.

Group 1 consists only of algae. The presence of *G. salicornia* and the absence of *Sargassum* species is characteristic for this vegetation type. Apart from *G. salicornia* other epilythic algae are found: *P. boreana, H. triquetra, U. cf lactuca.* All species were found on coral blocks.
C. myrica and *D. spec.* are epiphytes and were found on *H. triquetra.*

Group 2

Species:
Gracilaria salicornia
Sargassum spec. 1
Sargassum spec. 2
Caulerpa racemosa
Chaetomorpha crassa
Dictyota spec.
Hypnea cornuta
Halimeda opuntia
Cymodocea serrulata

The characteristic species of this group is *Sargassum spec. 1*. This group is closely related to the former group and is most frequently found on coral blocks. Only once a seagrass is found (*C. serrulata*) due to the fact that a quadrate that was placed at the edge of a coral block. By the presence of *Sargassum spec. 1* this sample is placed into this group.

Group 3

Species:
Gracilaria salicornia
Sargassum spec. 1
Acanthophora specifera
Hormophysa triquetra
Chaetomorpha crassa
Cystoseira myrica
Dictyota spec.
Hypnea cornuta
Amphiroa fragilissima
Gracilaria corticata
Halimeda opuntia
Cymodocea serrulata
Halodule uninervis
Cymodocea rotundata

The group is characterized by the occurrence of the mentioned seagrass species in combination with epiphytes. When coral blocks are present, also epilythic algae were found. The epiphytic algae were mostly found on the epilythic algae.

Group 4

Species:
Gracilaria salicornia
Sargassum spec. 1
Sargassum spec. 2
Acanthophora specifera
Chaetomorpha crassa
Cystoseira myrica
Dictyota spec.
Hypnea cornuta
Amphiroa fragilissima
Gracilaria corticata
Gracilaria foliifera
Gracilaria millardetii
Janea adherens

This group consists of epilythic algae in combination with epiphytes. Characteristic species are *D. spec.* and *G. corticata.* This group is distinct from group 5 by the absence of the seagrass *T. ciliatum.*

Group 5

Species:
Gracilaria salicornia
Acanthophora specifera
Hormophysa triquetra
Chaetomorpha crassa
Dictyota spec.
Hypnea cornuta
Amphiroa fragilissima
Gracilaria corticata
Halodule uninervis
Thalassodendron ciliatum

This group is based on the occurrence of *T. ciliatum* in combination with one or several epiphytic algae (mainly *D. spec. H. cornuta, A. fragilisima* and/or *G. corticata*). Only on two occasions epilythic algae were found (*H. triquetra*).
The plant species of this group cover the largest area of the creek. The substrate is mainly sand, but even on rocky bottoms with just a thin layer of sand *T. ciliatum* was found. The vegetation type was often found in the middle of the channel (Figure 4).
A high biomass of epiphytic algae was found; *D. spec.* and *G. corticata* forming the highest biomass.
The highest biomass of epiphytic algae was found on the stems of *T. ciliatum*.

Group 6

Species:
Thalassodendron ciliatum
Cymodocea serrulata
Halodule uninervis
Caulerpa sertularioides
Cymodocea rotundata
Enhalus acoroides

In this group mainly seagrass species without epiphytes occur. Only on one occasion an algal species was found (*C. sertularioides*). The presence of *T. ciliatum* without epiphytic algae is characteristic for this group.

Group 7

Species:
Halimeda opuntia
Cymodocea serrulata
Halodule uninervis

This group is very similar to group 6. It differs by the absence of *T. ciliatum*. Only a few species, mainly seagrasses, occur in this cluster. The dominant species is *C. serrulata*.

Group 8

Species:
Cymodocea serrulata
Halodule uninervis
Cymodocea rotundata
Enhalus acoroides
Thalassia hemprichii

This vegetation is clearly dominated by *E. acoroides* which was mostly found in sheltered regions of the creek. As known from the literature (Den Hartog, 1970) only a few species occur in combination with *E. acoroides*.

The distribution of the various vegetation types in the eastern creek is shown in Figure 4. No clear distribution pattern can be seen. It is a mozaic pattern of plant species. There seems to be a tendency, however, to find more macro-algae land inward towards the end of the creek, probably caused by lack of light due to shading by the surrounding trees. The distribution pattern is also influenced by the sediment composition. It is obvious that strictly epilythic algae only occur on coral blocks or hard substrates introduced by man. Most seagrasses need a more or less sandy substrate. In the field it seemed that *T. ciliatum* can grow on just a thin layer of coarse sand. *E. acoroides* was mainly found on silt. The vegetation type with *T. ciliatum* and attached epiphytes (cluster 5) dominates the eastern creek: cluster 5 has an area of 9819 m^2 which is 35.6 % of the total area (Table 3).

Table 3. Area covered by the vegetation types in the eastern creek.

Cluster 0 represents the group of samples without a vegetation.

Cluster	0	1	2	3	4	5	6	7	8	total
area										
m^2	4519	1192	2467	1359	1781	9819	1284	1538	3600	27559
%	16.4	4.3	8.9	4.9	6.5	35.6	4.7	5.6	13.1	100

The biomass of the vegetation in the eastern creek

T. ciliatum has the highest aboveground biomass in the eastern creek (Table 4). As cluster 5 dominates the eastern creek (Table 3), it can be concluded that *T. ciliatum* is the single most abundant species. *E. acoroides* within its vegetation group shows a high biomass also. Together with *T. ciliatum*, *E. acoroides* forms the major part of the seagrass vegetation.

Of the macro-algae, *G. corticata* shows the highest biomass. Like *D. spec.*, it was found attached to *T. ciliatum*.

Table 4. Aboveground biomass (g DW m^{-2}) of the vegetation in the eastern creek.

Vegetation type:	1	2	3	4	5	6	7	8	total
Percent of total area:	**4.3**	**8.9**	**4.9**	**6.5**	**35.6**	**4.7**	**5.6**	**13.1**	**840**
Gracilaria salicornia	107	23	2	24					8
Sargassum spec 1.		200	22	51					22
Sargassum spec 2.		31		44					6
Caulerpa racemosa									0
Padina boreana	15								1
Ulva cf lactuca									0
Acanthophora specifera	3		4						0
Hormophysa triquetra	43		16		9				6
Chaetomorpha crassa					1				0
Cystoseira myrica				3					0
Dictyota spec.		16	4	52	30				16
Hypnea cornuta		1		44	3				4
Amphiroa fragilisima				17					1
Cracilaria corticata			30	12	64				25
Gracilaria follifera				2					0
Gracilaria millardeti				2					0
Ganea adheren									0
Thalassodendron cilatum					647	647			261
Halimeda opuntia		2	77				220		16
Cymodocea serrulata		4	45			13	76	4	8
Halodule uninervis			2			1	8		1
Cymodocea rotundata			4			16		4	1
Caulerpa sertularioides						5			0
Enhalus acoroides						29		200	28
Thalassia hemprichii								1	0

The vegetation types of the western creek

The distinction of the vegetation in the western creek is mainly based on the occurrence of seagrasses. In the following, a description of the various vegetation types as indicated by twinspan analysis (appendix Table 5) is presented.

Group 1

Species:
Halophila ovalis

Group 2

Species:
Thalassia hemprichii
Cymodocea rotundata

The characteristic species of this group is *T. hemprichii*.

Group 3

Species:
Halophila stipulacea
Halodule uninervis
Caulerpa sertularioides
Cymodocea rotundata

In comparison with the other groups, a lot of samples belong to this cluster.

Group 4

Species:
Cymodocea rotundata
Cymodocea serrulata

This group is characterized by the occurrence of both *C. rotundata* and *C. serrulata*.

Group 5

Species:
Cymodocea serrulata

Group 6

Species:
Caulerpa scalpelliformes
Avrainvillea spec.
Halimeda macroloba

In this cluster only macro-algae occur.

Figure 5. shows the distribution of the vegetation types in the western creek. The blank parts of the map indicate that no vegetation was found. In contrast with the eastern creek, the biggest part of the western creek is without a vegetation (nearly 82 % of the sampled area, Table 6). The vegetation type with *H. stipulacea* and *C. rotundata* covers the largest area. No distinct pattern of distribution is recognizable except the fact that no vegetation was found in the middle of the creek. There are two possible reasons for that: the water current is too high or the plants suffer from a lack of sufficient light because of the water depth and the turbidity of the waterlayer. In the field, a lot of sediment transport by the watercurrent was noticed. Further research will be needed to study the limiting factors of plant growth in the West creek.

Table 6. Area covered by the vegetation in the western creek.

Cluster	0	1	2	3	4	5	6	total
Area								
m^2	151483	3276	2164	20695	1450	3678	2498	185244
%	81.8	1.8	1.2	11.2	0.8	2.0	1.3	100

The biomass of the vegetation in the western creek

The total biomass of the vegetation in the western creek is very small. Locally *T. hemprichii* is showing the highest biomass locally, but over the whole area *C. rotundata* is the dominant species.

Table 7. The aboveground biomass (g dry weight m^{-2}) of the vegetation of the western creek.

Vegetation type:	1	2	3	4	5	6	total
Percent of total area	1.8	1.2	11.2	0.8	2.0	1.3	18
Avrainvillea spec.						2	0
Caulerpa scalpelliformes						2	0
Halimeda macroloba			2				0
Haluphila stipulacea			3				0
Halodule uninervis							0
Caulerpa sertularioides							0
Thalassia hemprichii		33			8		1
Cymodocea rotundata		2	14	1			2
Cymodocea serrulata			2	1	19		1
Halophila ovalis	3						0

Concluding remarks

The vegetation of the eastern creek is better developed than that of the western creek. The vegetation is more diverse, the vegetation is more abundant and has a higher biomass.

The vegetation in the eastern creek is dominated by *T. ciliatum* with epiphytes like *G. corticata, Dictyota spec.* and *A. fragilissima.* It is likely that there is a correlation between the sediment composition and the vegetation. Whether this relation is direct or indirect is difficult to say. Other factors (like water current or wave action) interfere. In the eastern creek the availability of light seems to limit the vegetation. In the deepest part of this creek and in very heavily shaded areas, no seagrasses occur and only a few species of macro-algae were found. The vegetation in the western creek is probably limited by several factors. The presence of pioneers (*H. ovalis, H. stipulacea*) point in the direction of instability. Due to high water currents sediments will be transported forming an unfavourable situation for the settlement and establishment of plants. Due to the high currents sediment particles will cause a high turbidity limiting the vertical distribution of the plants. Also the presence of the fresh water stream can play an important role, as nutrient and salt gradients can form a chemical barrier for plant species.

References

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Appendix table 1. The vegetation of the eastern creek.
Output of twinspan. The samples, listed horizontal, and the species, listed vertical, are separated with numbers (0 and 1). The samples with the same code (within a line) are similar.

gra sal: *Gracilaria corticata*; sar sp1: *Sargassum* spec. 1; sar sp2: *Sargassum* spec. 2; cau rac: *Caulerpa racemosa*; pad bor: *Padina boreana*; ulv lac: *Ulva cf lactuca*; aca spe: *Acantophora specifera*; hor tri: *Hormophysa triquetra*; cha cra: *Chaetomorpha crassa*; cys myr: *Cystoseira myrica*; dic spe: *Dictyota* spec.; hyp cor: *Hypnea cornuta*; amp fra: *Amphiroa fragilissima*; gra cor: *Gracilaria corticata*; gra fol: *Gracilaria follifera*; gra mil: *Gracilaria millardeti*; jan adh; *Janea adherens*; tha cil: *Thalassodendron ciliatum*; hal opu: *Halimeda opuntia*; cym ser: *Cymodocea serrulata*; hal uni: *Halodule uninervis*; cym rot: *Cymodocea rotundata*; cau ser: *Caulerpa sertularioides*; enh aco: *Enhalus acoroides*; tha hem: *Thalassia hemprichii*.

```
                341234717 4 244486 21562668 627   223333344
               872270490465180674091992071774522344923568 38

17 gra  sal    3353333-3333--------12--------4-------------
22 sar  lsg    -------343335445443-11--3---3413------------
23 sar  nvt    -------53-----------------44----------------
13 dip  bor    ---1-3-----------------------------------------
24 ulv  lac    -1---------------------------------------------
28 cau  rac    ---2----1--------------------------------------
 7 aca  spe    --2----------------1----2---1----------------
19 hor  tri    -5----------------------3--------------------
10 cha  cra    ---------1--1---1--1----1-----1-------12-1--
11 cys  myr    ------1-----------1------1----2------------
20 hyp  cor    ------------2-----1---1-1-111-43232-21-3---1
12 dic  spe    ---1-----4----1---2-1-1-2334232--2334323-2--
 8 amp  fra    --------------------1-----51-1--3222111-2-112
14 gra  cor    --------------------13-3213-221334213333-213
15 gra  fol    ------------------------------2--------------
16 gra  mil    ------------------------------2--------------
21 jan  adh    --------------------------11-----------------
 6 tha  cil    ---------------------------------555555555545
18 hal  opu    ------------------2--3533--------------------
 2 cym  ser    -------3-----------33-33---------------------
 4 hal  uni    ----------------------12-----------------2---
 1 cym  rot    ----------------------2----------------------
 9 cau  fil    ---------------------------------------------
 3 enh  aco    -------------------------5------------------
 5 tha  hem    ---------------------------------------------

               00000000000000000000000000000000000000000000
               00000000000000000001111111111111111111111111
               00000001111111111110000001111111111111111111
               01111110011111111111011111000000011111111111
```

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44555566777888888113827755783166499169155112352
89236869013801235878163671059433511058264514297 65

------------------1---------------------------5-  00
-------------------------------------------------  010000
-------------------------------------------------  010000
-------------------------------------------------  010001
-------------------------------------------------  010001
-------------------------------------------------  010001
--------------------1-----------------------------  01001
----------------------5-2-------------------------  010100
------------------1---1-----------------------------  010101
-------------------------------------------------  01011
13----1------1----111---------------------------1-  011000
-2-13233-32-3413211--11---------------------------  011001
2121-2-----11113113---11--------------------------  011010
3321-122---311325-54541---------------------------  011010
-------------------------------------------------  011011
-------------------------------------------------  011011
-------------------------------------------------  011011
5555555555555555524--32253--------------------  0111
--------------------------------35---------------  100
---------------------------2223233433-------------  10100
---------------------------2---2221-------------3  10101
-------------------------32--------------------3--  10110
---------------------------2----------------------  10111
---------------------------33-----455554443333353  110
-------------------------------------------------2  111

00000000000000000000000011111111111111111111111
11111111111111111111111100000000011111111111111
11111111111111111111111100001111100000000000001
11111111111111111111111001100011000000000111111
```

Appendix table 2. The vegetation types of the West creek.
Ouput of twinspan. The samples (listed horizontal) and species (listed vertical) are separated with a number (0 and 1).

