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II. THE WEST COAST.

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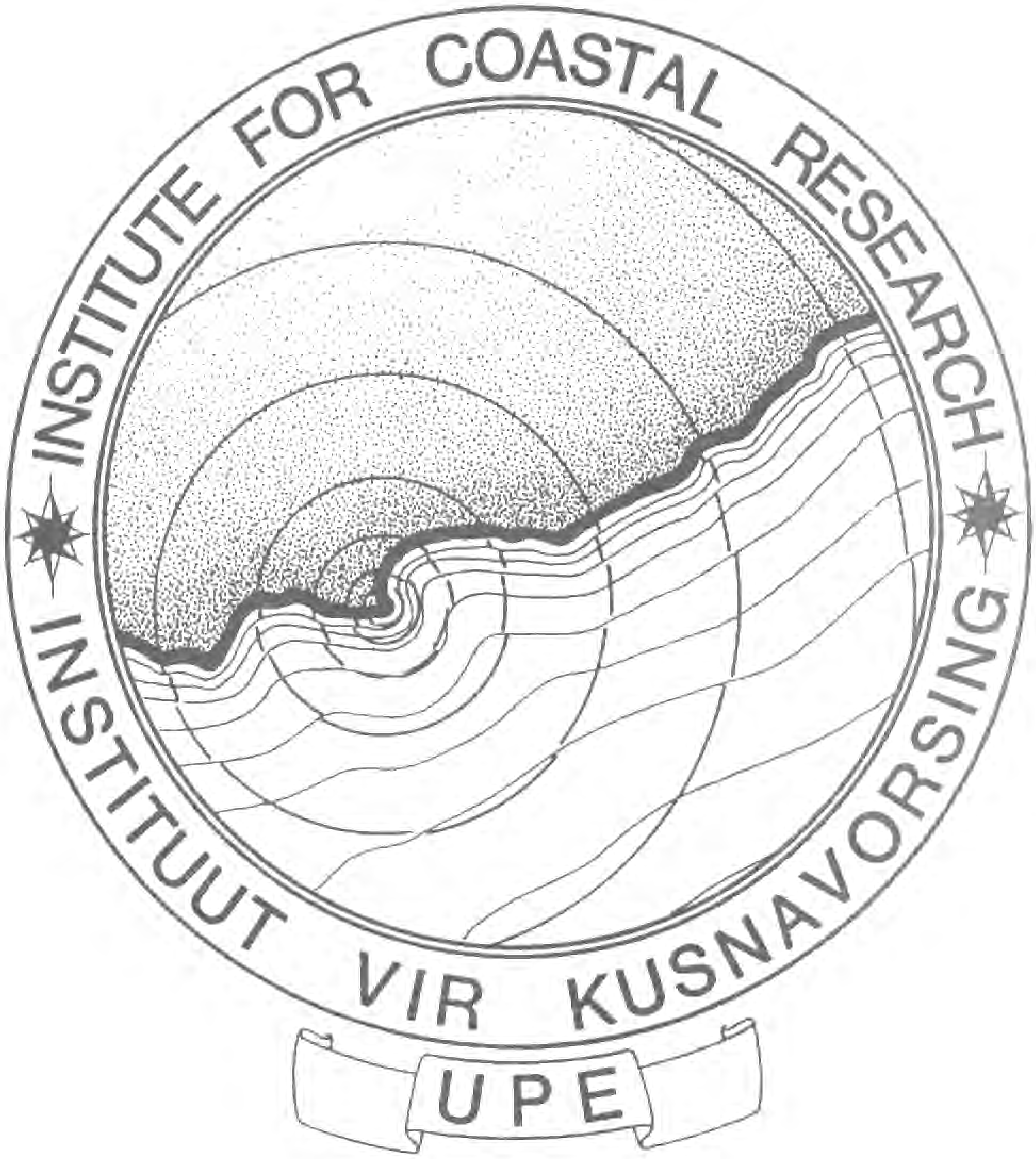

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REPORT NUMBER

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1. INTRODUCTION

1.1 The Surf-Zone Ecosystem

It is a widely held view concerning the phytoplankton of the littoral and inner sublittoral zones of the ocean that high standing stocks only occur in areas having a stable substrate to which benthic plants can attach. Consequently exposed sandy beaches, where the shifting substratum precludes attachment of macroalgae have been regarded as zones of low primary production (Brown, 1964). Sandy beaches which do not host phytoplankton accumulations are considered to be "subsidized" to some extent from oceanic and landwater sources (McLachlan, 1980). Those beaches which contain phytoplankton accumulations constitute an exception to this rule (Lewin and Schaefer, 1983).

Because of the presence of rich phytoplankton accumulations in the surf, maintained by special cell mechanisms together with water gyres which retain nutrients, McLachlan (1980; McLachlan *et al.*, 1981) proposed that the sand and water envelope of the surf-zone is a viable, semi-closed ecosystem. This ecosystem had the drift line and outer limit of water gyres as its boundaries. Talbot and Bate (1986) took this concept further and reported that no surf diatoms could be found in the nearshore behind the breaker line except on a single occasion, making the system closed at least with respect to surf diatoms.

In this report, terminology is used which has developed following investigations at the Sundays River beach surf ecosystem. The surf-zone terminology used by McLachlan, (1980, 1983) and Talbot (1986) has been adapted as follows: The surf-zone ecosystem comprises the entire sub-aerial beach and the breaker zone. For the purposes of the present study, because the study was undertaken from the beach without the facilities to sample the nearshore, the latter area of exchange by rip currents is excluded. The ecosystem is considered to be a closed or semi-closed system the dimensions of which are shown in Figure 1.

In the past, the "bloom" has been used to describe the brown water phenomenon in surf-zones. This has caused some confusion with the result that the following terms are applied strictly in this work:

Bloom - High cell concentrations resulting from exponential cell division of a phytoplankton species.
Accumulation - High cell concentrations caused by physical concentrating forces, such as water currents.
Patch - The discolouration of water due either to bloom formation or accumulating forces.

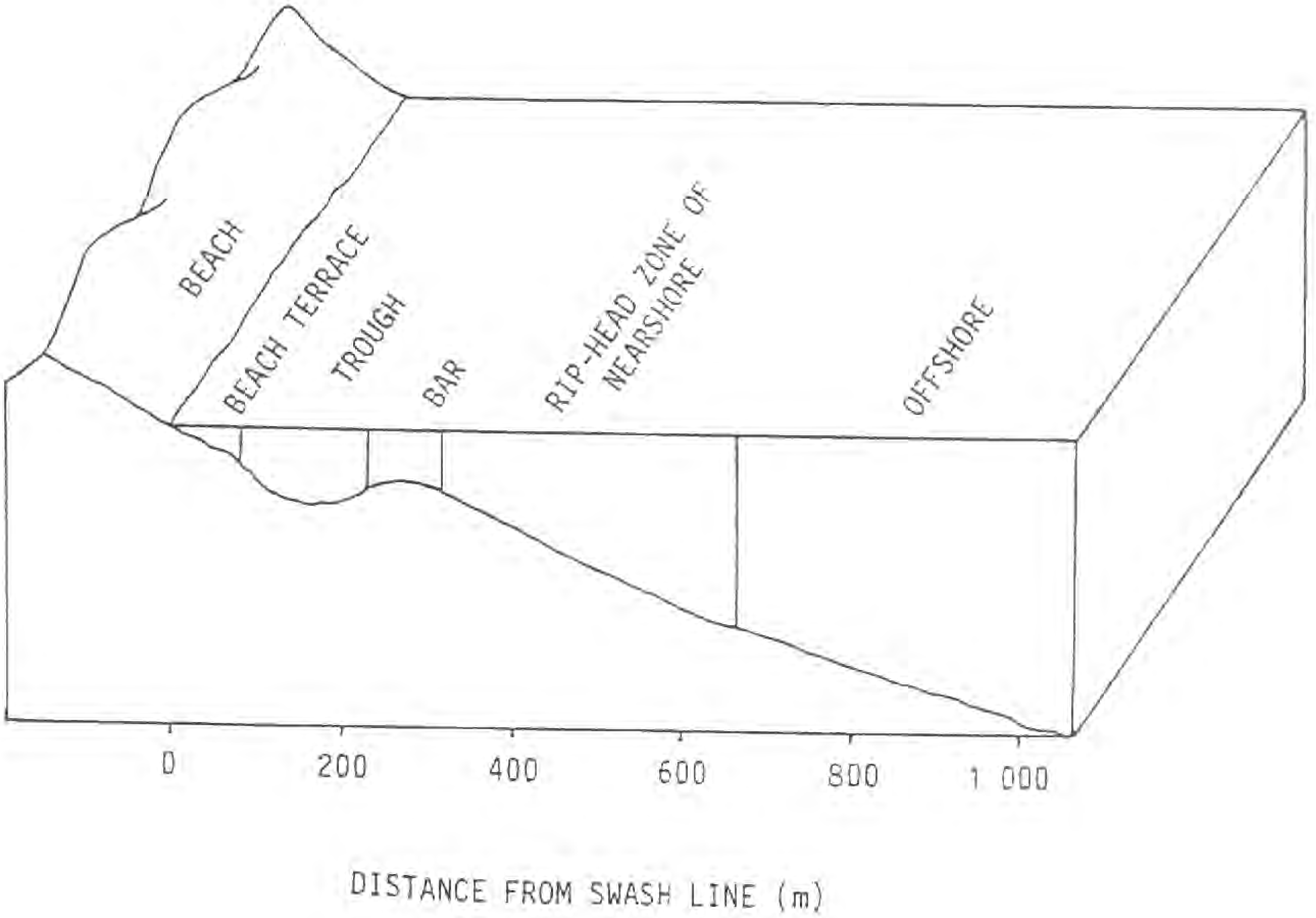

Figure 1. The dimensions of, and terminology used in describing surf-zones in this report.

1.2 The Importance of the Coastline

The coastline is a junction between the sea and land, yet it is much more than just a physical meeting. Man has been fascinated by the seashore for millennia and today it forms an important economic entity in the financial structure of all countries bounded by a coastline. Historically, the coast became especially important when international trade expanded with the development of ships capable of negotiating the hazards of the sea and its storms. For this reason, the early importance of the coast was related to the industrial and commercial development of areas with suitable ports.

With the increase in the population around the world, the coast, which was previously more important as an industrial and trade area, began to be settled more densely. Many of the people who moved to these areas were no longer directly associated with shipping. This led to the expansion of facilities in these areas which in turn resulted in increased development.

With settlement came housing, roads, pollution and a build-up of pressure in an area which, from the point of view of stability, was equated to inland areas. Inexperience in coastal zone management resulted in exceeding the carrying capacity of many of such coastal areas. This, in turn, resulted in an increase in engineering works to keep the coastline stable.

Today, the coastline is recognized as a sensitive zone and legislation has been enacted in many parts of the world to enforce suitable strategies for coastal use and management, controlling the dumping of noxious wastes, the use of estuaries as sewer lines and the development of coastal dunefields. The artificial stabilization of wind-blown dunefields has been recognised as having potentially adverse effects at other points along the coast. The abstraction of water from coastal aquifers is no longer seen as merely the use of water which would otherwise flow wastefully into the sea; such water is now recognised as having a role to play in the holistic environment in which Man and all other life-forms exist on earth.

At present much is being written about the possibility of an imminent substantial change in the level of the sea - a phenomenon which has indeed been going on since the oceans were formed. All developments in the coastal zone will be greatly affected by such an event and the ripple-effect will spread to all parts of the world, both physically and economically. An understanding of the impacts of such an occurrence in both the long-term and the short-term is needed. Only with such an understanding will advance planning reduce the impact of the phenomenon.

An understanding of the coastal zone does not necessarily follow a purely philosophical consideration of the coast. Such understanding is born out of experience and knowledge following investigation and study. This report supplies information on some aspects of the coastal zone which will extend our understanding of the ecosystem involved and raise other questions to spur us on to examine the coast in even greater detail to facilitate future planning.

1.3 Past International Research on Surf-Zones

Early reports on surf-zones containing high concentrations of phytoplankton date from the 1960's (Cassie and Cassie, 1960). There have been other reports since then (Lewin and Norris, 1970; Gunter and Lyles, 1979). In all these early reports the occurrence of brown patches caused by phytoplankton in the water, were referred to as "blooms", now known to be accumulations (Talbot and Bate, 1987). Accumulations have been reported from all around the world (listed in Campbell, 1987).

The phytoplankton which accumulate in surf-zones all belong to one of the following genera: *Anaulus*, *Asterionella*, *Aulacodiscus* or *Chaetoceros* (McLachlan, 1983). The occurrence of overwhelming dominance by a single species in coastal water has also been reported for species of other genera such as *Skeletonema costatum* (Greville) Cleve (Hulburt, 1985) and *Ceretaulina pelagica* (Cleve) Hendey, which has been reported to bloom off the north-east coast of New Zealand (Taylor *et al.*, 1985). The cell concentrations of 10^3 to 10^6 cells l^{-1} (Hulburt, 1985) measured on these occasions do not approach those recorded for accumulating-type phytoplankton (10^9 cells l^{-1}; Schaefer and Lewin, 1984; Campbell and Bate, 1987).

A list of international literature referring to sandy beach surf-zone phytoplankton is given in Appendix 1.

1.4 Past Research on the South African Coastline

Local research on the South African coastline can be divided into two sections. The nature and ecology of our rocky shore coastline has been studied in great detail by Branch and his group. "The Living Shores of Southern Africa" (Branch and Branch, 1981) is perhaps their best-known publication.

With regard to sandy beaches, work began in 1979 when Lewin visited South Africa and initiated studies into the ecology of sandy beaches under the leadership of McLachlan (McLachlan and Lewin, 1981). The botanical work lagged behind until 1982 when, following the initial report of McLachlan and Lewin (1981) an investigation began into the distribution of phytoplankton accumulations in the surf-zone of the Sundays River beach (Sloff, *et al.*, 1984). At this point the dominant phytoplankter was considered to be *Anaulus birostratus* (cic.), later identified as *Anaulus australis* sp. nov. Drebes *et* Schulz.

Subsequent to 1983, detailed work described the phytoplankton ecology, physiology and population dynamics for the Sundays River beach. The ecology has been summarized in a review by Talbot *et al.* (1990). More detailed physiological work to explain the ecology is still under investigation.

A list of local literature referring to sandy beach surf-zone phytoplankton is given in Appendix 2.

The major diatom species, *Anaulus australis* Drebes *et* Schulz has only been reported in large quantities on the south coast of South Africa. Its presence has prompted investigation into the following aspects: 1) the distribution of phytoplankton in the water column; 2) the distribution of phytoplankton in the sand; 3) seawater chemical composition; 4) nature of nutrients delivered to the surf-zone from land based sources and 5) the possible interrelationships between the aforementioned.

Following the initial aerial survey of the coast (Campbell and Bate, 1990a) during which features potentially linked to surf-zone phytoplankton dynamics were mapped, the coast was subdivided into three sections on the basis of presence or absence of phytoplankton patches. No phytoplankton accumulations have been observed on the west coast from Cape Point to Cape Cross in Namibia, although brown patches of "gilven-foam" (storm foam; Kirk, 1983) were common. The phytoplankton standing stock along this section of coast is high (Hart and Currie, 1960).

The three phytogeographic zones are (Fig. 2):

West Coast : Cunene River to Cape Point
(17°15'S:11°45'E to 34°22'S:18°30'E)
South Coast: Cape Point to Cintsa Bay
(34°22'S:18°30'E to 32°50'S:28°07'E)
East Coast : Cintsa Bay to Kosi Bay
(32°50'S:28°07'E to 26°51'S:32°53'E)

The studies of south coast beaches are reported in Campbell and Bate (1990b) and the east coast studies in Campbell and Bate (1990c), while this report is concerned with the data collected on the west coast beaches.

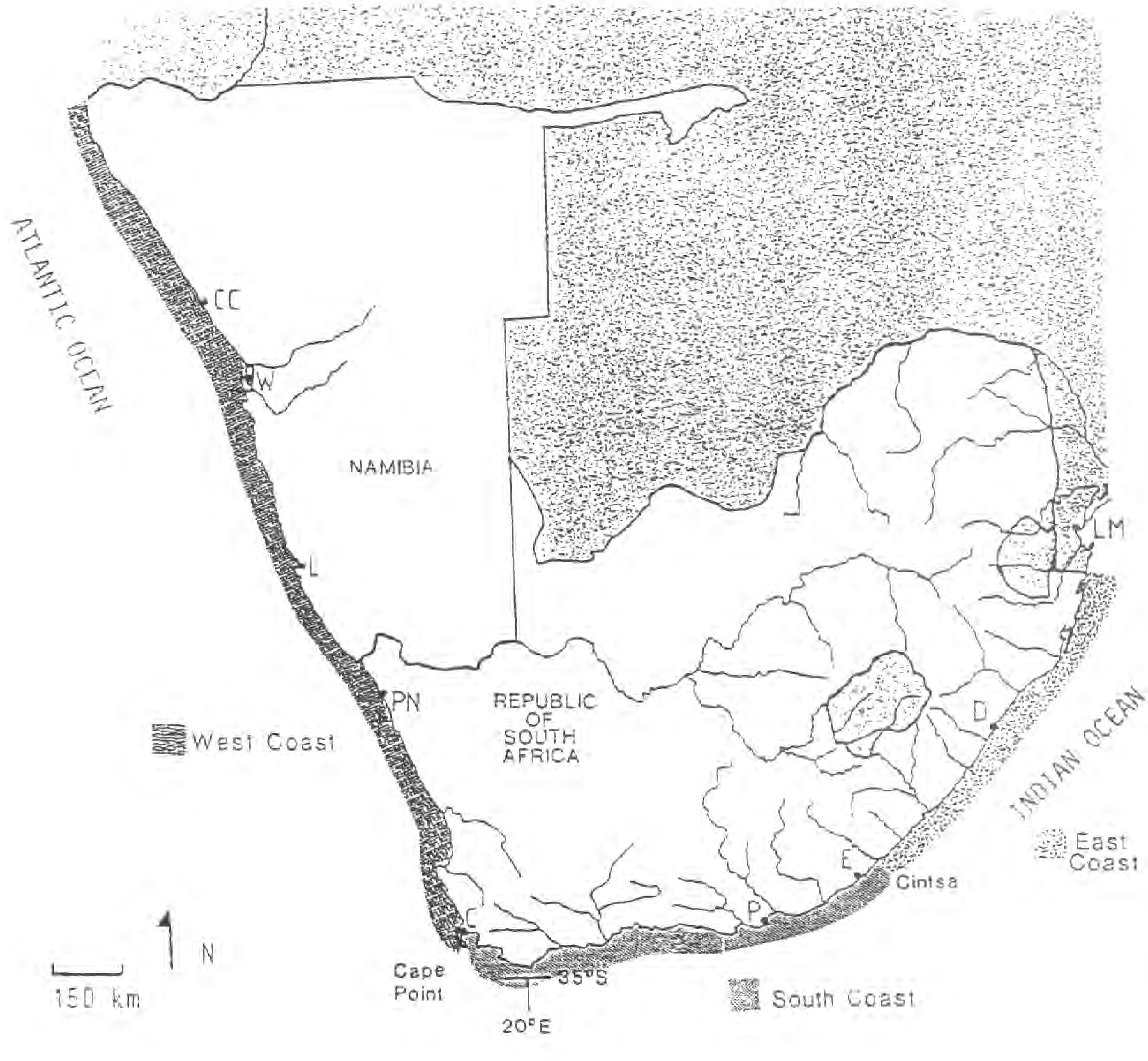

Figure 2. A map of southern Africa showing the three microalgal phytogeographic zones. CC - Cape Cross; W - Walvis Bay; L - Lüderitz; PN - Port Nolloth; C - Cape Town; P - Port Elizabeth; E - East London; D - Durban; LM - Maputo.

2. MATERIALS AND METHODS

2.1 Sites

The linear west coast line allows us to refer to the sample beaches simply by their latitude value, which we have transformed into a decimal value, i.e. Melkbosstrand, latitude 33°43'S, is identified as 33.72°S. The location of the sampling sites along the west coast is given in Figure 3. The date and time of sampling as well as the beach state at the time of sampling are given in Table 1.

Figure 3 indicates the extent to which the west coast was sampled. The main reason for the limited number of sampling points was the difficulty involved in reaching many of the beaches. Large stretches of the west coast are without roads, lie within restricted areas of diamond mining operations, or are sites with known diamond deposits. While the sites chosen represent only a small portion of the whole area, Figure 3 indicates that the entire length may be considered to have been represented as the selected beaches cover the entire range of latitude and longitude.

2.2 Nutrients

Water collected for mineral nutrient determinations was not preserved but was analyzed on the day of collection. Sea water samples were taken at the beaches from Port Nolloth to Mile 108. The data, however, indicated that there were no significant correlations between nutrient content in surf-zone water and either geographic position or other biological feature. For this reason, further surf water analyses were discontinued.

In an attempt to determine the mineral content of fresh water seeping into the sea from aquifers along the coast, samples were analyzed where such aquifers were known to exist near the coast. Additional data were subsequently obtained from the Departments of Water Affairs of both Namibia and South Africa. Water quality data have been published for Namibia but not for South Africa; however, some hand-drawn maps of coastal aquifers were supplied by the Hydrology section of the Department of Water Affairs, Cape Town.

Nitrate-N was analyzed according to the method outlined in Bate and Heelas (1975) following reduction to nitrite which was subsequently analyzed by the method of Greiss (1879) and Ilosvay (1889).

Ammonium and silicate were measured according to the methods of Strickland and Parsons (1972).

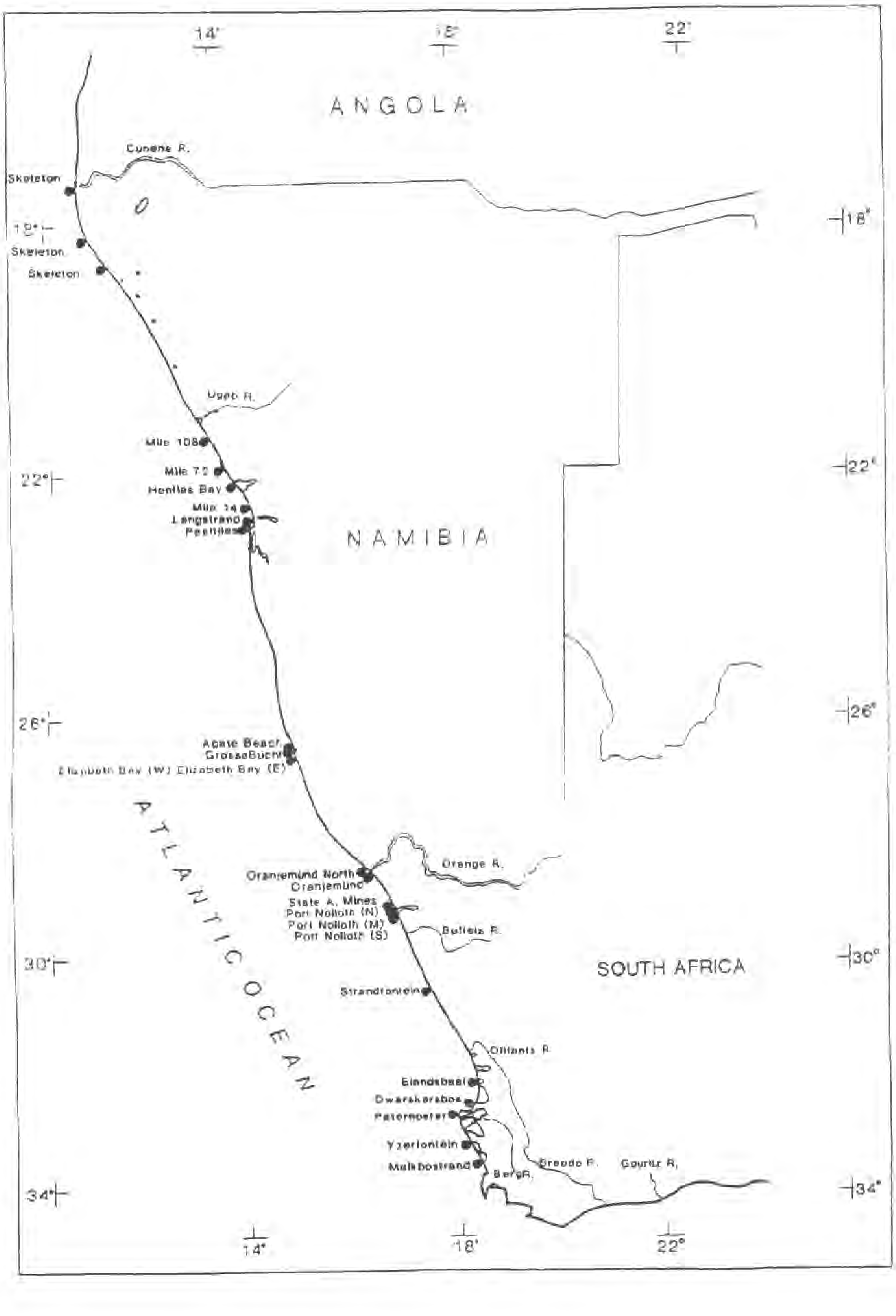

Figure 3. The location of beaches sampled along the west coast.

Table 1. The sites at which samples were collected. The beach co-ordinate (given in decimal degrees latitude), beach state, the date (month and year) and time at which samples were taken are given.

