Investigating the ecology of invasive aquatic weeds at Westlake: detrimental effects and management options

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1: INTRODUCTION

1.1 Aquatic weed research

Excessive growth of aquatic plants is a problem in many parts of the world. As many aquatic plant species have rapid growth rates they cover large expanses of open water and block drainage lines in very short spaces of time (Spencer and Bowes 1990). Aquatic plants are identified as weeds if they exibit uncontrolled growth (Davies and Day 1998), interfere with human use of a water body (Pieterse 1990), or alter ecosystem and community dynamics (Nichols 1991).

Aquatic weeds can be alien plants or invasive native species and one species is not necessarily problematic everywhere it occurs. Identification of an aquatic weed problem depends very much on the specific situation (Pieterse 1990). Urban areas and areas of intensive human use are often disturbed nutrient enriched systems which offer conditions beneficial to plant growth and it is often in these situations that aquatic plants become problematic. Aquatic weeds are thus often a consequence of other underlying environmental problems, not the cause themselves (Den Hartog 1991).

Effective studies of aquatic weeds therefore involve not only identification of the extent of the problem for a particular water body, but also an understanding of the underlying causes and the conditions associated with weed growth.

1.1.1 Identifying the problem: the effects of aquatic weeds

The nuisance value of a plant species in question needs to be judged in terms of:

1. public perception and hinderance of human activities (Gopal 1987)
2. effect on stream flow (Pitlo and Dawson 1990)
3. effect on water quality (Gopal 1987)
4. effect on other organisms in the environment (Nichols 1991)

These factors must be weighed against the plant’s function in an ecosystem and the possible benefits of its presence:

1. uptake of nutrients in eutrophic systems (Musil and Breen 1985)
2. increasing water clarity and oxygenating the water column
3. substrates for micro-organisms, refuges and feeding areas for fish and other aquatic fauna (Davies and Stewart, Quick and Harding 1994)

1.1.2 Understanding the problem: conditions controlling weed growth

Factors which have been shown to be important in aquatic weed growth are:

1. light availablity (Spencer and Bowes 1990)
2. temperature (Spencer and Bowes 1990)
3. nutrient supply (Spencer and Bowes 1990)
4. salinity (Haller et al 1956)
5. channel shape and stream flow rate (Gopal 1987)
6. competition and herbivory (Van Donk & Otte 1996)

This is the context in which the aquatic weed problem on the Westlake wetland in False Bay, Cape Town, will be assessed.

1.2 Project background

1.2.1 Study area

The Westlake wetland, is a freshwater wetland connected to the more saline Zandvlei system which flows into False Bay, Cape Town (Figure 1). The wetland is used for recreational purposes such as fishing, bird watching and canoeing but excessive weed growth often interferes with these activities. Investigation into the aquatic weeds in the system was initiated by the local residents because there is a general perception that the quantity of aquatic weeds in the wetland has been increasing and it was felt that an ecological assessment would be beneficial for evaluating the management alternatives.

While chemical and biological control methods have been attempted in the past, they have not proved successful and at present the weeds are cleared mechanically once a year (Quick and Harding 1994). In March 1998 an extensive mechanical and manual eradication programme was conducted after a very serious infestation occurred.

The morphology and water level of the Zandvlei system have been manipulated since the 1870's (Heydorn and Grindley 1983). Salinity and water levels are controlled with a weir (Harding 1994), and in Westlake itself deep canals have been excavated, and artificial levee's built up along the river courses (Figure 2). The system is eutrophic in terms of the OECD open-boundary classification and nutrient levels are reported to be increasing (Harding 1994)

While the vlei has been extensively studied (Davies 1982, Harding 1994, Davies and Day 1998) information on the Westlake wetland is restricted to a survey of the emergent vegetation (Azorin 1988) and various nutrient measurements taken by the Cape Metropolitan Council.

1.2.2 Aims of project

This project will investigate the community ecology of the plants of the Westlake wetland in more detail, and assess the applicability of global aquatic weed research to the specific weed problems of the Cape Peninsula. I therefore aim to:

- elucidate the specific detrimental effects caused by the aquatic weeds and thus acertain the extent of the water weed problem.
- investigate the abiotic and biotic conditions associated with the growth of the weeds in the wetland.