```
                  22 1412244   1333444443333  111222222311   113344
                  89196727122340234034591567671240134560355896889 78
   10 avr  spe    ----------------------------------------------2  1
    9 cau  sca    ----------------------------------------------1-  1
    4 hal  mac    ----------------------------------------------1--  1
    8 tha  hem    -----334-------------------------------------------  011
    7 hal  uni    -------------3-----1-------------------------------  011
    6 hal  sti    --------1-122321112-221222----------------------  011
    1 cau  ser    --------11------------------------------------------  011
    2 cym  rot    ------2---------------1322441143444223 33---------  010
    5 hal  ova    11222-----------------------------------------------  00
    3 cym  ser    ---------------------------------------22443133---  00
                  00000000000000000000000000000000000000000000000111
                  00000111111111111111111111111111111111111111111111
                  00111000000000000000000000000000000011000000
```

avr spe: *Avrainvillea* spec.; cau sca: *Caulerpa scalpeliformis*; hal mac: *Halimeda macroloba*; tha hem: *Thalassia hemprichii*; hal uni: *Halodule uninervis*; hal sti: *Halophila stipulacea*; cau ser: *Caulerpa sertularioides*; cym rot: *Cymodocea rotundata*; hal ova: *Halophila ovalis*; cym ser: *Cymodocea serrulata*.

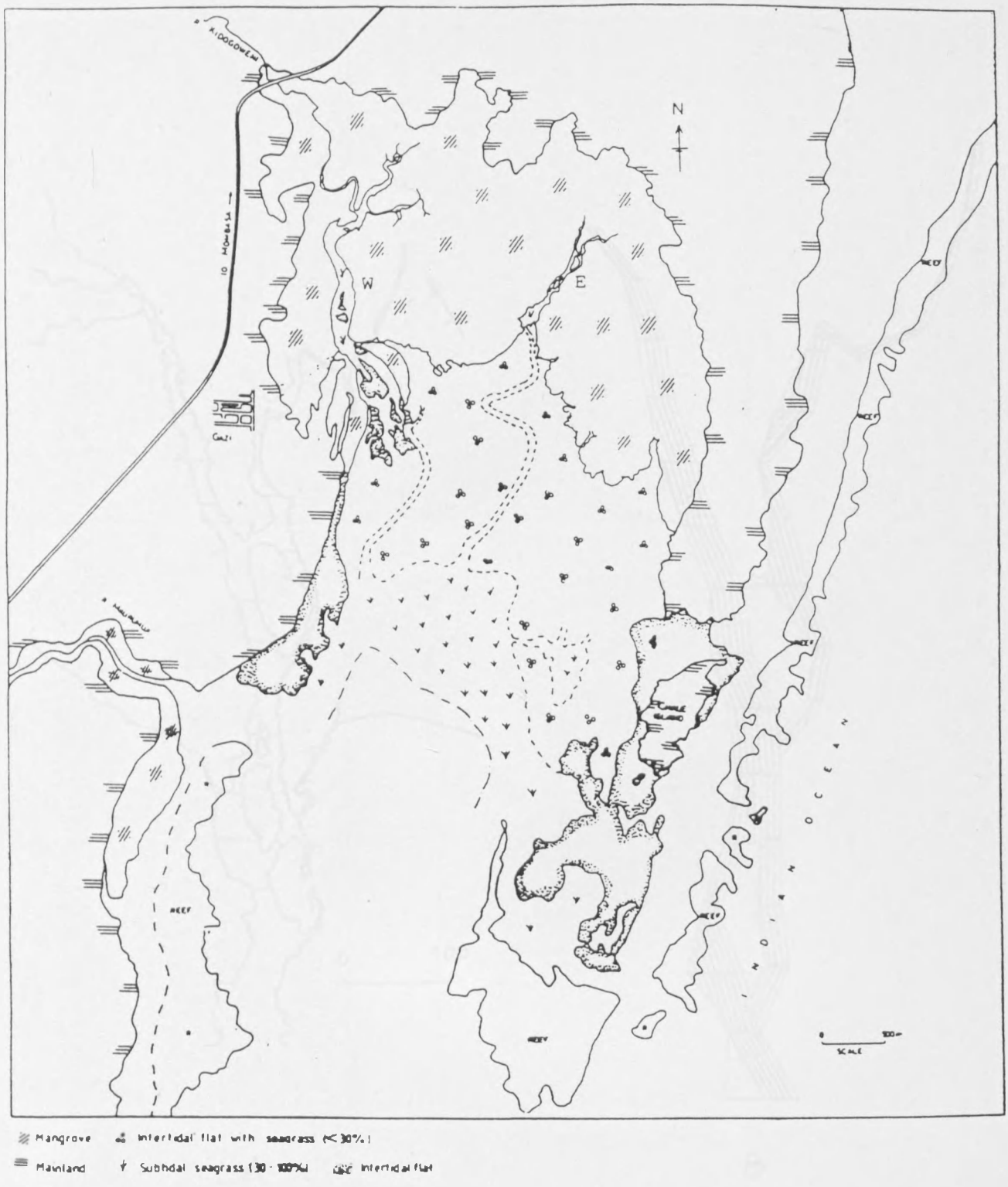

Figure 1 : Detailed map of Gazi Bay with the eastern creek (E) and the western creek (W).

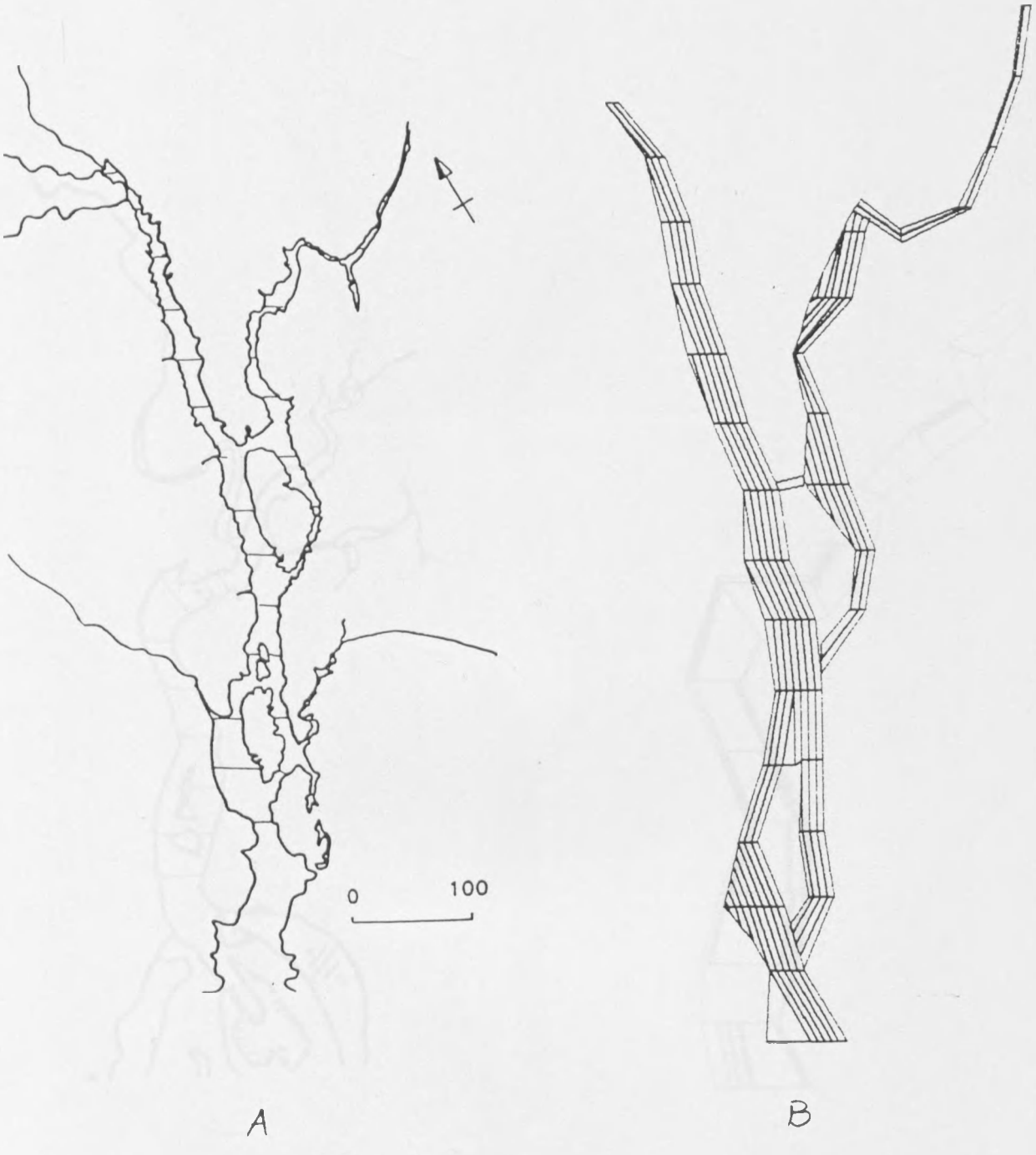

Figure 2 : (A) Detailed map of the eastern creek. Each line indicates the location of a transect. (B) GIS map of the eastern creek. The lines indicate the border of cells with vegetation.

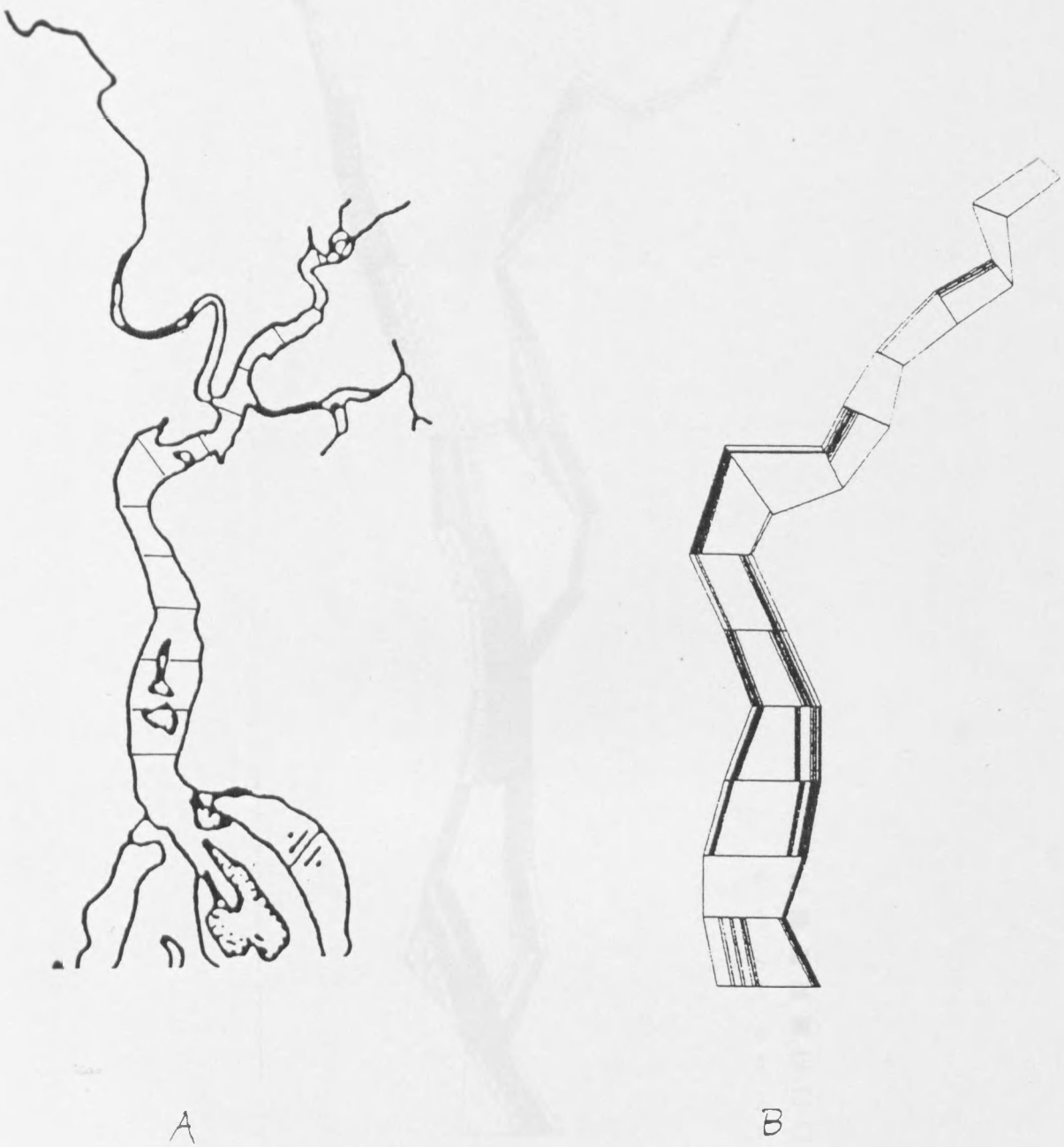

Figure 3: Detailed map of the western creek. (B) GIS map of the western creek. Each line indicates the location of a transect or the border of a cell with vegetation.

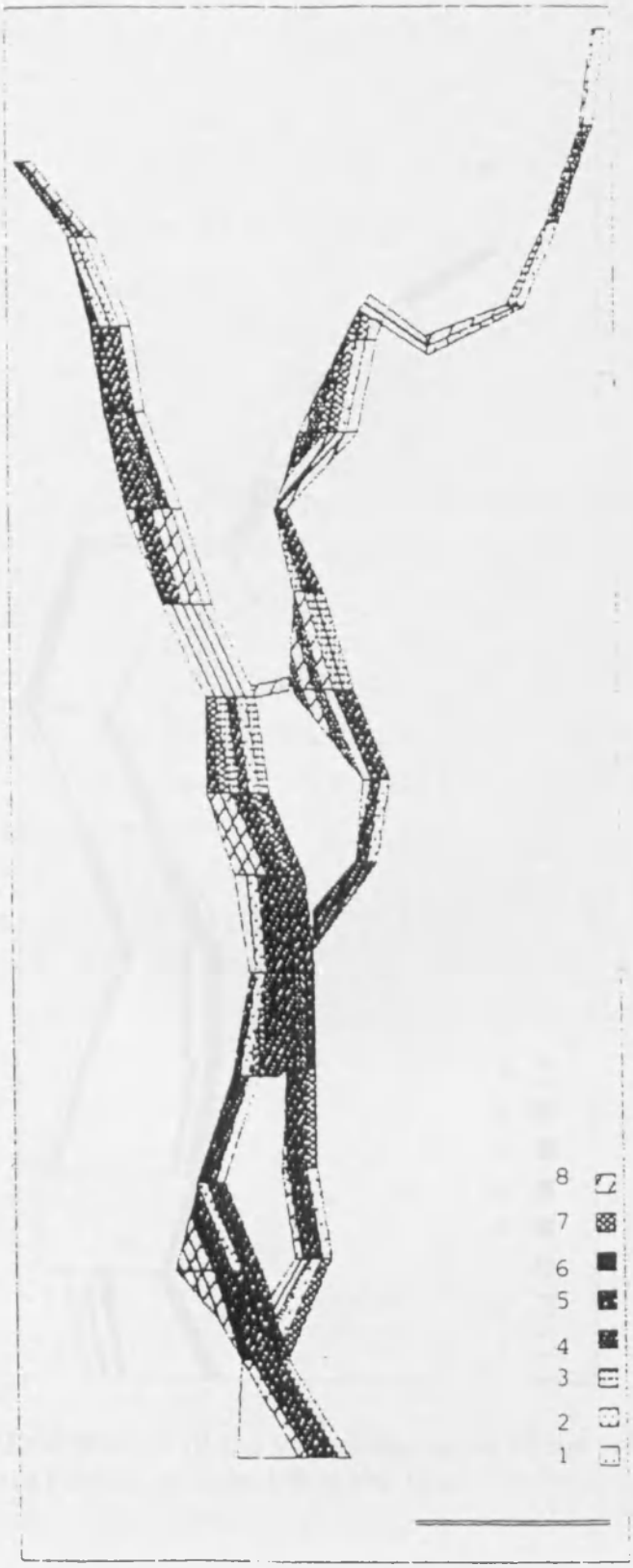

Figure 4 : Distribution of the vegetation types of the eastern creek. Codes 1-8 in the figure refer to groups 1-8 in the text.

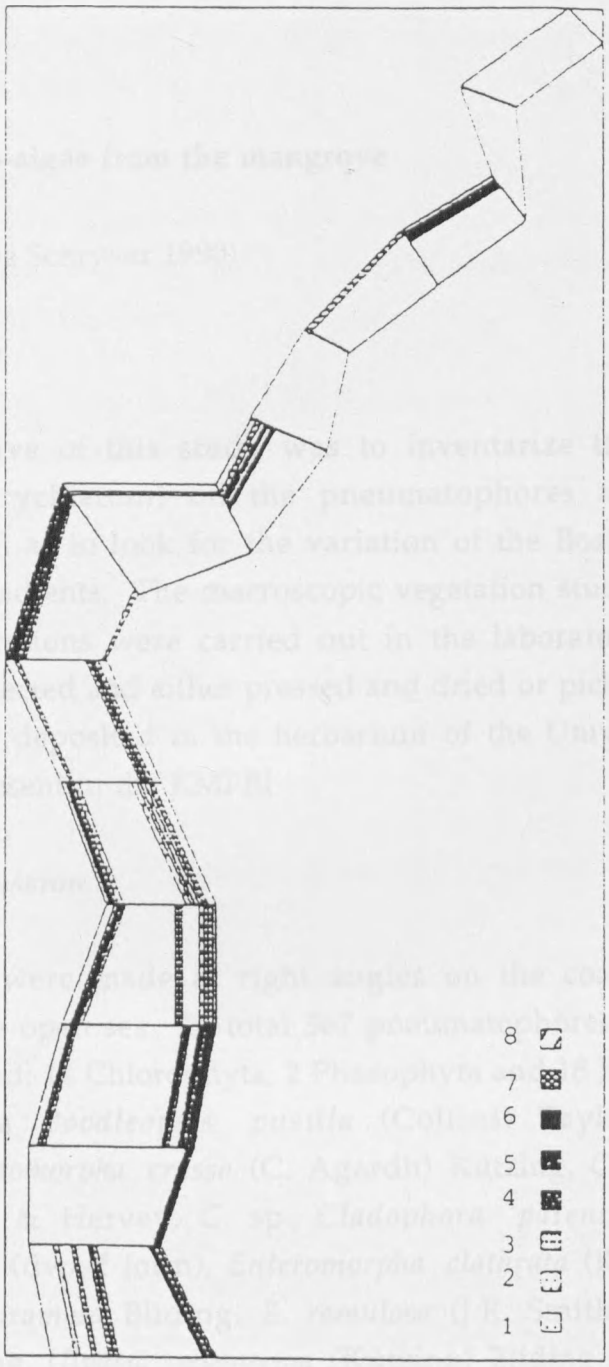

Figure 5 : Distribution of the vegetation types of the western creek. Codes 1-8 in the figure refer to groups 1-8 in the text.

3.2.2. Epiphytic macro-algae on mangroves and seagrasses

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3.2.2.1. The macro-algae from the mangrove

(M. Sc. thesis of De Schryver 1990)

Aims of the study

The main objective of this study was to inventarize the epiphytic macroalgal vegetation (Bostrychietum) on the pneumatophores and rhizophores of the mangrove as well as to look for the variation of the Bostrychietum along several environmental gradients. The macroscopic vegetation study was done on the spot, whereas identifications were carried out in the laboratory in Ghent. Therefore samples were collected and either pressed and dried or pickled in 4 % formalin. The samples are now deposited in the herbarium of the University of Ghent (GENT); duplicates are present in the KMFRI.

Results and Discussion

Seven transects were made at right angles on the coastline and at increasing distance from the open sea. In total 367 pneumatophores were collected. 36 algal species were found: 14 Chlorophyta, 2 Phaeophyta and 18 Rhodophyta.
Chlorophyta: *Boodleopsis pusilla* (Collins) Taylor, *Caulerpa fastigiata* Montagne, *Chaetomorpha crassa* (C. Agardh) Kützing, *C.* cfr. *gracilis* Kützing, *C. minima* Collins & Hervey, *C.* sp., *Cladophora patentiramea* f. *longiarticulata* Reinbold, *C.* sp. (dwarf form), *Enteromorpha clathrata* (Roth) J. Agardh, *E. kylinii* Bliding, *E. multiramosa* Bliding, *E. ramulosa* (J.E. Smith) Hooker, *Rhizoclonium africanum* Kützing, *Ulvaria oxysperma* (Kützing) Bliding.
Phaeophyta: *Dictyota adnata* Zanardini, Ectocarpaceae (sterile).
Rhodophyta: *Bostrychia radicans* Montagne, *B. tenella* (Vahl) J. Agardh, *Caloglossa leprieurii* (Montagne) J. Agardh, *Catenella caespitosa* (Withering) L. Irvine, *Ceramium maryae* Weber van Bosse, *Gelidiella myriocladia* (Børgesen) Feldmann & Hamel, *Gracilaria* cfr. *salicornia* (C. Agardh) Dawson, *Herposiphonia*

tenella f. *secunda* (C. Agardh) Hollenberg, f. *tenella* (C. Agardh) Ambronn, *Hypnea valentiae* (Turner) Montagne, *Laurencia perforata* (Bory) Montagne (2 growth forms), cfr. *Lejolisia*, *Lophosiphonia reptabunda* (Suhr) Kylin, *L. subadunca* (Kützing) Falkenberg, *Murrayella periclados* (C. Agardh) Schmitz, *Platysiphonia miniata* (C. Agardh) Børgesen, *Polysiphonia scopulorum* Harvey, *Stictosiphonia tangatensis* (Post) King & Puttock.
Cyanophyta: only the macroscopic *Brachytrichia quoyi* (Agardh) Bornet & Flahault has been included in this study.

Relative cover estimates for all species were obtained for each vertical zone of 5 cm high. The resulting data-matrix comprises 1092 relevés. The data were analyzed using TWINSPAN, DCA and CCA. In addition the standing crop of the epiphytes was studied on five locations with a dense cover.
The four red algae, characterizing the Bostrychietum worldwide are also present in the mangrove system of Gazi Bay. *Bostrychia tenella*, *Catenella caespitosa* and *Caloglossa leprieurii* are the three most frequent taxa. *Murrayella periclados*, another characteristic species, was found in all transects, though with lower abundancies.

Differences in emersion period, resulting from the increasing distance to the open sea, are also reflected in floristic differences between the transects. Close to the open sea, the green algal species of the genera Chaetomorpha and Enteromorpha were frequently found; coverage however was very low. The green alga *Ulvaria oxysperma* was exclusively found in these transects with a short emersion period.
A second gradient in emersion period with increasing distance from the tidal channel was reflected in a strong decline of species diversity and total cover. This was only found in the longer transects from the mixed stands on the western bank.

Epiphytic growth was generally maximal in the 5 - 15 cm zone (above the substrate). Above and below this zone a decline in cover was noted. This was also found in other mangrove systems. The zone of maximal cover tends to become lower on the pneumatophores with increasing distance from the open sea. *Bostrychia tenella* most clearly shows a zonation pattern. This species is characterized by its resistance to desiccation. High covers were found even in the upper segments of the pneumatophores. *Catenella caespitosa* also shows a marked resistance to desiccation though less than *Bostrychia tenella*.
A strong exposure to direct sunlight is reflected in lower cover estimates. Especially among the red algae this sciaphilous character is prominent. The green alga

Ulvaria oxysperma on the other hand was found with highest relative covers in strongly sun-exposed areas. This phenomenon was also observed in other studies.

Most species did not show a preference for a certain mangrove species except for *Bostrychia tenella* and *Ulvaria oxysperma*. The former species seems to prefer hard substrates like *Rhizophora* and old *Sonneratia* pneumatophores. It is absent on young and on dead *Sonneratia* pneumatophores which are very soft. *Ulvaria oxysperma* on the other hand seems to prefer these soft substrates.

Bostrychia tenella was absent on places with a fine sediment, probably as a result of the very high turbidity. This species however is very resistant to strong wave action (and therefore also grows on surf exposed vertical, shaded rocky cliffs). Smaller red algae are much less tolerant to wave action. The mathematical analysis showed the importance of the distance to the open sea as a main controlling factor for the epiphytic vegetation. *Boodleopsis pusilla, Dictyota adnata, Stictyosiphonia tangatensis* and *Bostrychia tenella* seem to prefer localities further away from the open sea. *Polysiphonia scopulorum* is an indicator species for localities near the open sea. The above mentioned green algae were distinctly separated from the other taxa in the ordination diagrams.

However it is important to note that our data are less suited for ordination and TWINSPAN analysis due to the strong heterogeneity in cover estimates, diversity and to the complexity of environmental factors in the mangrove ecosystem.

The discovery of *Dictyota adnata* in the mangrove is biogeographically very interesting: the species has been described from Indonesia in 1878 and recorded there again in 1926 and in 1984 (by ourselves). The presence of *D. adnata* along the Kenyan coast results in a disjunct distribution, both known growth places being at the eastern and western end of the Indian Ocean.

With respect to the biomass, the largest DM-values were found at Gazi Beach (352 g/m^2. The negative influence of sun-exposure on epiphytic growth was clearly reflected in a lower biomass (down to 0 g/m^2). Biomass was comparable on both *Avicennia* and *Sonneratia* pneumatophores (if their total surface was taken into account). A distinct trend emerged from the analysis of the vertical distribution of the biomass. Largest biomass levels were found in the zone between 5 and 15 cm above substrate. Above this zone biomass declined gradually, below this zone biomass levels were also much lower. Especially in stations with a fine sediment the latter was very marked. This again shows the negative influence of high turbidity on epiphytic growth.

3.2.2.2. The epiphytic macro-algae on seagrasses

(M.Sc. thesis of De Wit, 1988)

Aims of the study

The epiphytic algal component on seagrasses has only been studied on *Thalassodendron ciliatum* because this species forms extended meadows in the vast sublittoral area of Gazi Bay.

Material and Methods

A series of upright shoots of *Thalassodendron* was collected and pickled. In the laboratory each plant was subdivided in several zones: the stems in zones of 5 cm length, starting from the leaves, the leaves in 3 zones: a basal, an intermediate and an apical part. Moreover, upper and lower surface of the leaves were considered separately and a distinction was made between the older (outer) and the younger (inner) leaves. The analysis resulted in 214 relevés and 23 algal species.

Results and Discussion

Epiphytic algal species from the releves: it is important to stress that some of the remarkable larger epiphytes (*Dictyota, Dictyopteris*) do not appear on the randomly collected plants.
Chlorophyta: *Cladophora* cfr. *nitida* Kützing, *C. patentiramea* f. *longiarticulata* Reinbold, *Boodleopsis pusilla* (Collins) Taylor.
Phaeophyta: *Giffordia rallsiae* (Vickers) Taylor, *G. turbinariae* Jaasund, *Sphacelaria furcigera* Kützing.
Rhodophyta: *Centroceras clavulatum* (Agardh) Montagne, *Ceramium camouii* Dawson, *C. codii* (Richards) Mazoyer, *Griffithsia* sp., *Spyridia filamentosa* (Wulfen) Harvey, *Herposiphonia secunda* (Agardh) Ambronn, *Murrayella periclados* (Agardh) Schmitz, *Polysiphonia crassicollis* Børgesen, *Gracilaria corticata* Agardh, *Gracilaria edulis* (Gmelin) Silva, *Gracilaria salicornia* (Agardh) Dawson, *Champia parvula* (Agardh) Harvey, small encrusting Corallinaceae.

TWINSPAN analysis makes a well marked difference between the photophilic community on the leaves and the sciaphilic community on the stems; but no clear

difference is made between old and young leaves, old and young parts of a single leaf, upper and lower surface of a leaf.

It is clear that this is only a first approach of a study of the epiphytic vegetation on seagrasses; more detailed studies could lead to more subtle conclusions.

3.2.2.3. Microphytobenthos

(M. Sc. thesis Van Zele, 1992)

Aims of the study

The microphytobenthic communities of intertidal zones in tropical regions still remain almost unstudied, although they most probable have an important role as primary producers and as food source for a large number of zoobenthic organisms.

In view of such a research a preliminary inventarisation of the microphytobenthic diatoms has been carried out in the mangrove, the seagrass beds and the tide channel (including sand banks) of Gazi Bay.

Material and Methods

The macroscopic vegetation study was done on the spot, whereas identifications were carried out in the laboratory in Ghent. Therefore samples were collected and either pressed and dried or pickled in 4 % formalin. The samples are now deposited in the herbarium of the University of Ghent (GENT); duplicates are present in the KMFRI.

Sampling was done in September 1991. From each station 2 samples were taken from the upper 1 cm. One was used for the identification and counting of diatoms, the second one for sediment analysis (grainsize distribution). Temperature and conductivity were measured on the spot; salinity was sometimes determined by refractometry.

Identification was done on cleaned material (H_2O_2) with the help of light and scanning electron microscopy.

Results and Discussion

The relative abundance of the different taxa in each sample was determined. The resulting dataset was then processed with the computer programs TWINSPAN, a classification technique and DCA, an ordination technique.

A total of 279 taxa was found; 66 of these could only be identified up to genus level. The identification of these taxa requires further microscopical investigation, literature study and examination of type specimens. Summarizing we can say that Gazi Bay has a rich and diversified intertidal diatom flora.

The majority (about 89 %) of the taxa belong to the Pennatae. From the 279 taxa, the most abundant genera are: *Mastogloia* (13 %), *Navicula* (11.5 %), *Nitzschia* (10 %), *Amphora* (9 %) and *Achnanthes* (6.5 %).

Among the Centricae (about 11 %) the most abundant were: *Coscinodiscus* (1.8 %), *Auliscus* (1.4 %), *Biddulphia* (1.4 %) and *Triceratium* (1.4 %).

The multivariate analysis revealed 2 main groups, corresponding with the two rivers, the Kidogoweni and the Mkurumuji. There is also a relation with salinity and the texture of the sediment.

Future research

Because of the importance of the relationships between the benthic organisms of mangrove and seagrass ecosystems, emphasis should be laid on the study of the composition, distribution, biomass and interrelationships between microphyto-benthos and zoobenthos.

References

Strictly restricted to our own results on the research carried out in Gazi Bay.
All these works have also been deposited in the library of the Kenya Marine and Fisheries Research Institute.

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3.3. PHYTOPLANKTON PRIMARY PRODUCTIVITY

O. A. Wawiye (Kenya Marine & Fisheries Institute, Mombasa, Kenya)

3.3.1. Objectives of the research

Phytoplankton in the oceanic environment is the principal contributor of primary energy flow as they are responsible for pelagic primary production. Primary production values can give us an indication of the fertility of the open sea and a rough estimate of its potential on a fishery resource. However in the mangrove ecosystem primary energy flow may be either from a detrital source arising out of breakdown of detrital matter produced from breakages of mangrove and seagrass parts, from macro-algae or from phytoplankton. This report is an attempt to quantify the production attributable to the phytoplankton and to determine its characteristics i.e. whether it shows a seasonal trend or horizontal stratification and what abiotic factors affect it. Two distinct wind patterns, the north-easterly winds from December to April and the south-easterly winds from May to November characterize the east-African coast. The SE monsoon extends from April to June and the north-east monsoon period cover October and November. However, the precise timing and extent of the monsoons varies considerably (Grove 1986). In this report the timing of the two monsoon seasons and the two intermonsoon have been established on the basis of rainfall patterns. The present study covers period from March 1990 to August 1991.

Previous work done in Gazi creek on phytoplankton productivity during period June 1986 to April 1989 found the creek to have an average productivity of 65 $mgC/m^3/hr$ with the highest productivity in the month of October (113.54 $mgC/m^3/hr$) and the lowest in December 16.66 $mgC/m^3/hr$ (de Souza, 1988). Abiotic parameters of temperature and salinity did not fluctuate much between the stations.

The objective of this research was to assess the magnitude of phytoplankton primary productivity in the creek and the abiotic factors that affects its seasonality.

3.3.2. Materials and methods

(a) Temperature

Temperature was determined using a mercury thermometer which was left in water for 3 min. before reading taken.

(b) salinity

Salinity was measured using a refractometer. Water sampled for salinity was drawn from the same sample as that from which productivity were drawn.

(c) transparency

Transparency was monitored using the secchi disc.

(d) rainfall

Rainfall data was obtained from meteorological department Mombasa station.

(e) Production

In the present study primary production measurements were carried out twice a month whenever possible in Gazi along 3 stations situated at the mouth (station 1), head (station 3) and at a station (station 2) roughly intermediate between the two fish landing points. Productivity was determined using the Winkler method of light and dark bottles and calculated using procedure as outlined by Daro (1986).

Replicate 125 ml BOD glass bottles were filled with water collected using a 12 litre capacity Niskin vertical sampler. The bottles were then suspended at the depth of collection of the water sample via help of a buoy and sinker. Depth of bottle suspension was 0 m and 2 m. The dark bottles were darkened using scotch tape covered over by aluminium foil. The bottles were suspended for 3 hrs. before removal and fixation. Prevention of direct sunlight and scattered light effects once bottles were suspended was not done. About 15 min. were taken later from sample surfacing using the Niskin vertical sampler to lowering of BOD bottles. BOD bottle surfacing to fixing was immediate, never exceeding 3 min. Duration of fixed storage was upto 24 hrs. in dark at room temperature. After acid addition filtration was done after period of 30 min. but never exceeding 2 hr.

3.3.3. Results

Temperature

The temperature did not show any marked variations in the three stations and hence the data collected for the three stations were pooled together. The highest temperature was recorded in March 1990 (32.6 °C) while the lowest was recorded in July (26.1 °C), see Figure 2.

Salinity

Except for the SE monsoon period covering April 1991 - June 1991, salinity did not fluctuate much between the stations (Figure 1). However it could periodically show marked variations from station to station after rains when it could reduce considerably in the inner mangrove station due to influence of the river Kidogoweni. In station 1 at the mouth of the creek, the highest salinity was recorded in May 1990 and December 1990 (37 ‰) while the lowest was in May 1991 (32 ‰). In station 2 at the fish landing point, the highest salinity recorded was in May 1990, September 1990, December 1990 and February 1991 (37 ‰), the lowest was in May 1991 (21 ‰). In station 3 at the head of the creek the highest salinity was recorded in May 1990, September 1990 and February 1991 (37 ‰) while the lowest was in July 1991 (14 ‰) on pooling data on salinity for the three stations together the highest salinity was recorded in May 1990, September 1990 and December 1990 (37 ‰) while the lowest was recorded during the month of May 1991 (23 ‰).

Transparency

Mean transparency of water was high relative to depth of water column in almost all recorded cases the secchi disc was visible until it touched the bottom or until the 2 m depth where depth exceeded 2 m. Station 3 however had a greater concentration of suspended material than the other two stations.

Rainfall

Rainfall was maximal in October 1990 (186.5 mm) and least in February 1991 (0.4 mm) (Figure 3). The two intermonsoons were relatively dry compared to the monsoons.

Gross production

The difference in the mean gross production of the three stations was not significant in any of the seasons (Figure 4, Table 2). On pooling the data on gross productivities collected from the stations together to get an average value for the gross productivity of the creek, the highest column gross productivity was recorded during the month of June 1990 (272.24 mg $C/m^2/hr$) and the lowest in April 1990 (28.01 mg $C/m^2/hr$). However the difference between the productivities of the 4 seasons was found not to be statistically significant ($F=1,51$ $F_{0.05\,(1)\,3.12} = 3.49$).

Net production

The difference is the mean net production of the three stations was not statistically significant (Figure 4, Table 3) in any of the seasons. Pooling the data on productivities of the three stations to represent creek net column productivity the highest productivity was recorded during the month of June 1990 (97.46 mg $C/m^2/hr$) while the lowest was during the month of April 1990 (3.57 mg $C/m^2/hr$). No significant differences were found between the mean net production measured in the various seasons.

Table 1. Mean seasonal values of productivity and abiotic variables at Gazi Creek.

Season	Temp. (° C)	Sal (‰)	Surface G.P. $mgC/m^2/hr$	Bottom G.P. $mgC/m^2/hr$	Surface NP $mg/m^2/hr$	Bottom NP $mgC/m^2/hr$	rainfall mm
Intermonsoon Season 1 July '90-September '90	26.4	36	94.35	79.43	31.28	21.54	31.6
North East monsoon October '90-Dec. '90	30.1	36	89.32	65.91	33.95	32.19	130.8
Intermonsoon Season 2 January '91 - March '91	30.7	35	64.64	57.45	39.32	14.27	18.7
South east monsoon April '91-June '91	29.3	30	35.53	69.23	15.22	20.07	-
Annual Average	2.91	34	70.96	68.02	29.94	22.02	

Table 2. Mean column gross productivity (mgC/m^2hr) for the three stations in the four seasons.

Seasons	Column productivities ($mgC/m^2/hr$)			
	Station 1	Station 2	Station 3	Average productivity
Intermonsoon season 1 July '90-September '90 F= 0.47 $F_{0.05(1)\ 2,8}$ = 4.46*	118.56	136.87	195.70	150.38
North East Monsoon October '90-December '90 F= 0.18 $F_{0.05(1)\ 2,8}$ = 4.46*	114.09	98.89	118.54	110.51
Intermonsoon Season 2 January '91-June '91 F= 1.14. $F_{0.05(1),\ 2,9}$ = 4.26*	169.01	123.13	80.70	124.28
South East monsoon April '91-June '91 F=0.53 $F_{0.05(1)\ 2,7}$ = 4.74*	102.46	137.16	64.29	101.30

* Between stations F-values from ANOVA for specific seasons.

Table 3. Mean column net productivity ($mgC/m^2/hr$) for the three stations in the four seasons.

Seasons	Column productivities ($mgC/m^2/hr$)			
	Station 1	Station 2	Station 3	Average column productivity mg $C/m^2/hr$
Intermonsoon season 1 July '90-September '90 F= 0..50 $F_{0.05(1)\ 2,8}$ = 4.46*	36.57	72.70	55.45	54.91
North East Monsoon October '90-December '90 F= 0.15 $F_{0.05(1)\ 2,8}$ = 4.46*	43.52	48.47	51.13	47.41
Intermonsoon Season 2 January '91-June '91 F= 0.22. $F_{0.05(1),\ 2,9}$ = 4.26*	36.67	35.21	49.68	40.52
South East monsoon April '91-June '91 F=0.72 $F_{0.05(1)\ 2,7}$ = 4.74*	43.33	36.21	12.73	30.76

* Between stations F-value from ANOVA for specific seasons

Table 4. Variation of temperature and salinity with season in the three stations.

Seasons	Station					
	Station 1		Station 2		Station 3	
	Temp. (°C)	Salinity (‰)	Temp. (°C)	Salinity (‰)	Temp. (°C)	Salinity (‰)
Intermonsoon Season 1 July '90-September '90	26.2	36	26.3	36	26.7	35
North East Monsoon Oct '91-Dec '90	29.4	36	30.2	36	30.8	35
Intermonsoon Season 2 January '91-March '91	29.7	34	31.4	35	30.8	35
South-East monsoon April '91-June '91	28.4	34	29.5	30	29.5	28
Annual average	28.4	35	29.4	34	29.4	33

3.3.4. Discussion and Conclusion

Surface water temperature is generally determined by the amount of solar radiation striking the sea surface. (P.M.B. Bhattalthisi 1982). In Gazi creek, surface water temperature was lower during the period characterized by south-easterly winds relative to north-easterly wind characterized periods due to the higher cloud cover and relatively lower solar insolation found during this period.

The low value of salinity during the SE monsoon period April 1991 - June 1991 in stations 2 and 3 was due to fresh water discharge into the area at the time of sampling caused by the seasonal river Kidogoweni after precipitation. However this effect is usually not persistent but fluctuates with the tidal pattern: salinity increases with high tide and decreases with low tide.

Due to the shallowness of the creek, the secchi disc was in many cases visible upto bottom. Station 3 situated at the head of the creek had however relatively less clear water due to a greater presence of suspended solids than either station 2 or 1. The high mixing caused by the tidal flushing on the shallow creek ensures that the phytoplankton populations receives adequate sunlight for photosynthesis.

The differences between the average productivities of the three stations was not significant. The highest gross productivity was recorded during the intermonsoon season July 1990 - September 1990 characterized by south-easterly winds (150 mg $C/m^2/hr$) while the lowest was recorded during the SE monsoon period April 1991 - June 1991 (101 mg $C/m^2/hr$). There was some indication of an inverse relationship between productivity and rainfall.

Gross and net productivities were not very much affected by the above four seasonal demarcations but were rather affected by the monthly precipitation patterns, the period of rising rainfall corresponding to periods of falling productivity. During the rainy periods the higher than usual cloud cover and increased turbidity arising out of presence of suspended solids from runoff of land and river make light the most likely limiting factor of production. However immediately after the rains dispersion of the suspended solids is effected by the high tidal flushing and light ceases to be the limiting factor. Increased nutrient input in the creek after the effects of the runoff thus results in increased production. Station 3 with its greater nutrient load does not show a significant difference in productivity from station 1 as light is the limiting factor here due to greater predominance of suspended solids whereas in the outer station 1, nutrients may be the limiting factor.

3.3.5. References

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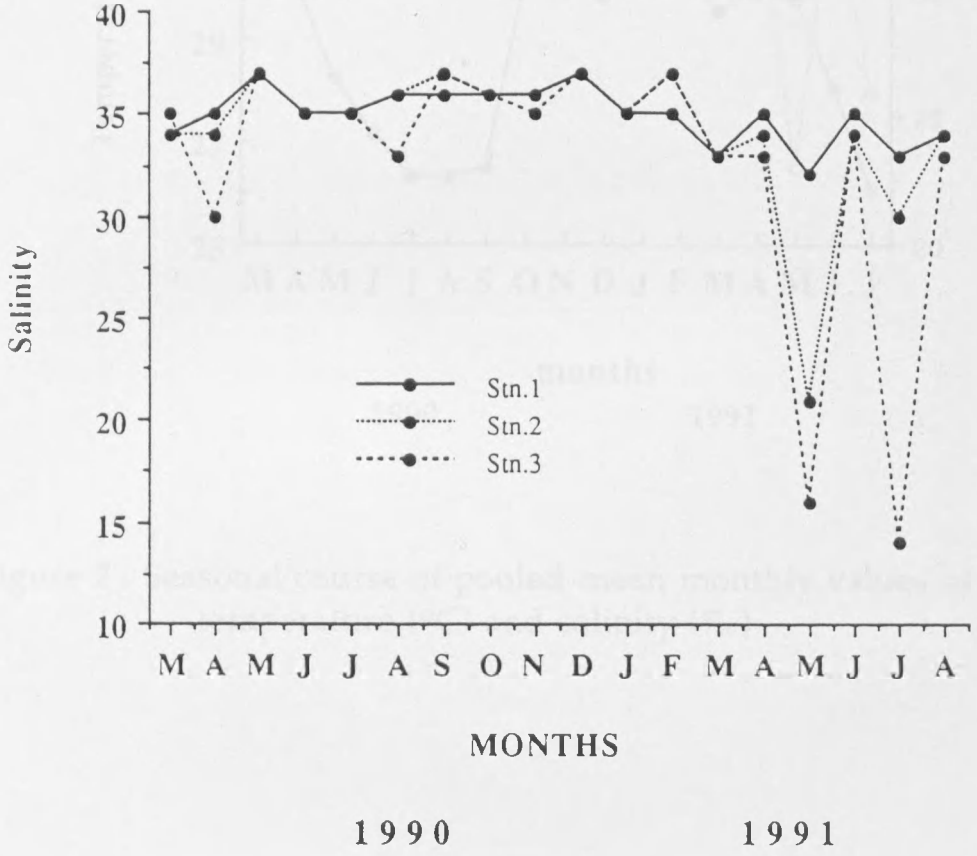

Figure 1 : Mean monthly salinity for the three stations

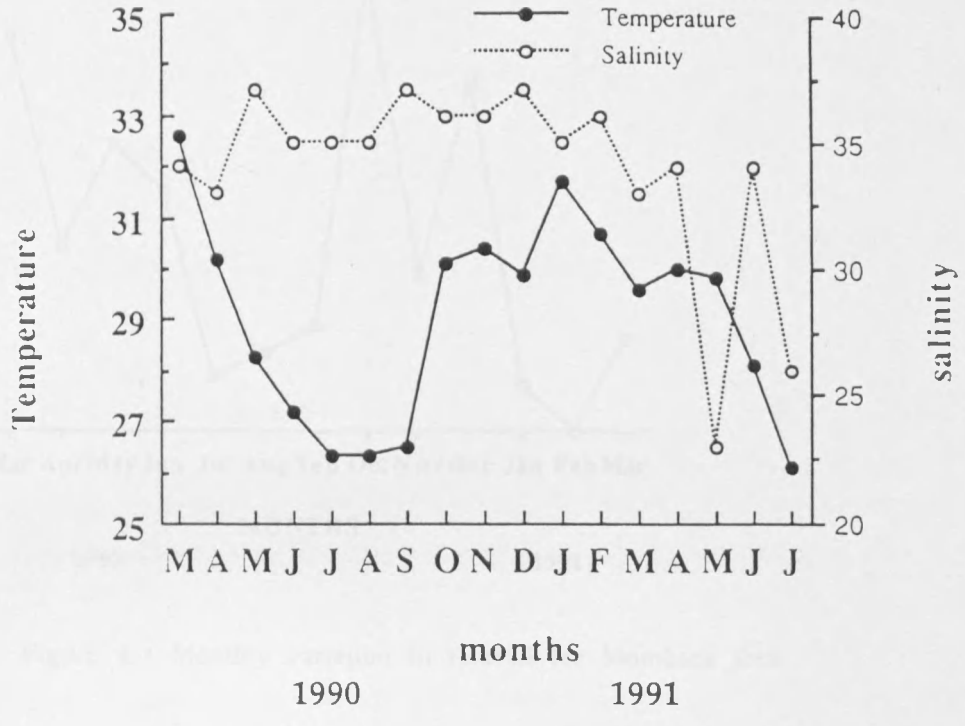

Figure 2 : Seasonal course of pooled mean monthly values of temperature (°C) and salinity (‰)

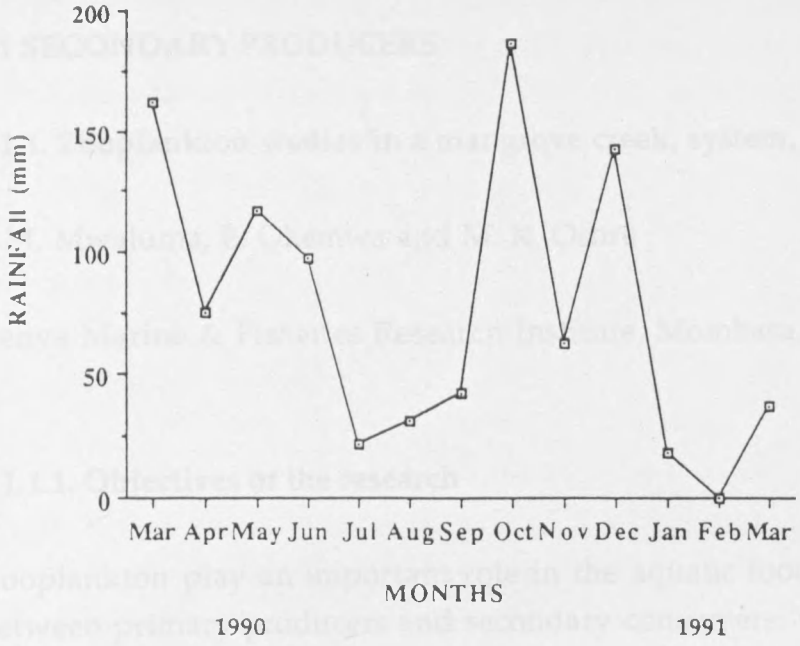

Figure 3 : Monthly variation in rainfall for Mombasa area

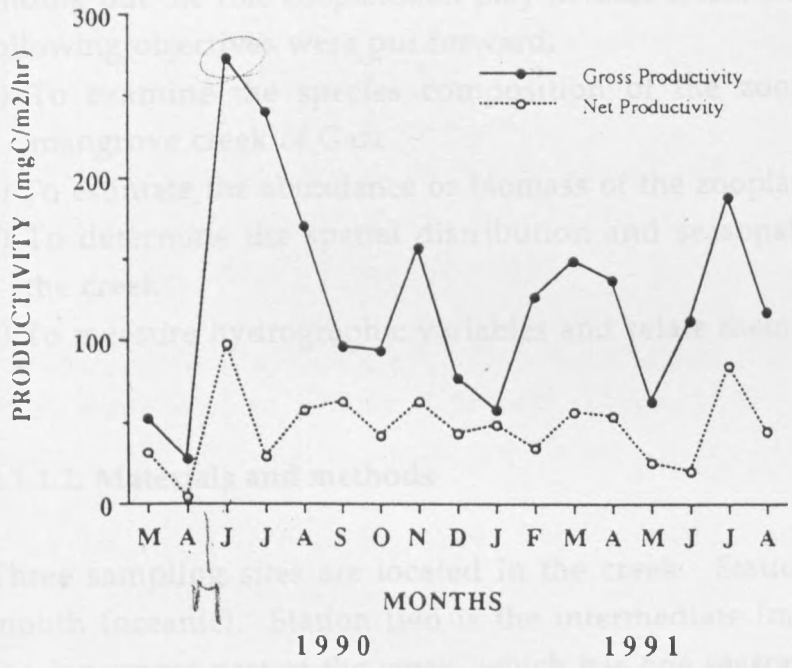

Figure 4 : Monthly variation in gross and net production (mean of 3 stations)

4. *FATE OF ORGANIC MATTER AND NUTRIENTS*

4.1 SECONDARY PRODUCERS

4.1.1. Zooplankton studies in a mangrove creek, system, Gazi

J. M. Mwaluma, E. Okemwa and M. K. Osore

Kenya Marine & Fisheries Research Institute, Mombasa, Kenya.

4.1.1.1. Objectives of the research

Zooplankton play an important role in the aquatic food chain by acting as the link between primary producers and secondary consumers. They form a vital link in the transfer of energy from lower to higher trophic levels. Apart from that, early life stages of commercially important species of fish, crustaceans and molluscs start their life as zooplankton. It is in this light, that a study was initiated with the aim of finding out the role zooplankton play in Gazi creek, a tropical mangrove creek. The following objectives were put forward:

1) To examine the species composition of the zooplankton community in the mangrove creek of Gazi
2) To estimate the abundance or biomass of the zooplankton in the creek
3) To determine the spatial distribution and seasonal variation of zooplankton in the creek
4) To measure hydrographic variables and relate them to zooplankton distribution.

4.1.1.2. Materials and methods

Three sampling sites are located in the creek. Station one is located at the creek mouth (oceanic). Station two is the intermediate (mid-creek) and station three is the innermost part of the creek, which has one seasonal river Kidogoweni draining into it. Sampling was carried out on an average of twice a month alternating between spring and neap tide, during high tide. A 335 μm mesh-size plankton net was towed in near surface water for 5 minutes using a rubber dinghy. Three tows were done in each station each lasting for five minutes. The volume of water flowing through was monitored using a flow meter tied across the mouth of the net. The collected zooplankton was rinsed into a plastic container, and samples

were preserved in 5 % formaldehyde for laboratory analysis. At the same time environmental variables: pH, salinity, dissolved oxygen and temperature were taken and recorded, transparency was determined using a secchi disc. Lab-work involved sorting out the zooplankton into taxa and counting under the wild Heerbrugg M3C microscope.

