Long-term salinity trends in Zandvlei estuary and implications for dominant macroalgae

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Abstract

Zandvlei is a system that has been highly modified by the urban environment of Cape Town. Salinity is a major driver determining the physical environment of estuaries. The macroalgal community of estuaries forms an important part of the ecology of these systems as primary producers. The salinity of this environment is an important parameter determining the composition, abundance and diversity of these communities. Patterns of salinity fluctuations in the long term (1978-2003) and annually are described in order to establish how communities may vary. Zandvlei is in a Mediterranean climate and salinity was found to vary seasonally and monthly with fluctuations in rainfall. Historical records of macroalgae identified in the estuary were summarized and no record of the *Polysiphonia* sp., now dominant in the estuary, was found. Dominant macroalgae in the estuary were identified and grown under a range of salinities (0, 1, 5, 10, 20, 29 ppt). Dominant macroalgae included *Cladophora* sp., *Polysiphonia* sp. and *Enteromorpha prolifera.* None of these algae survived at 0 ppt. In 1 ppt *E. prolifera* survived but growth was retarded, *Polysiphonia* sp. survived but did not grow and *Cladophora* sp. grew successfully at this salinity. All three species have different optimum ranges for growth with *E. prolifera* preferring higher salinities, *Cladophora* sp. grew similarly across the range from 1 to 29 ppt and *Polysiphonia* sp. grew most rapidly at 5 ppt. Depending on the salinity range in the estuary different macroalgae will be dominant. This makes the macroalgae community quite resilient to fluctuating salinities. There should therefore always be estuarine macroalgae present in the estuary provided salinity does not drop below 1 ppt for an extended period. If salinities did drop below 1 ppt there could be an increase in freshwater algae.

Introduction

Estuaries are dynamic systems, their ecology is complex and there are many factors that drive the physical and biological environment. Salinity is one of the major physical drivers, determining composition of biotic communities including primary producers such as the macroalgae.

In estuaries salinity conditions vary naturally and patterns of freshwater input vary with the climate and size of the estuary (Kamer & Fong 2000). The Western Cape has a Mediterranean climate and consequently rainfall varies greatly across the seasons, winter having high rainfall and summer having low. Salinity in estuaries around the area should vary according to the freshwater inputs, decreasing in winter with the high rainfall and low temperatures while increasing in the summer with low rainfall and high temperatures. Winter storms would also have a noticeable impact on salinity as large quantities of water end up in the estuaries within a short space of time. The effect of these events depends on the nature of the storm and the rainfall history of the area (Kamer & Fong 2000). Salinity also fluctuates with tidal flow, during high tides, especially spring tides, seawater flushes up through the estuary. This input of saline water varies daily but the seasonal fluctuation has a greater influence on the saline inputs. During summer seawater is able to seep into the estuary through the sandbar that forms across the mouth as the freshwater current moving out of the estuary is weak. Larger influxes of saline water occur during high spring tides. During winter tidal flux does not have as large an effect on salinity as the freshwater current moving out if the estuary is much more powerful.

Salinity is of great consequence for aquatic organisms as it is part of their immediate environment and has a direct impact on physiological function. Salinity can be defined as grams of salt per kilogram of solution (Lobban and Harrison 1994). Biological roles of importance include ion concentrations, density of seawater and osmotic pressure (Lüning 1990). Important salinity effects are those of osmosis or the movement of water molecules along water potential gradients and flow of ions along electrochemical gradients (Lobban and Harrison 1994). A semi-permeable membrane that surrounds cells, chloroplasts, mitochondria and vacuoles regulates these processes (Lobban and Harrison 1994). In order to maintain turgor pressure internal ion concentrations of organic osmolytes are adjusted (Lüning 1990). Growth of macroalgae can be reduced in high salinity conditions because of enzyme effects and reduced turgor pressure slowing cell division (Lüning 1990, Lobban and Harrison 1994). Conversely if conditions become too fresh for extended periods of time growth is reduced or death results because they are unable maintain turgor pressure. Between the extremes of high and low there are optimum salinities for photosynthesis and growth of macroalgae.

Research on the impacts of a fluctuating salinity regime is varied. Most work has been on the impacts on animals such as penaiid prawns estuarine sea anemones and estuarine snail and polychaete larvae (Kamer & Fong 2000). For macroalgae, *Enteromorpha* is a genus that has received the most attention as it is a genus found world-wide which grows rapidly, particularly in eutrophic conditions (Davies and Day 1998). Most urban estuaries are eutrophic at some point and so this species is of interest as it thrives in these environments. Impacts of reduced salinity on the macroalga *Enteromorpha intestinalis* have been investigated by Karsten and Kirst (1989). They found that low salinity reduced the photosynthetic rate and growth rate of the estuarine macroalgae.

Zandvlei is a coastal lake and an estuary and utilized by the surrounding community for several recreational activities (Davies and Day 1998). In spite of being a highly modified system it provides a habitat for a diversity of biota. There are a variety of macrophytes in the estuary *Potomogeton pectinatus* being of the most concern. This macrophyte, along with several others (eg *Ruppia maritime*), has been harvested since the late 1970’s (Davies and Day 1998). If it is not controlled it chokes up the estuary and forms rotting mats preventing recreational users from utilizing it (Morant and Grindley 1982). It also supports macroalgae species such as those from *Cladophora* and *Enteromorpha* (Davies and Day 1998). A common invertebrate found in the estuary is *Ficopomatus enigmatica*, it was found during the field collections forming large colonies along the cement walls of the estuary. Essential to the functioning of this system is the salinity regime and one part of the community that depends on it is that of the macroalgae. One of the questions posed in this study concerns salinity variation and how this variation can be understood and predicted. In order to gain some understanding of the salinity regime, long-term data from April 1978 to March

2003 was used in order to establish trends and model the seasonal and yearly salinity fluctuations as well as the relationship with rainfall.

The second question concerns the macroalgae community and what the optimum salinity conditions are for the dominant species. To establish this, the responses of the dominant macroalgae in Zandvlei with respect to growth rate were tested at a range of salinities.

Study area

Zandvlei is a shallow estuarine lake located on the north western-shore of False Bay (34˚05' S: 18˚28'E) (figure 1). Bordered by a 34 ha wetland to the west and a marina property development to the east, the estuary is 1.4 km in length and the channel to the sea is approximately 1 km long (Harding 1994). The dominant wind direction in summer is S/SE and in winter it is N/NW. The mouth is opened occasionally during the winter months and closed during the summer. A rubble weir at the mouth of the outlet channel artificially controls the water level. The weir is artificially breached if unseasonal weather occurs and the properties in the marina are threatened (Harding 1994). Three rivers drain into the estuary. These are the Sand River and Keysers River from the north and Westlake River from the northwest (Veldhuis 1983). The immediate catchment area is predominantly urbanized (Davies and Day 1998) while the outskirts are forestry and there are some agricultural and undeveloped elements (Davies and Day 1998, Harding 1994). There is also a light industrial area within the catchment (Heinecken *et al*. 1983) and in the last few years a new light industry area has been developed at Westlake. Since it is an urban estuary there are many anthropogenic sources of freshwater. This would include agricultural runoff from the farms upstream of the three major tributaries that feed it as well as water from sewage facilities and municipal water. Hardening of the many surfaces in the catchment results in water flowing directly into the estuary instead of percolating into the groundwater (Zedler 1996). These constant sources of freshwater could result in natural salinity of the estuary being artificially lowered.