This information will be:

- compared to the global literature available on the ecology of the aquatic weeds
- used to assess the relative merits, in economic, social and ecological terms, of the different options which are available for managing the aquatic weeds in the Westlake wetland.

1.3 Summary of the aquatic weeds on the wetland

In this study the term 'aquatic weed' will exclude emergent plants such as *Phragmites* and consider only plants with most of their leaf and stem tissue on or under the water surface (Pieterse 1990). This is because emergent weeds are sufficiently different in their effect on a wetland (Pitlo and Dawson 1990) and in their possible control measures (Wade 1990) for them to fall out of the bounds of this study.

The main aquatic weeds in the Westlake wetland are *Eichhornia crassipes Mart.* (water hyacinth), *Ceratophyllum demersum L. (*coontail), and *Azolla filiculoides Lam*. Other classified 'weeds' present or recorded in the past include *Myriophyllum aquaticum, Lemna spp*, and *Salvinia molesta. Potamogeton pectinatus* is also present but is mainly concentrated in the vlei itself.

Eichhornia crassipes

Eichhornia crassipes is a well known floating aquatic weed. Coming originally from South America it has now become a nuisance weed in practically every country in the world (Pieterse & Murphy 1990). Although it does reproduce sexually it is its pronounced vegetative propagation that causes it to be a problem (Pieterse & Murphy 1990). It can take full advantage of nutrient rich conditions by increasing its growth rate and has been shown to double its biomass in as little as 11 days (Gopal 1987). *Eichhornia* often has a direct effect on human utilisation of a wetland area and is thus considered to be highly noxious weed (Gopal 1987). *Eichhornia* first appeared in the Westlake system in the late 1980's (John Fowkes pers.comm).

Azolla filiculoides

Azolla filiculoides is also very apparent on the wetland. It is a fern which has a symbiotic relationship with a nitrogen-fixing blue-green alga *Anabaena azollae (*Wagner 1997) but also shows increased growth in nutrient rich conditions. It can double its mass in 3.2 days. It is often not considered as a weed because being smaller than *Eichhornia* it does not interfere directly with human activity (van der Zweerde 1990). Being a surface collonising plant however, it is possible that its effects on water quality are greater than its biomass would predict. There is no record of the first appearance of *Azolla filiculoides* on the wetland.

Ceratophyllum demersum

Ceratophyllum demersum is another prominent weed in the system. It is a cosmopolitan aquatic weed and it is unclear whether it is an alien in South Africa or not (Schulthorpe 1967). It is a submerged weed and although it does not have roots, it can anchor itself to a certain extent to the substrate with modified leaves (Best and Visser 1987) Being a submerged weed its effects on a system and environmental requirements are fairly different from those of the other two species (Carpenter and Lodge 1986). It reproduces sexually and asexually and has been shown to be an initial coloniser in cleared conditions (Howard-Williams, Schwarts and Reid 1996).

2:METHODS

2.1 Study site

From April to September 1998 the weeds were studied on the Westlake wetland (Figure 2). The wetland consists of two inflowing rivers, a series of two meter deep channels, an open water area (Rutter backwater), and extensive reed beds. The aquatic plants in question grow in the rivers and the channels and to a certain extent on the open Rutter backwater. These areas were cleared of weeds in March 1998.

2.2 Seasonal changes in aquatic plant cover

Seasonal changes in aquatic plant cover were monitored over 5 months: After the clearance in March a descriptive study of the pattern and rates of regrowth of the weeds was undertaken. Four sites on the wetland were chosen for intensive monitoring (Figure 2): one at the point of entry of the wetland to the vlei (Railway), one on each of the rivers (Keisers and Westlake), and one in the Rutter backwater. From June onwards another sampling site was added in one of the channels (Figure 2). These sites were 2mX2m in area (or 2m stretches of river) and were sampled approximately every three weeks from 28th April and every two weeks from 15th July to 30th September.

The percentage of the surface covered and the relative cover of each aquatic plant species were estimated at each site. Accurate measures of relative importance were difficult because aquatic plant species range from spreading submerged plants to minute floating fern's. Because the *Ceratophyllum* is a submerged plant it was possible to have 100% of the surface covered by floating plants with 100% cover of submerged plants underneath. This situation was presented as 50% submerged and 50% floating cover in the results. Photographs of the five sites were taken each time to supplement this information.