4.1.1.3. Results

Environmental variables

Maximum temperatures were recorded during the pre-monsoon period, and in March temperatures were as high as 32.3 °C. Minimum temperatures recorded was during the monsoons with temperatures of 25.5 °C in August. Usually the innermost creek (station 3) gave higher readings than the other two stations. Minimum temperatures at any given time were found in Station 1 (oceanic region) and ranged between 25 - 29 °C, this could be due to the influence of the sea, keeping the station much cooler than the rest. Temperature variation between the intermediate and the innermost creek was often low. This area being shallow always had a higher temperature than station 1. Temperature was high usually in December and January and cooler during the rainy season between April and May.

Dissolved oxygen readings varied within the range of 3.87 and 6.90 mg/l. High dissolved oxygen readings were reported in March, 6.90 mg/l, but were lowest in June, July and January around 4.0 mg/l.

Salinity was fairly constant at 35 ‰, except for the rainy season April and December when salinity fell to around 30 ‰. At any one time, salinity was always highest at station 1 and reduced in the innermost part of the creek. This could be due to the influence of the oceans into the creek.

pH was within the range of 7.50 and 8.63. The pH was low during the rainy season and higher in the dry season.

Biological features

About 40 different taxa have so far been recorded in Gazi. Monthly average abundance varied between 25 - 425 organisms/m^3. Copepoda were identified as the most important group forming upto 92 % of total 300 plankton species. Other important groups included Chaetognaths, Amphipods, Branchyuan larvae Isopods and Cumaceans.

The copepoda group comprised Calanoids, Cyclopoids and Harpacticoids. The most dominant taxa was *Pseudodiaptomus sp.* and *Oithona spp.* Other calanoids were *Undinula, Tortanus, Labidocera, Acrocalanus* and *Acartia.* Important cyclopoid species were *Oithona, Corycaens, Oncacea,* and *Saphirella.* Harpacticoids were dominated by *Methis ignea* and *Setella* species. *Pseudodiaptomus* and *Oithona* species were found almost throughout the year mostly in the middle and inner creek parts.

Zooplankton diversity on the Margalef Index ranged between 2.00 and 4.53 units. The highest diversity (4.53) was observed at station 1 in August. On average, station 3 always had the least diversity.

4.1.1.4. Discussion

Gazi creek supports a diverse zooplankton community. Copepoda were established as the single most important taxon forming upto 92 % of total zooplankton community. Zooplankton population was seen to be highest in April (pre-monsoon) and gradually falls with the approach of the S.E. monsoons. This is probably due to the fact that during the monsoons a lot of rain falls into the creek hence diluting the creek waters. This could be unfavourable for zooplankton production as it lowers the level of salinity. Apart from that, the seasonal R. Kidogoweni pours fresh water into the innermost part of the creek (station 3) and indeed low salinity has been recorded in the rainy season, i.e. 30 ‰.

Environmental condition between the middle and inner creek parts is seen do not to vary significantly, hence probably do not affect zooplankton distribution between these two stations much. In the outer oceanic station, environmental conditions are different. Species diversity has been found to be higher at this station as compared to the inner creek stations. To some extent, the zooplankton in Gazi creek exhibit localisation, especially were dominated by *Pseudodiaptomus* species which was absent most of the times in station 1. At the same time other groups like

fish larvae, bivalve larvae and gastropod larvae have been found in the inner creeks. Hence in this sense we could say that environmental conditions have played a role in their distribution. Perhaps another factor that could play a role in zooplankton distribution along Gazi creek is the bottom and surrounding vegetation of the creek. Station 3 (innermost) is characterized by mangrove growth and the bottom is shallow and has seagrass beds. Hence in this station lots of amphipods and cumaceans are found which probably feed on the sea weeds. Lots of harpacticoids are also found here, they probably feed on the decaying vegetation of the mangroves. These are species that are not found in station 1. Station two is characterized by seagrass beds, and also surrounded by mangroves an a little bit of coral growth, a lot of cryptonicid larvae (isopods) and amphipods have also been recorded. Station 1 is characterized by seagrass and coral growth and lesser amount of amphipods and isopods are recorded, and greater variety of copepod species are found. To summarise, station 1, the oceanic region has a greater amount of zooplankton diversity but lesser amount of biomass as compared to the middle and inner creeks, which amounts numerically and biomass.

4.1.1.5. Conclusion

In future it would be necessary to find out what effects the tides have on zooplankton distribution in Gazi creek, because our sampling was only done during high tide because it was the period during which the rubber boat could move. At low tide little pools of water usually remain in the inner creeks especially mid creek (station 2) hence trapping organisms which have been brought by the tide. At high tide the organisms which have been trapped may be washed away into the sea and a different population trapped, so we don't know whether that population is the same or a different one. It would be good to find out whether that population of zooplankton in Gazi is "resident" or "temporary" because the area is shallow and the tidal influence is evidently present. For this to be done sampling both at high tide and low tide is recommended, the only problem would be, the inner creek, station 3, would be inaccessible, because it is slightly far and muddy. Station 1 (oceanic) always has water at low tide.

Remark

Some of the results are already published in Hydrobiology :

Osore, M.K.W. (1992). Zooplankton studies in a Tropical Mangrove Creek System, Gazi, Kenya. Hydrobiology

Table 1. Zooplankton taxa recorded at Gazi

Taxa	STN 1	STN 2	STN 3
Annelida			
Polychaete larvae	xx	x	xx
Polychaetes	xx	x	xx
Amphipoda			
Hyperia	xxx	xx	x
unidentified	xx	x	x
Appendicularia			
Oikopleura	xx	x	x
unidentified	x	x	x
Brachiopoda			
Cladocera	x	x	x
Chaetognatha			
Sagitta spp. x	xx	x	x
unidentified	x	x	x
Cirripedia			
cirripedia nauplii	xx	x	x
Cnidaria			
siphonophora	xx	xx	x
Hydromedusae	x	x	x
Cumacea			
cumacea	xx	xx	xx
Copepoda			
calanoida	xxx	xxx	xxx
copepodid	xxx	xxx	xxx
cyclopoida	xxx	xx	xx
Harpacticoida	x	x	xx
Monstrilloida	x	x	x
Decapoda			
penaeidae	x	x	x
sergestidae	x	x	x
Decapod larvae			
Anomuran Zoea	x	x	x
Brachyuran Zoea	xxx	xx	x
Brachyuran Megalopa	xx	x	x
Caridean larvae	xx	x	x
Insecta	x	x	x
Isopoda			
Paragnatha	xx	xx	xx
unidentified	x	x	x
Mollusca			
Bivalve larvae	xx	xx	xxx
Gastropod larvae	x	x	xx
Pteropoda	x	x	xx
Heteropoda	x	xx	x
Mysidacea			
Mysids	x	x	xx
Nematoda	x	x	xx
Ostracoda	xx	xx	xx
Pisces			
Fish eggs	xxx	xx	xx
Fish larvae	xx	xx	xx
Stomapoda	x	x	x

xxx = abundant xx = common x = rare

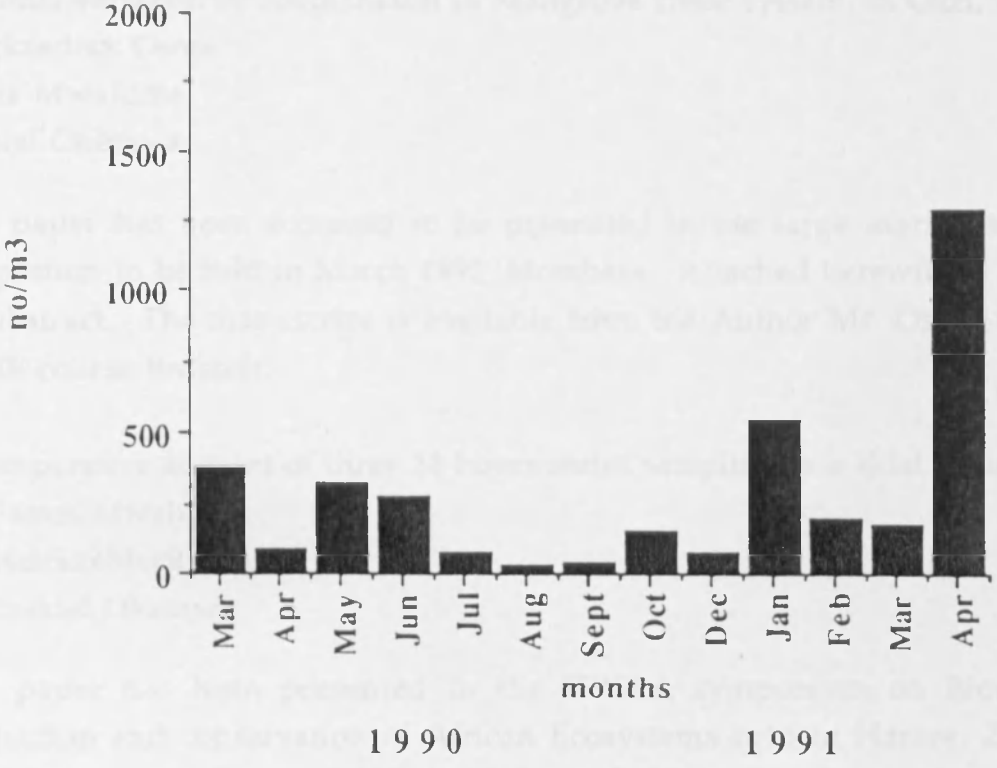

Figure 1 : Monthly variation of total zooplankton

4.1.1.6. Publications

(1) Seasonal variation of zooplankton in Mangrove creek system, in Gazi, Kenya by
Melckzedeck Osore
James Mwaluma
Ezekiel Okemwa

This paper has been accepted to be presented in the large marine ecosystem symposium to be held in March 1993, Mombasa. Attached herewith is 2 copy of the abstract. The manuscript is available from the Author Mr. Osore who is in FAME course Brussels.

(2) A comparative account of three 24 hours series sampling in a tidal estuary, Gazi, by : James Mwaluma
Melckzeldeck Osore
Ezekiel Okemwa

This paper has been presented in the HYSEA symposium on Biodiversity, production and conservation of African Ecosystems held in Harare, Zimbabwe on 14-17 December 1992. It has also been accepted as a poster in the on coming large marine Ecosystem Symposium to be held in Mombasa in March 1993. Attached herewith is a copy of the manuscript.

4.1.2. Ecological study of the benthos of the mangroves and surrounding beaches

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[2]. Kenya Marine & Fisheries Research Institute, Mombasa, Kenya.

4.1.2.1. Aims of the study

The community-ecological picture of the meio- and macrozoobenthos of the mangroves of Gazi Bay, near Mombasa, Kenya, is presented. Habitats differing according to the type of mangrove vegetation (namely *Avicennia, Bruguiera, Ceriops, Rhizophora* and *Sonneratia*) and to the sediment in all its characteristics (e.g. sandflat-mangrove, inundation) are investigated.
The abiotic data have been written down as completely as possible.
Densities, diversities and biomass data of the benthos (e.g. infauna) have been calculated and, where possible, mathematically processed in order to produce a reliable community-ecological pattern.

4.1.2.2. Study area

The sampling sites are situated at Gazi Bay (at about 50 kms south of Mombasa) (Figure 1). Twelve sites have been chosen: G1, G2, G3, G4, G5, G6, G7, G8, *G9, *G10, *G11 and *G12 . The sites G3, G4, G5, G6 and G7 are the same as those studied by Vanhove (1990). Possible comparisons are evaluated. They are situated in the mixed mangrove described by Gallin et al. (1989) and sampling was carried out on the sediment of 5 mangrove vegetations (*Avicennia marina, Bruguiera gymnorrhiza, Ceriops tagal, Rhizophora mucronata, Sonneratia alba* resp. G4, G3, G6, G5, G7).
The new sites are G1 and G2 (EC-plots), G8 (near Gazi-beach) and *G9, *G10, *G11 and *G12 (without mangrove vegetation).

station G1 : *Rhizophora mucronata*, not cut
station G2 : *Ceriops tagal*, not cut
station G3 : *Bruguiera gymnorrhiza*, cut
station G4 : *Avicennia marina*, cut
station G5 : *Rhizophora mucronata*, cut

station G6 : *Ceriops tagal*, cut
station G7 : *Sonneratia alba*, cut
station G8 : *Sonneratia alba*, strongly cut
station *G9 : sand flat
station *G10 : entirely cut mangrove (little beach)
station *G11 : sand flat
station *G12 : sand flat (with seagrass)

4.1.2.3. Materials and methods

Abiotic factors

At each site, granulometric variables and the amount of organic material have been determined. After a preliminary drying at 100 °C (to remove peat), the organic content was measured via the loss of weight during a 600 °C combustion. Instead of a mechanical sieve shaker and a graded series of standard sieves (Buchanan, 1984), a Coulter RLS Particle Size Analyser was used to define the % of gravel, sand and silt, the median particle size, the curtosis and the skewness of the total sediment. The interstitial water of the sediment was examined for nutrient contents (NH_4-N, PO_4-P, NO_2-N, NO_3-N and Si), salinity, temperature, acidity, redox potential and oxygen content.

Biotic factors

M e i o b e n t h o s

Only two (G1 & G2) of the twelve stations are investigated for meiofauna distribution and compared with the five stations of Vanhove (1990). According to the method described by McIntyre & Warwick (1984) three standard plastic transparent handcores (3.6 cm diameter, 30 cm length) were taken for meiofauna to a depth of 20 cm. Each core was preserved in a hot (60 °C) 4 % neutralized formaline solution. Laboratory treatment consisted of extracting the meiofauna by a combination of sedimentation, sieving (38 µm) and centrifugation and of staining with Rose Bengal. Major meiofauna taxa were identified and counted under a stereoscopic microscope.

The nematodes were determined to genus level and mean fresh and dry weight per individual and total fresh and dry weight for nematodes in 10 cm^2 was measured. The method used is described by Vanhove (1990).

Macrobenthos

As described by Holme & McIntyre (1971), a metal cylinder (diameter 13 cm and a surface area of 133 cm^2) was used to take three handcores to a depth of 20 cm. The sediment was preserved in a cold 4 % neutralized formaline solution. In the laboratory the macrofauna was extracted by using two sieves with a 1 and 2 mm mesh width and by picking out pieces of peat and roots by hand. The animals were stained with Rose Bengal. Major macrofauna taxa were identified and counted under a stereoscopic microscope (WILD, type M3). The Isopoda, Amphipoda, Tanaidacea, Cumacea and Polychaeta were determined to family level (even to genus or species). By determining the mean ash free dry weight for Oligochatea, Polychaeta, Bivalvia, Gastropoda, Isopoda and Amphipoda (with a Mettler M3 microbalance) it was possible to find the total biomass per taxon and per m^2

Mathematical analysis

Diversity indices were calculated for the meio- and macrobenthos taxa and the nematode genera. We were especially interested in the Shannon-Wiener diversity index H', the Simpson index SI and Pielou's evenness J (Hurlbert, 1971; Peet, 1974). To find some patterns, interactions and relations between densities and abiotic factors, we used TWINSPAN (Hill, 1979) and CA, PCA and DCA (Jongman et al., 1987). These mathematical analyses were done with meio- and macrofauna data in order to get an idea about community ecology in the studied area. The Spearman-rank correlation coefficient (Sokal & Rohlf, 1981) was calculated to determine relationship between biotic and abiotic variables.

4.1.2.4. Results

4.1.2.4.1. Abiotic factors (Table 1)

Sediment

- **Median**

The median of the total sediment lies between 276 and 544 µm. The stations *G9 and *G11 show the highest median (quite coarse sediment), the sites G2, G4 and G7, have the lowest values (rather muddy) and the others lie in between.

- Particle size percentage

The percentages of the different particle sizes vary strongly but sand always forms the biggest part (around 90 %).

Nutrients

The different sampling sites vary strongly in nutrient content. Only the stations G4, G5, G6, G7 and *G9 are very similar in nutrient concentrations.

Organic material

The organic content lies between 0 and 22.5 %. In general, one can state that this percentage is especially influenced by type and density of mangroves, cutting and burning effects, influence and closeness of the ocean related to tides and currents, presence of seagrasses, etc. Each station has to be examined separately for these elements.

Others

Temperature, salinity, pH, oxygen content and redox potential vary along the different sites. No real patterns are recognizable.

4.1.2.4.2. Biotic factors

Meiobenthos

Seventeen taxa are identified and the nematodes constitute the biggest part followed by copepodes and turbellarians. The total meiobenthos densities (Figure 2) are 3100 and 6101 ind./10 cm^2 for the stations G1 and G2. Together with the data of VANHOVE (1990) the mean total density becomes 3932 ind. per 10 cm^2.

- Nematode community

* Nematoda have densities ranging from 1709 to 5640 ind. per 10 cm^2 or from 65 % to 97 % of the total meiofauna (Figure 3).
* Patterns of length distribution of Nematoda seem more significant in depth profiles (Vanhove, 1990) than is the case with the horizontal variation.

* The average biomass per individual and the total biomass do not show a clear pattern for the horizontal distribution in the mangrove region either.
* For the nematode composition (which is only examined for Rhizophora (G2) and Ceriops (G1)), a great difference exists in diversity on the basis of the number of the genera: station G1 has 31 genera with an H' of 4.43 whereas G2 consists of 19 genera with an H' of 4.34.
* For both sites the feeding categories which are present can clearly be related to available food and kind of sediment.
The biggest part of the nematodes in station G1 consists of epistrate feeders followed by omnivore/predators. Station G2 is especially characterized by selective and non-selective deposit feeders (about the same density).

Macrobenthos

The total macrobenthos densities (Figure 4) for the stations G1 to *G12 vary between 265 and 6025 ind./m^2. Eighteen taxa are distinguished.

The Mollusca are represented between 0 (G5) and 2250 ind./m^2 (G3), the Crustacea between 0 (*G9) and 1125 ind./m^2 (*G12) and the Annelida show for all stations rather high values (especially for G2, G4, *G10 and *G12 with resp. 2300, 1850, 1602 and 1450 ind./m^2). Station *G12 has a conspicuously high number of Nemertini whereas the stations G2, G5, G7, *G9 and *G12 have many macro-Nematoda.
As far as the families of polychaetes are concerned, the large presence of the Nereidae is remarkable.

The Amphipoda and Isopoda are, in contrast to what the literature indicates, not that frequent (2 and 3 families respectively). We used Fauchald & Jumars (1979) and Fauchald (1977) to study the Polychaeta systematically and autecologically.

With the necessary caution the difference in diversity of the macrobenthos will, in contrast to what is said about the Nematoda, prove to be the result of a different distribution of the individuals over the taxa (this seems, however, to be logical as large taxa are being used to calculate the diversity indices). The H' values of the stations stay in between 1.65 and 3.35 with a mean value of 2.6.

Concerning biomass (Figure 5), conclusions are difficult to make because we had to decide on a standard mean weight.

4.1.2.4.3. Mathematical analysis

Meiobenthos

Multivariate analysis of the data points to a similarity of the *Rhizophora* regions on the basis of the high number of Nematoda and the muddy sediment. The *Ceriops* regions on the contrary show a less strong relationship except because of the low number of Polychaeta and the absence of Kinorhyncha. The *Sonneratia* station discerns itself from the rest. Although all this points to a strong influence of the nature of the type of mangrove vegetation, *Avicennia* and *Bruguiera* in the meiofaunacomposition resemble each other well as does the sediment.
Conclusion: the sediment lies at the basis of the determinations of the meiofauna communities.

Macrobenthos

The mathematical analysis of the densities of the large taxa shows the following patterns:
* The stations of *Avicennia* and *Bruguiera* and the completely cut beach (which used to be overgrown with a mixed mangal as well) show a lot of polychaetes and molluscs and are at the same time sandy.
* The *Rhizophora* and *Ceriops* regions belong together because of the great quantity of oligochaetes, mud and organic material. Here a close relation appears between vegetation and sediment.
* The *Sonneratia* sites and the two sampled sand flats are all quite sandy and correspond reasonably well as far as composition is concerned. Only the number of crustaceans divides them into *Sonneratia* and sand flat.
* The sand flat with puddles and seagrass closest to the ocean clearly discerns itself from all other stations.
Conclusion: the type of vegetation is not really the decisive factor in determining the pattern. The separation between sand flat and mangrove on the other hand is striking.

4.1.2.5. Discussion

Meiobenthos

The compared literature is mainly based on data from Australia (Hodda & Nicholas, 1985 and 1987; Alongi, 1987; Nicholas et al.,1991), Cuba (Lalana-Rueda & Gosselck, 1986) and South Africa (Dye, 1983 and 1983b). A discussion of our data together with the literature and Vanhove (1990) (data from Kenya) shows the following:

* There is a large difference between the densities of Gazi and those of the literature (especially because of the number of nematodes). The reason for this could be more related to the method used, e.g. different methods of counting, different depth of sampling, inaccurate methods,... Environmental factors, however, can not be excluded.
* For the biomass the same applies as for the densities (only the nematodes are measured).
* It is striking that it is not so much the kind of vegetation that influences the communities but that 'quantity' of vegetation or other factors, which directly or indirectly constitute the basis of the sediment, are determining.

Macrobenthos

The literature which is used here is the following: Wade (1972), Maurer & Vargas (1984), Guelorget et al. (1990), Lalana-Rueda & Gosselck (1986), Alongi (1989 and 1990) and Warwick & Ruswahyuni (1987).

Discussion of our data in relation to the literature :

* The density of the macrobenthos of Gazi is much higher than those found in the literature. As is true for the meiobenthos this could be especially caused by methodical differences such as the mesh size, the way of counting,... Here again, however, environmental factors are not to be excluded.
* For the biomass the same patterns occur (which is expected because of the method used). These data do correspond with certain literature data which points to the fact that the animals in Gazi are much smaller than those in other areas.
* In comparison with the estuary or lagune areas it is striking that the richness (densities and biomass) is smaller than that of the Gazi-mangroves. Within the Gazi stations themselves this already becomes clear.
* As was true for the meiobenthos the influence of the vegetation is not the decisive factor in determining the community ecology.

4.1.2.6. Conclusion

It can be said that Gazi is richer in density and biomass than other 'similar' areas. Whether this is the result of 'method' or 'environment' still has to be determined. The fact that the mangals of Gazi are richer than the estuaries in general is also clearly shown (contrary to what Alongi (1990) claims).
Patterns in community ecology are only vaguely related to the type of vegetation. That relationship only exists because the mangrove type, among others, forms the basis of other, more decisive factors, such as sediment,... Fauna composition could possibly be tied to the kind of mangrove tree, but this cannot be concluded from this study.
More data (biotic but also abiotic) will provide a better insight into the complex benthos-system bringing us closer to a thoroughly analysed ecosystem. Only then will these areas be conserved in a responsible way.

4.1.2.8. References

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Table 1: Sediment characteristics for the twelve stations.

Station	G1	G2	G3	G4	G5	G6	G7	G8	*G9	*G10	*G11	*G12
% mud	3.35	11.27	0.39	6.96	4.22	2.52	3.78	2.37	0.32	3.3	0.78	0.84
% sand	93.2	85.51	97.82	85.37	87.75	92.3	90.93	84.42	93.87	79.83	87.42	94.46
% gravel	3.45	3.22	1.79	7.67	8.03	5.18	5.29	13.21	5.81	16.87	11.8	4.7
median	369.8	276.4	409.1	287.7	357.1	357.7	281.2	366.5	518.7	334.9	544.5	312.9
skewness	-2.56	-1.56	-2.30	-2.07	-1.54	-2.24	-1.74	-1.69	-3.40	-2.11	-4.76	-1.62
curtosis	11.43	3.252	19.46	6.569	4.592	9.804	7.223	6.057	34.46	8.553	40.82	10.04
% organic material	19.41	22.47	0.79	2.11	7.04	3.09	7.38	1.3	0	6.44	0	1.47

Table 2: Density (ind./m^2) of the families of Amphipoda, Isopoda, Polychaeta and Tanaidacea, for the twelve stations.

Station	G1	G2	G3	G4	G5	G6	G7	G8	*G9	*G10	*G11	*G12
Gastropoda	225	25	100	550				300	275	150	150	150
Bivalvia		25	2150			38	150	75	25	713	25	75
Isopoda												
Amphipoda												
Tanaidace												
Cumacea							25	50				25
Decapoda					50						25	50
Oligochaeta	600	2075	375	200	425	75				263		225
Polychaeta												
Nematoda		350			50		200		25			550
Nemertini					50		50	25			25	2525
Sipuncula		25		125	25			225			225	25
Echiura										75		
Cnidaria												25
Insect larvae		25		25		38						
Pisces												25

Table 3: Density (ind./m^2) of the families of Amphipoda, Isopoda, Polychaeta and Tanaidacea for the twelve stations.

Station	G1	G2	G3	G4	G5	G6	G7	G8	*G9	*G10	*G11	*G12
Isopoda												
Euridicidae	0	0	800	25	0	0	0	0	0	0	0	0
Sphaeromatidae	0	0	50	0	25	0	0	0	0	0	0	0
Olibrinidae	0	0	0	50	25	25	0	0	0	0	0	0
Amphipoda												
Ampeliscidae	0	25	25	0	0	0	25	0	0	38	0	0
Corophiidae	188	0	0	150	0	0	100	75	0	113	0	75
Polychaeta												
Amphinomidae	0	0	0	0	0	0	0	0	0	113	0	0
Cirratulidae	0	0	175	0	0	0	0	0	0	75	0	0
Eunicidae	0	0	0	25	25	0	100	0	0	0	0	75
Capitellidae	0	0	0	1425	75	0	250	50	0	0	25	0
Paraonidae	0	0	0	0	0	0	0	0	0	75	0	325
Nereidae	113	50	250	25	25	38	325	50	0	512	0	125
Nephtyidae	0	0	0	0	50	0	75	0	0	150	0	0
Hesionidae	0	0	0	50	0	38	0	75	0	113	75	0
Phyllodocidae	0	25	0	0	0	0	25	25	50	38	150	25
Terebellidae	113	25	0	25	0	0	175	0	0	263	0	325
Glyceridae	0	0	0	0	50	0	0	25	0	0	0	250
Syllidae	38	0	25	75	0	0	0	0	0	0	0	25
Polyodontidae	0	0	0	0	0	0	0	0	0	0	0	25
Orbiniidae	0	0	175	0	25	0	0	0	0	0	0	50
Polynoidae	0	50	0	0	25	0	25	0	0	0	0	0
Lacydoniidae	0	75	0	0	0	0	0	0	0	0	0	0
Spionidae	0	0	0	0	0	0	0	0	100	0	25	0
Maldanidae	0	0	0	25	0	0	0	0	0	0	0	0
Tanaidacea												
Paratanaidae	0	50	0	0	75	38	0	125	0	0	0	1075

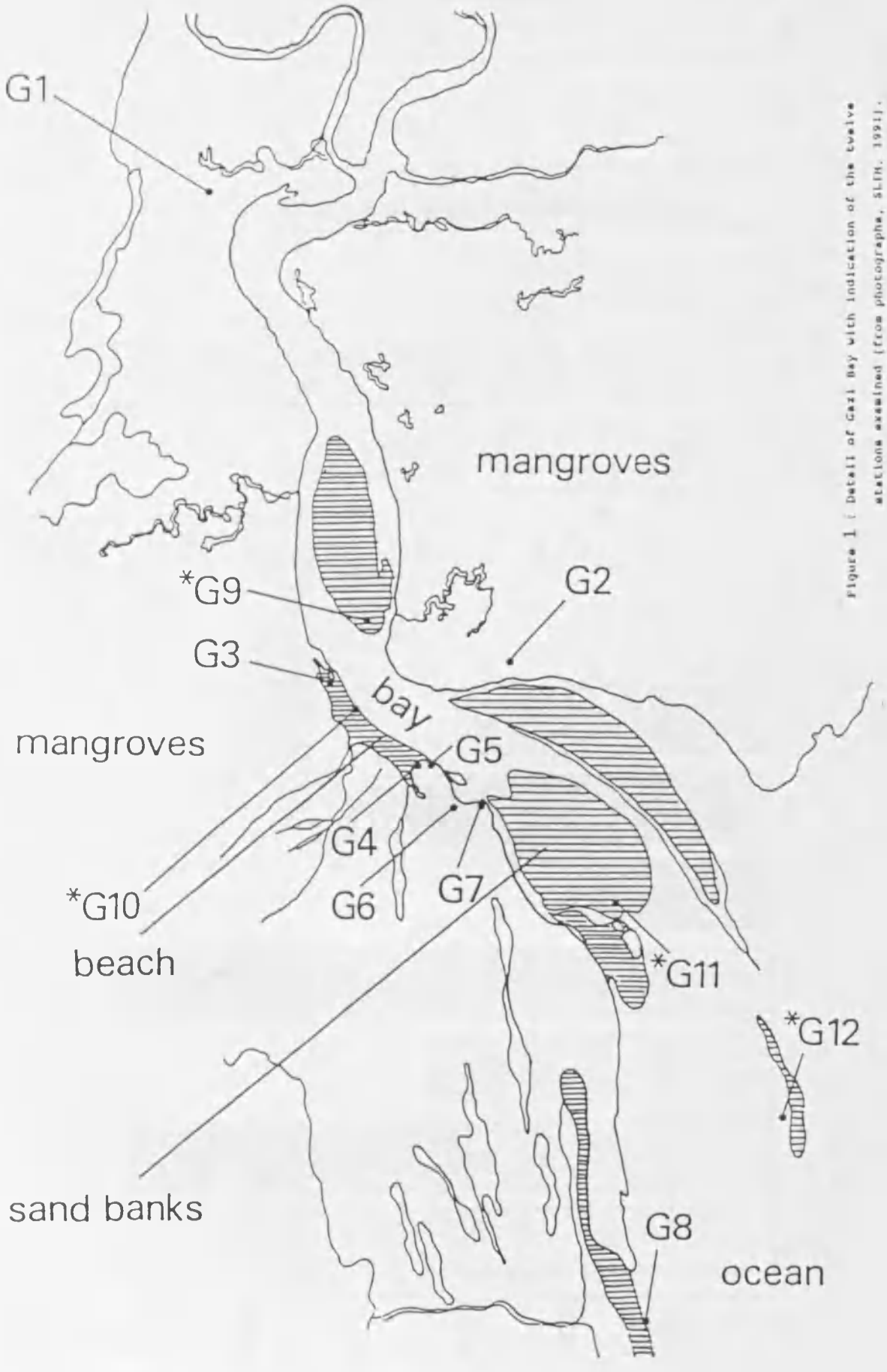


Figure 1 : Detail of Gazi Bay with indication of the twelve stations examined (from photographs, SLIM, 1991).

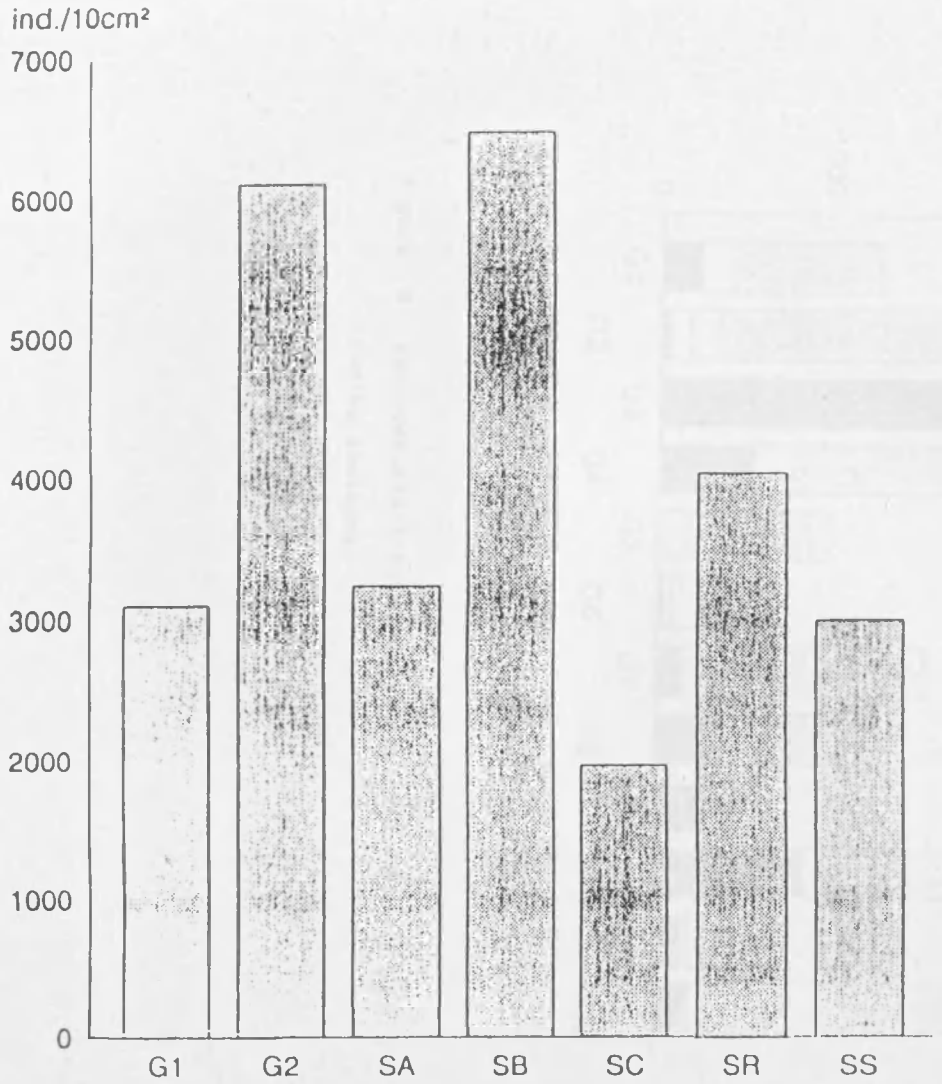


Figure 2 : Meiobenthos : total densities (ind./10cm²) for the station G1 and G2 (+ the stations of VANHOVE, 1990).

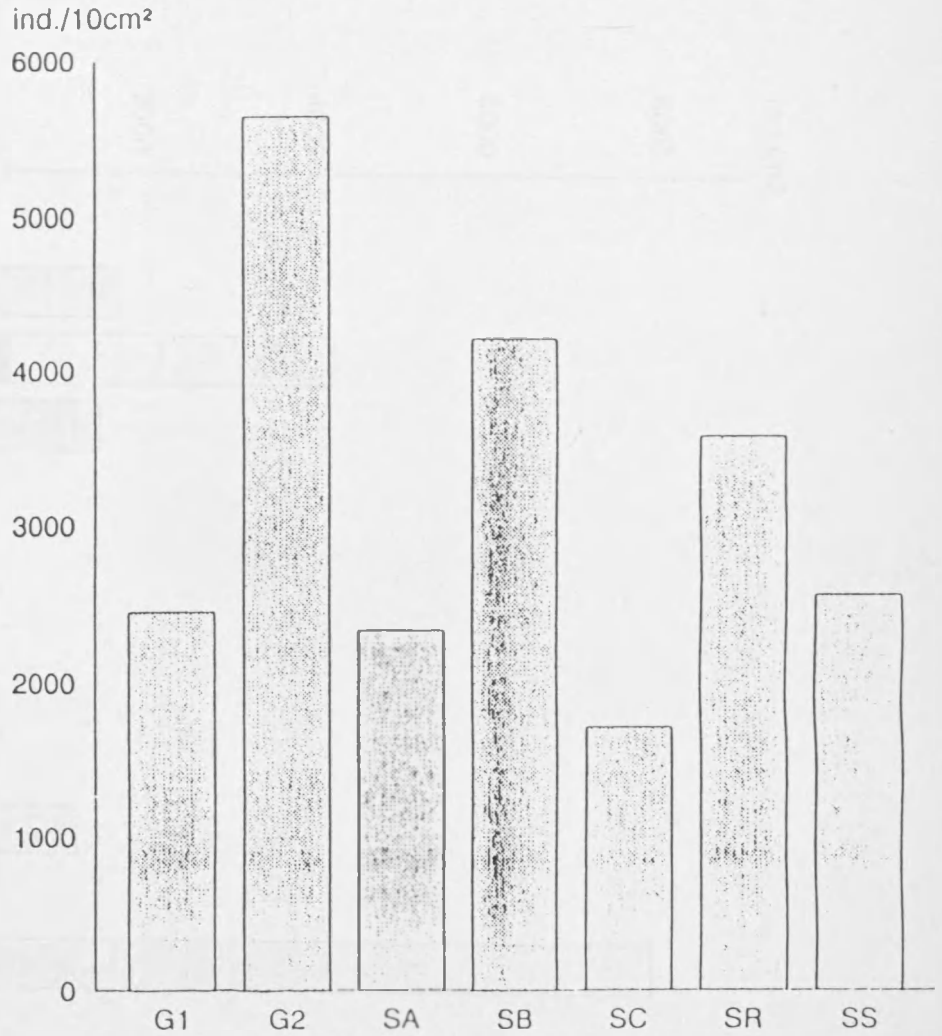


Figure 3 : Meiobenthos : total densities (ind./10cm²) of nematodes for the station G1 and G2 (+ the stations of VANHOVE, 1990).

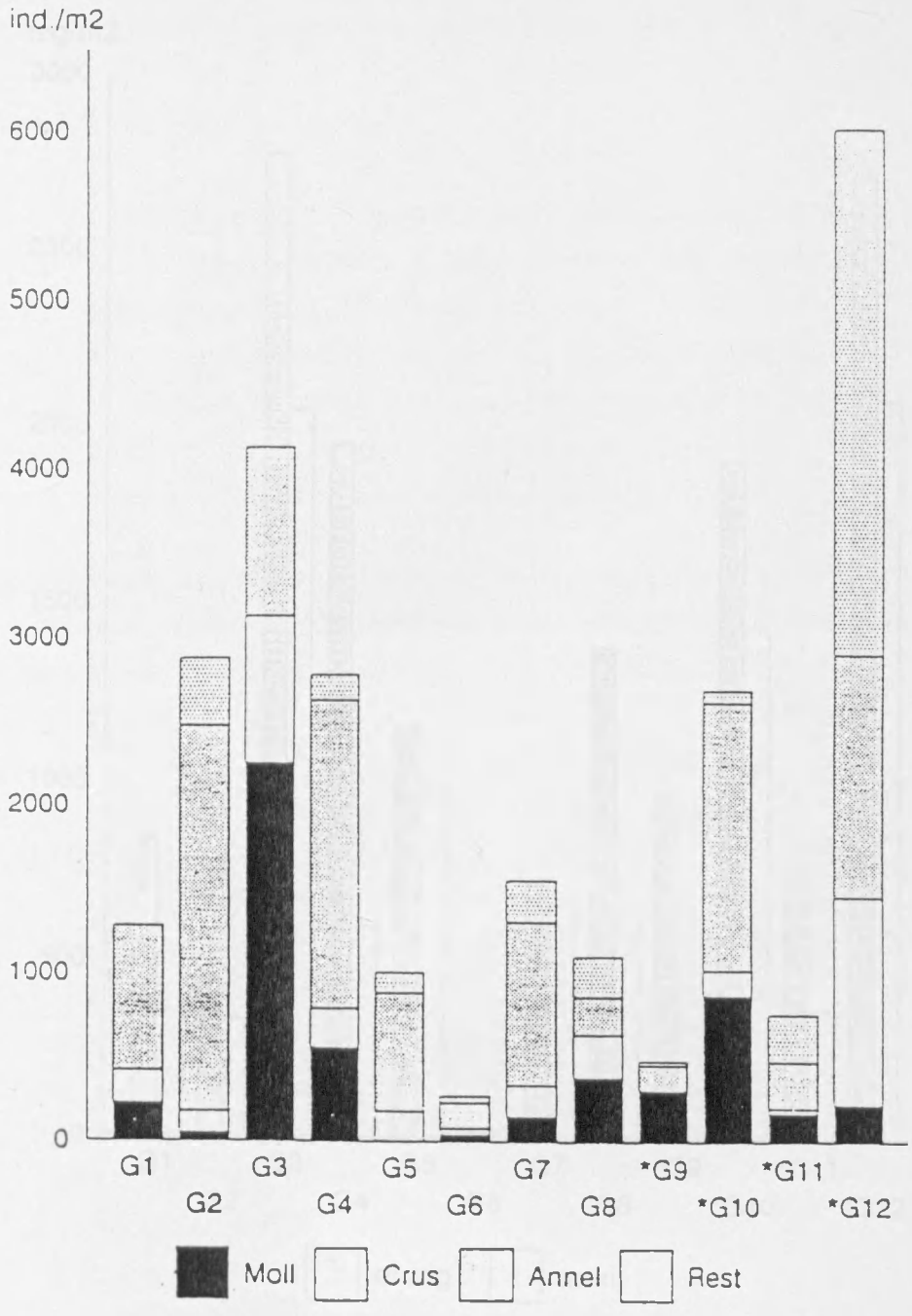


Figure 4 Macrobenthos : total densities (ind./m²) for the twelve stations.

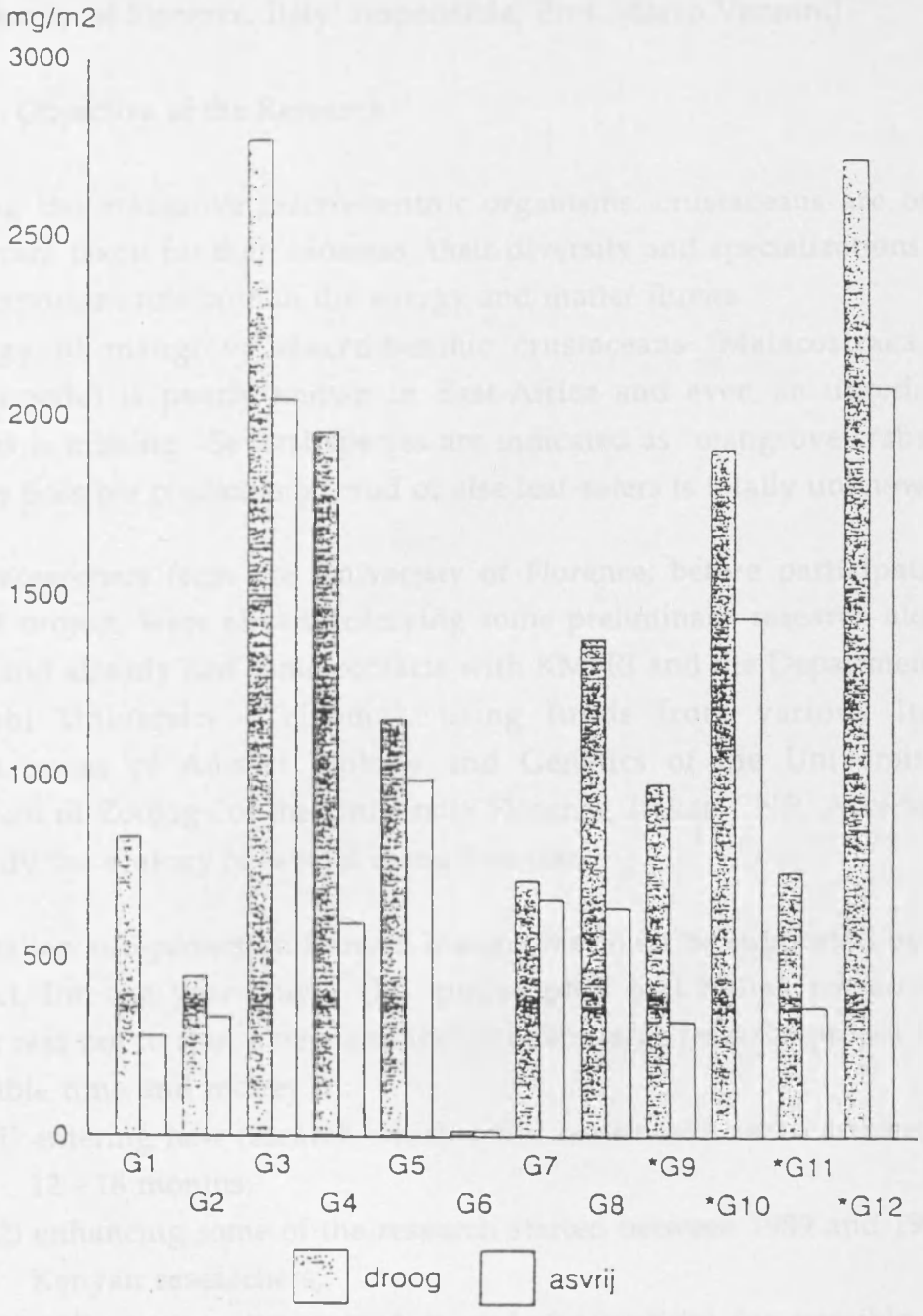


Figure 5 : Macrobenthos : total biomass (mg/m²) (dry = dark, ash free = light) for the twelve stations.

4.1.3. Ecological research on mangrove crustaceans

(University of Florence, Italy; responsible: Prof. Marco Vannini)

4.1.3.1. Objective of the Research

Among the mangrove macro-benthic organisms, crustaceans are one of the most important taxon for their biomass, their diversity and specializations, their different and important role both in the energy and matter fluxus.
Ecology of mangrove macro-benthic crustaceans (Malacostraca, Isopoda and Amphipoda) is poorly known in East-Africa and even an uptodated list of the species is missing. Several species are indicated as "mangrove-crabs" but their real role as possible predators or mud or else leaf-eaters is totally unknown.

The researchers from the University of Florence, before participating to the EEC STD-2 project, were already carrying some preliminary research along the Kenyan coast and already had some contacts with KMFRI and the Department of Zoology of Nairobi University (Chiromo), using funds from various Italian agencies (Department of Animal Biology and Genetics of the University of Florence, Museum of Zoology of the University Florence, Italian CNR, Accademia dei Lincei) to study the ecology of several mangrove taxa.

The Italian sub-project on Kenyan mangroves could be supported by the EEC STD-2 project, for one year only. The "philosophy" that Italian researchers decided to adopt was not to start a new and independent large research project but to invest the available time and money in:

1) entering new research which could realistically reach concrete results within 12 - 18 months,
2) enhancing some of the research started between 1989 and 1991 by including Kenyan researchers,
3) collecting preliminary data and observations for possible research future development.

Consequently, the main research lines to be activated were:

1) mangrove crustaceans (mostly Decapoda and Isopoda) ecology,
2) relationships between Decapoda, Isopoda and other mangrove macrofauna,
3) relationships between macro-crustaceans and mangroves,
4) taxonomic research and other accessory research.

Establishing relationships and co-operation links with Kenyan researchers and Institutions which may be the base for future research, was also considered and important objective.

In fact, few months ago, a formal agreement has been arranged between KMFRI and the Italian Centrum for the Study of Tropical Ecology and Faunistics of CNR (previously engaged in Somalia) for developing future common research along the Kenyan coast.

Furthermore, two EEC STD-3 projects have been set up, with the co-operation of teams from Belgian, Dutch and English academic Institutions.

4.1.3.2. Material and Methods

Material was collected or inspected during regular surveys whose rhythmicity was depending upon the specific taxon or problem.
Observation linked with animal migrations were usually carried on every five minutes for 9 hours a day (tree vertical migrations of medium size Brachyura) of 4 times every Low Tide (horizontal, platform migration of large Brachyura).
The visited mangroves were Lamu, Ngomeni, Robinson Island, Mida creek, Kilifi, Mtwapa, Gazi, Shimoni.
Part of the laboratory work was conducted in the wet laboratory of KMFRI, in Mombasa.
Three research visit to Kenya took place:

1) 20th October - 30th November 1991, by:

Prof. M. Vannini	(University of Florence)
Dr. G. Messana	(CNR)
Mr. R. Vezzosi	(Univ. of Florence; Ph.D. student)
Miss S. Barbaresi	(Univ. of Florence; M.Th. student)