Beach	Latitude (°S)	Sampling		Energy State
		Date	Time	
Melkbosstrand	33.72	03.89	10.00	High
Yzerfontein	33.35	03.89	11.00	High
Paternoster	32.82	03.89	12.00	High
Dwarskersbos	32.70	03.89	13.00	Low
Elandsbaai	32.32	03.89	16.00	Medium
Strandfontein	31.75	03.89	10.00	Medium
Port Nolloth	29.25	01.89	14.00	Low
State Alluvial	29.20	01.89	15.00	Medium
Oranjemund	28.63	10.89	10.00	High
Oranjemund North	28.60	10.89	16.00	High
Elizabeth Bay	26.92	01.89	11.00	Low
Grossebucht	26.73	01.89	10.30	Low
Agate Beach	26.63	01.89	12.00	Low
Paaltjies	23.00	01.89	14.10	Medium
Langstrand	22.85	01.89	16.15	High
Mile 14	22.48	01.89	13.00	Medium
Henties Bay	22.12	01.89	11.50	High
Mile 72	21.87	01.89	10.30	High
Mile 108	21.45	01.89	09.45	High
Skeleton Coast 1	18.63	02.89	11.30	Not known
Skeleton Coast 2	18.20	02.89	11.30	Not known
Skeleton Coast 3	17.32	02.89	13.00	Not known

2.3 Phytoplankton Species Composition

Water samples (between 100 and 500 ml) were collected 20 cm below the water surface. If a brown discolouration of the water was observed, foam was collected as well. Samples were fixed in 0.4% neutralised formalin prepared by adding 200 g Hemamin (hexamethylene-tetramine) to one litre of 40% formalin, standing for one week, before being filtered and diluted with distilled water to 20% formalin equivalent. This was used as the concentrate.

Sand samples were taken in the swash zone, approximately mid-way between the lowest waterline and the highest swashline. The sand was taken to represent a depth of about 50 to 100 mm. After the sand samples had been collected from the swash zone they were placed in a container with some neutralised formalin preservative. The sand and formalin were well mixed to ensure that no microbial activity occurred during storage lasting up to two months before the samples were analyzed. The samples of sand were eluted by placing the weighed sample into a 250 ml Erhlenmeyer flask containing 20 ml of preservative. The mixture was shaken well and the liquid emptied into a separate flask. The washing with 20 ml of preservative was repeated three times to ensure the removal of all phytoplankton cells.

Cell numbers were determined by settling 10 to 60 ml of the eluted fluid samples in an Utermöhl settling chamber. The samples were settled for 24 hours before studied using a Zeiss IM 35 inverted microscope at a magnification of 630x either in brightfield illumination or with Nomarski interference. All the samples were stained with Rose Bengal (4,5,6,7-tetrachloro-2',4',5',7'-tetraiodo-fluorescein, Sigma) to facilitate identification of biological content. Cell counts were continued until either 200 cells or 200 frames were counted. The actual number of cells counted was normalized to number of cells per ml in the case of water samples, or number of cells per gram dry beach sand in the case of cells extracted from the sediment.

Identification of the various phytoplankton cells is based on an artificial key devised for use with a light microscope (Campbell and Bate, 1990d).

The species composition was analyzed using several methods. Indices of species diversity and dominance are based on Odum (1971):

$$d=\frac{S-1}{\log(N)}$$

where d = diversity index;

S = the number of species;

N = the number of individuals.

Also:

$$di=\Sigma\left(\frac{n}{N}\right)^2$$

where di = dominance index;

n = the number of individuals of a species;

N = the total number of individuals.

Detrended canonical correspondence, CANOCO (Ter Braak, 1986) and TWINSPAN (Hill, 1979) analyses were also performed on the species composition data.

2.4 Chlorophyll-*a* Concentration

Chlorophyll-*a* analyses were performed on ethanol extracts using the spectrophotometric method recommended by Nusch (1980). The chlorophyll-*a* concentration of some of the samples was also measured using high performance liquid chromatography (HPLC) using a 1608 Micro Pak HCH-5n reverse-phase column and isocratic elution with 70% methanol:30% acetone. Duplicate samples showed less than 5% difference using the two methods.

2.5 Sand Grain Size

Sand stripped of phytoplankton was washed in distilled water and oven dried at 105°C. The total sample was then passed through different mesh sizes (212, 600, 850, 1 700, 3 350 and 4 750 µm; the less than 212 µm fraction was referred to as the 100 µm fraction) and the mass of each sub-sample determined.

2.6 Biogenic Content of the Sand

Each of the subsamples of sand in the different size fractions was treated with excess 1.5 N hydrochloric acid in order to dissolve all carbonate present. The weight difference after washing the acid-treated sample in distilled water and drying at 105°C provided an indication of the calcium carbonate content. The biogenic content is considered equal to the calcium carbonate content.

2.7 Primary Production Estimates

Access to high energy surf-zones is normally restricted as a result of the extreme turbulence of these areas. In the past attempts to determine primary production using the radiocarbon method of Steeman-

Nielsen (1952) have failed because many bottles are lost or broken. For this reason, the *in situ* method of measuring primary production was not considered for this study. Even though this method is considered by many to be the most accurate, the so-called "simulated *in situ*" method is the most widely used (Harrison *et al.*, 1985). In the study of a system over a period of time, *in situ* measurements approximate the real values only if they represent time-integrated environmental conditions. In a high energy surf-zone where it is not possible to practice the *in situ* method, a combination of the "simulated *in situ*" and modelling approaches is more suitable. This involves the assessment of abiotic and biotic variables over the period of estimation, followed by an assessment of the physiological responses of the organism to these variables (Harrison *et al.*, 1985). An accounting model may then be used to integrate the rate of primary production over the period during which the abiotic variables were monitored. This approach was used to estimate the annual rate of primary production by the phytoplankton of the Sundays River beach ecosystem (Campbell and Bate, 1988); the same approach was used in the present study. The model was run by means of the interactive modelling aid programme DRIVER (Furniss, 1977) with PASCAL implementation by Hahn (1987). Values for biomass and surf-zone states inserted into the model were derived from this study but all the remaining variables were based on the Sundays River beach model (Campbell, 1987; Campbell and Bate, 1988).

3. RESULTS

3.1 Environmental Variables

3.1.1 Temperature

The west coast cold water generally had a temperature of 15-18°C south of Swakopmund (Table 2); the temperature north of Swakopmund increased to 20°C.

3.1.2 Wave Height

The different beaches sampled had widely varying wave height (Table 2) from 0.5 m to 4 m waves; these beaches can therefore be considered to cover a wide range of energy states expected along our coasts.

3.1.3 Surf-zone Topography and Width

The topographic state of the surf-zones ranged from reflective to dissipative (Table 2) and width from 10 m to 150 m wide, making the samples representative of all the beach states found along the west coast.

3.1.4 Aquifers

After having drilled several holes with an auger (4 m) in the sand on the beaches investigated, and finding no water, it became clear that there was little fresh water seeping into the surf-zones along the west coast. A map of the known aquifers along the west coast was obtained from the Departments of Water Affairs of Namibia and South Africa. The aquifers along the coast north of Sandwich Harbour are mapped in Figure 4 and those south of the Orange River in Figure 5.

No aquifers are known between Sandwich Harbour and the Orange River. The only significant aquifers which could deliver fresh water into the surf-zones along the Namibian coast are at Hentiesbaai and Sandwich Harbour. The aquifers along the west coast of South Africa associated with the beaches sampled are at Port Nolloth, Elandsbaai and Dwarskersbos.

Table 2. The water temperature, wave height and surf-zone topography at the beaches sampled. Dis = Dissipative; LBT = Longshore Bar-Trough; Ref= Reflective.

Beach	Water Temperature (°C)	Wave Height (m)	Surf-zone	
			Width (m)	State
Melkbosstrand	17	2.0	150	Dis
Yzerfontein	17	2.0	150	Dis
Dwarskersbos	18	0.5	10	Ref
Elandsbaai	18	2.5	150	LBT
Strandfontein	17	2.5	150	LBT
Port Nolloth	15	0.5	10	Ref
State Alluvial	15	2.5	100	LBT
Orange River	15	4.0	150	Dis
Elizabeth Bay	17	1.0	150	Dis
Grossebucht	17	1.0	150	Dis
Agate Beach	17	0.5	20	Ref
Paaltjies	15	3.0	100	LBT
Langstrand	15	2.5	150	Dis
Mile 14	20	2.5	100	LBT
Hentiesbaai	20	3.5	100	LBT
Mile 71	20	2.5	150	Dis
Mile 108	20	2.5	150	Dis

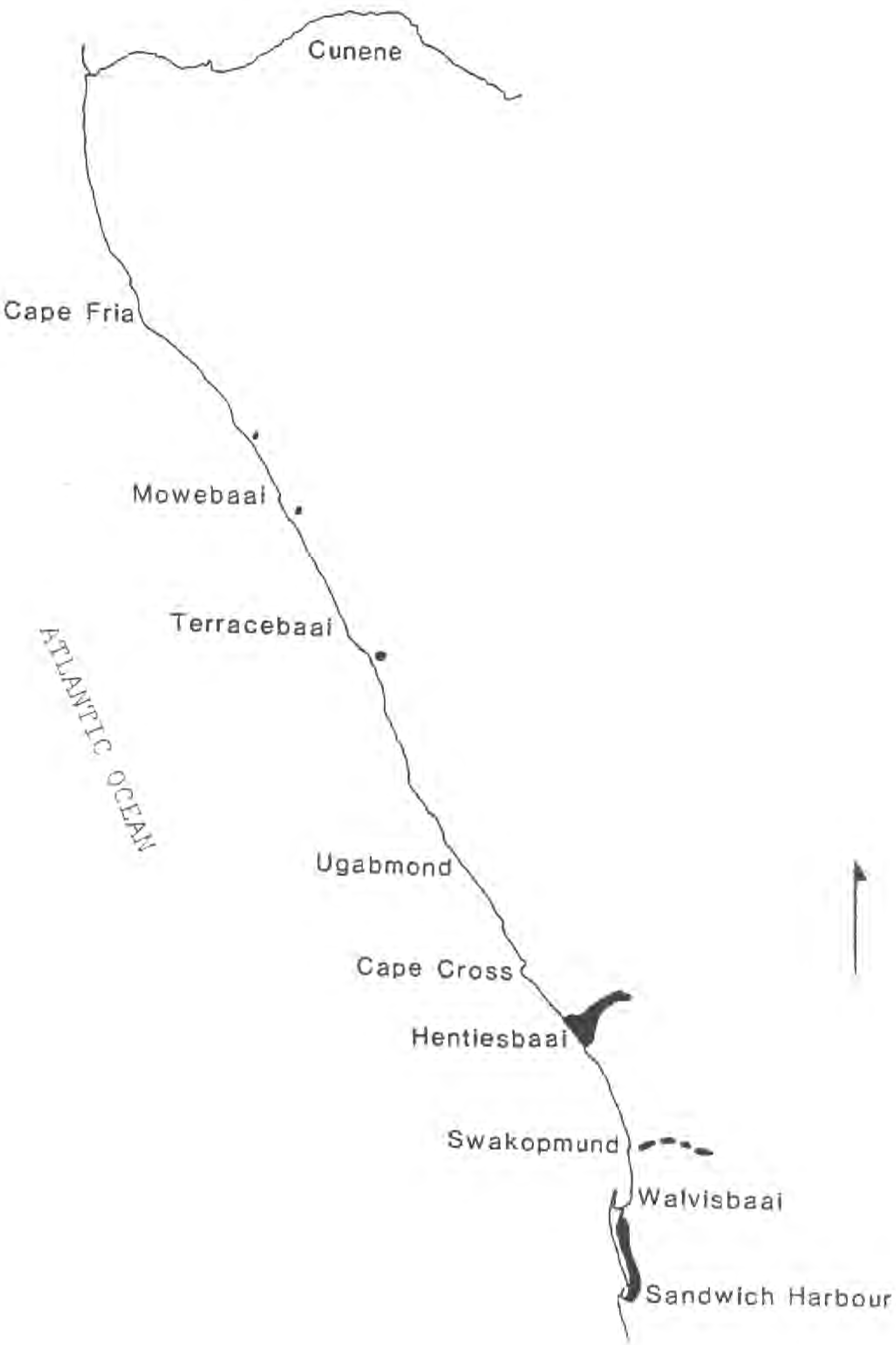

Figure 4. The aquifers of the Namibian coast north of Walvisbaai shown in black.

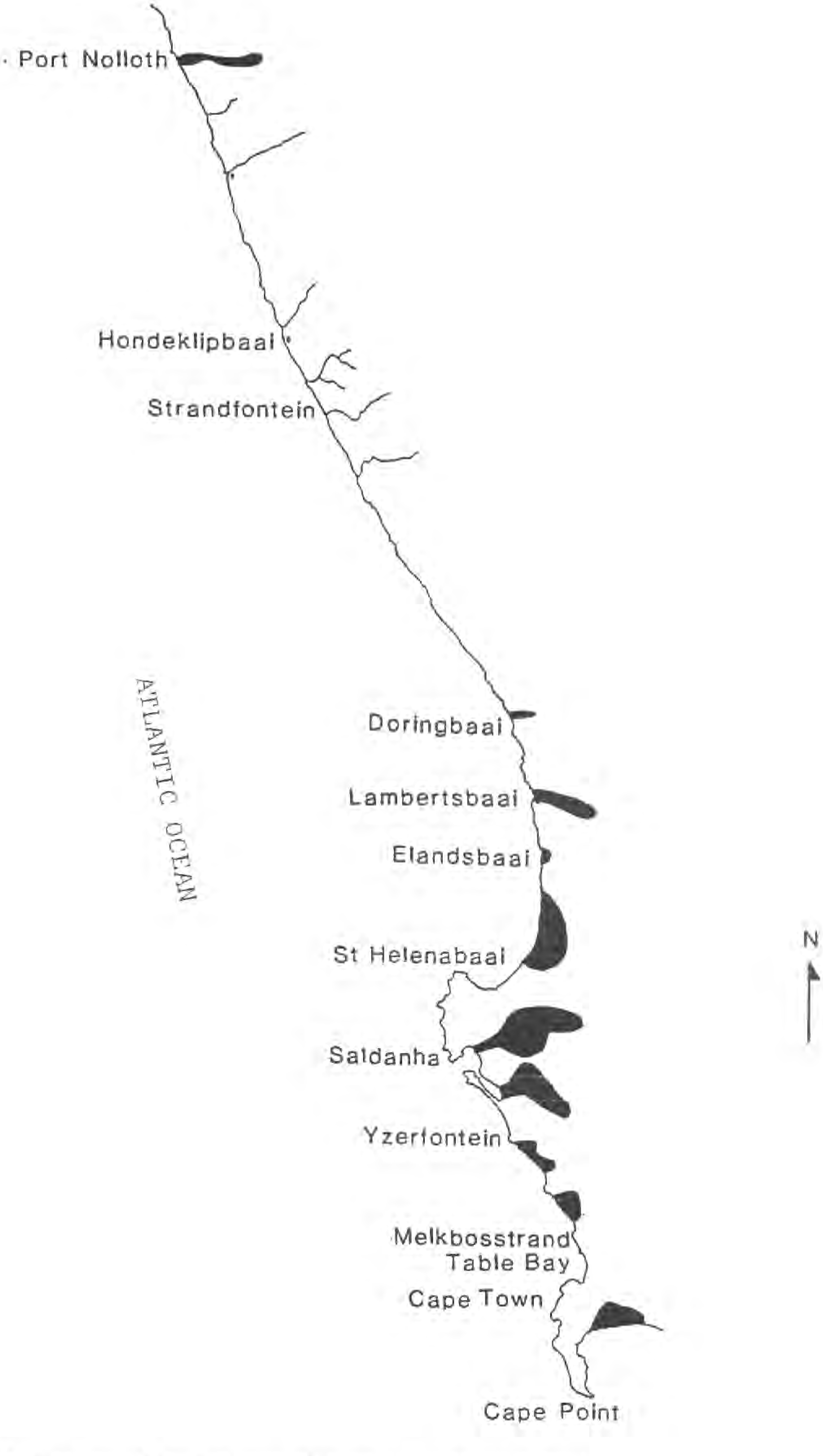

Figure 5. The aquifers of the west coast of South Africa shown in black.

3.1.5 Nutrients

Nutrient content of aquifers at Port Nolloth, Paaltjies and Mile 14 as well as nutrient content in the seawater at several beaches, is given in Table 3. Aquifer water contained about 15 times more nitrate than seawater at Port Nolloth and Mile 14; ammonium concentration was higher in aquifer water than in seawater at Mile 14 only (7 times higher). The soluble reactive silicon content of aquifer water at Port Nolloth and Mile 14 was about 10 times higher than that of seawater. It therefore appears that the aquifer water could be a source of nutrients to the surf-zone.

3.1.6 Sand Grain Size

The size distribution of sand particles is depicted in two ways in Figures 6 and 7. Most of the sand particles are in the smaller grain size fraction (<600 µm). At Agate Beach the size distribution was different, half of the sand being in the 850-1700 µm size fraction; this peak is ignored in the computer analysis (Figure 6) but appears shaded in Figure 7. Just over 40% was in the <210 µm fraction. This was the only site with a bimodal grain size distribution.

3.1.7 Biogenic Content of the Sand

The proportion of biogenic sand was generally low (Figure 8). Three geographic areas can be identified on the basis of percentage biogenic sand. Sites north of 23^{0}S had little biogenic component in the sand (below 5%), at sites between 26^{0}S and 32.5^{0}S the biogenic component was between 5% and 10%. South of 32.5^{0}S the proportion of biogenic sand was high, 20% to 75% of the sand having a biogenic origin.

When the separate fractions were analysed for biogenic components, it was evident that there were three section of coast with different biogenic sand characteristics. The percentage biogenic component in each fraction is given in three different ways in Figures 9, 10 and 11. The first division is clear from Figure 9. North of 21^{0}S there is little biogenic sand in any of the fractions. A further subdivision can be recognised from Figure 10 and Figure 11. Figure 11 contains the same data as Figure 10 but with fewer contours shown and the 40% level shaded. Between 21^{0}S and 29^{0}S there are two maxima, one in the 1 500 µm region and one in the >4 700 µm region. North of 29^{0}S the biogenic sand was mostly in the smaller fractions.

Table 3. The nitrate, ammonium and soluble reactive silicon content of aquifer water and seawater at selected beaches.

Site	Beach	Nitrate (μmol l^{-1})	Ammonium (μmol l^{-1})	Silicon (μmol l^{-1})
Seawater	Port Nolloth	3.6	1.7	21.1
		4.2	1.9	21.1
	State Alluvial	0.0	3.7	14.5
	Elizabeth Bay	6.6	4.2	28.9
		6.1	0.4	18.9
	Grossebucht	5.5	4.0	24.9
	Agate Beach	6.2	1.0	49.1
	Paaltjies	1.2	0.9	1.3
	Langstrand	0.7	8.3	30.8
	Mile 14	1.4	3.4	26.9
	Hentiesbaai	0.8	5.5	0.3
	Mile 72	3.4	2.0	25.5
	Mile 108	1.0	3.0	0.5
Aquifer	Mile 14	34.3	23.8	204.4
	Paaltjies	0.8	1.5	2.8
	Port Nolloth	30.6	2.4	144.7

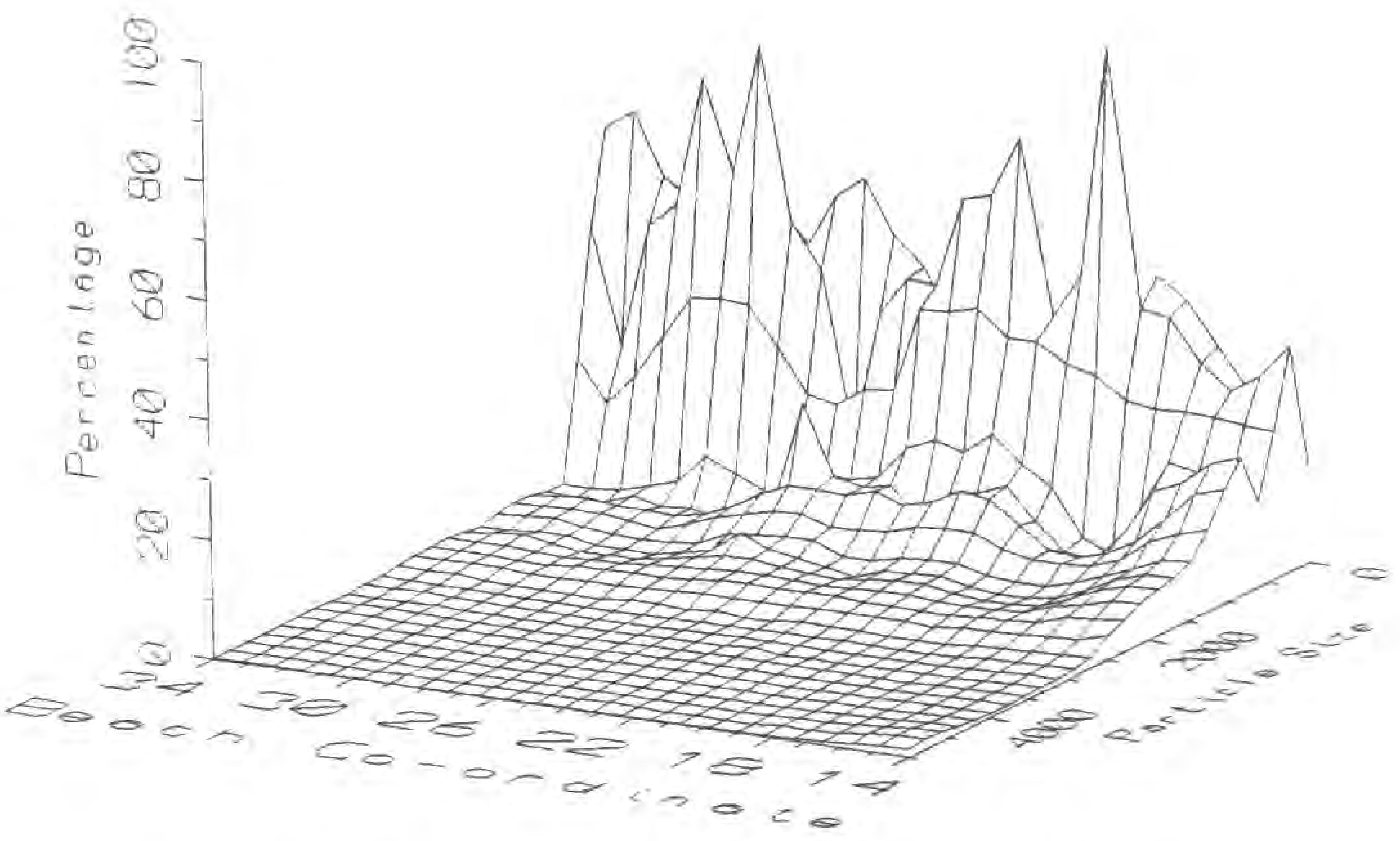

Figure 6. The size distribution of the sand particles along the west coast of South Africa and Namibia.

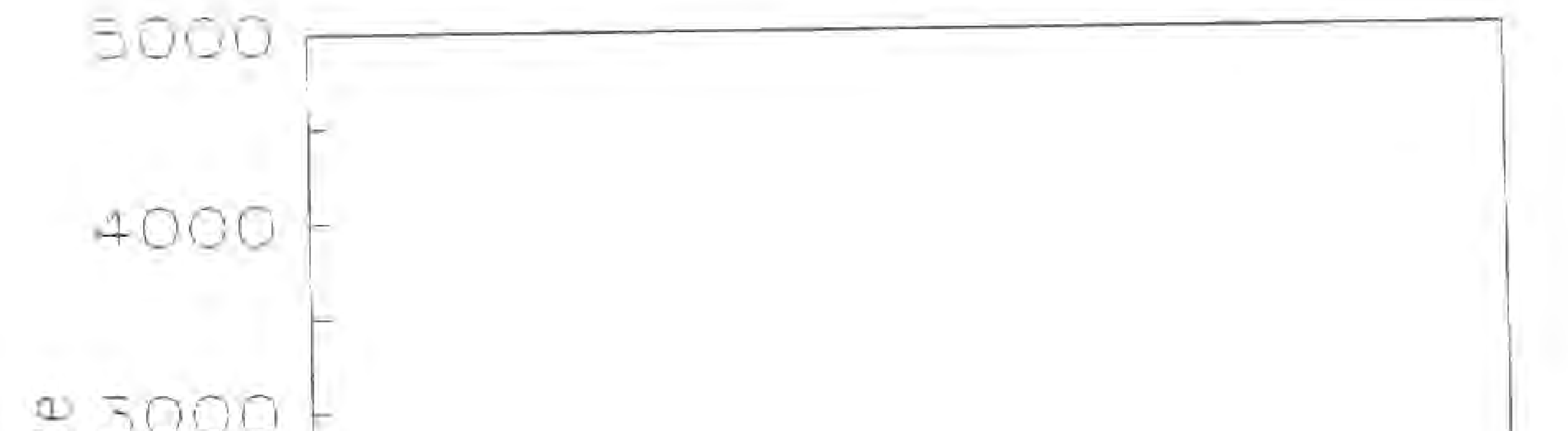

Figure 7. The size distribution of the sand particles along the west coast of South Africa and Namibia.

