Diatoms: indicators of tidal influx in a hydraulically regulated estuary, Zandvlei, in the southern Cape.

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Abstract

Estuarine systems are characterised by relatively high levels of salinity due to its connection with the sea. Zandvlei has been victim to much manipulation for the sake of flood prevention, recreation and water level regulation. One of the largest impacts on the system is the rubble weir placed at the mouth of the outlet channel that was built to maintain water levels in the drier summer months. There is evidence that the salinity in the estuary is declining, as the weir inhibits sufficient tidal ingress. Resultant consequences include encouraging the growth of alien invasive weeds, the decline of indigenous aquatic fauna and flora, and a shift in ecosystem functioning. Plans to increase the circulation of seawater have already been proved to be necessary, but the process needs to be monitored. Diatoms are used regularly in Europe to monitor water quality in terms of eutrophication and pollution. This study attempts to describe the change in diatom composition after the mouth has been manually opened, in terms of the influencing factors, namely salinity and temperature. The species response was found to be a shift in species dominance rather than a species turnover. Key indicator species were distinguished by the response to salinity. Diatoms can also be informative of the stability of the Vlei and therefore act as a valuable tool for monitoring purposes.

Contents

Introduction

Zandvlei is a seasonal estuary situated on the northwest shores of False Bay, in the south western Cape. Seasonality refers to the estuary's seasonal connection with the sea. Zandvlei is cut off from the sea in the summer months when a sandbar forms, preventing tidal ingress. The estuary is small (surface area = 1 km^2) and shallow (1-2 metres deep), estimated to hold a volume of 1.33 x 106 m^3 of water. The level of water is being artificially maintained using a rubble weir situated close to the mouth outlet at the end of the outlet channel to prevent flooding and to maintain depths deep enough for water activities. The weir stands 0.8m above mean sea level (AMSL), raising the water level in the estuary to 0.83m AMSL in winter and 0.92m AMSL in summer (Quick and Harding, 1994).

Zandvlei is fed by three main tributaries: Keysers River, Westlake River and the Sand River, amongst other smaller seasonal streams, which collect water from a catchment of 92km^2. The Sand and Keysers River contribute the most to the volume of the estuary, as expected from the proportionally larger drainage drainage basins. Due to the Mediterranean climate, the seasonal streams flow in winter after rainfall, and stop flowing in drier summer months.

The vlei also remains well mixed. The combination of high wind velocities which run parallel the length of the estuary (north to north-western and south to south-easterly) and its shallow depth, keep the vlei well mixed for the most parts of the year (Thornton et al., 1995). Zandvlei also functions as an important fish nursery for False Bay. Marine fish such as white steenbras, flat-head mullet, leervis and Cape stumpnose are heavily dependent on estuaries during the juvenile stage (Quick and Harding, 1994).

There are a number of estuaries along the south-west coast, but what is of particular interest about Zandvlei, is that although it has been highly manipulated, it still functions as the only ecologically significant estuary (Heydorn and Grindley, 1982) in the False Bay area. In addition, Zandvlei remains a recreational venue and concerns to maintain the integrity of the vlei have been voiced.

Zandvlei managed to escape human interference until 1866, when in response to a long drought and an attempt to retain some of the water, the mouth of the vlei was closed. When the winter rains drained from the catchment areas, the reclaimed land was flooded. Since then, the vlei has been highly manipulated, changing its natural functioning as an estuary. In 1882, the railway encouraged the recreational use of the estuary. In 1947 the vlei was dredged to minimise the fluctuations in water levels and in 1961,was deepened to allow recreational boating. In 1969 the residential development of Marina da Gama on the eastern shores of the vlei began (Thornton et al., 1995). The marina is a man-made set of canals that are cut off from the vlei by a large island approximately 0.3km long. To make matters worse, a rubble weir was constructed near the mouth to control the water levels, decreasing the access of seawater to the vlei (Quick and Harding 1994). All these events have certainly had irreversible effects that have radically changed the functioning of the vlei. One of the most obvious outcomes is the change in salinity which inturn has resulted in a shift in ecosystem functioning. Sufficient seawater has not been allowed to enter and it has come to the attention of researchers that Zandvlei estuary is becoming fresher in nature. This is made evident by the proliferation of freshwater macrophytes such as *Myriophyllum aquaticum* (Azorin, 1988 cited in Thornton et al., 1995) and *Eichhornia crassipes* (Thornton et al., 1995 and Archibald, 1999). This may consequently produce unfavourable conditions that allow for the invasion of these alien freshwater weeds (as noted by Archibald, 1998). It has been suggested (by Quick and Harding, 1994), that opening the outlet channel should be considered as part of a management program to maximise seawater intrusion. They showed results of a large decrease in ambient salinity from 1978-1991 and then an increase in response to the manipulation of the sand bar at the mouth, which allowed tidal ingress into the seasonal estuary (lake). Associated with the drop in salinity, there appeared to be a large decrease in *Potamogeton* stands. These aquatic macrophytes from an important component in the functioning of the estuarine system (Davies et al., 1989). After the mouth was opened and salinity levels were some what restored, *Potamogeton* stands recovered.

Although Zandvlei doesn't seem to reflect any decline in quality in terms of water and aesthetics, there is evidence of eutrophication (Harding, 1994) and invasion of alien weeds (Archibald, 1998) which make recreational activities impossible and a possible health risk. The state of Zandvlei estuary was analysed by Heydorn (Ed., 1986) as being in poor condition (has been physically altered) but in a good enough state to be maintained under conservation standards in addition to allowing low intensity, strictly controlled development. Not only is it necessary to maintain the vlei for these reasons, but we also need to maintain the natural integrity and functional ecology essential to such complex systems for conservation purposes.

A number of management plans were suggested and adopted by the Cape Town City Council in 1990 (Harding, 1994). These included, dredging, deepening the main vlei, and improving the circulation of seawater by building a new weir. The progress of recovery needs to be monitored during and after such plans and programs are implemented. The Cape Town City Council is presently using chlorophyll a, phosphorus, nitrogen (amongst others) as indicators, as well as bacteriological monitoring. If the main task/plan were to increase the seawater circulation and therefore raise the salinity of the vlei, one would need to monitor how far up the estuary the seawater reached. Another good reason to increase salinity levels was provided by Archibald (unpublished, 1998). Her study of the freshwater macrophytes in the wetland on the north west end of the main vlei, suggested that improved seawater circulation (raised salinity levels) could retard the growth of some alien invasive weeds such as *Eichhornia* (water hyacinth) while maintaining the growth of the more tolerant indigenous species.

Estuarine systems are extremely complex water bodies with a large number of factors playing important roles in the function of the system. Estuaries are subject to large variations in salinity due to the combination of tidal ingress and floodwater from river catchments after heavy rainfall. To be able to survive in such an environment, organisms have acquired a tolerance for extreme conditions. Organisms that haven't are limited to areas of the estuary where variability is not as extreme, such as the mouth of the outlet where a relatively high salinity is maintained, or at the top of the estuary where the tributaries enter and where salinity remains relatively low.

Firstly we need to address the question of why we need bio-indicators in the first place when one can measure the physical and chemical parameters directly? Firstly, instrumentation may be costly and secondly, these parameters would need to be monitored continuously. Even if the parameters were measured continuously, events that impact key organisms in the community could be missed (Pan and Lowe, 1996). It doesn't seem logical to measure the biological quality of water using abiotic measurements. Bio-indicators contain direct information about their environment, therefore results attained using these would be more informative than the indirect method of just measuring the environmental factors such as pH, salinity and nutrients. Not only are they more informative, but the implications of the results are far more reliable than, say, a measure of nitrogen. Bio-indicators summarise all the environmental factors into one response that can easily be assessed. This is far more convenient than having to measure directly, each and every environmental factor.

Diatoms are ideal indicators for a number of reasons. Diatoms are protected by a hard silica shell. This physiological attribute is advantageous, as the cell is resilient to decay and is normally collected with no signs of damage. It is also the feature most commonly used for identification.

In contrast to fish or invertebrates, diatoms are not freely mobile. Organisms such as invertebrates and fish tend to be mobile enough to remain in favourable conditions at the top or bottom of the estuary or move when conditions become intolerable, therefore providing very little evidence of the effect of tides and salinity, except possibly by absence or presence. The path of planktonic diatoms is determined by the tides, therefore permitting one to track tidal ingress.

Aquatic macro-algae are slightly better indicators, as they are non-mobile. They can therefore store and preserve information about their direct environment over long periods of time. All algae are primary producers and therefore interact directly with the nutrients and chemicals in the water (Lowe and Pan, 1996). Information such as biomass, reproductive status and photosynthetic rate can be useful for determining the state of the water body. This can serve as an advantage when conservation issues addressing long term effects and management plans can be easily assessed using plant communities.

Diatoms also fit into this category, but tend to address short-term effects. Diatoms are also advantageous as monitors as they reproduce at relatively rapid rates; therefore diatoms would respond rapidly to any disturbance or change that occurred in water quality. Diatoms are also easier to sample and once key species have been determined, identification is relatively easy.

Diatoms have been used frequently, especially in Europe, as bio-monitors in rivers to assess water quality. Most of the literature focuses on their use in rivers and lakes, but the information implied by such studies is by no means limited and can be applied to estuarine systems. Dell' Uomo (1996) used an index method which requires previous knowledge and information of diatom species, when he studied the Chienti River, in Italy. The author referred to the EPI index, which integrates organic pollution, eutrophication and total mineralisation. The indices of the species together with their abundance can derive the state of the water body. Dell' Uomo tested the use of diatoms as monitors by correlating the index values to the main chemical properties of the water. The author found that the EPI values correlated significantly with the environmental factors therefore confirming 1) the valid use of diatoms as water monitors and 2) the validity of the index. The U.K is interested in implementing a diatom based monitoring program using the trophic diatom index (TDI) (Kelly et al., 1996). Sabater et al. (1996) studied the River Ter in Spain. They found that the species composition, before and after several sewage works were installed in the river, were similar but that the dominant taxa had changed. Using multivariate analysis, the trend of temporal changes indicated that there was an increase in abundance of taxa less tolerant to organic pollution. They also found the temporal changes correlated significantly with nitrate levels. The authors added that although community ecology can be informative, key indicators are more practical, as it is difficult to interpret changes in species composition of the whole community.