Miss G. Innocenti	(Univ. of Florence; M.Th. student)
Mr. R. K. Ruwa	(KMFRI)
Mr. M. Osore	(KMFRI)
Mr. J. Mwaluma	(KMFRI)
Miss D. Anyona	(KMFRI)

2) 21st June-14th July 1992, by:.

Prof. M. Vannini (University of Florence)
Mr. R. Innocenti (photographer, Univ. of Florence)
Mr. R. K. Ruwa (KMFRI)

3) 16th November - 21th December 1992, by:

Dr. G. Messana (CNR)
Mr. R. Vezzosi (Univ. of Florence; Ph.D. student)
Mr. S. Cannicci (Univ. of Florence; Ph.D. student)
Mr. M. Bonazzi (Univ. of Torino; M.Th. student)
Miss M. Owili (KMFRI)
Mr. R. Mdodo (Univ. of Nairobi)
Miss D. Anyona (KMFRI)

Data on Anomura taxonomy and their stomach content were analysed in the Florence University laboratory, by Mr R. K. Ruwa (March 1992).

4.1.3.3. Results (summary)

4.1.3.3.1. Decapods ecology

1. Migration and territorialism of the swimming crab, *Thalamita crenata* (Portunidae)
2. Commensalims, population structure and behaviour of *Heteromysis harpax* (Mysidacea)
3. *Sphaeroma terebrans* (Isopoda) population and family structure
4. *Sesarma leptosomum* (Grapsidae) vertical tree migration

4.1.3.3.2. Relationships between decapods and other mangrove animals

5. Predation and ecological role of the swimming crab, *Thalamita crenata* (Decapoda, Portunidae)
6. Zonation, food chain position and stomach content of mangrove crabs (Decapoda, Brachyura)

4.1.3.3.3. Relationships between decapods and mangroves

7. Ecological role of the wood borer *Sphaeroma terebrans* (Isopoda)
8. Ecological role of the tree crab *Sesarma leptosomum* (Decapoda, Grapsidae)

4.1.3.3.4. Other research

9. hydrostatic pressure response of the crab *Thalamita crenata* in laboratory
10. New records of Anomurans in Kenya
11. New records of mangrove crabs in Kenya

4.1.3.4. Results (in detail)

1. *Migration and territorialism of the swimming crab, Thalamita crenata (Portunidae)*

R. Vezzosi, D. Anyona, S. Barbaresi, M. Vannini

a) During 1991, observations were made in Mida Greek, by marking about 200 animals and following for 4 weeks their movements, by recording every low tide their position. The density of crabs is very high (even 4/m^2), being very common all along the bare platform, about 100 m wide, in front of the seaward edge of the mangrove belt.
b) Patterns of activity and territorialism have been investigated. Burrow and crabs were marked with plastic tags on a 60 x 50 m surface. Crabs are not migrating neither wandering at random but remain "faithful" to their burrow or to a system of 2 - 3 burrows which are visited in turn, making only occasional short excursions for feeding and/or mating.
c) During 1992 experiments were made in Mida Creek, to study the homing performance of artificially removed crabs. Burrow and crabs which proved to be "faithful" to one or more burrows, were marked. Marked animals were dislodged and their path was recorded after releasing. Releasing took place from 5 - 7 m, in one series of experiments and from 50 - 200 m in another series. Different tests were made at night and at day time, with intact and blinded animals.
Intact animals released from 5 - 7 m, especially at day time, could locate their home-refuge assuming a straight path while blind crabs were seen walking at random as well as crabs released from longer distances.

References

Vezzosi R., Cannicci S., Anyona D., Vannini M., 1993. Field observations on territorial behaviour and homing in *Thalamita crenata* (Decapoda, Portunidae). Mar. Behav. & Physiol (in preparation).

2. *Commensalims, population structure and behaviour of Heteromysis harpax (Mysidacea)*

G. Innocenti, R. K. Ruwa, M. Vannini

a) *H. harpax* is an obligate commensal, which lives in monogamous pairs inside the shells of various species of tropical *Dardanus* hermit crabs. No relationship seems to exist between the sex, size and species of hermit and the probability of its shell being inhabited by the mysids. Male and female occupy distinct areas inside the shell, sometimes with their offsprings belonging to several broods (6 - 7) of different age classes (until 77 individuals). This is the first record of a real familiar in group in marine Crustaceans. The crowds of young were composed of individuals belonging to several distinct age classes, which presumably correspond to separate broods of similar or different age produced by the resident adult pair.
b) Using glass transparent shells it was possible to observe that *H. harpax* is a plankton feeder and does not perform active cleaning behaviour. It can easily follow the hermit when it changes shell and can also avoid expulsion when the hermit moults.
c) Preliminary experiments showed that *H. harpax* probably employs both visual and chemical cues to identify suitable shells for habitation. The mysids were not attracted to shells occupied by hermits of a different genus (*Calcinus*).

References

Innocenti G., Vannini M. & Ruwa R. K., 1993. Notes on the behaviour Heteromysis harpax, a mysid, living commensal in hermit crab shells. Ethol. Ecol. & Evol., Special Issue 3: (in press)

Vannini M., Innocenti G. & Ruwa R. K., 1993. Structure of familiar groups in Mysids, commensals of hermit crabs. Trop. Zool. 6(2): (in press)

3. Sphaeroma terebrans population and family structure (Isopoda)

Messana G., Osore M., Mwaluma J., Owili M.

a) About 350 samples were taken in 7 mangroves (from Shimoni to Lamu) of mangrove roots inhabited by *Sphaeroma terebrans* and by other Corallanidae isopods to study zonation, effect and intensity of the boring activity of this isopod on the various mangrove species, in the different Kenyan mangrove swamps.
b) Among the above samples (about 400 S. terebrans were collected) about 25 were "families" made by a single adult female and several young, usually of the same size. In a few case young of different size or single sub-adult males were recorded.
c) The study of the maternal behaviour, digging technique and rhythm were studied both in field and in KMFRI laboratory, using a TV camera, on S. terebrans.

References

Messana G., Bartolucci V., Mwaluma J. & Osore M., 1992 Osservazioni preliminari sulle cure parentali in *Sphaeroma cf. terebrans* Bate 1886 (Isopoda, Sphaeromatidae), perforatore del legno di mangrovia. Paper presented at AISASP meeting, 6/1992.

Messana G., Bartolucci V., Mwaluma J. & Osore M.,1993. Preliminary observations on parental care in Sphaeroma cf. terebrans Bate, 1866 (Isopoda, Sphaeromatidae) a Mangrove wood borer from Kenya. Ethol. Ecol. Evol. (Spec. Issue) 5: (in press)

Messana G., Bartolucci V., Carli A., Owili M. & Turillazzi S., 1993. The behaviour of Sphaeroma terebrans from Kenya (in prepar.).

4. Sesarma leptosomum (Grapsidae) vertical tree migration

Vannini M., Ruwa R. K.

a) *S. leptosomum*, is the only East-African mangrove crab spending all its life on the roots and branches of mangroves (mostly of *R. mucronata*, *B. gymnorhiza* and *C. tagal*) and feeding on fresh leaves. It never enters the water neither, during low water, it ventures on the free mud surface. S. leptosomum spends part of the day and the night on the lower part of the mangrove roots, searching for food and water.

Until now only another species, the West Atlantic related species, *Aratus pisoni*, was known to be able to feed on fresh leaves.

Twice a day, from about 06:00 to 08:00, in the morning, and from 16:00 to 18:00 in the evening, *S. leptosomum* migrates towards the top of the tree, reaching the leaves and feeding among these, probably just of these. Its permanence among the leaves is anyway quite short: from about 07:00 to 10:00, and, again, from 17:00 to 19:00, two downwards migration flows drive the crabs back again towards the roots.

b) Comparing the migration time patterns of two different periods of the year ("winter" and "summer") it is shown that the number of crabs migrating along the trunk is modulated by the spring-neap tidal cycle while the daily migration onset seems mostly controlled by the light level and/or by other climatological cues. The adaptive meaning of this migratory behaviour is probably related to both avoiding predation and feeding advantage.

References

Vannini M., Ruwa R. K., 1993. Vertical migrations of the tree crab, Sesarma leptosomum (Decapoda, Grapsidae). Mar. Biol. (in press).

Vannini M. & Ruwa R. K., 1993. Light effect on vertical migrations of the tree crab, Sesarma leptosomum (Decapoda Grapsidae). (in prepar.).

5. Predation and ecological role of the swimming crab, Thalamita crenata (Decapoda, Portunidae)

R. Vezzosi, D. Anyona, M. Vannini

a) The role of this swimming crabs as one of the most powerful predator of mangroves has been studied. *T. crenata* is mostly active between HW and LW. It preys on every sort of invertebrates and it is the main food for crab eating birds such as the Crab Plover, one of the commonest large shore birds in Mida Creek.
T. crenata is the commonest mangrove predator (among crabs) and it may account for 2/3 of the whole predation due to crustaceans. Knowing its density, its predation spectrum, and its feeding turn- over, it would be possible to evaluate its real role in the mangrove food-chain.
Several stomachs are still under study and laboratory experiments were made, both in 1991 and in 1992, to study the feeding turnover.

6. Zonation, food-chain position and stomach content of mangrove crabs (Decapoda, Brachyura)

M. Vannini, A. Oluoch

a) Most littoral animals can make use of their habitat by adopting an Iso-Phasic (IP) or Iso-Zonal (IZ) spatial strategy. IP species migrate along the substratum, according to the tidal oscillation, so as to remain always in the same respiratory phase (i.e. *Grapsus spp.* on rocky shores or Talitrus on sandy beaches, migrating vertically or horizontally, respectively); IZ species always stay in the same zone and spend the "wrong" tidal phase hidden in suitable refuges (i.e. *Uca spp.*).
In the mangroves, IP decapods are facing an unique spatial problem since they could avoid the high water both by migrating, horizontally, through the mangrove belt or vertically, along the mangrove trunks. Among the several decapod species inhabiting Kenyan mangroves, some Grapsidae (at least 2 spp. of Metopograpsus) and Sesarmidae (2 spp. of *Selatium* and *Sesarma leptosomum*) are clearly IP species, avoiding high water by climbing mangrove trees. To this moment no species has ever been found to avoid the incoming tide by migrating all through the mangrove wood. Some IZ species may occupy the lower portion of the trunks and, at low tide, actively forage around (i.e. *Sesarma guttatum*) or rest among the roots (i.e

Clibanarius laevimanus). *S. leptosomum* is highly specialised and can climb *Rhizophora* trees as high as 15 m, feeding on leaves, thus apparently vicariating the West Atlantic species, Aratus pisoni.

References

Vannini M. & Oluoch A., 1992. The tree-climbing decapods of East African mangroves. Paper presented at: 1st European Crustacean Conference, Paris, Aug. 1992.

Vannini M. & Oluoch A., 1993. Notes on Merguia oligodon the Indo- Pacific semi-terrestrial (Hippolytidae, Natantia). Trop. Zool. 6(2): (in press)

Vannini M. & Oluoch A., 1993. The tree-climbing crabs of Kenya. Tropical Zoology 7(2): (in press)

7. Zonation and ecological role of the wood borer Sphaeroma terebrans (Isopoda)

Messana G., M. Osore M., Mwaluma J.

a) The zonation of this mangrove borer (and allied species) is under study as well as the preference for different mangrove species. More samples will also elucidate the possible relationship between its damaging activity and the general health conditions of the trees.

b) A preliminary microbiological analysis was attempted searching possible Vibrionaceae on the exoskeleton of some *S. terebrans* from Mida Creek.

c) On a part of the *S. terebrans* samples collected in 1991 and 1992, a DNA finger print analysis is now attempted to study the relationships between the members of these "families" (in connection with research 3).

An analogous study, using DNA finger print, will also be made to compare genetic homogeneity between individuals collected within the same mangrove and from different mangroves.

Isopods (directly developing in the mother's marsupium) are expected to be more homogeneous within the same creek than between adjacent mangrove. If the above technique will be able to reveal this, the whole research procedure will be applied to many other important animal taxa. We hope, in this way, to be able to

measure the degree of migration (i.e. the possibility of recolonization) between different creeks of several crustaceans and fishes.

References

Fani R., Bazzigalupo M., Messana G., Mwaluma J., Osore M. & Vannini M., 1993. A first attempt to analyse parental relationships in populations of Sphaeroma terebrans from Kenya trough a DNA technique. Boll. Zool. (in prepar.)

8. Ecological role of the tree crab Sesarma leptosomum (Decapoda, Grapsidae)

Vannini M., Ruwa R. K.

a) Analysis of feeding activity of *S. leptosomum* will be made in March - April 1993 to determine the impact of this species on the mangrove leaves and on the mangrove health.
b) A study will also be attempted to understand the scanty distribution of this species which occasionally is very abundant (in some areas within Mida Creek, more than 300 animals per tree) but, at the same time, is totally lacking from most of the Kenyan mangroves.

9. Hydrostatic pressure response of the crab Thalamita crenata in laboratory

Vezzosi R., Anyona D., Vannini M.

a) Activity rhythm of Thalamita crenata was studied both in field (1991) and in laboratory (1992). Animals were collected in Gazi and Mtwapa in order to establish the activity pattern in relationship with the tide and hydrostatic pressure.
Several tests were made in each of which, the movement of 4 animals, kept in small aquaria, were recorded every 2 mins, for 72 hours (i.e. 3 days). Two crabs were kept in constant conditions, in the third aquarium the water level was varying in phase with the tide, in the fourth, in anti-phase with the tide.
Animals are more active at day time than at night time. The major activity peaks occurred while the water was rising and lowering, roughly between 5 and 25 cm of

water level, confirming thus the previous observations in Mida Creek. The results were not related to the actual phase of the tide leading one to think that a real pressure detector must exist among T. crenata. Information on hydrostatic pressure are necessary in nature, to avoid water levels higher than a certain level (about 25 cm) which can allow the dangerous visits of several predators (cuttle-fishes, parrot fishes, ray fishes, etc.).

References

Vezzosi R., Anyona D., Barbaresi S. & Vannini M., 1993. Activity modulation in Thalamita crenata: biological clock or pressure gauge ? Mar. Behav. Physiol. (in prep.)

Vezzosi R., Anyona D., Barbaresi S., Vannini M., 1993. Field observations on activity rhythms of Thalamita crenata (Decapoda, Portunidae). Ethol. Ecol. & Evol. (in preparation)

10. New records of Anomurans in Kenya

Ruwa R. K., Vannini M.

a) Three species of terrestrial hermit crabs (fam. Coenobitidae) are reported for the first time from Kenya, and some ecological notes are given: *Birgus latro, Coenobita brevimanus* and *Coenobita perlatus*.
b) The problem of an ecological explanation for the strict island preference of some terrestrial decapods, compared with congenerics widely present on African continent is put forward.

References

Ruwa R. K. & Vannini M., 1993. New records of terrestrial hermit crabs in Kenya (Decapoda, Anomura, Coenobitidae) and the problem of the "island species". Bull. Atoll. Res. (in press)

11. New records of mangrove crabs in Kenya

Vannini M., Ruwa R. K.

a) Four species of Sesarmidae, new for Kenya, were discovered in the Mida Creek mangrove and notes on their zonation as well as on their ecological role were recorded: *Sesarma leptosomum, S. villosum, S. longipes* and *Selatium brocki*. *Sesarma leptosomum* was found to climb trees as high as 10 - 12 m and feed directly on green leaves, *Selatium brocki* only lives on mangrove trunks (like the related well known species, *Selatium elongatum*) but only among the proximal *Avicennia* belt (instead of the distal *Sonneratia* and *Rhizophora* which are inhabited by *S. elongatum*). The remaining two species have only been found on the floor, under debris of wood and rocks, in the upper level of the intertidal belt.

4.1.3.5. Publications

Fani R., Bazzigalupo M., Messana G., Mwaluma J., Osore M. & Vannini M., 1993. A first attempt to analyse parental relationships in populations of Sphaeroma terebrans from Kenya trough a DNA technique. Boll. Zool. (in prep.)

Innocenti G., Vannini M. & Ruwa R. K., 1993. Notes on the behaviour Heteromysis harpax, a mysid, living commensal in hermit crab shells. Ethol. Ecol. & Evol., Special Issue 3: (in press)

Messana G., Bartolucci V., Mwaluma J. & Osore M., 1992. Osservazioni preliminari sulle cure parentali in Sphaeroma cf. terebrans Bate 1886 (Isopoda, Sphaeromatidae), perforatore del legno di mangrovia. Paper presented at AISASP meeting, 6/1992.

Messana G., Bartolucci V., Mwaluma J. & Osore M., 1993. Preliminary observations on parental care in Sphaeroma cf. terebrans Bate, 1866 (Isopoda, Sphaeromatidae) a Mangrove wood borer from Kenya. Ethol. Ecol. Evol. (Spec. Issue) 5: (in press)

Messana G., Bartolucci V., Carli A., Owili M. & Turillazzi S., 1993. The behaviour of Sphaeroma terebrans from Kenya (in prep.).

Ruwa R. K. & Vannini M., 1993. New records of terrestrial hermit crabs in Kenya (Decapoda, Anomura, Coenobitidae) and the problem of the "island species". Bull. Atoll. Res. (in press)

Vannini M., Innocenti G. & Ruwa R. K., 1993. Structure of familiar groups in Mysids, commensals of hermit crabs. Trop. Zool. 6(2): (in press)

Vannini M., Oluoch A. & Ruwa R. K., 1993. Vertical migrations of the tree crab, Sesarma leptosomum (Decapoda, Grapsidae). Mar. Biol. (in press).

Vezzosi R., Anyona D., Barbaresi S. & Vannini M., 1993. Activity modulation in Thalamita crenata: biological clock or pressure gauge ? Mar. Behav. Physiol. (in prep.)

Vezzosi R., Anyona D., Barbaresi S., Vannini M., 1993. Field observations on activity rhythms of Thalamita crenata (Decapoda, Portunidae). Ethol. Ecol. & Evol. (in prep.).

Vezzosi R., Barbaresi S., Anyona D., Vannini M., 1993. Field observations on territorial behaviour and homing in Thalamita crenata (Decapoda, Portunidae). Mar. Behav. & Physiol. (in prep.).

Vannini M. & Ruwa R. K. 1993. Light effect on vertical migrations of the tree crab, Sesarma leptosomum (Decapoda Grapsidae). (in prep.)

4.1.3.6. Oral communications

1. Gherardi F., Micheli F. & Vannini M., 1989. Ricerche preliminari su Clibanarius longitarsus in Kenya. Paper presented at the S.I.E. meeting, Perugia 1989.

2. Gherardi F., Micheli F. & Vannini M., 1989. Preliminary observations on the clustering behaviour of the tropical hermit crab Clibanarius laevimanus. Ethol. Ecol. Evol. (Spec. Issue) 1: 151-153

3. Gherardi F., Micheli F. & Vannini M., 1989. Ricerche preliminari su Clibanarius longitarsus in Kenya. Paper presented at the S.I.E. meeting, Perugia 1989.

4. Gherardi F., Micheli F. & Vannini M., 1990. Movement patterns and dispersal of the hermit crab Clibanarius longitarsus in a mangrove swamp. Mar. Behav. Physiol. 16: 209-223

5. Gherardi F., Micheli F. & Vannini M., 1991. Preliminary observations on the clustering behaviour of the tropical hermit crab Clibanarius laevimanus. Ethol. Ecol. Evol. (Spec. Issue) 1: 151-153

6. Micheli F., Gherardi F. & Vannini M., 1991. Feeding and burrowing ecology of two East African mangrove crabs. Mar. Biol. 111: 247-254

7. Gherardi F. & Vannini M., 1992. Hermit crabs in a mangrove swamp: clustering dynamics in Clibanarius laevimanus. Mar. Behav. Physiol. 21: 85-104.

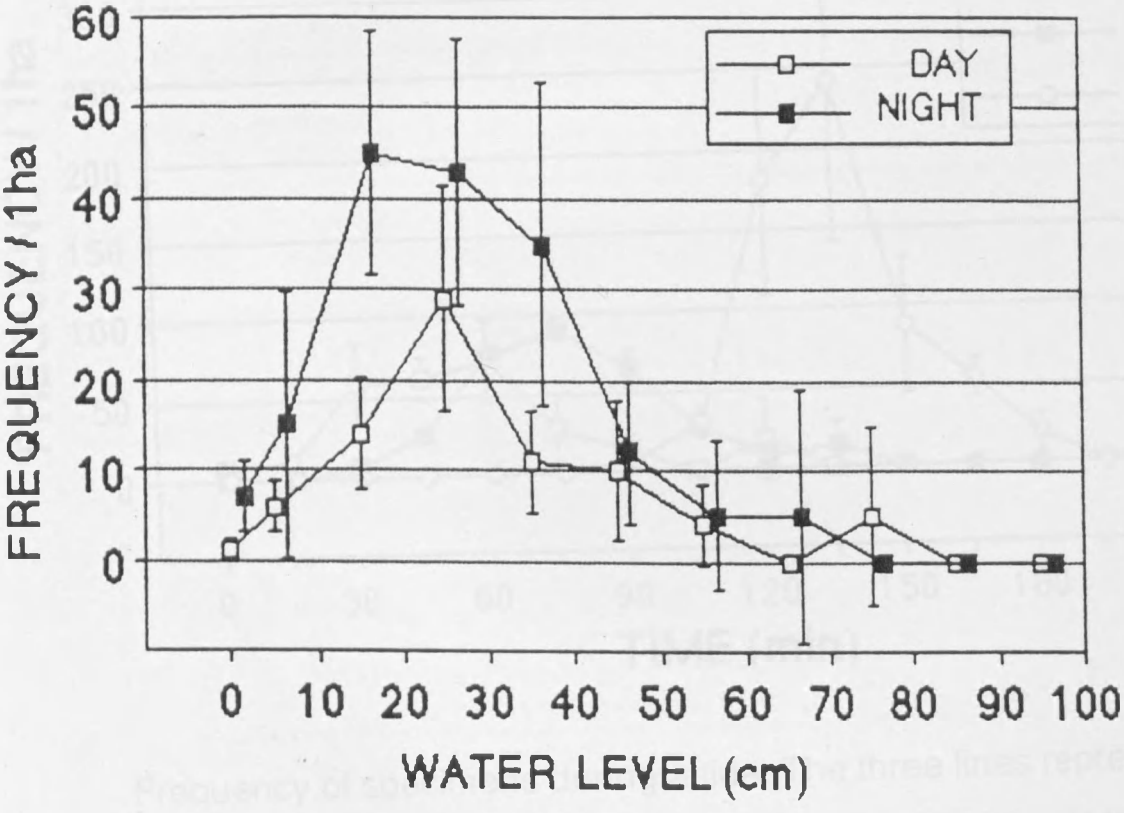
8. Gherardi F. & Vannini M., 1992. Hypotheses on proximate and ultimate factors influencing clustering in the tropical hermit crab Clibanarius laevimanus. Ethol. Ecol. & Evol., Special Issue 2: (in press).

9 Vannini M. & Oluoch A., 1992. The tree-climbing decapods of East-African mangroves. Paper presented at : 1st European Crustacean Conference, Paris, Aug. 1992.

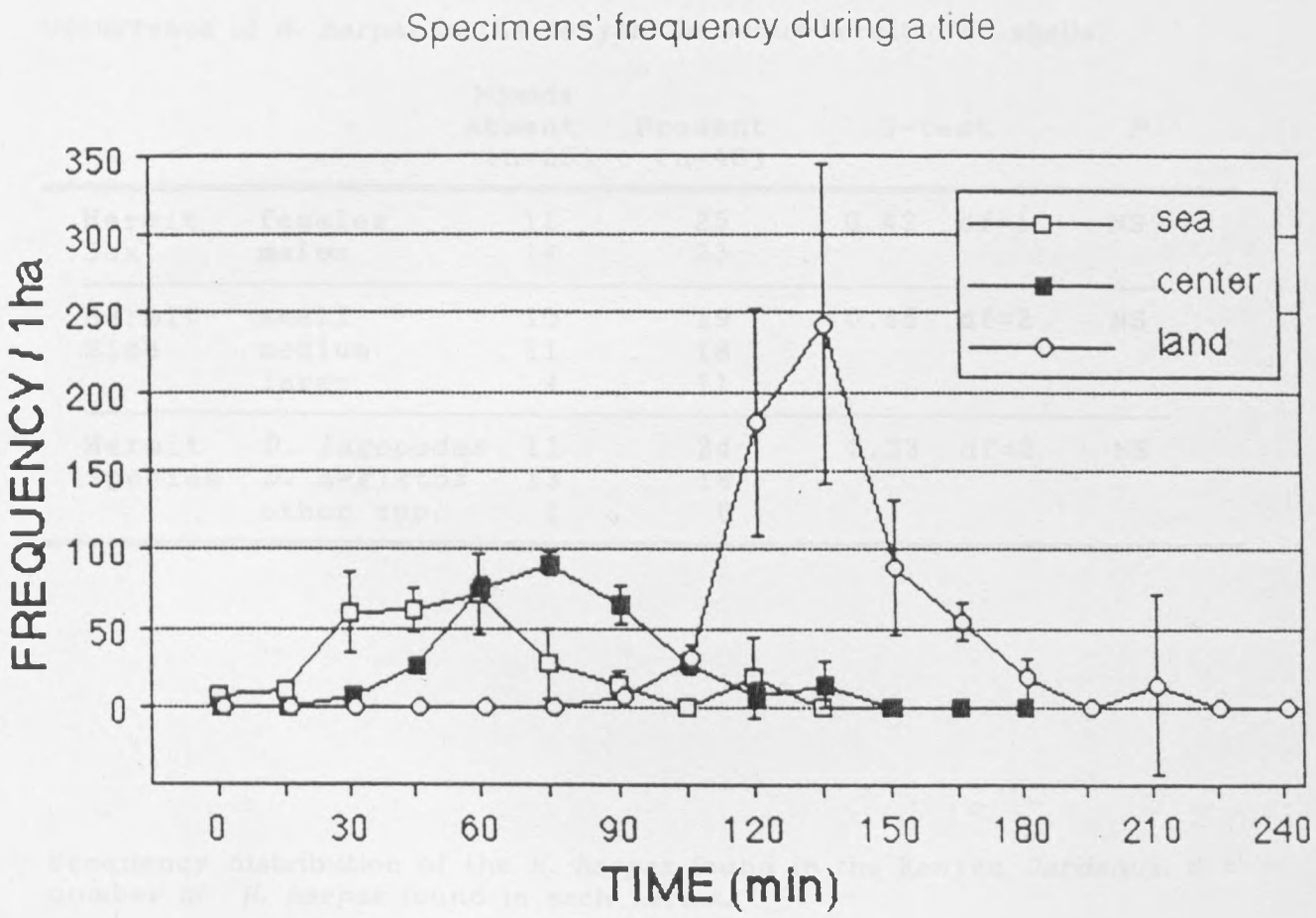
10 Vannini M. & Oluoch A., 1993. Notes on Merguia oligodon the Indo-Pacific semi-terrestrial (Hippolytidae, Natantia). Trop. Zool. 6(2): (in press)

11 Vannini M. & Oluoch A., 1993. The tree-climbing crabs of Kenya. Tropical Zoology 7(2): (in press)

Specimens' frequency during a diurnal and nocturnal tide



Frequency of specimens during a diurnal and nocturnal tide. Filled squares= nocturnal tides; open squares= diurnal tides.



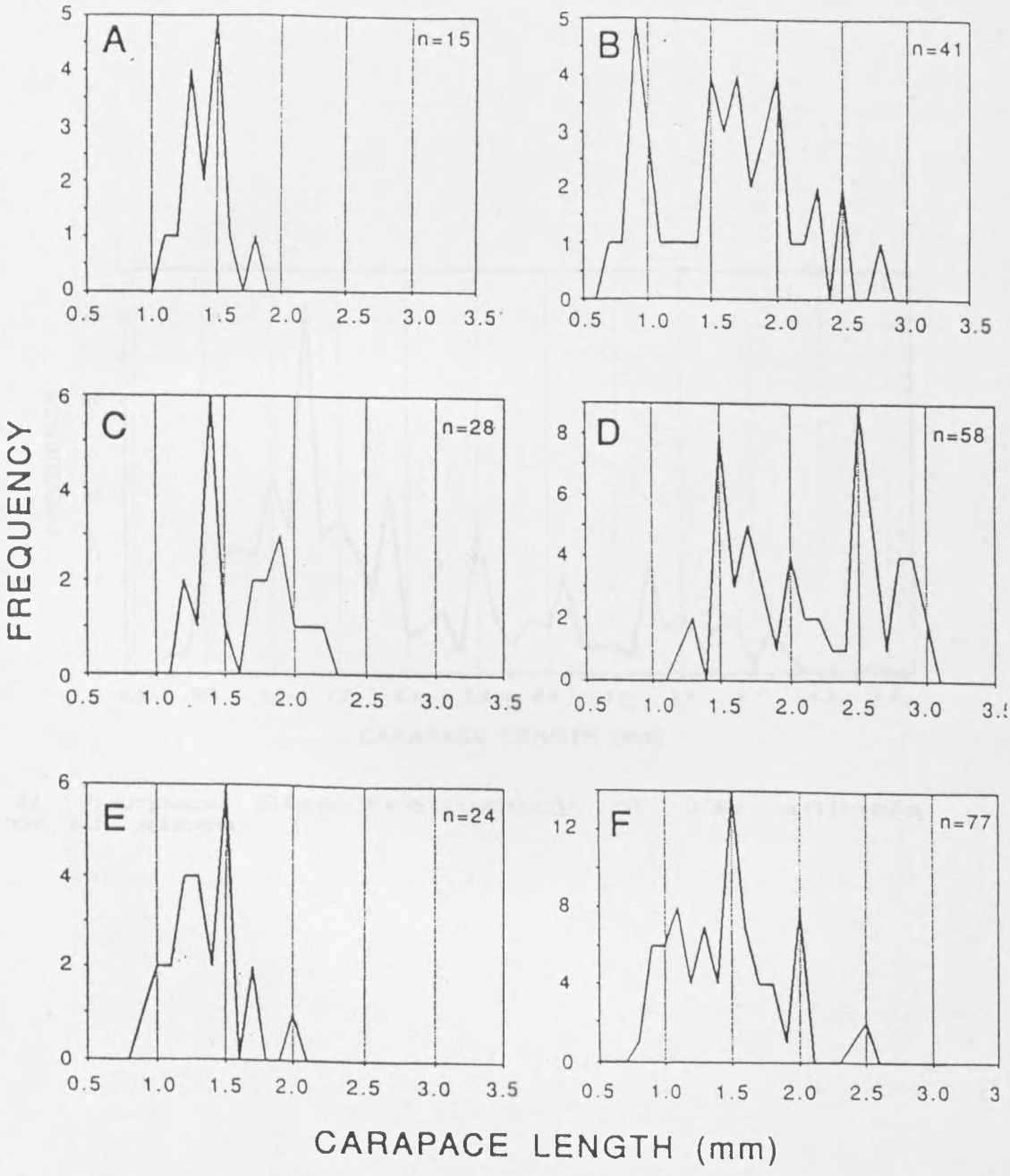
Frequency of specimens during a tide. The three lines represent the crabs sighted in three different transects: open square= seaward transect; filled square= central transect; open circles= landward transect.

Occurrence of *H. harpax* in the Kenyan *Dardanus* hermit crab shells.

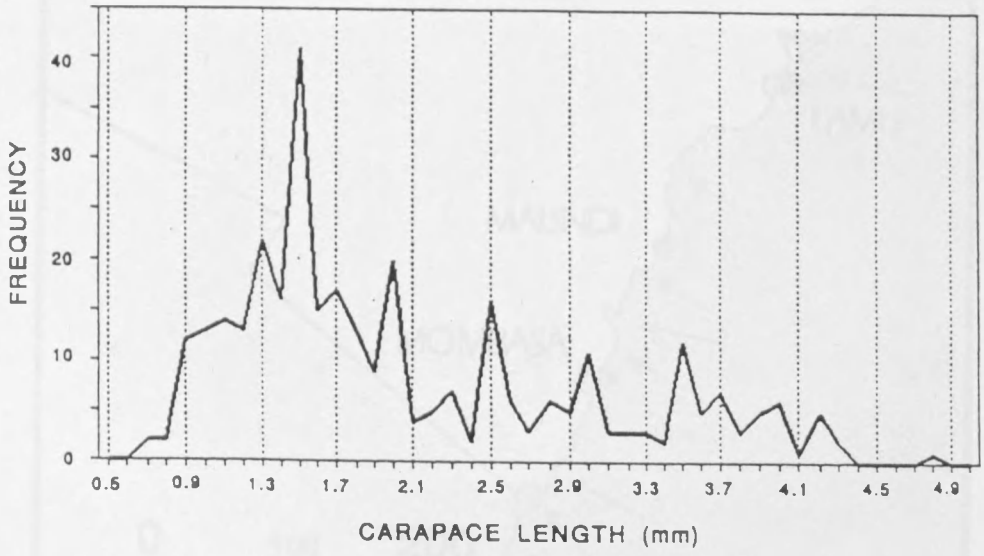
		Mysids Absent (n=25)	Present (n=48)	G-test		P
Hermit Sex	females	11	25	0.42	df=1	NS
	males	14	23			
Hermit Size	small	10	19	0.55	df=2	NS
	medium	11	18			
	large	4	11			
Hermit Species	*D. lagopodes*	11	24	2.23	df=2	NS
	D. megistos	13	18			
	other spp.	1	6			

Frequency distribution of the *H. harpax* found in the Kenyan *Dardanus*. N = number of *H. harpax* found in each hermit.

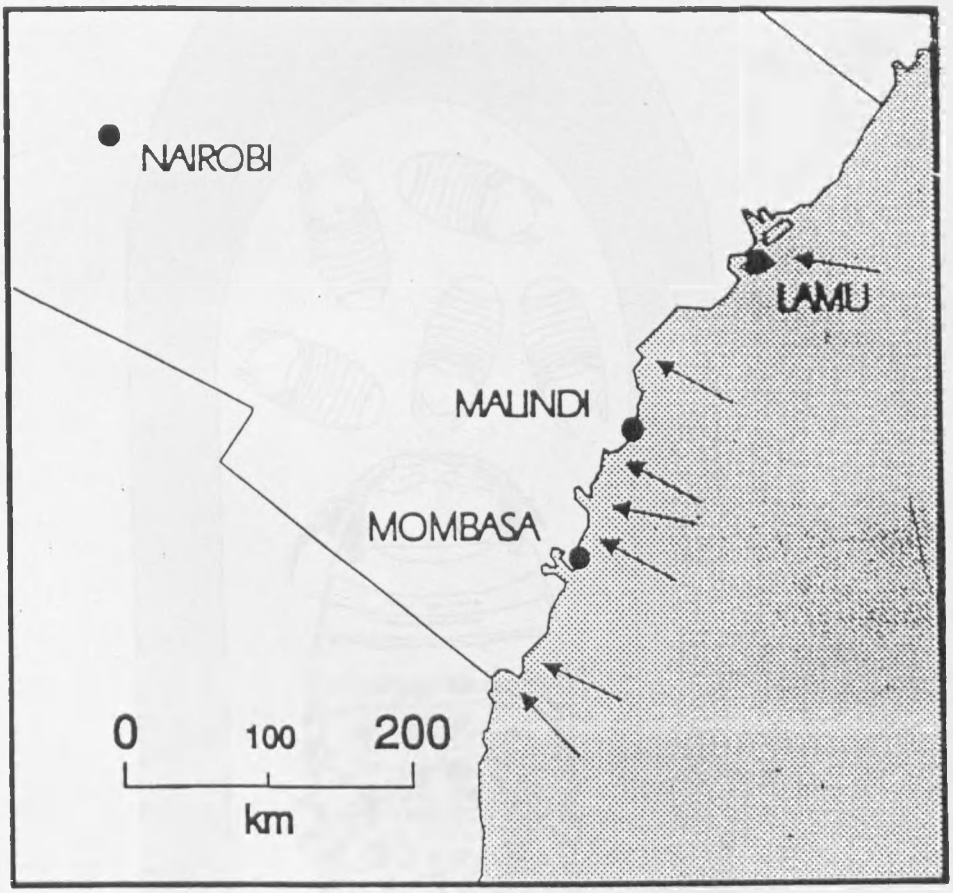
N	0	1	2	3	>=10
Frequency	25	5	35	1	7



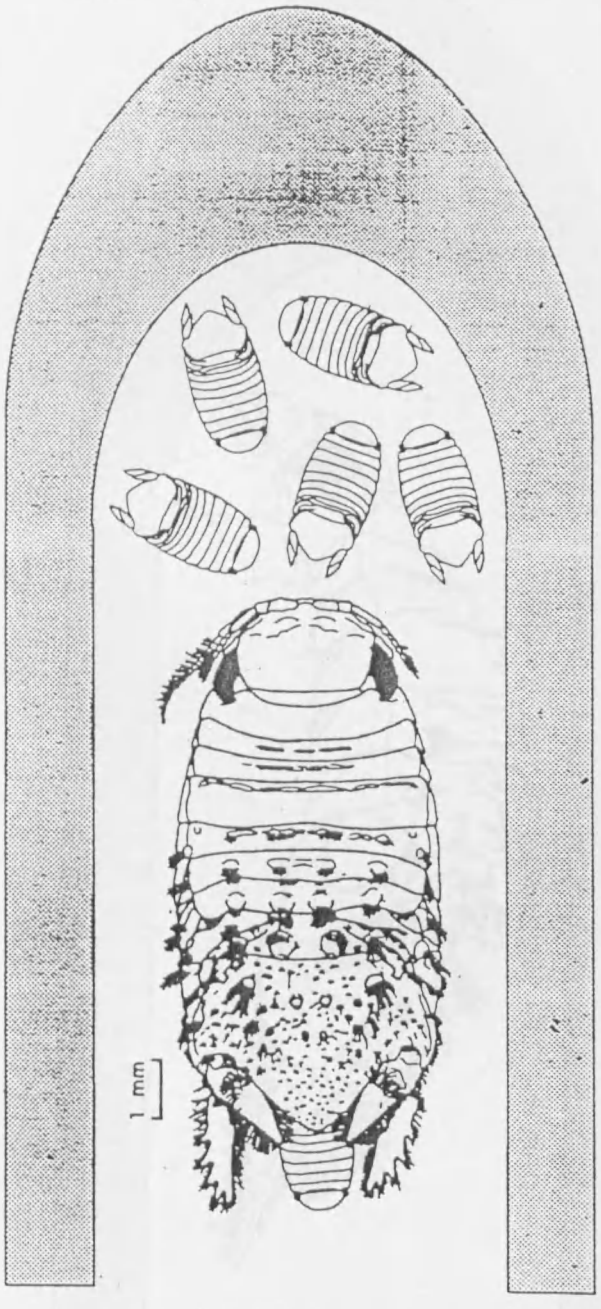
Heteromysis harpax. Size frequency of the young of the six largest families.



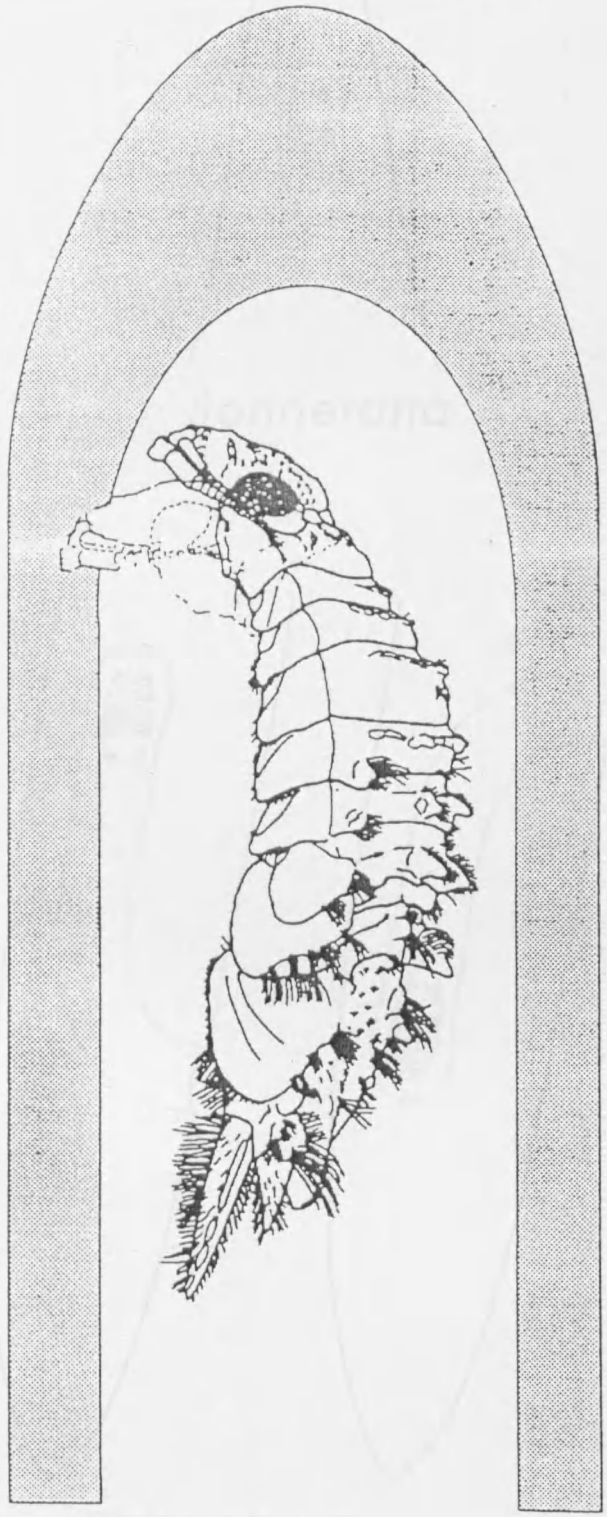
H. harpax. Size frequency of 332 animals of all sizes.



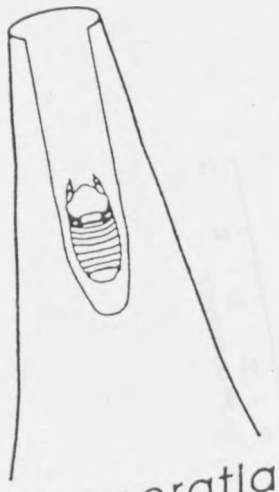
Sphaeroma terebrans. Collecting sites.



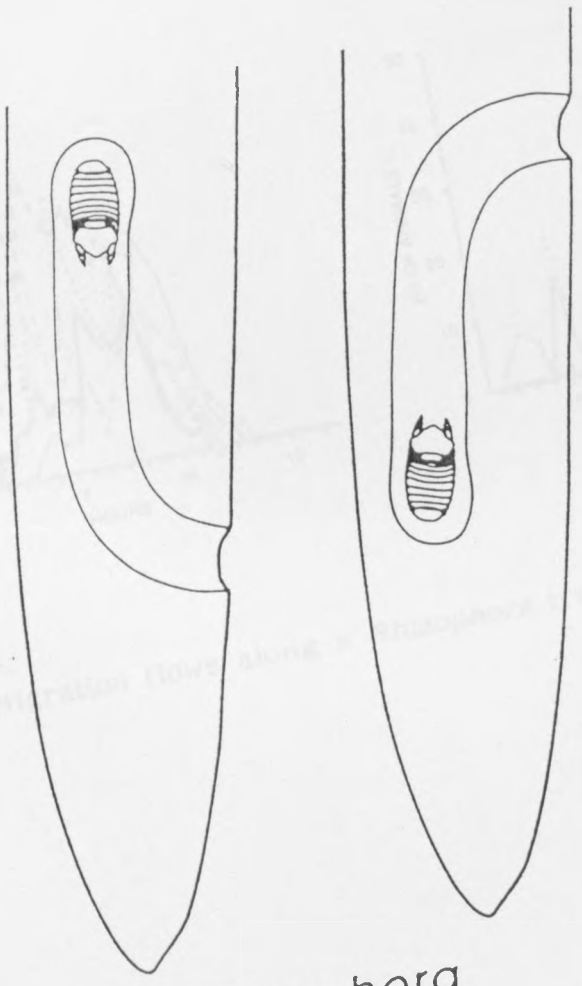
Mother with her young.



S. terebrans. Digging behaviour.

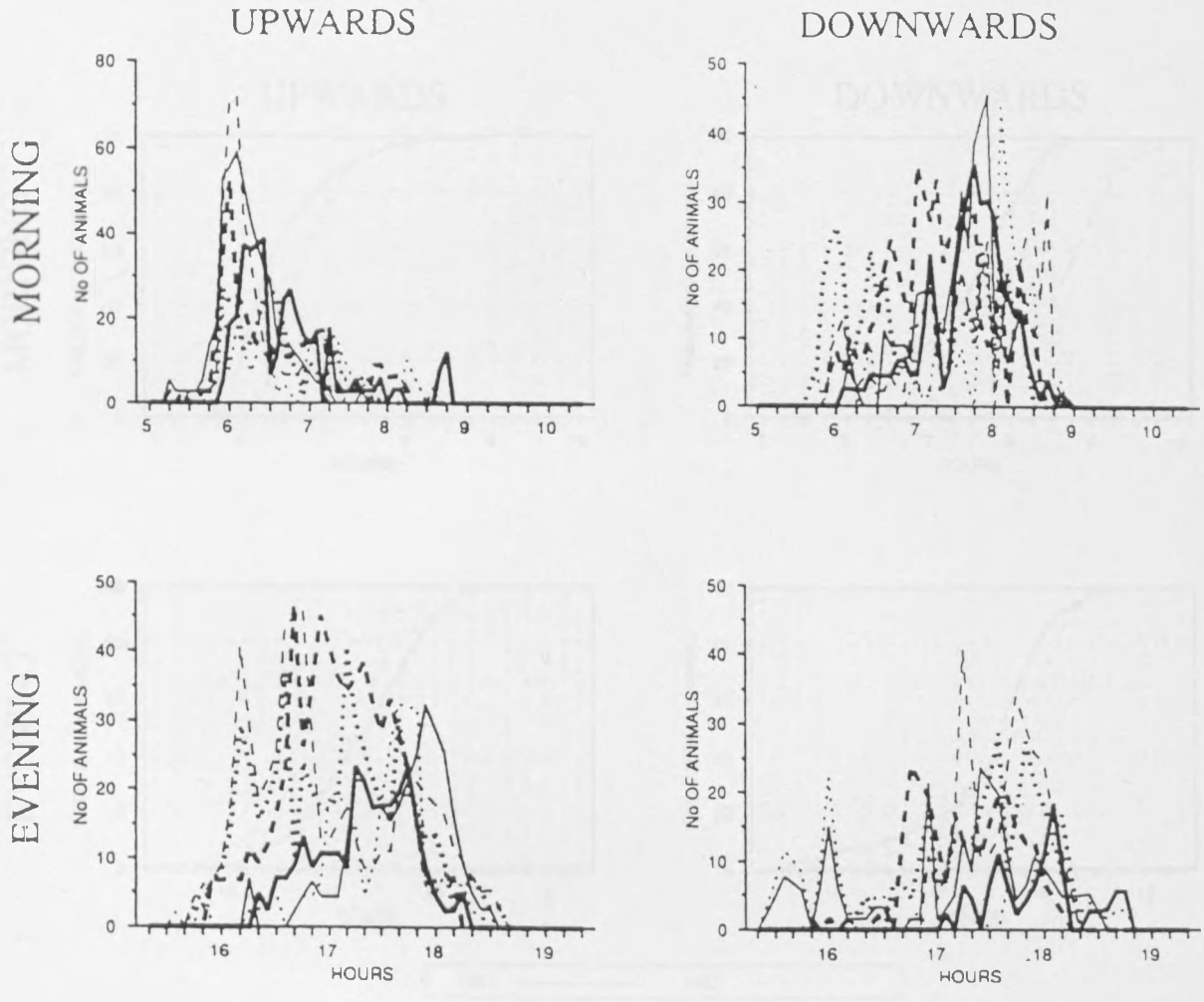


Sonneratia

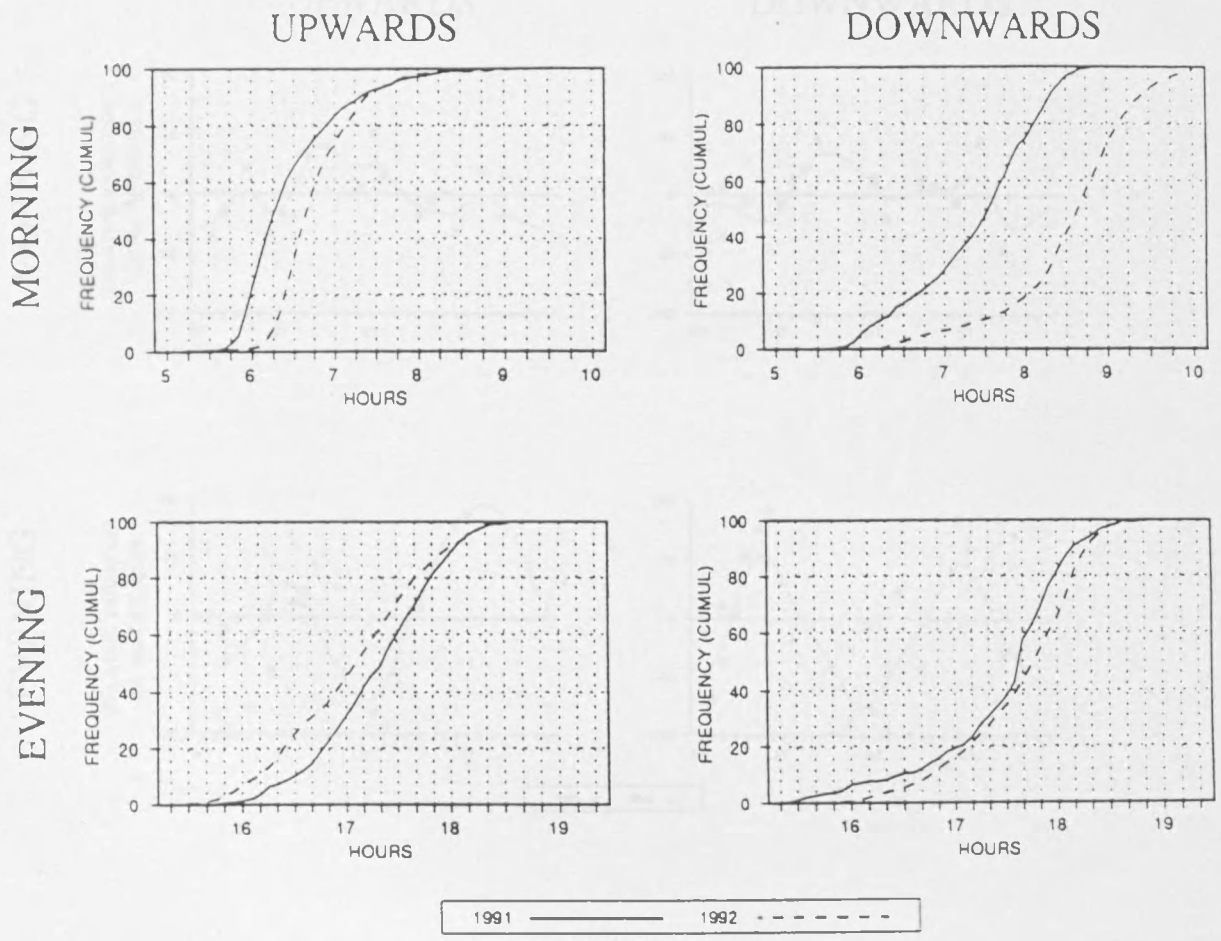


Rhizophora

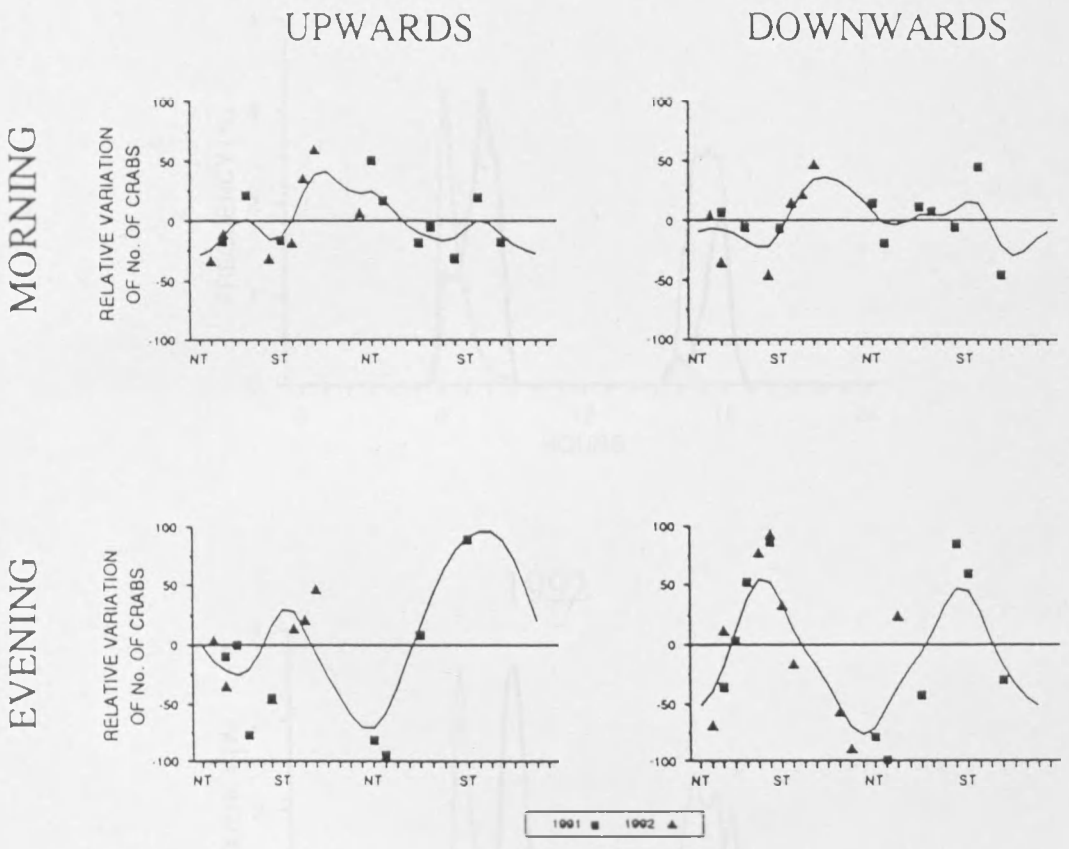
S. terebrans. Typical tunnels through the mangrove aerial roots.



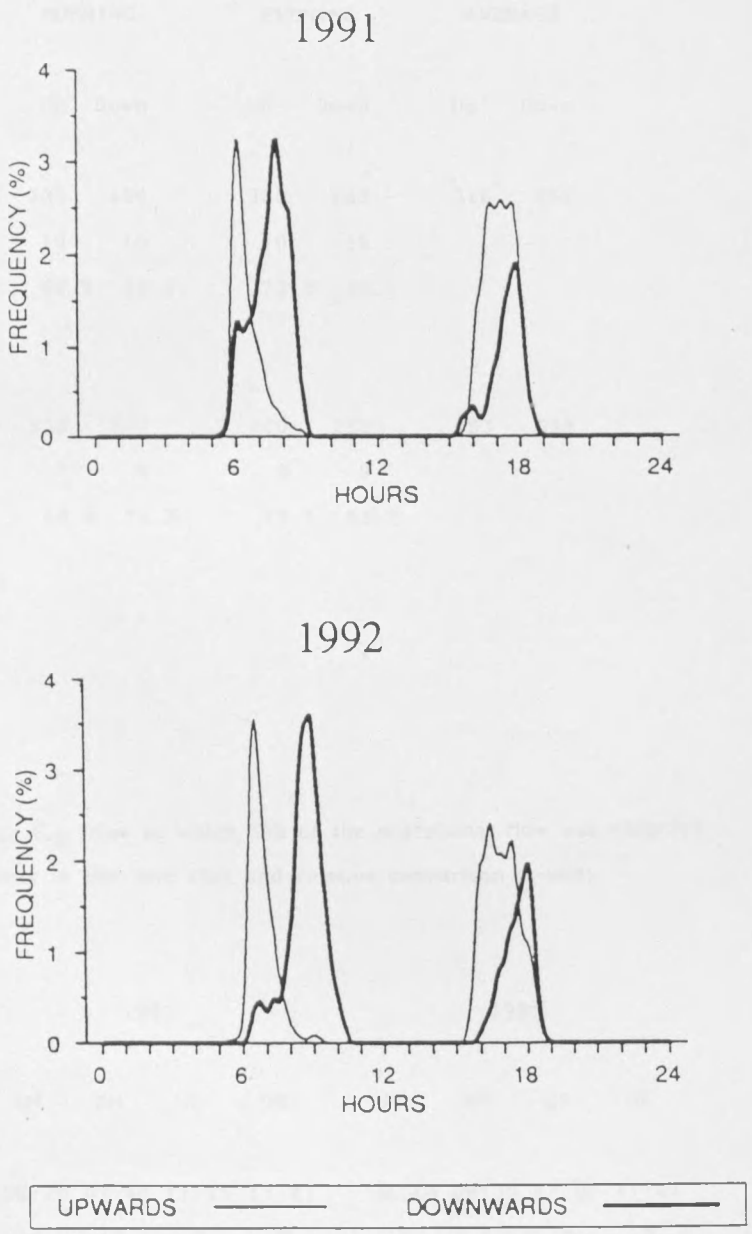
Sesarma leptosomum. Migration flows along a *Rhizophora* trunk (6 days; X-1991).



S. leptosomum. Differences in cumulative frequencies of migratory activity (1991 vs 1992).



S. leptosomum. Variation in crab migration time, over a synodic month.



S. leptosomum. Average migration flow along a *Rhizophora* trunk (19 days, 1991 and 1992).

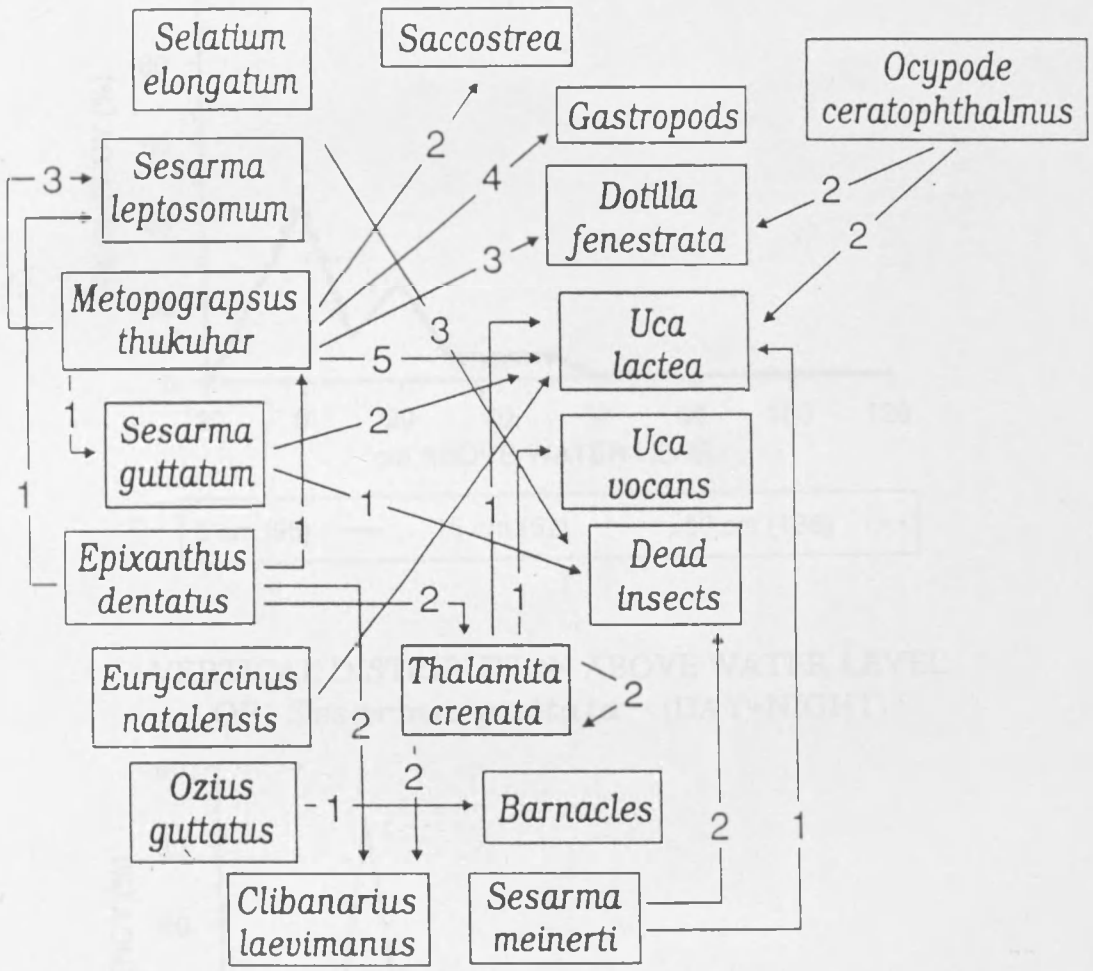
Average number (n) and standard error (SE) of crabs participating in the four migration flows.

	MORNING		EVENING		AVERAGE	
	Up	Down	Up	Down	Up	Down
1991						
average	333	428	300	169	316	298
n	10	10	10	10		
SE	26.9	31.9	73.5	34.1		
1992						
average	522	517	400	252	453	358
n	7	6	9	9		
SE	69.9	74.3	75.1	53.7		

Average F_{50} (time at which 50% of the migrational flow was recorded) for different flows in 1991 and 1992 and relative comparison (t-test).

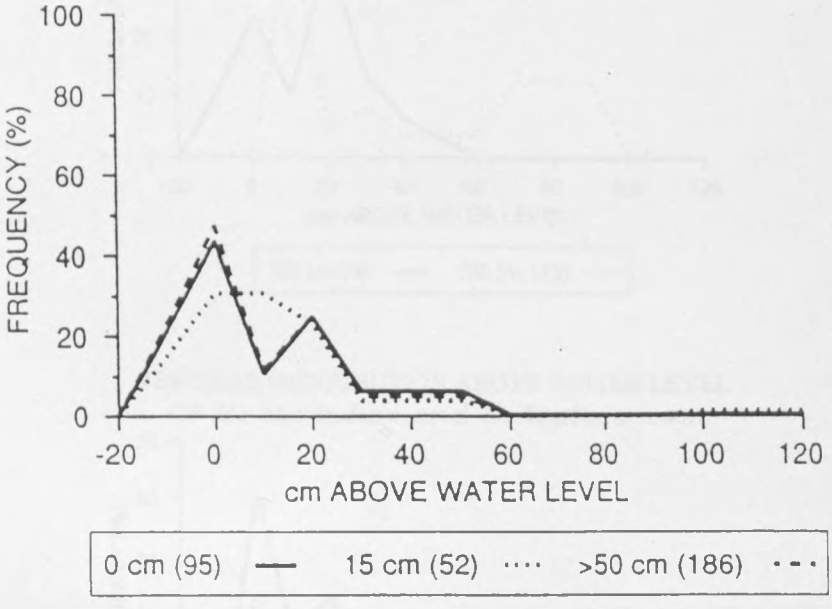
	1991				1992			
	UM	DM	UE	DE	UM	DM	UE	DE
average F_{50}	06:20	07:40	17:15	17:41	06:40	08:39	17:00	17:44
n	10	10	7	7	7	6	9	9
SD	16'	18'	20'	15'	12'	14'	29'	16'

comparisons:	t	df	P<=	differ.(92-91)
UM91 vs UM92	2.923	15	0.02	20'
DM91 vs DM92	6.937	14	0.01	59'
UE91 vs UE92	1.167	14	n.s.	- 15'
DE91 vs DE92	0.456	14	n.s.	4'

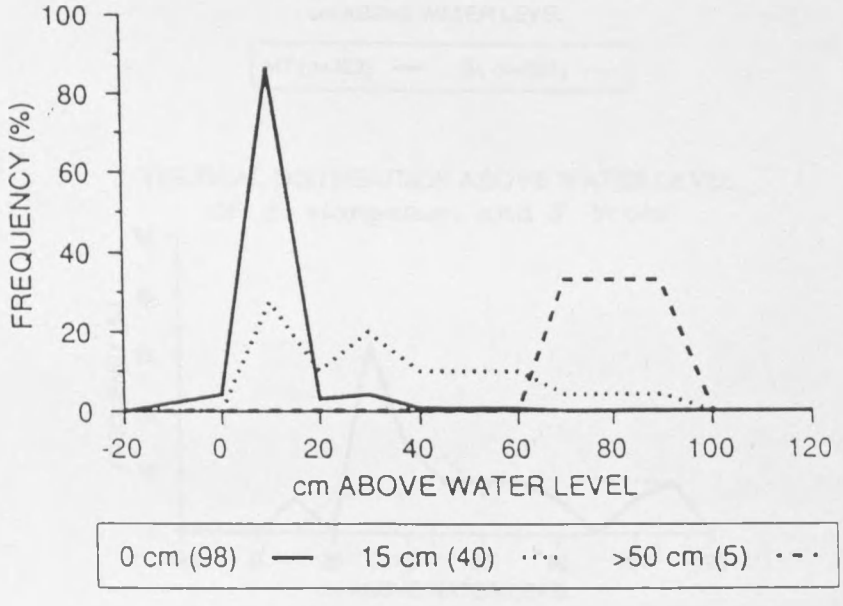


Recorded predation acts among mangrove decapods (data from direct observations and stomach content analysis).

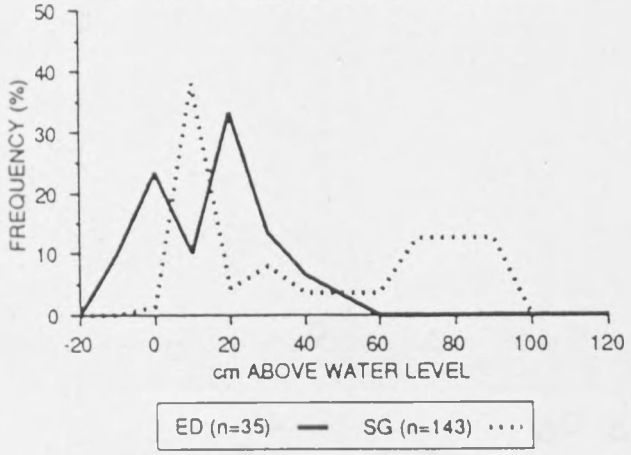
VERTICAL DISTRIBUTION ABOVE WATER LEVEL
OF *Metopograpsus thukuhar* (DAY+NIGHT)



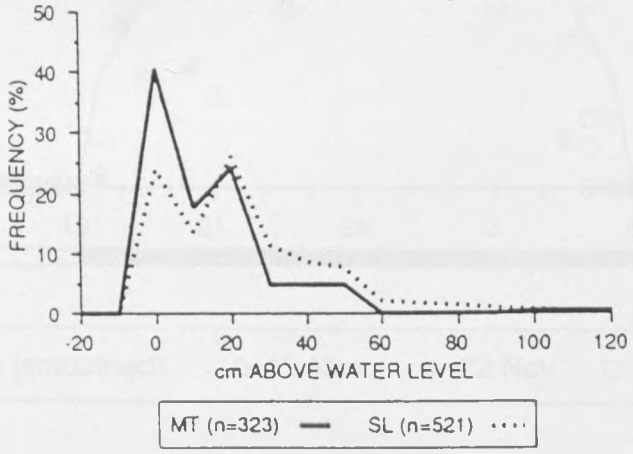
VERTICAL DISTRIBUTION ABOVE WATER LEVEL
OF *Sesarma guttata* (DAY+NIGHT)



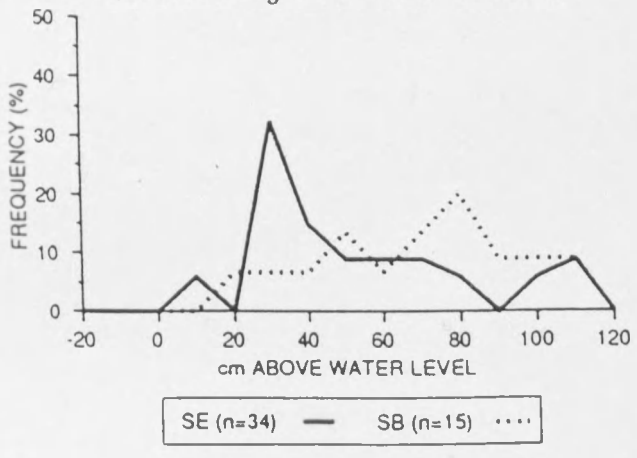
VERTICAL DISTRIBUTION ABOVE WATER LEVEL
OF *E. dentatus and S. guttata*

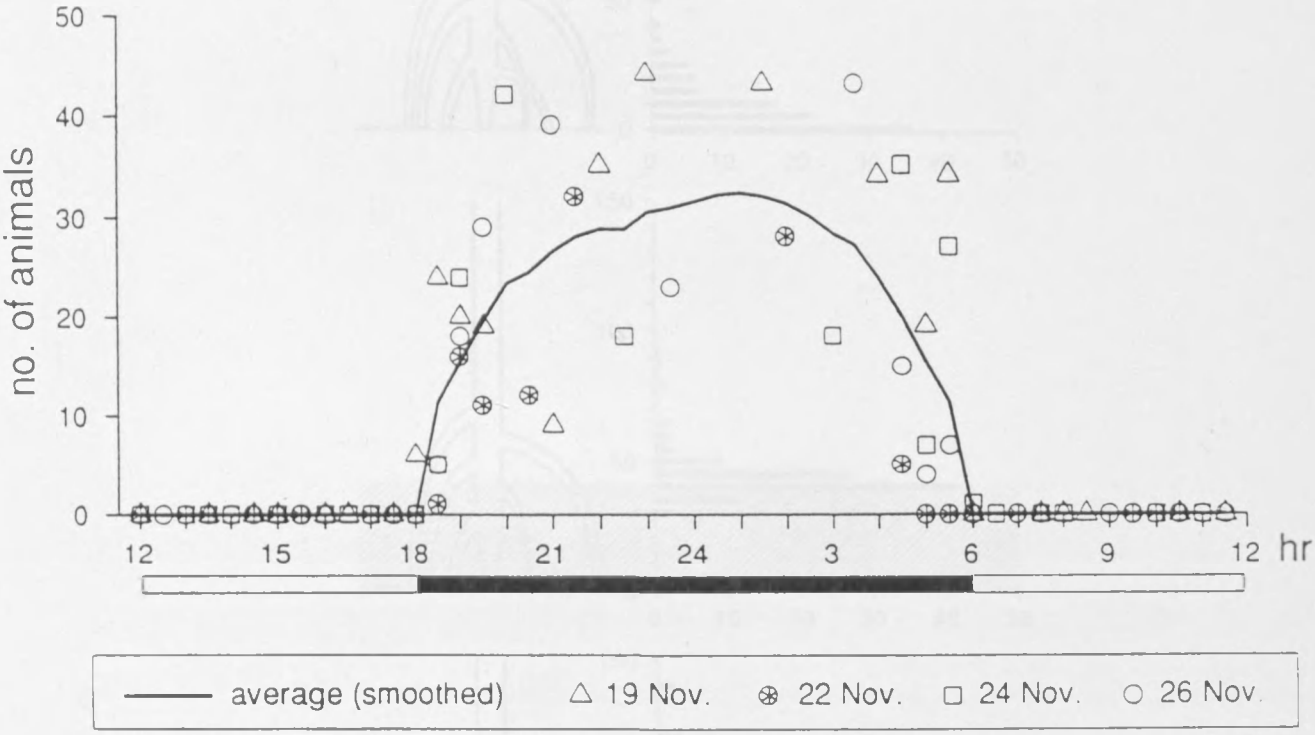


VERTICAL DISTRIBUTION ABOVE WATER LEVEL
OF *M. thukuhar and S. leptosomum*

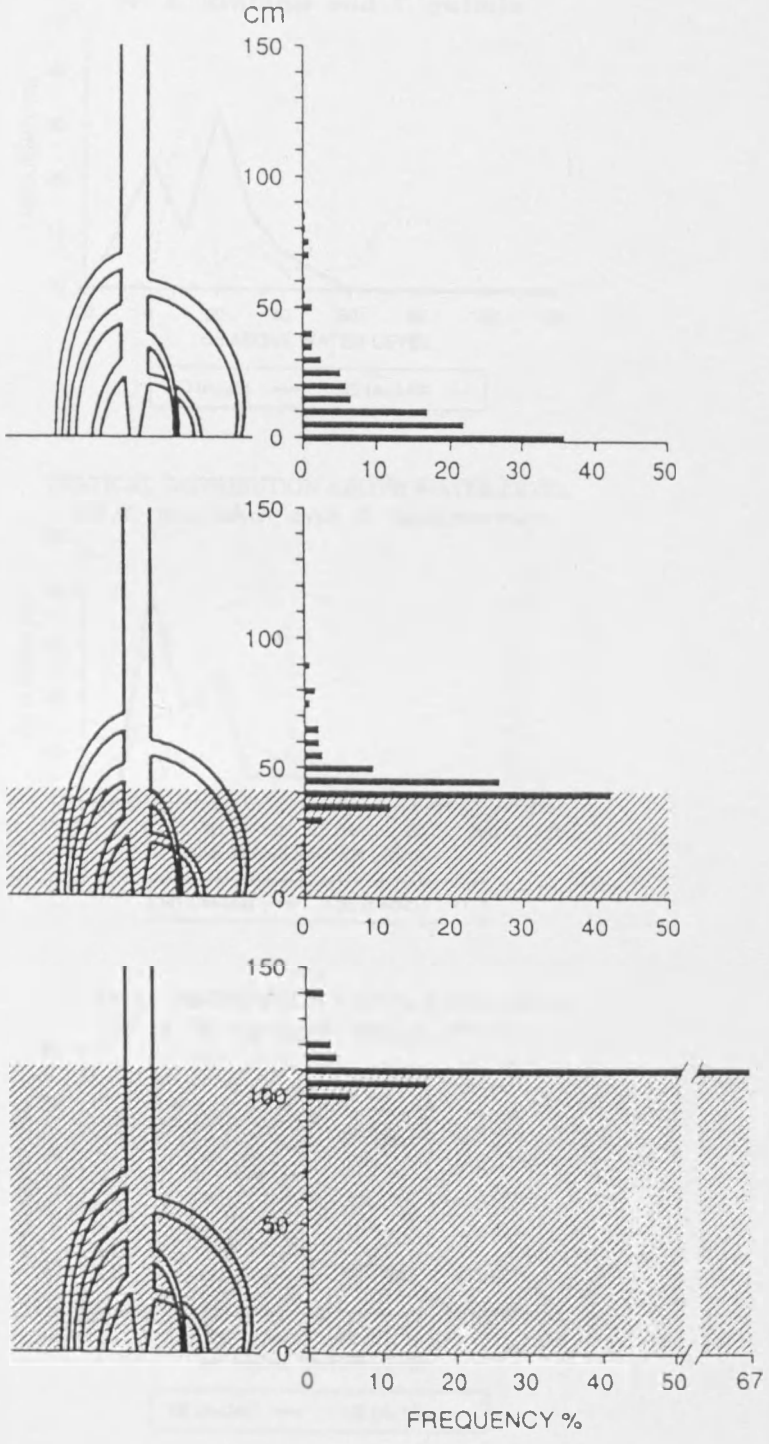


VERTICAL DISTRIBUTION ABOVE WATER LEVEL
OF *S. elongatum and S. broki*



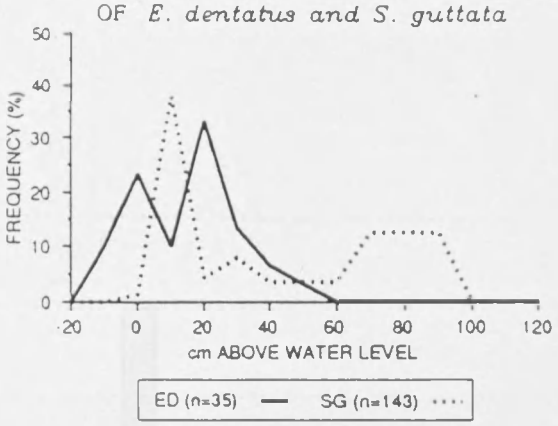


Merguia oligodon. Number of animals counted over 4 days, along a 30 m transect on or near 20 *Rhizophora* trunks (n = 583).

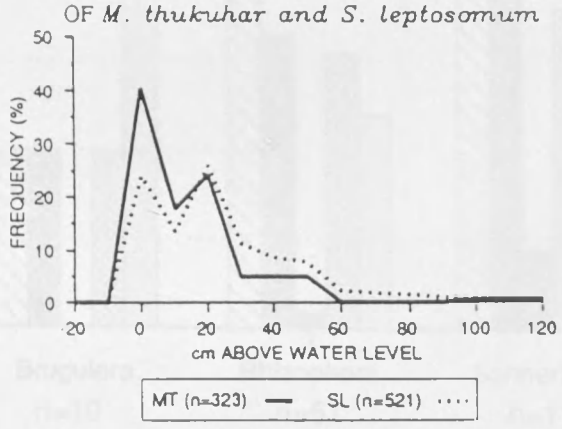


M. oligodon. Relative altimetric distributionat different tidal levels: low water (n = 278). medium level (n = 170). high water (n = 135). from the top dow.

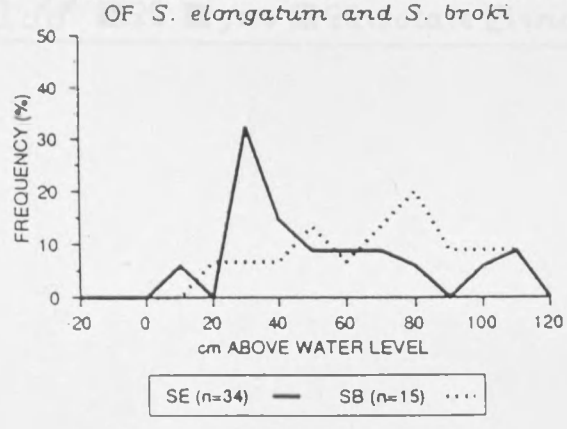
VERTICAL DISTRIBUTION ABOVE WATER LEVEL
OF *E. dentatus and S. guttata*

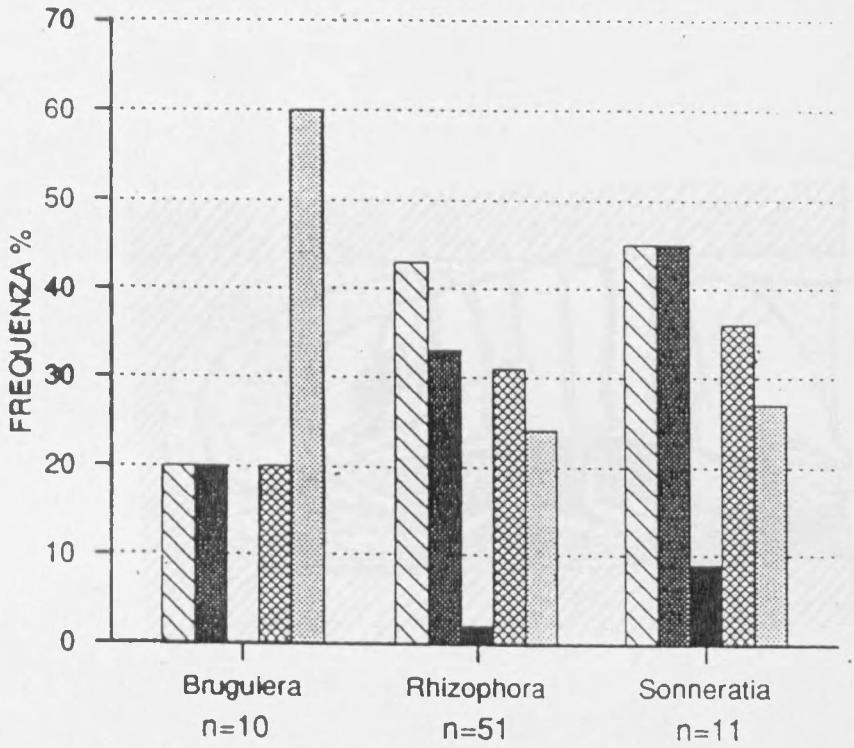


VERTICAL DISTRIBUTION ABOVE WATER LEVEL
OF *M. thukuhar and S. leptosomum*

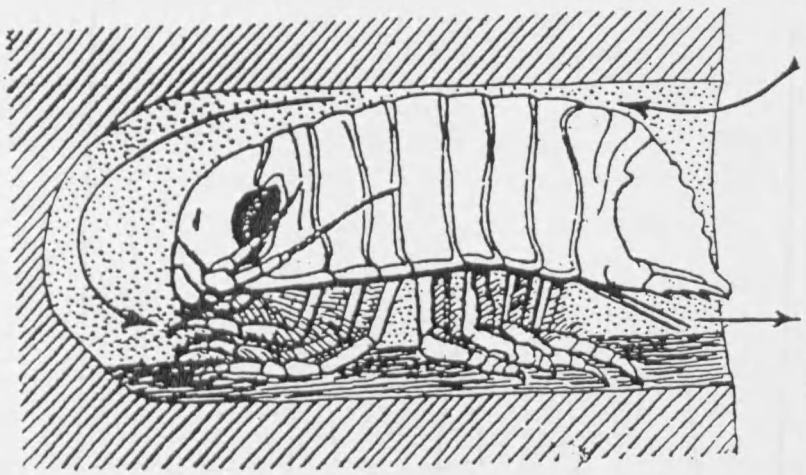


VERTICAL DISTRIBUTION ABOVE WATER LEVEL
OF *S. elongatum and S. broki*





S. terebrans . Distribution among the different mangrove species.



S. terebrans . Water circulation within the burrow.

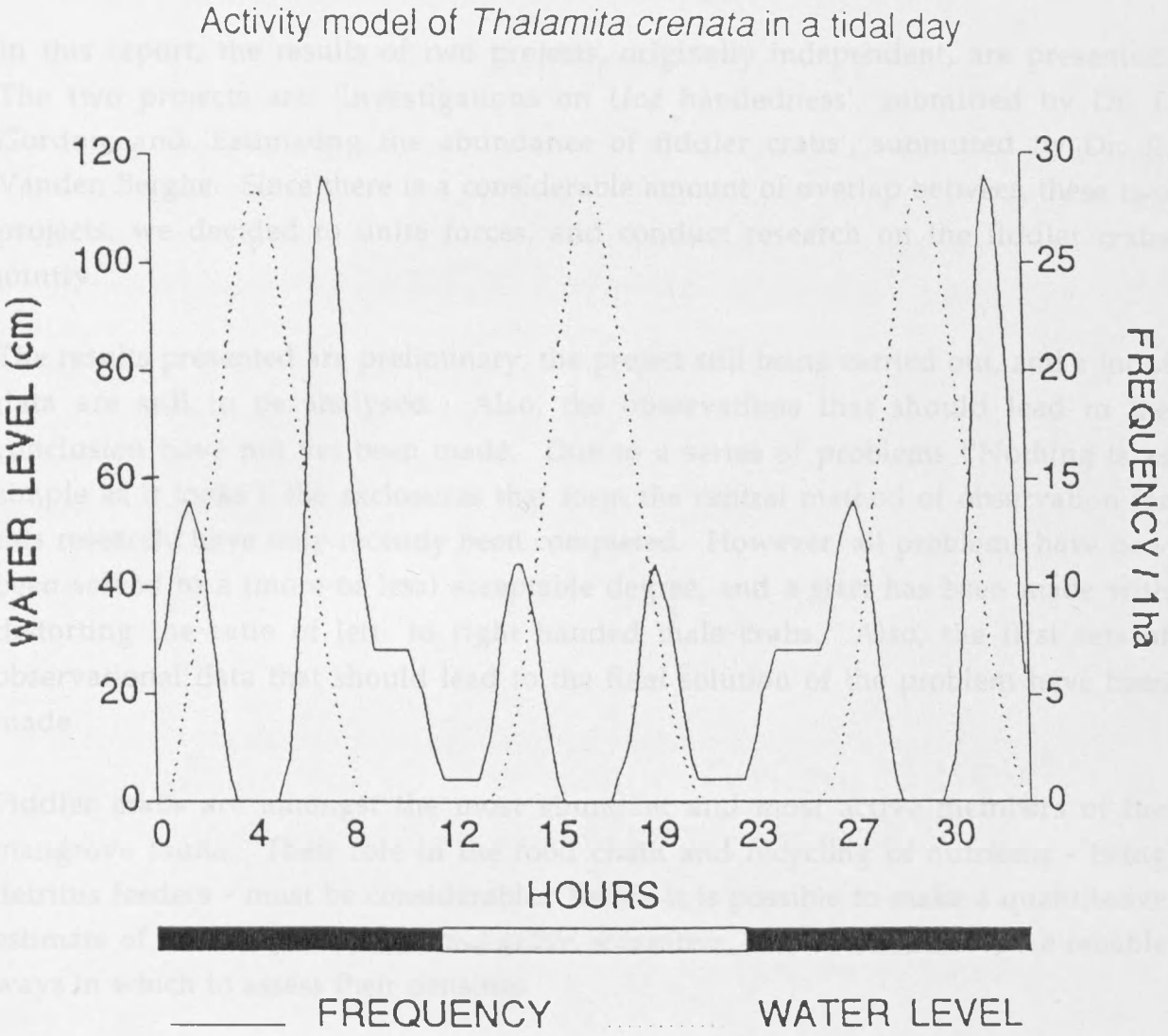


Fig.1 - Activity model of *Thalamita crenata* between two nocturnal tides. Dotted line= water level; solid line= frequency of crabs per ha; black bars= nocturnal hours, white bars= diurnal hours.

4.1.4. Report on *Uca* (fiddler crab) research

I. Gordon, L. Depew, M. Kagoda, A. Oluoch & E. Vanden Berghe

University of Nairobi, Dept. Zoology., Kenya.

4.1.4.1. Introduction and objectives of the study

In this report, the results of two projects, originally independent, are presented. The two projects are: 'Investigations on *Uca* handedness', submitted by Dr. I. Gordon, and 'Estimating the abundance of fiddler crabs', submitted by Dr. E. Vanden Berghe. Since there is a considerable amount of overlap between these two projects, we decided to unite forces, and conduct research on the fiddler crabs jointly.

The results presented are preliminary, the project still being carried out, and a lot of data are still to be analysed. Also, the observations that should lead to the conclusion have not yet been made. Due to a series of problems ('Nothing is as simple as it looks'), the exclosures that form the central method of observation for this research, have only recently been completed. However, all problems have now been solved to a (more or less) acceptable degree, and a start has been made with distorting the ratio of left- to right handed male crabs. Also, the first sets of observational data that should lead to the final solution of the problem have been made.

Fiddler crabs are amongst the most abundant and most active members of the mangrove fauna. Their role in the food chain and recycling of nutrients - being detritus feeders - must be considerable. Before it is possible to make a quantitative estimate of their impact on the mangrove ecosystem, it is necessary to have reliable ways in which to assess their densities.

The main objectives of this project are:

1. developing reliable techniques to investigate abundance and activity of the fiddler crabs
2. investigating a possible advantage of a minority group
3. an investigation of the allometric relationships describing relative claw size (relative to body size)

Preliminary results of the research have been compiled and presented at the third HYSEA conference, Zimbabwe, December 1992. Abstracts of the presentations are presented here.

4.1.4.2. Abstracts, HISEA Conference, December 1992

1. Estimation of fiddler crab densities in mangroves

I.J. Gordon, L.A. Depew and E. Vanden Berghe

Uca crabs constitute a substantial proportion of the animal biomass in mangroves and satisfactory methods for the estimation of their densities are a pre-requisite for mangal ecosystem studies. The following techniques were applied in the Gazi mangrove on the Southern Kenyan coast: transects, quadrats, digs, drop-traps, photographs, burrow counts, exclosures and mark-recapture. The results are presented and the various methods compared. Large scale exclosures are particularly recommended. The prevention of lateral movement within a vertically zoned system permits the isolation of sub-populations which can be subjected to detailed study and experimental manipulation.

Key words: mangroves, *Uca*, densities, techniques

2. The effect of handedness on agonistic interactions and male reproductive success in Uca inversa

L.A. Depew, E. Vanden Berghe and I.J. Gordon

In male fiddler crabs either the right or the left cheliped is greatly enlarged, accounting for up to 40 % of the body weight. This massive investment, together with the resulting halving of the feeding rate in males as compared to females, makes the major cheliped of *Uca* crabs a spectacular example of an expensive male secondary characteristic that must have evolved through sexual selection. In most *Uca* species the ratio of left to right handed males is 1:1. We here report the results of observations on the effects of handedness in *Uca inversa* populations in which handedness ratios have been experimentally perturbed.

Key words: *Uca inversa*, handedness, frequency-dependent selection