2.3 Water chemistry

On the same day between 2pm and 3.30pm at each site pH, dissolved oxygen, conductivity and temperature were measured 0.1-0.2m below the surface from a canoe. Instruments used were: YSI dissolved oxygen meter (model 50B), Crison pH meter 506. Until 27th August a Jenway model 4070 conductivity meter was used, followed by a Crison 523 meter.

In September, pH, temperature, dissolved oxygen and light intensity were measured in open water, pure stands of *Ceratophyllum*, and under mats of *Eichhornia* and *Azolla*. These measurements were taken in one of the 2m deep channels where the water was not perceptably flowing (X- Figure 2). The *Eichhornia* and *Azolla* mats had *Ceratophyllum* growing underneath. Six replicates of each vegetation type were taken at 0.2m depth. While these factors do change with depth, it was considered that for the purposes of comparison between vegetation types one standard measuring depth was sufficient.

The measures of light intensity were done with a LI-COR underwater type SA sensor and the light intensity (in µmol/s/m^2 per µA) was measured at 100mm depths down the water column. From this the depth at which 5% of the surface light was left (light compensation point for most aquatic plants- Spencer and Bowes 1990), was calculated.

Data on water chemistry and nutrient concentrations in the two rivers, the Rutter backwater and the vlei from 1978 to present were obtained from the Scientific Services branch of the Cape Metropolitan Council. Methods for the chemical analysis of these samples can be found in Harding (1992).

2.4 Plant biomass

At the same site (X), at the same time, the wet weight of plant material contained in a 0.5X0.5m quadrat of a pure stand of each of *Azolla* and *Eichhornia* was weighed in the field with a spring balance. For the submerged *Ceratophyllum* a different harvesting technique was employed: plant matter from a unit area was obtained using a quanititative sampler developed by Howard-Williams and Longman (1976). This consists of a metal pole with a scythe-like attachment for cutting the weed. The pole can be lowered to the bottom, twisted to cut the plants, and then raised with all the plant matter still attached. The sampler was developed for *Potamogeton* and effectively sampled a 0.0625m^2 area of this plant, but because *Ceratophyllum* has a more branching growth form the area harvested in each sample was greater. The area harvested was always the same but could only be estimated at roughly 0.56m^2. Six replicates of each vegetation type sampled were taken from the same area. Because at the time that these measurements were taken the mats of *Azolla* on the main wetland were sparse and discontinuous some additional measures of *Azolla* weight were taken from a small area of standing water on the other side of the levees (marked Y in Figure 2) where very dense stands of *Azolla* proliferated.

The biomass of *Ceratophyllum* found under mats of each floating weed was also recorded in the same way. Ten samples of each plant were taken back and dried to determine wet:dry mass ratios.

2.5 Dynamics in the Westlake system

To monitor the control that wind and current strength have on the position and permanence of the weed mats a release experiment was performed. Square polystyrene markers of different colours were tied to unimodular *Eichhornia* plants and released at four points on the wetland: one on each river, one on the NW and one on the SE side of the rutter backwater (the dominant wind directions) - A-C Figure 2. Twenty plants were tagged at each site and every two weeks the position and the number of modules of each plant was noted. Data on windspeed and direction, and rainfall over the period of study were obtained from the meteorological office of Cape Town International Airport.

2.5 Data Analysis

Methods for data analysis follow Zar (1996). Statistical tests were run on STATISTICA (version 5). Where assumptions of normality did not hold the appropriate non-parametric tests were used. All ANOVA's were followed by Tukey's HSD test for post-hoc comparison of means.

3: RESULTS

3.1 Aquatic plant list

Appendix I is a list of all the aquatic plants recorded in the system over the study period.

3.2 Nutrient changes with time

Table 1 summarises the average concentrations of various nutrients in the wetland for two time periods (from 1978-1982 and 1993-1998). There is no significant increase in the concentrations of most of these nutrients in the system (t-test independent samples, $p<0.05$). Total phosphorus concentrations have decreased in the two rivers but increased in the vlei. Nitrate and nitrite have increased in the Westlake river. Ammonium has decreased in the Keisers river. Other nitrogen and phosphorus values have not changed significantly but total suspended solids and conductivity have decreased significantly in almost all cases.