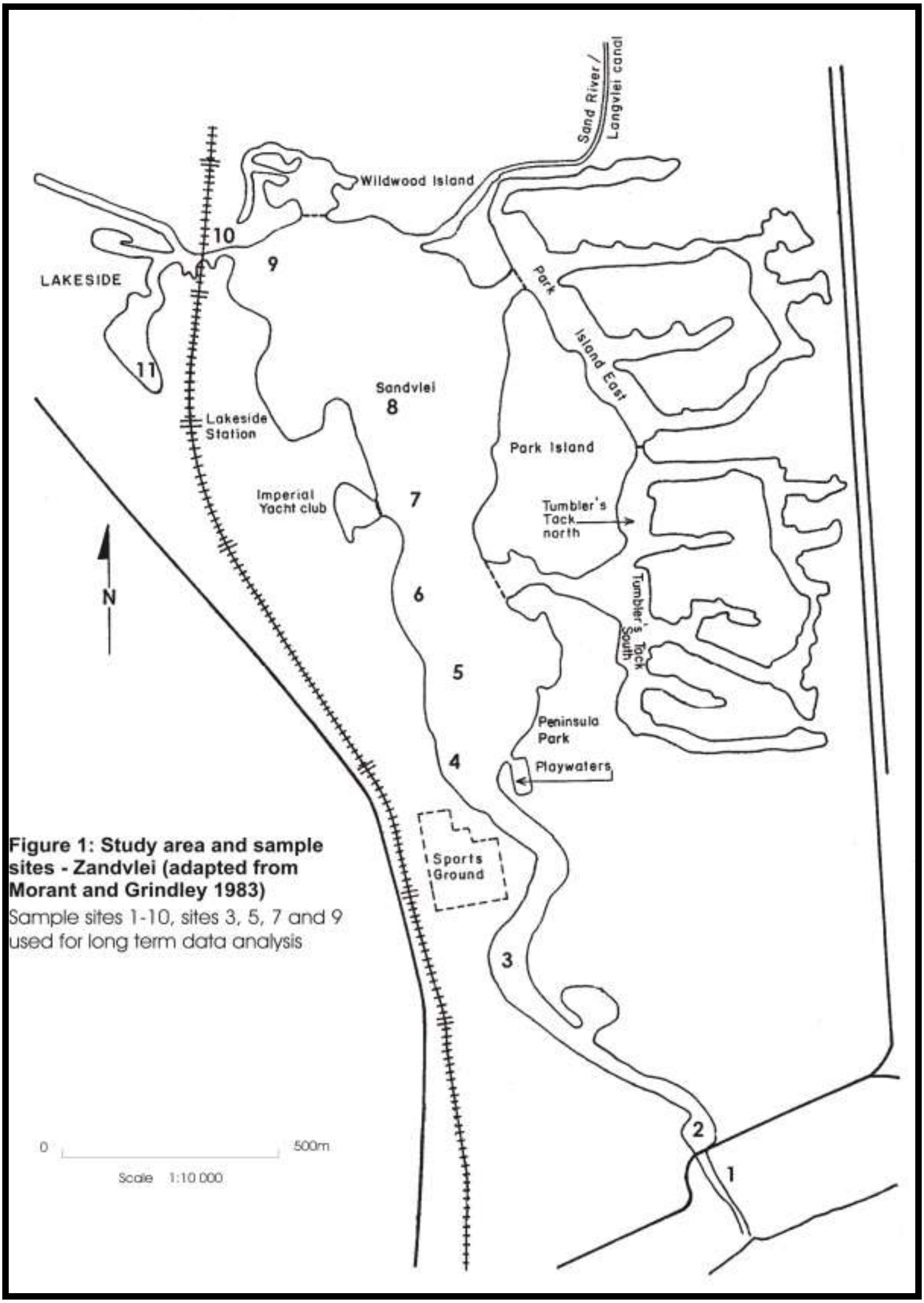

Figure 1: Study area and sample sites - Zandvlei (adapted from Morant and Grindley 1983)

Sample sites 1-10, sites 3, 5, 7 and 9 used for long term data analysis

History of Zandvlei

Zandvlei is an urban estuary and both the catchment and the estuary itself have been altered by human development since people moved into the area (Morant *et al*. 1982, Harding 1994). Early sources (Walker 1922) indicate that Zandvlei had a wide mouth and a drainage channel that changed according to various physical variables such as outflow, volume, tides, longshore drift and winds (Morant *et al*. 1982). Three hundred years ago Zandvlei probably functioned as a true estuary, which was tidally flushed for most of the year and closed during the driest months (Morant *et al*. 1982). Zandvlei has been dredged and altered since the railway causeway was constructed in the late 1800's (Figure 1) (Morant *et al*. 1982, Harding 1994). Initially the estuary was shallow with gently graded shores and the water level fluctuated seasonally and over a wide range (Morant *et al*. 1982). After the Second World War Zandvlei was dredged and the shores stabilized, this resulted in the creation of steep banks. The mouth too was altered and the area quickly became urbanised. The estuary itself has been heavily utilised for recreational activities since the start of the 20th century (Morant *et al*. 1982). From 1982 the estuary was managed to keep the water level between 0.7 and 0.9 metres above sea level (Morant *et al*. 1982) for recreational purposes, primarily sailing. The urban development close to the estuary has disturbed tidal flow. The mouth of Zandvlei is often closed for extended periods of time, particularly in the summer months. A settlement (Marina da Gama) was built in the late 70's on the eastern side for which banks were stabilized and a weir constructed to control the flow of water so that homes in the marina do not flood.

Methods

Long-term salinity data analysis

The Cape Town City Council (CTCC) has collected salinity data for the period from 1978 to 1999 for several sites around the estuary. Measures (parts per thousand) were taken at the surface and the bottom of the estuary 1-4 times a month. From 2000 onwards another data set (M.T. Hoffman, unpublished data) was collected on a monthly basis. Four of the sites sampled by Hoffman were in the same position as those of the CTCC and the surface salinities of these four sites were used for analysis. Surface readings were used because macroalgae are not found on the bottom of the estuary where poor light conditions prevent growth. The first reading of every month was used from the council data as this correlated most appropriately with the timing of the recent data capture from 2000 onwards. Rainfall data from 1978 until March 2003 was provided by the South African Weather Bureau for the Kirstenbosch station (33° 59' S, 18° 26' E), adjacent to the catchment of Zandvlei. This station which is 89 m above sea level, was used, as it was the closest one with a complete data set for the same period as the salinity data set. The general long-term trend in salinity was calculated using the average salinity of the first measure of each month for all four sites. Salinity was averaged for all four sites and regressed against rainfall from the previous month to determine the relationship between rainfall and salinity (Zar 1984). Points for April 1990, April 1992, April 1999 and May 1996 were omitted as the readings for salinity were taken near the end of months with high rainfall preceded by a low rainfall month. These data points were therefore not a true reflection of the relationship between salinity and rainfall amount in the previous month.