3. *Aspects of the biometry of Uca lactea annulipes (Ocypodidae): dimorphism of the major cheliped*

E. Vanden Berghe, I.J. Gordon, L.A. Depew and M. Kagoda

Throughout the genus *Uca*, each species shows a dimorphism for the major cheliped of the male crabs. One form is long and slender, with reduced tubercles, the other short and stout, with more pronounced tubercles. These forms are known as the leptochelous and brachychelous forms, respectively. The basis of this dimorphism is unclear, and could be either genetic in origin, or result from regenerating chelipeds. Regenerating limbs of decapods are smaller than non-regenerating ones in many cases.

A study was undertaken to investigate this dimorphism in *Uca lactea* annulipes, quantifying the size of the major cheliped in relation to body size. Results not only indicate that the leptochelous form is smaller than the brachychelous one, but also that residuals from a regression of cheliped length vs. carapace width forms a multimodal distribution. This is taken to be a strong argument for the regeneration hypothesis, where different modi in this distribution correspond with different phases of regeneration of the cheliped.

4.2. TERTIARY PRODUCERS

4.2.1. Species composition and shuttle movement of fish

Ntiba, M.J[1]; Wakwabi, E.O[2], Mwatha, G.K[2] & Kimani, E[2]

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[2] Kenya Marine and Fisheries Research Institute, P.O. Box 81651, Mombasa, Kenya.

4.2.1.1. Introduction and objectives of the research

Mangrove creeks have been assigned the role of nursery grounds for juveniles of some marine tropical fishes (Macintosh, 1982) and have been shown to be important fishing grounds for both fin fish and shellfish (Krishnamurthy et. al., 1979). While Stone (1986) studied the community structure of the juvenile and adult fish in similar ecosystems in Puerto Rico the only related work in the West Indian Ocean area is that of Little et. al., (1988) in the Tudor creek, Kenya.

This study describes the species diversity, abundance and the temporal occurrence of the fish species in Gazi creek on an annual cycle. The work also tries to establish the life history status of the species found and provides baseline information for future studies on the shuttle movements of fish between mangrove creeks and the adjacent seagrass beds and coral reefs.

4.2.1.2. Material and Methods

Four sampling stations were selected from the mouth of the main channel to the upper reaches of the creek. These stations were fished, with a beach seine 40 m long and 2 m high with a mesh size of 5 mm over a period of 3 consecutive days at low tide around spring tides from March 1991 to April 1992. Day and night samples were taken. Each catch was sorted out into species, weighed, total length and standard length measured to the nearest millimetre and a subsample preserved in 5 % formalin for analysis of the stomach contents back in the laboratory. The identification of the material was done following the available literature (Smith,1979; Fisher & Bianchi, 1984, Smith & Heemstra, 1986).

4.2.1.3. Results

Table 1. shows the percent annual abundance of families of fish caught in Gazi creek from March, 1991 to April, 1992. It is clear that the family Gerreidae is outstandingly abundant followed by Antherinidae which in terms of numbers comprised about 31.47 % and 8.86 % respectively. Apart from these two the other families that are significantly abundant in the creek include Teraponidae, Lutjanidae, Sillaginidae, Acropomidae, Clupeidae, Lethrinidae, Belonidae, and Scaridae. Also of some importance in the creek are the families Siganidae, Sphyraenidae, Fistulariidae, Apogonidae, Triodontidae, and Pomacentridae each constituting between 1 and 2 % of the total community numerical abundance. The remaining 28 families encountered in the creek during this study contributed less than 1 % each to the total numerical abundance of the community.

This table further shows that the species richness per family ranges from 1 to 9. The cardinals (Apogonidae) are the best represented with 9 species followed by Mullidae and Lethrinidae each with 7 species; Lutjanidae, Carangidae, and Synodontidae are represented by 5 species each while Gobiidae, Acanthuridae, Bothidae, and Clupeidae have 4 species each. However there is no relationship between the number of species encountered in a family with its contribution to the total numerical abundance of the ichthyocommunity of Gazi creek. The Shannon-Weaver indices of community diversity (H) (Zar, 1984) in Gazi are shown for the different monsoon seasons in Table 2. These indices are higher during the southeast and northeast monsoons than in the intermonsoon period.

The contribution by different species to the over numerical abundance of a particular family in the creek was highly variable (Figure(s) 1 (a), (b), (c)) and that *Gerres oyena* (97 %), *Herklostsichthys quadrimaculatus* (75 %) and *Lutjanus fulviflamma* (62 %) are numerically the most important species amongst the Gerreidae, Clupeidae and Lutjanidae respectively. *Trachinotus blonchii* (37 %) and *Caranx ignobilis* (35 %) are the most important species amongst the kingfishes (Carangidae) in the creek (Figure 1 (d)). Similarly *Lethrinus harak* contributed 69 % of the total numerical abundance amongst the 7 Lethrinids caught in the creek in this study. In the Apogonidae, the best represented family in species richness in the creek, *Apogon cookii* (39 %) and *A. nigripes* (24 %) were the most abundant.

The temporal variation in the numerical abundance of each species in the creek is shown in Table 3. It is apparent that some species such as *Gerres oyena, Lethrinus harak, Therapon jarbua, Sphyraena jello, Siganus sutor, Herklostsichtys quadrimaculatus, Trachinotus blonchii* and *Leptoscarus vaigiensis* occur in the

creek round the year. This pattern of occurence is shown only for *T. jarbua, S. sutor* and *G. oyena* in Figure 2 (a), (b) and (c) respectively. *Lutjanus fulviflamma, Caranx ignobilis, Thylosurus acus* (Figure 3 (a), (b) and (c)) and *Parupeneus barberinus* occur in the creek from January to June. The other species seem to have no definite pattern of occurrence in Gazi creek.

4.2.1.4. Discussion and conclusion

The number of species recorded in this study is not surprising since with more sampling and better spatial cover of the creek this list will grow longer. The fishes caught were small averaging in length between 3.9 to 43.9 cm. On an annual basis the species-abundance-distribution of the community of fish in Gazi is high and homogenous (H = 1.07). However, during the inter-monsoon periods the community abundance is dominated by *G. oyena* in April/May while in October, during the SE/NE intermonsoon, the species diversity was lowest and dominated again by *G. oyena* and *Shilago sihama*. Whether this was caused by the reversal of the monsoon gyres is hard to explain without further research.

Based on comparison of the average sizes of fish obtained in this study (Table 4) and the maximum sizes reported for these species in the Indian Ocean (Smith & Heemstra, 1986) it is clear that the Gazi fish community is a mixture of adult and juveniles. Emperical calculations show that on the average fish become sexually mature at 35 % of their maximum total length (Nzioka, 1981, Ntiba, 1986; Ntiba, 1990; Ntiba & Jaccarini, 1988) and the smallest mature fish in any stock is on the average 30 % of the maximum total length of the species. Going by this principle 47 % of the species shown in table 4 are juveniles that have not attained sexual maturation and thus use the creek as a nursery ground. The species which are indicated as adults in this Table 3 must play an important role in the trophic relationships of the creek and this has been shown for the Apogonidae (Vivien, 1975) in Malagasy coral reef.

The occurrence round the year of, for example, *H. quadrimaculatus, G. oyena, L. harak, T. jarbua, S.jello, S. sutor,* and *L. vaigiensis* could be interpreted in two ways. One, the species could be adults resident in the area or, two, they are juveniles originating from adult population(s) within the vicinity whose spawning occurs throughout the year. Based on the information given in tables 3 and 4 *H. quadrimaculatus, G. oyena* appear to resident in the creek round the year while the other species are juvenile fishes spawned elsewhere and come to the creek. Ntiba & Jaccarini, 1990 showed strong seasonality for the juvenile *S. sutor* in the Tudor

creek, Mombasa, Kenya where they appeared from March to April and again from September to October. The same authors showed that these juveniles were from two definite spawning seasons of adult one and a half months earlier. Based on examination of gonads of fish in the East African marine waters Nzioka (1979) points out that spawning lasts from July to February with a peak in October in the Lutjanidae. He further postulates two spawning peaks for the Lethrinidae in September/October and January/February and for the Mullidae in March and November.

Although the hatching time of eggs of marine fish in tropical waters is very short (Pauly & Paulin, 1988) there is no information on the time taken by the larvae to grow and attain the juvenile stages caught in Gazi apart for *S. sutor* (Ntiba & Jaccarini, 1988) which would be 3 months old. Continuing research off the Kenyan inshore waters indicates that in *L. fulviflamma* spawning lasts September to March (Kaunda, Pers. com) which agrees with the findings of Nzioka (1979). These finding are further corroborated by the appearance of the juveniles of *L. fulviflamma* in Gazi creek from January to June. Earlier reports from Kenya (Ntiba & Jaccarini, 1988), Palau and Singapore (Lam, 1974) and Guam (Kami & Ikehara, 1976) show strong spawning seasonality amongst siganids. Nzioka (1979) also reports strong spawning seasonality for *L. harak* in the East African marine waters. But contrary to these reports juveniles of *S. sutor* and *L. harak* in this study were encountered all the year round. Bwathondi (1981) reported that siganids off the Tanzanian coast breed throughout the year. What this may mean is that some areas are more preferred as nursery grounds by the juvenile fish so that if there are several spawning adult population(s) whose timing of spawning are not synchronized the post larvae would migrate to more important mangrove nursery areas thus explaining the all year round temporal occurrence of some juveniles of species known from other lines of evidence to have a highly synchronized oocyte development in their ovaries. If this argument is true then it could well be that the juveniles reported to appear seasonally by (Lam, 1974), (Kami & Ikehara, 1976) and (Ntiba & Jaccarini, 1988) were probably enroute to some ecologically more suitable nursery grounds. Gazi creek could therefore be one of these important nursery grounds for the juvenile marine fish in Kenya.

However, it should be pointed out that to a certain the spawning times of our fishes simultaneous sampling is needed for the cycle of gonad maturation of the adults as well as plankton surveys for the eggs and larvae. Further data on the juveniles such as the present on could equally be useful if the growth parameters for the species are known since it would allow the time taken by the larvae after hatching (Pauly & Paulin, 1988) be calculated from the empirical growth equation. Currently

these equations are only known for *S. sutor* (Ntiba & Jaccarini, 1988) and *L. Fulviflamma* (Kaunda, Pers Com.) in the inshore waters of Kenya.

Gazi creek is also used as a spawning ground by some fishes such as *Antherinomorus lacunosus* (Antherinidae) which come to the creek in huge schools, the apogonids *Archamia mozambiquensis, Apogon nigripes, Apogon cookii,* and the clupeid *Sardinella bibbosa.*

This study has shown the importance of Gazi creek as (a) an major nursery ground for the young of fish that support the artisanal fishery in Kenya and for other lesser species which do not feature in the fishery but are of great importance in this creek's food webs, and, (b) a spawning ground for some resident and shoaling migratory species. For these reasons it is concluded that the Gazi mangrove area be protected and conserved for the continued survival of the fish species and other fauna and has a key role to play in the fisheries productivity in our inshore waters. The same should be done for other mangrove areas in the world.

Comments

The work on fishes in East African coastal ecosystems is in its infant stage. The species list must be completed not only for mangroves but also for the equally important seagrass beds and the coral reefs. In this part of the world nothing is known of the trophic interactions nor the shuttle movement of fish in these coastal biotopes. While the fishery is being exploited close to its maximum sustainable yield level, information on the biology of most exploited species, save for *S. sutor* and *L. fulviflamma,* is completely lacking. The spawning cycles and the spawning grounds for the adult fish species from which the juveniles recorded at Gazi in the present study must have come from, are unknown. Also there are many species not exploited commercially in these waters but whose ecological role is undoubtedly important and must be studied.

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We wish to thank Technical staff from KMFRI, especially Mr. Boaz and Mr. Rashid, for help in the field and Mr. Oswago, Zoology Department, University of Nairobi for producing the illustrations.

Table 1 : The abundance and the species richness of various families of fish in Gazi creek, Kenya.

Family	% Abundance	N° of species
Acanthuridae	.21	4
Acropomatidae	3.69	2
Antherinidae	8.86	1
Apogonidae	1.25	9
Belonidae	2.38	1
Bothidae	.78	4
Carangidae	3.75	5
Chaetodontidae	.03	1
Chanidae	.04	1
Chirocentridae	.07	1
Clupeidae	3.67	4
Dactylopteridae	.02	1
Diodontidae	.39	2
Engraulidae	.10	1
Ephippidae	.25	1
Fistulariidae	1.72	1
Gerreidae	31.47	3
Gobiidae	.20	3
Haemulidae	.08	2
Hemriramphidae	.04	2
Kyphosidae	.01	1
Labridae	.21	2
Leiognathidae	.26	3
Lethrinidae	3.30	7
Lobotidae	.04	1
Lutjanidae	4.87	5
Monacanthidae	.08	3
Monodactylidae	.84	1
Mugilidae	.60	1
Mullidae	.90	7
Ostraciidae	.90	1
Platycephalidae	.90	3
Plotosidae	.43	1
Pomacentridae	1.19	2
Scaridae	2.11	3
Scombridae	.07	1
Scorpaenidae	.18	3
Siganidae	1.90	2
Sillaginidae	4.22	1
Soleidae	.12	2
Sphyraenidae	1.78	2
Synodontidae	.34	4
Teraponidae	6.52	2
Triodontidae	1.21	2

Table 2 : The seasonal changes in the community diversity of fishes in Gazi creek, Kenya.

Season	Time of year	Shannon-Weaver Index (H)
NE - SE intermonsoon	April - May	0.86
SE monsoon	June - September	1.35
SE - NE intermonsoon	October	0.68
NE monsoon	November - March	1.19

The index of community diversity (H) for this area in general is 1.07

Table 3.: Reported maximum lengths (Ly) compared with the mean total lengths (MLT) of the fish species in Gazi. The species life-history stage is given as: A, Adult, J, Juvenile.

Species Name	Family	(L.) cm	(MLT) cm
Acropoma japonicum	Acropomatidae	20	6.06 ± 0.46 A
Antherinomorus lacunosus	Antherinidae	14	7.49 ± 0.91 A
Apogon frenatus	Apogonidae	10	8.70 ± 3.25 A
Apogon nigripes	Apogonidae	7	7.10 ± 1.99 A
Cheilodipterus lineatus	Apogonidae	22	8.37 ± 0.44 A
Apogon cookii	Apogonidae	10	9.95 ± 1.10 A
Thylosurus acus	Belonidae	125	28.75 ± 4.20 J
Bothus manchus	Bothidae	42	13.50 ± 1.34 J
Bothus pantherinus	Bothidae	30	8.70 ± 4.13 J
Trachinotus blochii	Caraginidae	54	12.40 ± 1.40 J
Scomeroides tol	Carangidae	60	4.71 ± 1.50 J
Sardinella bibbosa	Clupeidae	17	12.30 ± 2.20 A
H. quadrimaculatus	Clupeidae	14	6.63 ± 0.45 A
Spratelloides delicatus	Clupeidae	7	6.16 ± 1.80 A
Pellona ditchela	Clupeidae	14	8.60 ± 1.10 A
Caranx ignobilis	Crangidae	165	1.66 ± 1.64 J
Platex pinnatus	Ephippidae	30	8.39 ± 1.56 J
Gerres oyena	Gerreidae	25	8.98 ± 0.53 A
Gerres filamentous	Gerreidae	25	12.20 ± 3.09 A/J
Gerres poeti	Gerreidae	25	11.91 ± 5.40 A/J
Oplopomus aplopomus	Gobiidae	8	7.80 ± 0.10 A
Chelio inermis	Labridae	50	14.40 ± 0.66 J
Stethojulis strigiventer	Labridae	15	6.70 ± 0.19 A
Leiognathus equula	Leiognathidae	25	6.01 ± 0.97 J
Lethrinus harak	Lethrinidae	60	7.44 ± 1.30 J
Lethrinus nebulosus	Lethrinidae	75	8.70 ± 1.17 J
Lethrinus lentjan	Lethrinidae	-	7.70 ± 1.78 J
Lutjanus fulviflamma	Lutjanidae	30	8.18 ± 1.67 J
Lutjanus ehrenbergi	Lutjanidae	30	6.63 ± 0.81 J
Lutjanus angentimaculatus	Lutjanidae	100	37.40 ± 6.45 J
Aluterus scriptus	Monacanthidae	100	14.50 ± 4.95 J
Paramonacantus barnadi	Monacanthidae	9	9.31 ± 0.80 A
Monodyctylus falciformis	Monodactylidae	31	11.78 ± 1.28 A

Species Name	Family	(L.) cm	(MLT) cm
Valamugil seheli	Mugilidae	50	14.40 ± 0.44 J
Parupenus indicus	Mullidae	32	13.80 ± 0.70 A
Upeneus tragula	Mullidae	20	9.58 ± 0.39 A
Parupenus cinabarinus	Mullidae	28	10.90 ± 2.52 A
Plotossus nkunga	Plotosidae	54	16.30 ± 0.43 J
Dascyllus carneus	Pomacentridae	7	3.65 ± 0.21 A
Dascyllus trimaculatus	Pomacentridae	14	8.01 ± 0.10 A
Leptoscarus vaigiensis	Scaridae	35	9.24 ± 2.25 A
Pterois miles	Scorpaenidae	31	12.00 ± 1.08 A
Parascorpaena mossambica	Scorpaenidae	10	7.78 ± 2.08 A
Siganus sutor	Siganidae	45	6.18 ± 3.30 J
Shillago sihama	Sillaginidae	30	18.50 ± 1.30 A
Solea bleekeri	Soleidae	17	13.63 ± 3.81 A
Sphyraena jello	Sphyraenidae	125	12.00 ± 4.66 J
Saurida gracilis	Synodontidae	20	14.35 ± 2.26 A
Therapon jarbua	Teraponidae	33	6.97 ± 0.71 J
Therapon theraps	Teraponidae	25	6.80 ± 0.71 J
Chelonodon laticeps	Triodontidae	20	19.35 ± 1.34 A
Arothon immaculatus	Triodontidae	30	18.41 ± 2.21 A

Table 4: Percentage temporal abundance of fish in Gazi creek, Kenya, from April 1991 to April 1992

Species Name	March	April	May	June	July	October	November	December	January	February	March	April
Acanthurus lineatus		.26	.17									
Ctenochaetus strigosus		.73										
Naso brevirostris							.60	.60				
Acanthurus xanthopterus												.16
Acropoma japonicum				18.41								
Acropoma spp.					.33						24.80	.81
Antherionomorus lacunosus	46.19			11.26	.16				45.32	.26	2.93	.32
Foa brachygramma			.34									
Apogon lateralis				.82								
Apogon flagellifer											.53	
Apogon frenatus											.53	.16
Apogon nigripes											3.47	.16
Archamia mozambiquensis												.16
Cheilodipterus lineatus												2.10
Apogon cookii											5.87	
Fowleria aurita				.82								
Thylosurus acus	1.37	6.52	3.44	.82					.73	5.94	4.27	5.48
Bothus myriaster	.20					4.36						
Bothus manchus		.28		.20						2.07		.16
Bothus pantherinus					.16						1.33	
Pseudorhombus arsius							.30	.30				
Caranx ignobilis	1.59	1.01	.86	1.43	.82				1.17	3.88	2.40	2.42
Trachinotus blochii			.34		.16		7.81	7.81	.15		.27	.16

Table 4: continuation

Species Name	March	April	May	June	July	October	November	December	January	February	March	April
Gnathanodon speciosus			.17	.41								
Trachenotus bailoni										8.79		
Heniochus acuminatus	.41											
Chanos chanos					.49							
Chircentrus dorab									.88			
Sardinella bibbosa	2.38								.73	4.13		
Herklostsichthys quadrimaculatus			.18	9.01	5.91		.60	.60	1.90		9.07	5.81
Spratelloides delicatus											1.87	.81
Pellona ditchela								1.10				
Scomeroides tol						1.74			.58		1.07	
Dactyloptena orientalis	.20											
Diodon hystrix									4.24			.16
Lophodiodon calori											.27	
Stolephorus holodon					1.15							
Platex pinnatus			.69	.20	.49							1.61
Fistularia petimba		.13			.33		8.11	8.11	.29			3.71
Gerres filamentous		.28			4.76				.58	1.03		.32
Gerres poeti											4.80	.81
Gerres oyena	19.55	65.62	55.70	10.64	16.26	37.04	32.13	32.13	20.61	28.17	10.67	36.94
Amblygobius albimaculatus		.26			.82							.16
Oplopomus aplopomus		.44										
Caffrogobius nudiceps							.30	.30				.16
Diagramma pictum			.17									
Plectorhinchus gatrinus									.15		.27	.32
Hyporhambus affinis			.17									

Table 4: continuation

Species Name	March	April	May	June	July	October	November	December	January	February	March	April
Hemriramphus far											.27	
Kyphosus bigibbus		.13										
Chelio inermis		.44		.61								.16
Stethojulis strigiventer		.61	.69									
Leiognathus elongatus			.18									
Leiognathus equula					.99					1.03	.27	
Gazza minuta							.30	.30				
Lethrinus malsenoides				.20								
Lethrinus harak	1.59	6.31		1.43	1.31	1.31	2.40	2.40	1.02			9.68
Lethrinus nebulosus	.20								.15			4.35
Lethrinus semicintus		2.42										
Lethrinus mahsena				.20								
Lethrinus lentjan					4.11							
Lethrinus elongatus										.52		
Lobotes surinamensis	.40	.26										
Lutjanus fulviflamma	1.97	1.28	5.50	.41	10.18				1.02	.78	8.00	7.10
Lutjanus ehrenbergi				.20			9.61	9.61				
Lutjanus bohar				.20								
Lutjanus angentimaculatus					.99						.27	
Lutjanus russelli						.87				.26	.27	
Aluterus scriptus		.26										
Stephanolepis auratus												.16
Paramonacanthus barnadi											.53	
Monodzctylus falciformis				5.52		4.58						
Valamugil seheli					6.73						.53	

Table 4: continuation

Species Name	March	April	May	June	July	October	November	December	January	February	March	April
Parupeneus barberinus	.20	.57	2.05	.41	.16		.60	.60			.53	.16
Parupenaeus macronema	.20											
Upeneus vittatus		1.14		.20								
Parupenus indicus					.33							
Upeneus tragula					1.15							
Parupenus cinabarinus					1.31							
Parupeneus pleurostigma							.60	.60				
Lactoria cornuta	1.19	.44					3.60	3.60	.29	.52	.80	.32
Grammaplites protuguesus				.20								
Platycephalus indicus												.16
Papilloculiceps longiceps												.16
Plotossus nkunga										5.17		
Dascyllus carneus									13.16		.53	
Dascyllus trimaculatus									.58			
Leptoscarus vaigiensis	1.76	.17			1.81		.90	.90		.26	1.60	
Scarus psittacus		1.57	8.77									
Scarus vaigiensis		.26	4.47									
Ratrelliger kanagurta					.82							
Scorpaneopsis cirrhosa				.29								
Pterois miles					.49							
Parascorpaena mossambica											1.33	.16
Siganus sutor	1.76	.85	2.58	1.64	.66	2.18	3.00	3.00		.52	.80	2.58
Siganus stellatus		.73	.17							52	1.87	
Shillago sihama		.71			11.99	34.86	.30	.30	1.02	2.07		
Solea bleekeri											1.07	

Table 4: continuation

Species Name	March	April	May	June	July	October	November	December	January	February	March	April
Pardachirus marmoratus												.32
Sphyraena jello	.60	1.82	3.43	1.02	1.80	.87			1.02	5.94	2.40	1.61
Sphyraena barracuda				.82								
Saurida gracilis	.20	.13	.51	.20					.15		1.33	.32
Saurida undosquamis				.20								
Synodus indicus					.33							
Trachinocephalus myops											.27	.48
Theraphon jarbua	.79	1.13	1.20		11.00	12.00	10.81	10.81	2.34	19.90	.27	1.61
Theraphon theraps		.45	1.89		3.94							
Chelonodon laticeps	.20						6.31	6.31	.15		.53	.65
Arothon immaculatus									.44			

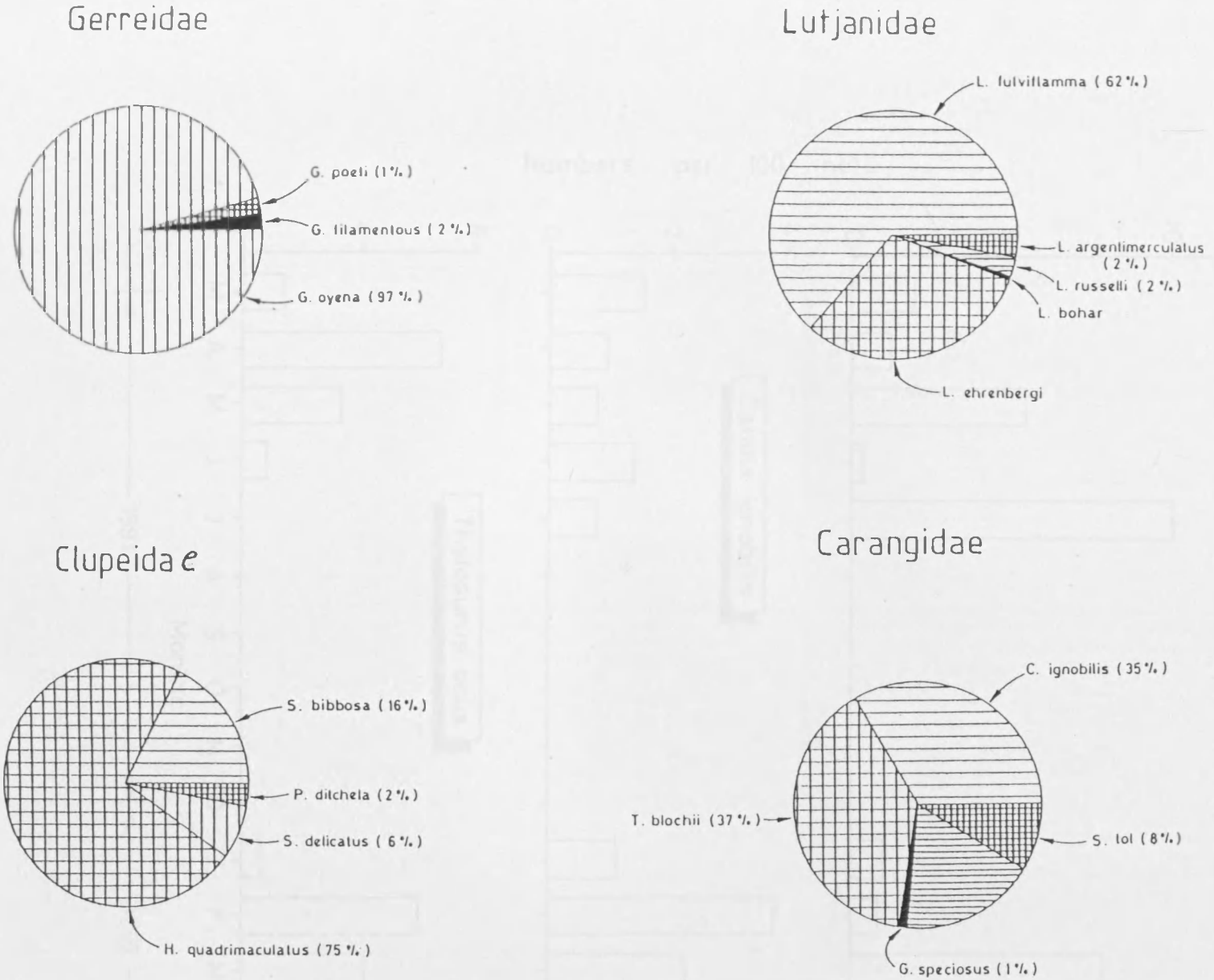

Figure 1. The percent abundance of fishes in the family Gerreidae (a), Clupeidae (b), Lutjanidae (c) and Caranginidae (d) in Gazi creek, 1991/92.

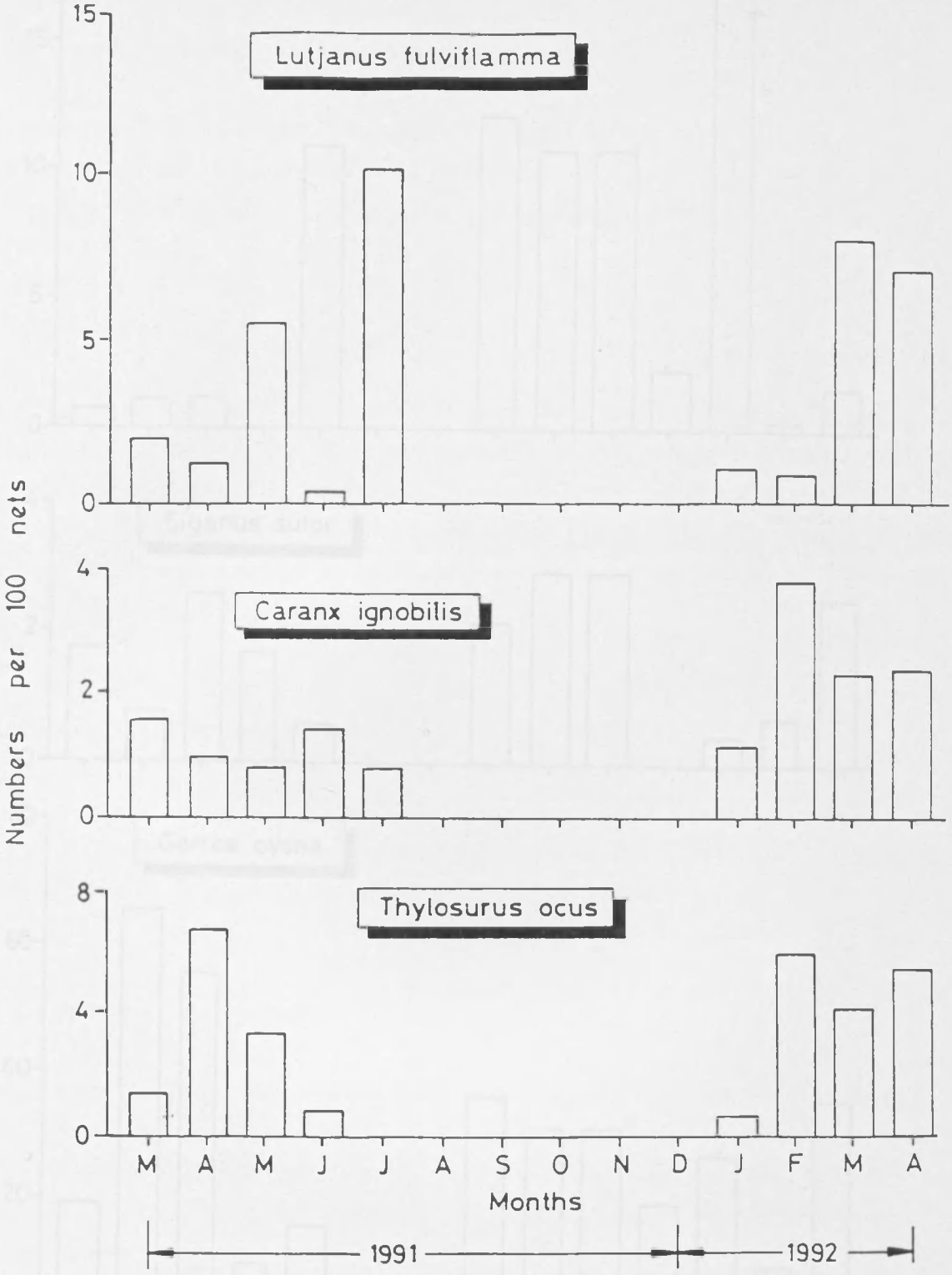

Figure 2. The variation in the temporal numerical abundance of *I. jarbua* (a), *S. sutor* (b) and *G. oyena* (c) in Gazi creek, 1991/92.

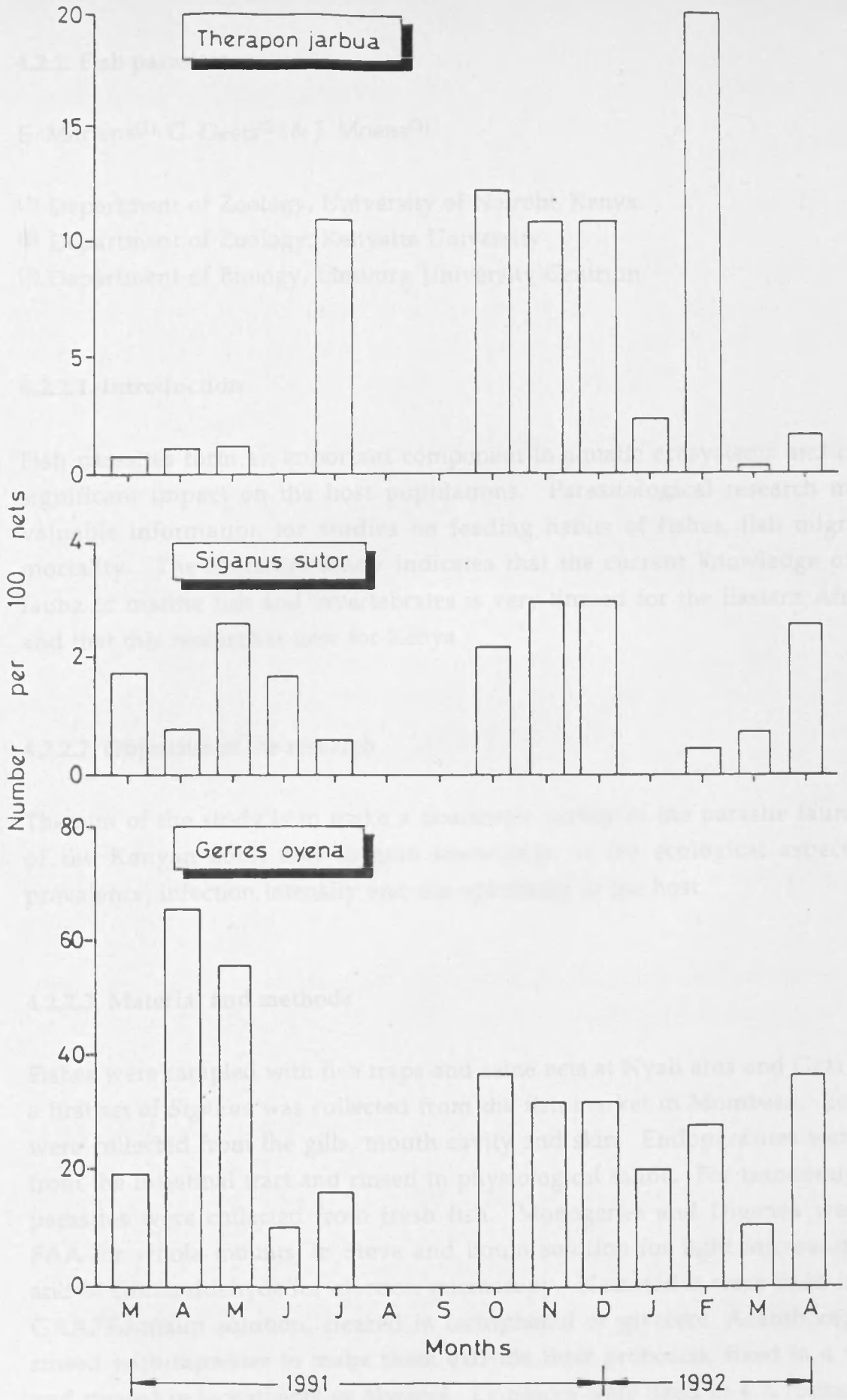

Figure 3 The variation in the temporal numerical abundance of *L. fulviflamma* (a), *C. ignobilis* (b) and *T. acus* (c) in Gazi creek, 1991/92.

4.2.2. Fish parasites

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4.2.2.1. Introduction

Fish parasites form an important component in aquatic ecosystems and can have a significant impact on the host populations. Parasitological research may reveal valuable information for studies on feeding habits of fishes, fish migration and mortality. The literature study indicates that the current knowledge of parasitic fauna of marine fish and invertebrates is very limited for the Eastern African coast and that this research is new for Kenya.

4.2.2.2. Objective of the research

The aim of the study is to make a taxonomic survey of the parasite fauna in fishes of the Kenyan coast and to gain knowledge of the ecological aspects such as prevalence, infection intensity and site specificity in the host.

4.2.2.3. Material and methods

Fishes were sampled with fish traps and seine nets at Nyali area and Gazi Bay, while a first set of *Siganus* was collected from the fish market in Mombasa. Ectoparasites were collected from the gills, mouth cavity and skin. Endoparasites were collected from the intestinal tract and rinsed in physiological saline. For taxonomic study the parasites were collected from fresh fish. Monogenea and Digenea were fixed in FAA for whole mounts, in Steve and Bouin solution for light microscopy sections and in Glutaraldehyde for electron microscopy. Nematodes were fixed in Berland's GAA/Formalin solution, cleared in lactophenol or glycerol. Acanthocephala were rinsed with tapwater to make them extrude their proboscis, fixed in 4 % formalin and cleared in lactophenol or glycerol. Crustacea were fixed in 4 % formalin. Of the

gill and intestinal parasites encountered the numbers and distribution in the host were recorded: on gill arch 1 to 4 or 5, left and right side; in intestine part 1 to 4.

4.2.2.4. Results

As the taxonomic survey has been hampered by the lack of the literature needed, identification of the specimens is still ongoing. Therefore, the unidentified parasites are now distinguished as "types". Representatives of the different parasite groups found in the fish species studied till now are given in Table 1.

For the parasites in *Siganus sutor* the infection prevalence and intensity of infection is given in Table 2.

4.2.2.5. Conclusions

The identification of the different parasites found has been hampered by the time needed to gather the taxonomic literature. From the different Monogenea and Digenea now distinguished as "types", some might be allometric forms of one species. It is therefore essential to identify the species and describe new ones first, before the quantitative data can be accurately analysed for the ecological aspects. From the data analysed till now can be seen that for *Siganus sutor*, a herbivorous fish, the prevalence of infection is quite high, especially in the adult sizes (market sample).

After more intensive sampling of other fish species comparisons will be related to the fish feeding habits and abiotic characteristics of sampling location.

4.2.2.6. Oral communications

Parasitological study of Siganus sutor, a commercially important fish species of the Kenyan coast. IZWO Workshop "Marine research in Kenya", Ostend - May 1992.
First parasitological study of marine fish species of the Kenyan coast. HYSEA 1992 Symposium, Harare - December, 1992.

Table 1: Gill and intestinal parasites found in different fish species.

Fish species (nr studied)	Gill parasites	Intestinal parasites
Siganus sutor (59)	Monogenea: *Pseudohaliotrema* sp. 1 *Pseudohaliotrema* sp. 2 *Tetrancistrum sigani* *Microcotyle mouwoi* type 1 Copepoda: Caligidae: 2 types Hatschekiidae: 1 type Isopoda: Gnathiidae: 1 type	Digenea: *Opisthogonoporoides* sp. *Gyliauchen papillatus* *Hexangium sigani* 3 types Acanthocephala: *Neorhadinorhynchus* sp. Nematoda: *Procamallanus* sp.
Lutjanus rivulatus (12)	Monogenea: 3 types Caligidae: 1 type Hatschekiidae: 12 type Copepoda: 2 types	Digenea: 3 types Acanthocephala: 1 type
Lutjanus fulviflammus (9)	Monogenea: 1 type Hatschekiidae: 1 type Crustacea: 1 type	Digenea: 2 types
Lethrinus nebulosus (7)	Monogenea: 3 types Hatschekiidae: 1 type	Digenea: 1 type Acanthocephale: 1 type
Scarus ghobban (15)	Monogenea: 2 types Hatschekiidae: 2 types Copepoda: 1 type	Digenea: 2 types
Scarus forsteri (1)	Hatschekiidae: 1 type	
Leptoscarus vaigiensis: (5)	Monogenea: 2 types Hatschekiidae: 1 type Isopoda: 1 type	Digenea: 1 type
Abudefduf saxatilis (11)	Monogenea: 3 types Copepoda: 1 type	Digenea: 3 types Acanthocephala: 1 type
Gerris oyena (1)	Hatschekiidae: 1 type	

Table 2: Prevalence and mean intensity of infection in *Siganus sutor*

Parasite	Prevalence (%)		Mean intensity	
	I	II	I	II
Tetrancistrum sigani				
Pseudohaliotrema spp.	100	100	97.4	89.8
Microcotyle mouwoi				
Monogenea type 1		14.8		4.3
Caligidae		11.1		7.5
Hatschekiidae	43.7	37.0	9.7	6.8
Gnathiidae	62.5	33.3	5.3	4.2
Opisthogonoporoides sp.	81.8	77.7	168.2	81.3
Gyliauchen papillatus	100	88.8	201.6	92.3
Hexangium sigani	68.2	59.2	21.1	9.8
Digenea type 1		74.1		48.3
type 2		51.8		23.4
type 3		14.8		3.1
Neorhadinorrhynchus sp.	81.8	48.2	2.7	2.3
Procamallanus sp.	90.9	63.0	21.9	11.6

I = market sample (for gill parasites: 32 fishes, intestinal parasites: 22 fishes), mean total length = 24.5 cm (G. Geets & E. Martens)

II = fresh fish catches (27 fishes), mean total length = 15.8 cm (E. Martens & J. Moens)

4.3. SUSTAINABLE MANAGEMENT

4.3.1. The autecology of the mangrove oyster Saccostrea cucullata (von Born, 1778)

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4.3.1.1. Introduction