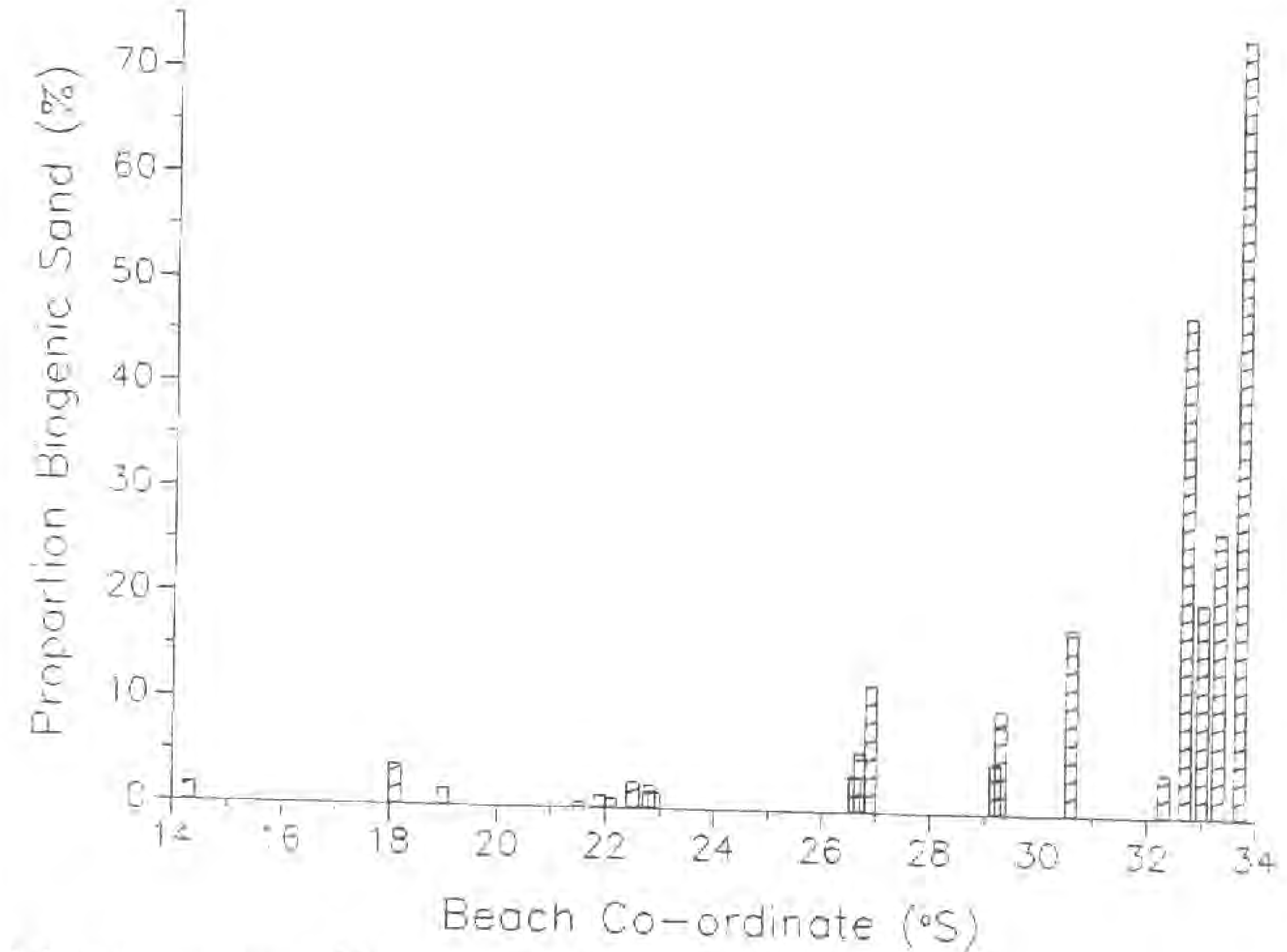

Figure 8. The proportion of biogenic sand along the west coast of South Africa and Namibia.

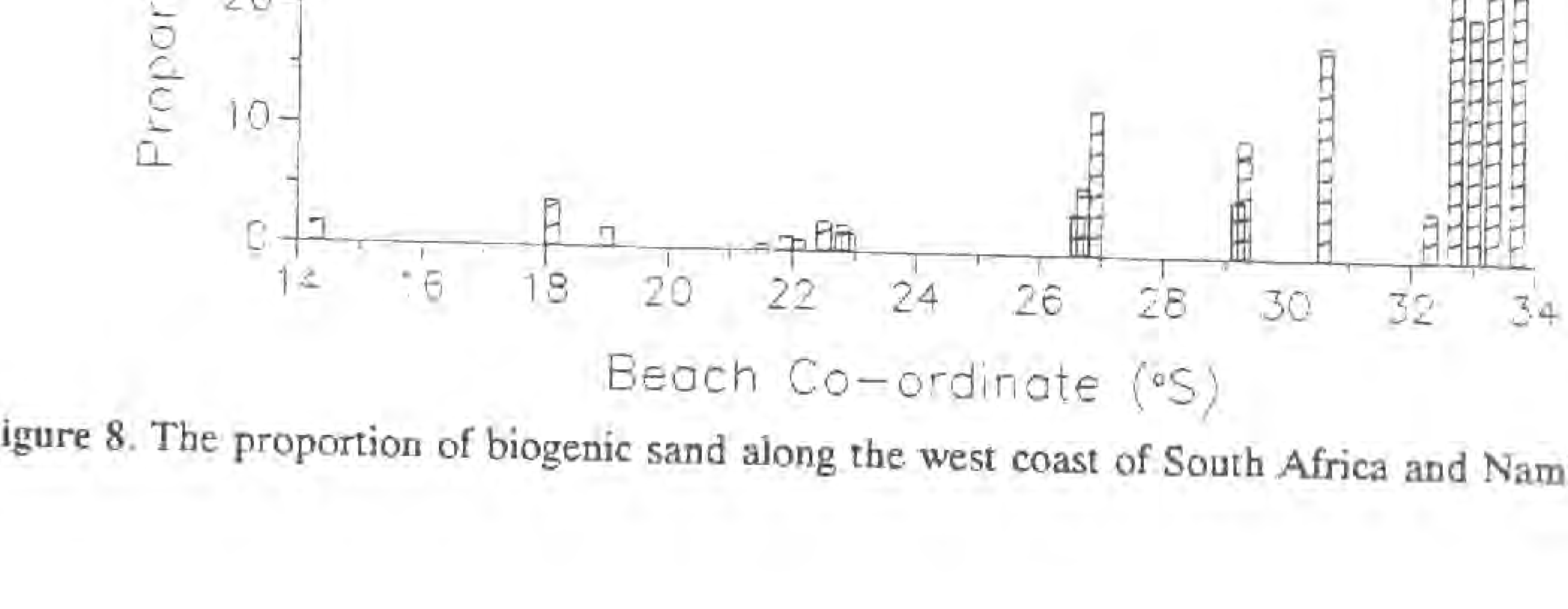

Figure 9. The biogenic component of the different size fractions of the sand along the west coast of South Africa and Namibia.

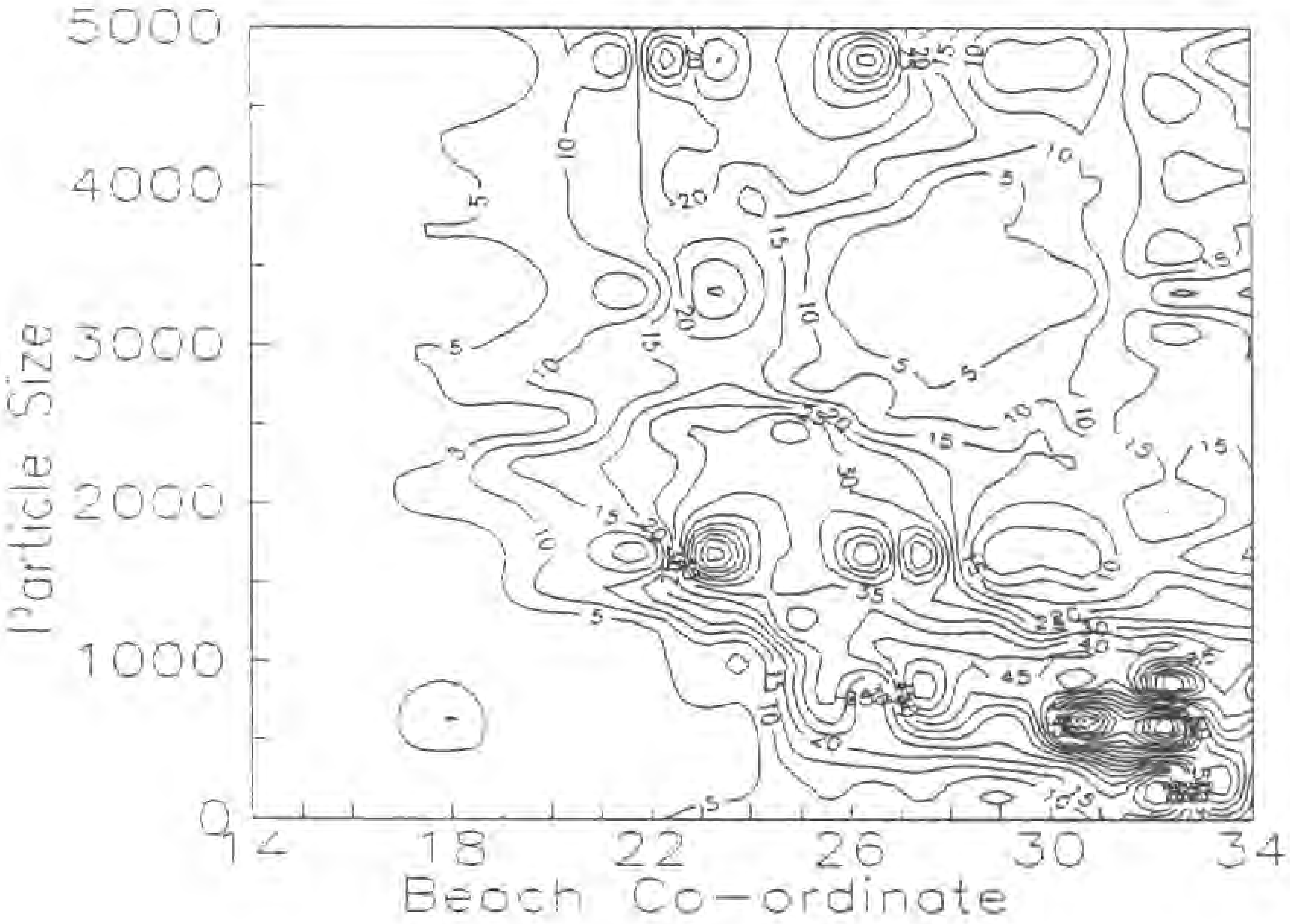

Figure 10. The biogenic component of the different size fractions of the sand along the west coast of South Africa and Namibia.

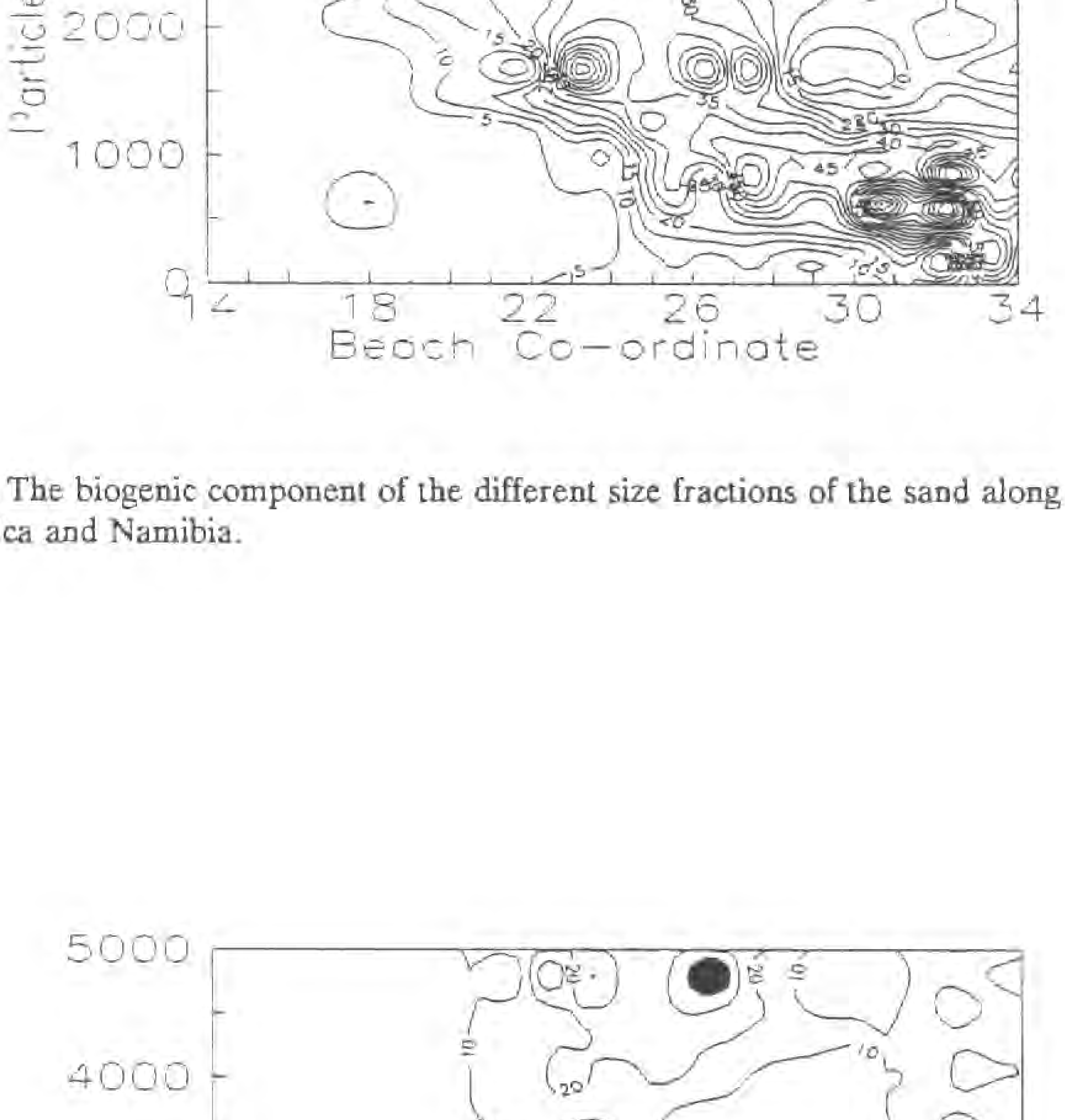

Figure 11. The biogenic component of the different size fractions of the sand along the west coast of South Africa and Namibia.

3.2 Phytoplankton Species Composition

A list of all the species recorded is given below. Appendix 3 gives a table of the raw data with percentage occurrence of each species in the populations.

3.2.1 Species Found in the Water

No.	Species	Species Code Number
1	*Actinoptychus splendens*	3
2	*Anaulus australis*	7
3	*Asterionella glacialis*	8
4	*Biddulphia* sp.	15
5	"Blue-Greens"	18
6	*Ceratium furca*	24
7	*Chaetoceros didymus*	28
8	*Chaetoceros* A	130
9	*Chaetoceros* spores	120
10	*Chaetoceros* B	29
11	*Cocconeis* sp.	37
12	*Delphineis* sp.	121
13	*Dunaliella* sp.	134
14	*Eucampia* sp.	49
15	Flagellates	51
16	*Grammatophora angulosa*	135
17	*Grammatophora marina*	55
18	*Guinardia flaccida*	137
19	*Gyrodinium* sp.	57
20	*Helgolandinium* sp.	139
21	*Leptocylindrus danicus*	60
22	*Licmophora* sp.	62
23	*Melosira* sp.	65
24	*Navicula* A	146
25	*Navicula* B	140
26	*Navicula* C	123
27	*Navicula* D	70
28	*Navicula* E	71
29	*Navicula* F	141
30	*Navicula* G	73
31	*Navicula* H	142
32	*Navicula* I	143
33	*Navicula* J	118
34	*Navicula* K	155
35	*Navicula* L	133
36	*Navicula* M	145
37	*Navicula* N	72
38	*Navicula* O	105
39	*Navicula* P	125
40	*Nitzschia closterium*	77
41	*Nitzschia delicatissima*	78
42	*Nitzschia longissima*	79
43	*Nitzschia seriata*	81

44	*Peridinium* A	148
45	*Peridinium brevipes*	149
46	*Peridinium pallidum*	89
47	*Peridinium* B	150
48	*Peridinium* C	87
49	*Peridinium steinii*	151
50	*Plagiogramma brockmanii*	152
51	*Plagiogramma* sp.	153
52	*Plagiogramma van heurckii*	92
53	*Pleurosigma* sp.	93
54	*Porosira glacia*	154
55	*Prorocentrum micans*	94
56	*Rhizosolenia* sp.	98
57	*Schroederella schroederi*	102
58	*Schroederella* sp.	103
59	*Skeletonema costatum*	104
60	*Stephanopyxis* sp.	106
61	*Synedrosphaenia* sp.	156
62	*Tetraselmis* sp.	157
63	*Thalassionema nitzs.*	110
64	*Thalassiosira* A	132
65	*Thalassiosira decipiens*	111
66	*Thalassiosira fallax*	158
67	*Thalassiosira levanderi*	159
68	*Thalassiosira polychorda*	131
69	*Thalassiosira* B	113
70	*Thalassiothrix* sp.	114
71	Unknown A	161
72	Unknown B	178
73	Unknown C	133
74	Unknown D	162
75	Unknown E	136
76	Unknown F	138
77	Unknown G	122
78	Unknown H	147
79	Unknown I	160

3.2.2 The Species found in the Sand

No.	Species	Species Code Number
1	*Actinoptychus granii*	163
2	*Actinoptychus splendens*	3
3	*Ampiprora* sp.	4
4	*Anaulus australis*	7
5	*Asterionella glacialis*	8
6	"Blue-Greens"	18
7	*Chaetoceros* spores	120
8	*Chaetoceros* B	29
9	*Cocconeis* sp.	37
10	*Delphineis* sp.	121
11	Dinophyte	167
12	*Dunaliella* sp.	134
13	*Surirella* sp.	179
14	Flagellates	51
15	*Gonyaulax* sp.	168
16	*Grammatophora angulosa*	135
17	*Grammatophora marina*	55
18	*Navicula* B	140
19	*Navicula* Q	170
20	*Navicula* C	123
21	*Navicula distans*	171
22	*Navicula* D	70
23	*Navicula* R	73
24	*Navicula* S	172
25	*Navicula* F	141
26	*Navicula* G	142
27	*Navicula* I	143
28	*Navicula* J	118
29	*Navicula* K	155
30	*Navicula* L	144
31	*Navicula* M	145
32	*Navicula* N	72
33	*Navicula* P	125
34	*Nitzschia bilobata*	126
35	*Nitzschia seriata*	81
36	*Peridinium* C	173
37	*Peridinium* A	148
38	*Peridinium* B	87
39	*Plagiogramma brockmanii*	152
40	*Plagiogramma* sp.	153
41	*Plagiogramma van heurckii*	92
42	*Tetraselmis* sp.	157
43	*Thalassiosira* A	132
44	*Thalassiosira granii*	166
45	*Thalassiosira* B	113
46	Unknown A	164
47	Unknown J	164
48	Unknown K	165
49	Unknown C	133
50	Unknown F	138
51	Unknown L	169

52 Unknown H	147
53 Unknown M	175
54 Unknown N	174
55 Unknown O	177
56 Unknown P	176

3.2.3 Community Analyses

The number of species recorded in the water at each of the sites is given in Figure 12. There were between 7 and 22 species recorded with an average of 14 species per sample. The number of species recorded in the sand at each of the sites is given in Figure 13. The number of species ranged from 3 to 20 species recorded per site with an average of 11 species per sample.

Diversity indices calculated for the water (Fig. 14) and sand (Fig. 15) showed that there was a slight decrease in diversity between 18°S and 25°S in the water. Sand samples showed no trend in diversity, being slightly lower (average of 2.20) than the water (2.83).

In terms of species dominance two groups of samples can be identified. Most of the water samples (Fig. 16) had a low index of dominance of 0.2. Four of the sites (Grossebucht, Strandfontein, Elandsbaai and Dwarskersbos) had high indices of dominance (above 0.55); *Chaetoceros* spores were dominant at Grossebucht, *Skeletonema costatum* at Strandfontein and a small *Navicula* at Elandsbaai and Dwarskersbos. In the sand indices of dominance were also 0.2 (Figure 17) except for one site, Mile 108, where the index was 0.75. Here *Chaetoceros* spores were dominant. The dominance was stronger in the water (average of 0.31) than in the sand (0.27).

The phytoplankton community in the water column and beach sand of the west coast is dominated by diatoms (Fig. 18 and 19), most of the samples containing more than 90% diatoms and none containing less than 50%. In the Port Nolloth area as well as at Agate Beach the contribution of diatoms to the community was somewhat lower. In both cases, green microplankton made up most of the remainder of the community. In the sand, one of the Skeleton coast sites, Hentiesbaai and Elandsbaai had less than 80% diatoms.

Dinoflagellates were represented in most of the water samples (all but 5; Fig. 20) but largely absent from the sand samples (all but 7; Fig. 21).

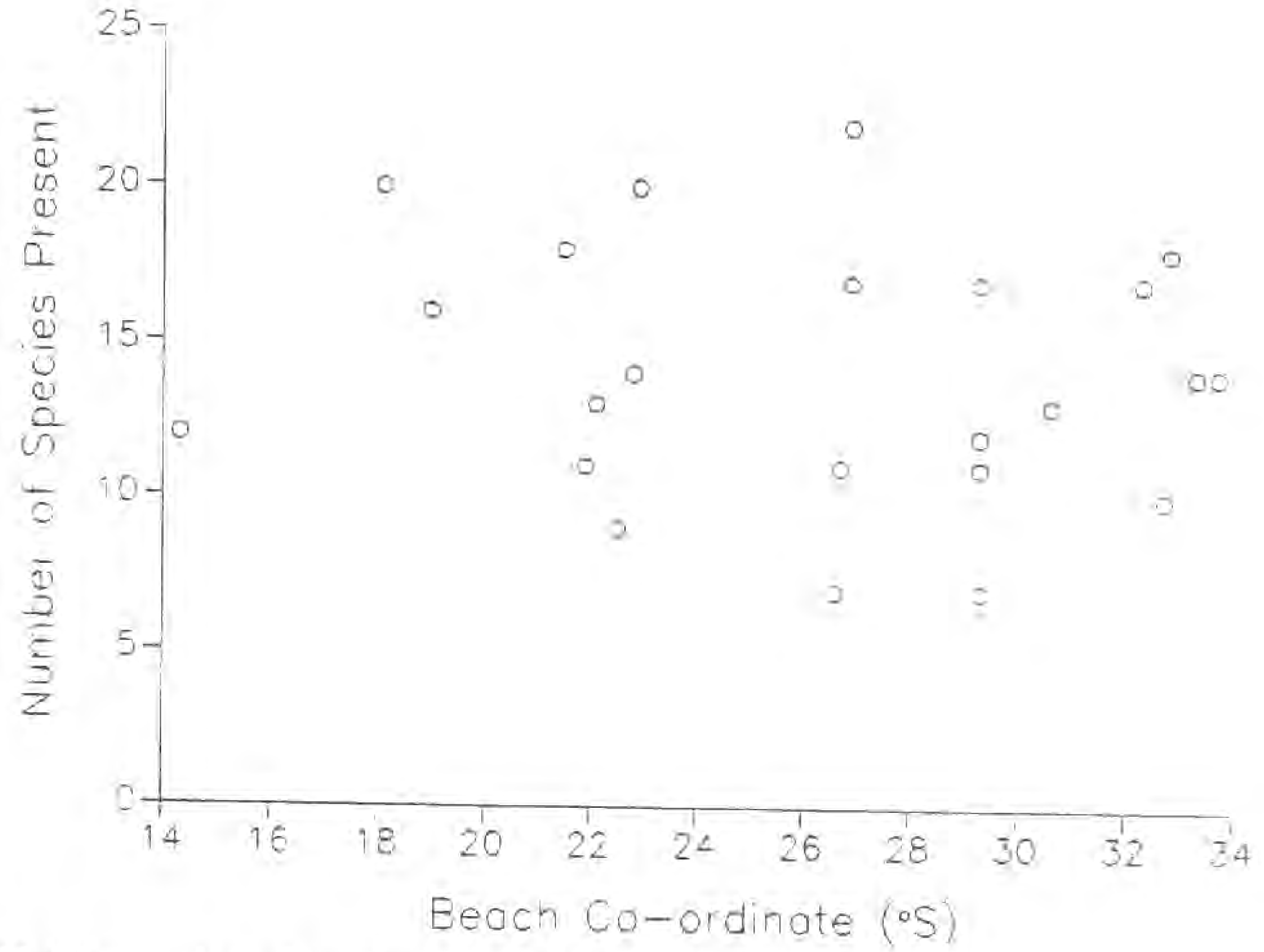

Figure 12. The number of species recorded in the water of the surf-zones along the west coast of South Africa and Namibia.

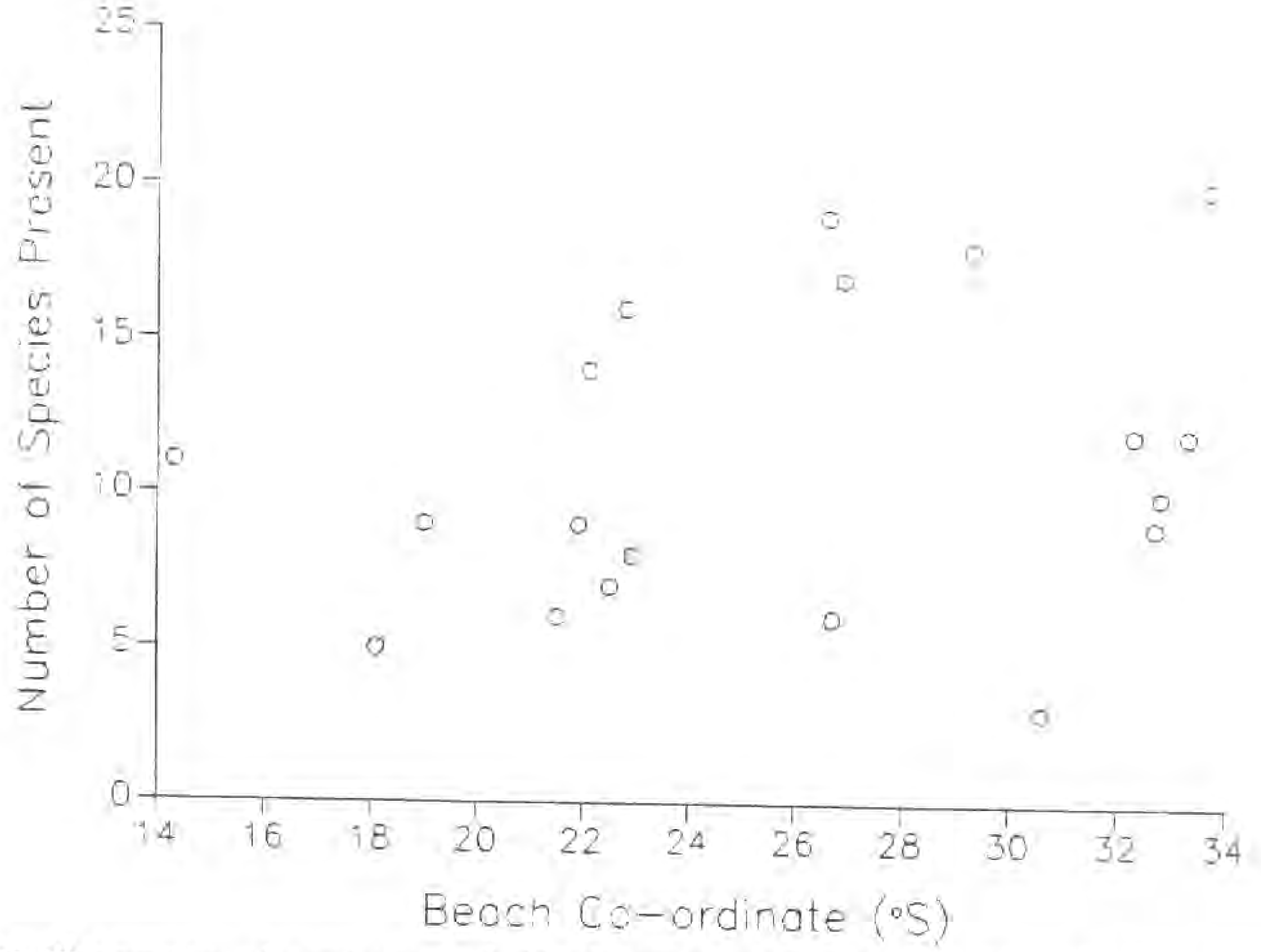

Figure 13. The number of species recorded in the sand of the surf-zones along the west coast of South Africa and Namibia.