A problem associated with the research at Zandvlei is that there is very little historical evidence or data (especially diatom data) from which to work. There is no evidence pertaining to the initial state of Zandvlei, which make decisions on how to manage the estuary difficult. (A technique that could possibly give insight on this matter would be a paleolimnological study). Harding (1995) stated that maintenance of acceptable water quality is dependent on the stabilising effects of ambient salinity. What is meant by this statement is that to prevent the estuary from becoming 'too' eutrophic and dominated by phytoplankton or too saline and dominated by macrophytes, such as *Potamogeton pectinatus*, one needs to maintain a level of salinity that would discourage either to happen. But what salinity is accepted as satisfactory and what gradient do we expect along the estuary from the tributary inlets to the estuary outlet?

In consideration of the above, the aim of this project is to introduce micro-algae and in particular, diatoms, as possible water monitors of seawater circulation. It would be useful to pinpoint some key organisms that would describe the state of the vlei as well as provide information on the impact of opening the mouth thereby aiding long-term management plans. The objective will be achieved by identifying diatom communities and the relative abundance of the species, and recording changes in the temperature and salinity, before and after the mouth is opened. Therefore as a preliminary study (on which further investigation and research may develop) I would like to determine the diatom composition and the change in composition after an influx of seawater. This would point out key indicators of water quality in terms of salinity, which can be used to aid long-term water management.

Methods

Sampling

The sampling was done along five sites located by previous studies (Harding 1994). Sites 1-5 (figure 1) were placed along the length of the estuary starting with one at the fresh-water end where the tributaries enter and extending down to five at the mouth where the weir is located. To test the effect of the tidal ingress sampling was performed once before the mouth was opened (30 April) and once after it had been opened a day after a spring tide had occurred (15 June). The sample of all the sites before the mouth was opened therefore formed the first set of samples and after the mouth was opened a second set. In the first set of samples, site 5 (at the mouth) was too shallow (approximately 0.5 m deep) to sample both a top and a bottom layer (no stratification and would be relatively homogenous), and so this site was recorded as only having a top layer.

Both the top and bottom layer was sampled to observe differences in salinity, temperature and species composition. The top layer was sampled by scooping water into a 10L bucket and filling a 2-litre bottle. Bottom samples were taken just above sediments using a 2m x 40mm PVC pipe, simply using a hand as a valve at the end of the pipe.

The need to sample both layers can be explained by the movement of tidal water into an estuary. The tide containing colder, denser water pushes in underneath the warmer, less dense estuarine water (Dyer, 1997). The tide also enters in a wedge (Figure 1.) with the foremost (fastest) tip of the ingress in the middle of the estuary where there is less surface friction (Dyer, 1997), hence all the sites are positioned in the centre of the vlei.

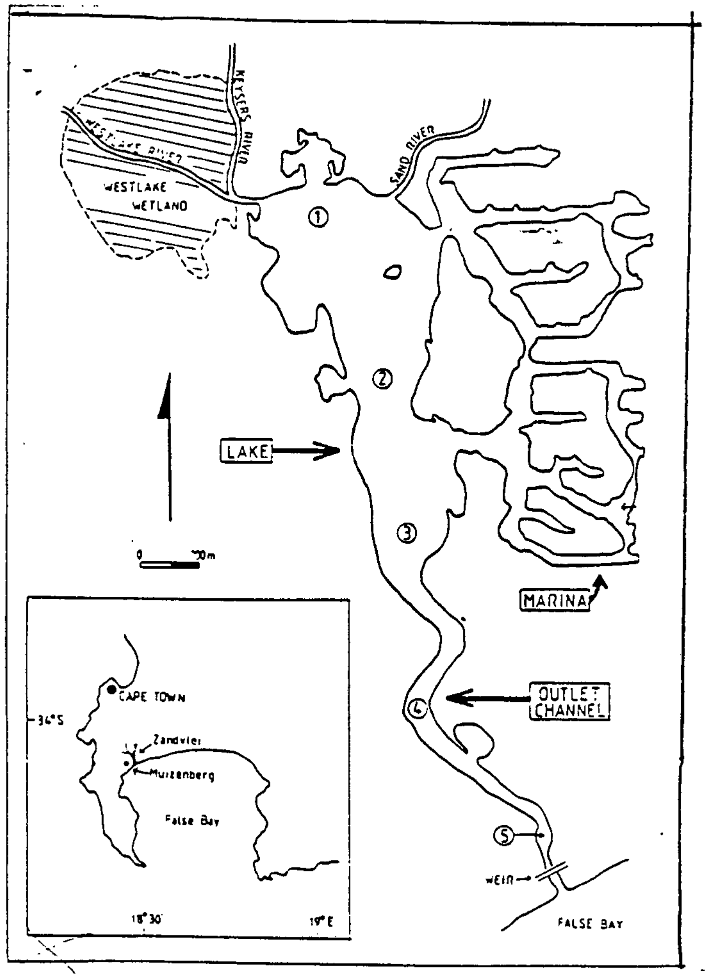

Figure 1. Map of Zandvlei estuary, its tributaries, main lake and outlet channel as used by Harding (1994). It also illustrates the location of the sites. 1-3 located in the main lake and 4 and 5 situated in the outlet channel.

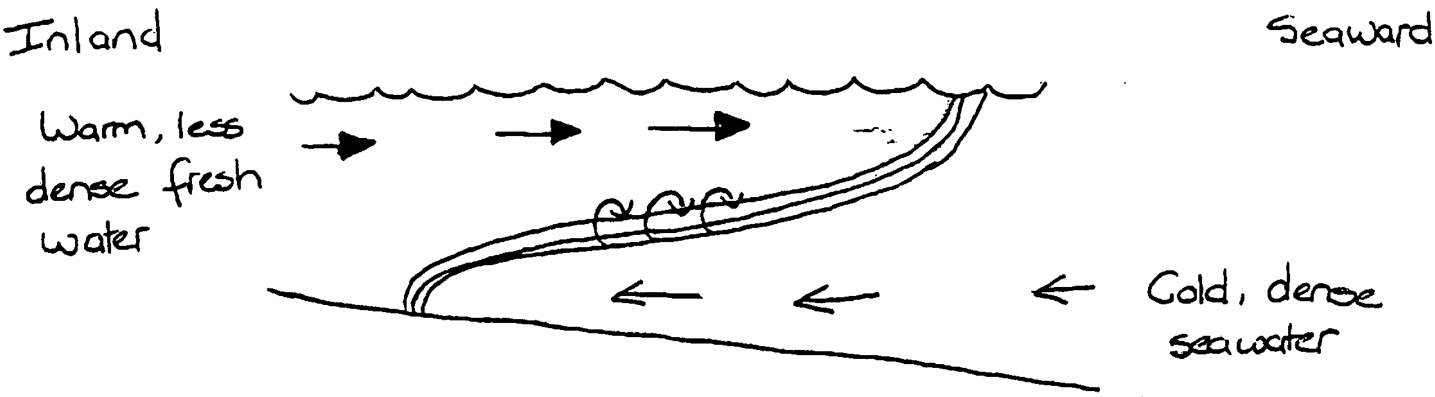

Figure 2. Tidal ingress before extensive mixing. The top layer consists of fresh water flowing seawards and the bottom layer consists of seawater as a wedge forced up the estuary by a tide.

Each sample consisted of 2 litres of collected water. Replicate samples (of two litres each) were taken at each site from both the lower and upper level, which means that 20 samples were taken before the mouth was opened and 20 samples taken afterward. The temperature and salinity of the sample was measured and recorded before its was placed into 2l bottles using a hard head thermometer and a refractometer respectively. Once all the sites were sampled, 20ml of Lugol's solution (mixed according to proportions recommended by Hötzel and Croome, 1998) was added to kill the diatoms and stain the chloroplast. This was done as soon as possible because the diatoms could keep multiplying even after bottling and zooplankton can consume large numbers of diatoms, therefore not reflecting an accurate representation of the actual abundance. The staining of the chloroplast serves to help identify the diatom, as this can sometimes be an important distinguishing feature. Lugol's solution also acts as preservative and the samples can be kept for years. This can be advantageous when one wants to compare present data with those collected previously.

To concentrate the diatoms, I used the gravity method as explained by Hotzel and Croone (1998). After leaving the samples for longer than the required time, 2.3 days for average plankton and 4.6 days for centric diatoms, so that the diatoms could settle to bottom of the bottles. The top 90% of the sample was siphoned off, leaving 20ml. The remaining fluid was well mixed and transferred into 20ml glass bottles for observation and preservation.

Identification

The samples were subsampled by placing a few drops (after rigorously shaking to mix the sample well) on to a slide. The diatoms were identified and relative abundance was recorded. This was achieved by observing the subsample on both 40x and 100xoil immersion magnification, to avoid a large size bias. There will obviously be a size bias, as only those diatoms that can be seen and identified at these magnifications were recorded, and the data by no means is a representative of the whole diatom community. For the purposes of singling out specific taxa, which can easily be observed by the untrained eye with a minimal expense of equipment, larger diatoms would be preferable. The taxa that are identified as possible indicators would need to provide a convincing amount of environmental information and would need to be easily identifiable especially when implementing a management program. And so possible biases towards those diatoms that may be eye catching in shape and texture may be useful and would not undermine the results.