The mangrove oyster *Saccostrea cucullata* was described for the first time by von Born (1778) as *Ostrea cuccullata*. Because the original spelling *cuccullata* is orthographically wrong von Born (1780) corrected the name to *cucullata*. Following the International Code of Zoological Nomenclature the spelling *cuccullata* can be considered as a *lapsus calami* or unintentional mistake within the meaning of art. 32c ii. This means that *cuccullata* is under consideration for correction to *cucullata* (art. 32d) or emendation (art. 33b ii.). Under these circumstances the name of the author and the date of the original spelling are kept. Dollfus & Dautzenberg (1920) placed this species in the genus *Saccostrea*. So the correct name of the mangrove oyster mentioned is *Saccostrea cucullata* (von Born, 1778).

There exists a lot of confusion about the nomenclature of this species. The two main reasons for this problem are the great variation in form, and the fact that some authors have regarded *Saccostrea* as a junior synonym of *Crassostrea*. The latter is believed to be erroneous, because the two can be distinguished consistently by shell features.

Since 1954 *Crassostrea cucullata* and *Saccostrea cucullata* have been used for the same species. Following the arguments above, preference has to be given to the name *Saccostrea cucullata* (von Born, 1778). *Saccostrea cucullata* is found on the trunk and the stilt roots of mangrove trees and rocky substrata in brackish marine environments. Especially in the mangrove forests, they can be very abundant, and are the dominant species of the fauna.

We studied several aspects of the autecology of *S. cucullata* growth rates, and size and form as related to the distribution within the interidal zone of the Kenyan coast. Results from these studies can now be used in setting up a commercial oyster culture in Gazi Bay.

4.3.1.2. Results

4.3.1.2.1. Size as related to vertical distribution

The littoral oyster *S. cucullata* occurs between 1.05 and 3.35 m above chart datum, with the highest density occurring between 1.85 and 2.75 m. Its distribution is related to size specimens occurring lower in the intertidal zone tend to be larger. To quantify this trend, two studies were carried out. In the first study, a sample of 1470 oysters has been measured on a rocky shore near Mkomani. The second study involved measuring 2825 oysters growing on the trunks and stilt roots of mangrove trees in Gazi.

The Mkomani sample

Oyster were randomly selected in an area of about 4 by 2.5 m, on a vertical rising cliff. Shell lengths (maximum linear dimension) were measured to the nearest 0.1 mm using Vernier callipers. The reduction in size of the oysters is demonstrated by computation of correlation coefficients (r) and regression equations between length (dependent variable) and height (independent variable). Because of the non-linearity of the overall relationship, the data were divided in three groups, according to height above datum. The regression parameters and correlation coefficients are given in Table 1. All correlation coefficients are significant at p = 0.001. Mean length for all oysters in consecutive 10 cm bands are plotted in Figure 1.

Table 1: regression parameters of oyster length versus height above datum; the date have been split into three groups, according to different heights above datum.

Heights	slope	intercept	r^2
1 -1.85	- 6.49	43.64	-.569
1.86-2.75	- 17.14	62.67	-.941
2.76-3.35	- 24.85	91.44	-.899

The Gazi sample

Observations were made along five parallel transects. The first transect was located at the entrance of the main channel. The others were at a distance of approximately 400, 800, 1200 and 1600 m inland. Apart from height above datum, as in the Mkomani study, other factors were taken into account: approximate density of the oyster growth, and proximity to the bottom.

Density of the oyster was estimated by setting out small line transects over the substrate. Density expressed as percentage cover was taken to be the percentage of the length of the line going over oysters. Height above the bottom was measured directly, to the nearest cm.

The results showed that oyster length was weakly correlated (rank correlation) with the approximate density of the oysters. However, for densities equal to and higher than 65 % there was a fairly strong negative correlation. This demonstrates the influence of density on oyster length for densities higher than 70 % cover. The influence increases as density increases, as shown in Figure 2. Other authors have similarly demonstrated that density may affect growth rate and size in littoral bivalves.

Shell lengths of *S. cucullata* are small at a height lower than 0.25 m above the bottom as compared to oysters growing farther from the bottom. This may be due to the higher sediment load closer to the muddy bottom. Because oysters are filter feeders, they may have to expend more energy in filtering the water at lower levels to get an equal amount of food compared to the oysters growing at higher levels.

Table 2: Regression parameters, rank correlation coefficient and sample sizes for regression of length versus height above datum. Oysters growing closer than 25 cm to the bottom, or with a density of larger than 70 %, are not included in this analysis.

Transect	Slope	Intercept	r^2	n
I	-11.671	67.28	.85	543
II	-14.421	70.09	.35	536
III	-11.190	62.31	.75	194
IV	-12.192	62.64	.69	150
V	-13.091	62.46	.69	52

The fairly strong negative rank correlation between oyster length and the height above datum (after removing all oysters growing lower than 0.25 m above the bottom and all oysters growing on substrata with a density higher than 70 % cover) demonstrates that *S. cucullata* exhibits size-related patterns in vertical distribution. This is even more clear when the five transects are studied separately. Regression parameters, correlation coefficients and sample sizes are given in Table 2. A scatter plot for one transect (transect I) is included as Figure 3. The other transects show similar patterns.

Height above chart datum, and thus percentage of time immersed, seems to be the primary factor determining the shell length of the oysters. This relationship is obscured by the influence of crowding and proximity to the bottom. Competition for space is the obvious mechanism by which crowding can influence the length of the oyster shell. The way in which proximity to the bottom influences oyster growth remains to be investigated, but a probable mechanism is the interference of high sediment load with the filter feeding of the oysters. As with the correlation between form and height above chart datum, it seems logical to look for an explanation for the correlation between shell length and the time an oyster is submerged (feeding time).

One problem with harvesting oysters on a commercial basis is their small size as compared to European oysters. From these results it is clear that, in an oyster culture the oysters should be grown as low as possible in the intertidal zone, but keeping a minimum distance of 25 cm from the bottom. This study also demonstrates the importance of keeping the density of the oysters low.

4.3.1.2.2. Growth rates

From our data, the calculated growth curves showed that the growth rate decreased in an upward direction and secondly the growth was fastest before the age varying from 8 to 10 months, after which it slowed with increasing age. At elevation 1.1 m above the Kilindini datum the growth rate ranged from 3.6 to 3.9 mm per month, for oysters that were 8 to 10 months old, and with shell lengths ranging from 31.6 to 34.2 mm. At an elevation of 2.7 m, the growth rate at similar ages ranged from 21 to 22 mm per month with shell lengths ranging from 19.6 to 21.8 mm. The oysters translocate from 1.1 m to 2.9 m showed decreased growth rate which ranged between 2.3 and 2.6 mm per month with shell lengths ranging from 21 to 22 mm at ages between 8 and 10 months. In the inverse experiment, oysters were translocated from a height of 2.9 m to 1.1 m. These oysters grew faster (3.0 to 3.3 mm per month)

and reached a higher shell length (ranging from 26.1 to 33.7 mm) at similar ages than the oysters that had already settled at 1.1 m and were translocated to 2.9 m. Growth rates and shell lengths on different heights are summarised in table 3.

Table 3 : Growth rate of oysters on heights above datum. Initial height and final height refer to height above datum before and after translocation, respectively.

Initial height	Final height	Growth range	Length range
1.1	1.1	3.6 - 3.9	31.6 - 34.2
2.7	2.7	2.1 - 2.2	19.6 - 21.8
1.1	2.9	2.3 - 2.6	21.0 - 22.0
2.9	1.1	3.0 - 3.3	26.1 - 33.7

S. cucullata commonly settled between 1.0 end 3.0 m above datum with profuse settlement below 2.0 m. Settlement below 1.0 m was hampered by the prolific growth of hydrozoans, bryozoans, sponges, and the annelids, *Serpula* sp. and *Spirobis* sp. The barnacles settled profusely between 1.6 and 3.2 m above chart datum with *Eurpahia withersi* confined to the highest levels between 2.4 and 3.2 m.

From these observation it is clear that the nuisance of fouling by barnacles can be reduced if the oysters are cultured between 1.0 and 1.7 m above datum where advantageously the growth rate of the oysters is even faster. The nuisance of self-fouling by the oysters can be tackled by mechanical destruction of the spat within two months after the short and long rains, thereby encourage fastest growth.

4.3.1.2.3. Form in relation with several environmental parameters

For this aspect of the autecology of *S. Cucullata*, we made observations on 85 oyster shells. Apart from recording observations necessary to describe the form, the following environmental factors were recorded: height above datum, height above bottom, diameter of the substrate on which the oyster was growing, density, and species of the mangrove tree serving as substrate. In a first approach the shell form was described using a single variable, the second approach involved a description of the shell form by Fourier analysis.

Shell form: univariate method

The form of the oyster shell, as seen in a projection, was described by a shape factor SF = pc/p. p is the circumference of the oyster, pc is the circumference of a circle with the same area as the oyster. Defined in such a way, SF will vary inversely with the irregularity of the oyster; an oyster that is more or less circular will have SF approximately equal to, but always less than, unity. If the outline of the oyster is very irregular, if the oyster grows large, winglike projections, SF will be lower.

Rank correlation of Sf with height above chart datum was -0.726 ($p < 0.01$; $n = 85$), leading to the conclusion that the form of the oyster is more irregular when growing higher in the intertidal zone. Typical oyster forms are drawn in Figure 5. Figure 5.1 and 5.2 are oysters growing high in the intertidal zone, 5.3 and 5.4 came from a lower spot. A possible explanation for this phenomenon is that *S. cucullata* tries to enlarge the contact surface between the seawater and its phenomenon is that *S. cucullata* tries to enlarge the contact surface between the seawater and its gills. This would enable oysters which are in the water for a short period to collect as much food as oysters which are submerged in the water for a longer period.

Shell form: Fourier analysis

We calculated Fourier coefficients for the outlines of the same 85 oyster shells. Those coefficients were used in a cluster analysis. It is clear from the results that the form of the oyster shell is influenced by both height above datum and the diameter of the substrate: oysters that were collected from the same tidal level tended to cluster together, as did oysters growing on substrates of the same diameter. The results of the cluster analysis are given in Figure 4. 'Misclassifications' were defined as oysters that clustered together with oysters growing on different tidal levels, and/or oysters growing on different diameter substrate. They are represented in Figure 4 as capital, rather than lower case characters.

Height above datum has the most important influence, as reflected in the fact that the two groups were separated at the highest level of distance. Differences of form resulting from differences of diameter of the substrate were smaller. The number of misclassifications for this last environmental variable was small in this study, but this was caused by the way in which the sampling was performed: sampling was done on the complete range of tidal level, but only on the extremes for substrate diameter.

The distinction between these four groups can be related to the appearance of the oysters. Oysters growing on small diameter substrates are more elongated than the ones growing on large diameter substrate. This allows them to attach a large portion of their shell to the substrate and improves the structural strength of the shell. Typical oysters for the four different environmental conditions are given in Figure 5.

Orientation with respect to main tidal current was treated in the same way as the two environmental parameters discussed above. Orientation seems to have a weaker, but still clear influence on the form. This is also apparent from a visual inspection of the outline of the oysters, as demonstrated in Figure 6. Oysters growing perpendicular to the tidal current often have lobes all around their outline, as opposed to oysters growing parallel to the current, which have lobes mainly on one side.

This study has demonstrated the existence of a relationship between environmental parameters and the form and size of the oysters. The next step in research should be the construction of a functional model to investigate the causal relationship between shell morphology of *S. cucullata* and the environmental variables.

4.3.1.3. List of publications

Okemwa, E, R.K. Ruwa & P. Polk, 1986. The autecology of the edible oyster *Crassostrea cucullata* Born, 1778: size related vertical distribution at Mkomani, Mombasa. Kenya Journal of Sciences Series B 7(2): 9-14.

Ruwa, R.K., 1988. Towards improving shellfish production through appropriate techniques in the culture of the edible oyster, *Crassostrea cucullata* Born. In: Proceedings of the UNESCO/UTAFITI Workshop on the Ecology and Bioproductivity of the Marine Coastal Waters of Eastern Africa, University of Dar-es-Salaam, Tanzania, 18-20 January 1988, PP. 66-74.

Ruwa, R.K., 1990 & P. Polk, (in press). Patterns of spat settlement of the tropical oyster *Crassostrea cucullata* (Born, 1778) and the barnacle, *Balanus amphitrite* (Darwin, 1854) in a mangrove creek. Tropical Zoology.

Tack J.F., E. Vanden Berghe & P. Polk, 1992. Ecomorphology of *Crassostrea cucullata* (Born, 1778) (Istreudae) in a mangrove creek (Gazi, Kenya). Hydrobiologia 247, 109-117.

4.3.1.4. List of presentations of conferences

Vanden Berghe, E., E. Martens and P. Polk, 1988. The form of the oysters in relation to the form of the substrate. Generation of a hypothesis. 1st HYSEA Conference, Nairobi, December 1988.

Vanden Berghe E, P; Polk and M. Poznanski, 1988. The form of the oysters in relation to the form of the substrate: Test of a hypothesis. 1st HYSEA Symposium, Nairobi, December 1988.

Tack J.F., E. Vanden Berghe and P. Polk, 1990. Size of the Mangrove oyster *Crassostrea cucullata* (Ostreidae) in a mangrove creek (Gazi, Kenya) in relation to environmental parameters. Symposium 'The ecology of mangroves and related ecosystems', Mombasa, September 1990.

Vanden Berghe, E., Tack J.F. and P. Polk, 1990. Variations of form of *Crassostrea cucullata* as related to environmental parameters. Symposium 'The ecology of mangroves and related ecosystems'; Mombasa, September 1990.

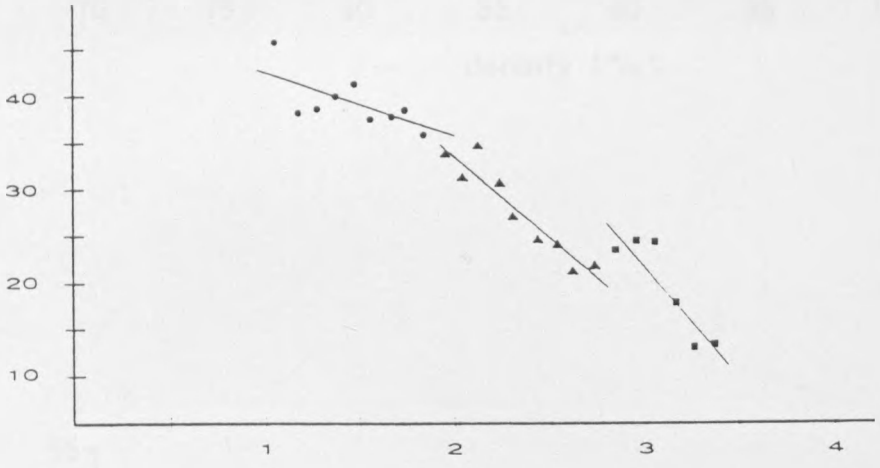


Figure 1 : Density and relationship between mean shell lenghts of S. cucullata and shore levels (elevation) above datum.

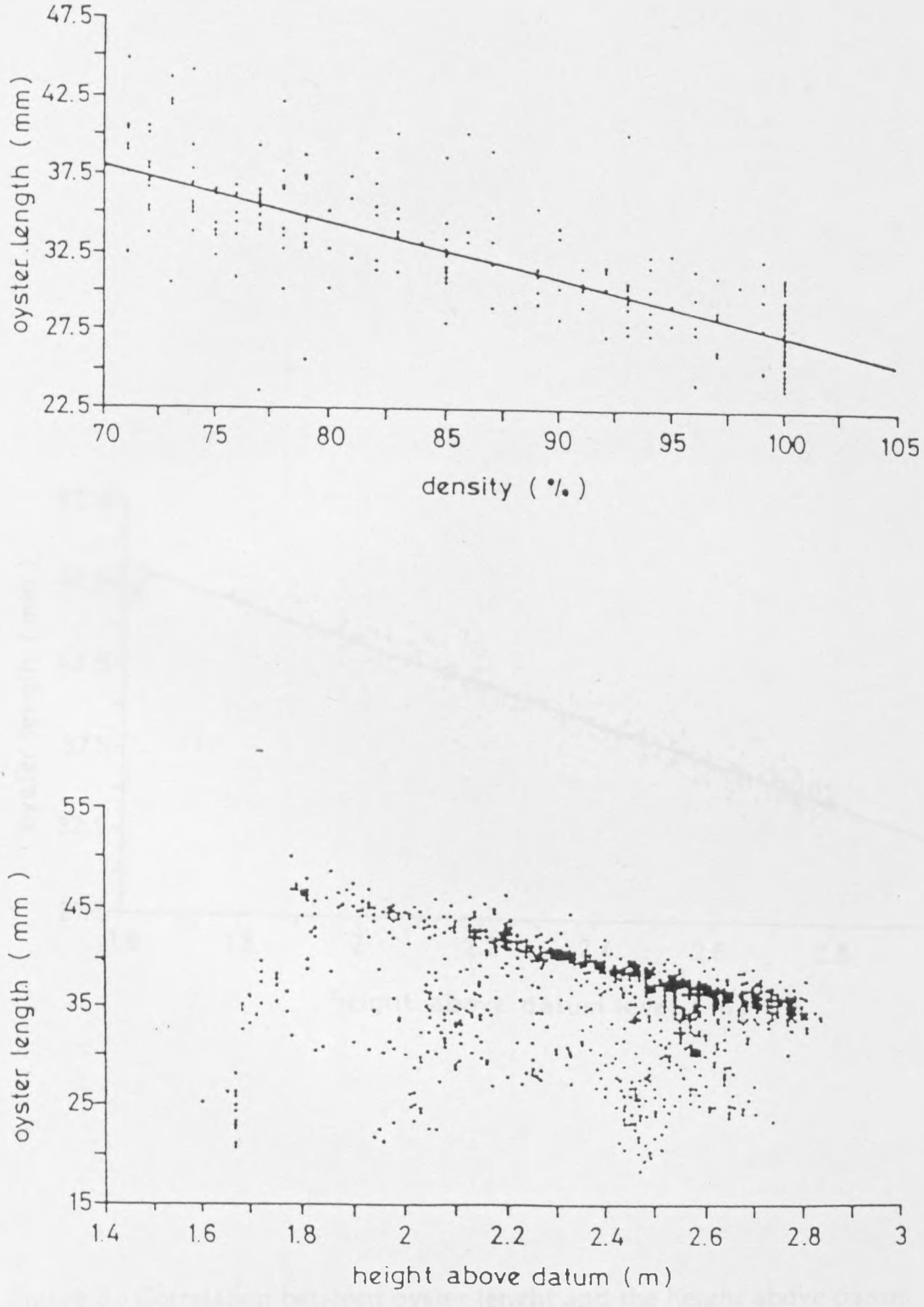


Figure 2 : Influence of density and height above datum on oyster lenght.

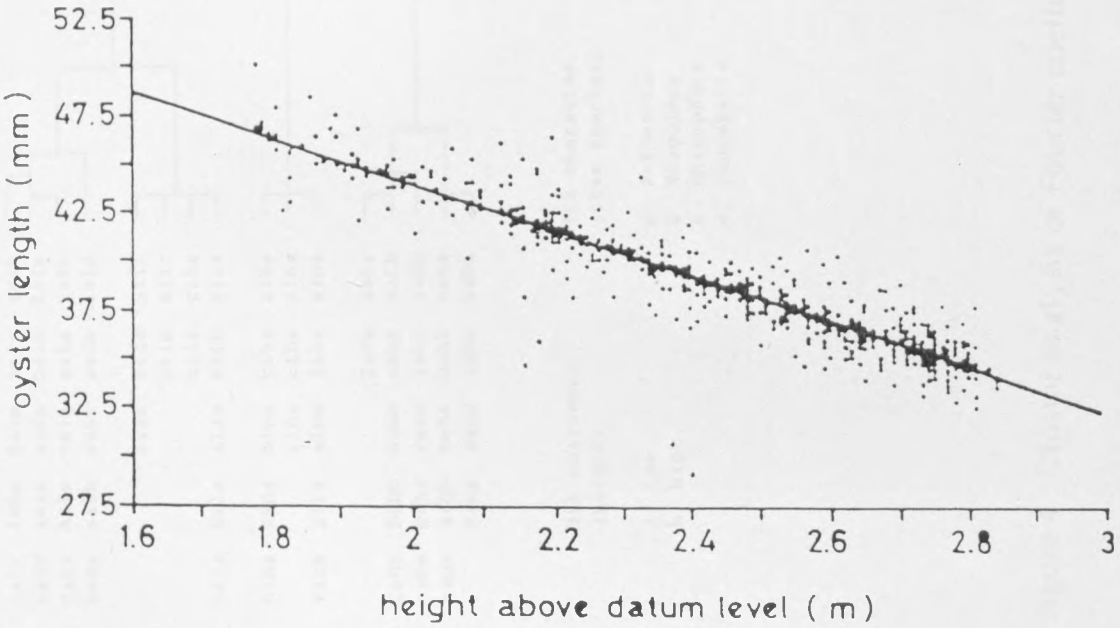
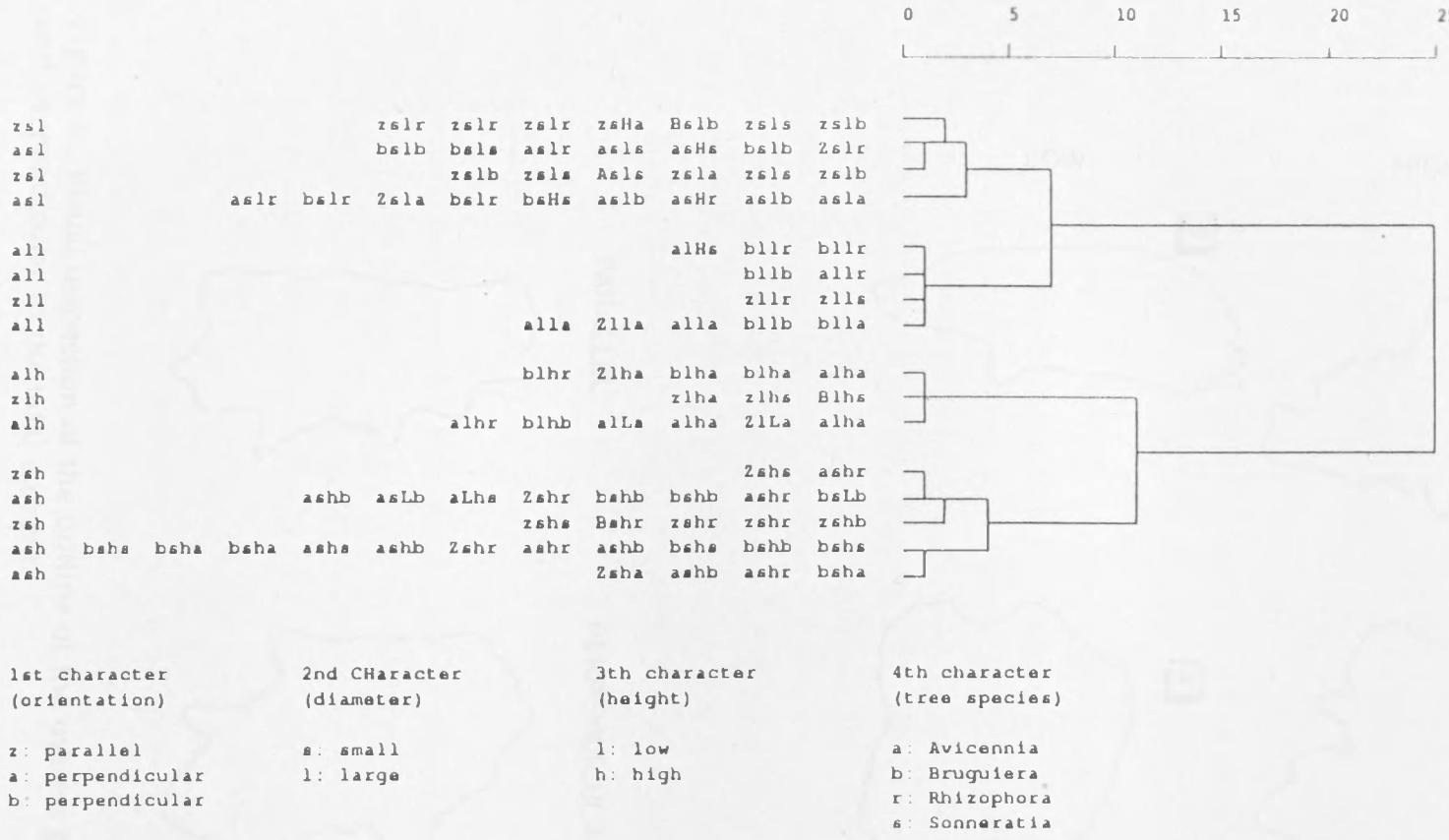


Figure 3 : Correlation between oyster lenght and the height above datum.



1st character (orientation)

z: parallel
a: perpendicular
b: perpendicular

2nd CHaracter (diameter)

s: small
l: large

3th character (height)

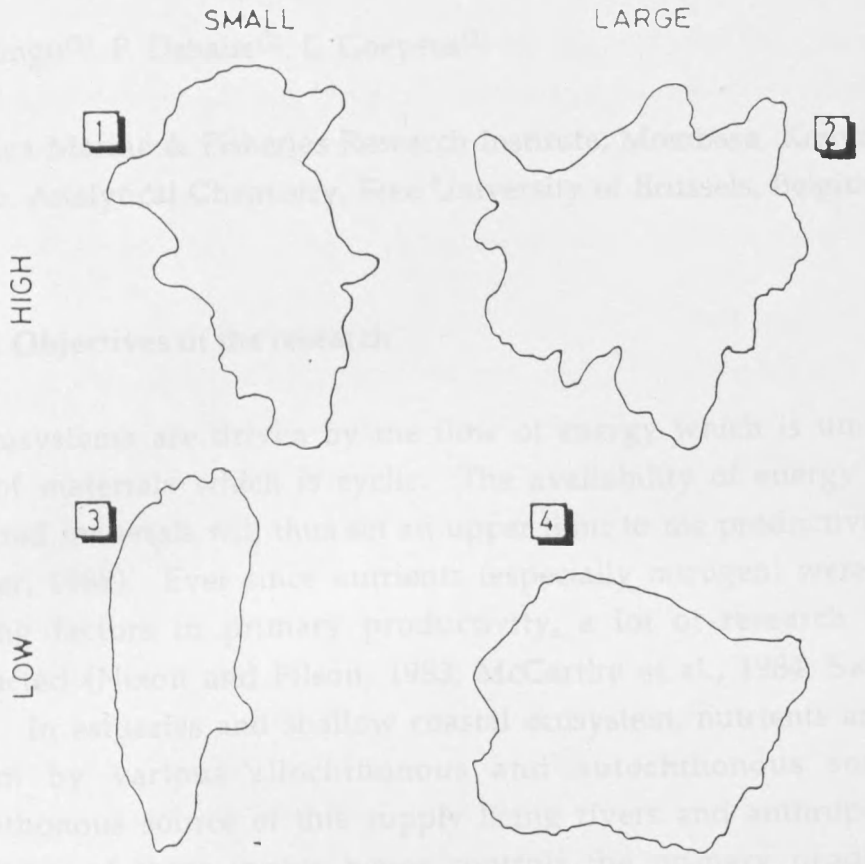
l: low
h: high

4th character (tree species)

a: Avicennia
b: Bruguiera
r: Rhizophora
s: Sonneratia

Figure 4 : Cluster analysis of Fourier coefficients

Figure 5 : Typical oyster forms



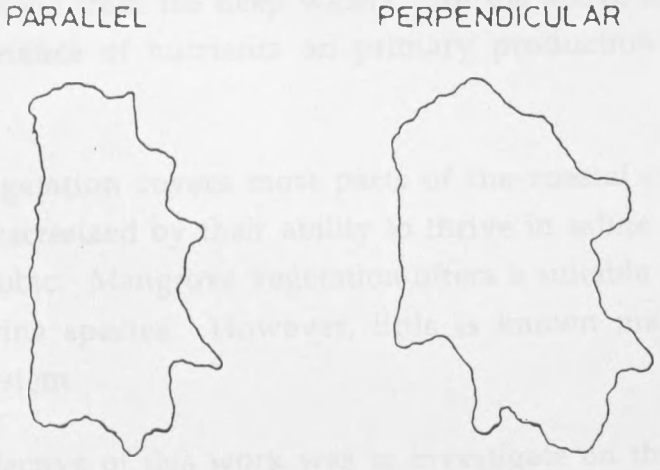


Figure 6 : Visual inspection of the outline of the oysters growing parallel and perpendicular to the tidal current.

4.4. BIOGEOCHEMICAL CYCLES

4.4.1. Distribution of nutrients and particulate organic material in Gazi Bay

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4.4.1.1. Objectives of the research

All ecosystems are driven by the flow of energy which is unidirectional and the flow of materials which is cyclic. The availability of energy and the cycling of restricted materials will thus set an upper limit to the productivity of the ecosystem (Selmer, 1988). Ever since nutrients (especially nitrogen) were cited as the major limiting factors in primary productivity, a lot of research on them has been conducted (Nixon and Pilson, 1983; McCarthy et al., 1984; Sweeney and Kaplan; 1980). In estuaries and shallow coastal ecosystem, nutrients are supplied into the system by various allochthonous and autochthonous sources. The main allochthonous source of this supply being rivers and anthropogenic inputs. The variations of these inputs hence controls the primary production of a coastal ecosystem. In the open sea, primary production is mainly controlled by the supply of regenerated (autochthonous) nutrient supply (Glibert, 1988). Upwelling regions are usually associated with high primary productivity and active fisheries activity. This high production is usually due to the allochthonous input of nutrients into the euphotic zone from the deep waters. All the above mentioned examples stress on the importance of nutrients on primary production and ultimately fisheries distribution.

Mangrove vegetation covers most parts of the coastal creeks in tropical regions. They are characterized by their ability to thrive in saline inter tidal areas that may also be anaerobic. Mangrove vegetation offers a suitable shelter for many different types of marine species. However, little is known material (POM) distribution within the system.

The main objective of this work was to investigate on the distribution of nutrients in mangrove ecosystem in order to assess the importance of mangroves in the supply of dissolved nutrients.

4.4.1.2. Materials and methods

b) sampling

Figure 1 shows the sampling stations established within the study site. Stations G1, G2, G3 and G4 and G4 are sampling stations along the Gazi creek while stations K1, K2 and K3 are stations along river Kidogoweni. Station M was established at the entrance of Mkurumuji estuary to monitor the inter tidal fluctuation of nutrients and particulate organic material entering the Bay through the estuary.

Water samples for nutrients (NO_3^-, PO_4^{3-} and SiO_4^{3-}) determination from the water column were collected in 100 ml plastic sampling bottles and fixed immediately with about three drops of chloroform before storing in cool boxes pending transportation to the laboratory. At the laboratory the determinations were done by a Technicon Autoanalyzer II system using the standard methods of Armstrong et al. (1967) and Chan and Riley (1970). Salinity determinations were performed using the Knudsen titration methods where the water samples are titrated against standardized silver nitrate solution.

For Particulate Organic Material (POM) samples, one to two litters of the water from the particulate station was filtered onto pre-combusted Whatman GF/F filters. The filters were stored in petri-dishes in cool boxes pending transportation to the laboratory where they were dried at 80 °C for 24 hrs. These samples were latter stored in desiccators and eventually taken to Free University of Brussels for carbon, nitrogen and carbon isotope analysis. The carbon and nitrogen analysis were done using a Carlo Erba NA1500 Nitrogen Analyzer with acetanilide as standard while the carbon-isotope measurements were performed using the same equipment in line with a Finnigan Mat Delta E mass spectrometer interfaced with a Finnigan Mat trapping box.

Carbon-13 abundance is expressed in δ units where

$$\delta^{13}C\,‰ = \left[\frac{(^{13}C/^{12}C)\text{sample}}{(^{13}C/^{12}C)\text{standard}} - 1\right] x1000$$

The standard value against which all measurements are referenced is the one for PDB carbonate.

4.4.1.3. Results and discussion

River Mkurumuji is established to contribute positively in the supply of dissolved nutrients into Gazi Bay during the rainy season. Figures 2a - 2d display various profile of parameter observed at the mouth of Mkurumuji estuary during a six-hour time series conducted during rainy season (mid-May 1991). It is seen that at low tide (indicated as t = 0 hr) salinity values were very low (< 1.0 ‰) while between the third and forth hour the values changed to ca. 34.0 ‰ (Figure 2a). The same trend was noticed for the nutrients profiles. At low tide, phosphate, nitrate and silicate concentrations were relatively higher than observed during the high tide.

Phosphate concentrations changed from about 3.2 µg at-P/l to values below 1.0 µg at-P/l (Figure 2b) during the change from low tide to high tide. Nitrate concentrations changed from about 4.5 µg at-N/l to about 1.0 µg at-N/l while silicate changed from about 160 µg at-Si/l to ca. 30 µg at-Si/l during the same 24-hr period . Time series conducted at the same station two weeks latter confirmed the same features. At high tide (indicated as t = 0 hr) salinity values were ca. 33 ‰ (Figure 3a) which decreased to < 1.0 ‰ at low tide (t = 6 hr). However, it was strange to note that at the second expected high tide (t = 12 hr) there was no significant change in salinity values. A significant change came at the repeat of the entire tidal cycle (t = 24 hr) when the salinity was again observed to raise to ca. 33 ‰. Nutrient profiles (Figure 3b, 3c, 3d) are seen to exhibit the same features. While relatively high nutrient values were noticed at t = 6 hr corresponding to low tide, these values were not changed significantly during the second high tide (t = 12 hr). Dissolved oxygen profile (Figure 3c) indicated the same feature as that observed for salinity. The two extreme high tides (t = 0 hr and t = 24 hr) had water with relatively higher D.O. values (ca. 6.8 ml/l) while values at the two low tides (t = 6 hr and t = 18 hr) and the second high tide (t = 12 hr) were lower at ca. 3.5 ml/l associated with the Mkurumuji river contribution. 24-hr time series conducted earlier during the dry season (March 1991) also displayed some similar features as those noticed during the rainy season. However there was no significant contribution of dissolved nutrients by the river into the bay. Nitrate and phosphate concentrations were both below 1.0 µg at/l even during low tide. Salinity profile showed that at high tide salinity values were ca. 35 ‰ which decreased to about 30 ‰ at low tide. At the second high tide (t = 12 hr), no significant change was observed.

Hourly tidal height measurements taken during the 24-hr time series of May 1991 (Figure 3 - 7) indicates that there was a tidal height difference of about 1.0 metre between the first and second high tide (or second and third high tide). It therefore seems that the extra water brought in by the first and third high tide is responsible

for the significant changes. Otherwise during the second high tide, it is only water within the Bay and its environs that is pumped up the estuary. This observation is also supported by stable carbon isotope studies involving particulate organic matter (POM). Carbon isotopic composition of POM is gaining popularity as a tool of investigating organic matter flow pattern in many estuaries (Fleming, et al., 1990; Rezende, 1990; Gebauer and Schulze, 1991). Checking the $\delta^{13}C$ values against time (Figure 5), we also see that the second high tide (t = 12 hr) had no effect on the carbon isotopic values. $\delta^{13}C$ values (ca. - 20.0 - 21.00 ‰) characteristic of marine waters (Rezende, 1990) were noticed during the first and third high tide. At low tide, $\delta^{13}C$ values were found to be between - 25.0 ‰ and - 26.0 ‰ which is characteristic of POM dominated by mangrove influence (see section 4.4.2.3.). There was no significant change between the low tide and the second high tide (Figure 5).

Salinity and nutrient profiles (average values for May and June) observed in River Kidogoweni (Figure 6a - d) indicates that the rive acts as an additional input of nutrients into the Bay during the rainy season. During the dry season the river had insignificant effect.

Figure 7a - d shows the average salinity and nutrient profiles observed in Gazi creek during the rainy season (May) and dry season (January/February/March). Salinity values increases from about 35.5 ‰ at station G1 to about 36.5 ‰ at station G4 during the dry period. This increase is most probably due to evaporation as the creek gets shallower towards station G4. During the rainy season salinity values ranges from about 33 ‰ at station G1 to about 22 ‰ at station G4, marking the significant influence of river Kidogoweni. Silicate concentrations along Gazi creek are shown to be around 20 µg at-Si/l throughout the creek during dry season. However during the rainy season, there is a steady increase from about 30 µg at-Si/l at station G1 to about 150 µg at-Si/l at station G4. Nitrate and phosphate values were also observed to be low throughout the creek during the dry season as compared to the rainy season (Figure 7c and 7d). The reduced nitrate and phosphate values at station G2 and G3 could be due to higher uptake rate by primary producers. This would be checked latter with labelled nitrate compounds.

Table 1 shows the $\delta^{13}C$ distribution of POM in Gazi creek during the dry season (January 1991). A progressive decrease of $\delta^{13}C$ values is noticed from station G1 to G4. Since marine POC has been shown to have a characteristic value of - 20.50 ‰ and mangrove POC having a value of - 26.77 ‰ (see section 4.4.2.3.) it is clearly seen that there is a progressive influence of mangrove contribution as one moves deeper into the creek.

Table 1: $\delta^{13}C$ (‰) distribution of POM in Gazi creek during the dry season (January 1991).

Station	G1	G2	G3	G4	K1	K2
$\delta^{13}C$ (‰)	-21.74	-23.15	-23.20	-25.83	-25.52	-25.20

Table 2 displays $\delta^{13}C$ values of POM at station G3 on a six-hour time series during a dry period (October 1992). Whereas at high tide (t = 0 hr) the $\delta^{13}C$ values indicated marine POC dominance (relatively high values) at low tide (t = 6 hr) $\delta^{13}C$ values characteristic of mangrove POC dominance were observed as the water was moving out. This means mangrove detritus is exported out of the system both during the wet and dry season.

Table 2: $\delta^{13}C$ (‰) values of POM at station G3 on a six-hour time series during a dry period (October 1992). t = 0 hr corresponds to high tide while t = 6 hr corresponds to low tide.

Time	t = 0	t = 1	t = 2	t = 3	t = 4	t = 5	t = 6
$\partial^{13}C$ (‰)	-20.93	-21.07	-20.98	-22.08	-23.99	-24.23	-24.51

4.4.1.4. Conclusion

Though mangrove ecosystems are very important as safe grounds for many different types of marine species, no clear evidence has emerged to indicate that mangroves supply significant contribution of dissolved nutrients into the system. In Gazi Bay, rivers Mkurumuji and Kidogoweni have been shown to supply dissolved nutrients into the bay during rainy season. When this supply is minimized during the dry season, dissolved nutrient levels are also found to decrease significantly. Time series study of POM and nutrients at the mouth of the Mkurumuji estuary indicates that nutrients and particulate organic material supplied into the Bay during low tide are not washed out of the system immediately. Some of the material is in fact pumped back into the estuary during the following high tide hence creating a to and from movement of materials at the bay before it is eventually washed out. This is confirmed by the $\delta^{13}C$ analyses of

POM at the entrance of river Mkurumuji in which $\delta^{13}C$ values associated with mangroves and low tide waters not changed, significantly during the following high tide with relatively low tidal amplitude.

Though the supply of nutrients by the rivers into the Bay was found to be very minimal during the dry season, time series study both at river Mkurumuji entrance and in Gazi creek indicated that mangrove detritus are exported out of the system throughout the year. This therefore implies that mangrove ecosystems export out nutrients in particulate phase and not inorganic dissolved phase as suggested by Ong'anda's (1992) modelling studies explained elsewhere in this text (section 7).

4.4.1.5. Future work