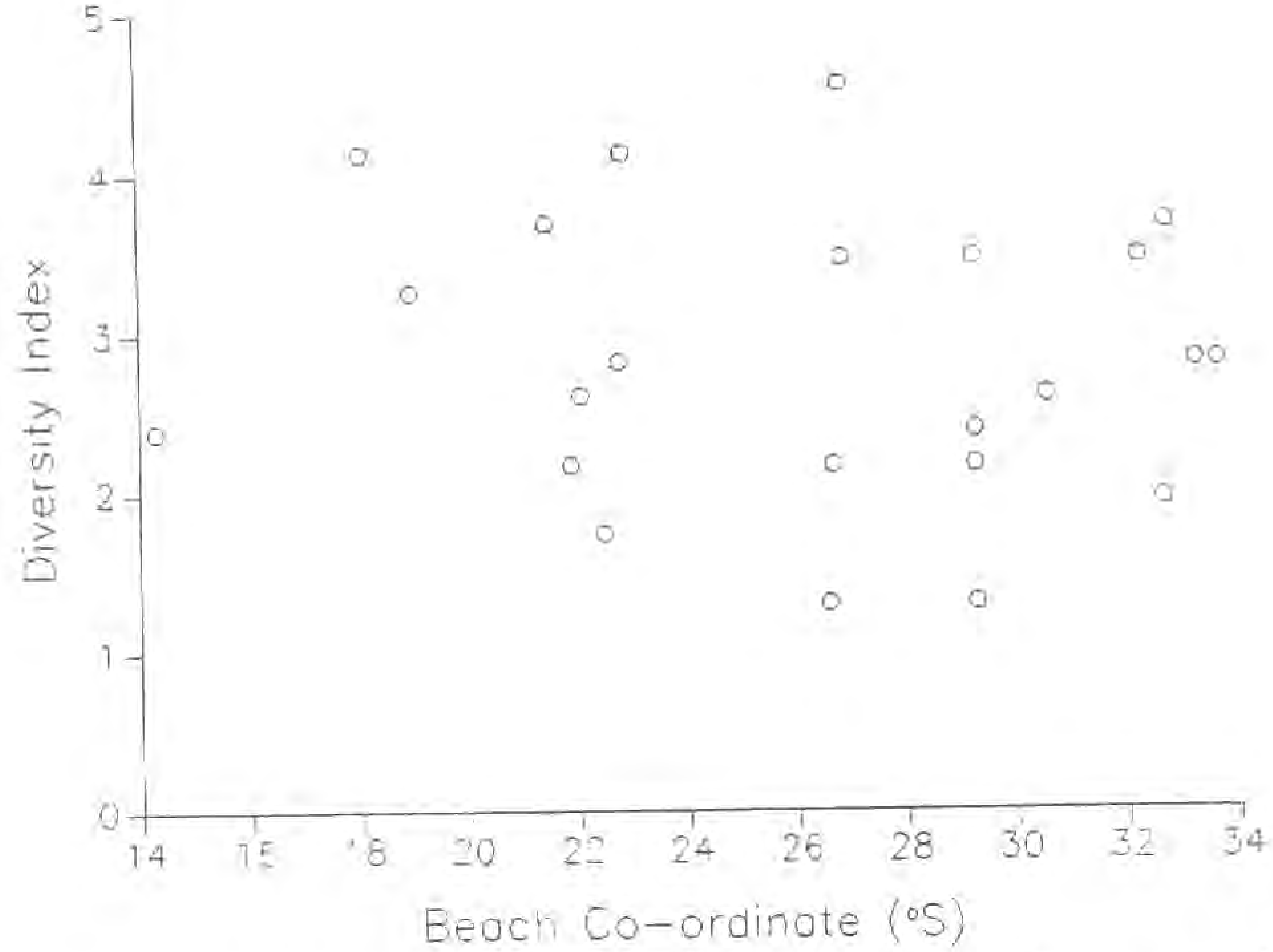

Figure 14. The diversity index of the populations in the water of the surf-zones along the west coast of South Africa and Namibia.

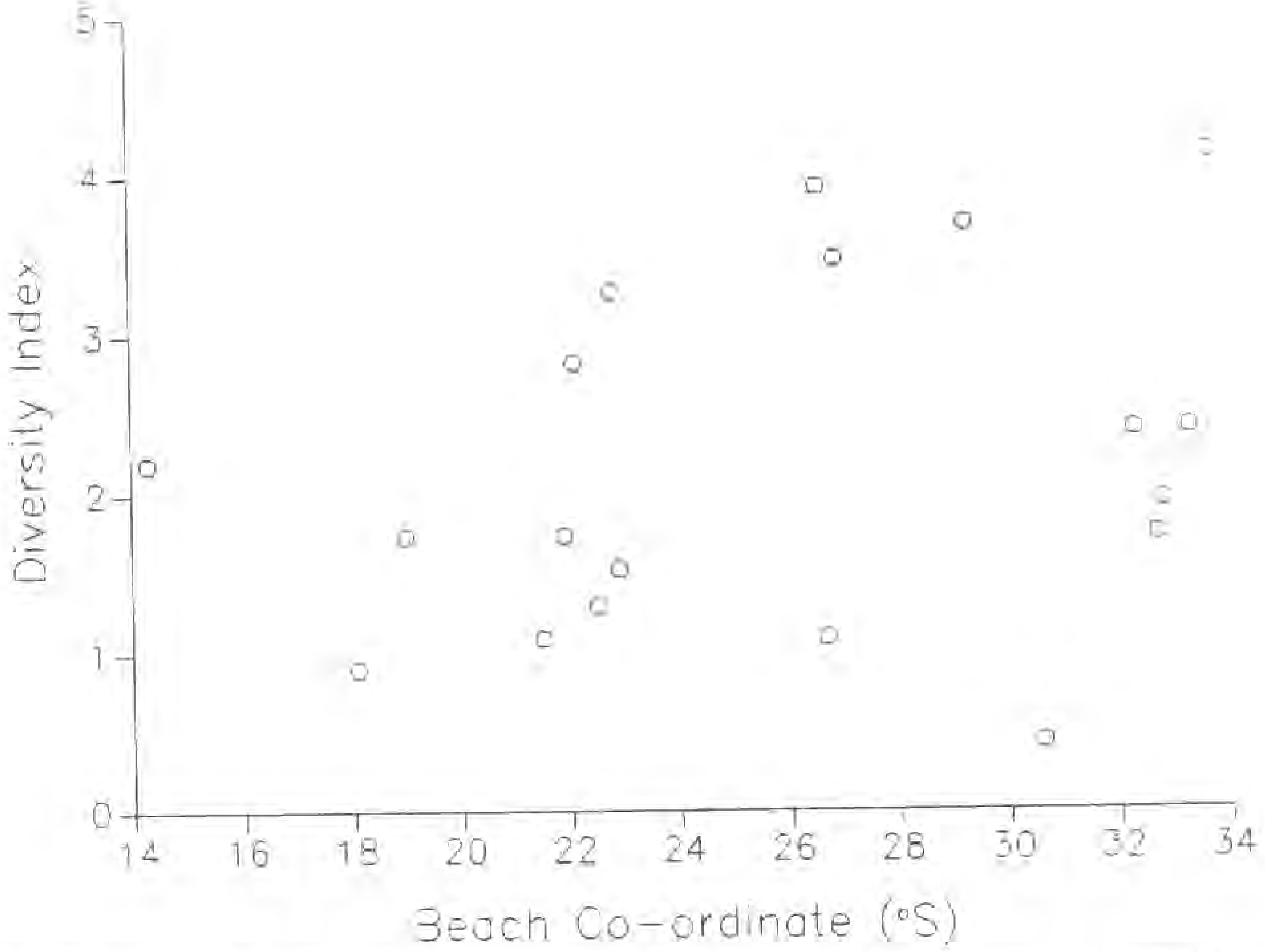

Figure 15. The diversity index of the populations in the sand of the surf-zones along the west coast of South Africa and Namibia.

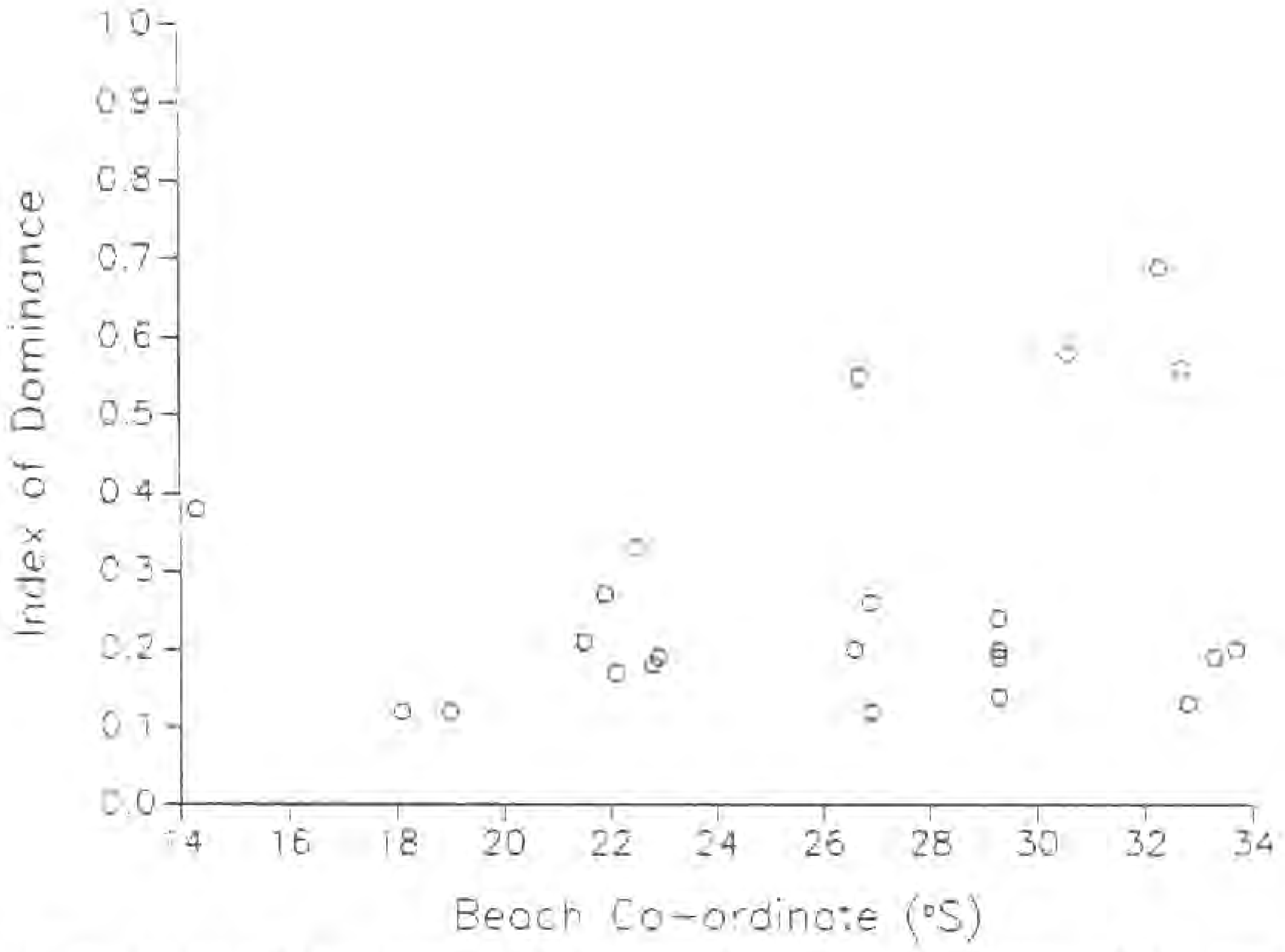

Figure 16. The index of dominance of the populations in the water of the surf-zones along the west coast of South Africa and Namibia.

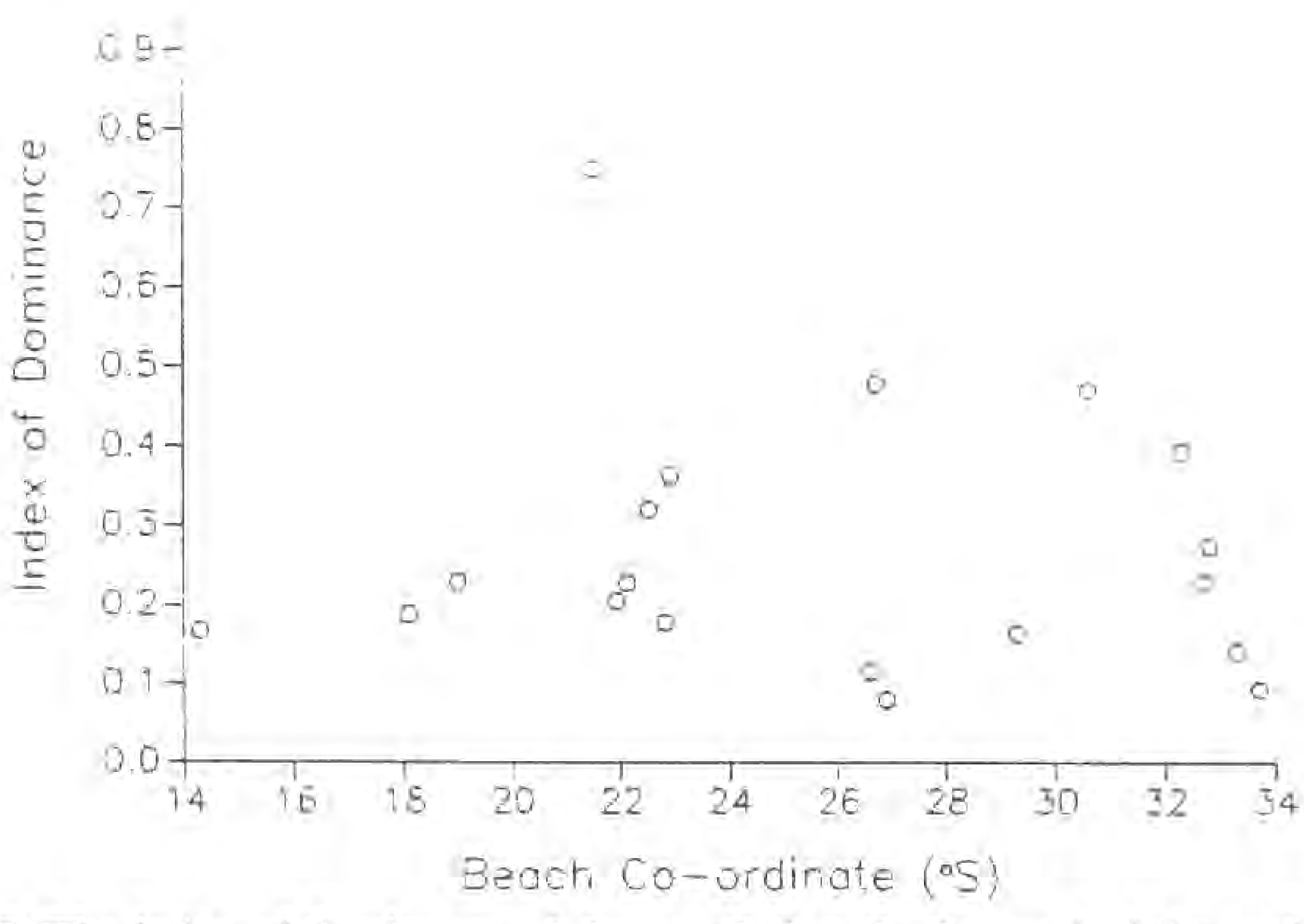

Figure 17. The index of dominance of the populations in the sand of the surf-zones along the west coast of South Africa and Namibia.

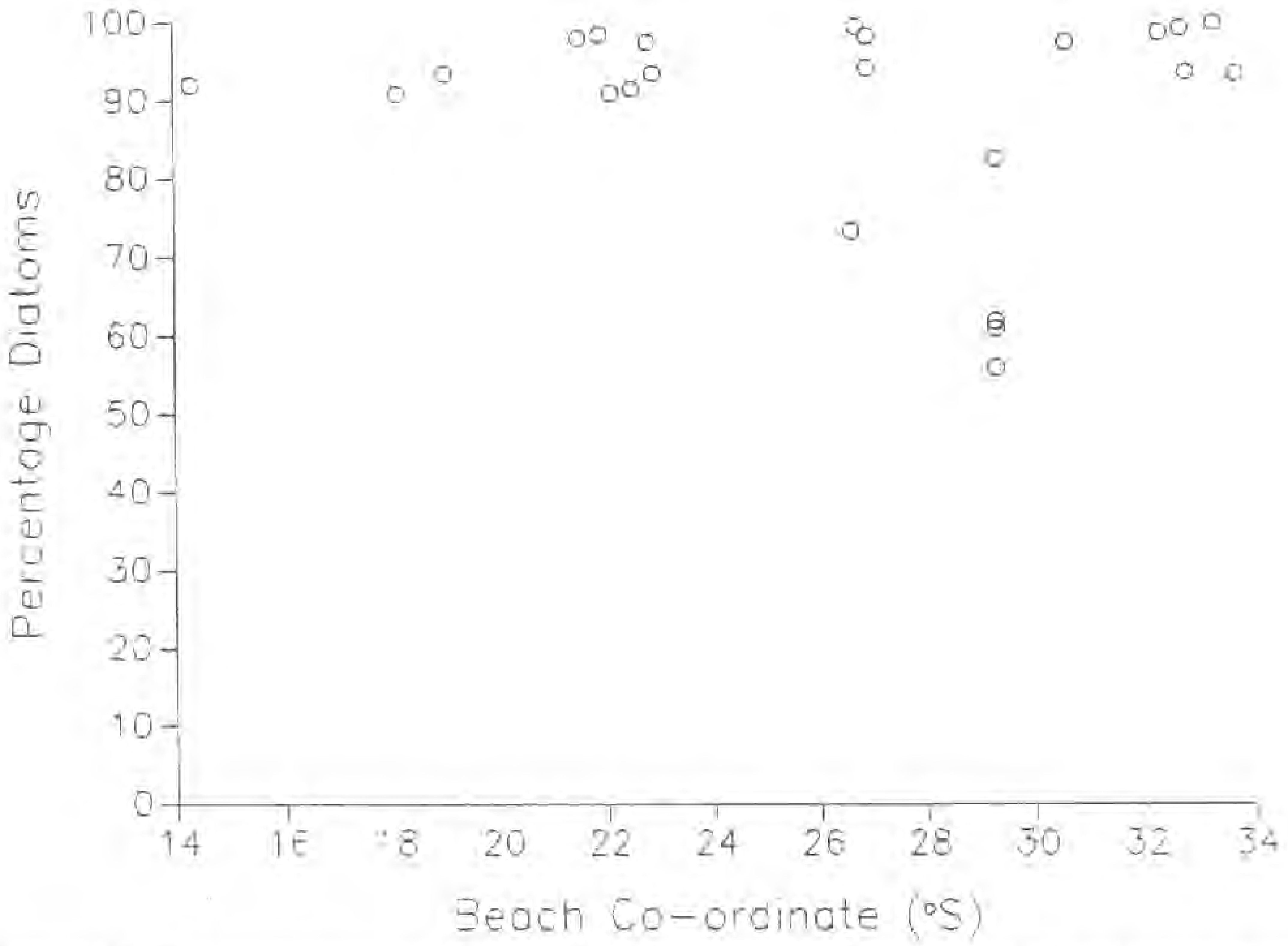

Figure 18. The percentage of diatoms in the community in the water of surf-zones along the west coast of South Africa and Namibia.

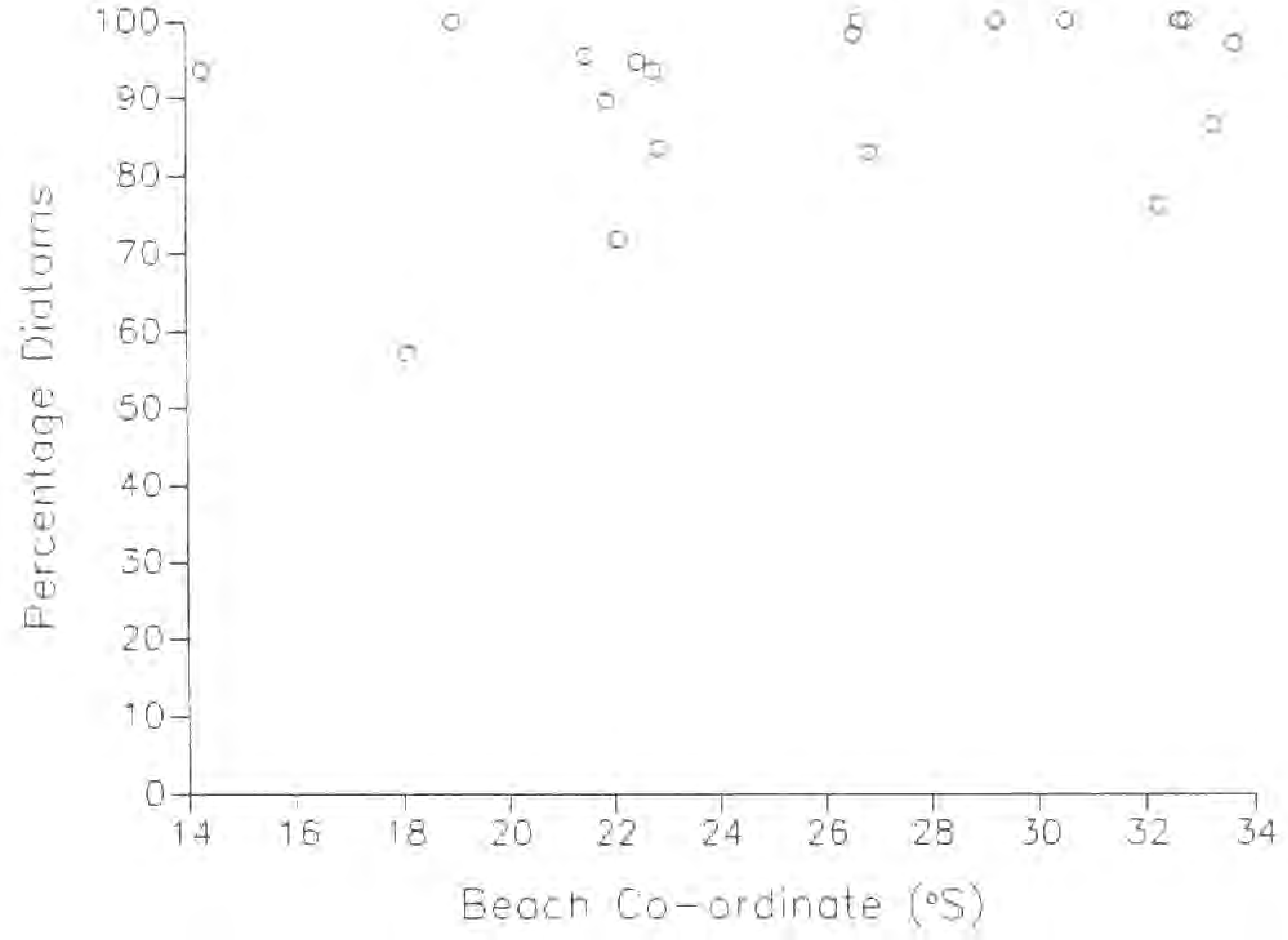

Figure 19. The percentage of diatoms in the community in the sand of surf-zones along the west coast of South Africa and Namibia.