Data from four sites (3, 5, 7 and 9 see Figure 1) were used to derive a mean monthly average for salinity at each site. They were regressed against the mean monthly rainfall for the period from April 1978 to March 2003 (Zar 1984).

Historical Data

The presence of macroalgae observed in previous studies were collated and presented as a table with species, the reference and year that it was found. Comments about species distribution within the estuary were also extracted.

Field Collection

The initial survey of macroalgae in the estuary was carried out at 11 sites around the estuary previously used as sample sites by the CTCC. The estuary was sampled on two occasions both from 8:30 am to 11:30 am. The first date sampled was 26/6/2003 for which the weather was clear and cold with no rain prior to the day for several weeks. The second sampling day (12/8/2003) was cold, windy and overcast with heavy rains the preceding the day. At each site salinity was measured using a conductivity meter (Hanna HI 9835) that measured the salinity as parts per thousand. At each site samples of the algae were collected by hand and kept in plastic bags. In the lab the algae were cleaned and identified using a microscope. From these samples a reference collection was made for each site and preserved in 5% formalin in 50% seawater. The four most common algae were *Polysiphonia* sp., *Ectocarpus* sp., *Enteromorpha prolifera* and *Cladophora* sp. These were cleaned and used for a growth experiment from the second sampling.

Growth rates experiment

Pravasoli ES nutrient solution was mixed according to Starr and Zeikus (1987). pH was adjusted to 7.8 and the solution made up to 500 ml using distilled water as the solvent. The Es solution was then autoclaved and placed in a 10˚C room. The salinities mixed were seawater at 29 ppt, then 20 ppt, 10 ppt, 5 ppt, 1 ppt and 0 ppt (distilled water). Distilled water and seawater were placed in a water bath and raised to 80˚C for 3 hrs, allowed to cool and then stored at 15˚C prior to use. Three replicates were used and algae were grown in 100ml conical flasks. Therefore the total medium required for each treatment was 1200ml. To 1200ml of the experimental medium 7.2 ml of ES nutrient solution was added.

The following quantities were used to make up the growth media:

Salinity (ppt)	0	1	5	10	20	29
Seawater (ml)	0	41.4	206.9	413.8	827.6	1200
Distilled water (ml)	1200	1158.6	993.1	786.2	372.4	0
Total (ml)	1200	1200	1200	1200	1200	1200

These were mixed in 2000 ml flasks and for each salinity, twelve 100ml conical flasks were filled. The macroalgae were cleaned and then blotted before being weighed using an electronic scale and placed in conical flasks. The mouths of the flasks were covered with parafilm to prevent evaporation and then incubated in a controlled temperature room. They were placed with lighting from ‘cool white’ fluorescent tubes. The light that it emitted ranged from 72-106 μ.mol.m $^{-2}$s^{-1}. Temperature in the flasks was 20°C. The flasks were randomly rotated everyday to prevent some of the flasks from benefiting from better light conditions. Daily observations included water clarity, fragmentation of samples and presence/absence of bubbles. On day four of the experiment the algae in each bottle was blotted and weighed. The flasks were emptied and any residue cleaned out and the medium replaced. On day 8 the samples were removed, blotted and final weights taken. Growth was calculated as a percentage growth per day according to the following equation (Evans 1972 adapted by Lüning 1990):

$$\mathrm{SGR}\ (\%\ \mathrm{day}^{-1}) = 100\frac{*\ln Nt/No}{t_2-t_1}$$

t = time (days)
No = initial weight
Nt = weight at time t

Data was tested for normality and homogeneity and differences between the mean changes in biomass in different solutions were tested using one-way ANOVA (Zar 1984). The results are presented as box and whisker plots. *Ectocarpus* results were erroneous as the sample was contaminated by other macroalgae.

Results

Analysis of long term salinity data and its relationship to rainfall

Over the 25 year sampling period, salinity at four sampling sites in the Zandvlei estuary, varied between 0 and 25 ppt with a mean value of 7 ppt (Figure 2). Salinity values fluctuated in a regular pattern with peaks evident in the summer months and troughs in the winter. This pattern mirrors the seasonal rainfall pattern in the broader winter-rainfall catchment area where the winter months (May-August) are clearly the peak rainfall periods (Figure 3). Even though some years show lower peaks than others (e.g. the period 1990-1992 exhibits relatively low salinity values) there is no obvious overall downward trend in salinity. There does seem to be a downward trend in salinity peaks from January 1978 to January of 1987. January 1988 could be an erroneous point and from 1990 to 1995 there is an increasing trend in salinity peaks. After January 1995 there is a decreasing trend in salinity peaks and since January 2000 salinity peaks have been increasing.

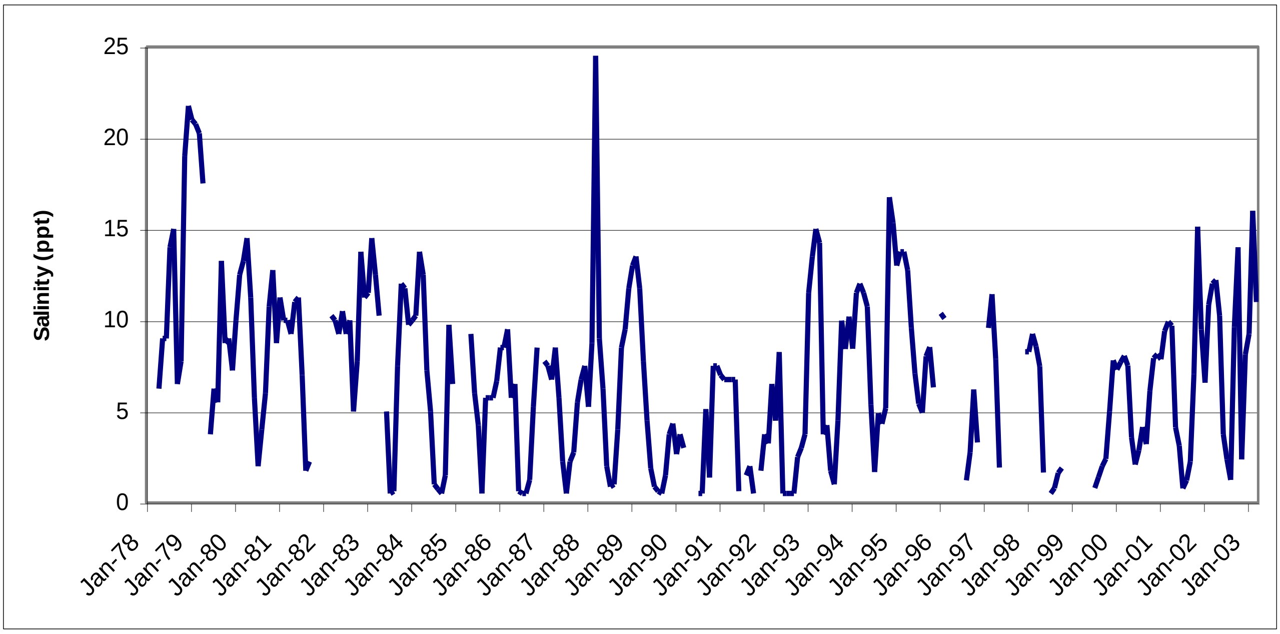

Figure 2: Salinity trend for Sandvlei for the period from April 1978 to March 2003 using the monthly averages of sites 3, 5, 7 and 9 (see Figure 1 for the location of the sampling sites in the estuary).