Diatoms are relatively easy to identify according to the ornamentation. Numerous identification keys are available (Lund and Lund, 1995, Davis, 1955, Shillinglaw, 1980 and Truter, 1987) and I attempted to identify the specimens to family where possible. The only problem associated with identifying the diatoms was the confusion in the literature. New names have been assigned to taxa and families and therefore nomenclature seems to contrast between different authors. Due to my inexperience in the field of taxonomy and identification of diatoms, some of the diatoms may possibly be incorrectly identified, but this should not detract from any significant ecological finding associated with the diatom itself. For all intents and purposes, I am looking for indictor species which can, without much effort, be recorded and hold some information of the state of the estuary in terms of the proportion of seawater present, and to a degree, whether the level of seawater is of a satisfactory standard.

The whole slide was observed by running the lens systematically up and down the slide in columns. Approximately 90% of the whole slide were observed in this manner. Due to the intense nature of the observation, combined with time constraints, unfortunately only a single subsample of each sample was taken. Diagrams of diatoms that reflect a trend, either as an increase or decrease in relation to site location and salinity, were drawn in as much detail as possible (refer to appendix). Nineteen taxa were recorded. Having identified the taxa, relative abundance was measured using five categories:

Table 1. Summary of the categories and the corresponding abundance values.

Category	**Abundance**	**Relative percentage**
1	Extremely rare	0-4%
2	Rare	5-19%
3	Occasional	20-49%
4	Common	50-69%
5	Extremely common	70-90%

Table 2. Data matrix prepared for CCA. Tidal ingress is coded as (0) before and (1) after effect. The layers are coded as (0) being the top and (1) being the bottom. Temperature is measured in Degrees Celcius, salinity in parts per thousand. All samples were coded as (1) when sampled in the corresponding site. Sample codes: a) represents the first sample set, b) the second data set. The letter 's' refers to site and the number following refers the number of the site. 't' represent samples taken from the top layer and 'b' from the bottom layer.

	Tidal Ingress	Top/bottom layer	Tempera-ture (°C)	Salinity (‰)	Site 1	Site 2	Site 3	Site 4	Site 5
as1t	0	0	22	0.75	1	0	0	0	
as1b	0	1	21	2	1	0	0	0	
as2t	0	0	21.5	1.25	0	1	0	0	
as2b	0	1	20.8	1.25	0	1	0	0	
as3t	0	0	20.5	2	0	0	1	0	
as3b	0	1	20.4	2	0	0	1	0	
as4t	0	0	21	2.5	0	0	0	1	
as4b	0	1	20.4	2	0	0	0	1	
as5t	0	0	22.1	4.75	0	0	0	0	
bs1t	1	0	16.6	5.75	1	0	0	0	
bs1b	1	1	15.9	7.25	1	0	0	0	
bs2t	1	0	15.8	5.5	0	1	0	0	
bs2b	1	1	15.5	11	0	1	0	0	
bs3t	1	0	16	6.5	0	0	1	0	
bs3b	1	1	15.9	15.5	0	0	1	0	
bs4t	1	0	15.8	6.25	0	0	0	1	
bs4b	1	1	15.9	20.25	0	0	0	1	
bs5t	1	0	16.5	5.25	0	0	0	0	
bs5b	1	1	16	8.75	0	0	0	0	

Table 3. Species abundance coded according to categories specified in table 1

	as1t	as1b	as2t	as2b	as3t	as3b	as4t	as4b	as5t	bs1t	bs1b	bs2t	bs2b	bs3t	bs3b	bs4t	bs4b	bs5t	bs5b
Navicula1	1	0	0	2	0	1	0	0	0	3	1	0	0	0	0	0	0	0	0
Diploneis	4	3	4	4	3	4	1	2	0	3	3	3	2	3	4	1	1	1	1
Cyclotella	4	4	4	4	3	4	4	4	0	4	4	4	5	3	3	2	1	2	1
Plantoniella	3	1	3	0	2	0	1	2	0	4	4	3	5	4	2	4	0	3	3
Cymbella	0	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0
Nitzschia 1	0	0	0	0	0	0	0	1	2	0	0	0	0	0	5	1	5	3	2
Centronella	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Denticula	2	1	0	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0
Nitzschia 2	1	0	2	1	1	0	0	0	0	1	0	0	1	0	0	0	0	0	0
Navicula 3	0	0	0	1	1	2	0	0	0	1	0	1	0	1	0	0	0	2	0
Amphiphrora	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Navicula 2	0	0	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Anaulus	1	0	2	2	1	2	2	4	0	5	5	5	5	5	5	5	5	5	5
Amphora	0	0	1	0	1	3	0	3	0	2	0	2	1	0	2	0	2	1	1
Spike	0	0	0	0	0	0	0	0	0	2	2	4	3	2	2	4	0	5	5
Achnanthes	2	0	2	1	1	2	1	0	0	0	1	0	0	0	0	0	0	0	0
NOID	0	0	0	0	0	1	1	2	0	0	0	0	0	0	0	0	0	0	0
FT	0	0	0	0	0	0	0	0	0	3	1	1	0	0	0	0	0	0	0
BGT	0	0	0	0	0	0	0	0	0	0	0	0	4	0	3	0	1	0	0

Analysis

Canonical components analysis using CANOCO vs. 4.02(ter Braak and Smilauer, 1997) was carried out. CCA has been used by ecologists to attempt to relate the environment to the existing species composition and their distribution. CCA achieves this by combining ordination and multiple regression. The analysis assumes that species respond to environmental parameters in a unimodal fashion (Lowe and Pan, 1996). The program does not however assume species composition, and change in species, to be directly consequential to the environmental factors, nor does it assume that the results are due to a response to these factors. It simply demonstrates a correlation and may imply a cause and effect mechanism. The axes are the products of reduced dimensionality representing a concise summary of the environmental variation. The length of each axis describes how strongly the environmental factor is correlated to the change in species community. The points plotted on the graph represent the diatom species and sites. Their positions reflect with which factor it is most strongly correlated.

The data was imported into the CANOCO from Excel using WcanoImp 1.0, which is part of the CANOCO for Windows package. The Windows package was used as it is much user-friendlier than the DOS program.

The environmental data included temperature and salinity and other factors including the layer of the sample (top or bottom layer), the set the sample can from (before or after the mouth was opened) and the site along the estuary (s1, s2, s3, s4 or s5). Each of these factors was coded for and the resultant matrix was (Table 2) run through the program.

The species data was transformed from a coded matrix into one representing the relative percentages (Table 3). All the above data was entered into the analysis

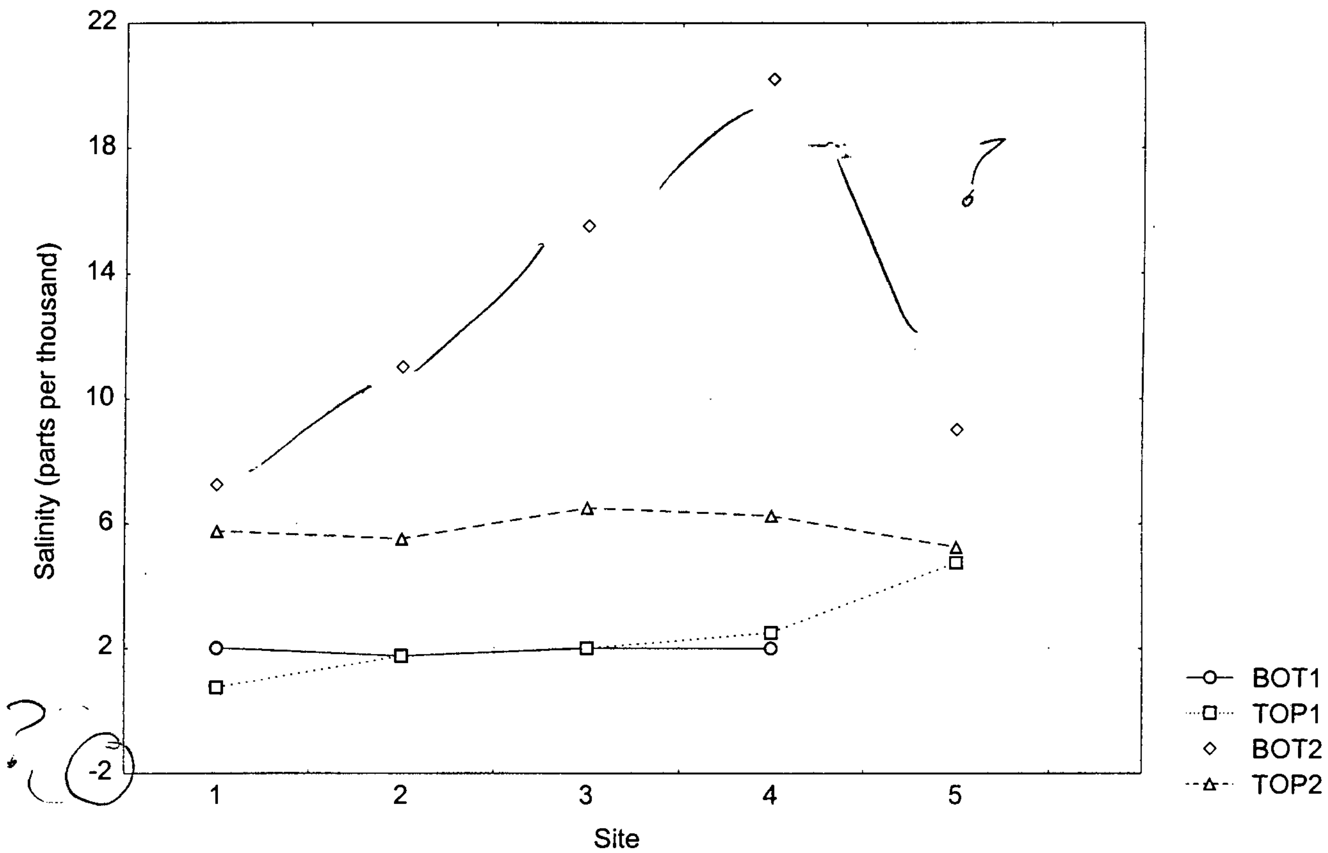

Figure 3. Salinity at the sites before (Bot and Top1) and after (2) tidal ingress