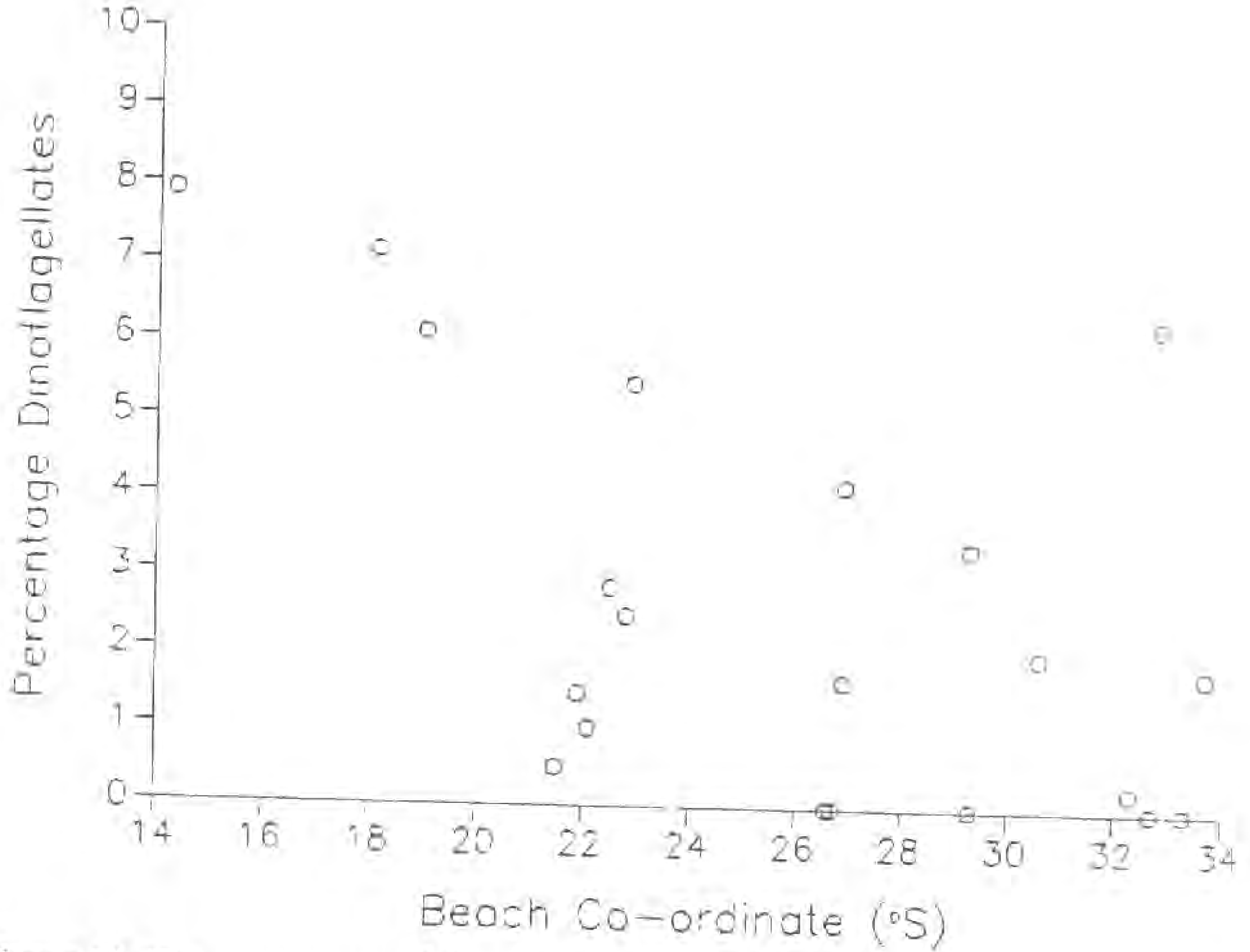

Figure 20. The percentage of dinoflagellates in the community in the water of surf-zones along the west coast of South Africa and Namibia.

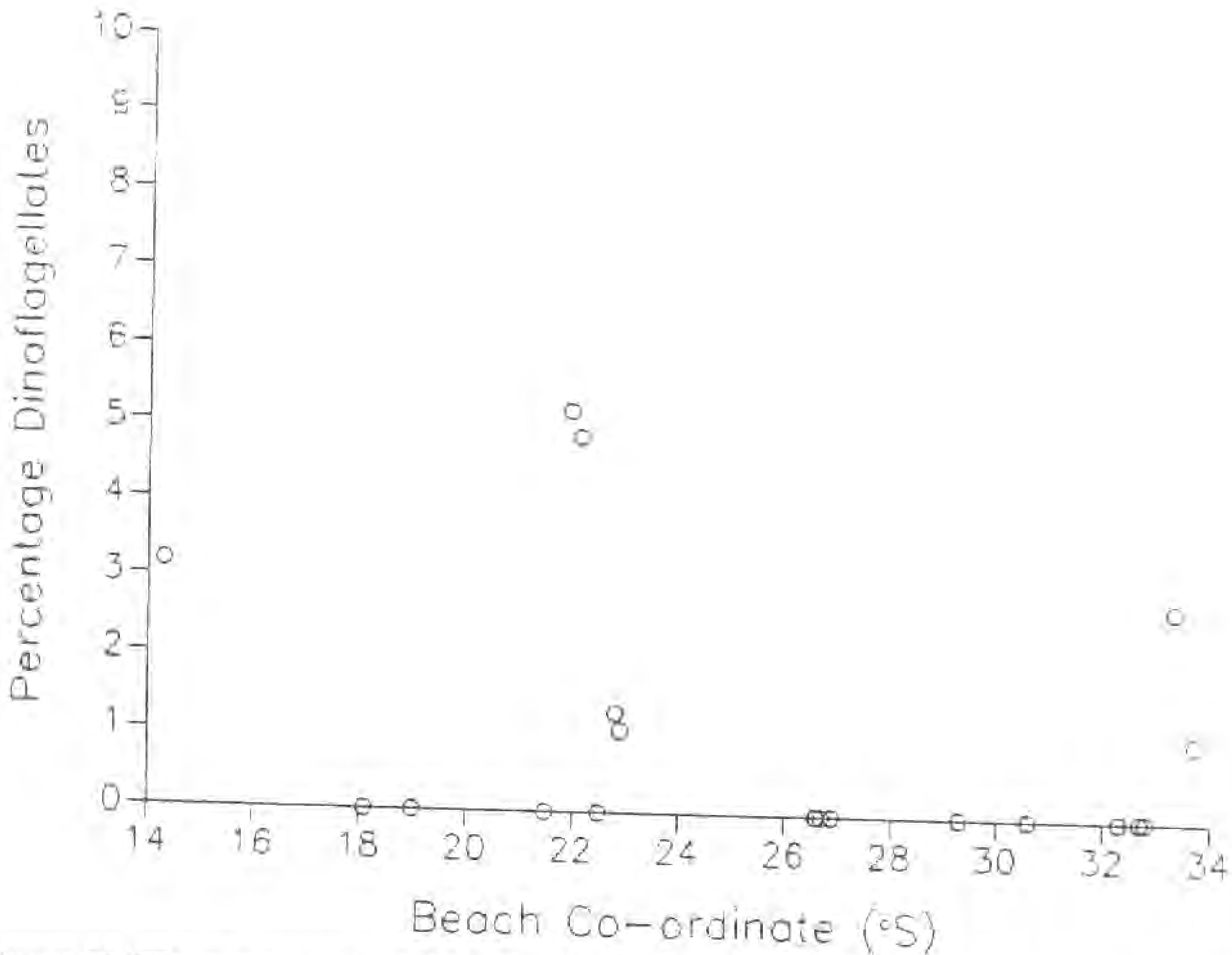

Figure 21. The percentage of dinoflagellates in the community in the sand of surf-zones along the west coast of South Africa and Namibia.

Green microalgae were found sporadically along the west coast, but were found in high numbers where they occurred (Fig. 22 and 23).

Other flagellates were not well represented in the water (Fig. 24 and 25) but common in the sand, reaching up to 28% of the community at one of the Skeleton Coast sites.

Bluegreen microalgae occurred in the water at 4 sites in the sand at 3 sites (Fig. 26 and 27), but in all cases comprised less than 3% of the community.

CANOCO analysis of the species occurring in all the samples (i.e. water and sand; Fig. 28) showed a clear separation between species resident exclusively in sand and those confined to the water. Species which occurred in both sand and water also separated into two groups: epipsammic species and pelagic species. *Anaulus australis* associates strongly with the epipsammic species; *Asterionella glacialis* falls in the transition between epipsammic and pelagic; and the numerically dominant *Delphineis* sp. is pelagic.

Several species which were only recorded from the water fell outside the limits of the pelagic group. They were four species of *Thalassiosira*, *Peridinium brevipes*, *Eucampia zoodiacus*, *Guinardia flaccida*, *Nitzschia closterium* and a *Schroederella* sp..

TWINSPAN analysis of the same data set also shows the trend for separation on the basis of "time spent" in the sand or water (Fig. 29). The numbers given in Figure 29 refer to the species code numbers given on page 22 to 25. The primary division is between species which occur mostly in the water and those that do not. In the group of species that are mostly in the water, the second division is between those that occur equally in the sand and water and those that are mostly in the sand. The latter group divides again separating those that occur only in the sand from those that occur in the water occasionally.

CANOCO analysis of the sites at which the samples were taken separate the sites into three groups (Fig. 30): 1) all sand samples; 2) water samples at and south of Lüderitz and 3) water samples north of Lüderitz.

The TWINSPAN analysis also separates sand and water and north and south sites (Fig. 31). However, the primary division is between water samples north of Lüderitz, and the rest of the samples. The next division is between water samples south of Lüderitz and the sand samples. There was more affinity between northern and southern sand samples than between northern and southern water samples, with the division between southern and northern sand samples being on two dendrogram levels.

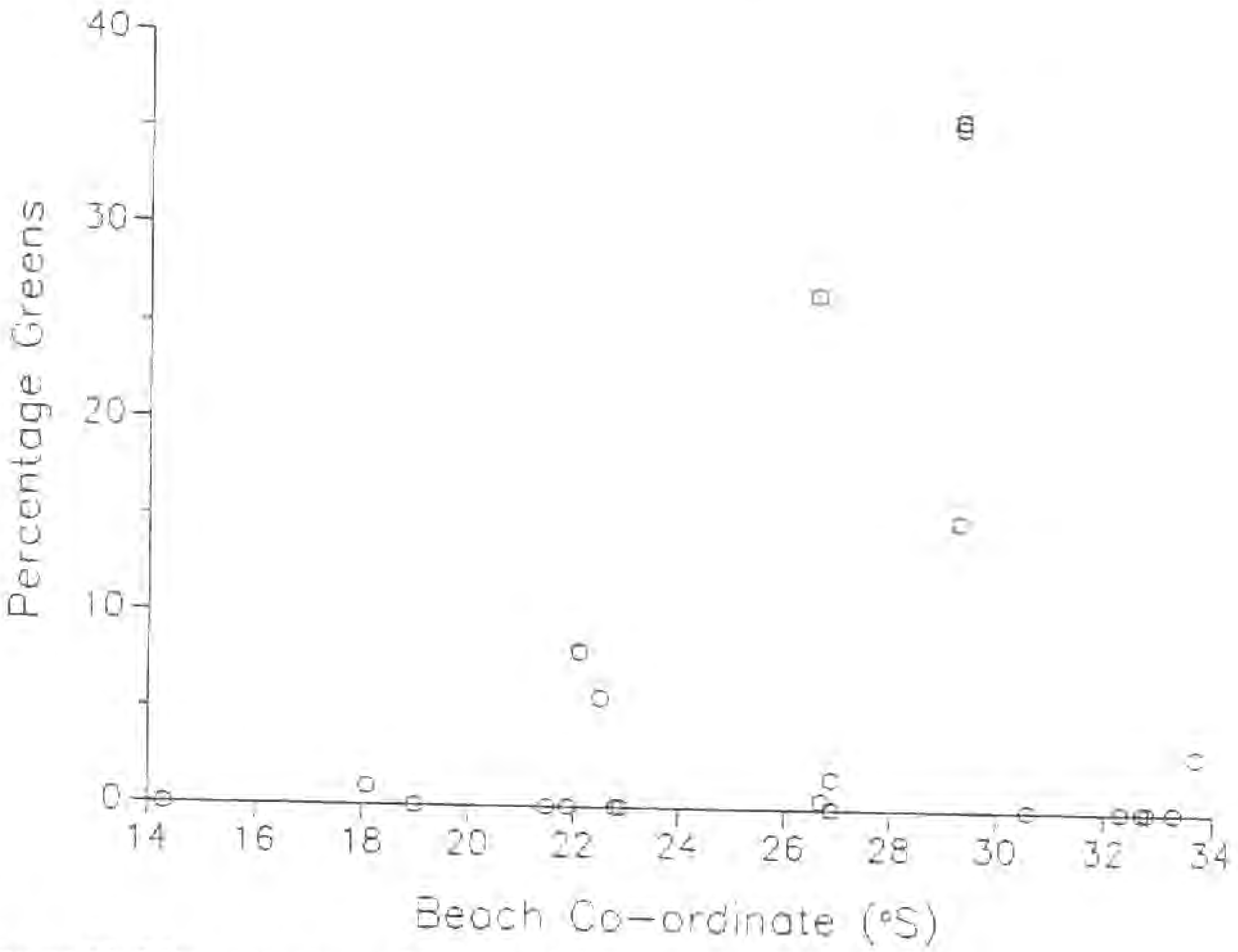

Figure 22. The percentage of "greens" in the community in the water of surf-zones along the west coast of South Africa and Namibia.

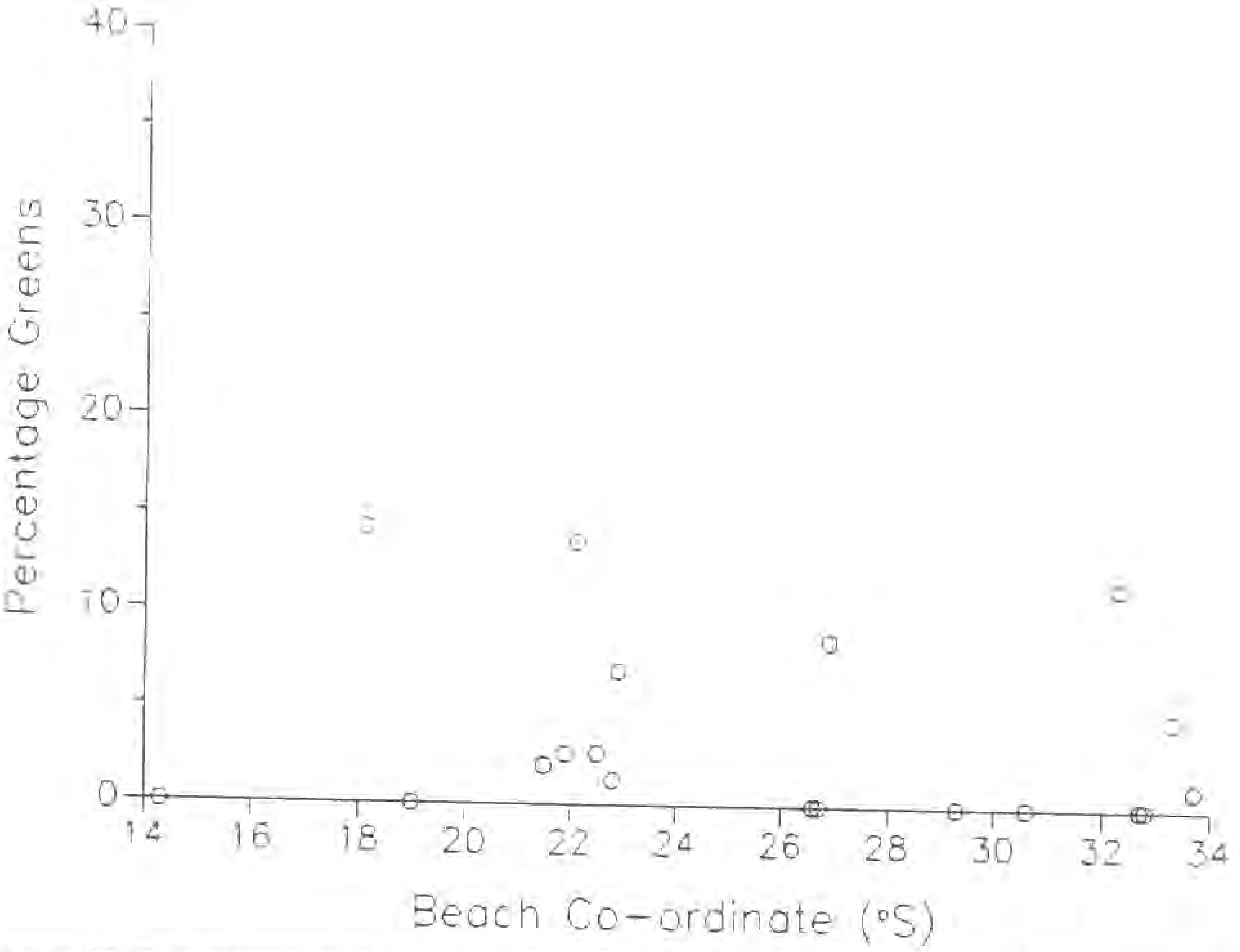

Figure 23. The percentage of "greens" in the community in the sand of surf-zones along the west coast of South Africa and Namibia.

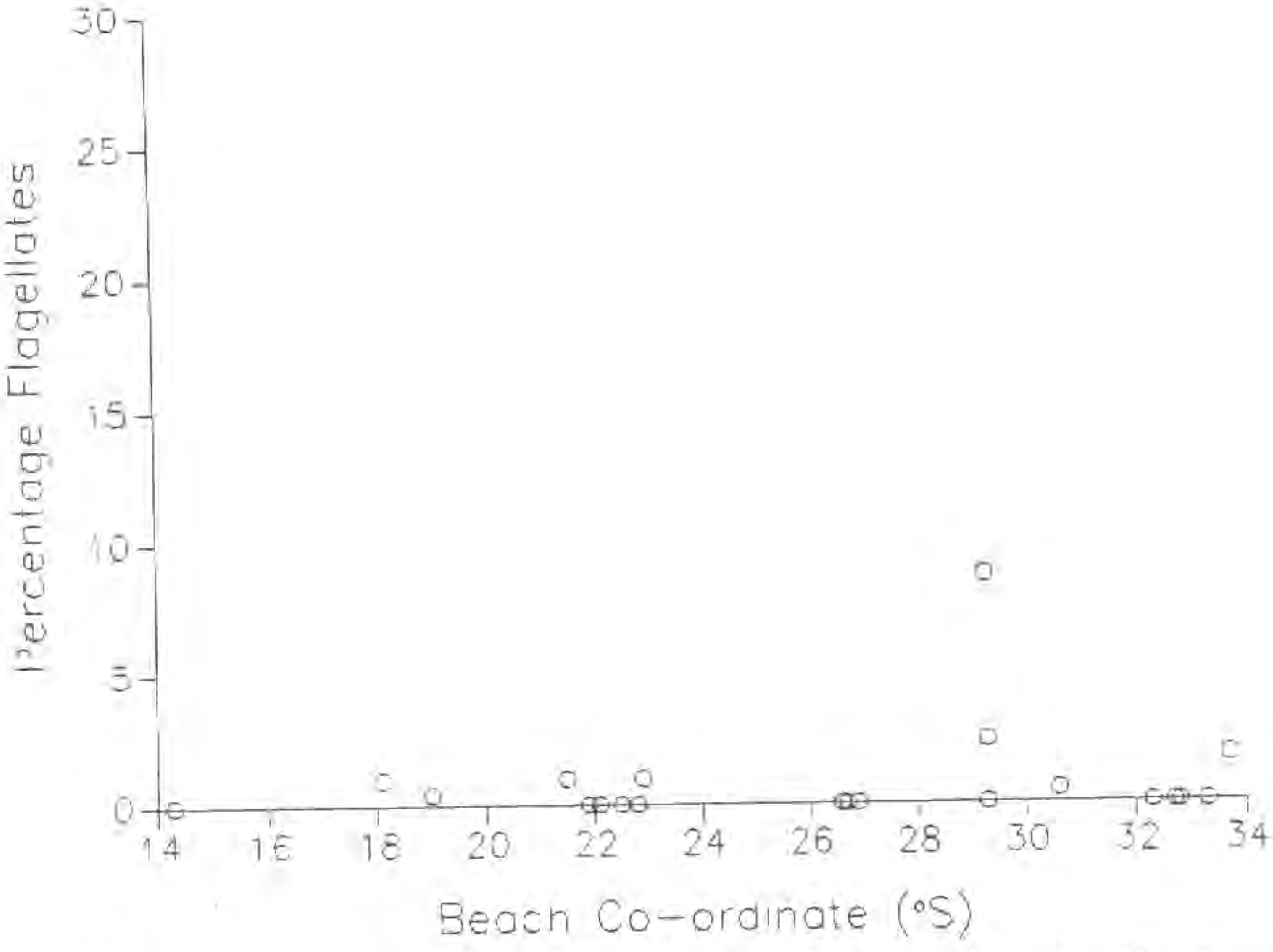

Figure 24. The percentage of flagellates in the populations in the water of surf-zones along the west coast of South Africa and Namibia.

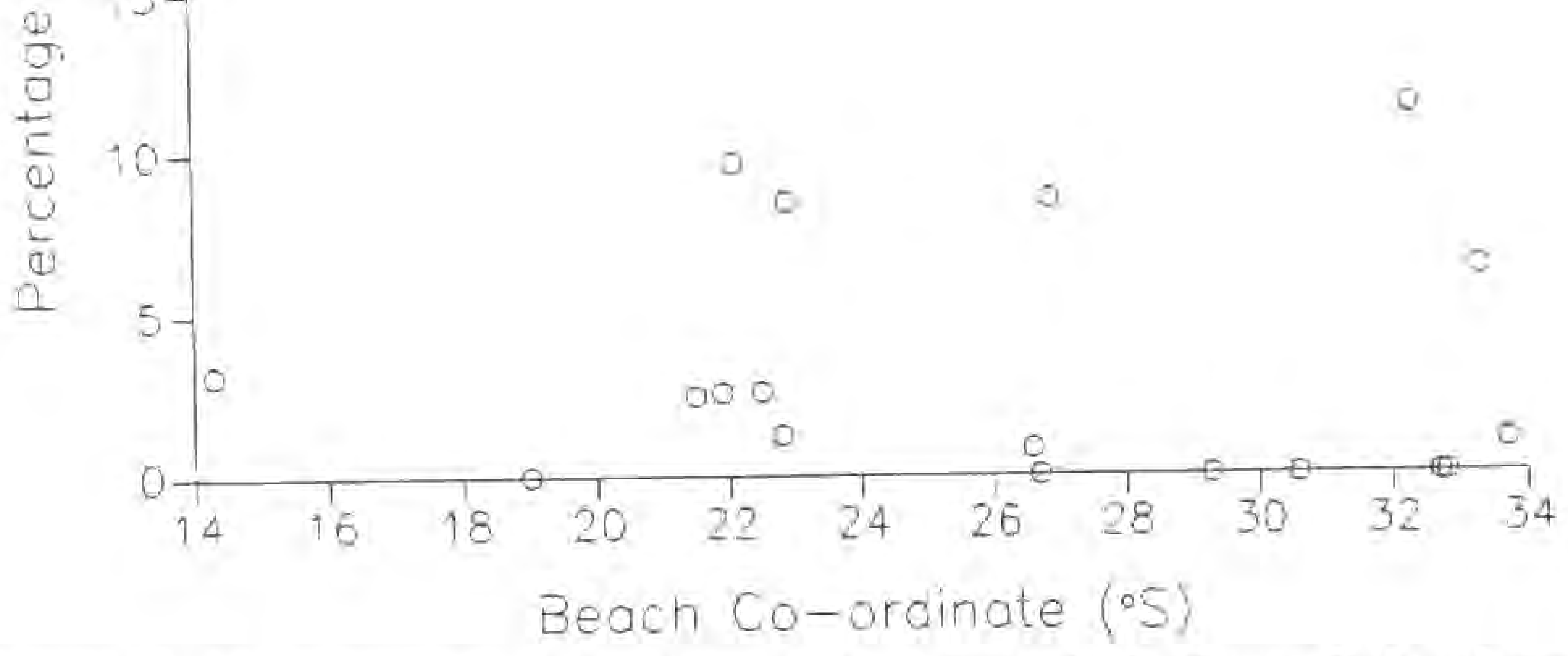

Figure 25. The percentage of flagellates in the community in the sand of surf-zones along the west coast of South Africa and Namibia.

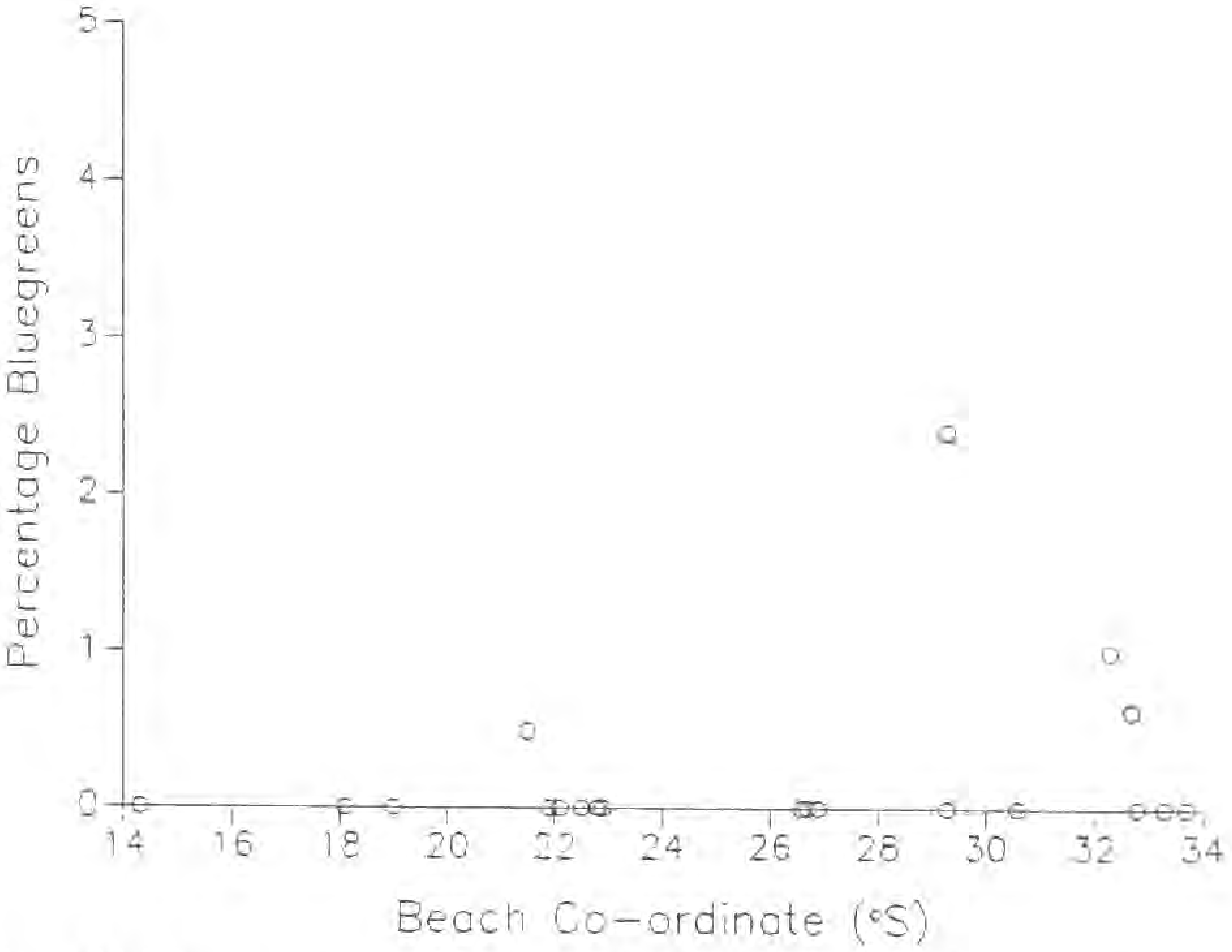

Figure 26. The percentage of bluegreens in the community in the water of surf-zones along the west coast of South Africa and Namibia.