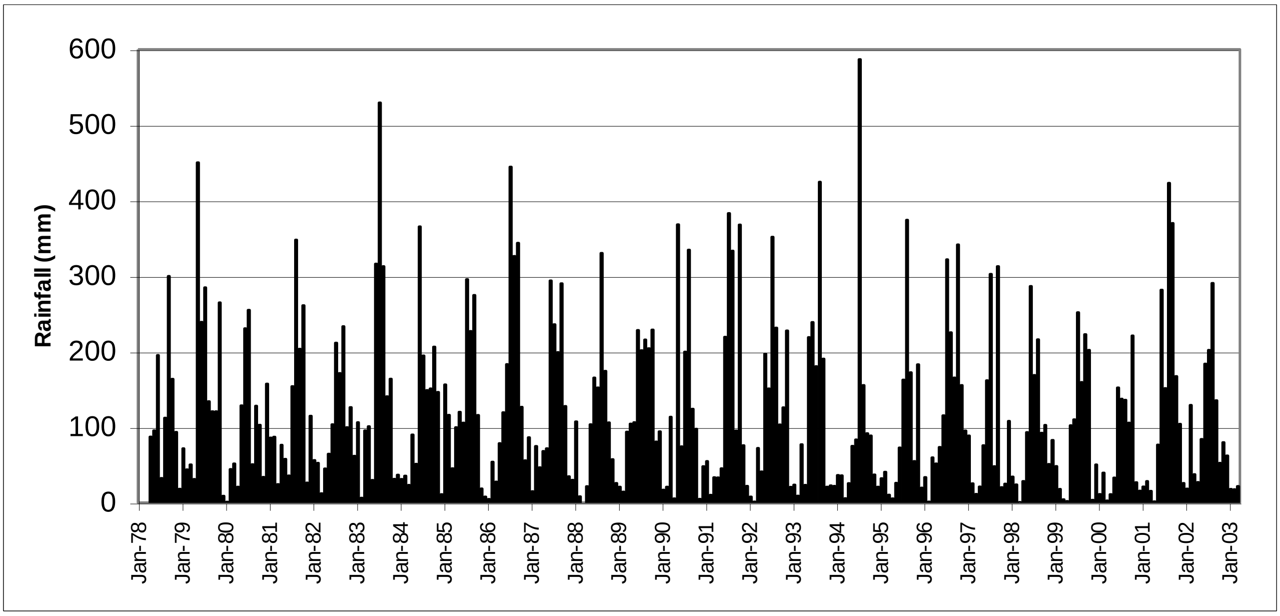

Figure 3: Rainfall for Kirstenbosch (mm per month) for the period from March 1978 to April 2003.

Annual salinity patterns (figure 4) indicate a peak in the summer months; the highest value was in March (13.3 ppt, site 3). Salinity troughs occurred in the winter months the lowest value was in August (2.4 ppt, site 9). There is a drop in salinity from November to December; thereafter salinity continues to increase for the remainder of the summer months. There was a greater range of salinities from site 3 (near the mouth) to site 9 (the top end of the estuary) during summer. The biggest difference (4.5 ppt) was in December between sites 3 and 9. During the winter months the range of salinities from site 3 to site 9 is much smaller. The smallest difference was in August (0.6 ppt). There is a small drop in salinity from November to December thereafter salinity continues to increase. The salinity curve is inversely related to the rainfall curve, peaks in salinity occurred where rainfall was low during summer months. Low salinity values occurred in winter where rainfall values were high.

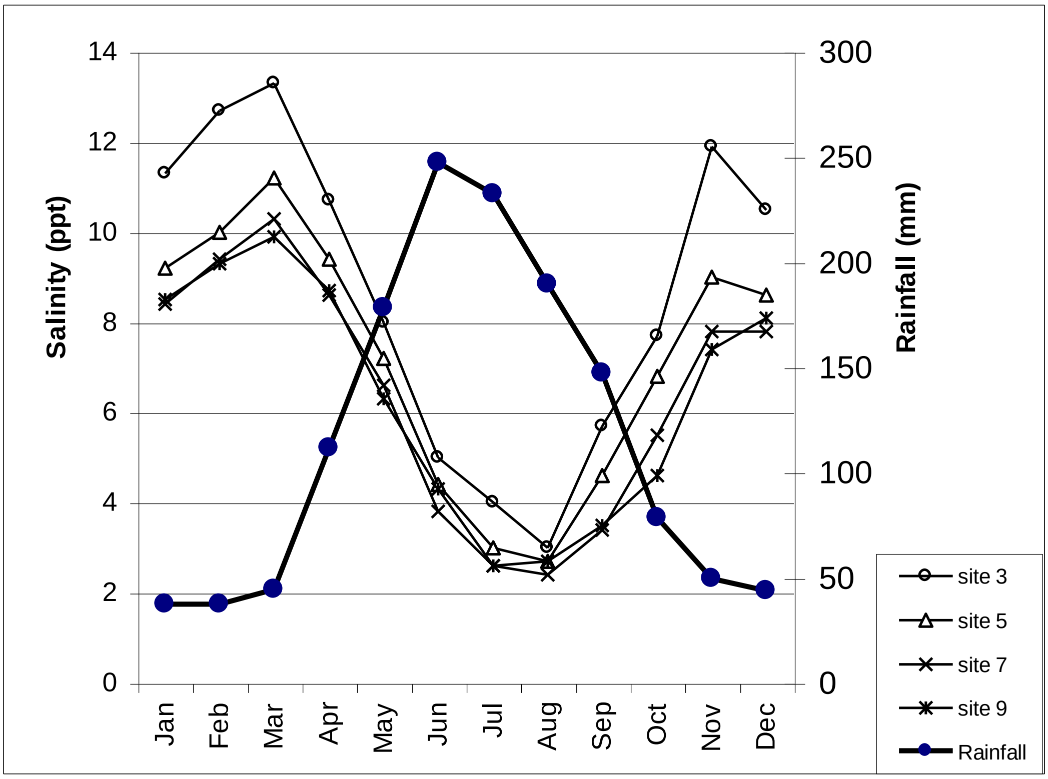

Figure 4: Mean monthly salinity (ppt) for the period from April 1978 to march 2003 for sites 3, 5, 7, 9. Site 3 is closest to the mouth and site 9 is situated at the northern end of the estuary (see figure 1 for sampling sites in the estuary).