3.3 Effects on water quality:

The effects that stands of pure *Ceratophyllum, Eichhornia,* and *Azolla* have on various physical properties of the water are shown in Figures 3 and 4. Both *Azolla* and *Eichhornia* decrease the light intensity to less than 5% of daylight within 10cm of the surface (Figure 3). *Ceratophyllum* has a much more gradual effect, but it still decreases light penetration relative to the open water.

The effect of the various vegetation types on light intensity (at 0.1m), pH, dissolved oxygen and temperature (at 0.1-0.2m) is shown in Figure 4. Temperature, dissolved oxygen and pH of the water are significantly higher in *Ceratophyllum* mats (1-way ANOVA, $F_{(3,16)}$ $p<0.01$). Although *Azolla* has a highly significant effect on light intensity (1-way ANOVA $F_{(3,13)}=163.79$ $p<0.001$) it does not influence temperature, dissolved oxygen or pH significantly. Dissolved oxygen and pH values are much lower under *Eichhornia* mats.

This difference that the effects of *Eichhornia* and *Azolla* have on the physical and chemical characteristics of the water medium is reflected in the amount of *Ceratophyllum* found growing under each species (Figure 5). While the amount of *Ceratophyllum* growing under the *Eichhornia* mat was significantly less than a pure *Ceratophyllum* stand (1-way ANOVA, $F_{(2,11)}=11.2$ $p<0.01$), under *Azolla* there was no significant decrease in *Ceratophyllum* biomass.

Table 3 shows the biomass per square meter of water and percent nutrient contents of each vegetation type.

Table 3: Biomass and nutrient contents of *Ceratophyllum*, *Eichhornia* and *Azolla*

	wet:dry mass ratio	sd	n	dry mass ($g\ m^{-2}$)	sd	n	nitrogen content (%dry mass)	phosphorus content (%dry mass)
Ceratophyllum	15.6	4.9	10	274	141	5	2.66(1)	0.26(1)
Eichhornia	15.7	4.3	8	614	204	6	3.12(2)	0.39(2)
wetland *Azolla*	19.7	6.3	11	46	18	3	3.84(3)	0.16(3)
dense *Azolla*	19.7	6.3	11	183	~	2		

Wetland *Azolla*= surface area covered by *Azolla* on the wetland in September 1998. Dense *Azolla*=maximum surface area cover attainded by *Azolla* during study. Nutrient contents from literature (1)- Boyd 1978 (2)- Gopal (1987) (3)-Cary & Weerts (1992)

3.4 Seasonal regrowth

Figure 6 shows the percentage cover of the major aquatic plants over the period of study. Water temperature and rainfall (an indication of current speed), are also included. Generally the water surface was covered very quickly (both after the clearing in March and after a disturbance such as high rainfall) but the relative amounts of the different plants change. In most cases *Ceratophyllum* comes in first, followed by *Azolla* and then *Eichhornia*.

More detailed seasonal changes for the Keisers river are shown in Figure 7, where water chemistry and nutrient data are related to vegetation cover.

Figure 8 shows how the number of modules of each tagged plant increased over the time of monitoring. Because the modules tend to break apart it is better to look at the maximum number of modules than at average number. The increase appears to be roughly linear.

3.5 System dynamics

The map in Figure 9 shows the total amount and direction of movement of the tagged *Eichhornia* plants over the period of study (winter). Movement was identified as due to current or due to wind depending on its direction and position. Current seems to be the main reason for movement in winter, but wind direction can be important on the Rutter backwater. Two individuals from the Westlake river ended up in the Rutter backwater which lends support to the idea that it recieves the bulk of the flood waters before they are released under the bridge.

Figure 10 summarises in more detail the movement noted on the wetland. The negative axis is the effect of current and the positive that of wind. For each sampling event the movement noted since the last sampling event was divided into wind and current movement. Thus each bar represents the total wind/current movement since the last sample and this can be related to the wind and rain patterns over the same time period. Over the winter period when there is a high rainfall, the movement is mostly due to rain rather than wind.

Table 1: Summary of water chemistry data for the periods 1978-1982 and 1993-1998 at five sample points.