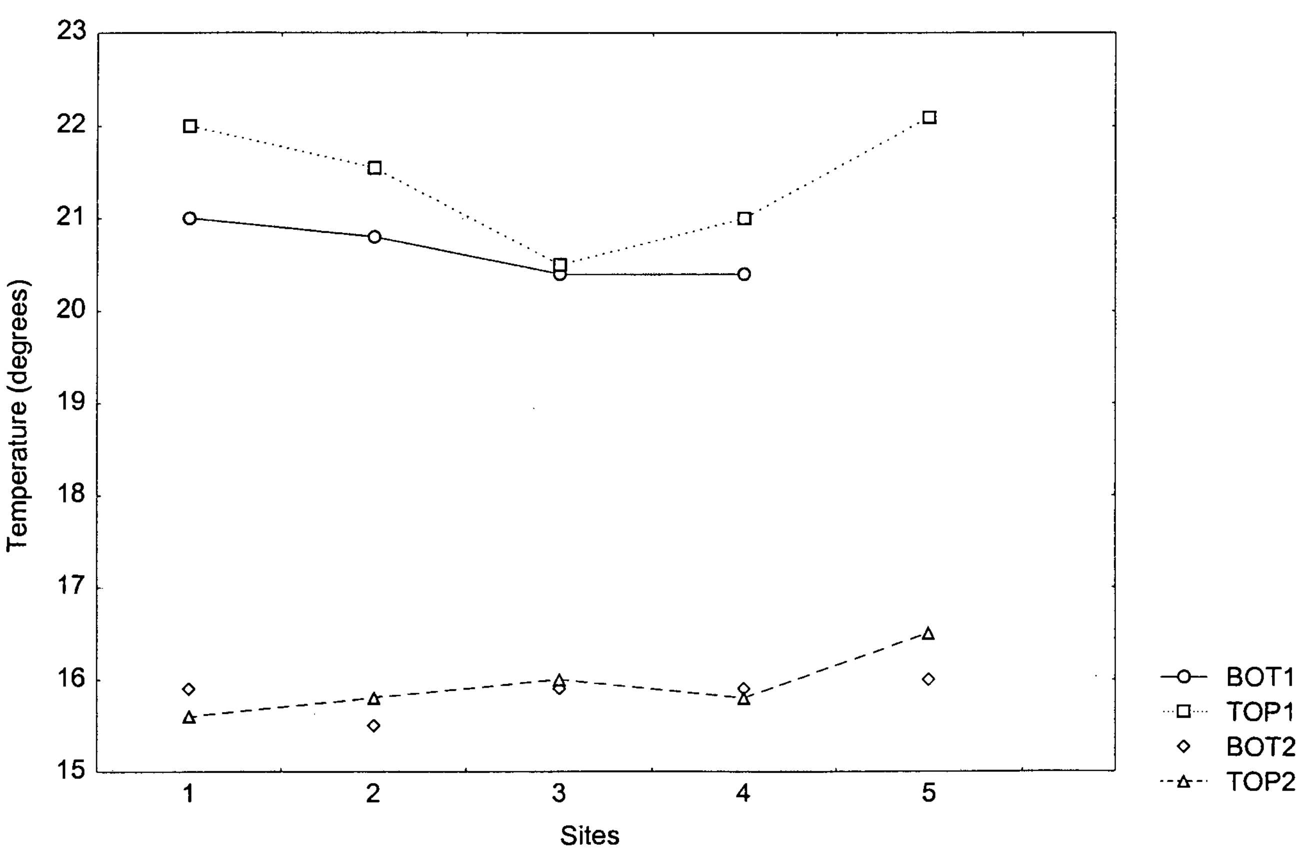

Figure 4. Temperature readings before and after opening the mouth

Graphs of temperature and salinity of both the bottom and top layer, before and after the mouth was opened were drawn to distinguish any significant differences between these variables. These were simply produced in Excel 97.

Results

Salinity (above and below, before and after)

The graph of salinity (figure 3) of each site shows that before the mouth opened, the salinity was relatively homogenous with low values of 0.5-2 ‰, rising slightly at site 5 to 4‰, which is expected to due to its close proximity to the sea.

After the mouth was opened and a spring tide had occurred, salinity levels increased to 6‰ in the top layer and up to 20‰ in the bottom layer. Typically the top layer would have a lower salinity as it contains fresher water. The salinity also remained relatively constant within the top layer. The salinity in the bottom layer is dramatically higher (which corresponds to the typical ingress of tides as described earlier. The salinity drops at site 5 where the water was very shallow (less than 0.5m deep). This can be explained by the heavy rainfall that was experienced a week prior to sampling. The top layer consists of fresh water delivered by the tributaries, flowing seaward. The low salinity recorded at site 5 is characteristic of top layer water flow.

Temperature (above and below, before and after)

The temperature graph (figure 4) also indicates a very significant change after the mouth was opened. The water is warmer (20 – 22°C) before the tidal ingress and drops to a low of 15 –

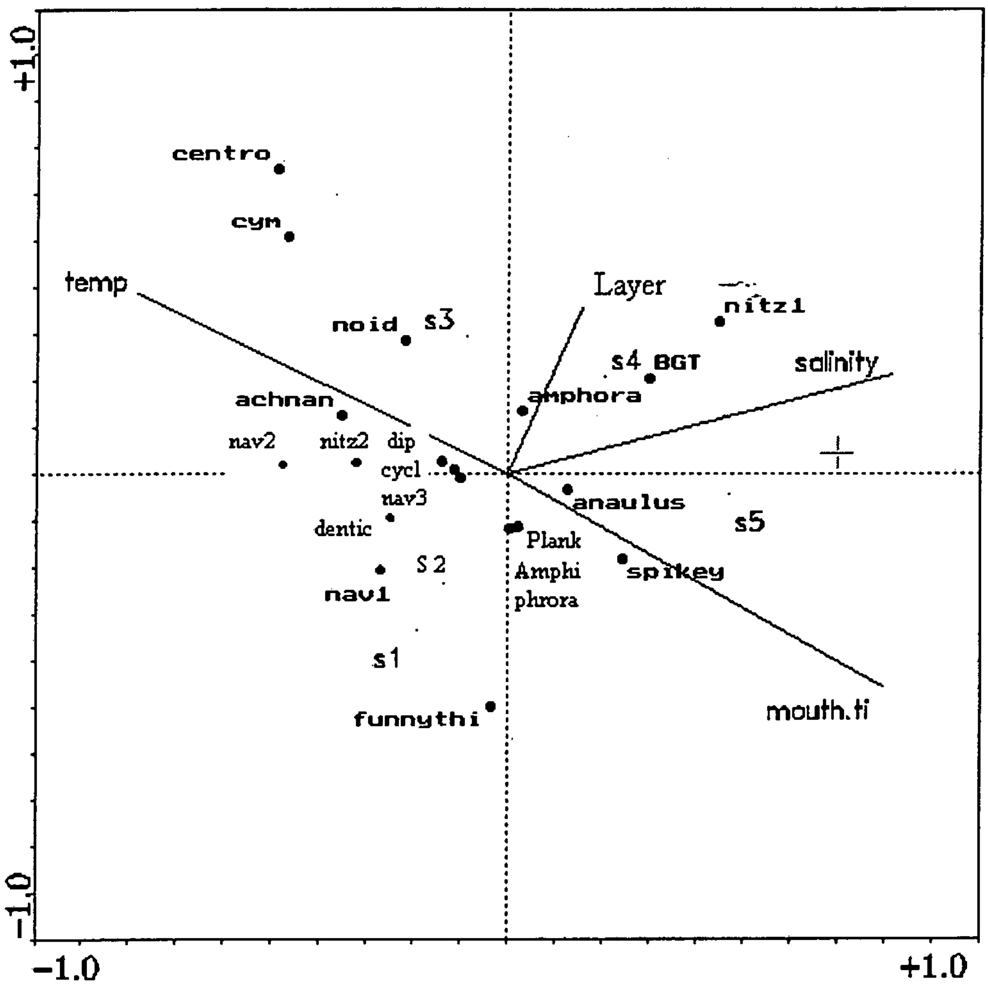

Figure 4. CCA diagram representing the environmental factors as axes. the smaller points represent sites and the larger ; indicate the species. Temp represents the factor temperature. Similarly, Layer indicates the layer inwhich sampling took Mouth. ti represents the effect after the mouth had been opened and a spring tide had occurred.

17°C. In contrast to salinity, temperature shows higher homogeneity at low temperatures after the tidal ingress. The temperature before the mouth was opened reflected slight stratification

Canonical component analysis

The CANOCO output (figure 5) showed that temperature and salinity were by far the two factors most strongly correlated to the change in species composition. Therefore the species most correlated with either of the environmental factors would be indicative of the state of either factor. The species known as 'spike', is correlated with the tidal ingress achieved by opening the mouth. *Amphora* is correlated with either being found in the top/bottom layer. BGT and *Nitzschia*1 are correlated with salinity and *Achnanthes*, *Navicula* 2 and *Nitzschia* 2 are strongly associated with temperature.