The relationship between rainfall and salinity was significant (figure 5) indicating that salinity declined exponentially with rainfall from the previous month. The spread of points was much larger when the rainfall was low, however as rainfall increased there was less spread in the salinity values. Several data points below the trendline (low rainfall and low salinity) are for months in spring (September and October).

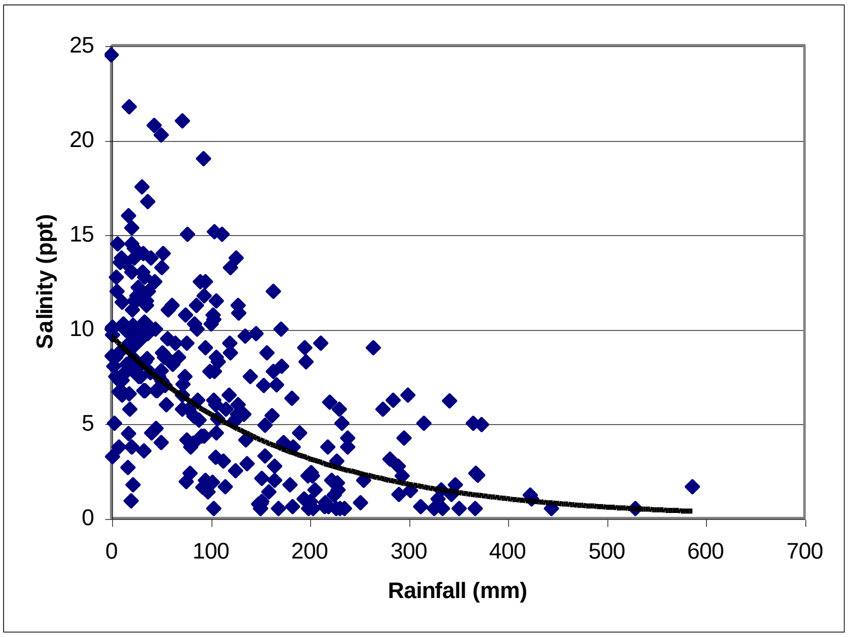

Figure 5: Regression using monthly rainfall (mm) from Kirstenbosch weather station as the independent variable and the average salinity of the first reading of the following month for sites 3, 5, 7 and 9 as the dependent variable (n = 269, R^2 =0.3911, p < 0.001).

The relationship between mean monthly salinity and monthly rainfall (figure 6) indicates that salinity values were significantly negatively related to rainfall. Summer months cluster around salinity values from 8.75 to 11.18 ppt and winter values are 3.05 ppt (July) and 4.38 ppt (June). Autumn months lie above the trendline while spring months lie below the trendline. Months are arranged in chronological order around the trendline, starting with January at the top end of the salinity range and proceeding clockwise.

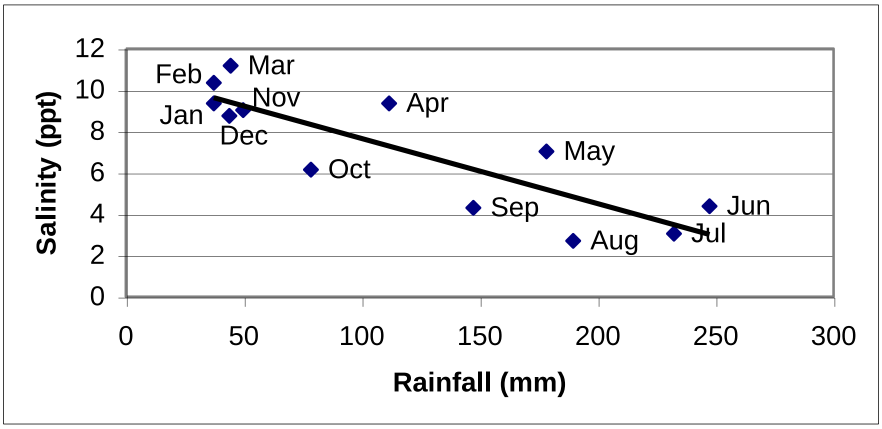

Figure 6: Relationship between mean monthly rainfall (Kirstenbosch station) and mean monthly salinity in Zandvlei for sites 3, 5, 7 and 9 (April 1978 to March 2003) (n = 12, R^2 = 0.7211, p< 0.001).

Community Analysis

According to the collated historical data (Table 1), a total of 7 genera of macroalgae with detailed data only available on 3 species of *Enteromorpha* have been recorded in the Zandvlei estuary since 1974. The most commonly recorded species were those of the *Enteromorpha* genus.

Table 1: Historical observations of macroalgae in Zandvlei.

Species recorded	**Comment**	**Reference**
Cladophora sp	1. Present in middle of estuary during summer (mouth closed), dominant during winter (mouth open) and wide spread 2. Epiphytic, found growing on *Potamogeton*, abundant in summer 3. Present at southern end of estuary during late summer as a fringe along the banks	1.Shelton (1975) 2.Bekenstein (1981) 3.Veldhuis (1983)
Chara fragilis	1.Present at the head of the estuary, sites 7-9 (see Fig 1) 2. Present at site 7 (see Fig 1)	1. Muir (1974) 2. Shelton (1975)
Ectocarpus sp.	1.Present throughout estuary at all sites at lower densities than *Enteromorpha sp.* except in June, disappeared in July/August	1.Veldhuis (1983)
Enteromorpha spp.	1.Abundant near the mouth 2.Present throughout estuary March to April, dense in middle reaches (sites 5-7, see Fig 1). Disappears from sites 7-9 from June to Sept 3.Present as a pest species	1.Muir (1974) 2.Veldhuis (1983) 3.Davies & Day (1998)
Enteromorpha flexuosa	1.Present near station 8 (see Figure 1) at low densities in March-April	1.Veldhuis (1983)
Enteromorpha intestinalis	1. Restricted to lower and middle reaches in summer, abundant and dominant right through estuary in winter 2.Present throughout year	1.Shelton (1975) 2.Veldhuis (1983)
Enteromorpha prolifera	1.Present near site 8 (see Fig 1) in March-April, disappears from May-June, reappears in August	1.Veldhuis (1983)
Lyngbya sp.	1.Dominant in throughout estuary summer 2. Present as floating mats near site 2 (see Fig 1) before May	1.Shelton (1975) 2.Veldhuis (1983)
Spirogyra	1.Dominant throughout estuary in summer	1.Shelton (1975)
Ulva	1.Restricted to mouth 2.Present at site 2, near the mouth (see Fig 1)	1.Muir (1974) 2.Shelton (1975)

Results of sampling for two separate days (table 2) indicate a small degree of variability in salinity and community composition between sample days but little variability within the estuary.