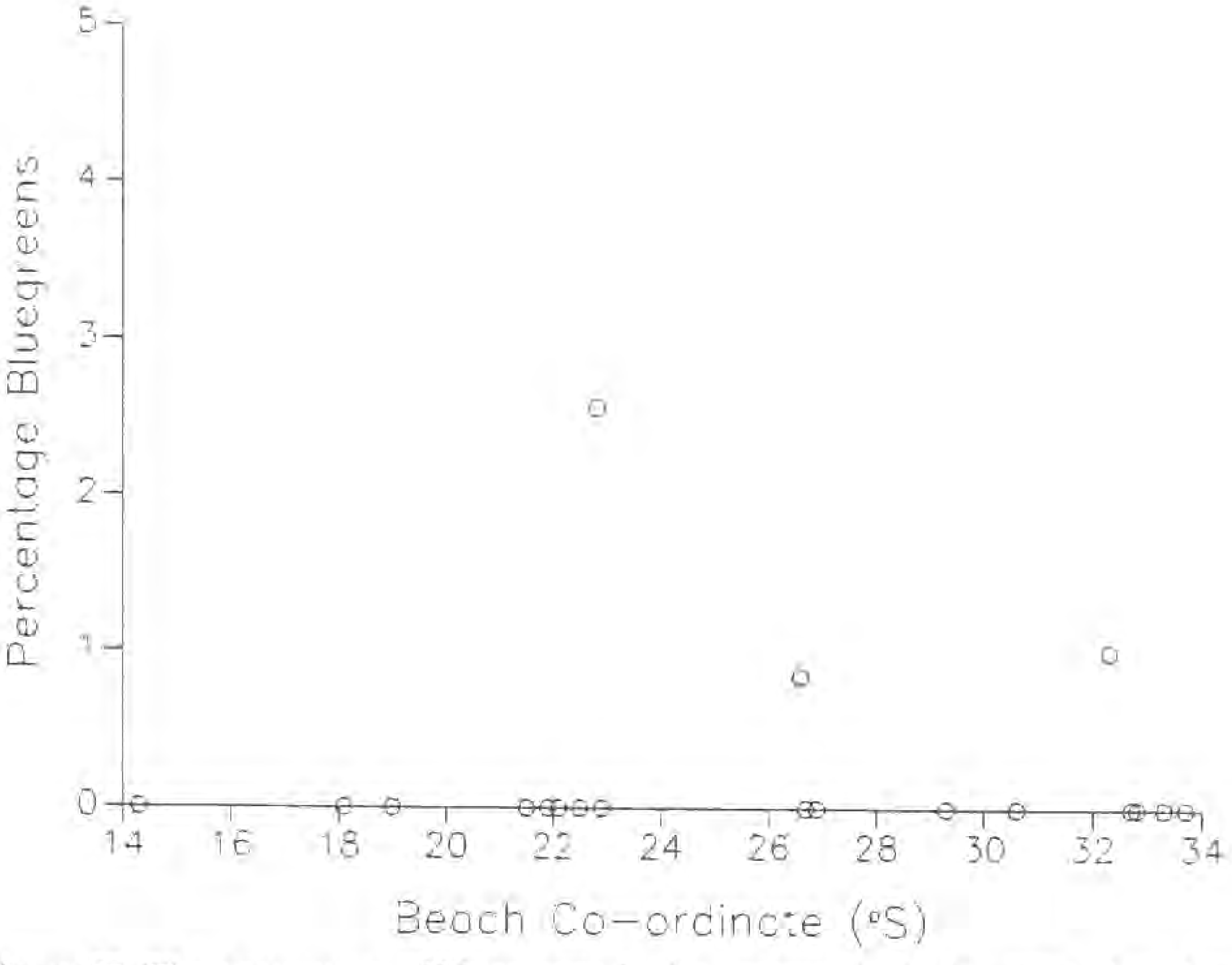

Figure 27. The percentage of bluegreens in the community in the sand of surf-zones along the west coast of South Africa and Namibia.

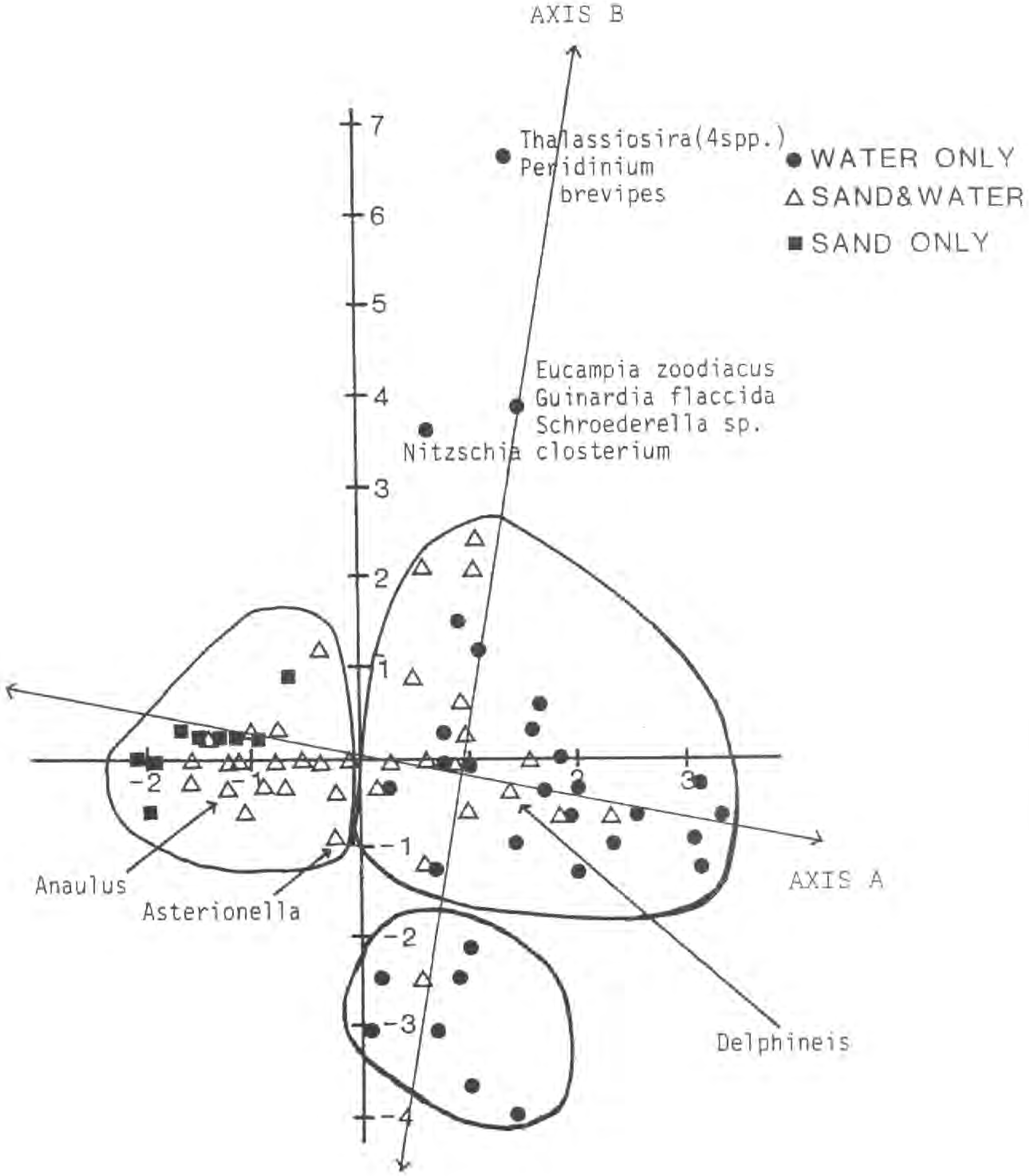

Figure 28. Detrended canonical correspondence analysis of the species found in the water and sand of surf-zones of the west coast of South Africa and Namibia.

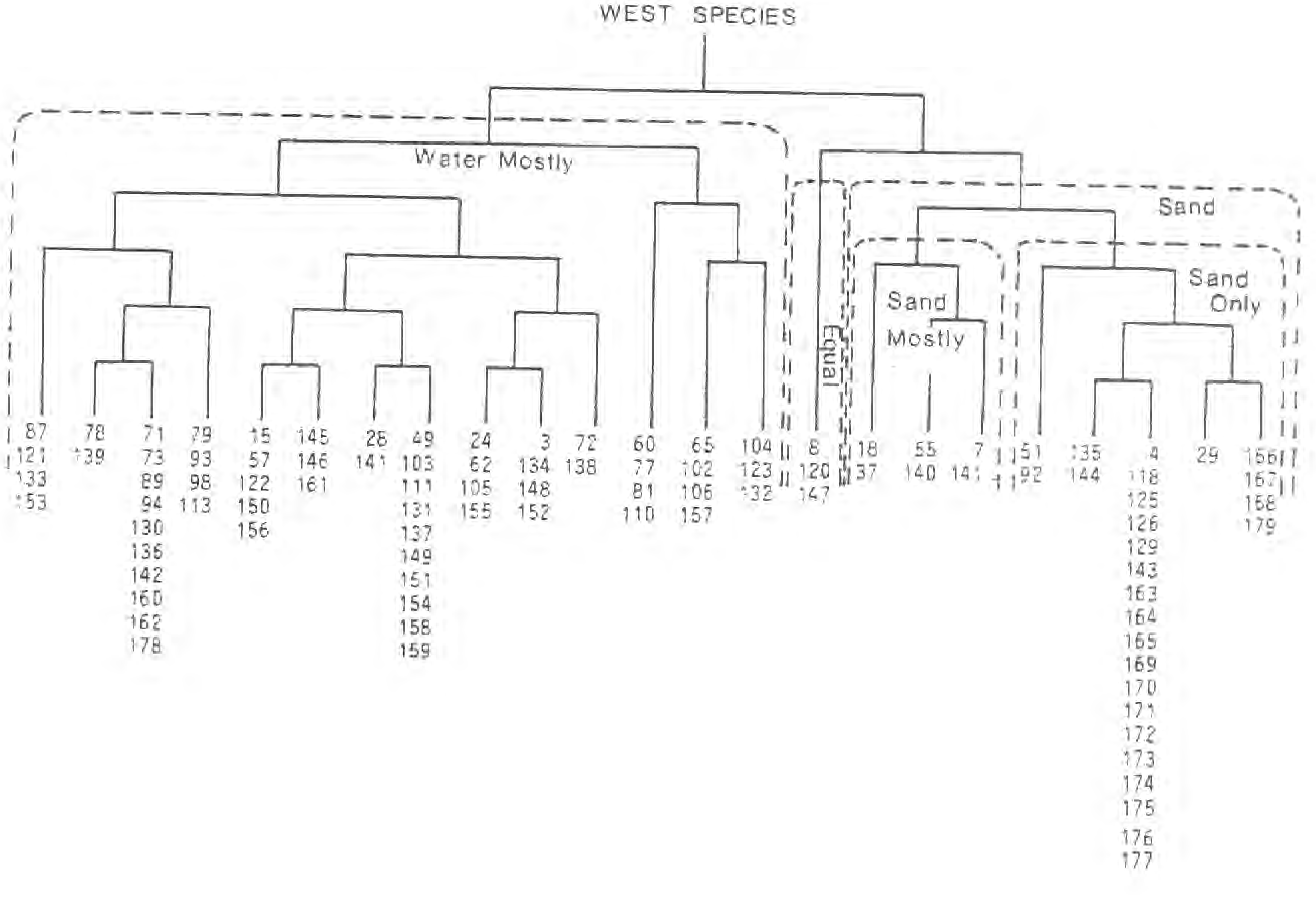

Figure 29. Dendrogram of the TWINSPAN analysis of the species found in the water and sand of surf-zones of the west coast of South Africa and Namibia.

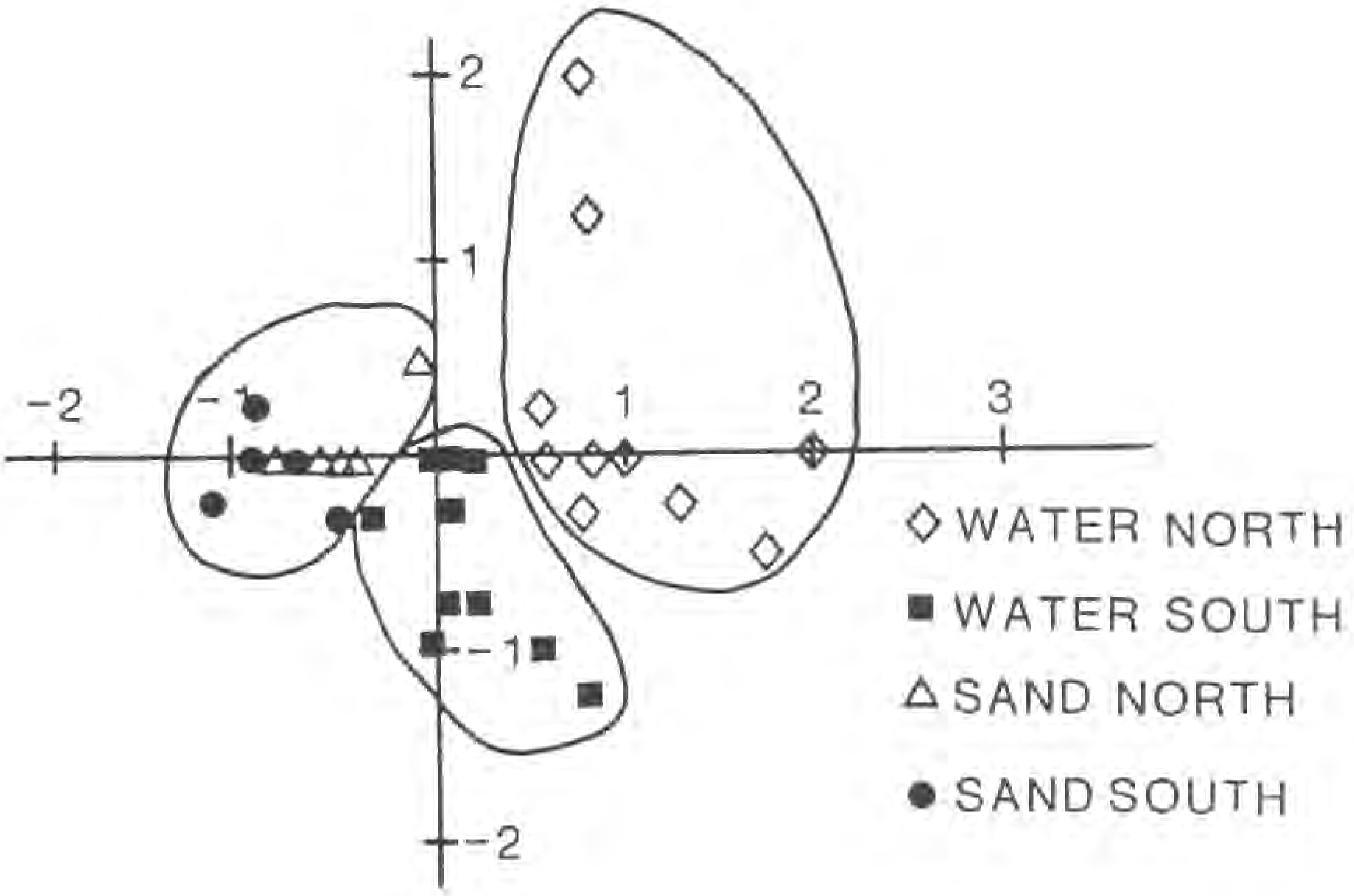

Figure 30. Detrended canonical correspondence analysis of the sites at which samples were taken along the west coast of South Africa and Namibia.

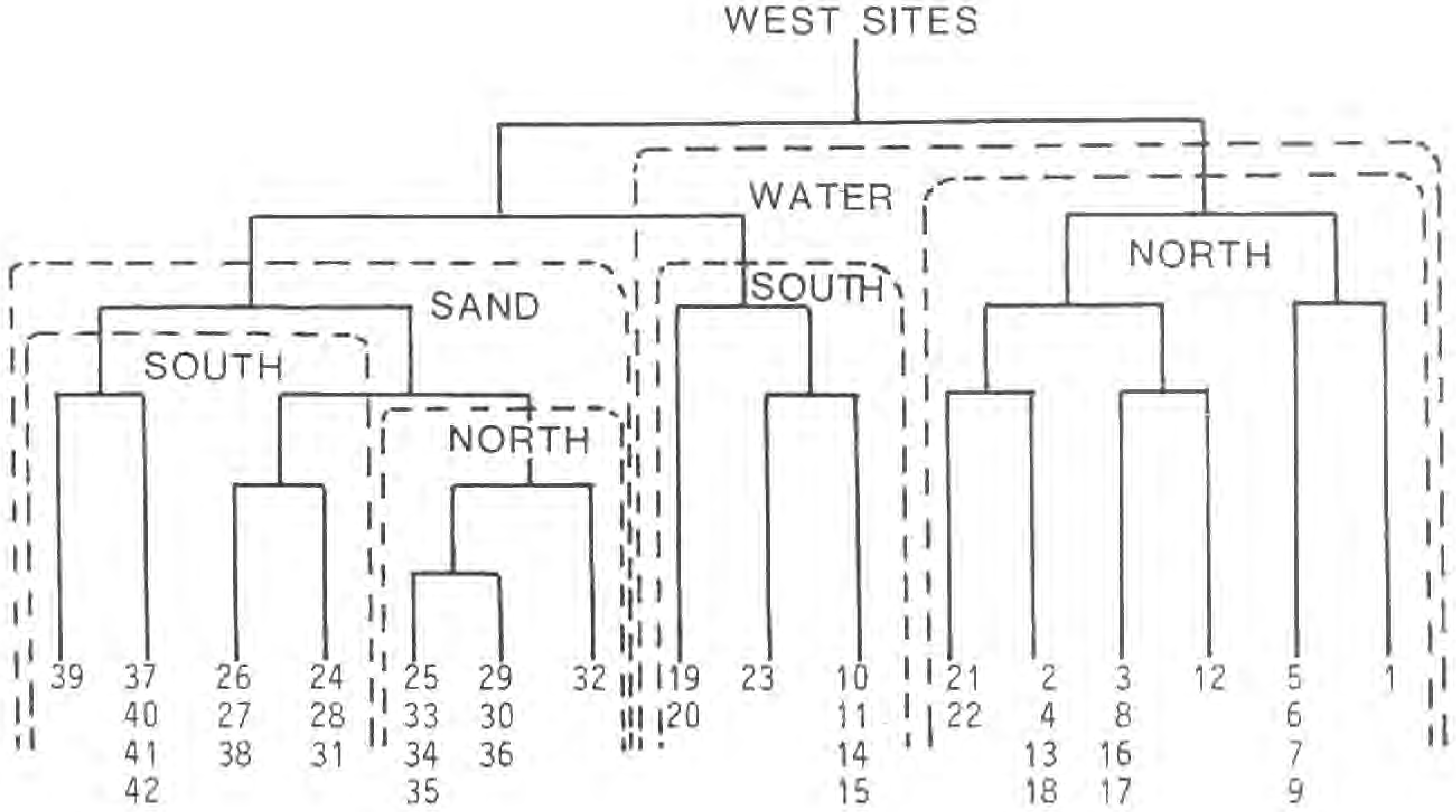

Figure 31. Dendrogram of the TWINSPAN analysis of the sites at which samples were taken along the west coast of South Africa and Namibia.

3.3 Cell Numbers

Cell numbers in surf-zones of the west coast ranged from 400 to 8 000 cells ml^{-1} (Fig. 32), highest cell numbers being recorded at Dwarskersbos and Elandsbaai. Most of the samples contained approximately 800 cells ml^{-1}.

The cell numbers in the sand ranged between 1 000 and 30 000 cells g $sand^{-1}$ (Fig. 33) except for Grossebucht where more than 170 000 cells g $sand^{-1}$ were recorded. Excluding the Grossebucht site, the ratio of cell numbers in the water to cell numbers in the sand (Figure 34) indicates that for most of the samples there were more cells in the sand than in the water. The only deviant sites were one of the Skeleton Coast sites, Dwarskersbos, Elandsbaai and Strandfontein.

3.4 Chlorophyll Concentration

Chlorophyll-*a* concentrations in the water ranged from as low as 1 mg chl-*a* m^{-3} to a high value of 850 mg chl-*a* m^{-3} (Fig. 35). Most of the values were between 15 and 50 mg chl-*a* m^{-3} with a mean of 84 mg chl-*a* m^{-3}.

Where brown foam was observed, chlorophyll-*a* measurements were taken in the discoloured foam. The values were not particularly high (Fig. 36), ranging from 10 to 280 mg chl-*a* m^{-3}; the mean of 118 mg chl-*a* m^{-3} is 1.4 times higher than that of water where there was no brown foam.

The standing stocks calculated from the chlorophyll-*a* data are presented in Figure 37. Because the foam represents such a small proportion of the total volume (Campbell and Bate, 1988), the standing stock distribution has the same pattern as that of the chlorophyll-*a* concentration in the water.

Standing stocks were between 600 mg chl-*a* m^{-1} and 430 000 mg chl-*a* m^{-1} with most of the values between 7 000 and 25 000 mg chl-*a* m^{-1} (Fig. 37, a mean of 42 300 mg chl-*a* m^{-1}).

3.5 Primary Production Estimates

The primary production estimates are shown in Figure 38. The primary production depended strongly on the beach state is shown in Figure 39. Primary production ranged from 7 kg C m^{-1} y^{-1} to 12 200 kg C m^{-1} y^{-1}, most of the values being between 200 kg C m^{-1} y^{-1} and 500 kg C m^{-1} y^{-1}; the mean is 1 140 kg C m^{-1} y^{-1}.

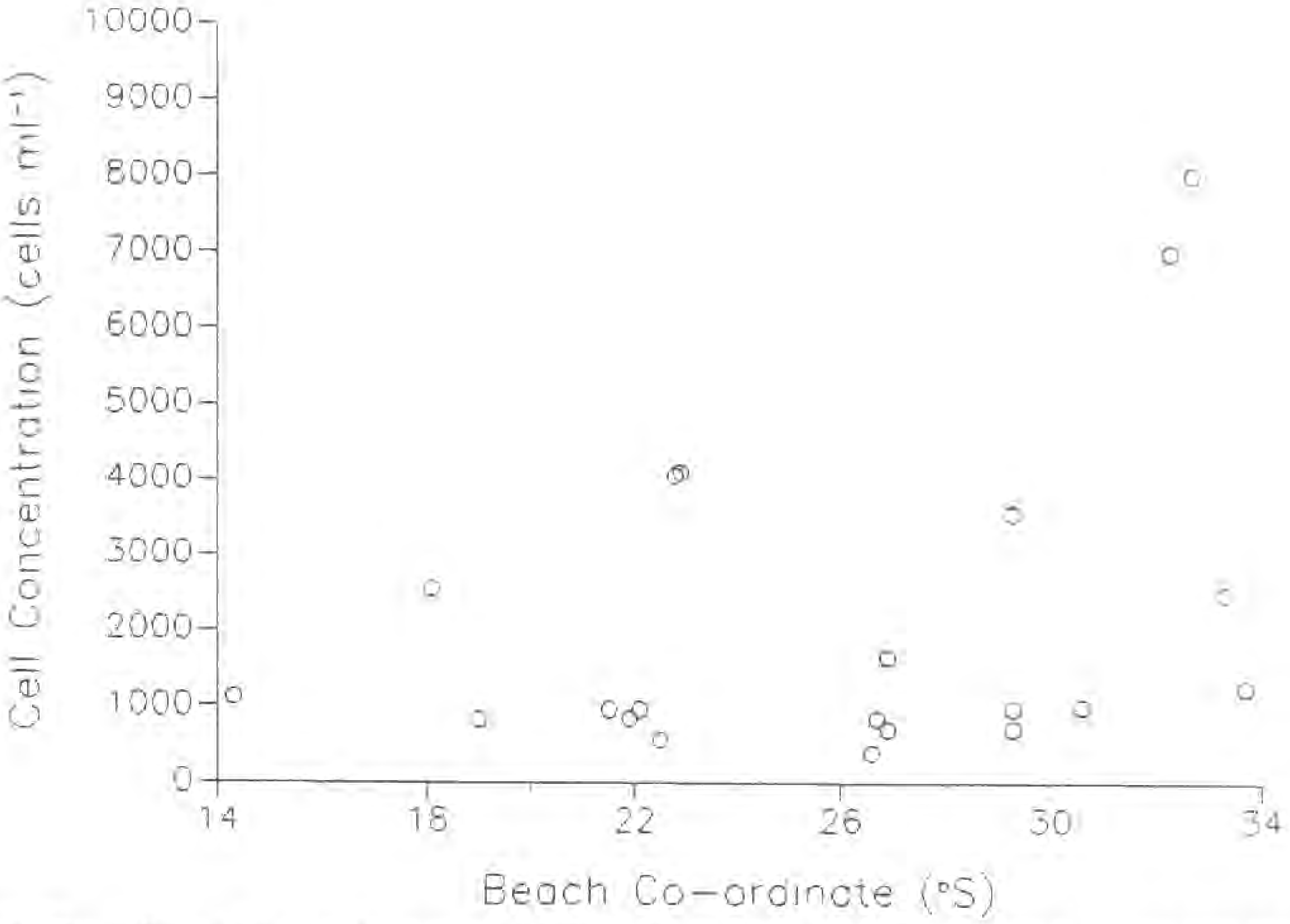

Figure 32. The cell numbers in the water of surf-zones of the west coast of South Africa and Namibia.