Generalist species are those species that were not effected (in terms of abundance) to any extent by the factors presented. The species that fall into this category are *Centronella*, *Cymbella*, '*funnythingy*', *Navicula* 1 and *Denticula*.

Species distribution

It is evident from the bar graphs presented by figure 6a,b and c, that there is no significant turnover in species composition, but rather a change in species dominance, from those species which perform better in lower salinity, to those that can tolerate higher levels. This indicates that salinity does not necessarily decrease or increase the species diversity. The low species diversity at site 5 (figure 6) however does imply that salinity levels close to that of seawater are not easily tolerated.

Temperature also plays an important role in the distribution of taxa. The change in species composition in highly correlated to the change in temperature. The ability of a diatom to

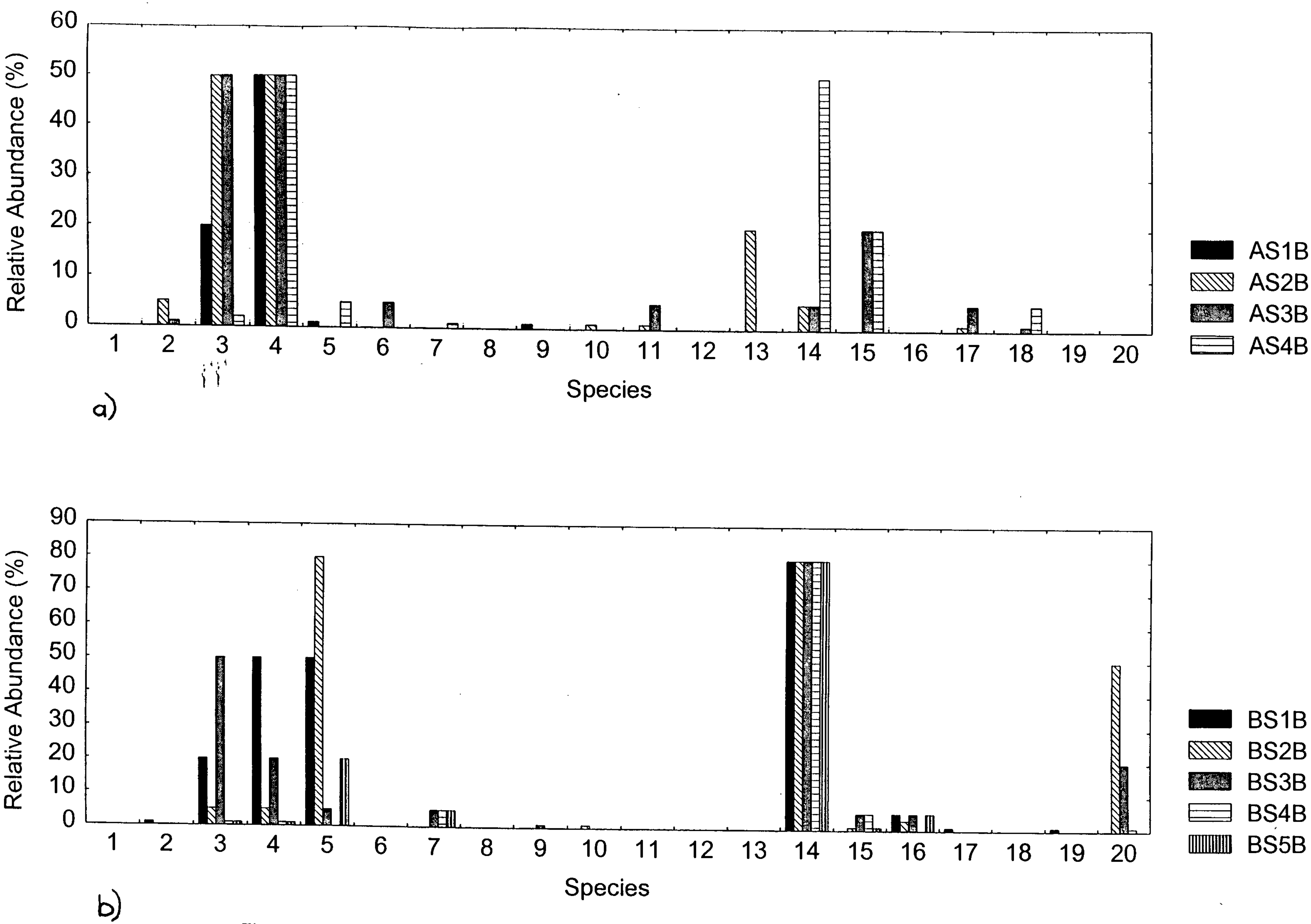

Figure 6. Represents the species abundance in the bottom layer at each site. a) Shows the abundance value of each species before the mouth was opened and b) shows the change in species composition af[redacted]e mo[redacted]ad b[redacted]pene[redacted] a sp[redacted]tide had occurred. The series-species list in the appendix can be consulted.

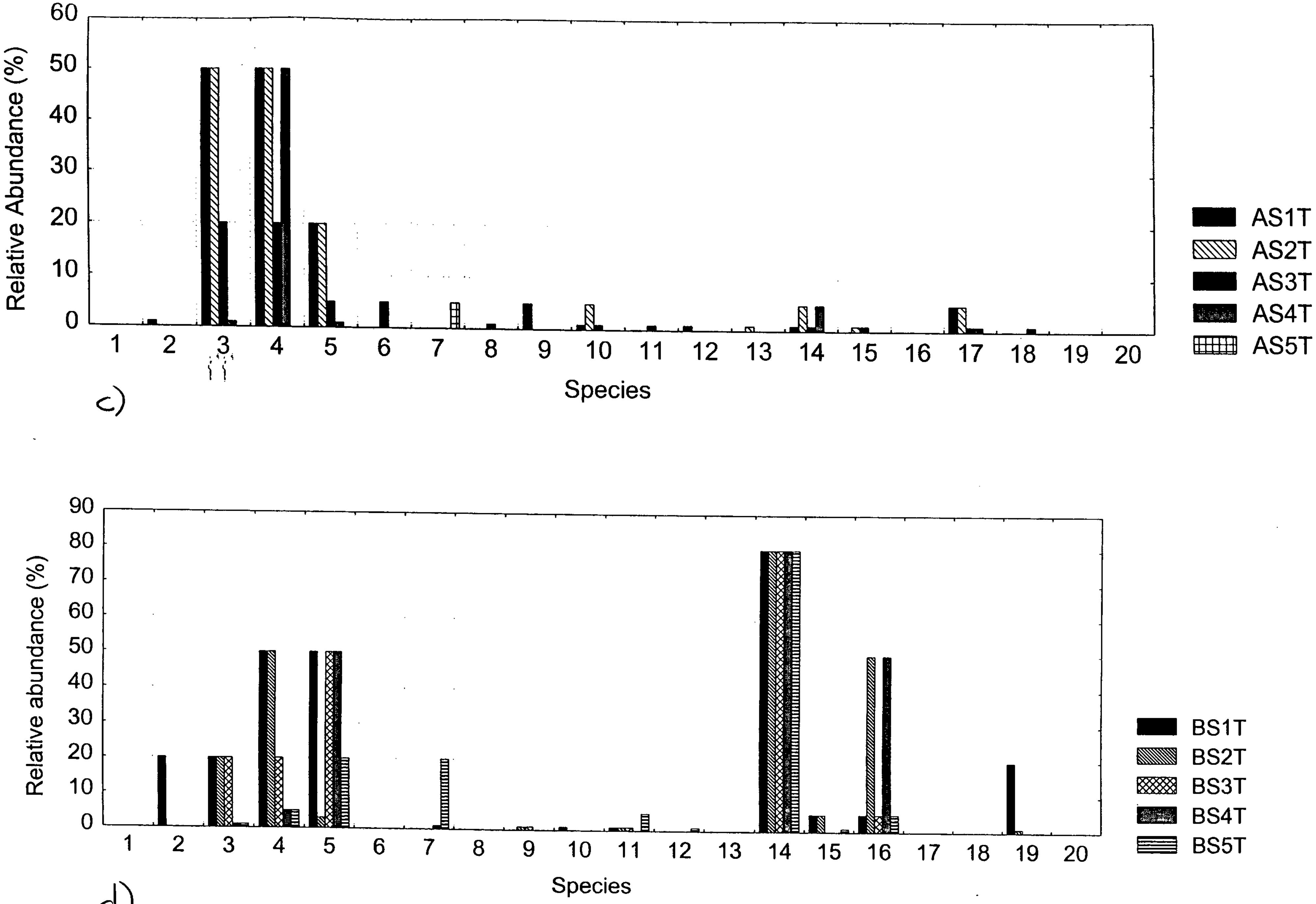

Figure 6. Represents the species abundance in the top layer at each site. c) Shows the abundance value of each species before the mouth was opened and d) shows the change in species composition after the mouth had been opened and a spring tide had occurred. The series species list in the appendix can be consulted.