The salinity did not vary much from site 1 to 9 for either sampling day. The range for 26/6 is 11.42 at the mouth to 9.09 at site 8 and for the 12/8 it was 6.89 at the mouth to 6 at sites 9 and 4. Macroalgae generally occurred throughout the estuary except in sites 10 and 11, only *Cladophora* sp. and *Rhizoclonium* sp. were found in these sites. *Enteromorpha prolifera* was present throughout the estuary on both sampling occasions except for sites 10 and 11 where salinity was very low. *Enteromorpha intestinalis* was distributed randomly throughout the estuary on both occasions not occurring as frequently as *Enteromorpha prolifera.* *Cladophora* was generally distributed throughout the estuary although it was not found at the mouth (site 1) for either sampling day. *Polysiphonia* sp. was found throughout the estuary on both occasions except on the 26/6 when it was not found in sites 1, 2 and 3, these being the sites closest to the mouth and slightly more saline than the other sites. *Lyngbya* sp. is a mat-forming, blue-green algae and was found growing on the concrete walls of the canal at site 1. *Melosira* sp. is a filamentous colonial diatom which was found coating several of the algae, *Polysiphonia* sp. in particular. *Rhizoclonium* sp. was found more frequently on the 12/8 than the 26/6 when it only occurred twice at sites 3 and 8. It was, however, present at site 10 and 11 on both days. Small fragments of the typically freshwater species *Spirogyra* sp. were found on both sampling days. These fragments which were generally entangled with flowering plants, could have been washed down into the estuary from the rivers. *Ectocarpus* sp. occurred throughout the estuary although it appeared to be more common on the 12/8 when it occurred from the mouth to site 9, while only occurring at site 2, 6, 8 and 9 on the 26/6.

Table 2: Salinities (ppt) for each of the 11 sample sites and species present at each site for sample day 26/6/2003 (with dry weather prior to the sampling) and 12/8/2003 (several weeks of rain prior to sampling). Species present = x. Refer to figure 1 for position of sites throughout the estuary.

Site	1		2		3		4		5		6		7		8		9		10		11	
Date	26/6	12/8	26/6	12/8	26/6	12/8	26/6	12/8	26/6	12/8	26/6	12/8	26/6	12/8	26/6	12/8	26/6	12/8	26/6	12/8	26/6	12/8
Salinity (ppt)	11.40	6.89	11.00	6.86	11.00	6.25	9.40	6.00	9.53	6.08	9.70	6.30	9.65	6.68	9.10	6.29	9.20	6.00	3.20	0.60	2.00	0.88
Cladophora sp				x	x	x	x	x	x	x	x	x				x	x	x			x	
Derbesia sp					x																	
Ectocarpus sp		x	x			x		x		x	x	x			x	x	x	x				
E. intestinalis			x	x		x	x	x		x		x		x	x							
E. prolifera	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x				
Melosira sp	x		x		x	x	x		x		x		x		x		x					
Lyngbya sp	x	x																				
Polysiphonia sp		x		x		x	x	x	x	x	x	x	x	x	x	x						
Rhizoclonium sp					x	x						x		x	x			x	x	x		x
Spirogyra sp							x						x		x	x						

Salinity tolerance of dominant macroalgae

Optimum salinity ranges for growth of *Enteromorpha prolifera*, *Cladophora* sp. and *Polysiphonia* sp. differ. Growth for *Enteromorpha prolifera* is lowest in 1 ppt with a 1.9 % increase in mass per day (%/day) and this rate of growth increases for each increasing salinity reaching a maximum of 2.9 %/day in 29 ppt. It did not survive in a salinity of 0 ppt beyond the first day. *Cladophora* sp. survived in a salinity of 0 ppt for two days without growing and grew successfully at 1 ppt (4.9 %/day) reaching a growth rate at this salinity equal to that of 20 ppt (4.9 %/day). Maximum growth rate was at 29 ppt (6.2 %/day). *Polysiphonia* sp. survived for one day in a salinity of 0 ppt without growing and survived but did not grow in a salinity of 1 ppt. It grew most rapidly in a salinity of 5 ppt (2.02 %/day). At salinities higher than this growth rates were much slower ranging from 0.21 %/day to 0.82 %/day.

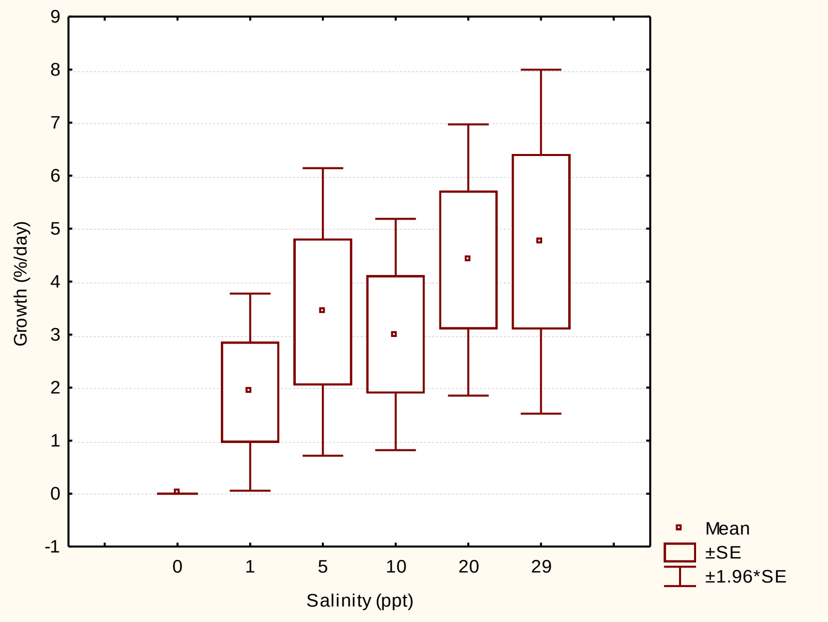

Figure 7: Growth per day for *Enteromorpha prolifera* as a percentage increase in wet mass, over 8 days for 0, 1, 5, 10, 20 and 29 ppt.

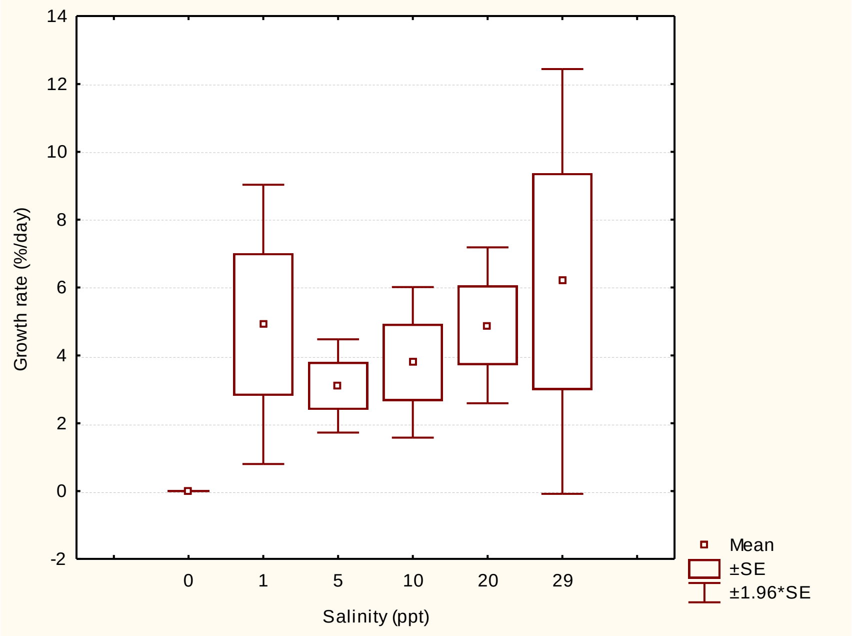

Figure 8: Growth per day for *Cladophora sp.* as a percentage increase in wet mass, over 8 days for 0, 1, 5, 10, 20 and 29 ppt.