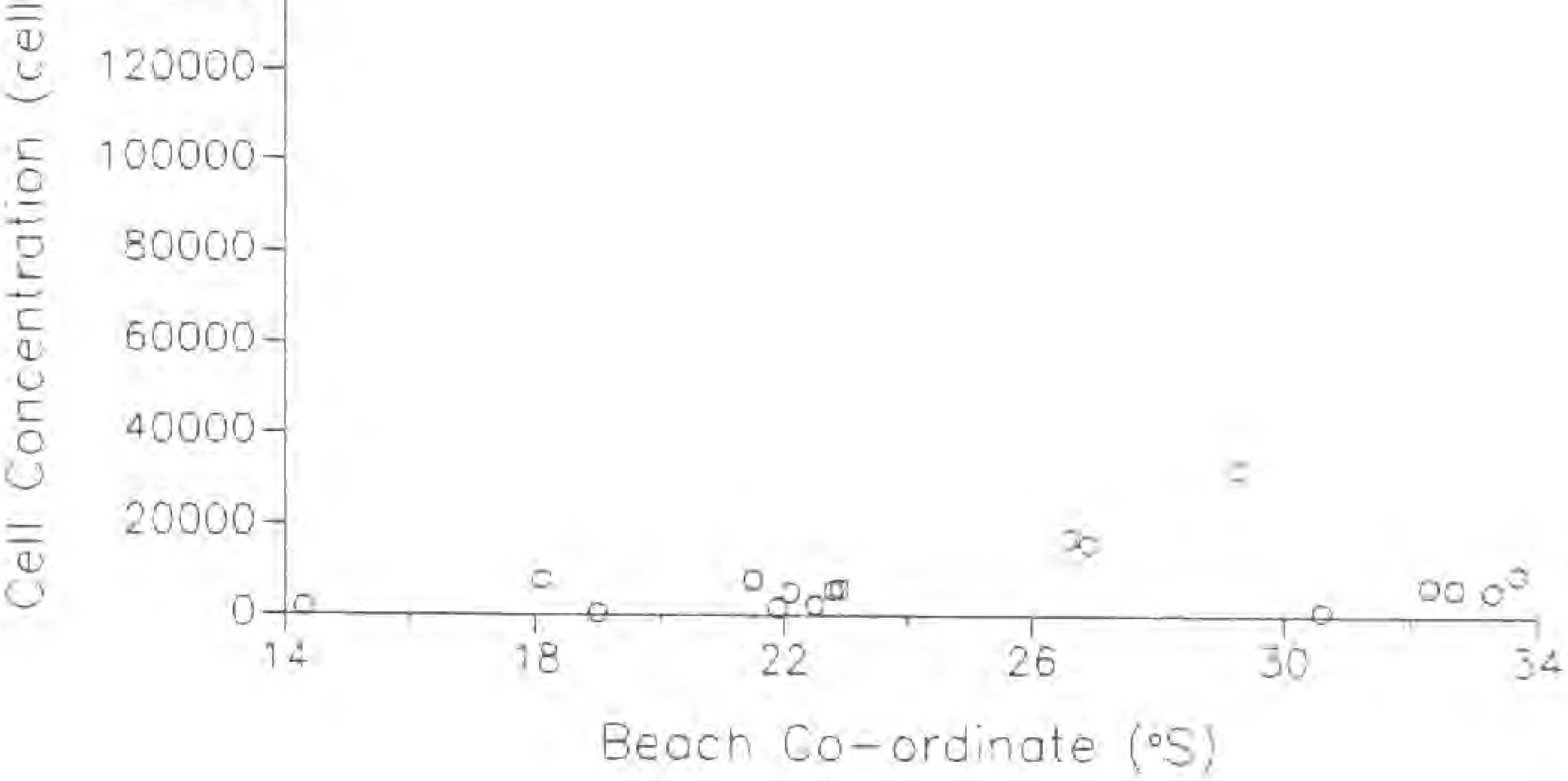

Figure 33. The cell numbers in the sand of surf-zones of the west coast of South Africa and Namibia.

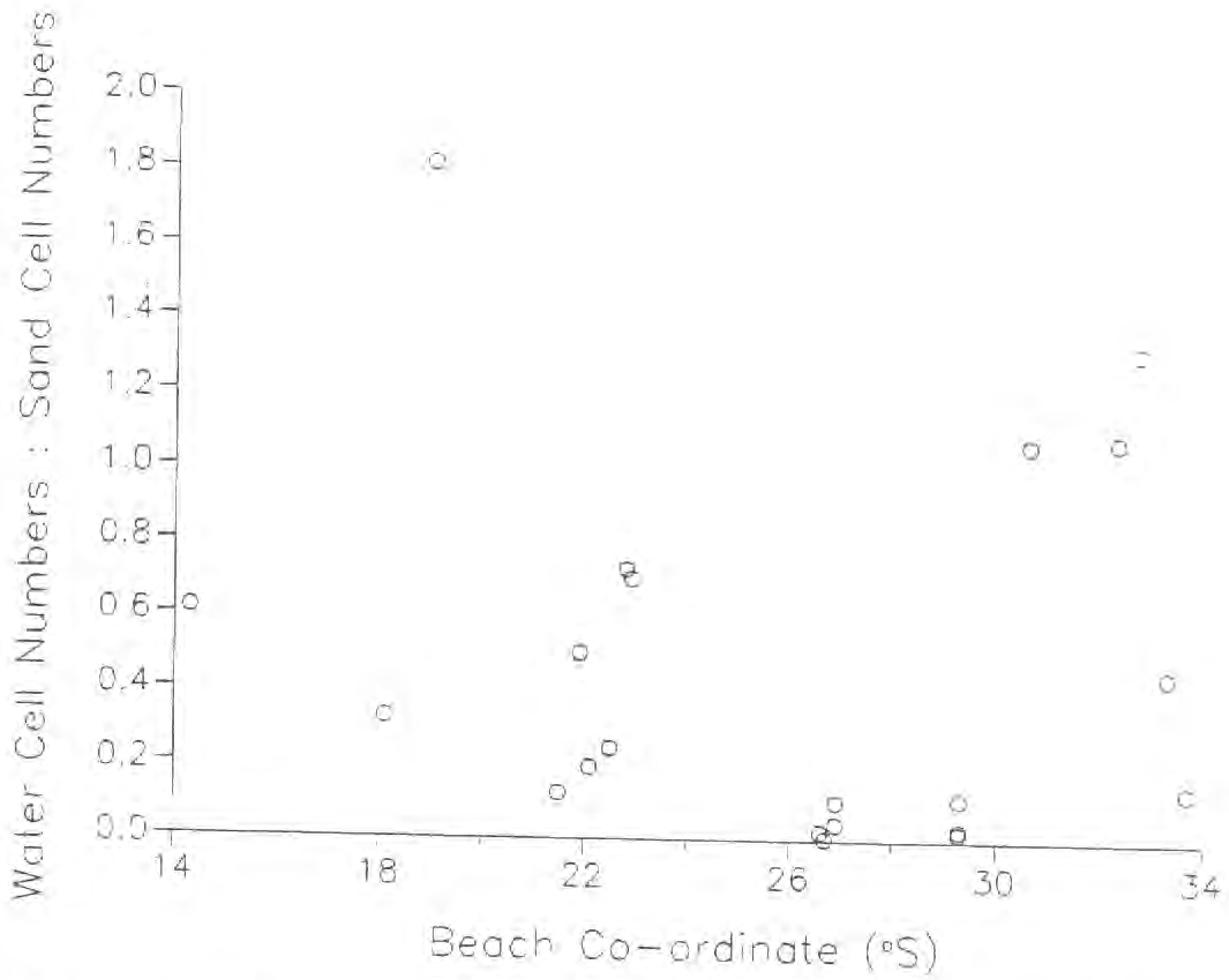

Figure 34. The ratio of cell numbers in the water to that in the sand of surf-zones of the west coast of South Africa and Namibia.

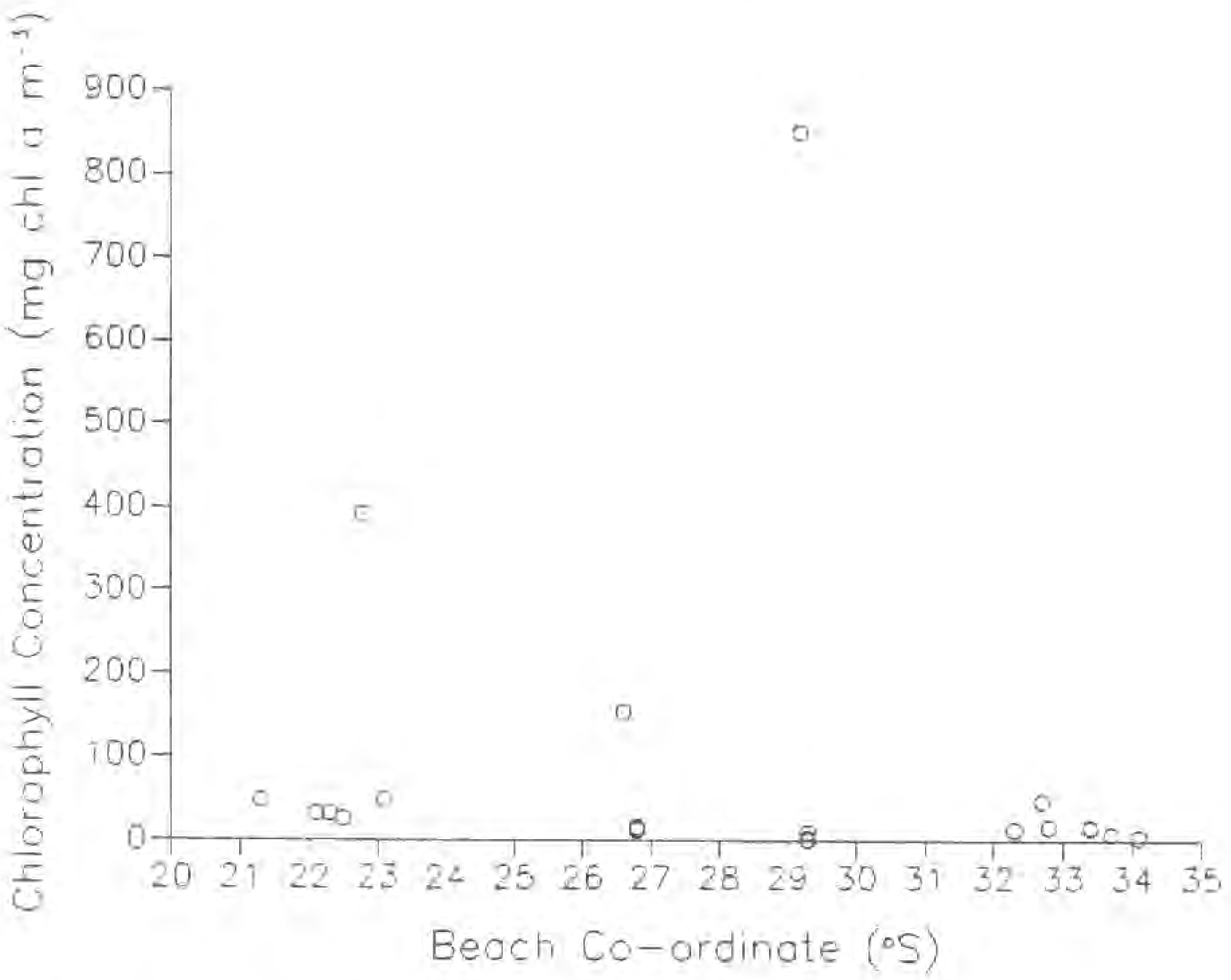

Figure 35. The chlorophyll-*a* concentration in the water of surf-zones of the west coast of South Africa and Namibia.

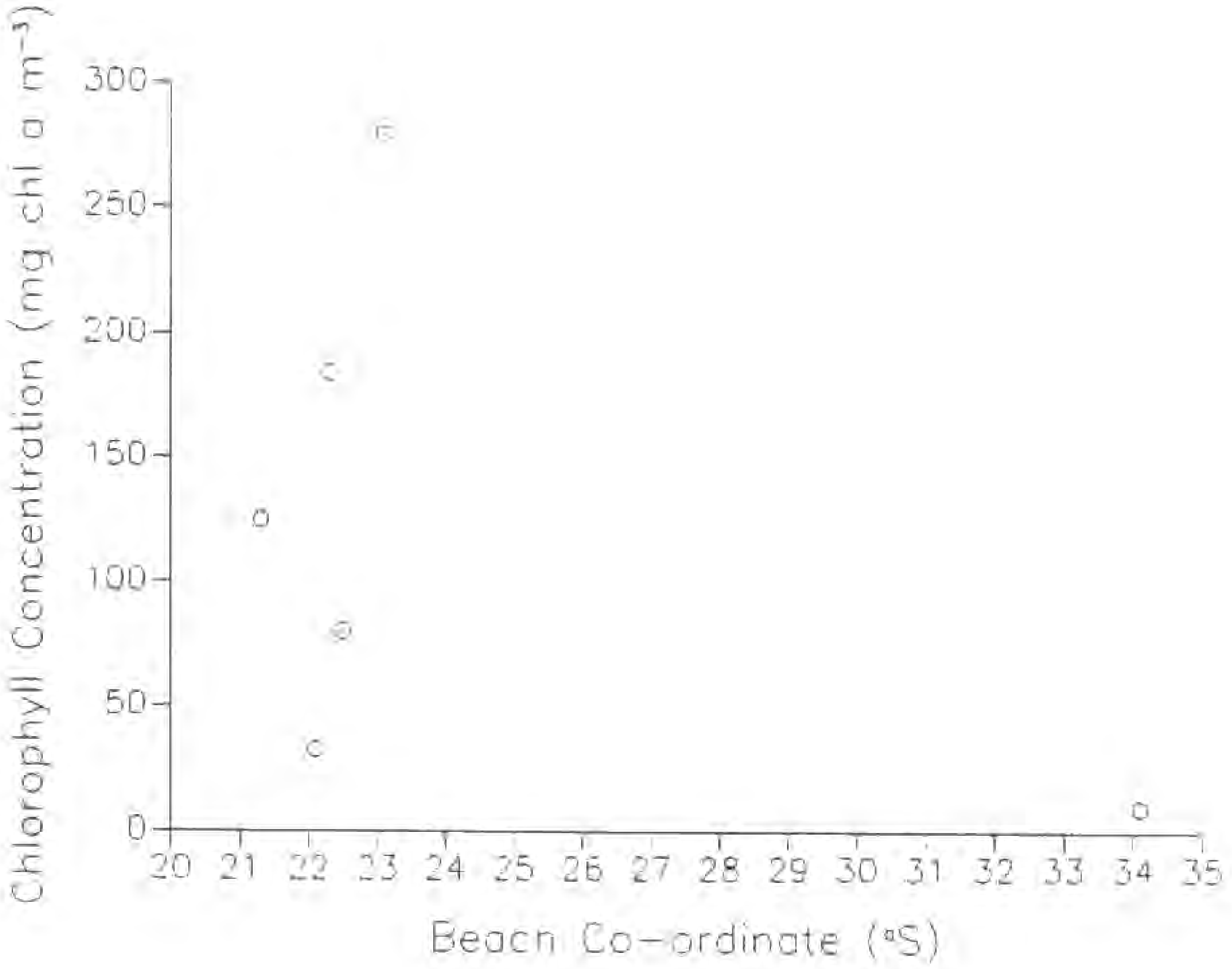

Figure 36. The chlorophyll-*a* concentration in the brown foam in surf-zones of the west coast of South Africa and Namibia.

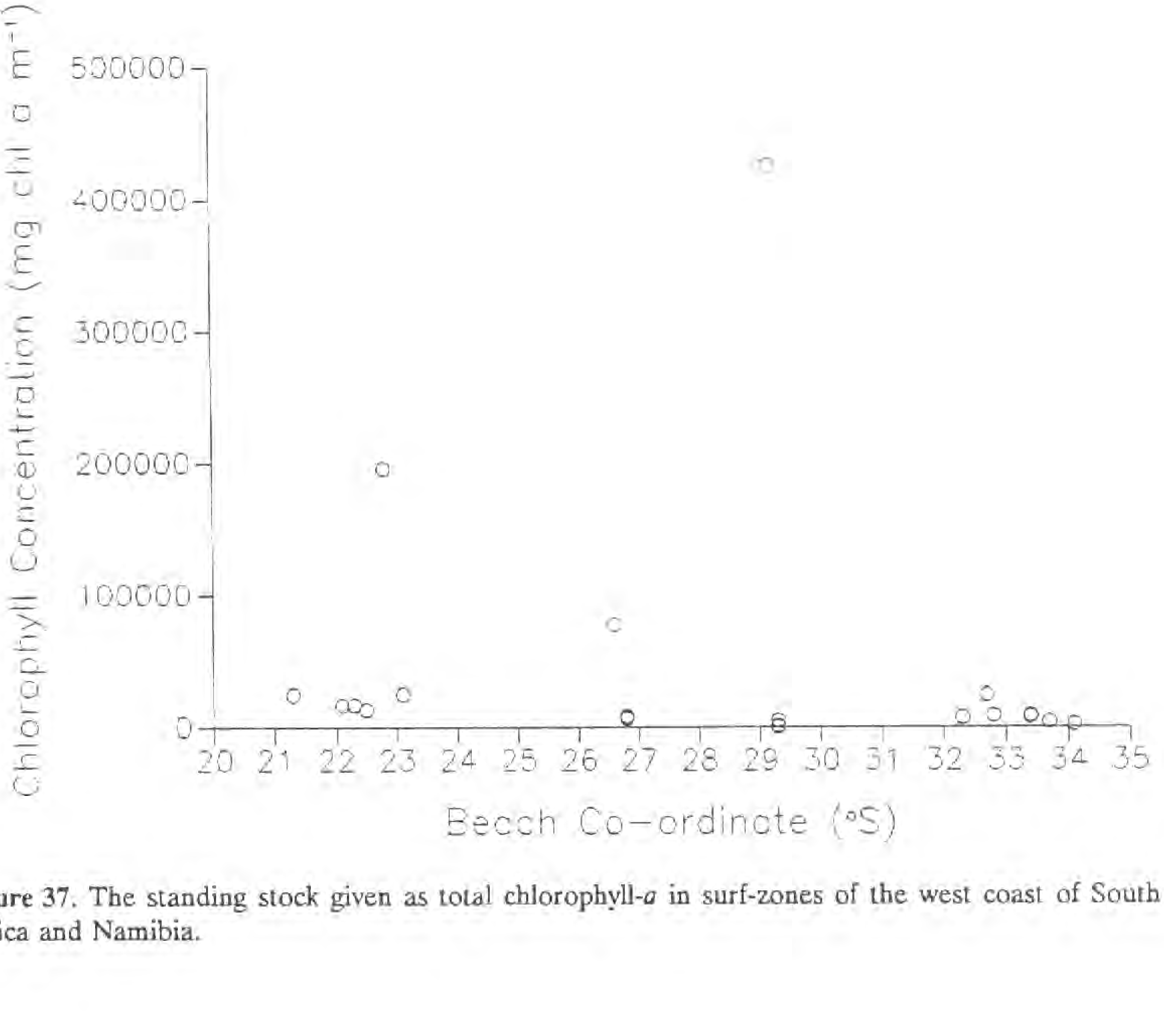

Figure 37. The standing stock given as total chlorophyll-*a* in surf-zones of the west coast of South Africa and Namibia.

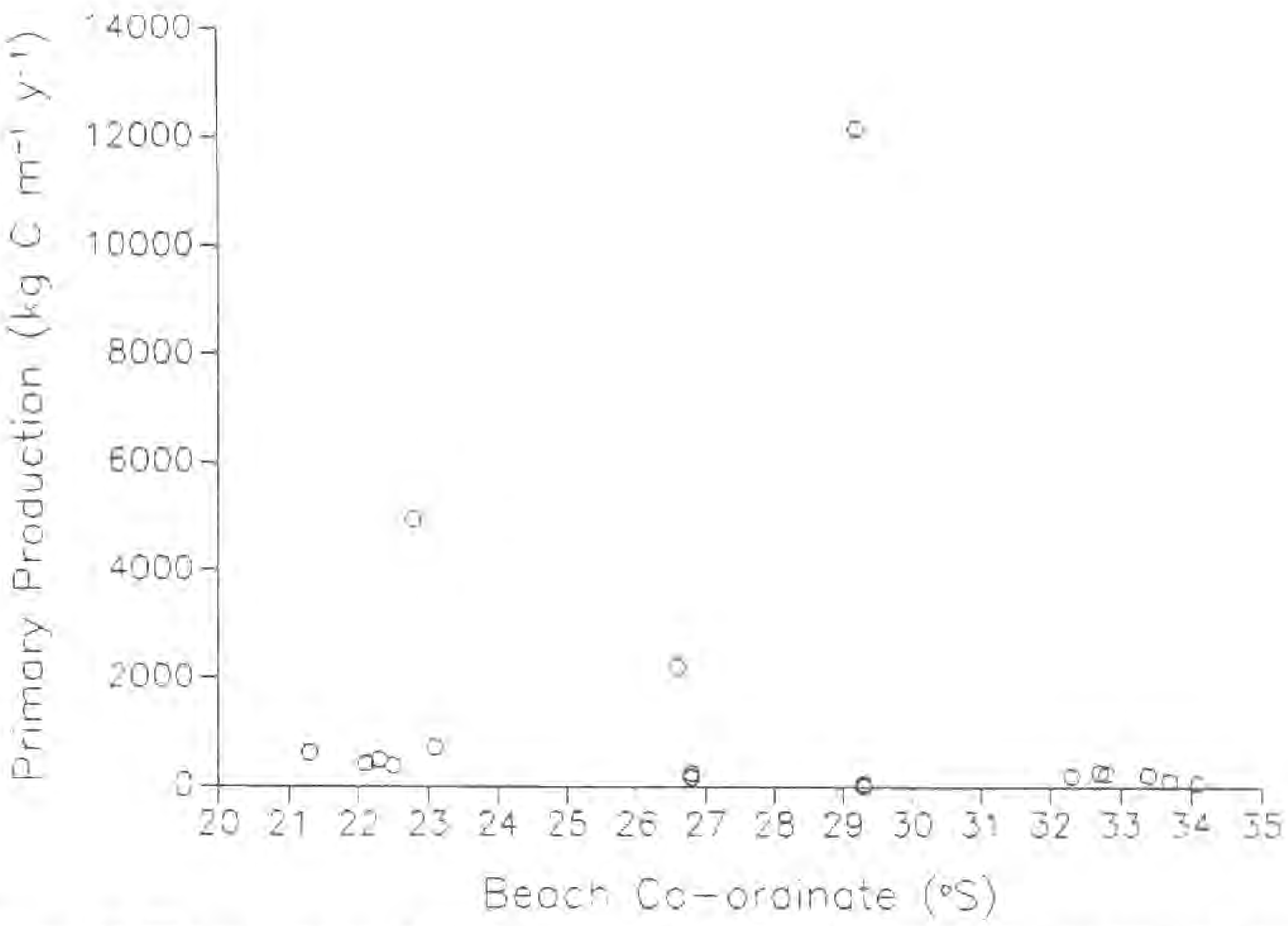

Figure 38. The primary production estimated for the surf-zones of the west coast of South Africa and Namibia.

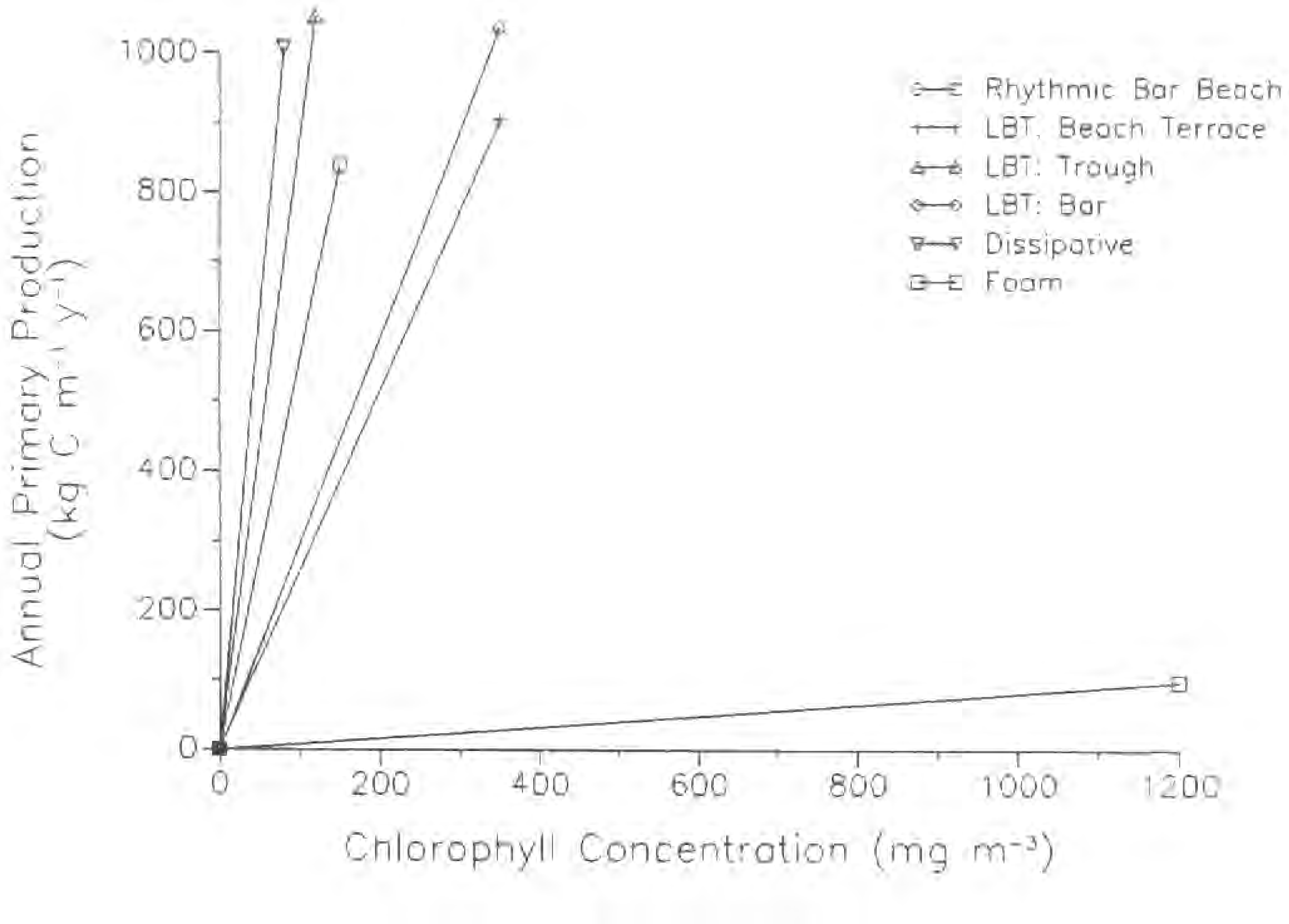

Figure 39. The primary production of the different beach states estimated from the surf-zone primary production model of Campbell and Bate (1988).