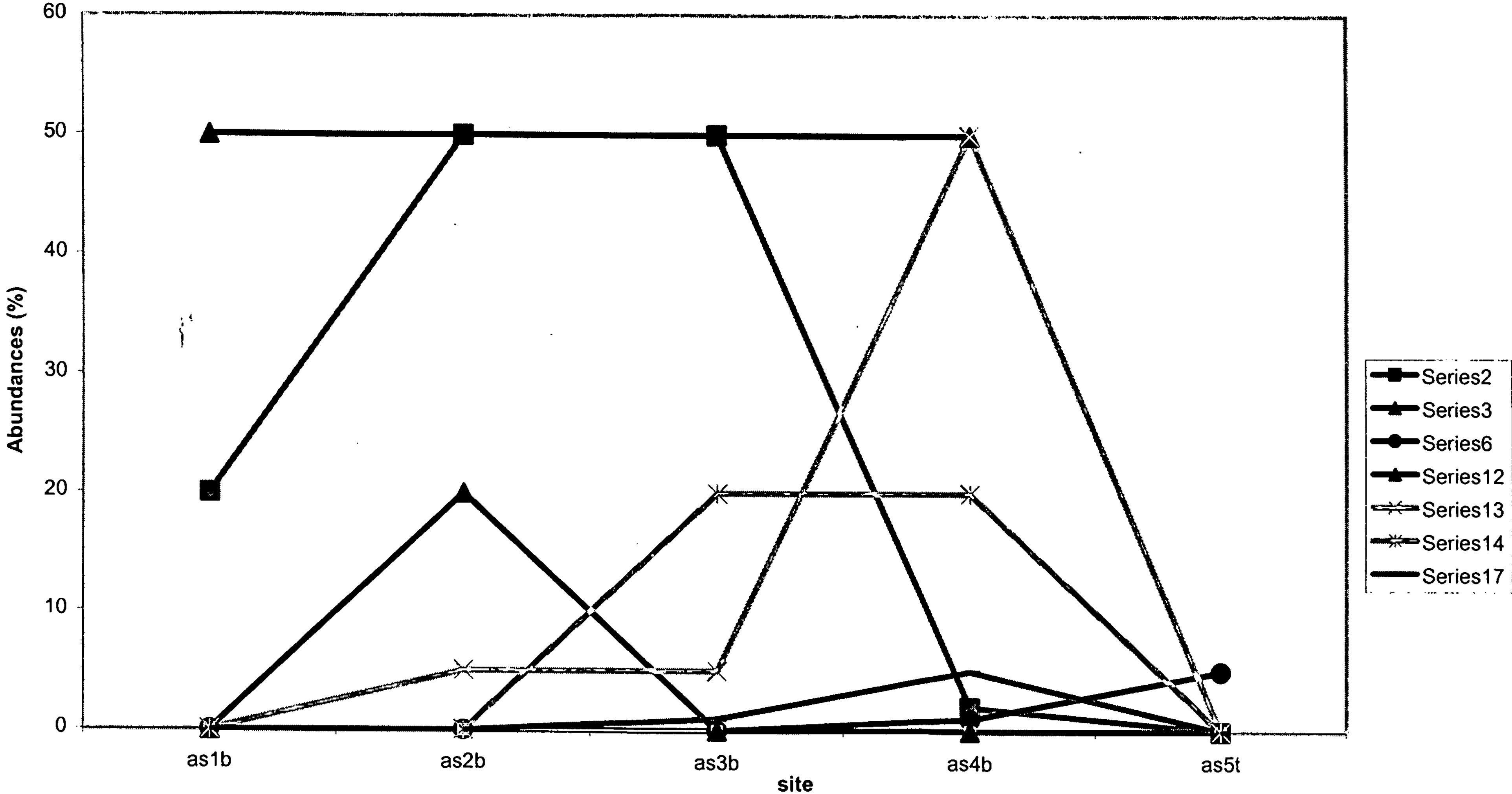

Figure 7a. Species abundance recorded in the bottom layer samples. Series 2 refers to the species Diploneis. Similarly series 3 refers to Cyclotella, 6 to Nitzschia1, 12 to Navicula2, 13 to Anaulus, 14 to Amphora and 17 to 'Spike'

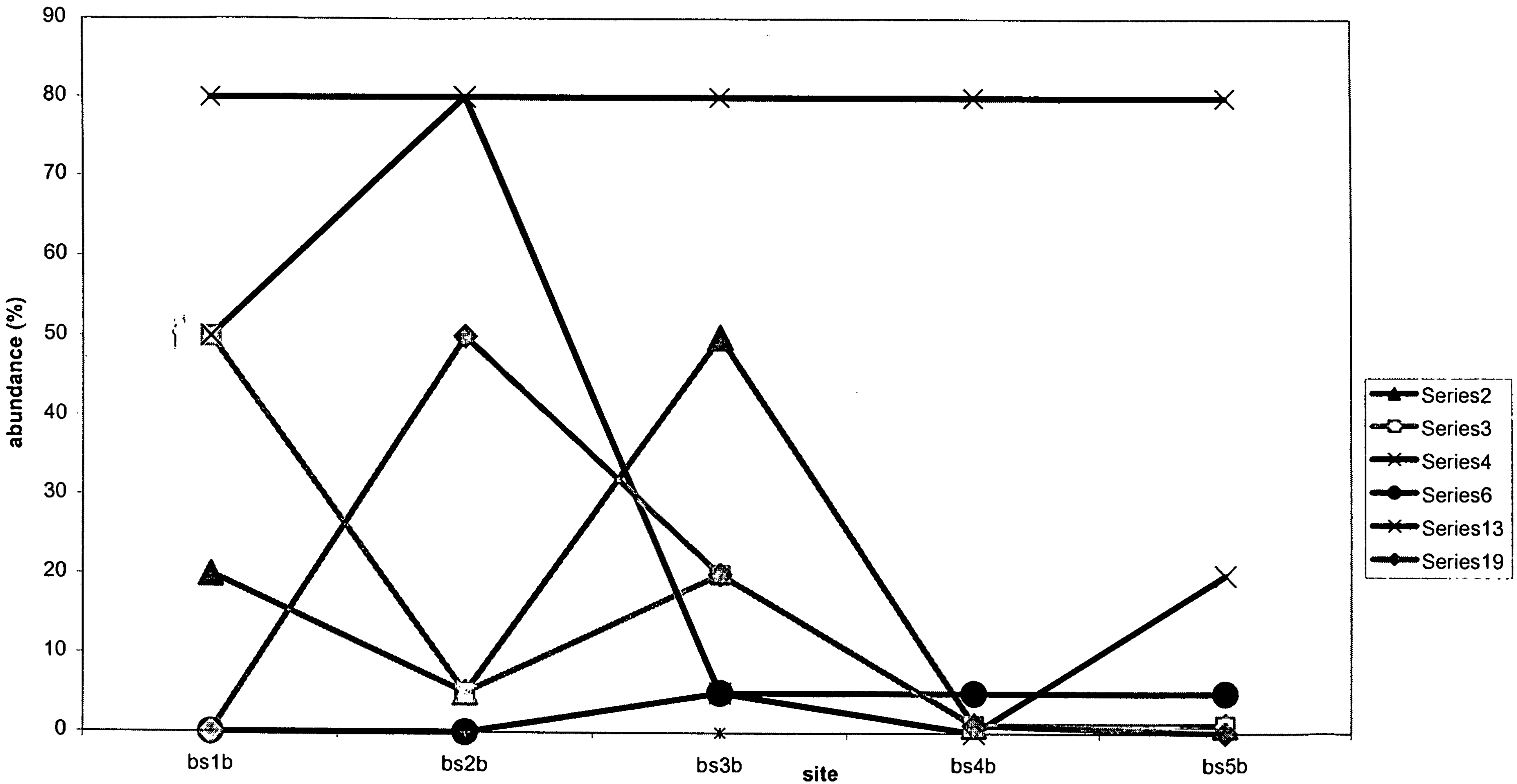

Figure 7b. Species abundance recorded in the bottom layers. Series 2 refers to Diploneis, 3 to Cyclotella, 4 to Planktoniella, 6 to Nitzschia1, 13 to Anaulus and 19 to BGT.

perform better in a lower temperature and therefore dominate, explains the change in dominance in species composition of the tidal intrusion.

Figure 7a) and b) emphasise the species that have undergone a relatively large change in abundance, firstly in association with the site at which they occur, and secondly the change in salinity and temperature. The graphs were drawn using the data from the bottom layer only, as this is where the tidal water would first have an impact due to the nature of ingress of seawater. The result indicates a decrease in most of the taxa, but *Nitzschia* 1 and *NOID* seem to respond favourably to the increase in salinity. Therefore a presence of these taxa could indicate a tidal influence. *Anaulus* is also present in high levels after the mouth has been opened.

Discussion

Temperature and salinity survival effects on diatoms in terms of rate of metabolism and osmoregulation. It was discovered that numerous species could occur in all conditions such as *Planktonella* and *Cyclotella*, and others were effected strongly by environmental factors, such as *Spike* and *Nitzschia* 1.

Research shows that salinity levels need to be maintained, but to what level and when? And does salinity reflect the health of the estuary as a whole?

To begin with, information concerning how much seawater is entering the estuary and how far up it is reaching should be one of the factors considered for long term management plans as pointed out by Harding (1994). This study would also give insight to an even further rise in salinity and therefore indicate the level of seawater circulation.

Zandvlei has remained fairly undisturbed for sometime. We would then assume that the present diatom composition (and change in composition), is a response to a set of stable processes which means that should no disturbance, such as dredging, occur, the cyclic pattern of species change in response to tidal ingress would be predictable. Should rehabilitation programs, such as those discussed previously by Harding (1994), be implemented, using the information available on 'stable environment' diatom species composition, it would be relatively easy to monitor the progress of the vlei back its 'stable state'.

Conclusion

By considering the aspects of residential development, recreation and catchment eutrophication as well as the parameters set out by maintaining the estuarine ecosystem, a strategy to control and manage the area becomes feasible.