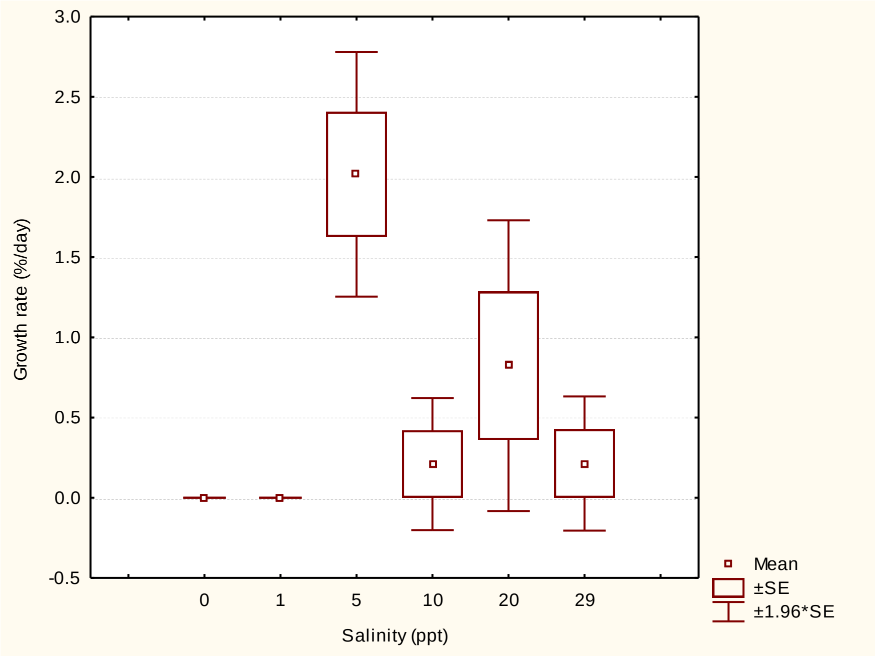

Figure 9: Growth per day for *Polysiphonia sp.* as a percentage increase in wet mass, over 8 days for 0, 1, 5, 10, 20 and 29 ppt.

Discussion

Long-term data

The long-term trend for salinity indicated variability in the timing and amplitude of salinity peaks and troughs, varying year to year but nevertheless a similar trend. There appeared to be a trend in salinity peaks, they increased yearly over a period of years and then decreased in a cyclical manner. Rainfall had the expected pattern of a Mediterranean climate, being high in winter and low in summer. Peaks in salinity occurred where there were low rainfall periods.

Salinity varied uniformly across the range of sites, indicating a general trend for salinity fluctuations. During the winter months salinity was very similar at all points around the estuary. This was probably because of a high degree of mixing from the large volumes of water entering the estuary. In conjunction with mixing, the constant flow of freshwater entering the estuary, flowing through and leaving via the mouth forces salt water out, preventing a salinity gradient from forming.

During the summer months a sand bar usually closes the mouth of the estuary and the freshwater inputs from the 3 rivers are greatly reduced. Generally salt water seeps in from the sea except during high spring tides when seawater mixes right up the estuary. Evidence of this is the occurrence of *Ecklonia*, a seaweed often found washed up in the upper reaches of the estuary after spring tide events. In addition to the saline inputs from spring tides, the combination of low freshwater inputs and high rates of evaporation result in much higher salinities throughout the estuary. The salinity gradient from the mouth to the source was not particularly exaggerated or steep, however site 3 (closest to the mouth) was noticeably more saline than sites 5, 7 and 9 by values between 3 to 5 ppt. This was probably because the low freshwater inputs and weak fresh current do not mix to the mouth of the estuary. As a result the water near the mouth of the estuary was not diluted. Physical modifications to the estuary itself have disturbed tidal flow. Apart from the mouth of Zandvlei being closed for extended periods of time there is urban marina development on the eastern side for which banks have been stabilized and a weir constructed to control the flow of water. This decrease in tidal flow reduces the degree of mixing between freshwater and seawater. Any unusual increase in freshwater inputs would therefore be further amplified by the lack of mixing and decrease salinity in the head region of the estuary (Kamer & Fong 2000).

These freshwater inputs are one of the major problems estuarine organisms need to cope with. During high rainfall events, especially flooding, salinity may be lowered to a point close to freshwater. Salinities have been recorded as 0 ppt at some points around the estuary on occasion. This can last for months and although estuarine organisms are able to tolerate a wide salinity range if there are extended periods when the water is fresh it may result in death of organisms. They simply are unable to adapt to these conditions physiologically. In the eutrophic system, Mondego estuary in west Portugal, *Enteromorpha* blooms occur regularly. However, in years of high precipitation and greatly increased runoff, these blooms are not observed (Martins *et al.* 1999).

The relationship between the average salinity for the sites 3, 5, 7 and 9 and the total rainfall was significant. The urban context of the estuary could explain why there was such a broad scatter of points when rainfall was low. Since 1978 the area has been increasingly developed creating more anthropogenic sources of freshwater. This would include agricultural runoff from the farms upstream of the three tributaries that feed it as well as water from sewage facilities and municipal water. Runoff from the agricultural, urban and municipal sources in the area could increase freshwater inputs sporadically during the dry summer season resulting in low salinities when rainfall is low. This would mean that the expected high salinity of the estuary would be artificially lowered. Salinity varied more predictably with higher rainfall consequently salinity conditions in the estuary can be anticipated when rainfall is approximately 200 mm or more.

There was a highly significant relationship between mean monthly rainfall and monthly salinity. The months with high salinities and low rainfall were all summer months (November, December, January, February, March) whereas the points with high rainfall and low salinity were the winter months (June and July). These extremes were clustered close to the mean at either end of the graph staying close to the expected pattern. The months above the trendline were April and May. These are both autumn months when rainfall is increasing. There is a lag effect on the salinity as the ground needs to become saturated before water runs off into the rivers and ultimately into the estuary. This was why they were above the mean trend line. The points below the trendline were October, September and August. These are spring months, a period when there is still a little rain and the ground is saturated from the winter season resulting in immediate runoff of excess precipitation into the estuary. This is again a lag effect of the seasonal weather patterns and explains why these months lay below the general trend line.