Though the mangrove system has been established to have very low dissolved nutrients, there is a higher probability that this could be a result of relatively high uptake of dissolved nutrients within the system. Vertical profiles of nutrients within the mangrove sediment system indicates very high (almost 6.0 times higher) nutrient concentrations in sediment as compared to ambient values within the water column. Assuming that these nutritional elements eventually diffuses out of the sediment, the mangrove systems are thus expected to have higher nutrients levels than those observed. The next phase of this project should be focused on fluxes of the nutrients between the sediment and water phase. This study should integrate remineralization rate of organic material in the mangrove system and uptake rates (or removal rates) of these elements. Stable nitrogen-15 isotope studies will be very useful for this investigation.

4.4.1.6. References

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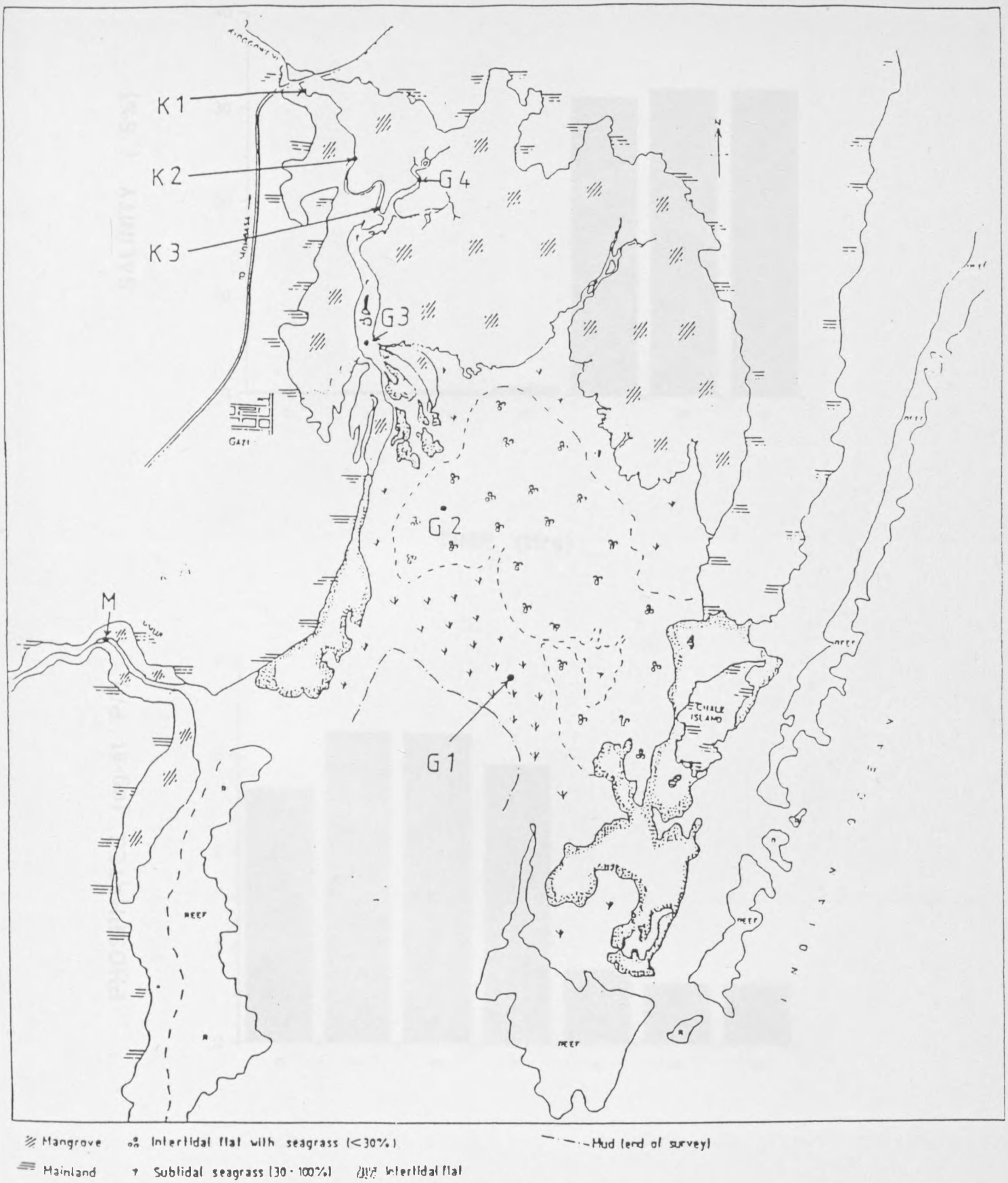
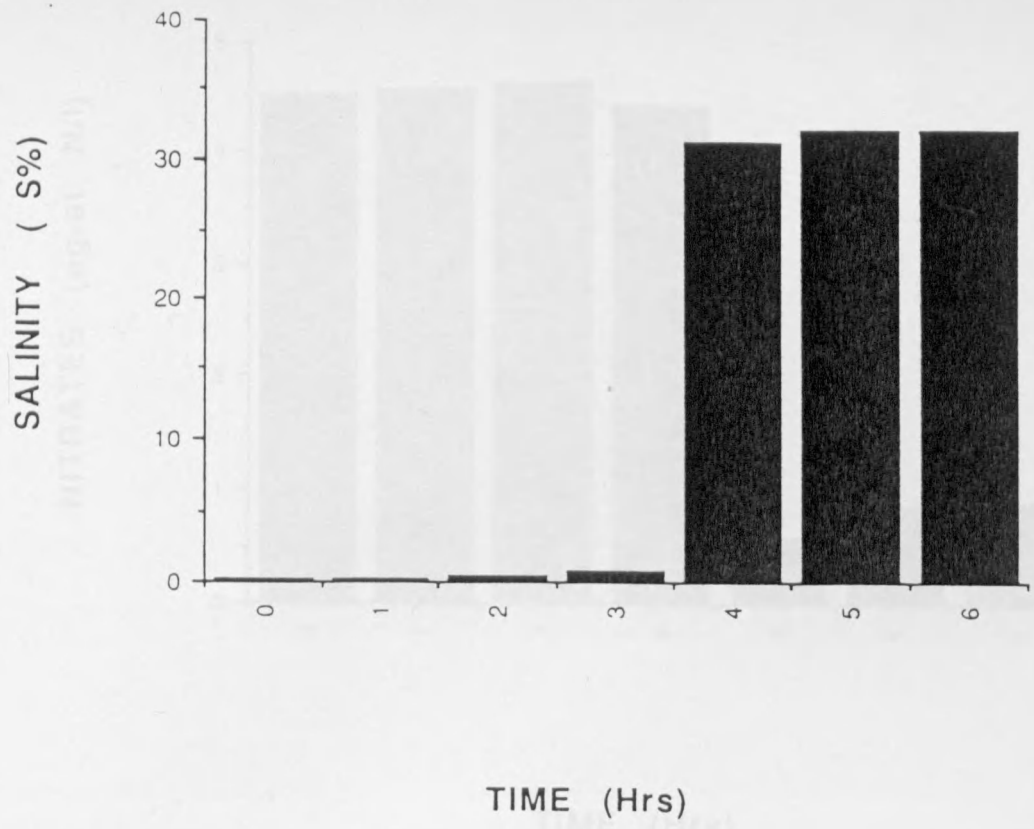


Figure 1 : Sampling stations established within the study site



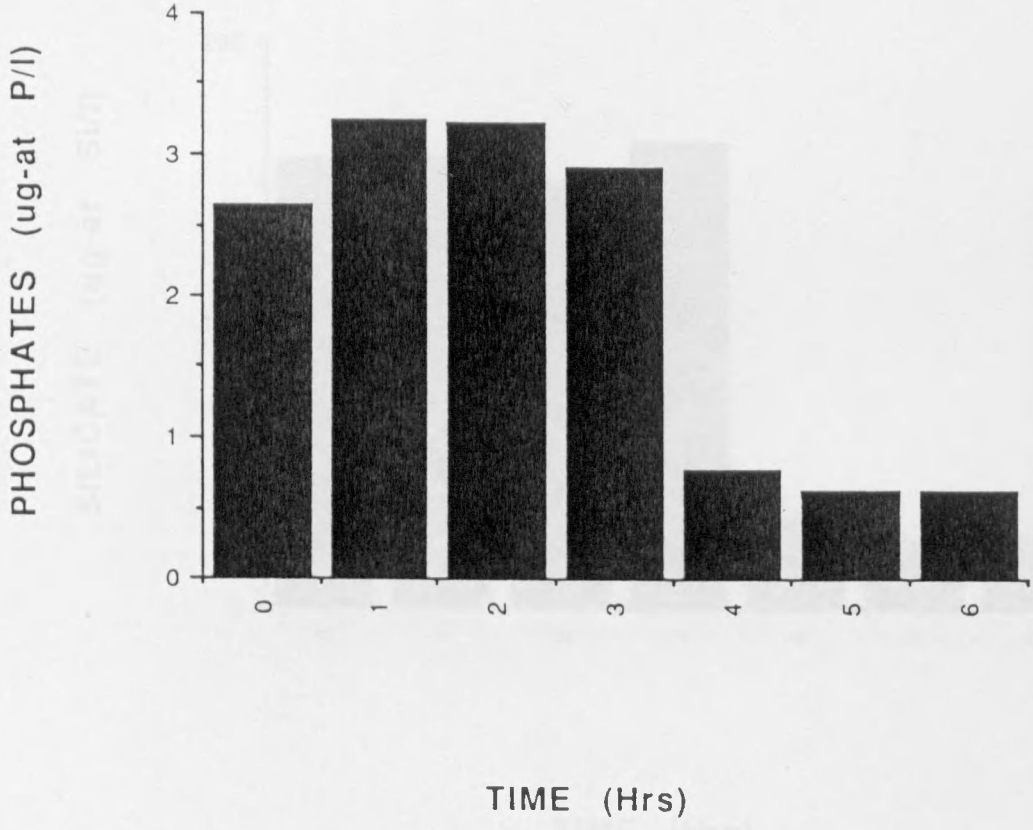
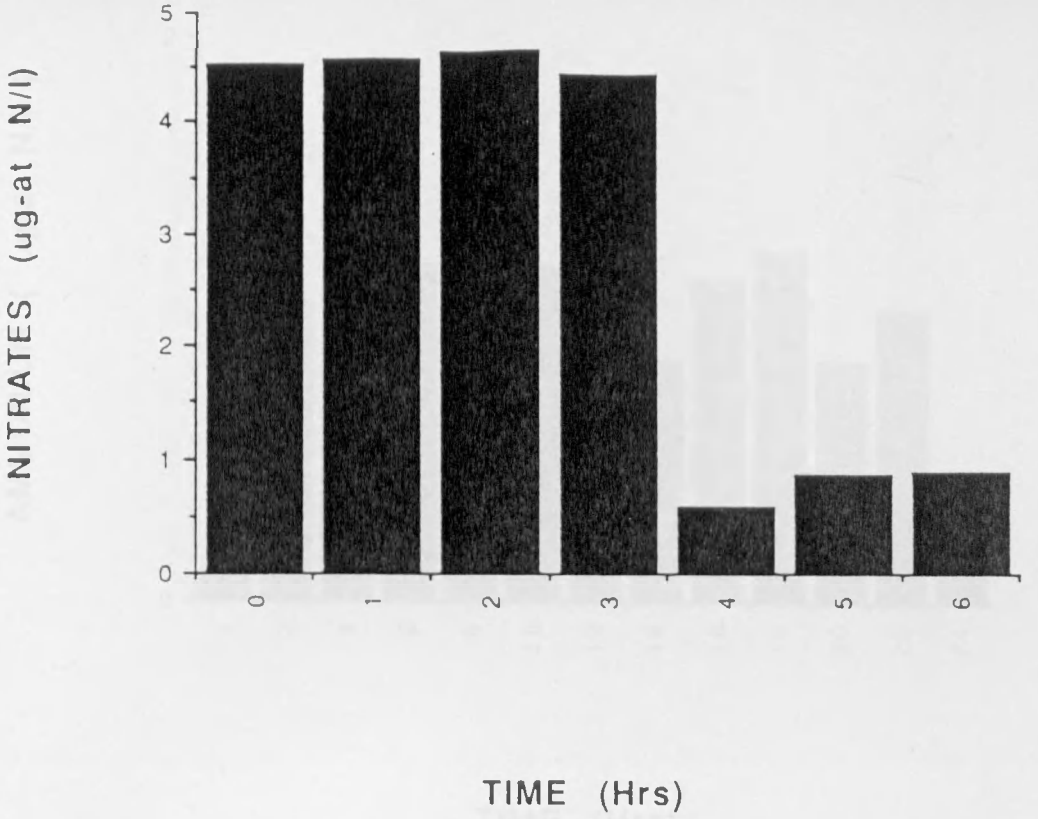


Figure 2 a, b : Salinity and Phosphate profiles respectively at station M during a six hours sampling series of mid-May 1991.
(t = 0 hr corrsponds to low tide while t = 6 hr corrsponds to high tide)



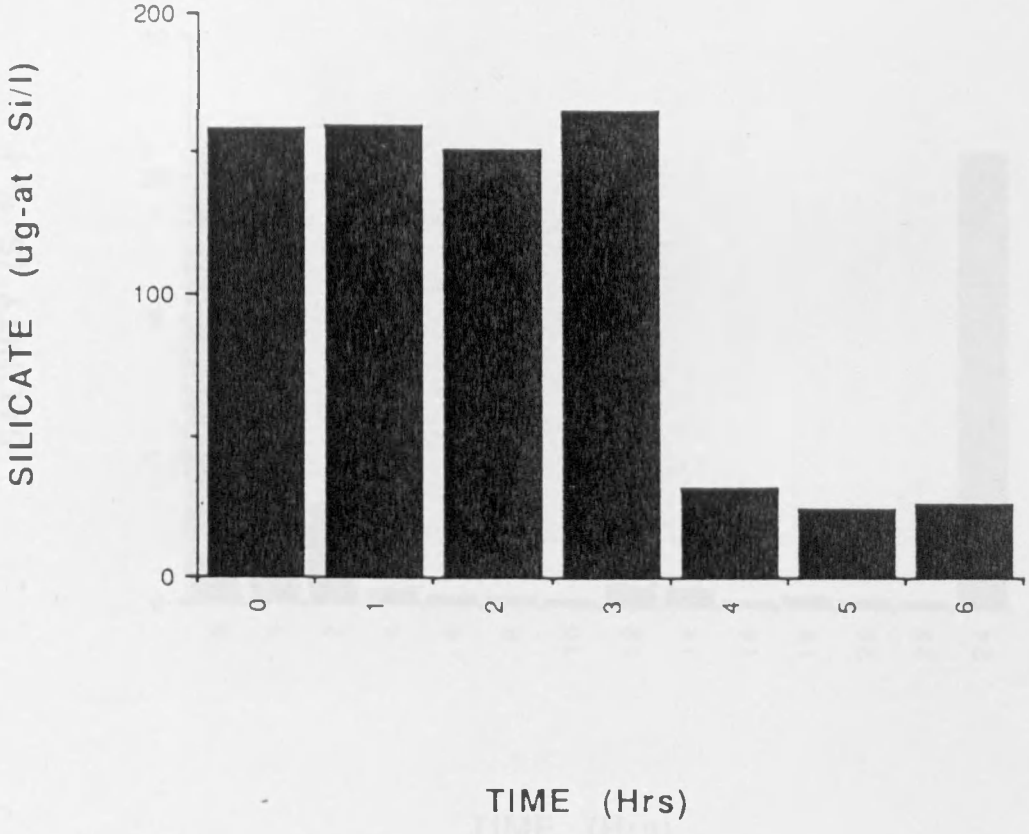
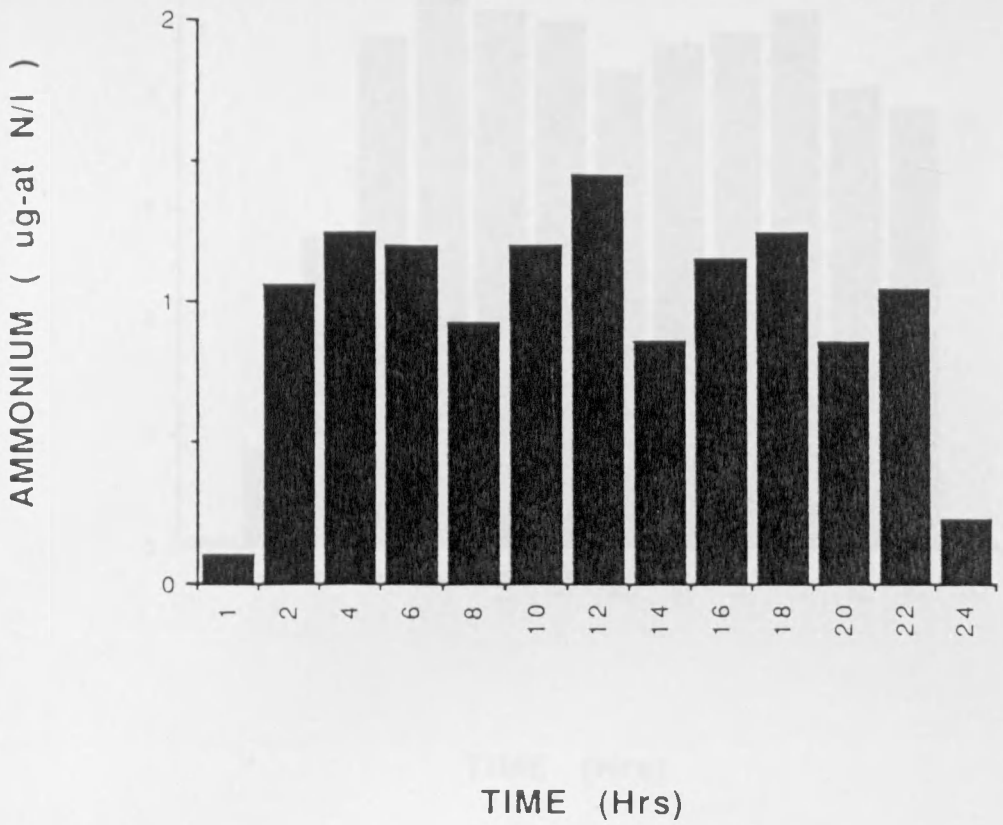


Figure 2 c, d : Nitrate and Silicate profiles respectively at station M during a six hours sampling series of mid-May 1991.
(t = 0 hr corrsponds to low tide while t = 6 hr corrsponds to high tide)



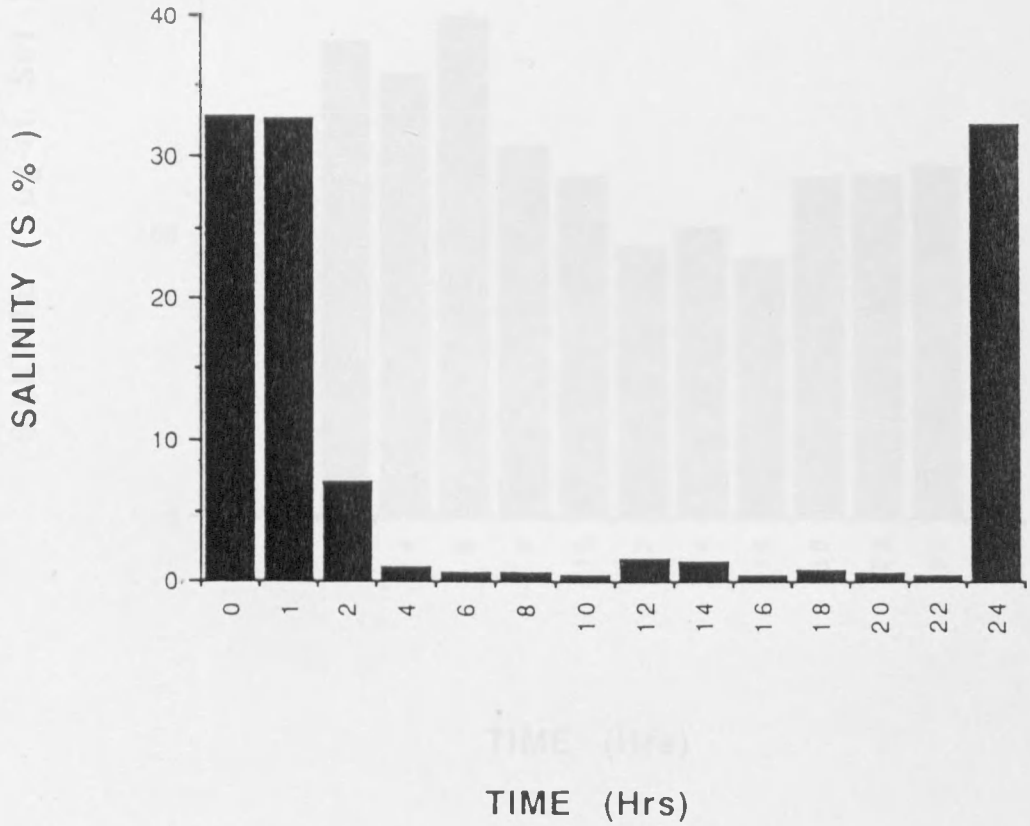
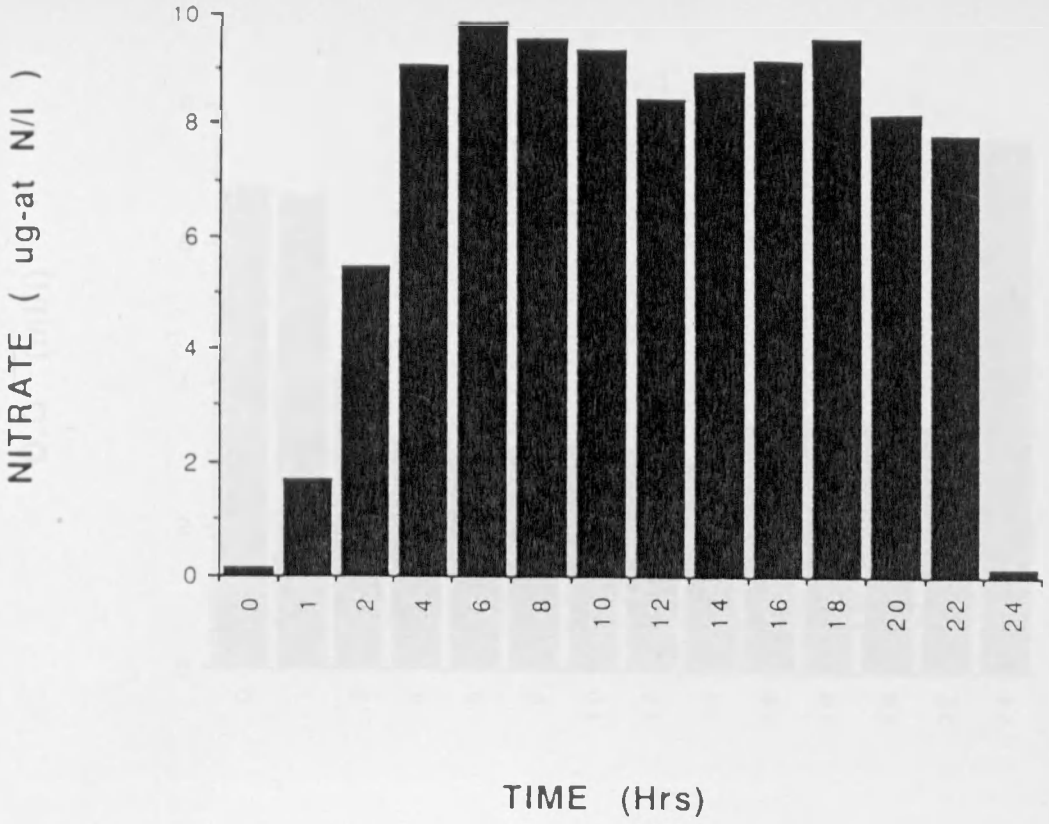


Figure 3 a, b : Ammonium and Salinity profiles respectively at station M during a 24 hours sampling series of 29-30 May 1991.
(t = 0 hr, t = 12 hr and t = 24 hr corresponds to 1st, 2nd and 3rd high tides)



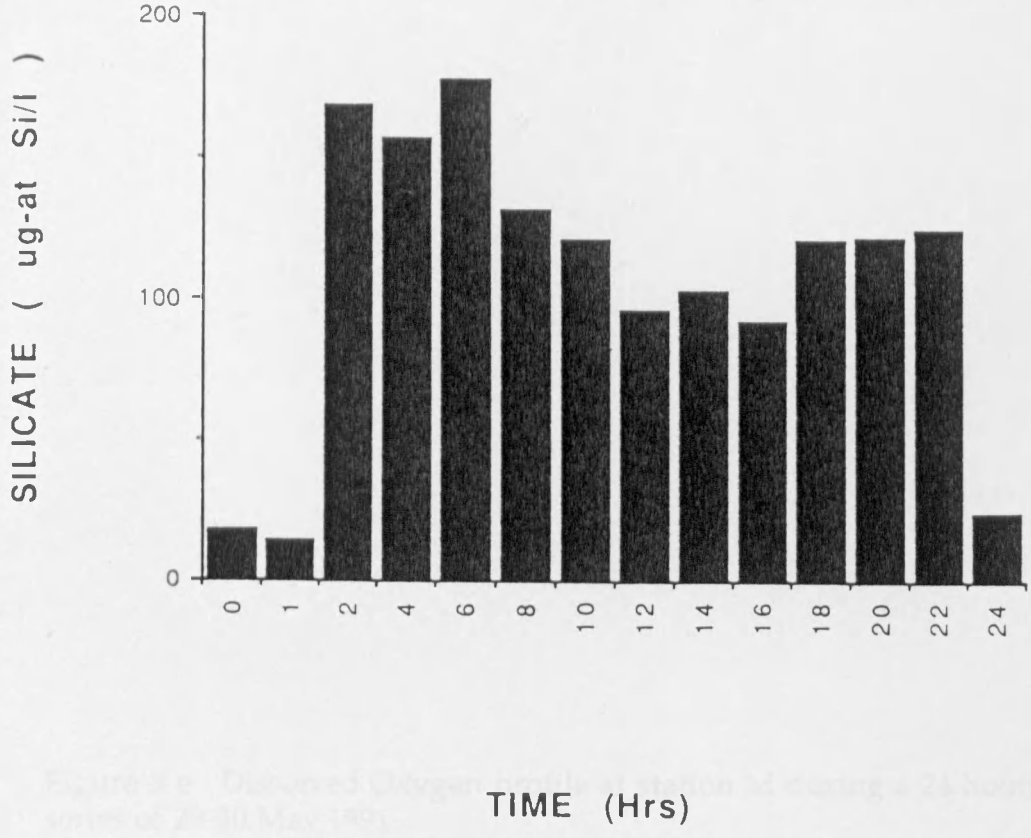


Figure 3 c, d : Nitrate and Silicate profiles respectively at station M during a 24 hours sampling series of 29-30 May 1991.
(t = 0 hr, t = 12 hr and t = 24 hr corresponds to 1st, 2nd and 3rd high tides)

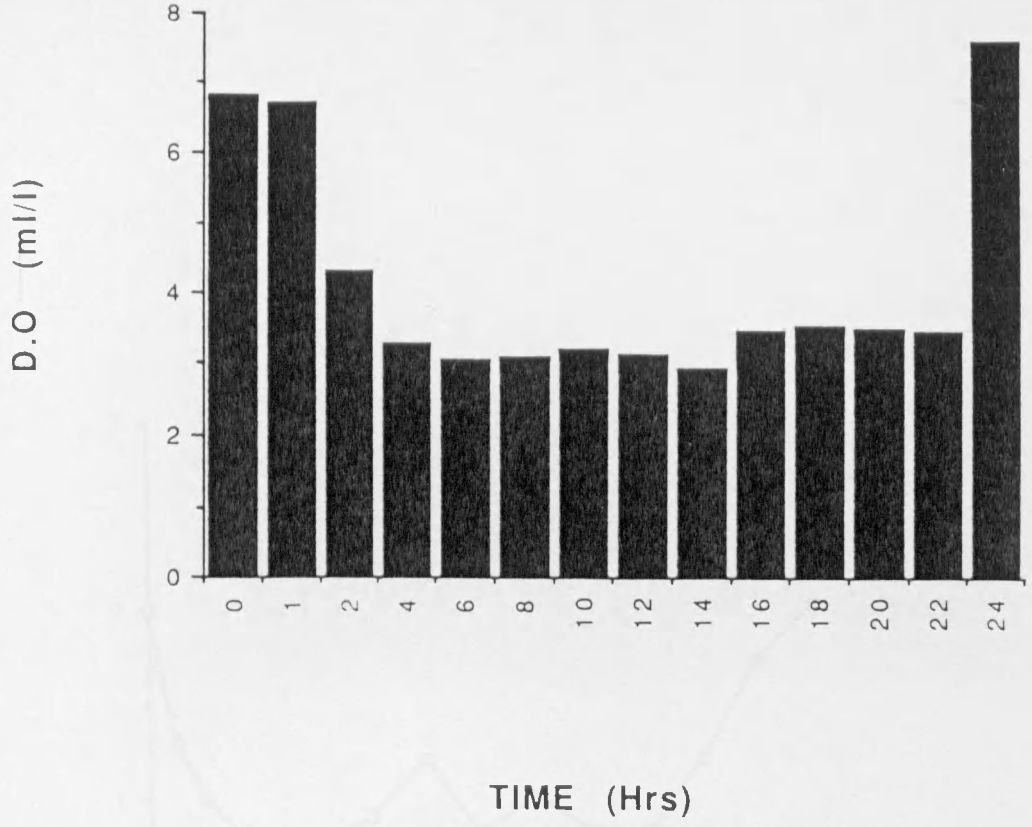


Figure 3 e : Dissolved Oxygen profile at station M during a 24 hours sampling series of 29-30 May 1991.
(t = 0 hr, t = 12 hr and t = 24 hr corresponds to 1st, 2nd and 3rd high tides)

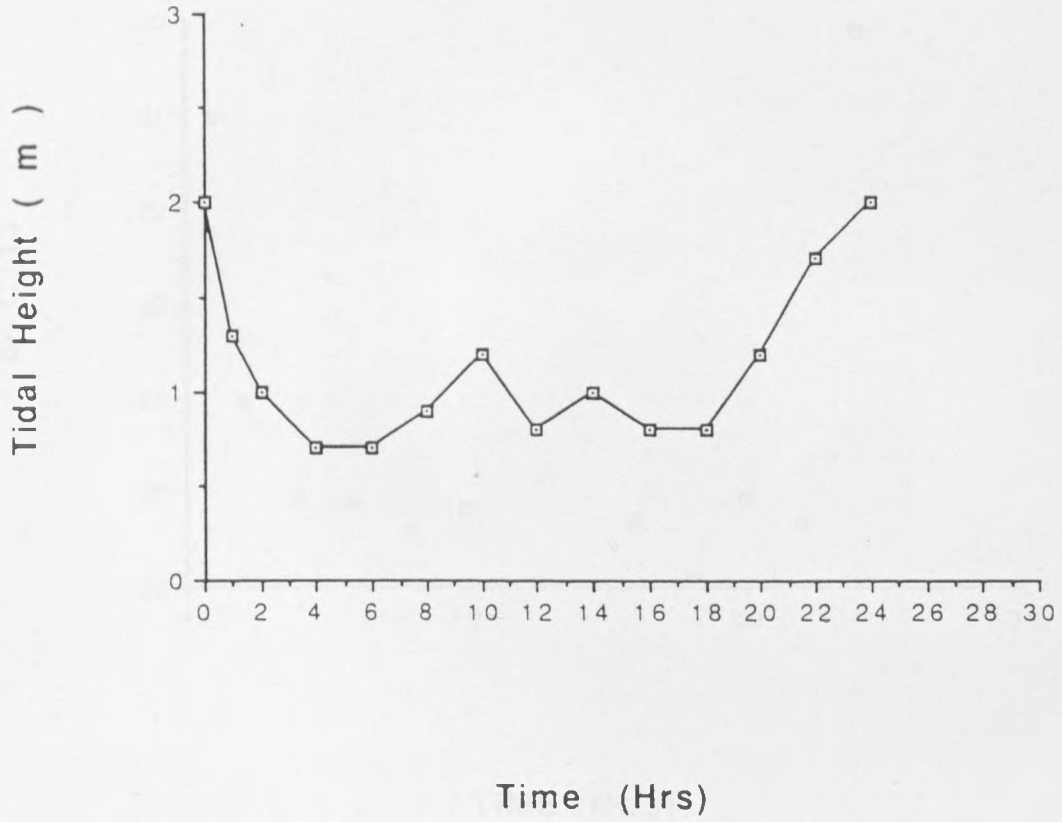


Figure 4 : Hourly tidal height measurements taken during the 24 hr sampling series of 29-30 May 1991.

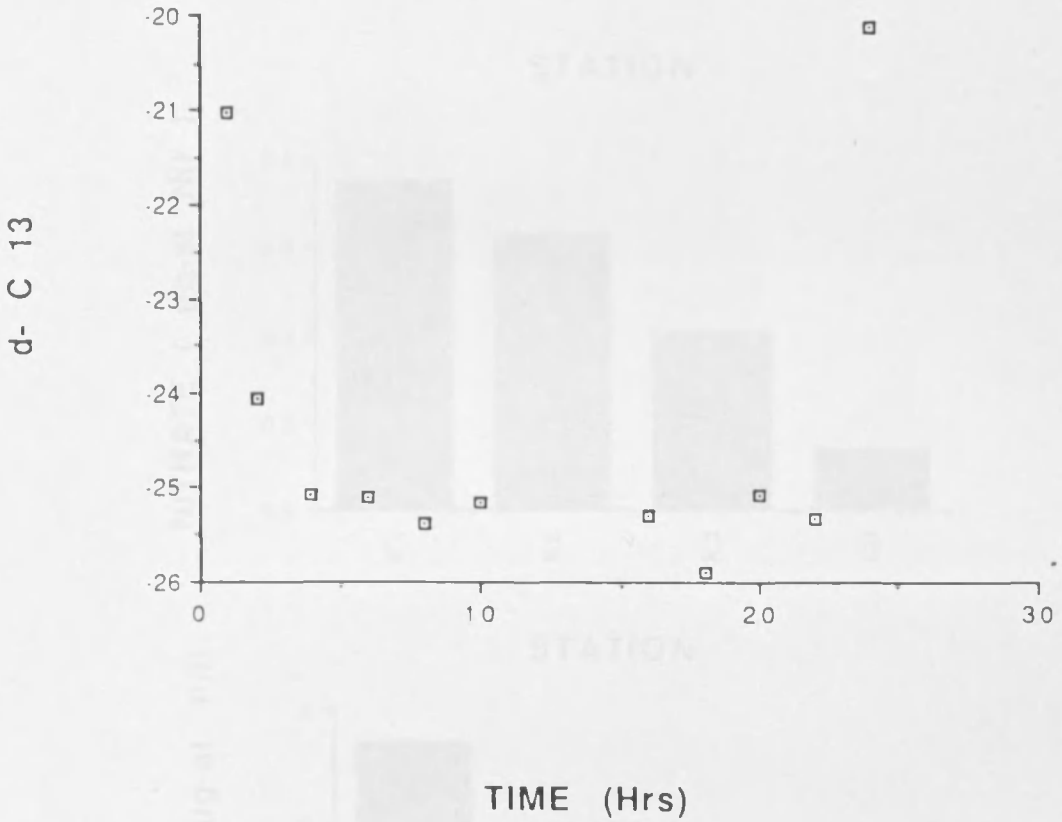


Figure 5 : $\partial^{13}C$ (‰) Isotopic composition of POM at station M during the 24 hr sampling series of 29-30 May 1991.

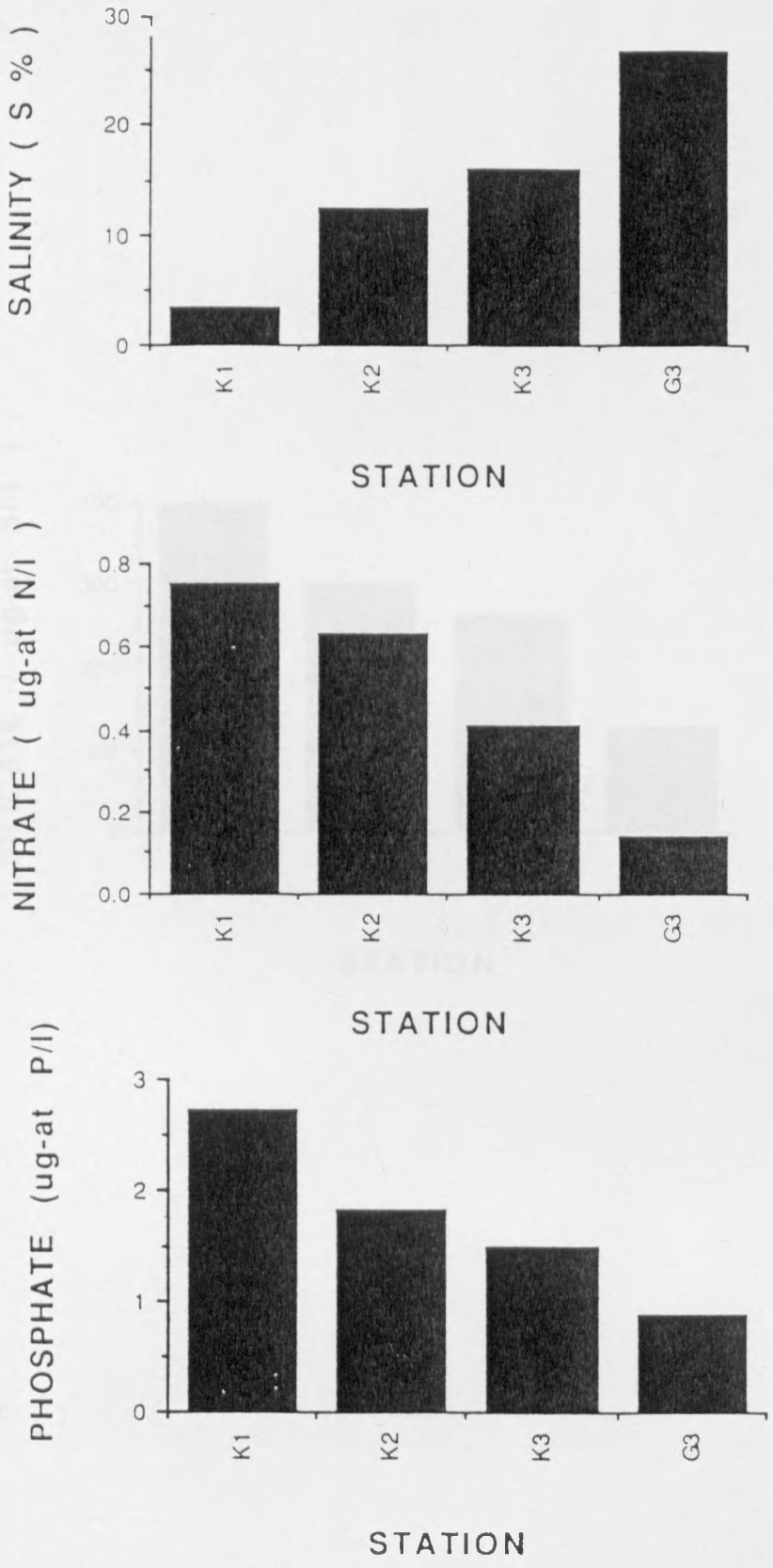


Figure 6 a, b, c : Average values of salinity, nitrate and phosphate profiles for stations along the river Kidogoweni during the rainy season 1991.

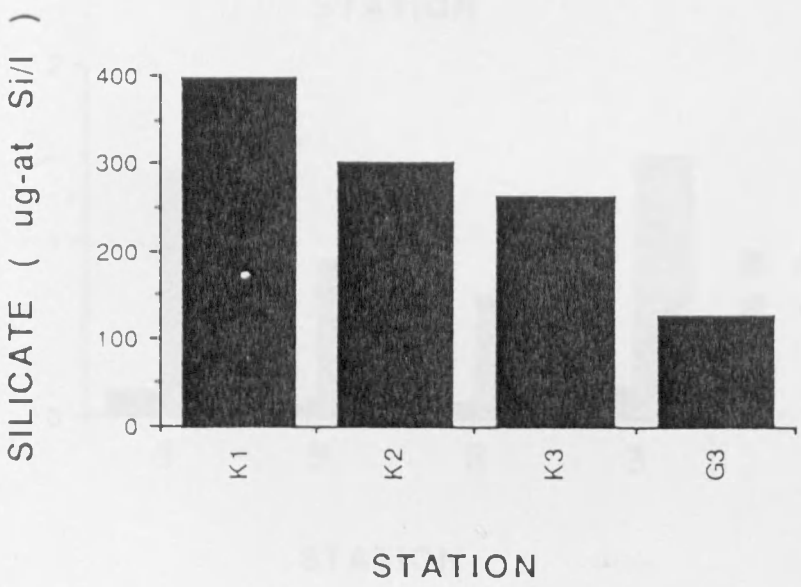


Figure 6 d : Average values of silicate profile for stations along the river Kidogoweni during the rainy season 1991.

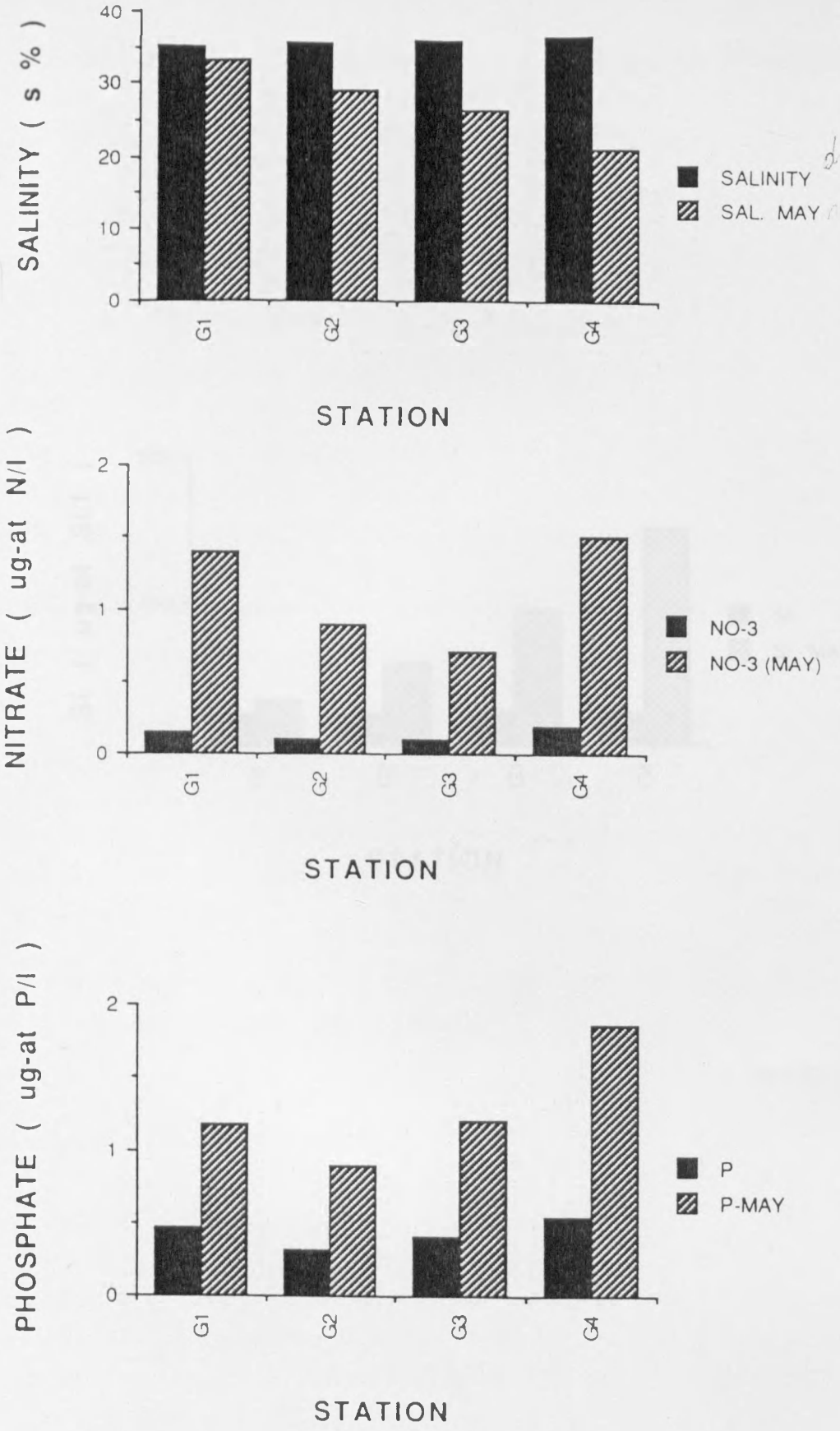


Figure 7 a, b, c : Average values of salinity, nitrate and phosphate profiles respectively for the stations along Gazi Creek.

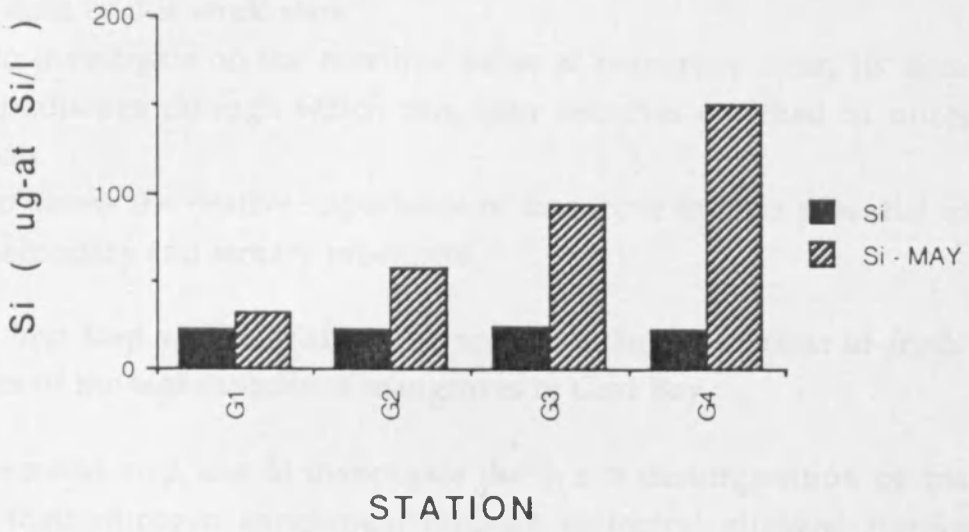


Figure 7 d : Average values of silicate profile for the stations along Gazi Creek.

4.4.2. Mangrove litter as nutritive source in the mangrove ecosystem

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4.4.2.1. Objective of the research

The aims of this work were:
(1) to investigate on the nutritive value of mangrove litter, its decomposition and the pathways through which this litter becomes enriched in nitrogen relative to carbon.
(2) to assess the relative importance of mangrove litter as potential source of energy for secondary and tertiary producers.

Our first step was to analyse the organic C and N content of fresh and senescent leaves of the eight species of mangroves of Gazi Bay.

The second step was to investigate the *in situ* decomposition of mangrove leaves and their nitrogen enrichment through biological nitrogen fixation during both rainy and dry season.

The third step was to start tracing mangrove carbon along the trophic chain of Gazi Bay using natural stable isotopic ratio $\partial^{13}C$.

4.4.2.2. Material and Methods

C and N composition of mangrove leaves

Fresh and senescent leaves from trees of the eight species of mangroves occurring in Gazi Bay, were gathered in November 1990 and February 1991. For *Avicennia marina*, fresh and senescent leaves were collected from trees growing on the main land and from the fringing forests (see section 3.1.: Mangrove vegetation in Gazi Bay). Fresh leaves of the same physiological age were collected, choosing the second one from the terminal bud. Senescent leaves were collected directly from the trees. The leaves were dried at 80 °C for five days, treated with liquid nitrogen and ground

into fine powder. Organic carbon and nitrogen were measured with an Elemental Analyzer Carlo Erba NA 1500.

Decomposition experiments and biological nitrogen fixation

In situ litterbag experiments were conducted in the 2 fieldwork plots described earlier in section 3.1.2. (*Ceriops tagal* plot, sandy sediment, inundated only during spring tides and *Rhizophora mucronata* plot, muddy sediment, inundated twice a day) selected as representative of the mangrove vegetation of Gazi bay. One experiment was conducted during the rainy season 1991 (May until August) and one experiment during the dry season 1991-1992 (December until February). Senescent leaves of *Rhizophora mucronata* and *Ceriops tagal* were picked directly from the trees. In the laboratory, they were dried at 80 °C for 5 days and cut into cross halves. Litterbags (mesh 1 mm) each one containing 3 half Rhizophora leaves or 5 half Ceriops leaves were weighted and placed back in the Rhizophora and Ceriops plot respectively, tightened to the aerial roots of the trees. Litterbags without leaves were also placed in the 2 plots as blanks for the nitrogen fixation measurements. The remaining halves were homogenized per litterbag and kept for analysis of initial C and N content.

During the rainy season 1991, 3 litterbags + 1 blank were collected randomly every week during a period of 50 days. During the dry season 1991-1992, 3 litterbags + 1 blank were collected every 2-3 days during the first 18 days and then every week till the end of the experiment (70 days). An additional experiment was conducted during the dry season, where litterbags with Rhizophora leaves were submerged in the creek during 46 days and collected after 1, 3, 5, 7, 14, 18, 25, 33 and 46 days to see the difference in decomposition rates between continuously submerged leaves and leaves placed on the forest floor with only tidal inundation.

Litterbags were brought back to the laboratory and gently washed under tap water to remove the attached sediments. They were assessed for nitrogen fixation activity using the acetylene reduction technique (Hardy et al. 1973). Litterbags were incubated for 8 hours in gas-tight enclosures under 10 % (by volume) of acetylene. Ethane was used as internal standard and gas was sampled every hour and analysed by gas chromatography using a Varian model 3300 to check for the reduction of acetylene in ethylene. At the end of the incubation experiments, leaves were taken out of the litterbags, gently washed again to remove the microbial film, dried to constant weight at 80 °C and analysed for C and N content.

$\partial^{13}C$ measurements

The measurements were performed with a delta E Finnigan Mat Isotope Ratio Mass Spectrometer. The CO_2 generated in the CN Analyzer was trapped in an on-line CT-NT Finnigan Mat Trapping Box for cryopurification before being injected into the Mass Spectrometer. Standard CO_2 gas was calibrated to the international standard (CO_2 in PeeDee belemnite). Stable carbon isotope abundances are presented as $\partial^{13}C$ values:

$$\delta^{13}C\,‰ = \left[\frac{(^{13}C/^{12}C)\text{sample}}{(^{13}C/^{12}C)\text{standard}} - 1\right] x1000$$

4.4.2.3. Results and Discussion

Carbon, $\partial^{13}C$ and nitrogen composition of mangrove leaves

Results for C, N and $\partial^{13}C$ are summarized in Table 1

Table 1 : Carbon, nitrogen contents of the leaves of eight mangrove species occurring at Gazi Bay; in weight % ± σ.; n = number of leaves analyzed. $\partial^{13}C$ in ‰ ± σ for 10 measurements on the same sample.

Species	Carbon % ± σ	Nitrogen % ± σ	C/N atomic ratio	$\partial^{13}C$ ‰ ± σ
Rhizophora mucronata				
Fresh leaves (n =20)	44.8 ± 2.1	0.67 ± 0.09	78 ± 9	-26.087 ± 0.026
Senescent leaves (n =10)	41.2 ± 2.0	0.25 ± 0.06	193 ± 45	-28.576 ± 0.013
Bruguiera gymnorrhiza				
Fresh leaves (n =16)	45.6 ± 1.6	0.76 ± 0.10	70 ± 9	-25.772 ± 0.042
Senescent leaves (n =10)	48.0 ± 0.4	0.30 ± 0.12	187 ± 6	-28.168 ± 0.019
Ceriops tagal				
Fresh leaves (n =19)	44.3 ± 1.6	0.75 ± 0.05	69 ± 4	-24.275 ± 0.031
Senescent leaves (n =20)	43.2 ± 2.0	0.23 ± 0.03	218 ± 26	-26.896 ± 0.009
Xylocarpus granatum				
Fresh leaves (n =20)	40.8 ± 3.2	1.24 ± 0.30	39 ± 7	-25.866 ± 0.011
Senescent leaves (n =10)	40.7 ± 0.3	0.48 ± 0.03	99 ± 7	-27.212 ± 0.020
Lumnitzera racemosa				
Fresh leaves (n =10)	39.2 ± 0.4	1.18 ± 0.40	39 ± 1	-27.166 ± 0.034
Senescent leaves (n =10)	37.2 ± 0.4	0.43 ± 0.01	101± 2	-26.491 ± 0.023
Sonneratia alba				
Fresh leaves (n =10)	33.9 ± 0.6	1.18 ± 0.04	34 ± 1	-26.495 ± 0.010
Senescent leaves (n =10)	28.9 ± 0.5	0.47 ± 0.03	72 ± 3	-27.178 ± 0.009
Avicennia marina				
Fresh leaves (n =20)	44.3 ± 0.6	1.90 ± 0.3	27 ± 5	-26.615 ± 0.015
Senescent leaves (n =10)	47.2 ± 0.4	0.63 ± 0.1	88 ± 6	-26.220 ± 0.010
Avicennia marina (fringing)				
Fresh leaves (n=10)	39.1 ± 0.3	1.65 ± 0.04	28 ± 1	-29.711 ± 0.029
Senescent leaves (n=10)	38.8 ± 0.5	0.50 ± 0.04	91 ± 7	-29.433 ± 0.041
Heritiera littoralis				
Fresh leaves (n =10)	50.5 ± 0.3	2.47 ± 0.07	24 ± 1	-28.779 ± 0.011
Senescent leaves (n =10)	53.9 ± 0.5	0.85 ± 0.04	74 ± 3	-27.878 ± 0.014

(* One sample only)

Heritiera littoralis has the lowest C/N ratio while *Rhizophora mucronata* has the highest. No significant difference was observed in C/N ratio between *Avicennia marina* leaves collected from the mainland and from the fringing forest.

Statistical analysis through one way ANOVA shows that the fresh leaves of the eight species differ significantly in carbon and nitrogen contents. *F* ratio, for nitrogen is 164.846 ($p = .0001$) and for carbon is 85.264 ($p = .0001$), at 95 % confidence interval. Further analysis through Fisher Protected Least Square Design and Scheffe F-test indicates that *S. alba, A. marina* and *H. littoralis* are significantly different from each other and also from the other species. *L. racemosa* and *X. granatum* show a similar composition as do *B. gymnorrhiza, C. tagal* and *R. mucronata.*

Among the four more important species of mangroves of Gazi bay (*A. marina, B. gymnorrhiza, C. tagal* and *R. mucronata*), *A. marina has* the lowest C/N ratio and thus the highest nutritive value and the three others have comparable nutritive value.

The $\partial^{13}C$ values for the mangrove leaves vary from - 25.2 ‰ to - 29.7 ‰. Those values are in agreement with values reported by Rodelli et al. (1984) in Malaysian mangrove swamps and are in the typical range of C-3 terrestrial plants (Gebauer & Schulze, 1991). The $\partial^{13}C$ values for the senescent leaves of some of the species (*Rhizophora, Ceriops, Bruguiera, Xylocarpus* and *Sonneratia*) are more negative than those of fresh leaves. Such results were also reported by Garten & Taylor (1992) who suggest that this difference could be attributed to biochemical changes prior to abscission. $\partial^{13}C$ values of *A. marina* (fringing) leaves are more negative by 3 ‰ than those of the same species from the mainland. This consistent difference suggests that variation within species of $\partial^{13}C$ values could be a function of the habitat, especially the possible effect of relative humidity of air on stomatal conductance, as reported also by Garten & Taylor (1992). As a result plants growing under conditions of higher relative humidity would have more negative $\partial^{13}C$. It is very possible that the air in Avicennia forest fringing the creek, has a higher relative humidity than the air in Avicennia forest from the mainland.

For all the species a change in mean C/N ratio for fresh leaves from 47 ± 21 to 129 ± 60 in senescent leaves indicates that approximately 64 % of nitrogen is resorbed by the plants as shown in Table 2.

Table 2 : Mean Nitrogen resorption in Mangroves of Gazi.

Species	Nitrogen resorption %
Avicennia marina	69
Avicennia marina (fringing)	69
Bruguiera gymnorrhiza	63
Ceriops tagal	69
Heritiera littoralis	68
Lumnitzera racemosa	62
Rhizophora mucronata	59
Sonneratia alba	53
Xylocarpus granatum	61

Mangroves trees at Gazi Bay are efficient in retaining nitrogen before senescence and abscission. Such results were also observed by other researchers. Twilley et al. (1986) and Boto & Bunt (1981), reported 45 % - 55 % decrease in nitrogen contents in senescent leaves of *A. marina* and *R. mangle*.

In table 3 we compare $\delta^{13}C$ values and C:N atomic ratios between mangrove leaves and organic matter in underlaying sediments for the *C. tagal* and *R. mucronata* field plots. Although organic matter in sediments tend to be more positive in $\delta^{13}C$ than the leaves for both plots, mangrove leaves appear to represent the main carbon source.

A ten fold decrease in C:N atomic ratio from the senescent mangrove leaves to the sediments indicates that nitrogen enrichment occurs during decomposition.

Table 3: C:N atomic ratio and $\delta^{13}C$ values of sediments at the *Ceriops* and *Rhizophora* plots of Gazi Bay

Study Site	C:N atomic Ratio	$\delta^{13}C$ in Sediments ‰ ± σ	$\delta^{13}C$ in mangrove leaves ‰ ± σ Fresh Senescent
Ceriops tagal plot	18	-24.165 ± 0.022	-24.275 ± 0.031 -26.896 ± 0.009
Rhizophora mucronata plot	21	-25.460 ± 0.027	-26.087 ± 0.026 -28.576 ± 0.013

Decomposition experiments

The results of leaf decomposition during rainy and dry season for both species of mangroves (*Ceriops tagal* and *Rhizophora mucronata*) are presented in Figure 1 as % dry weight remaining.

During the rainy season 1991, after 20 days of decomposition, there is a loss of dry weight (DW) of 80 % for *R. mucronata* and 35 % for *C. tagal*. After 50 days of decomposition we observed a DW loss of 100 % for *R. mucronata* and of 70 % for *C. tagal*.

During the dry season 1991 - 1992, after 20 days of decomposition, there is a DW loss of 30 % for *R. mucronata* and of 17 % for *C. tagal*. After 50 days we observed a DW loss of 52 % and 30 % for *R. mucronata* and *C. tagal* respectively.

For both species the decomposition appears to be twice as rapid during the rainy season compared to the dry season. Similar results were also observed by Twilley et al. (1986).

During both rainy and dry season, the rates of decomposition of Rhizophora leaves are higher than the decomposition rates of Ceriops leaves. The Rhizophora plot is inundated 2 times a day and the Ceriops plot only during spring tides, this can

explain the faster rate of decomposition observed in the Rhizophora plot as decomposition is increasing with the tidal frequency (Twilley et al. 1986).

The results of decomposition for leaves of *R. mucronata* continuously submerged in the creek and for leaves placed on the forest floor (submerged 2 times a day at high tide) are presented in Figure 1. We can see that during the first 7 days the rates of decomposition are very similar (20 % DW loss) but that after 10 days, the decomposition becomes more rapid for leaves placed on the forest floor. These results are in contradiction with observations of Flores-Verdugo et al. (1987) and Steinke & Ward (1987) who found that leaves constantly submerged decomposed at faster rate than those exposed to air for some period of time. In our case, leaves on the forest floor were inundated twice a day although in their case, leaves were only inundated during spring tides. Twilley et al. (1986) have shown that the forest floor hydrology influences the litter decomposition, with higher decomposition rates in wetter environment. In our study the difference between submerged and non-submerged leaves in terms of tidal inundation frequency was not as important as in the studies of Flores-Verdugo et al. (1987) and Steinke & Ward (1987). In our case, leaves on the forest floor are exposed to some period of desiccation during low tide. It has been shown for a temperate forest, that the alternation of desiccation and wetting periods enhance the activity of the microflora responsible for decomposition (Aber & Melillo, 1980). This can explain why we observed a faster decomposition rate for leaves placed on the forest floor compared to the submerged ones.

C/N evolution

Initial C/N compositions of *C. tagal* and *R. mucronata* leaves are shown in Table 4.

Table 4 : Initial C/N composition (± σ)

Species	(C/N)i dry season	(C/N)i rainy season
Ceriops tagal	178 ± 13	253 ± 36
Rhizophora mucronata	158 ± 16	188 ± 25

We can notice a significant difference in the initial C/N composition of the leaves of both species between dry and rainy season. As the carbon content stays constant, there is more initial nitrogen in senescent leaves collected during the dry season than during the rainy season.

The results of C/N evolution during decomposition expressed as % of initial C/N composition of the leaves, are shown in Figure 2.

We can see in all cases an immediate diminution of C/N ratio in decomposing leaves relative to the initial C/N value. As the carbon content stays relatively constant, this diminution is due to an increase in the nitrogen content of the leaves during decomposition. This enrichment in nitrogen is more pronounced during the rainy season for both mangrove species. Rhizophora leaves become more enriched in nitrogen than Ceriops leaves during both seasons.

Nitrogen evolution

To go into more details in nitrogen dynamics of leaves during decomposition we have plotted the relative nitrogen content (Nt/Ni x 100, with Nt = nitrogen after t days of decomposition and Ni = the initial nitrogen content) of leaves and the absolute nitrogen content (% N remaining, Nt corrected with dry weight loss) against time in Figure 3.

Concerning the relative N content we observed during the rainy season for both *C. tagal* and *R. mucronata*, a similar nitrogen enrichment from 200 % after 5 days of decomposition to 400 % after 20 - 25 days. During the first 50 days of the dry season, both *C. tagal* and *R. mucronata* are less enriched in nitrogen than during the rainy season with *R. mucronata* more enriched than *C. tagal*.

This relative nitrogen enrichment has been observed previously and is well documented in the literature (Fell et al., 1975, Rice & Tenore, 1981, Steinke & Charles, 1986). The nitrogen enrichment of leaf litter during decomposition includes adsorption and absorption processes by bacterial and fungal population as well as biological nitrogen fixation (Twilley et al., 1986).

During the dry season, the absolute N content (Figure 4) increased with time for both species and remained above the original N content (100 %). During the rainy season the absolute N content of *C. tagal* stays above the original value during the first 20 days. Following this period the absolute N content decreased below the original content with an increase again after 40 days and a decrease to 70 % of the

original N content on the end of the experiment. During the rainy season the absolute N content of *R. mucronata* is above the original value only during the first 3 days and decreased steadily to reach 20 % of the original N content on the end of the experiment, due to the almost complete disappearance of the leaves by decomposition.

During the dry season, we observed an absolute increase of nitrogen for both species, enhancing the recycling of nitrogen on the forest floor (Twilley et al, 1986). During the rainy season, there is an absolute increase of nitrogen only during the first 20 days and 3 days for *C. tagal* and *R. mucronata* respectively. After this period, there is a loss of nitrogen due to the decomposition process.

Nitrogen fixation

The results of nitrogen fixation expressed as the product of reduction of C_2H_2 (nmoles C_2H_4 produced/h/g DW) are presented in Figure 5.

During the rainy season 1991, we observed for *C. tagal* 2 peaks, one after 15 days of decomposition (400 nmoles) and one after 30 days (1140 nmoles). For *R. mucronata*, we observed a peak after 15 days (1200 nmoles) and a decrease in the nitrogen fixation activity to a zero value after 35 days due to the almost complete decomposition of the leaves.

During the dry season 1991-1992, there is for both mangrove species an increase in the activity during the first 10 days to reach a maximum value of 230 nmoles for *C. tagal* after 7 days and of 560 nmoles for *R. mucronata* after 10 days.

For both species the nitrogen fixation activity was higher during the rainy season and for both seasons the activity was higher in *R. mucronata* than in *C. tagal.*

Concerning the comparison between submerged leaves of *R. mucronata* and leaves placed on the forest floor during the dry season, we can see from Figure 5, the same evolution of nitrogen fixation activity with time with higher activity in leaves placed on the forest floor. As the activity of the decomposing microflora, the activity of the nitrogen fixing micro-organisms is also enhanced by the alternation of wet and dry period (Aber & Melillo, 1980).

If we take into account the theoretical conversion factor of 3/1 (C_2H_4/N_2) and a nitrogenase activity of 12 hours per day we obtain the following results for nitrogen fixation. For *C. tagal*, the maximum rates of nitrogen fixation vary from 26 µg

N/day/g DW (dry season) to 128 µg N/day/g DW (rainy season) and for *R. mucronata* they vary form 63 µg N/day/g DW (dry season) to 135 µg N/day/g DW (rainy season). These results are in the same range as those reported by Taylor cited in Fell et al. (1975): 24 to 96 µg/day/g DW.

Interesting results are obtained when we plot simultaneously nitrogen fixation rates and absolute nitrogen content against time (see Figure 6).

We observed in all cases, except for *R. mucronata* during the rainy season, that when a peak in the nitrogen fixation activity appears, it is followed with a time delay by a peak in absolute nitrogen content. This suggests that nitrogen fixation contributes significantly to the nitrogen enrichment of leaves during decomposition.

To quantify the contribution of nitrogen fixation to the absolute increase of nitrogen observed, we integrated the curves of nitrogen fixation to obtain the cumulative values of nitrogen fixation over the decomposition experiment, expressed in µgN/g DW (taking into account the conversion factor of 3/1 and a nitrogenase activity of 12 hours per day). The results were compared to the cumulative differences between absolute nitrogen content after decomposition and initial nitrogen content, expressed in µgN/g DW. The results are presented in Table 5.

Table 5 : Contribution of nitrogen fixation to the absolute leaves nitrogen enrichment

Species	N-fixation (µgN/gDW)	N gain (µgN/gDW)	N-fixation contribution (%)
C. tagal dry season (70 days)	340	6480	5
C. tagal rainy season (50 days)	750	943	80
R. mucronata dry season (70 days)	1505	17440	9
R. mucronata rainy season (3 days)	199	710	28

Nitrogen fixation can supply 5 to 80 % to the absolute nitrogen enrichment observed in the mangrove leaves of *C. tagal* and *R. mucronata* and the contribution of nitrogen fixation is more important during the rainy season than during the dry season.

4.4.2.4. Conclusion

Statistical analysis shows that the fresh leaves of the eight species of mangroves differ significantly in carbon and nitrogen contents. Among the four more important species of mangroves of Gazi bay (*A. marina, B. gymnorrhiza, C. tagal* and *R. mucronata*), *A. marina has* the lowest C/N ratio and thus the highest nutritive value and the three others have comparable nutritive value.

Mangroves of the Gazi Bay are efficient in conserving nitrogen by showing 64 % resorption before fall of the leaf.

The $\partial^{13}C$ values for the mangrove leaves vary from -25.2 ‰ to -29.7 ‰ and are in the typical range of C-3 terrestrial plants.

The rates of leaf decomposition and nitrogen fixation are higher during the rainy season compared to the dry season for both species of mangroves. The rates of decomposition and nitrogen fixation are higher for *R. mucronata* leaves than for *C. tagal* ones. Enrichment of nitrogen during decomposition is observed in both species during the rainy and the dry season but leaves of *R. mucronata* become more enriched in nitrogen than leaves of *C. tagal*. This is in agreement with the rates of nitrogen fixation measured and nitrogen fixation contributes significantly (5 to 80 %) to the nitrogen enrichment of leaves during decomposition.

4.4.1.5. References

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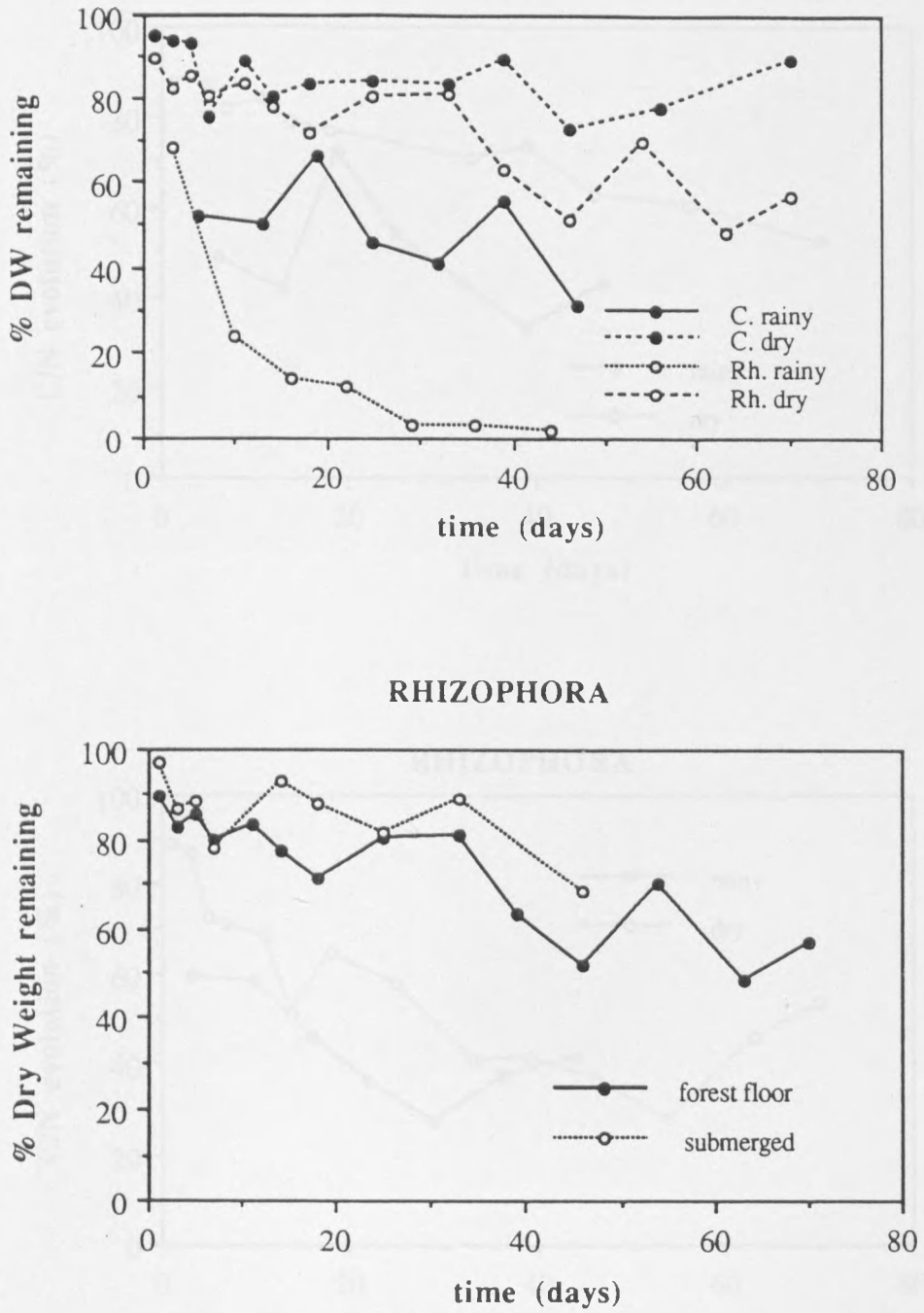

Figure 1 : Evolution of dry matter losses during decomposition in 2 species of mangroves (R. mucronata and C. tagal) during dry and rainy seasons.

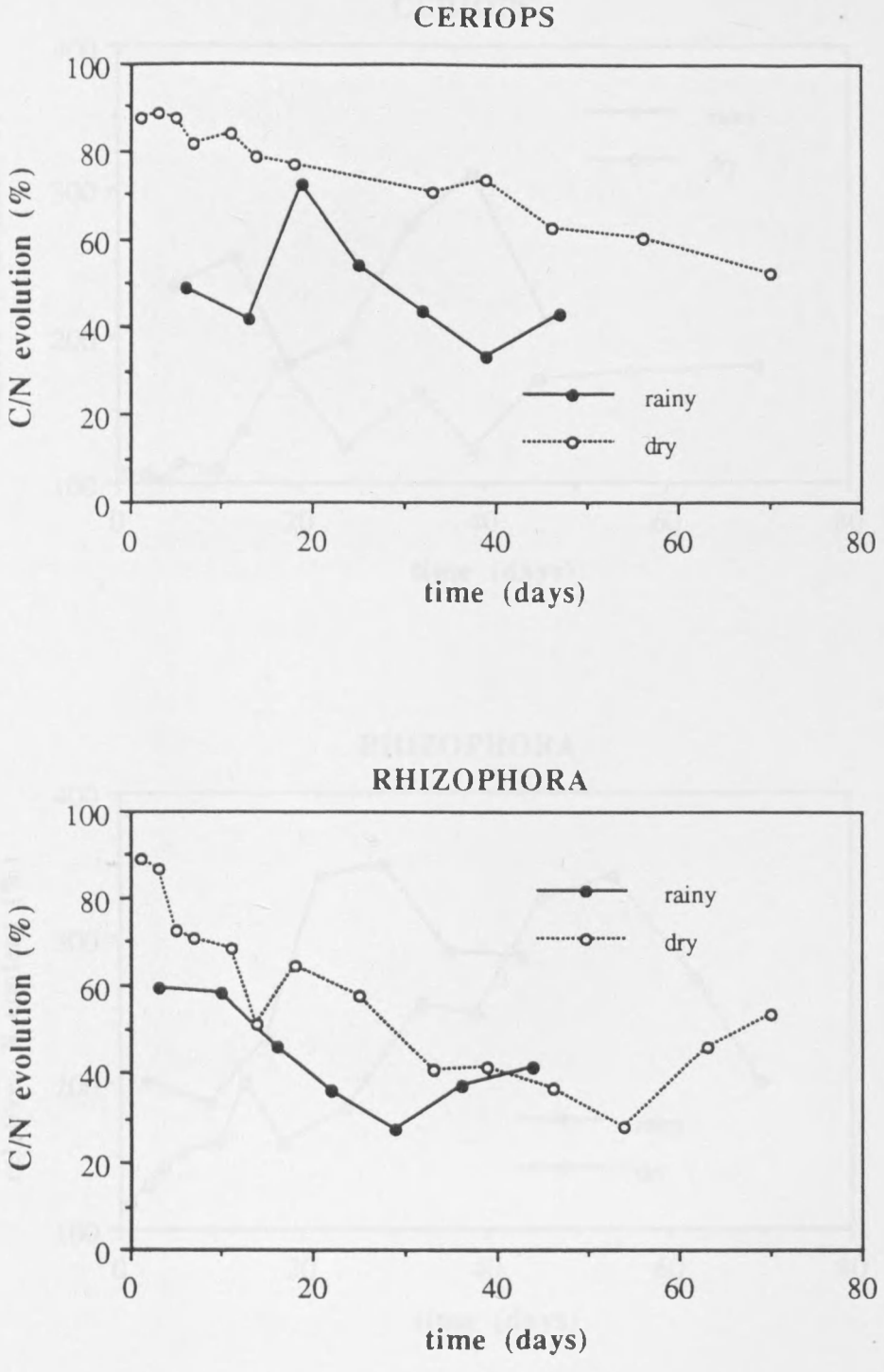

Figure 2 : C/N evolution during decomposition in 2 species of mangroves (R. mucronata and C. tagal), during dry and rainy season.

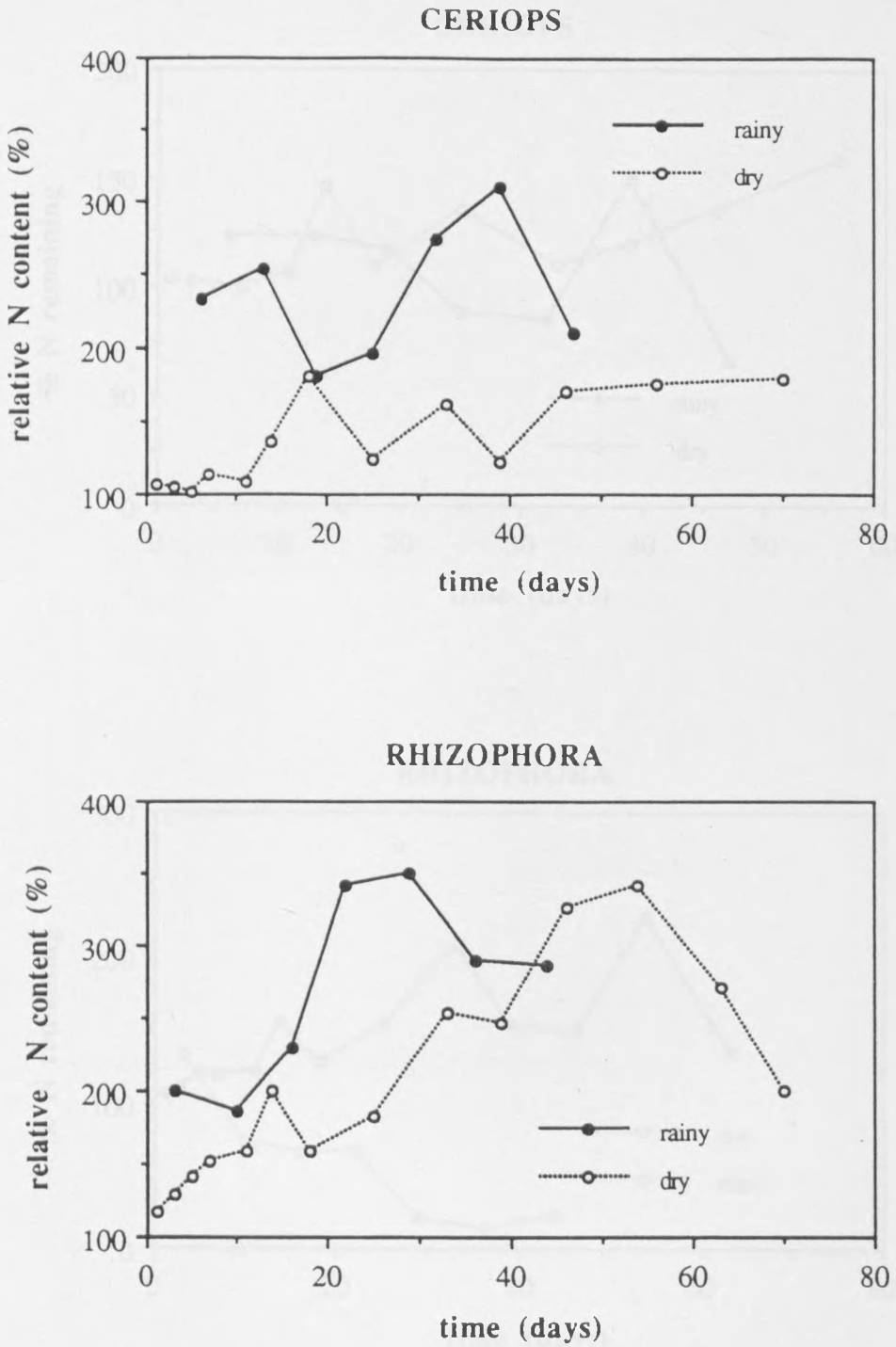

Figure 3 : Evolution of relative nitrogen content during decomposition in 2 species of mangroves (R. mucronata and C. tagal), during dry and rainy seasons.

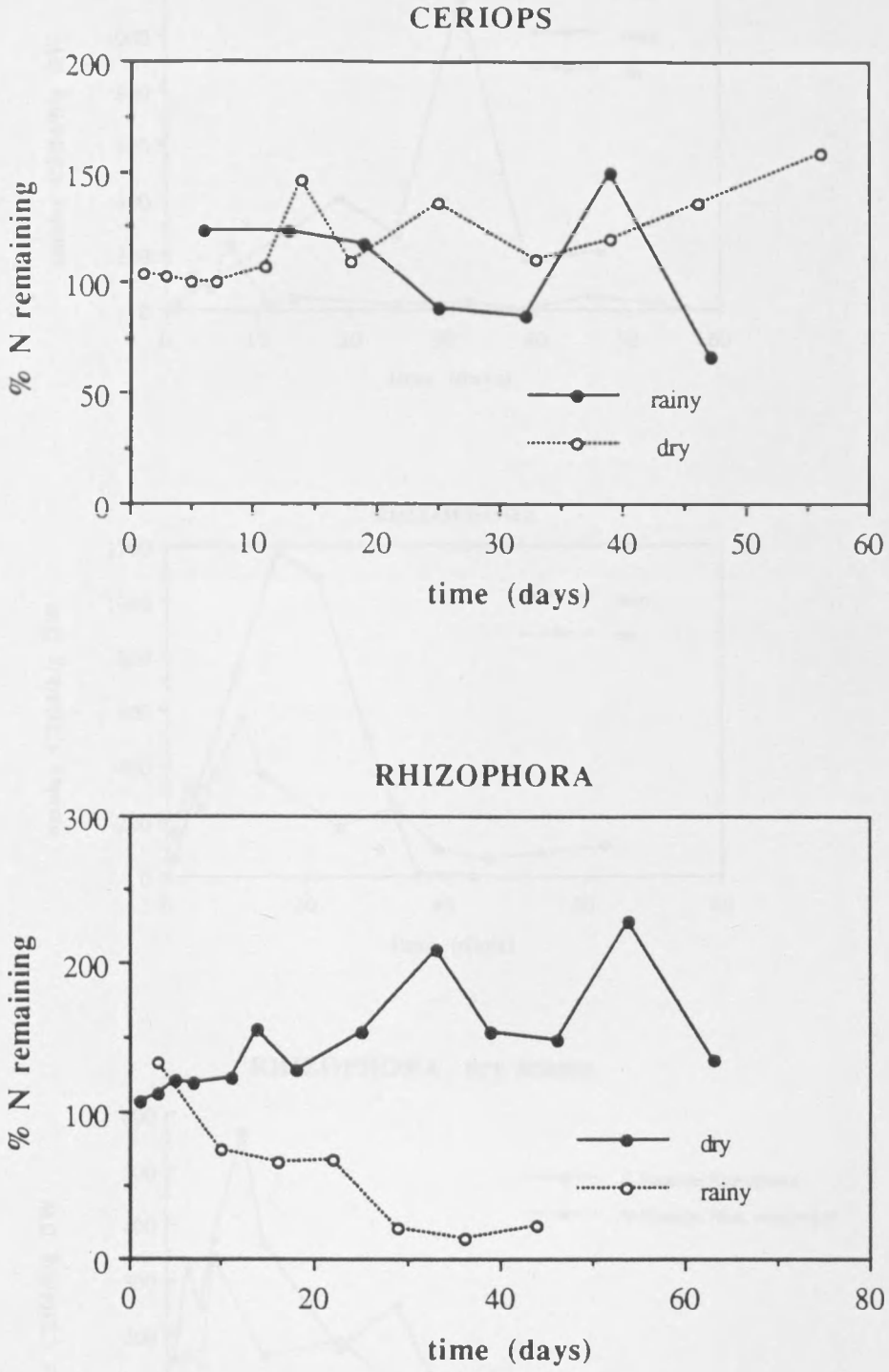

Figure 4 : Evolution of absolute nitrogen content during decomposition in 2 species of mangroves (R. mucronata and C. tagal), during dry and rainy seasons.

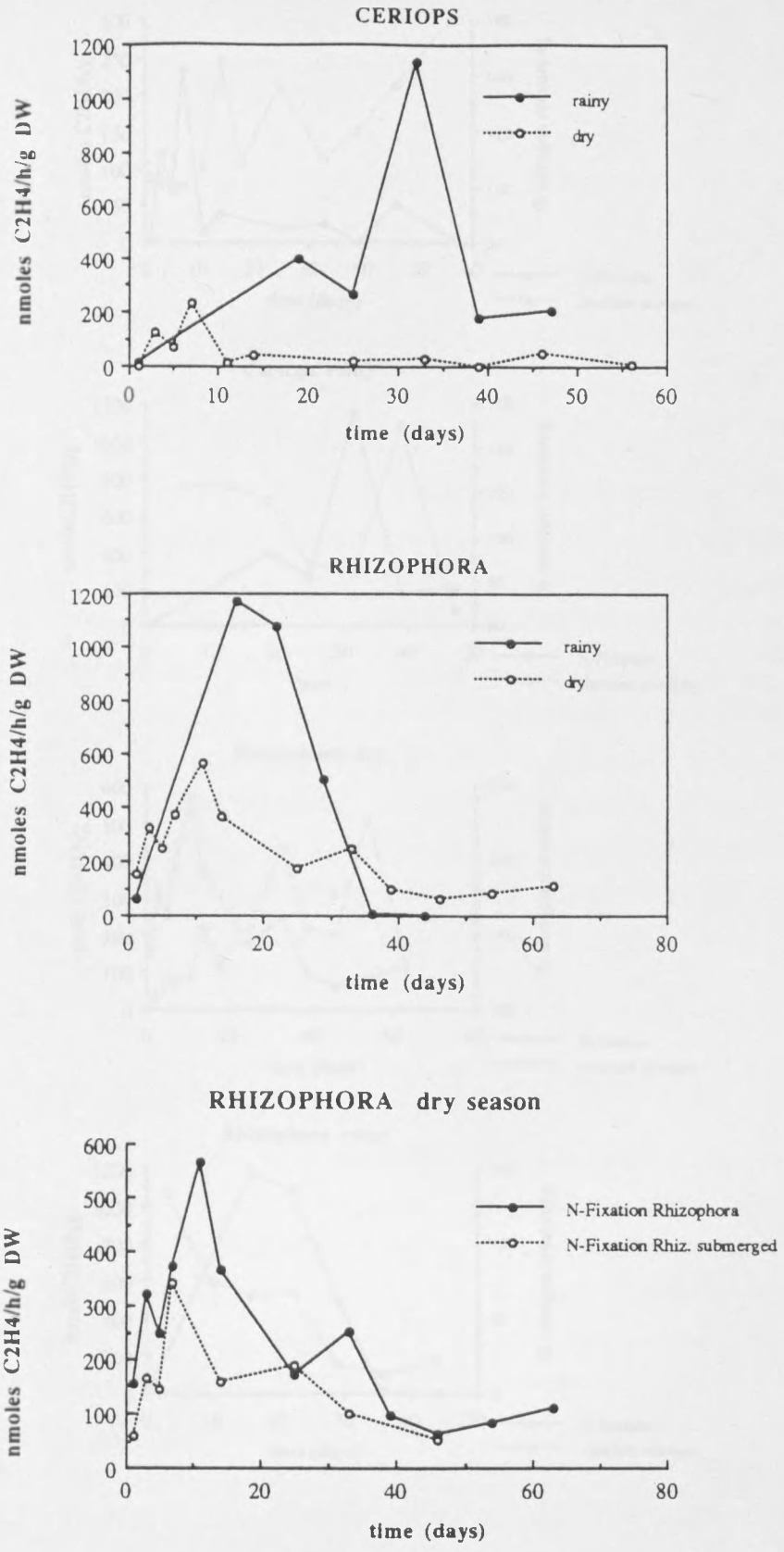

Figure 5 : Evolution of Nitrogen fixation activity during decomposition in 2 species of mangroves (R. mucronata and C. tagal), during dry and rain seasons.

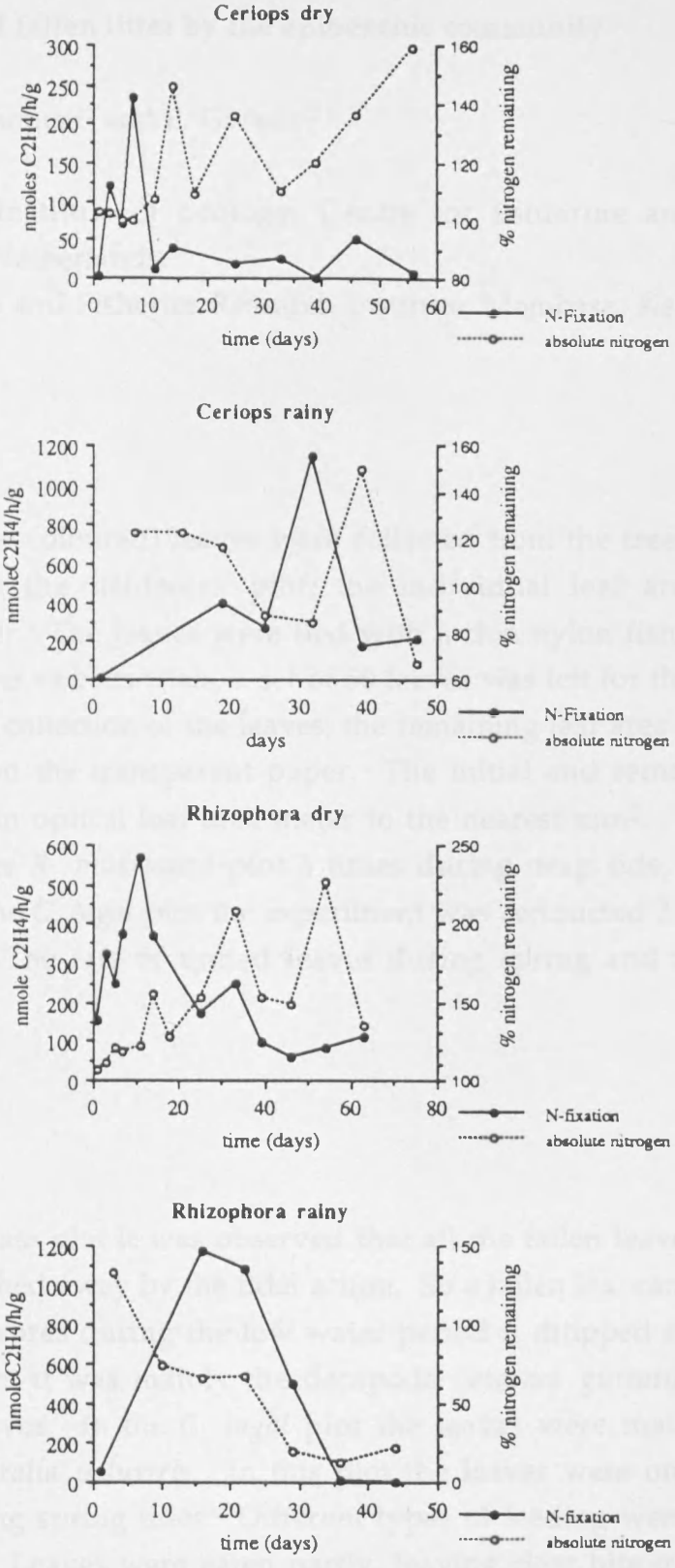

Figure 6 : Coevolution of nitrogen fixation rates and absolute nitrogen content during decomposition in 2 species of mangroves (R. mucronata and C. tagal), during dry and rainy seasons.

4.4.3. Removal of fallen litter by the epibenthic community

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4.4.3.1. Methods

Senescent (yellow coloured) leaves were collected from the trees. Before the leaves were set out in the fieldwork plot, the individual leaf area was marked on transparent paper. The leaves were tied with a thin nylon fishing line of circa 100 cm. In each of the various trials, a set of 50 leaves was left for the crabs and snails to eat (24 h). After collection of the leaves, the remaining leaf area was compared to its original image on the transparent paper. The initial and remaining leaf area was estimated with an optical leaf area meter to the nearest mm^2. The experiment was carried out in the *R. mucronata* plot 3 times during neap tide, and 2 times during spring tide. In the *C. tagal* plot the experiment was conducted 2 times during spring and neap tide. The fate of untied leaves during spring and neap tides was also observed.

4.4.3.2. Results

In the *R. mucronata* plot it was observed that all the fallen leaves during a low tide period were washed away by the tidal action. So a fallen leaf can only be attacked by epibenthic herbivores during the low water period it dropped from the tree. In the *R. mucronata* plot it was mainly the decapode *Sesarma guttatum* that was feeding on the fallen leaves. In the *C. tagal* plot the leaves were mainly attacked by the gastropod *Terebralia palustris*. In this plot the leaves were only washed away by tidal water during spring tides. Different types of feeding were observed in the *R. mucronata* plot. Leaves were eaten partly, leaving clear bite marks on the edge of the leaf, or were buried in the sediment. Most of the buried leaves were removed as a whole, leaving only their stalk on the thin wire to retrieve.

Figure 1 shows the leaf litter removal in the plots. During spring tide the fauna in the *C. tagal* plot is more active than during neap tides. This can not only been seen in the digging activity of the abundantly present fiddler crabs, *Uca inversa*, *U.*

vocans, U. lactea (pers. comm., J. Schrijvers), but is also reflected in our experiment. Whereas during neap tides only 44 % of the fallen leaf area is eaten by the snails this percentage increased to over 90 % at spring tides. In contrast, in the *R. mucronata* plot a decrease from 34 % to 25 % in eaten leaf area was observed. Litter removal in the last mentioned plot thus is quite stable throughout the spring-neap tide cycle, but is always less conspicuous than in the strong fluctuating *C. tagal* plot.