It must be noted that this study is by no means complete and should be seen as a preliminary study with the potential of further elaboration. The study does however pointed out some key processes that alter the species composition of diatoms. With these in mind one can extrapolate that a documented species response can be a powerful predictive tool. This study was carried out before and after the mouth was opened, which coincided with the rainfall season. The effects of tidal ingress that have been noted inn this study are short-lived as water draining from the drainage basins flush out the system. I would therefore suggest that to prolong tidal effects the sand bar at the mouth should be manually opened in the drier summer months.

Further studies are required to develop more conclusive arguments and strategies, but it is obvious that diatoms are useful and informative as water monitors.

Suggestions for further research

1. The use of indicator values of diatoms should be considered. The indicator value of a species is the value of the environmental variable preferred by that species. The value for all the species present is averaged to estimate the value of the environmental variable. The resultant value is weighted by the species abundance, with absent species having zero weight (ter Braak and Barendregt, 1986). Species response curves are also important in the re-weighting process (as discussed by terBraak and Barendregt, 1986). The reasoning behind the method is that plant species need particular conditions in which to grow and regenerate, and therefore one should be able to infer the environmental conditions based on what species are found. Prior knowledge of the species in terms of the pH, nutrient level and in this case salinity is required before such inferences can be made. Should the Council consider this approach, the diatom species found in Zandvlei would need to bioassayed, to determine their indicator values. This would serve as a powerful tool that can be used to infer the degree of circulation of seawater.
2. The second approach that would be informative for monitoring purposes is the Index approach. A number of indices already exist eg, Van Dam index and Trophic Diatom index (as used by the U.K.). The approach also requires prior knowledge of the species, but it works differently in that each index is calculated according to the parameters it is testing For example, the EPI (eutrophication/pollution index) consider factors such as mineralisation, pollution and of course eutrophication. The index value is calculated using

index values of diatom species (already listed) which reflects species sensitivity to disturbance factors. The abundance of each species is also incorporated into the calculation.

Although these indices exist, when applied, they do not always correlate with the actual quality of water and therefore invalid. Should this occur, an index unique to Zandvlei would need to be determined in terms of factors such as salinity, temperature and eutrophication.

Acknowledgements

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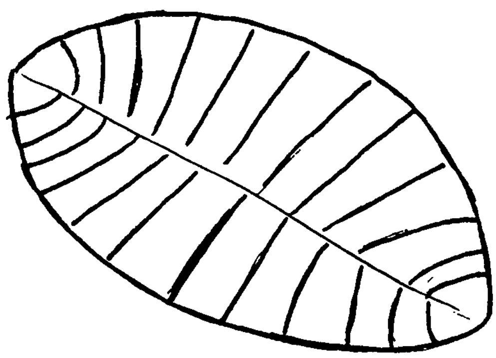
Appendix 1.

Rough drawings of diatom species. This is not a representation of all the species, but of the few that were obvious and identifiable under 100x magnification. Not all the species drawn were used in the analysis, as their abundance levels were low or non-existent.

Navicula 1 (Series 1)

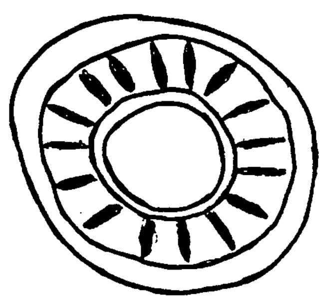
11,25 μm

Diploneis (Series 2)



50 μm

Cyclotella (Series 3)



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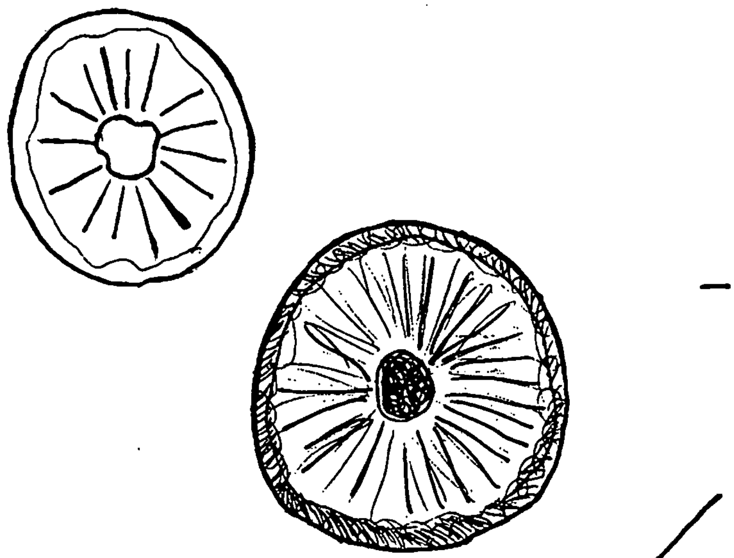
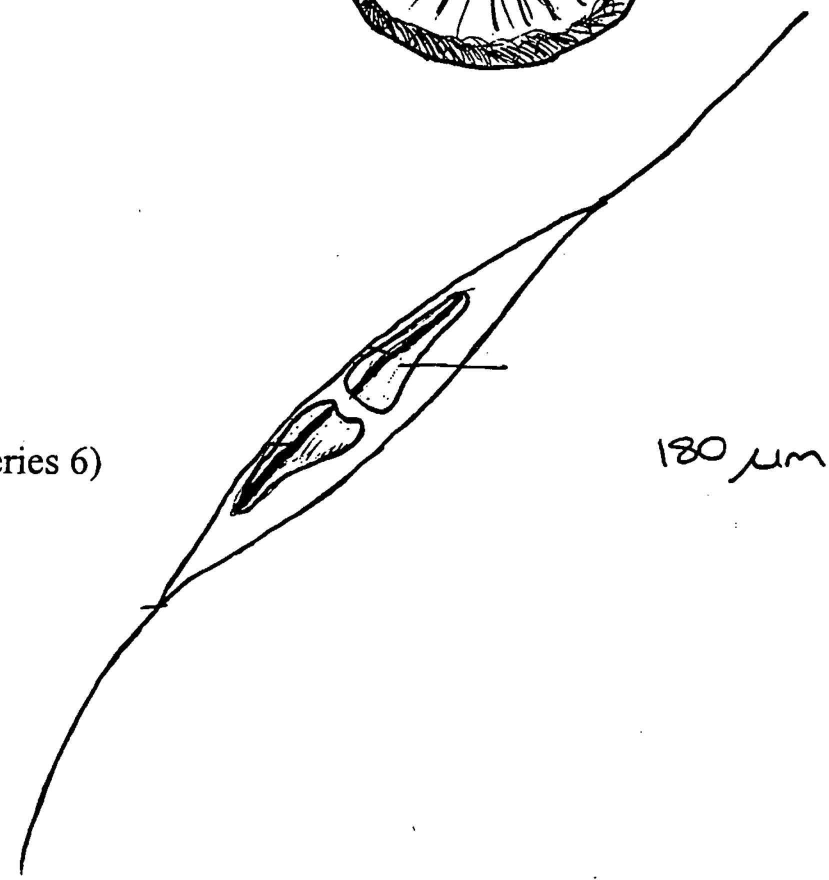
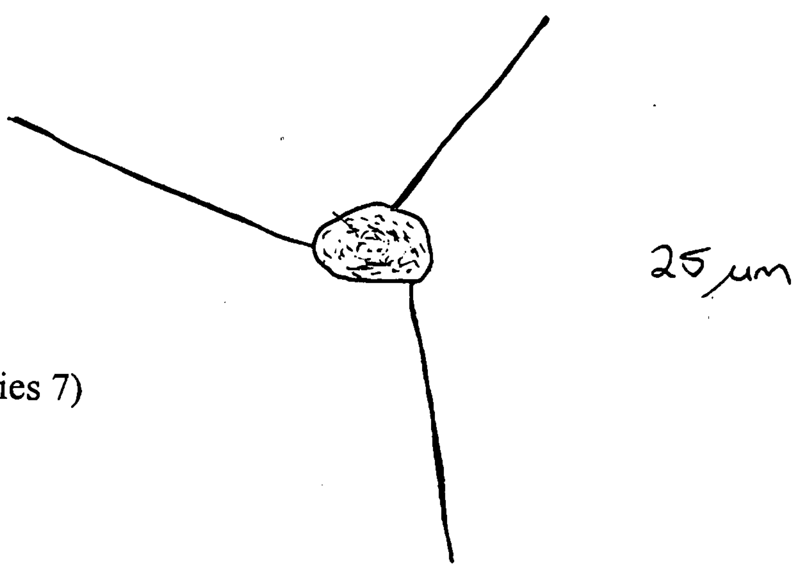


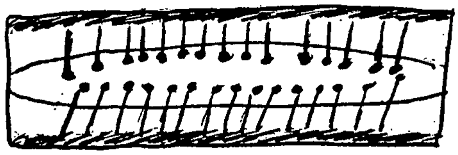
Plantoniella (Series 4)



Nitzschia 1 (Series 6)

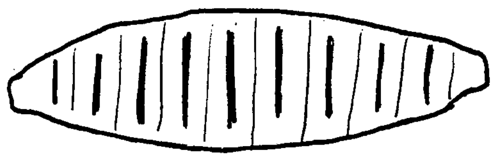


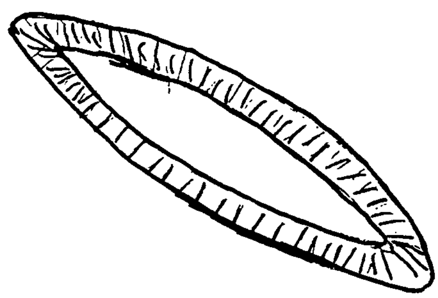
Centronella (Series 7)