Field Observations: Salinity

The salinity ranges sampled in June and August 2003 agree with the trends observed in the long-term data. When weather conditions had been clear with no rain for an extended period the difference between salinity at the mouth and the head of the estuary was much greater (2.33 ppt) than when there had been rain (0.89 ppt). Site 10 and 11 had low salinities because they were near to the freshwater tributaries. The drop in salinity throughout the estuary from the 26/6 to the 12/8 was approximately 3 ppt except for site 11 in Rutter road, which is quite separate from the main body of the estuary. This confirms the patterns observed from the long-term data. The salinity varied uniformly across the estuary and salinity at all points dropped by the same amount from the first sample day to the second.

Macroalgae community

The community was dominated by *Enteromorpha prolifera*, *Cladophora* sp., *Polysiphonia* sp. and *Ectocarpus* sp. The first three species found in equal abundance for both sampling days while the *Ectocarpus* sp. appeared to be more common at the lower salinity on the 12/8. The genus not found in the estuary in 2003 was *Chara fragilis*. Species found in 2003 that were not present in previous studies (table 1) were *Derbesia*, *Melosira*, *Polysiphonia* and *Rhizoclonium*. *Lyngbya* sp. is frequently found in brackish habitats but also occurs in fresh and salt water conditions (van den Hoek *et al*. 1995), hence its presence near the mouth in the historical data set and in the 2003 data set is expected as this is the most saline part of the system.

Historically *Enteromorpha* sp. were present throughout the estuary during the drier season when salinity would be higher. It was also abundant near the mouth where the influence of the sea is strongest. This implies that the genus prefers higher salinities. Sampling from 2003 found it present throughout the estuary, except in the sites with salinities close to freshwater, on both occasions. This indicates a tolerance of a wide range of fluctuating salinities. *Enteromorpha prolifera* appears to be a marine species that has invaded the estuary. It did not survive in salinities of 0 ppt and died after 1 day in freshwater conditions. At 1 ppt *Enteromorpha prolifera* survived but grew at a low rate. Reasons for its decreased growth could be that energy used for growth was used to regulate cell turgor at low salinities (Lobban and Harrison 1994). As salinity increased the growth rate increased reaching a maximum at 29 ppt which is close to the salinity of the ocean. *Enteromorpha* species are found on rocky sea coasts in the upper intertidal and can form dense mats on sandy shores in environments that are sheltered and still (van den Hoek *et al*. 1995). They are generally marine species but a few have entered the freshwater environment and are considered to be opportunistic (van den Hoek *et al*. 1995). *Enteromorpha* is a euryhaline species able to survive in the highly variable environment of estuaries (Davies and Day 1998; Lobban and Harrison 1994, Lüning 1990). This genus is particularly tolerant of osmotic stress and is able to cope with the fluctuating salinity environment of an estuary (Lüning 1990). In estuaries they are a noticeable component of the community often forming continuous mats across solid and sediment substrates (van den Hoek *et al*. 1995).

Cladophora sp. in the historical data was limited to the middle of the estuary in the summer months when there would have been higher salinity levels according to the long-term data. During the winter months it was more widespread when salinity would have been lower. According to the results from the growth experiments *Cladophora* sp. grew well at a salinity of 1 ppt and so it could be expected it to be more abundant when there is a greater freshwater input. It was found throughout the estuary on both days sampled in 2003. This was also expected as results from the growth experiment indicate that it does grow in salinities ranging from 1 ppt to 29 ppt. *Cladophora* species are found in fresh and marine environments and are widespread in the temperate and tropical seas (van den Hoek *et al*. 1995; Bold and Wynne 1985). They can form large free-floating mats in stagnant or eutrophic waters (van den Hoek *et al*. 1995). *Cladophora* is a genus able to cross the "salinity barrier" (Lobban and Harrison 1994). This could possibly explain why it grows equally well at 1 ppt and 20 ppt.

Polysiphonia sp. has not been observed in Zandvlei in any previous studies. It was however found in abundance in 2003. It was more widespread at lower salinities (12/8) and restricted to sites further from the mouth when salinity was higher (26/6). This could indicate a preference for lower salinity conditions. The growth experiment confirms this since *Polysiphonia* sp. grew most rapidly at a salinity of 5 ppt, although it did not grow in salinities much lower than this. *Polysiphonia* is an estuarine genus and is able to photosynthesize equally well over a broad range of salinities, they can therefore grow more successfully than marine species in the estuarine environment (Bold and Wynne 1985). It has not been recognized in the estuary before and may in fact be a new addition to the community.

Macroalgae are very important because they provide a community structure as primary producers, supporting a wide variety of other organisms. As algae grow they act as nutrient filters through high uptake rates and so retain large amounts of nutrients. Through processes of decomposition these nutrients are made available to the community again (Martins *et al*. 1999). They can form part of a cycle with the submerged plants, the algal community replacing the macrophyte community and vice versa depending on conditions in the estuary (Davies and Day 1998). Algae are involved in many different kinds of mutualistic relationships. Muir (1974) found that the majority of the fauna in Zandvlei were associated with weed beds composed of *Potomogeton pectinatus* and macroalgae such as *Enteromorpha* sp. and that when the macrophytes along with the macroalgae died back the fauna numbers fell as well. Shelton (1975) found a diverse epifauna associated with the macroalgae including several dipterans, gastropods, isopods and amphipods. These species were not present unless there was macroalgae present. Muir (1974) concluded that the majority of the fauna in Zandvlei were macrophyte epifauna, which is predominantly *Potomogeton pectinatus*. *P. pectinatus* in turn often supports an array of macroalgae also possibly associated with the invertebrate community.

Conclusion

Salinity in Zandvlei can be expected to vary with rainfall and consequently the salinity regime of the estuary can be modeled from the seasonal trends in rainfall. Dominant macroalgae *Enteromorpha prolifera, Cladophora sp.,* and *Polysiphonia* all have slightly different optimum salinities for growth. The structure of the macroalgal community can therefore be expected to vary with salinity and indirectly with rainfall. It can be expected that when salinity is higher (during summer months) the community will be dominated by *Enteromorpha prolifera* while with lower salinities (during winter) the species of *Cladophora* and *Polysiphonia* are favoured. Only if conditions become fresh for extended periods of time can the estuarine macroalgal community be expected to disappear.

In order to manage and protect water resources such as estuaries it is important to understand the structure and function of these communities. Salinity is a major driver in regulating the estuarine environment and therefore by understanding how the salinity of Zandvlei varies seasonally and over years it can be managed to prevent the salinity environment from becoming hostile to the macroalgal community. Zandvlei is a system that cannot realistically be returned to its original state but if appropriately managed can be a self-sustaining functioning system with an intact biotic community. Correct management of the salinity conditions in the estuary is a big step in this direction as it is such a fundamental part of the habitat. The long-term salinity trend indicates that salinity maximums fluctuate over years, this trend has continued in spite of alterations to the mouth and regardless of whether or not the mouth is artificially breached. The implication of this is that the system maintains its salinity fluctuations naturally and artificial breaching of the sandbar is unnecessary for maintaining the salinity regime. Breaching of the estuary is therefore only of real benefit to the fish which use it as a nursery.

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