4.4.3.3. Some comments on litterfall removal

Due to the tidal flooding of the *R. mucronata* plot less then 50 % of the total litterfall reaches the sediment surface and is available for the benthic community to feed on. From the leaves falling during low tide, between 25 % (neap tide) and 34 % (spring tide) is removed by crabs. Thus, on a daily basis, between 12.5 % and 17 % of the total litter fall is consumed by crabs. These values are low compared to other studies. Robertson (1986) finds values between 22 % and 42 % in Rhizophora dominated forests and in a later study (Robertson, 1989) values of 28, 84 and 82 % are reported for *Avicennia, Ceriops,* and *Bruguiera,* respectively. Although lunar activity patterns are well known for the intertidal fauna, no literature data are available which sheds light on litter removal relative to the lunar cycle. The decrease in eaten leaf area in the *Rhizophora* plot can be explained by a longer inundation period during spring tides, whereas the increase in the leaf area consumed in the Ceriops plot is most likely due to a higher activity of the snails during spring tide.

4.4.3.4. References

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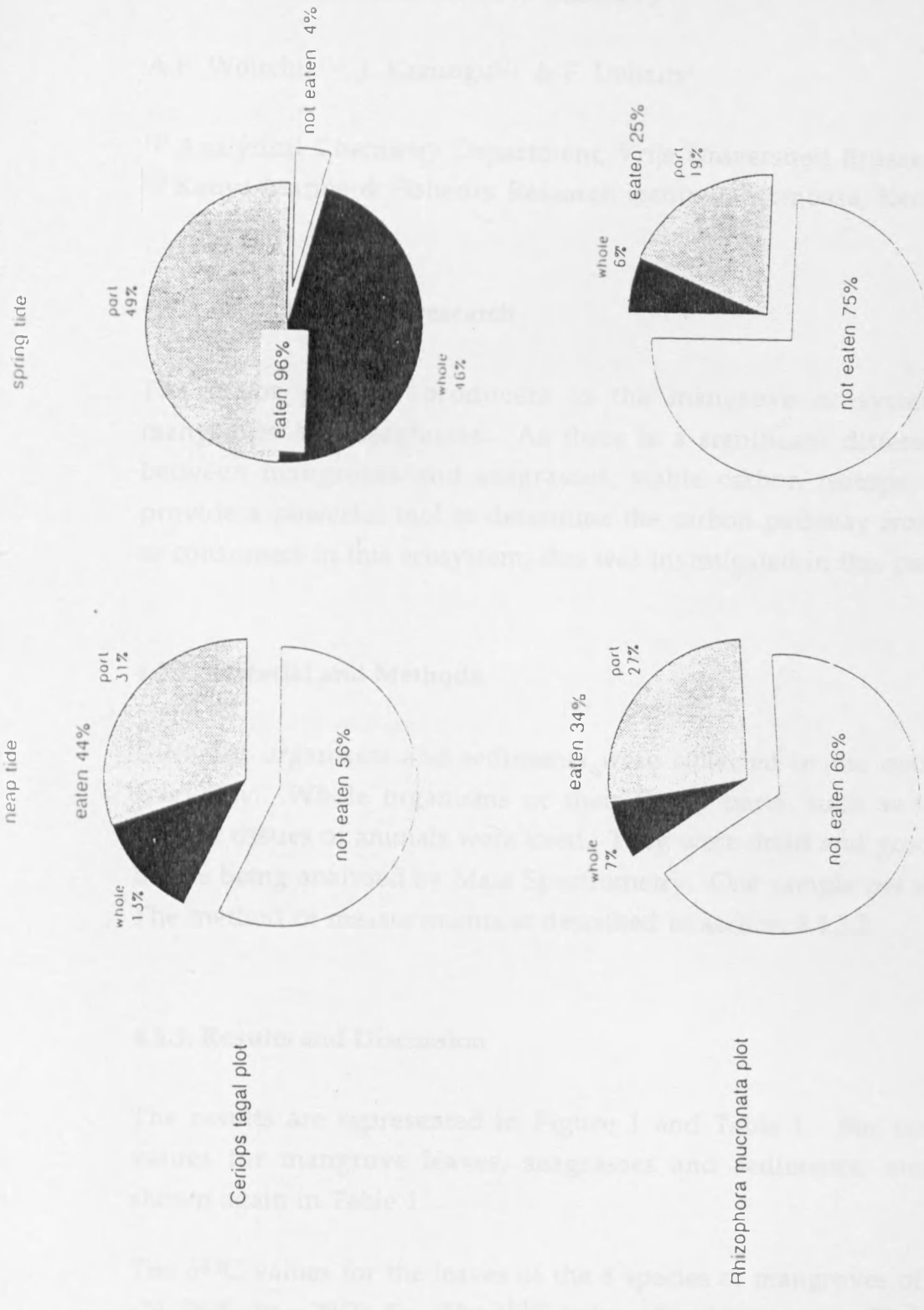

Figure 1 : Leaf litter removal in the mangrove field plots. Percentages expressed as part from total leaf area at start of experiment; not = leaf area not eaten, whole = leaf area eaten in the form of total eaten leaves, part = leaf area eaten as part from a leaf.

4.5. TRANSFER OF C FROM PRIMARY TO SECONDARY AND TERTIARY PRODUCERS : PRELIMINARY RESULTS

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4.5.1. Objective of the research

The major primary producers in the mangrove ecosystem of Gazi Bay are mangroves and seagrasses. As there is a significant difference in $\partial^{13}C$ content between mangroves and seagrasses, stable carbon isotope analysis is likely to provide a powerful tool to determine the carbon pathway from primary producers to consumers in this ecosystem; this was investigated in this part of our research.

4.5.2. Material and Methods

Different organisms and sediments were collected in the mangrove ecosystem of Gazi Bay. Whole organisms or their fleshy parts, such as leaves of plants and muscle tissues of animals were used. They were dried and ground into fine powder before being analysed by Mass Spectrometry. One sample per species was analysed. The method of measurements is described in section 4.4.2.2.

4.5.3. Results and Discussion

The results are represented in Figure 1 and Table 1. For convenience ranges of values for mangrove leaves, seagrasses and sediments, mentioned earlier, are shown again in Table 1.

The $\partial^{13}C$ values for the leaves of the 8 species of mangroves of Gazi bay vary from -24.28 ‰ to - 29.71 ‰. The $\partial^{13}C$ values for the seagrass *Thalassodendron ciliatum* vary from - 9.92 ‰ to - 20.22 ‰ along a transect going from the coral reef to the mangrove swamps respectively. These values are very different from the values obtained for the mangrove leaves. Thus we have a clear distinction in natural isotopic composition between the 2 primary sources of carbon in this ecosystem. The $\partial^{13}C$ values of sediments from the *C. tagal* and *R. mucronata* fieldplots, vary

from - 23.62 ‰ to - 26.48 ‰ respectively. This indicates that the major source of carbon in these sediments comes from the mangrove leaves. The $\partial^{13}C$ value of *Terebralia palustris* is - 24.23 ‰. This gastropod was sampled in the *C. tagal* plot and is known as a mangrove leaf eater. This is confirmed by the $\partial^{13}C$ value measured which shows the greatest similarity with leaves. The $\partial^{13}C$ values of the fishes (*Siganus sutor, Abudefduf xanthurus, Lethrinus harak, Leptoscarus vaigiensis*) vary from - 13.06 ‰ to - 16.11 ‰. The major source of carbon for those fishes could thus be the seagrasses. The $\partial^{13}C$ values of the copepods (*Pseudodiaptomus sp., Tortanus sp., Acartia sp.*), vary from - 19.29 ‰ to - 24.10 ‰ and the value of the prawn's larvae (*Caridea*) is - 17.69 ‰. The source of carbon for these organisms appears to come from a mixture of POC from mangrove and seagrass leaves or phytoplankton. We don't have yet the $\partial^{13}C$ value of pure phytoplankton, but literature values indicate $\partial^{13}C$ values for phytoplankton around -20 ‰ (Fry and Sherr, 1984). The $\partial^{13}C$ values of shrimp, mudskipper (*Periophthalmus sp.*) and oyster (*Saccostrea cucullata*) vary from -19.3 ‰ to -20.52 ‰. That indicates that their source of carbon is coming either only from seagrasses growing in the mangrove area or from a mixture of seagrass and mangrove leaves. The $\partial^{13}C$ values of fiddler crabs (*Uca vocans, Uca urvillei*) collected in the *R. mucronata* plot vary from -17.06 ‰ to -17.53 ‰. These crabs are micro-algae grazers and we don't have the $\partial^{13}C$ value of their food substrate.

Table 1: $\partial^{13}C$ values of different organisms in ‰ ± σ for 10 measurements on the same sample

Species	$\partial^{13}C$ ‰ ± σ
mangroves	-24.28 to -29.71
seagrass (*Thalassodendron ciliatum*)	-9.92 to -20.22
sediments	
Ceriops	-23.62 ± 0.022
Rhizophora	-26.48 ± 0.027
gastropod (*Terebralia palustris*)	-24.23 ± 0.026
zooplankton	
- copepods	
Pseudodiaptomus sp.	-20.09 ± 0.066
Tortanus sp.	-19.29 ± 0.038
Acartia sp.	-24.10 ± 0.053
- *Caridea*	-17.69 ± 0.098
oyster (*Saccostrea cucullata*)	-19.74 to -20.41
mudskipper (*Periophthalmus sp.*)	-19.30 ± 0.014
Shrimp	-20.52 ± 0.019
fishes	
Siganus sutor	-16.11 ± 0.019
Abudefduf xanthurus	-14.25 ± 0.010
Lethrinus harak	-14.02 ± 0.020
Leptoscarus vaigiensis	-15.13 ± 0.018
fiddler crab	
Uca vocans	-17.06 ± 0.025
Uca urvillei	-17.53 ± 0.040

4.5.4. Conclusion

Two isotopically distinct sources of carbon were found in the mangrove ecosystem of Gazi bay : mangroves with an average value of -27.3 ‰ ± 1.4 and seagrasses with an average value of -18.57 ‰ ± 4.2. Sediments of the mangroves have a similar isotopic signature than the mangrove leaves. *Terebralia palustris* has an isotopic signature in the range of mangrove leaves. The fishes we analysed, apparently derived their carbon source from the seagrasses. For the other organisms isotopic signatures indicate an assimilation of carbon from more than one source. This study was a preliminary survey of the stable isotopic ratios at different trophic levels in the ecosystem of Gazi bay and more studies will be needed to assess the respective role of mangrove, seagrass and phytoplankton carbon in supporting the food webs in this ecosystem. The importance of $\partial^{15}N$ as an additional tracer of energy flow through the trophic chain will be investigated.

4.5.5. Reference

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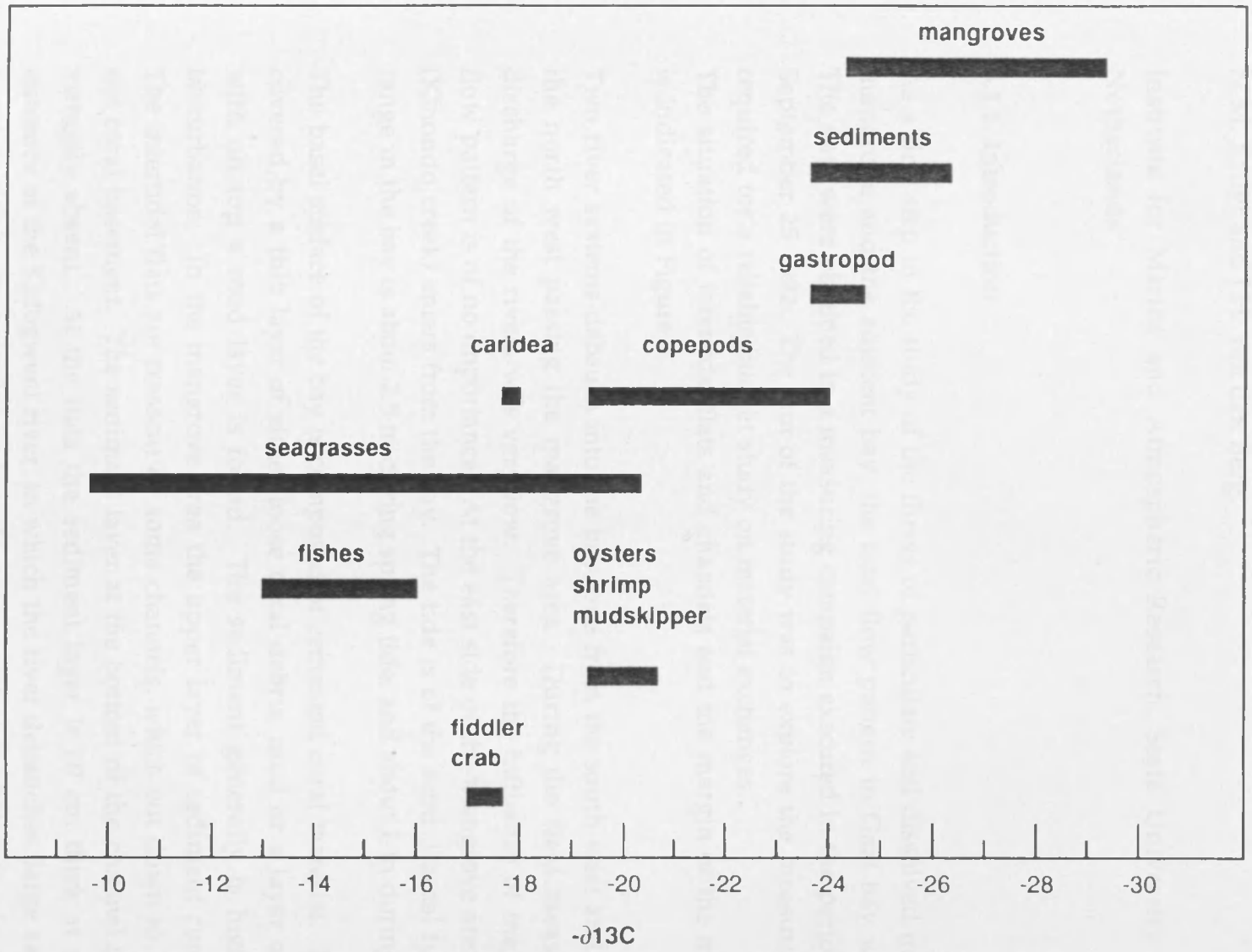

Figure 1 : $\partial^{13}C$ values ($^{o}/_{oo}$) in different compartments of the mangrove ecosystem

5. MATERIAL EXCHANGES BETWEEN MANGROVE AND ADJACENT WATER

5.1. HYDROGRAPHY OF GAZI BAY

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5.1.1. Introduction

As a first step in the study of the fluxes of particulate and dissolved matter between mangrove and the adjacent bay, the tidal flow pattern in Gazi bay was described. The data were obtained in a measuring campaign executed in the period August 22 - September 25 1992. The aim of the study was to explore the measuring conditions required for a reliable budget study on material exchanges.
The situation of intertidal flats and channels and the margin of the mangrove area is indicated in Figure 1.

Two river systems debauch into the bay, one from the south west and another from the north west passing the mangrove area. During the field measurements the discharge of the rivers was very low. Therefore the influence of the rivers on the flow pattern is of no importance. At the east side of the mangrove area a tidal creek (Kinondo creek) enters from the bay. The tide is of the semi-diurnal type. The tidal range in the bay is about 2.5 m during spring tide, and about 1 m during neap tide.

The basal surface of the bay is composed of cemented coral material. This surface is covered by a thin layer of either loose coral debris, mud or a layer of coral debris with on top a mud layer is found. The sediment generally is highly mixed by bioturbation. In the mangrove area the upper layer of sediment consists of mud. The intertidal flats are crosscut by some channels, which cut down to 1 m deep into the coral basement. The sediment layer at the bottom of the channel is very thin or virtually absent. At the flats the sediment layer is 60 cm thick at most. At the entrance of the Kidogweni river, in which the river debauches, large sand bodies are present with current ripples on top. In other parts of the bay just a few wave ripples appear, however generally there is no clear micro-morphology. In front of the river

in the south west is a delta with a straight front. The delta is wave and tide dominated.

The study area comprised a tidal channel (Kinondo Creek) and its surrounding tidal flats, near the margin of the mangrove swamp. To the west the study area was bordered by a tidal watershed as displayed in Figure 2. This watershed is an elevation of the topography. At the watershed the sediment layer is very thin (around 20 cm). Near the margin of the tidal flat the thickness of the sediment layer increases up to 60 cm.

5.1.2. Materials and methods

Equipment and measurement methods

First of all a map was constructed from aerial pictures. With an echo sounder and a levelling instrument the topography of the bay was recorded. With these data a rough elevation map was drawn. Some bench marks have been placed at known positions to determine the position in the field. Reference to the national elevation datum was impossible for the area of measurements. Therefore a gauge was placed on a stable location (coral bottom; Figure 1). All the elevations were related to this stable location.

To determine the hydrography a tidal gauge and current meters were used. The tidal gauge recorded the water level by a pressure sensor. This instrument measures the water column above the sensor. The values are analogous recorded in a graph. In the present analysis the graphs, containing a period of 848 hours, were digitized by hand by one reading for each hour. The scale of the tidal gauge was calibrated with readings from a metric gauge with a millimetre scale.

The flow velocity is recorded with propeller current meters (OTT current meter). The current velocity was simultaneously measured at two stations. A permanent station was located at a work platform erected near Kinondo channel (wp in Figure 1), the other station was mobile (dinghy). The measurements with the mobile station were distributed over the bay in such a way that the flow was measured on each morphological unit, i.e. tidal flats, channel, flat in creek and channel in creek (Figure 1). Unfortunately, it was not possible to measure the ebb as well the flood current at all locations. Because of the changing water depth 5 current meters were placed on top of each other. At the mobile station only 3 current meters were used because of the limited number of current meters available. The vertical velocity

profile was expected to approximate the theoretical logarithmic shape. Therefore each instrument was placed at a certain height above the bottom in such a way that equal distances are obtained in a logarithmic profile. The current velocity was measured each 10 minutes during 5 minutes. During each measurement period the water depth was also recorded. The current direction was measured by estimating the bearings of the current meter with a compass. Flow directions were obtained by measuring the travelling direction of floating buoys.

To determine the volume of suspended load during an ebb and flood cycle water samples were taken with a water sampler. The sampler was a large plastic tube with a diameter of 11 cm and a volume of about 2.5 l. This tube was lowered to the desired depth where it adjusted to the current in a way that the water flowed freely through the tube. After a while the tube was closed and the water sample was collected in a bucket. The samples were taken at 3 different depth above the bottom, 2/3 of the water depth, 1/2 of the water depth and 1/3 of the water depth. The 3 samples were mixed with each other in order to get an average estimation of the concentration for the whole water column. Each half a hour a sample was taken in the same way. 2 l of the mixed sample was filtered and dried in a stove before it was weighted with a balance.

Calculation of the mean current velocity

Each 10 minutes a vertical velocity distribution was measured. Thus for each 10 minutes a value of the depth-averaged current velocity could be obtained. This mean current velocity is assumed to remain constant during the measuring period. Two other assumptions are made to reconstruct the vertical velocity distribution. The first assumption is that at the bottom the current velocity is 0. The influence of a boundary layer is neglected. The second assumption is that the velocity at the water surface is the same as the velocity at the highest measured point in the vertical (Figure 3). Current velocities during the flood are considered as positive value. From the vertical velocity distribution the mean current velocity over the depth is calculated by

$$\bar{U} = \frac{1}{2}\int_{o}^{h} U_z \, d(z)$$

where $\bar{U}$ = mean current velocity over the depth [cm/s]
Uz = current velocity at z cm above the bottom [cm/s]
h = water depth [cm].

When current velocities of different tides are compared with each other the problem arise that each tide has another high and low water level. Therefore it is necessary to reduce the current velocities of each tide to a situation of a mean tide. For this reduction the average of all tidal ranges of the 848 hours tidal data set are used. Each tidal range is reduced by this average value (192.7 cm) so that for each tide a reduction coefficient is obtained. By multiplying this reduction coefficient with the current velocity a reduced current velocity is obtained. These reduced current velocities are comparable with each other.

Calculation of discharge

The discharge Qtide is calculated by

$$Q_{tide} = \sum_{t=o}^{T} b\bar{U} \qquad [m^3/tide]$$

where T = tidal phase (flood or ebb)
$\bar{U}_t$ = reduced mean current velocity at time t [m/s]
ht = reduced water depth at time t [m]
w = width [m]

Because measurements of different tides are compared with each other, the current velocity as well as the water depth has to be reduced for an average tide. The time step t is 600 seconds. Discharges are calculated for different topographical units. The sum of the discharges per each step t gives the total discharge during one tidal phase (flood or ebb) for the whole creek.

5.1.3. Results

During the measurements, the monsoon wind was south-east. The wind force has been estimated at about 3 to 4 Beaufort. The waves in the bay are of local origin as the ocean waves dissipate completely on the coral reef seaward of the bay. The highest waves were observed in the centre of the bay, the deepest part, and had a mean wave height of about 60 cm. At the research site wave height never exceeded 30 cm.

The record of the tidal gauge contains 848 hours. However from 4-9-1992 to 5-9-1992 a gap of 16 hours is present. The deflection of the tide curve at low water seems to be cut (Figure 4). It is possible that the pressure sensor malfunctioned at extreme low waters. The graph of the tides shows clearly the spring and neap tides. Any sequence of measurements of water levels or currents in a tidal area has a tidal component and a non-tidal component. The non-tidal component is the residual after the regular tides are removed. This is possible with a moving average with a window of 35 hours. The non-tidal component is the result of meteorological events, e.g. storms. The increase of the residual is probably the result of the malfunctioning of the sensor at low water. No distinct non-tidal component is present in the sequence. Difference between neap and spring tide is also expressed in the form of the tidal curve, especially at low tide as displayed in Figure 5. At neap tide the tidal curve is symmetric. The flood as well as the ebb period is for both 6 hours. At spring tide, after a quick fall of the water level the curve shows an extra tail at which the fall of the water level is much slower. Also, the period of the ebb becomes much longer (about 8 hours) than the flood period (about 4.5 hours).

At mean tidal range (i.e. data reduced to average tide) current velocities in the channel and the Kinondo creek velocities at the ebb are much smaller than the current velocities at the flood. The ebb current is 2 to 4 times larger than the flood current. Especially at spring tide the ebb current velocity is very high, reaching a maximum of up to 30 cm/s at the moment that the flats drain just before they emerge (Figure 6). The highest flood current velocities occur in the second half of the tide. The highest water elevation coincides with the turn of the tidal current. The ebb flow turns when the water level is already rising. At the flat the differences between the ebb flow and the flood flow are much smaller. Both flows are about the same velocity. At spring tide, just before the flat emerges it will be drained by a thin layer of water. At neap tide the flats are not emerging. The fluctuations in the time series of the current velocities is due to small malfunctions of the flow meters, like disturbance of the waves, disturbance by the dinghy and obstruction of the propeller

by floating material and seagrass. By smoothing the time series a regular coarse of the current velocities during the tide will be obtained.

In Figure 7 the flow vectors of all measuring sites, reduced to average tide, are given in 12 time steps of equal length during the tidal cycle. At high tide the water flows from the creek towards the bay. Water in the channel of the creek follows the channel until it enters the deeper parts of the bay. Water from the flat in the creek does not follow the channel but crosses the flat into the bay. In the final part of the ebb tide, just before the flats emerge, water flows from the flats towards the channel which drains the water off towards the deeper part of the bay.

At the start of the flood flow water flows through the channel. As the water level has risen high enough water flows over the flat. The flow direction is straight from the bay towards the margin of the mangrove area.

At the entrance of the creek the ebb as well as the flood current velocity was measured in the channel and on the flat. Because the topography was recorded by echo sounding a reliable estimate of the discharge could be made for the entrance of the creek (Figure 8). According to the discharge calculations during the flood period $2.4 * 10^5$ m^3 water flows into the creek. At the final phase of the flood period (the last 2 hours) the discharge enlarges. During the ebb period $6.4 * 10^5$ m^3 water is drained through the creek. At the start of the ebb period the discharge is the largest. After about 3.5 hours the discharge diminishes (Figure 9).

Concentrations of suspended matter were measured on September 13, 1992 (spring tide) and on September 16, 1992. The first measurement shows a relation between flow velocity and the concentration of suspended matter: the concentration increases with increasing current velocities as shown in Figure 10. The second concentration measurement does not show any correlation with the current velocity. The concentration sequence is probably only white noise. Therefore it is impossible to make any comparison between the two concentration measurements. However, the concentrations at the bay are very low up to 11 mg/l. The very large values of 30 and 45 mg/l have to be considered as measuring errors because mainly bed load was sampled.

5.1.4. Discussion

The results of the measurement provide a good impression of the water motions in the eastern part of Gazi bay. At flood the water flows steadily into the bay. At first the water flows through the channel. As the water level overtops the tidal flats the water flows straight into the direction of the mangrove swamp. During the ebb period the mangrove swamp is drained by the creek. This is sustained by the discharge measurements. At ebb the discharge in the Kinondo Creek is 2.6 times as much as the discharge at flood. Thus, the channel is an export system. Because this part of the mangrove is a closed system (no influx of water by other systems, e.g. rivers) water is only imported via the tidal flats during flood. In the mangrove area a circulation from the borders to the creek takes place (Figure 11). Water is drained by the channel as well as by crossing the tidal flat. Eventually, water from the channel and the tidal flat confluences in the deeper part of the bay. Just before the tidal flats emerge water from those flats is drained off sideways into the channel. The channel transports the last amount water at high current velocities. Therefore, the ebb current is still going on although the water level is already rising.

5.1.5. Recommendations for budget studies

Budget calculations are based on measurements of both current velocity measurements and concentration measurements, executed simultaneously during a complete tidal cycle. The following measuring procedure is proposed for calculation of nutrient exchange between the mangrove and tidal flats in the studied area at each station: the current velocities are measured with a OTT propeller current meter. The concentration is measured with a peristaltic (VERDER) pump which is connected by means of 6 mm diameter plastic tubes to intake nozzles. The current meter and the intake nozzle can be mounted in one streamlined carrier so that at different depths the velocity as well as the concentration may be measured. One measurement cycle takes various current velocity measurements, at each depth for about 2 minutes, and water intake at various depths. Because of the small concentrations at least 10 litre water has to be pumped. Because it is reasonable to assume that the nutrients are homogeneous distributed, an average concentration over the depth will be gained by pumping water samples continuously at the different depths. The sucked water samples are filtered and collected for further analysis. Each station needs a pump set and a flow meter. In total 6 measuring stations should operate simultaneously during a complete tidal cycle, starting at low water slack with a measuring frequency of 10

minutes. At one of the locations the water level and wave height is to be measured. The positions of the stations are indicated in Figure 11. The stations have to be something like floating constructions. It is stressed that a budget calculated from results of a measuring campaign covering only one tidal cycle probably will not be representative of any average condition. Therefore, if information on long-term net exchanges of nutrients is required, the measurements have to be repeated at all conditions that are regarded of possible important influence on the budget.

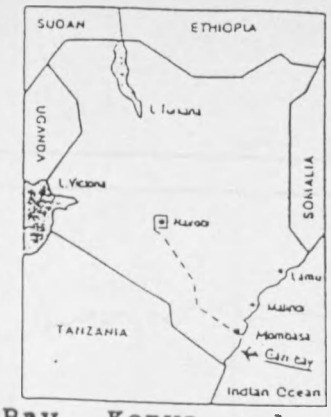


Figure 1 Study area at Gazi Bay, Kenya and positions of measurements.

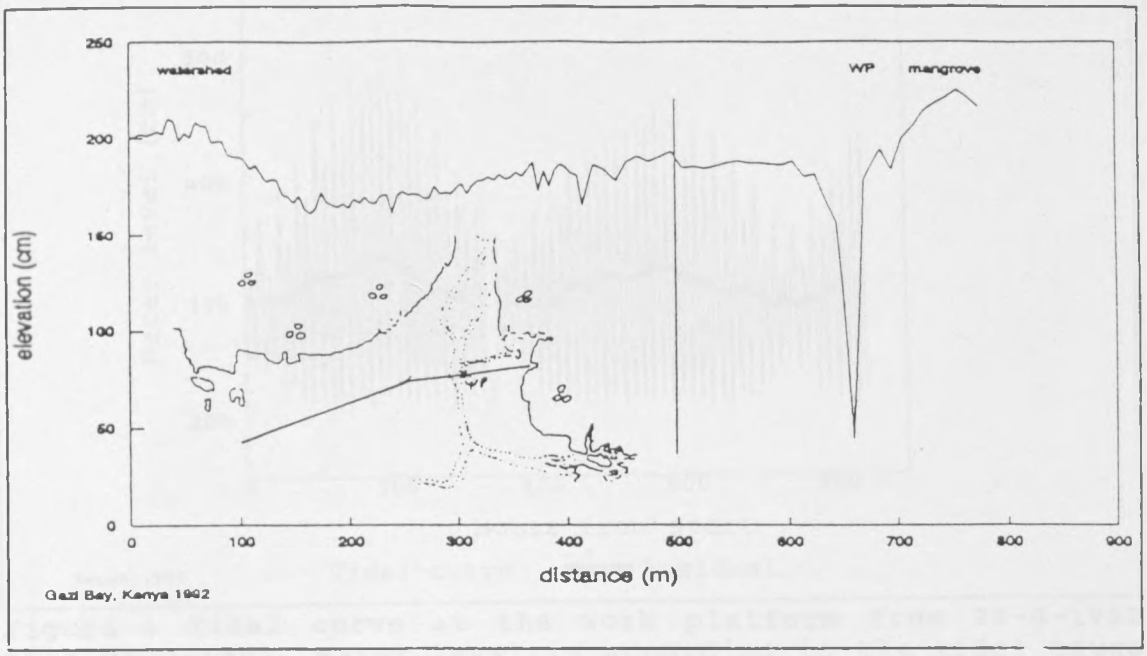


Figure 2 Topography near Work Platform

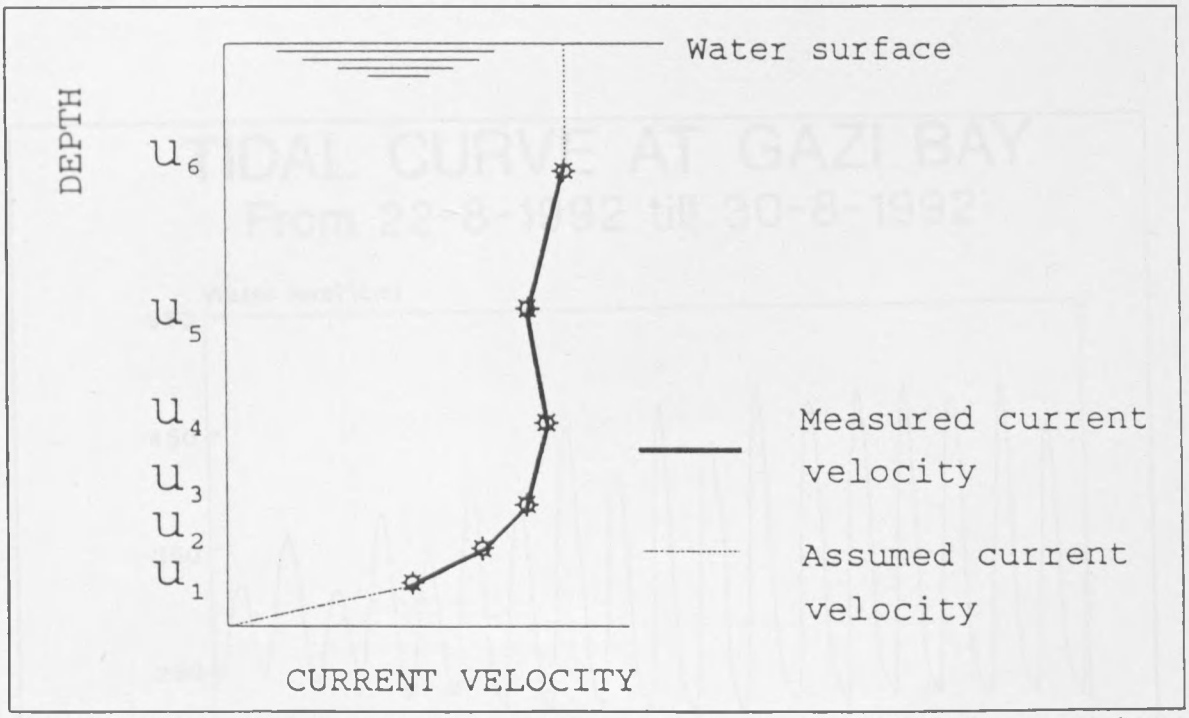


Figure 3 Assumptions for the reconstruction of the vertical velocity profile.

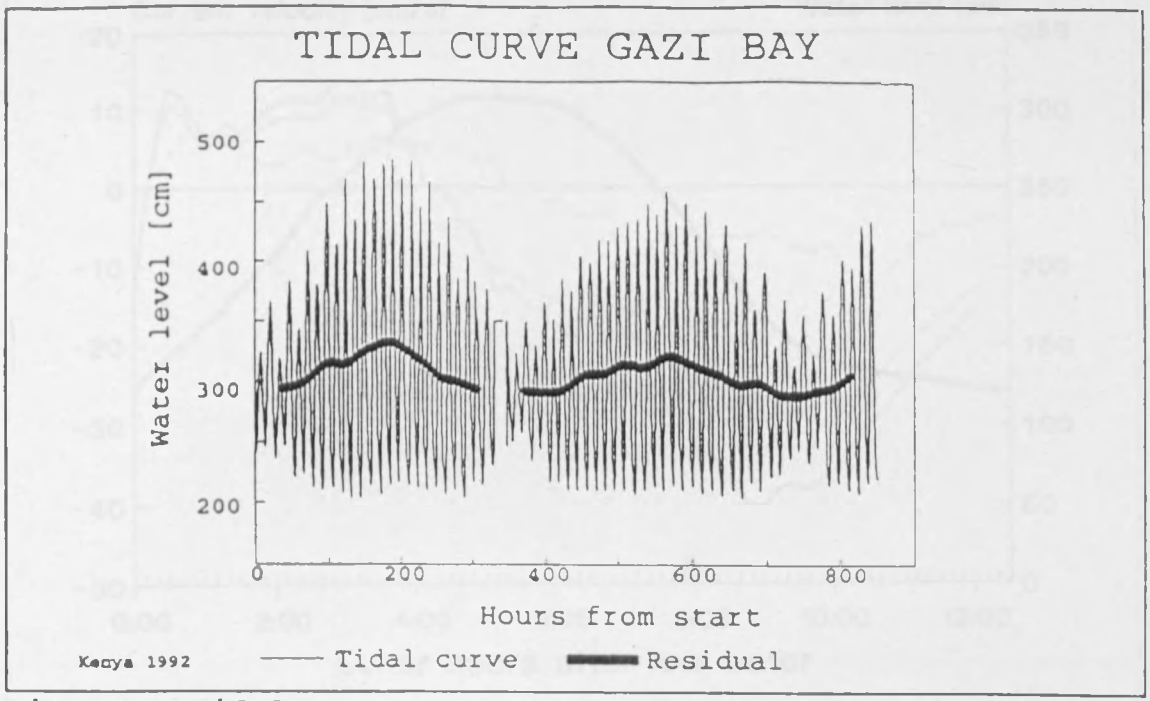


Figure 4 Tidal curve at the work platform from 22-8-1992 till 25-9-1992. Water level is according to the tidal gauge of the platform.

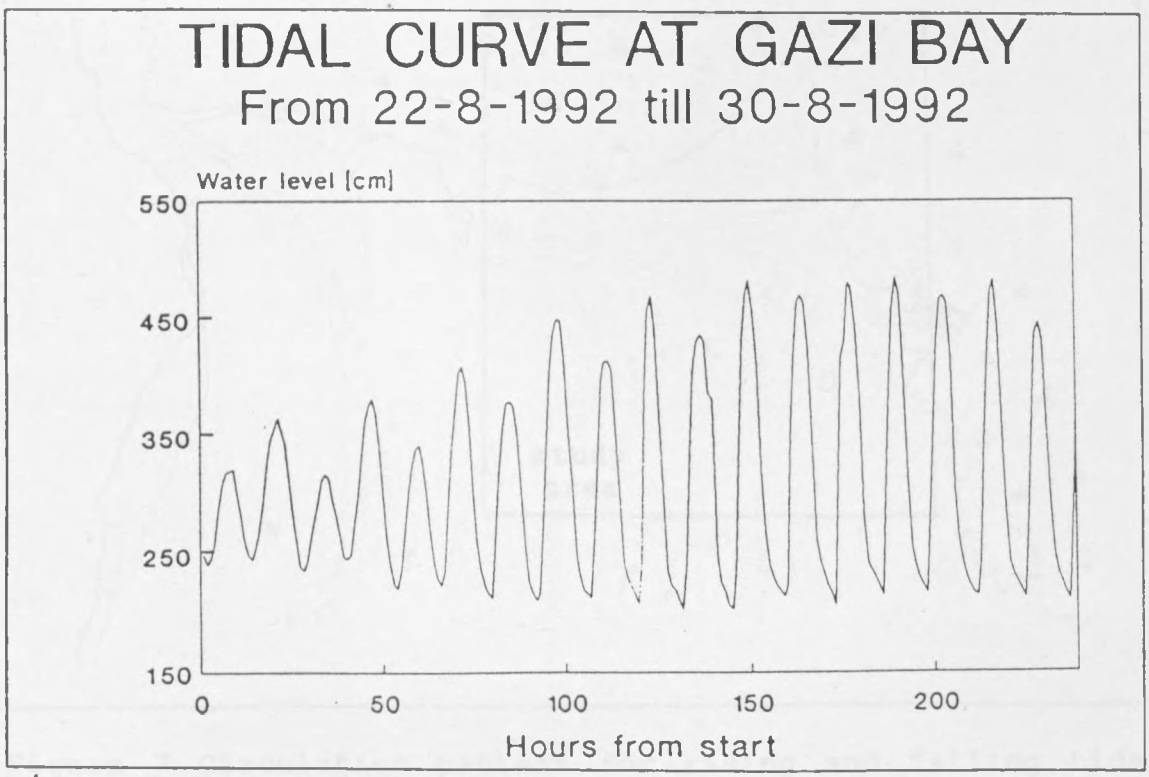


Figure 5 Part of the tidal sequence including neap and spring tide.

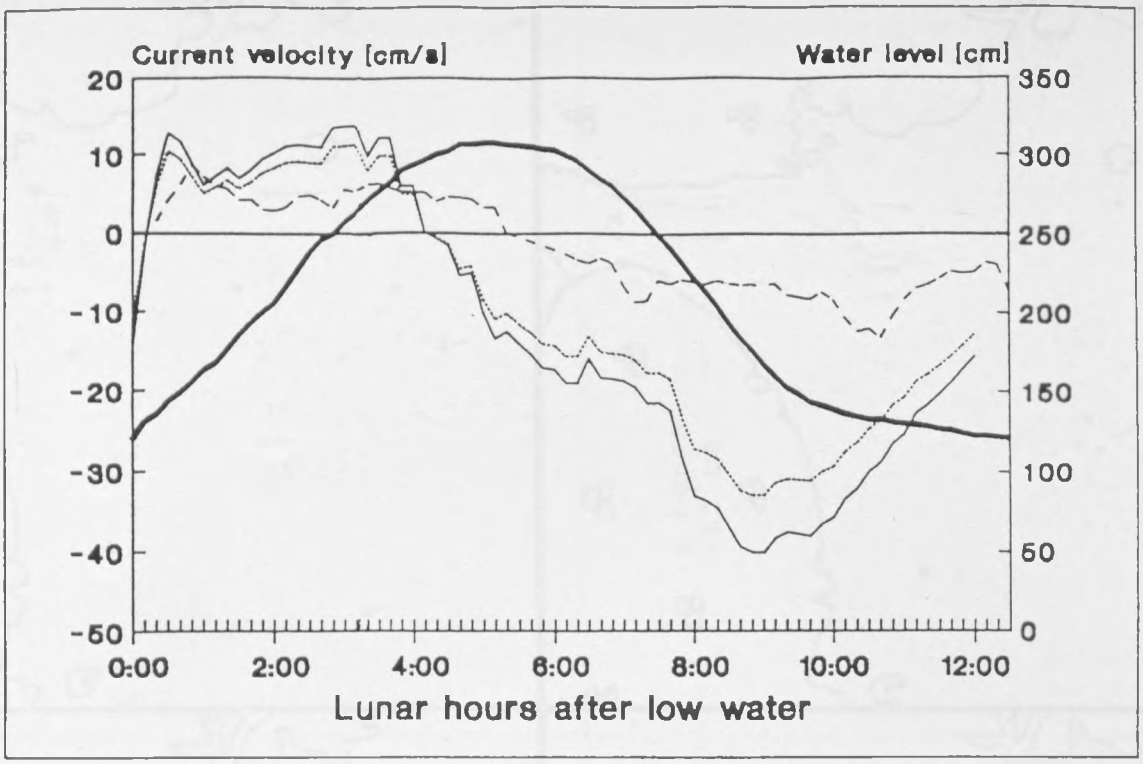


Figure 6 Current velocities in the channel near the Work Platform (WP) at spring tide ——— ,neap tide ---- and average tidal conditions ..... . The water level is for average tidal conditions ▬▬ .

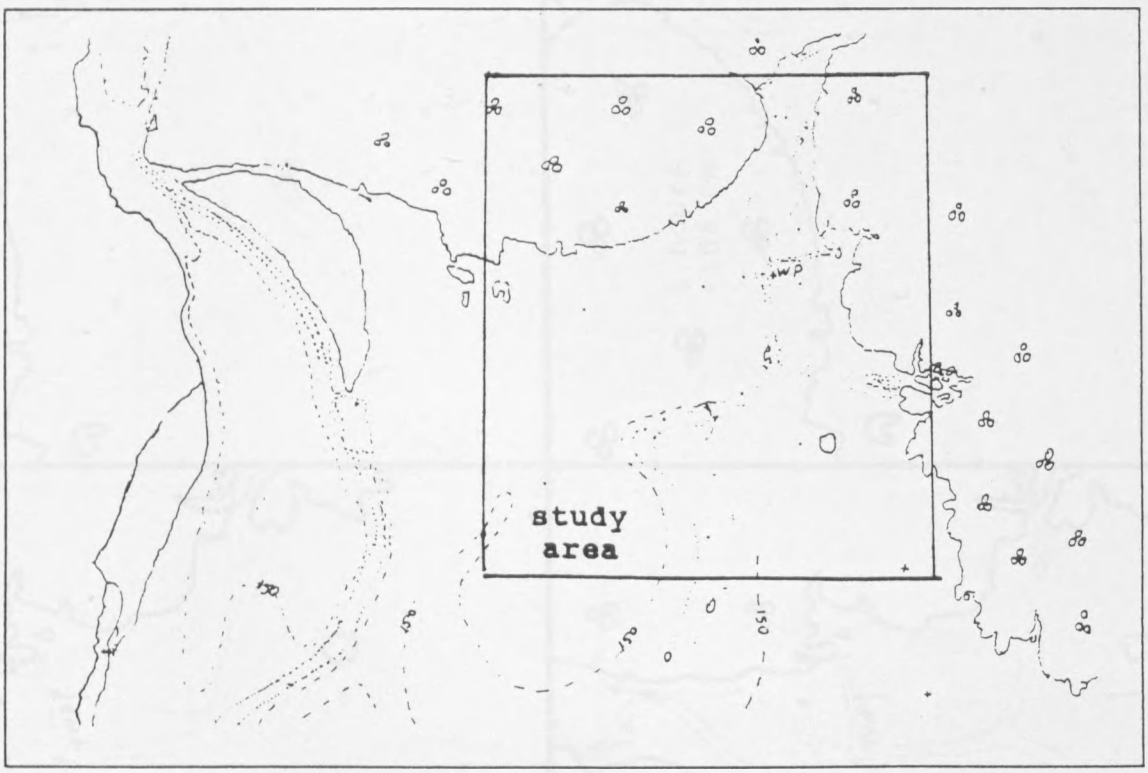


Figure 7 Circulation pattern for rising and falling tide per lunar hour. The start is at low water. The arrow indicates the flow direction as well as the reduced current velocity ← = 10 $^{cm}/_{s}$. o Indicates no current velocity.
▲ Indicates no current velocity measurement at this tidal cycle.

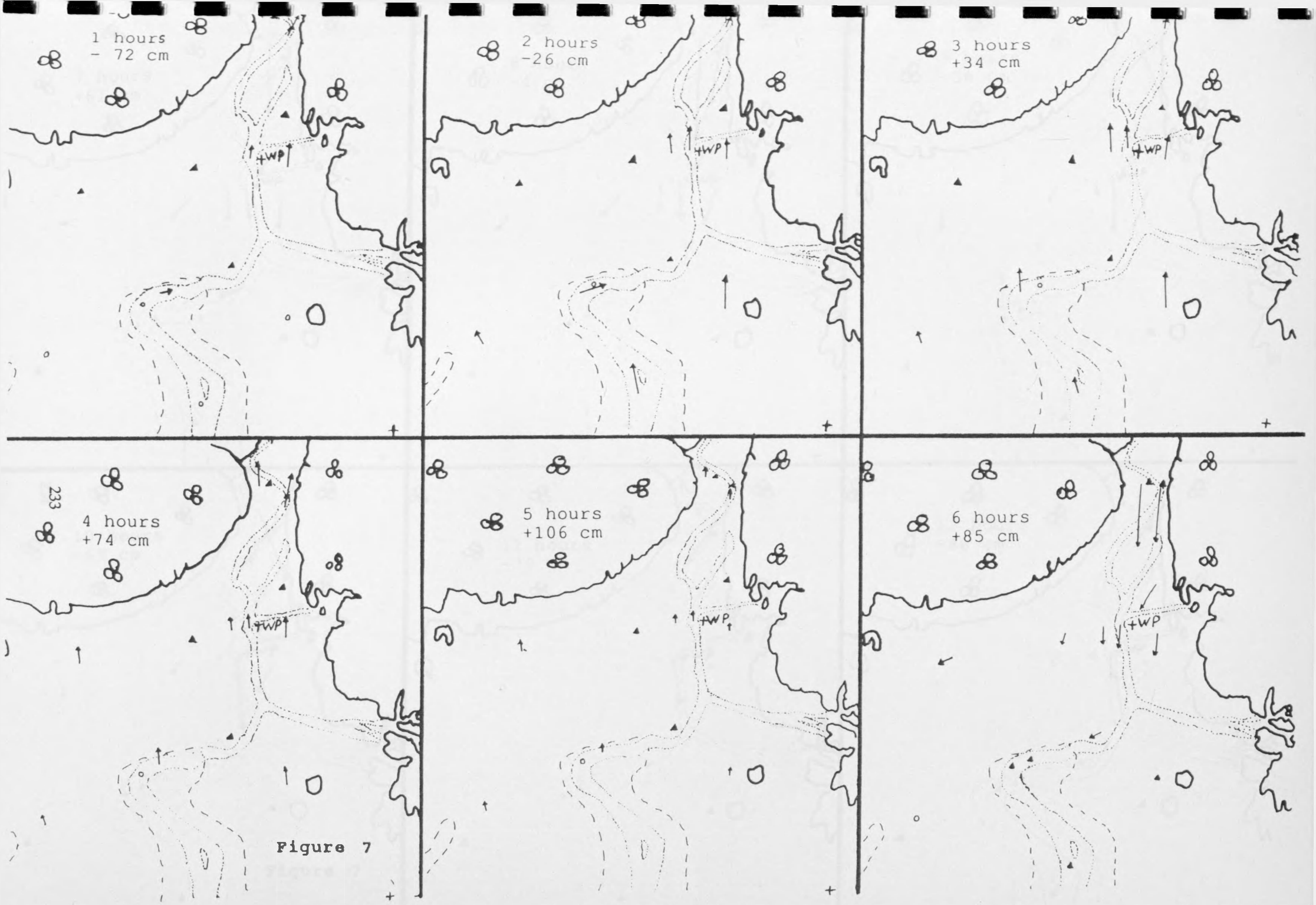

1 hours
- 72 cm
2 hours
-26 cm
3 hours
+34 cm
4 hours
+74 cm
5 hours
+106 cm
6 hours
+85 cm
+WP

Figure 7

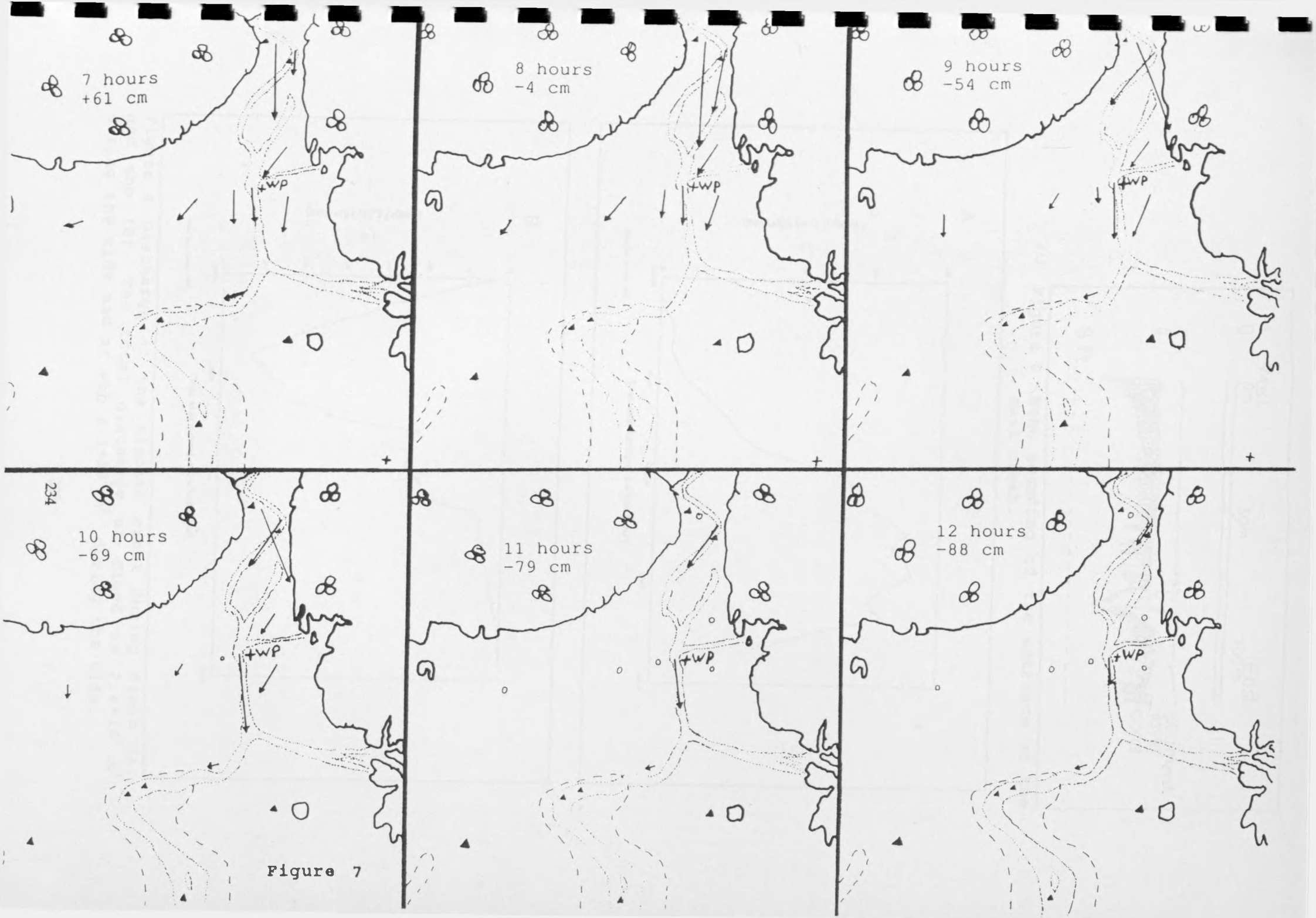
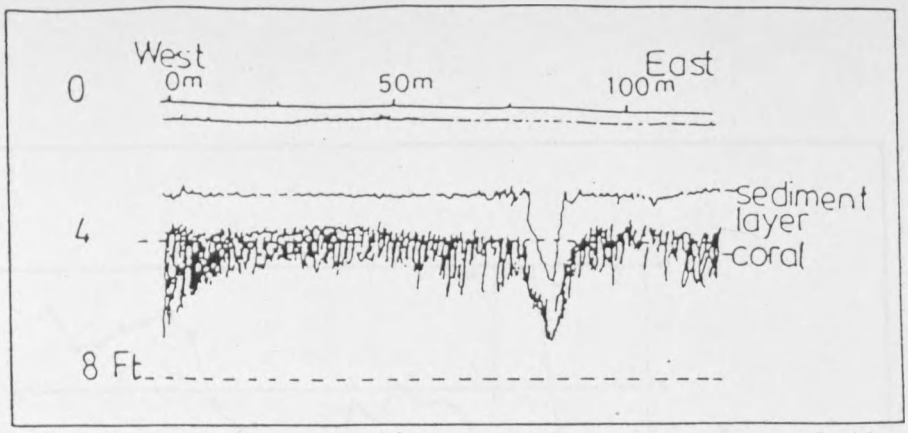
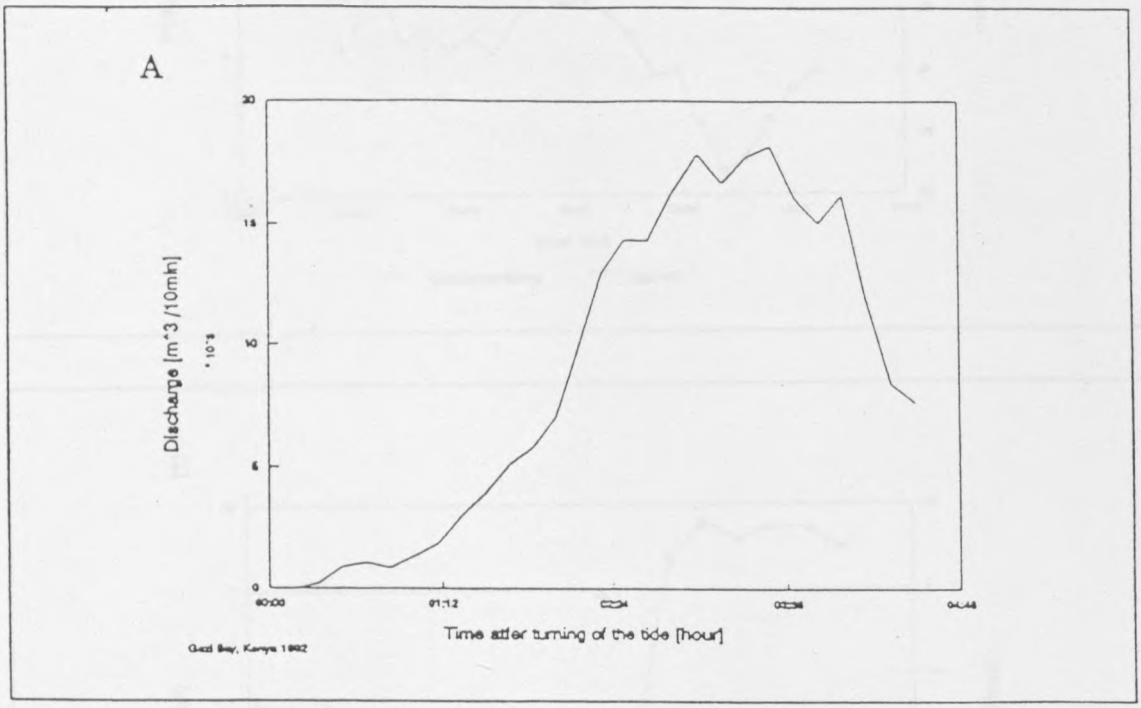

7 hours
+61 cm
8 hours
-4 cm
9 hours
-54 cm
10 hours
-69 cm
11 hours
-79 cm
12 hours
-88 cm
+WP

Figure 7



RU Figure 8 Echo sounding of the entrance of the east creek.



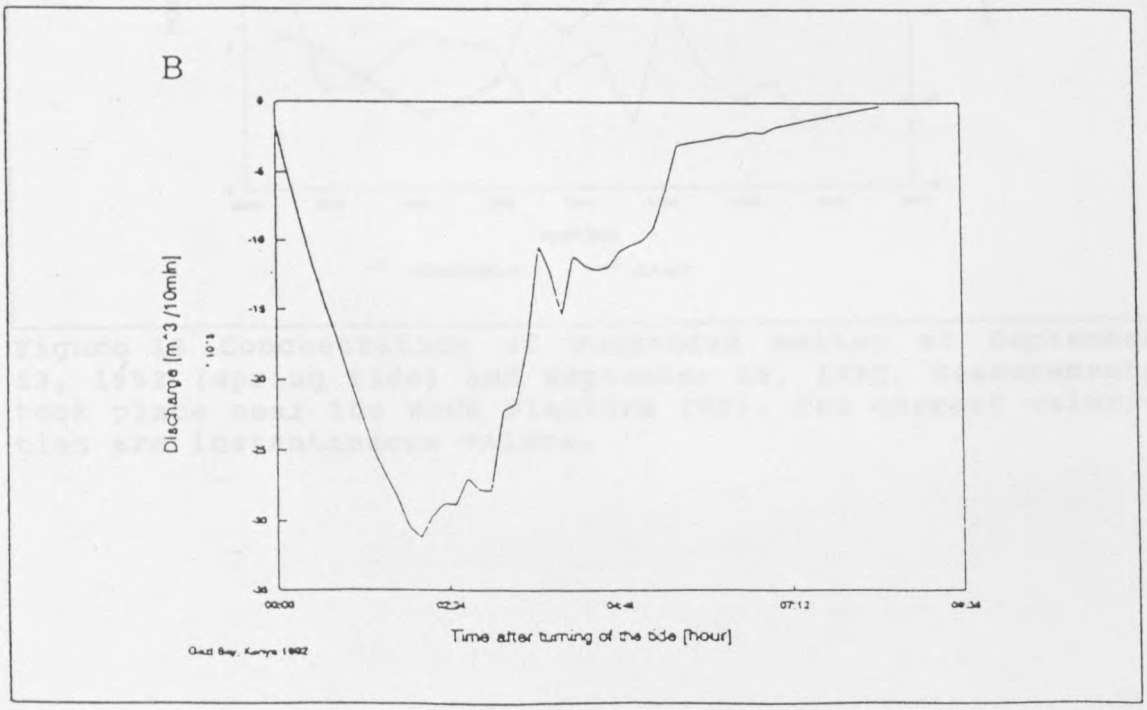
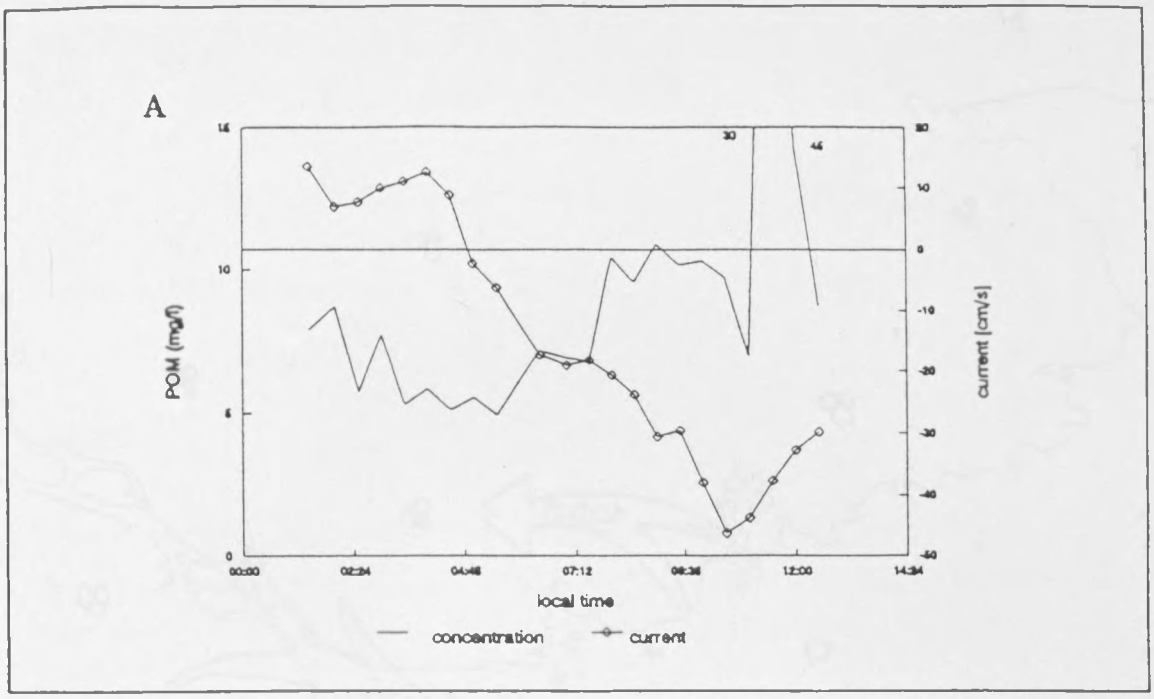


Figure 9 Discharge of the Kinondo creek during flood (A) and ebb (B). The total discharge at flood is $2.4*10^5$ m^3 during the tide and at ebb $6.3*10^5$ m^3 during the tide.



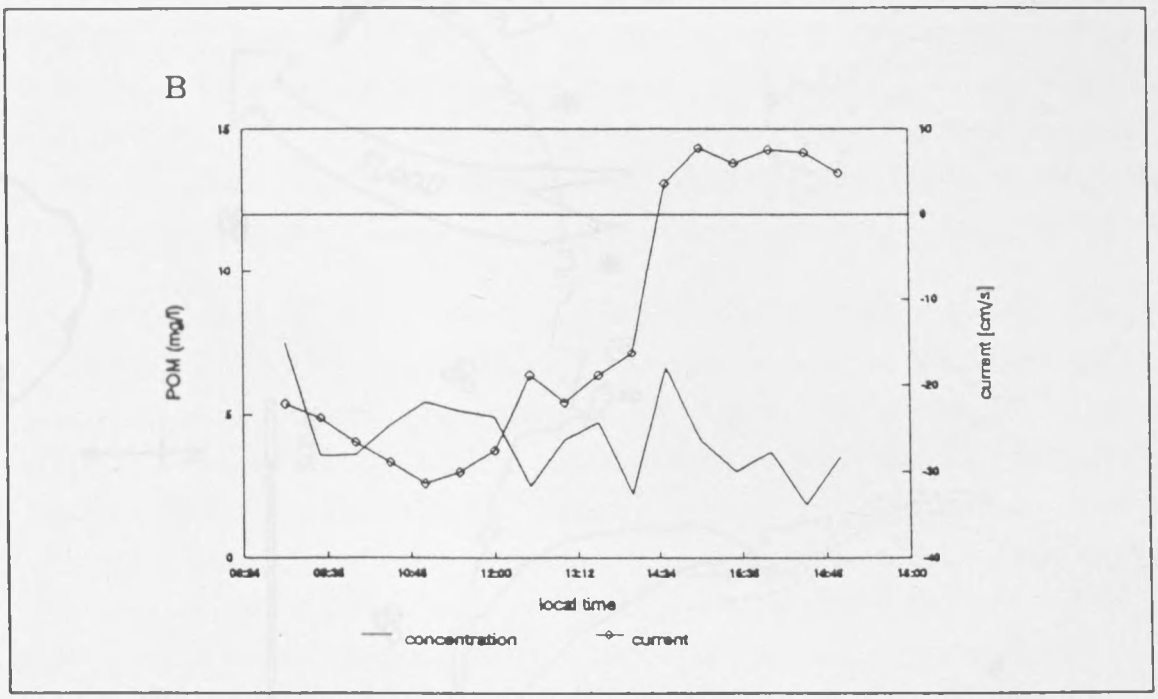


Figure 10 Concentration of suspended matter at September 13, 1992 (spring tide) and September 16, 1992. Measurements took place near the Work Platform (WP). The current velocities are instantaneous values.

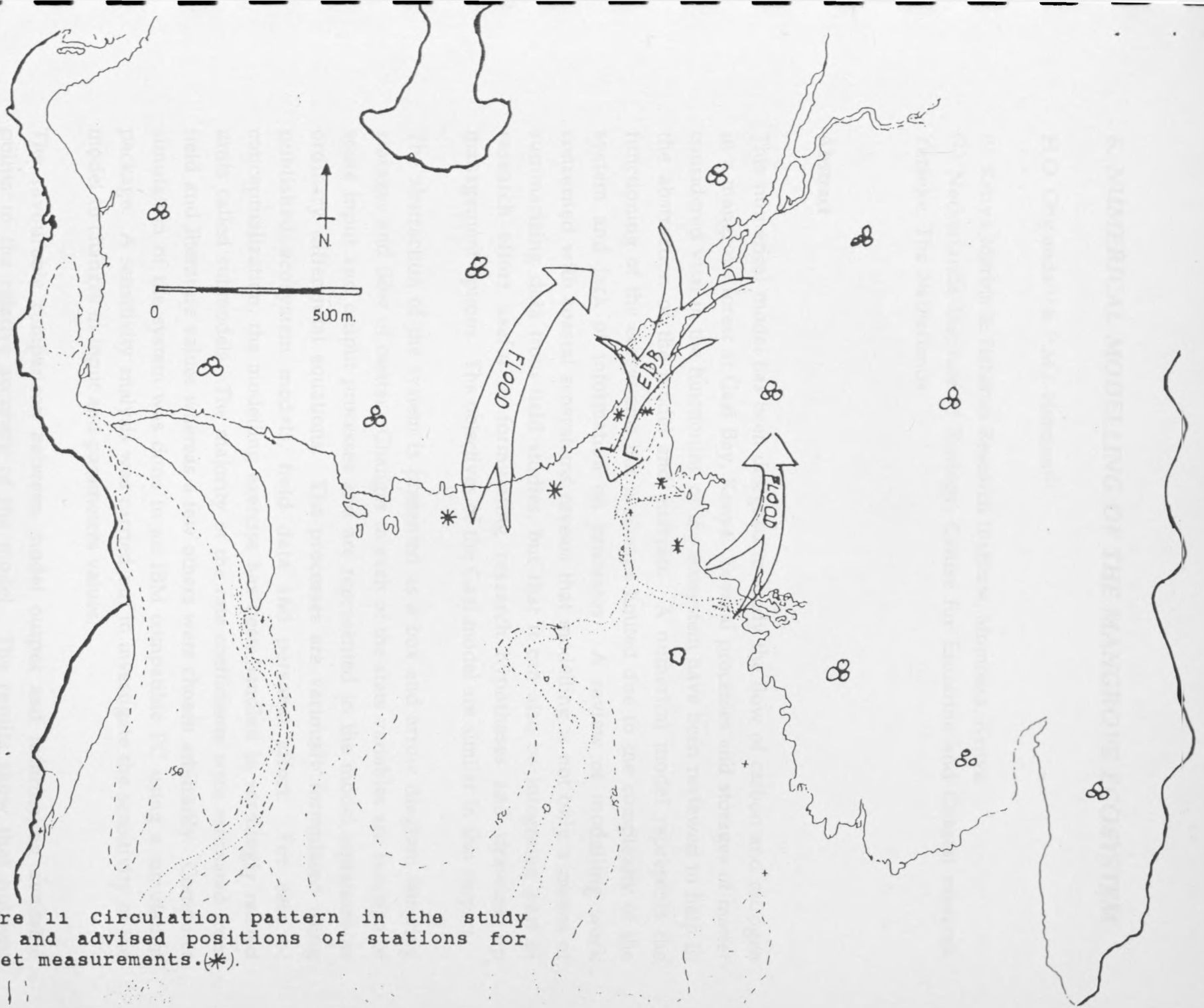


Figure 11 Circulation pattern in the study area and advised positions of stations for budget measurements.(*).

6. NUMERICAL MODELLING OF THE MANGROVE ECOSYSTEM

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Abstract

This numerical model has been designed to study the flow of carbon and nitrogen in a mangrove forest at Gazi Bay, Kenya. Several processes and storages of matter considered vital in the functioning of the ecosystem have been reviewed to help in the abstraction of the model and analysis. A numerical model represents the functioning of the ecosystems but is always limited due to the complexity of the system and lack of information on processes. A review of modelling work concerned with coastal ecosystems reveals that modelling is not only a means of summarizing data from field studies, but that it can also be integrated part of research effort useful in formulating research hypotheses and drawing up management options. The objectives of the Gazi model are similar in this respect.

The abstraction of the system is presented as a box and arrow diagram showing storages and flow of matter. Changes in each of the state variables are function of some input and output processes and are represented in the model equations as ordinary differential equations. The processes are variously formulated using published ecosystem models, field data and personal effort. For ease of conceptualization, the modelling exercise has been handled in seemingly related units called submodels. The majority of the rate coefficients were estimated from field and literature values whereas a few others were chosen arbitrarily. Computer simulation of the system was done in an IBM compatible PC using a simulation package. A sensitivity analysis was carried out to investigate the sensitivity of the model to changes in input and parameters values.

The favourable comparison between model output and information available points to the relative accuracy of the model. The results show that nutrient contribution of the mangrove ecosystem to the contiguous zones is negative. The system exports carbon largely consisting of detritus poor in nitrogen. The flow of nitrogen through bacteria account for 72 % of the total system nitrogen throughflow

(not including the import of nitrogen into the system). Mangrove trees can be harvested by adopting a cycle of management.

The mangrove ecosystem is critically dependent on incoming nitrogen. Of the dynamics of the inorganic nitrogen N_2-fixation and denitrification have little impact on the system. Most of the parameters and inputs are not certain but appear to be very important in the dynamics of the system. Response of detritivores to changes in the system suggests the need for more control mechanisms in the model.

There are limitations to the model prediction especially with regard to changes in the system. The mangrove ecosystem strongly consumes nitrogen and compensates for this by using inorganic nitrogen in the tidal water and possibly from sheetflow and underground seepage. The grazing habits of detritivores is uncertain and more information is needed. The manner in which different ways of mangrove harvesting may affect the regeneration of forest requires a model taking into consideration all factors related to harvesting.

Remark

The detailed research work is presented in a document annexed to this final report, called: "Dynamics of Carbon and Nitrogen in the Mangrove Forest of Gazi, Kenya: A Numerical Modelling Approach"