22,5 µm

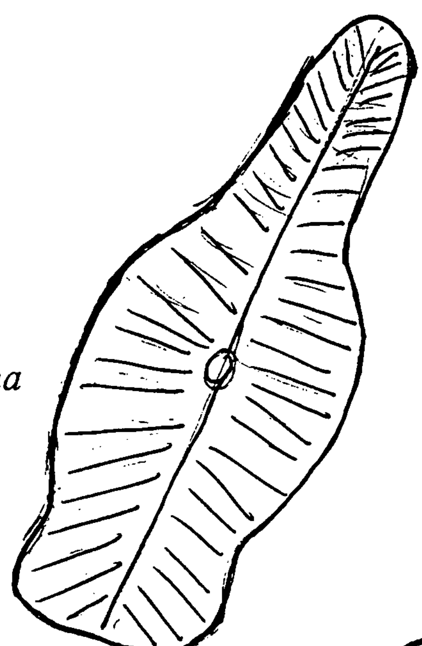
Denticula (Series 8)





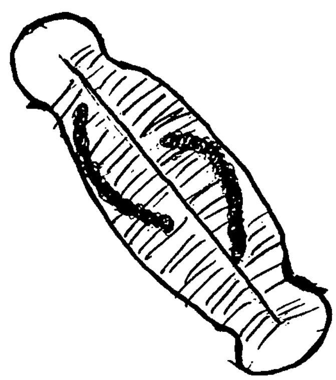
Breblissonia

45 µm



37,5 µm

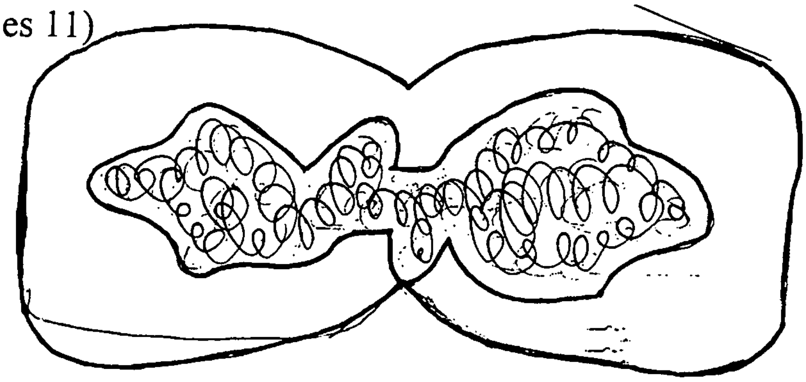
Gomphonema



21,4 µm

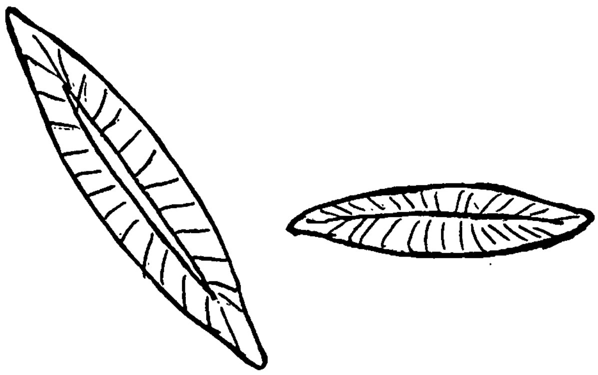
Navicula 3 (Series 10)

mphiphrora (Series 11)



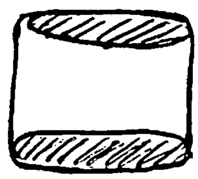
- large

Navicula 2 (Series 12)



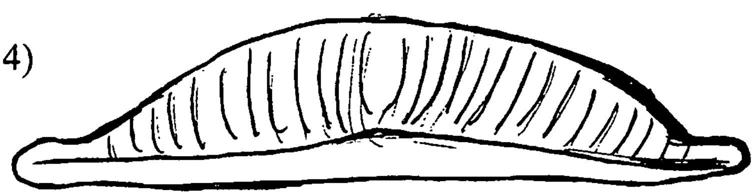
48 µm

Anaulus (Series 13)



3 µm

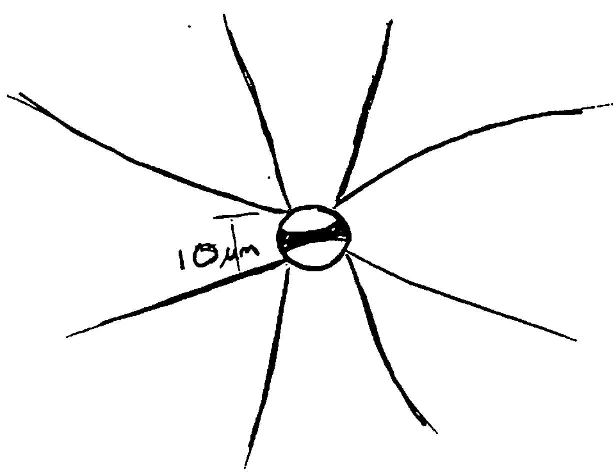
Amphora (Series 14)



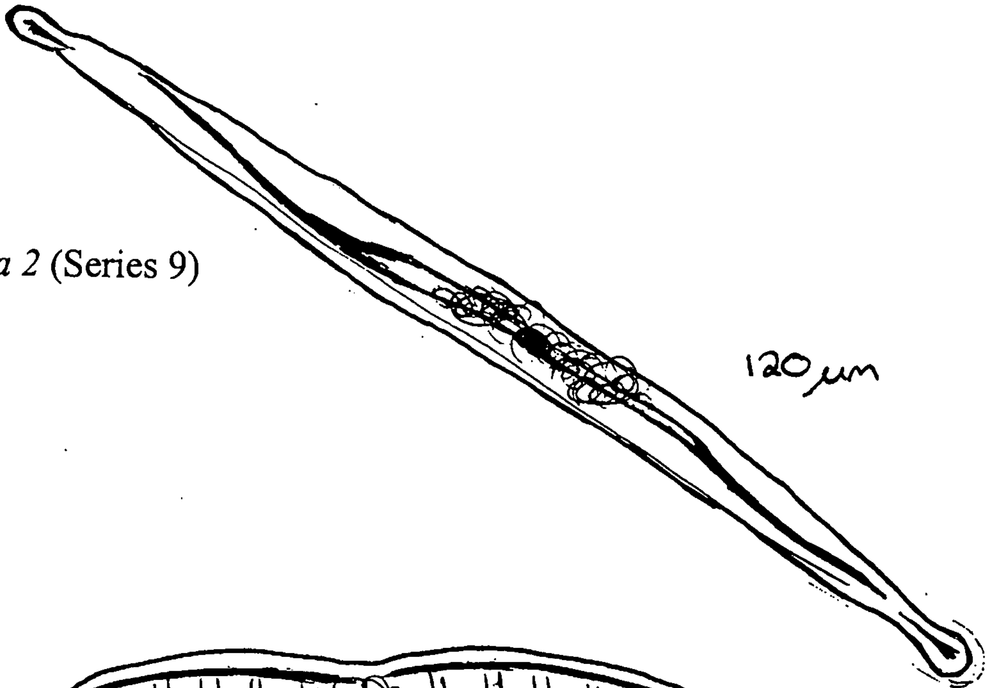
58 µm

'*Spike*' (Series 15)

- no ID

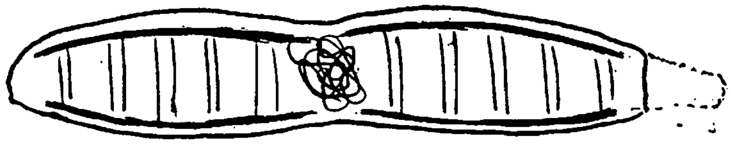


35µm



Nitzschia 2 (Series 9)

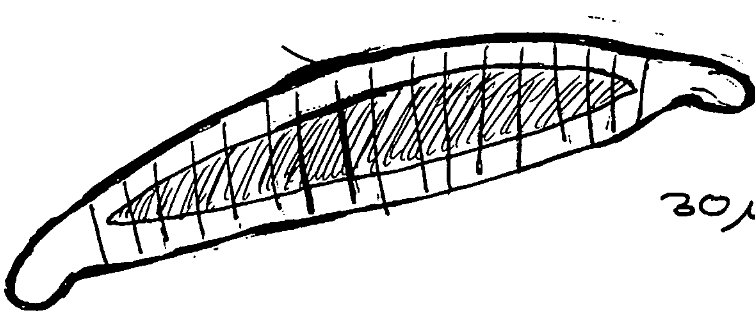
120µm



BGT (Series 19)

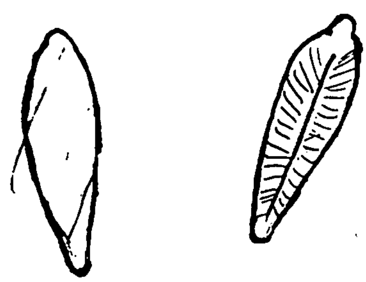
no ID

22,5µm



30µm

Cymbella (Series 5)



FT (Series 18)

no ID

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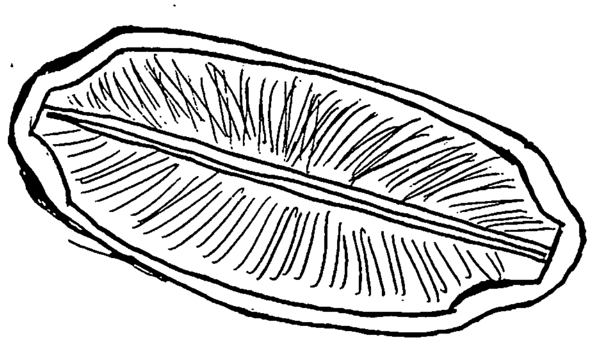

45µm

Achnanthes (Series 16)

–

NOID (Series 17)

no ID