The total primary production in the surf-zone of the west coast is 1 200 000 tonnes C y^{-1}. Using a ratio of 1:3 to convert carbon to dry mass and 1:10 to convert dry mass to fresh mass, the 1 200 000 tonnes of carbon is equivalent to 36 x 10^6 tonnes of fresh mass per year.

4. DISCUSSION

The west coast of southern Africa is well known for its cold water and high biomass (Hart and Currie, 1960; Raymont, 1980). The surf-zone along this highly productive coastline have strong waves and high energy beaches, except in sheltered bays where the surf-zone is protected from direct oceanic swell. The surf-zone is generally narrower than is to be expected from the high wave energy (Wright and Short, 1983) and a wide dissipative surf-zone with six or more wave bores are never found.

This coastline experiences seasonal upwelling (Hart and Currie, 1960), but it is not certain whether the upwelling water reaches the surf-zone before the nutrients are depleted by coastal phytoplankton. Sources of nutrients for the surf phytoplankton must, however, be from the seaward side because there are almost no landward souces. Input from coastal aquifers is sparse. The Hentiesbaai area is the only Namibian beach sampled which has an aquifer which could supply substantial nutrients to the surf-zone (Fig. 4). If the aquifer water enters the surf-zone at a rate of 1 m^3 per running metre of beach per day, as is the case at the Sundays River beach (McLachlan and Illenberger, 1985) and with nitrate and ammonium concentration in the groundwater similar to that of the groundwater at the Sundays River beach (Campbell and Bate, in press), the groundwater can be a significant source of nitrogen and silicon. Only the Port Nolloth, Elandsbaai and Dwarskersbos sites could be influenced by aquifer water (Fig. 5).

Nutrient content of the seawater was similar to that measured at other sites around the coast (Campbell and Bate 1990 b and c). Aquifer water contains ten times more nitrate and silicon than seawater (Table 3), which appears to be typical for coastal aquifer water (McLachlan and Illenberger, 1985).

Sand grain size distribution is similar along the whole coast (Fig. 6 and 7), except for Agate Beach, which is the only beach inside a deep bay, protected from the ocean by two islands in the bay mouth. The biogenic component of the beach sand increases from 3% to over 50% from north to south (Fig. 8). The high biogenic component in the southern area is associated with an area of coast that has extremely high standing stocks of filter feeders, isopods and crustaceans (T.E. Donn, pers comm.). The difference between the samples collected south of the Orange River and those north of this large source of mineral sand shows that sand transport must be largely to the north, similar to the transport of alluvial diamonds which are found to the north of the river mouth (most diamond mining operations are north of the Orange River mouth). The three Skeleton Coast sites have almost no biogenic sand, but this is evenly distributed through the different size fractions (Fig. 9, 10 and 11). The biogenic sand of the beaches north of the Orange River has two major size fractions in the biogenic component viz. the largest fraction, and the 600-1 700 μm size class. The southern beaches have a high biogenic component in the grain size fraction finer than 1 000 μm.

A total of 79 species were recorded in the water and 56 in the sand of the west coast; 39 species found in the water were never recorded in the sand, and 16 species recorded in the sand were never recowed in the water.

The dominant species on the west coast are not strongly dominant; sand and water samples both have an index of dominance of approximately 0.2 (Fig. 16 and 17). At two of the sites where the index of dominance was higher, *Chaetoceros* spores were numerically dominant. This is primarily due to the artificial combination of several *Chaetoceros* species spores into one taxon. It was impossible to identify the different species of *Chaetoceros* spores, with the result that the high dominance index in this case can be considered to be an artifact. At Strandfontein *Skeletonema costatum* was strongly dominant and at Elandsbaai and Dwarskersbos a small *Navicula* species was dominant. The latter two sites have freshwater input from coastal aquifers (Fig. 5) which may increase the availability of nutrients and enhance the dominance of the numerically abundant species. Diversity indices did not reflect this difference. The sand samples had less dominance and lower species diversity than the water samples (Fig. 14 to 17).

Diatoms were the dominant type of phytoplankton in both sand and water, most samples having over 90% diatoms recorded (Fig. 18 and 19). Dinoflagellates were present in most of the water samples; they can be considered to be background species (Fig. 20). They are rare in the sand (Fig. 21). Where present, green microalgae tended to occur in large numbers (Fig. 22 and 23); along the west coast the tason displayin extreme patchy distribution. Blue-green algae were rare.

In the CANOCO and TWINSPAN analysis of species composition both methods of multivariate analysis show a division of species into sand and water communities. The sand to water gradient (axis A, Fig. 28) separates those associations which occur mostly in the sand from those which occur mostly in the water on the basis of their affinity to the ones which occur in each mode exclusively. The second CANOCO axis (B, Fig. 28) applies to the species which occur mostly in the water and separates them on the basis of rarity. The globally ubiquitous species are clustered at the negative end of axis B.

The surf diatom *Anaulus australis* occurs in a different mode on the west coast compared to its behaviour on the south coast. This diatom is nocturnally epipsammic along the south coast (Talbot and Bate, 1988), the cells being almost exclusively in the water during the day. The CANOCO analysis (Fig. 28) shows that along the west coast *A. australis* associates strongly with the epipsammic group. In the

TWINSPAN analysis it falls in the "mostly in sand" group (Number 7 in Fig. 29). This is despite the fact that the samples were mostly taken before 15:00 which, according to south coast data (Talbot and Bate, 1988), should yield most of the cells in the water.

Another surf diatom, *Asterionella glacialis* (Number 8 in Fig. 29), lies in the transition zone in the CANOCO analysis and in the "equally in sand and water" category in the TWINSPAN analysis with no preference for either medium (Fig. 29).

Two other genera known to be surf accumulating species (McLachlan, 1983) are *Chaetoceros* and *Aulacodiscus*. *Aulacodiscus* species were not recorded at all along the west coast. Different *Chaetoceros* species occurred either in water or in sand (Numbers 28, 29, 120 and 130; Fig. 29).

When analyzing the west coast sites to text whether there are different phytogeographical regions, the water and sand samples separated out strongly. The CANOCO and TWINSPAN analyses both separated the northern and southern samples as well (Fig. 30 and 31). The affinity between the northern and southern sand samples was stronger than between the northern and southern water samples. However, the strong separation between northern and southern water samples, together with some separation in the sand samples justifies the separation of two phytogeographic regions: the division is between Lüderitz and Swakopmund. Unfortunately, this area is inaccessible due to diamond mining operations, but on the basis of the change in the nature of the coast north of Lüderitz (Campbell and Bate, 1990a) the division can be set at 25°S.

We have addressed the matter of species similarities between surf water and water from the Benguela Upwelling System along the west coast. In discussions with members of the study group for phytoplankton at the Department of Sea Fisheries in Cape Town, they expressed surprise at the few common upwelling species which appeared in the beach water samples. The phytoplankton of the Benguela system is dominated by centric diatoms whereas samples of beach water and sand yielded mostly pennate diatoms. This is further evidence that the beaches are ecosystems in their own right and not simply a broader region of oceanic biogeography.

The standing stock data presented here are based on comparatively few measurements along the west coast. Cell numbers of all species in the surface foam on the west coast were very much lower than the 10^6 cells ml^{-1} often counted on the south coast. Values for the west coast ranged between 500 and 9 000 cells ml^{-1}.

The chlorophyll-*a* content of the south coast beaches is about 27 $\mu g\ l^{-1}$ (Campbell and Bate, 1990b), which is similar to the average content on the southern west coast beaches (Fig. 35). The statistics in

Table 4 shows that the south coast and the southern west coast beaches are not dissimilar with respect to chlorophyll-*a* content. The absence of a statistically significant difference between the chlorophyll-*a* content on the southern and northern west coast beaches is largely due to the high variance of the north coast data. The east coast (Campbell and Bate, 1990c) is also different from the west coast so that latitude can be excluded as the causal factor. The mean chlorophyll-*a* content for the west coast north of Lüderitz was 71 mg chl-*a* m^{-3} ($n = 10$), while that at, and south of, Lüderitz was 17 mg chl-*a* m^{-3}; these values are significantly different.

The values for primary production reported here relate to phytoplankton which is normally found in the water column of the surf-zone. On the west coast there is evidence of far greater numbers of diatoms in the sand per unit mass than in the water column per unit mass. The species are also different in the two media as shown in Figure 28. What we are unable to determine at present is the contribution these organisms make to the total primary production of the surf-zone; the calculated values exclude primary production in the sand.

The total primary production for the whole west coast amounts to 1.2 million tonnes C per year (Table 5).

Table 4. Levels of significance ($p <= 0.05$) using a t-test between the values of chlorophyll-*a* content of surf water around the southern African coastline. An asterisk indicates significant. NS indicates non-significant.

Coast	East	South	West	West (N)	West (S)
East	-	*	*	*	*
South	-	-	NS	NS	NS
West (N)	-	-	-	-	*
West (S)	-	-	-	-	-

Table 5. Estimated total primary production for surf-zones of the west coast of southern Africa.

Sector	Primary Production (kg C m^{-1} y^{-1})	Coast Length (km)	Total Primary Production (tonnes C y^{-1})
Northern	1 158	895	1 036 410
Southern	227	703	159 581
TOTAL			1 196 165

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APPENDIX 3. THE SPECIES COMPOSITION OF THE SAND AND WATER SAMPLES COLLECTED ON THE WEST COAST OF SOUTHERN AFRICA.

WATER

Species Beach	Skel 2	Skel 3	Skel 1	Myl 108	Henties	Myl 72	Myl 14	Langstr	Paaltjie	Agate
Co-ord	14.3	19.0	18.1	21.5	22.1	21.9	22.5	22.8	22.9	26.6
Actinoptychus splendens	2.7	2.1	0.5	2.0						
Anaulus australis			3.9	0.5						
Asterionella glacialis		0.4								
Biddulphia sp.										
Blue-Greens				0.5						
Ceratium furca										
Chaetoceros didymus										
Chaetoceros solitary									1.0	
Chaetoceros spores	4.9	14.2	27.5	6.5	22.6	26.9		16.3	17.5	37.0
Chaetoceros sp.										
Cocconeis sp.		0.8		2.5				5.0	1.0	14.0
Delphineis sp.	8.9	3.3	11.8	22.0	27.7	55.7	64.7	14.4	37.0	
Dunaliella sp.										
Eucampia sp.		7.5								
Flagellates		0.4	1.0	1.0					1.0	
Grammatophora angulosa										2.3
Grammatophora marina								2.5		
Guinardia flaccida		2.1								
Gyrodinium sp.										
Helgolandinium sp.					0.5		3.7	3.5		
Leptocylindrus danicus										
Licmophora sp.			1.0	0.5				10.4	0.5	
Melosira sp.	0.8		1.0							
Navicula tiny								2.0		
Navicula bent										
Navicula cigar			1.5	2.5						
Navicula football				1.0						
Navicula giant									3.0	
Navicula medium										
Navicula oblong						1.0			1.5	
Navicula oilspot						4.0	4.4	1.5	11.0	
Navicula pointy nose				1.0						
Navicula sand				1.0						
Navicula small										
Navicula small square										
Navicula snouted			2.5							
Navicula sp.		0.8								
Navicula square			2.0	0.5						
Navicula waisted										
Nitzschia closterium										
Nitzschia delicatissima			14.7		27.7	0.5				
Nitzschia longissima		1.2		0.5	2.1	0.0	2.9		3.5	
Nitzschia seriata	1.1							1.0	0.5	
Peridinium 36										
Peridinium brevipes										
Peridinium pallidum						1.5	2.9			
Peridinium small without feet			5.4							
Peridinium sp.	5.1	6.2	2.0		1.0			2.5	5.5	
Peridinium steinii				0.5						
Plagiogramma brockmanii		12.9		40.0			5.9			
Plagiogramma sp.	60.7		1.5		0.5	0.5			2.0	
Plagiogramma van heurckii			3.4							
Pleurosigma sp.				1.5	0.5					
Porosira glacia										
Prorocentrum micans	2.8								0.0	
Rhizosolenia sp.									0.5	
Schroderella scheroederi	7.2									9.3
Schroederella sp.		23.2								
Skeletonema costatum										
Stephanopyxis sp.					0.5				0.5	
Synedrosphaenia sp.								33.2		
Tetraselmis sp.			1.0							29.2
Thalassionema nitzschioides										

Thalassiosira 52		16.6								4.7
Thalassiosira decipiens										
Thalassiosira fallax										
Thalassiosira levanderi										
Thalassiosira polychorda										
Thalassiosira sp.	3.8		7.4	16.0	2.1	5.5	8.8	1.0	8.5	
Thalassiothrix										
Unknown	0.9	5.8	2.5			3.5		0.5		
Unknown bitten apple					0.5					
Unknown Dividing capsule									2.0	
Unknown Giant									2.5	
Unknown Grapes					8.2		5.9			
Unknown Hamburger										
Unknown Lemon			1.0						1.0	
Unknown Others	0.9	2.5	8.8					6.4		3.5
Unknown The Ring					6.2	1.0	0.7			

Species

Actinop
Anaulus
Asterio
Biddulp
Blue-Gr
Ceratiu
Chaetoc
Chaetoc
Chaetoc
Chaetoc
Coccone
Delphin
Dunalie
Eucampi
Flagell
Grammat
Grammat
Guinard
Gyrodin
Helgola
Leptocy
Licmoph
Melosir
Navicul
Navicul
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Nitzsch
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Peridin
Peridin
Peridin
Peridin
Peridin
Peridin
Plagiog
Plagiog
Plagiog
Pleuros
Porosir
Proroce
Rhizoso
Schrode
Schroed
Skeleto
Stephan
Synedro
Tetrase
Thalass
Thalass
Thalass
Thalass
Thalass
Thalass
Thalass
Thalass
Unknown
Unknown

Species Beach	Grosseb	Elizab B	Elizab B	Pt Noll	Pt Noll	Pt Noll	Pt Noll	Strandf	Elandsb	Yzerfon
Co-ord	26.7	26.9	26.9	29.3	29.3	29.3	29.3	30.6	32.3	33.3
Actinoptychus splendens			1.6							
Anaulus australis					7.0	1.1	3.0			3.0
Asterionella Glacialis		1.3								1.5
Biddulphia sp.		0.3								
Blue-Greens					2.5				1.0	
Ceratium furca										
Chaetoceros didymus										
Chaetoceros solitary										
Chaetoceros spores	78.6	15.2	14.8	37.6	42.3	31.3	28.3	11.5	3.5	5.9
Chaetoceros sp.										11.8
Cocconeis sp.	7.9		1.1		11.9	1.1	13.4	0.5	0.8	
Delphineis sp.	4.7	1.7	6.5	2.4	7.0	9.2	2.5	2.5	1.3	2.5
Dunaliella sp.							6.5			
Eucampia sp.										
Flagellates				2.4		9.2		0.5		
Grammatophora angulosa	0.9									
Grammatophora marina	2.3						0.5		0.8	
Guinardia flaccida										
Gyrodinium sp.							1.0			
Helgolandinium sp.										
Leptocylindrus danicus									1.0	2.0
Licmophora sp.	2.8	0.3	1.1		5.5		2.0	0.5		
Melosira sp.	0.5									1.0
Navicula tiny		2.0				2.2	2.5			
Navicula bent							1.5			
Navicula cigar				13.6	1.0					
Navicula football						1.1		0.5	0.8	3.0
Navicula giant										
Navicula medium	0.5							0.5	0.3	
Navicula oblong										
Navicula oilspot			1.1							
Navicula pointy nose										
Navicula sand									0.3	
Navicula small		3.6				1.1				
Navicula small square			2.7						83.1	
Navicula snouted		25.5	24.4							
Navicula sp.							1.0			
Navicula square			1.1	4.0						
Navicula waisted							0.5		0.3	
Nitzschia closterium			1.6						1.0	
Nitzschia delicatissima		0.7			0.5				0.3	
Nitzschia longissima									0.8	
Nitzschia seriata						1.1		1.0	0.3	10.8
Peridinium 36			1.6					2.0	0.3	
Peridinium brevipes			2.7							
Peridinium pallidum										
Peridinium small without feet		1.7					3.5			
Peridinium sp.										
Peridinium steinii										
Plagiogramma brockmanii			3.8							
Plagiogramma sp.							1.0			
Plagiogramma van heurckii										
Pleurosigma sp.										
Porosira glacia			1.1							
Prorocentrum micans										
Rhizosolenia sp.		1.3								
Schroderella scheroederi										
Schroederella sp.										
Skeletonema costatum								76.9	4.5	37.9
Stephanopyxis sp.		1.3								11.8
Synedrosphaenia sp.										
Tetraselmis sp.	0.5		1.6	36.0	15.4	37.3	30.4			
Thalassionema nitzschioides										1.0
Thalassiosira 52	0.5		4.9		3.5			2.0		4.4
Thalassiosira decipiens			2.7							
Thalassiosira fallax			19.5							
Thalassiosira levanderi			1.6							
Thalassiosira polychorda			1.1							
Thalassiosira sp.		43.7					1.5			
Thalassiothrix										
Unknown		0.3	1.6			2.2	1.0	0.5		
Unknown bitten apple										

Unknown Dividing capsule										
Unknown Giant										
Unknown Grapes										
Unknown Hamburger		0.3								
Unknown Lemon		0.7								
Unknown Others	0.9		1.6	4.0	3.5	3.2		1.0		3.4
Unknown The Ring										

Species	Beach Co-ord	Dwarsker 32.7	Pater 32.8	Melkbos 33.7
Actinoptychus splendens				
Aneulus australis				
Asterionella glacialis			3.9	
Biddulphia sp.				
Blue-Greens		0.6		
Ceratium furca			4.8	1.8
Chaetoceros didymus			31.4	
Chaetoceros solitary				
Chaetoceros spores		14.6	9.2	45.3
Chaetoceros sp.				2.9
Cocconeis sp.		0.6		1.8
Delphineis sp.		2.2	3.9	3.5
Dunaliella sp.				
Eucampia sp.				
Flagellates				1.8
Grammatophora angulosa				
Grammatophora marina				
Guinardia flaccida				
Gyrodinium sp.				
Helgolandinium sp.				
Leptocylindrus danicus		2.5	1.9	
Licmophora sp.				
Melosira sp.				1.2
Navicula tiny		73.9	5.8	4.7
Navicula bent				
Navicula cigar			4.3	
Navicula football				1.2
Navicula giant				
Navicula medium				
Navicula oblong				
Navicula oilspot			2.4	
Navicula pointy nose				
Navicula sand				
Navicula small			1.9	1.2
Navicula small square				
Navicula snouted				
Navicula sp.				
Navicula square				
Navicula waisted				
Nitzschia closterium				
Nitzschia delicatissima		0.6		
Nitzschia longissima		0.6	9.7	
Nitzschia seriata		0.6	5.8	2.4
Peridinium 36			1.4	
Peridinium brevipes				
Peridinium pallidum				
Peridinium small without feet				
Peridinium sp.				
Peridinium steinii				
Plagiogramma brockmanii				
Plagiogramma sp.				
Plagiogramma van heurckii				
Pleurosigma sp.				
Porosira glacia				
Prorocentrum micans				
Rhizosolenia sp.				
Schroderella scheroederi				
Schroederella sp.				
Skeletonema costatum			1.4	20.0
Stephanopyxis sp.				
Synedrosphaenia sp.				
Tetraselmis sp.				2.9
Thalassionema nitzschioides				
Thalassiosira 52			1.9	
Thalassiosira decipiens				
Thalassiosira fallax				
Thalassiosira levanderi				
Thalassiosira polychorda				
Thalassiosira sp.				
Thalassiothrix			1.4	
Unknown			2.4	
Unknown bitten apple				

Unknown Dividing capsule			
Unknown Giant			
Unknown Grapes			
Unknown Hamburger			
Unknown Lemon			
Unknown Others	3.7	6.3	9.4
Unknown The Ring			

SAND

Spec

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SAND

Species	Beach	Dwarsker	Strandf	Elandsb	Yzerfon	Pater	Myl 14	Myl 72	Skel 3	Skel 2	Skel 1
	Co-ord	32.7	30.6	32.3	33.3	32.8	22.5	21.9	19.0	14.3	18.1
Actinoptychus granii											
Actinoptychus splendens							2.6			8.3	
Ampiprora sp.											
Anaulus australis				1.0							
Asterionella glacialis		3.4				1.9			3.4		
Blue-Greens				1.0							
Chaetoceros spores		24.7	61.5	7.5	17.3	19.2	40.8	20.8	24.7	11.5	19.0
Chaetoceros sp.		40.4	28.8	10.0	23.6	48.1	40.8	13.0	40.4	19.1	14.3
Cocconeis sp.				2.0	2.7	5.8	2.6	3.9		3.8	
Delphineis sp.										4.5	
Dinophyte										3.2	
Dunaliella											
F2/#2							5.3	11.7			
Flagellates				11.4	4.5		2.6	2.6			14.3
Gonyaulax								5.2			
Grammatophora angulosa		2.2							2.2		
Grammatophora sp.											
Navicula bent											
Navicula bulb ended											
Navicula cigar											
Navicula distans		3.4			5.5	2.9		2.6	3.4	3.8	
Navicula football											
Navicula large											
Navicula long beaded											
Navicula medium											
Navicula oilspot											
Navicula pointy nose					4.5						
Navicula sand		16.9		60.2	7.3	2.9			16.9		
Navicula small				1.5							
Navicula small square				2.0	2.7	2.9					
Navicula snouted				1.0							
Navicula sp.											
Navicula waisted		4.5		1.0	22.7	9.6			4.5		
Nitzschia bilobata											
Nitzschia seriata					1.8						
Peridinium 35											
Peridinium 36											
Peridinium sp.					2.7						
Plagiogramma brockmanii										31.8	
Plagiogramma sp.								35.1			
Plagiogramma van heurckii										5.7	9.5
Tetraselmis sp.											
Thalassiosira 52									2.2	3.8	
Thalassiosira granii											
Thalassiosira sp.		2.2									
Unknown						3.8					
Unknown baby bottle											
Unknown beaded rectangle											
Unknown dividing capsule											
Unknown hamburger											
Unknown hot water bottle											
Unknown others		2.2	9.6	1.5	2.7	2.9	5.3	5.2	2.2	1.3	28.6
Unknown pointy											
Unknown spaceship with lips											
Unknown upturned cup											
Unknown W											

Species	Beach	Paaltjie	Myl 108	Henties	Langstr	Melkbos	Grosseb	Agate	Pt Noll	Elizab B
	Co-ord	22.9	21.5	22.1	22.8	33.7	26.7	26.6	29.3	26.9
Actinoptychus granii										0.7
Actinoptychus splendens										
Ampiprora sp.										2.9
Anaulus australis					12.8	2.0	66.7	19.3	34.5	15.0
Asterionella glacialis			0.5							
Blue-Greens					2.6			0.8		
Chaetoceros spores		27.7	86.0	24.3	16.7	16.0	1.4	6.7	10.2	5.7
Chaetoceros sp.		52.7	10.0	40.8	35.9	18.5	5.6	17.6	10.2	7.9
Cocconeis sp.				3.9	2.6	3.5	3.3	12.6	4.1	10.0
Delphineis sp.						1.0				
Dinophyte		1.1		1.9						
Dunaliella				3.9						
F2/#2				6.8	1.3			2.5		
Flagellates		6.9	2.0	9.7	1.3	1.0				8.6
Gonyaulax				1.0						
Grammatophora angulosa										
Grammatophora sp.								9.2	0.5	5.7
Navicula bent									3.0	
Navicula bulb ended						1.0				
Navicula cigar						1.0			4.1	
Navicula distans		5.9	0.5	1.9	7.7	8.0		5.0	5.1	7.9
Navicula football					1.3		17.8	0.8	0.5	10.0
Navicula large						1.0				
Navicula long beaded						2.0				
Navicula medium					2.6			0.8	1.5	2.9
Navicula oilspot				1.9						
Navicula pointy nose				1.0		4.5		0.8	0.5	1.4
Navicula sand		1.1			3.8	12.5		0.8	12.2	2.9
Navicula small										
Navicula small square					3.8	9.0		14.3	8.6	4.3
Navicula snouted						1.0				
Navicula sp.									0.5	
Navicula waisted					2.6	4.5		1.7	1.0	7.9
Nitzschia bilobata						1.0				
Nitzschia seriata										
Peridinium 35					1.3					
Peridinium 36				1.0						
Peridinium sp.				1.0		1.0				
Plagiogramma brockmanii								1.7		
Plagiogramma sp.										
Plagiogramma van heurckii		1.1					4.7	0.8		
Tetraselmis sp.			0.5							
Thalassiosira 52										
Thalassiosira granii				1.0						
Thalassiosira sp.					1.3					
Unknown										
Unknown baby bottle									0.5	
Unknown beaded rectangle									0.5	
Unknown dividing capsule								0.8		
Unknown hamburger								1.7		
Unknown hot water bottle						6.0				
Unknown others		2.1				5.5				4.3
Unknown pointy										2.1
Unknown spaceship with lips					1.3					
Unknown upturned cup								0.8		
Unknown W									2.5	

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