	TIME PERIOD	KEISERS RIVER			WESTLAKE RIVER			RUTTER BACKWATER			VLEI SURFACE			VLEI BOTTOM		
		mean	sd	n	mean	sd	n	mean	sd	n	mean	sd	n	mean	sd	n
total phosphorus	1978-1982	0.116	0.081	81	0.214	0.262	81	--	~	0	0.074	0.030	84	0.081	0.045	84
total phosphorus	1993-1998	0.085	0.068	41	0.081	0.088	37	0.087	0.029	32	0.087	0.041	43	0.090	0.044	44
SRP	1978-1982	0.018	0.035	84	0.042	0.081	84	--	~	0	0.006	0.013	85	0.005	0.012	85
SRP	1993-1998	0.026	0.030	42	0.024	0.029	38	0.009	0.008	32	0.014	0.017	45	0.014	0.014	45
nitrate and nitrite	1978-1982	0.383	0.324	83	0.348	0.293	83	--	~	0	0.155	0.153	84	0.131	0.125	84
nitrate and nitrite	1993-1998	0.448	0.480	37	0.908	0.423	34	0.079	0.129	35	0.142	0.209	38	0.096	0.125	38
ammonium	1978-1982	0.110	0.066	85	0.124	0.078	85	--	~	0	0.095	0.140	84	0.096	0.102	84
ammonium	1993-1998	0.084	0.073	48	0.145	0.122	45	0.108	0.240	40	0.067	0.068	48	0.089	0.153	50
total nitrogen	1978-1982	--	~	0	--	~	0	--	~	0	--	~	0	--	~	0
total nitrogen	1993-1998	1.759	0.698	18	2.756	0.524	15	1.317	0.504	19	1.086	0.475	19	0.963	0.451	19
total SS	1978-1982	37.278	62.461	79	33.909	66.287	77	--	~	0	29.231	17.578	78	41.385	35.780	78
total SS	1993-1998	9.046	7.625	28	22.616	49.09	26	12.647	7.071	17	21.000	9.823	30	29.333	13.717	30
conductivity	1978-1982	134.5	212.4	88	220.4	433.2	88	~	~	1	1434.9	608.5	103	1652.8	690.0	103
conductivity	1993-1998	48.9	10.2	78	55.6	36.7	69	363.3	370.3	54	945.5	549.8	84	1196.4	678.7	77

SRP= soluble reactive phosphorus, total SS= total suspended solids. All nutrient values are in mg l^{-1}, conductivity in mS m^{-1} 25°C. Data from Scientific Services, CMC. Significant differences ($p<0.05$) marked in bold.

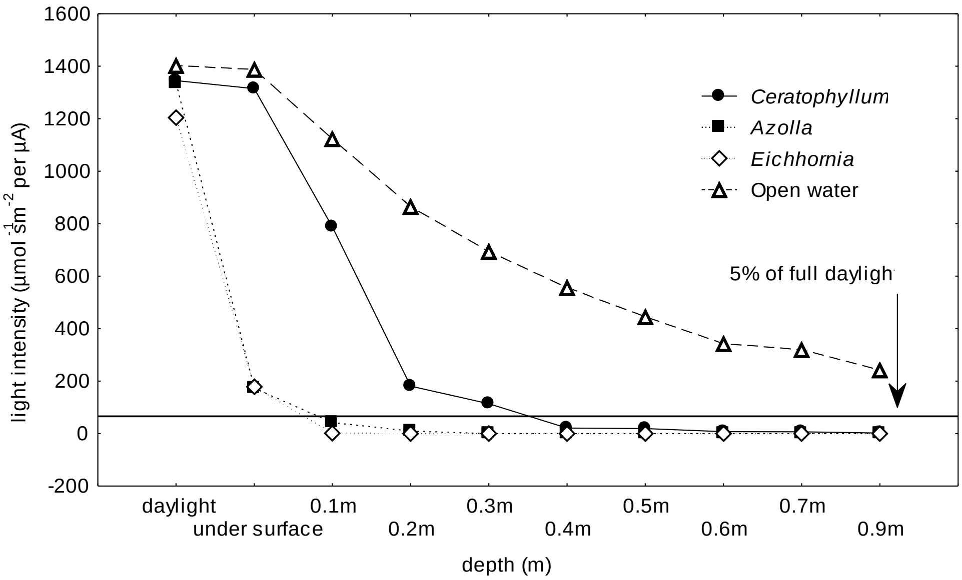

Figure 3: The decrease of light with depth under pure stands of *Eichhornia, Azolla, and Ceratophyllum*. (n=6).

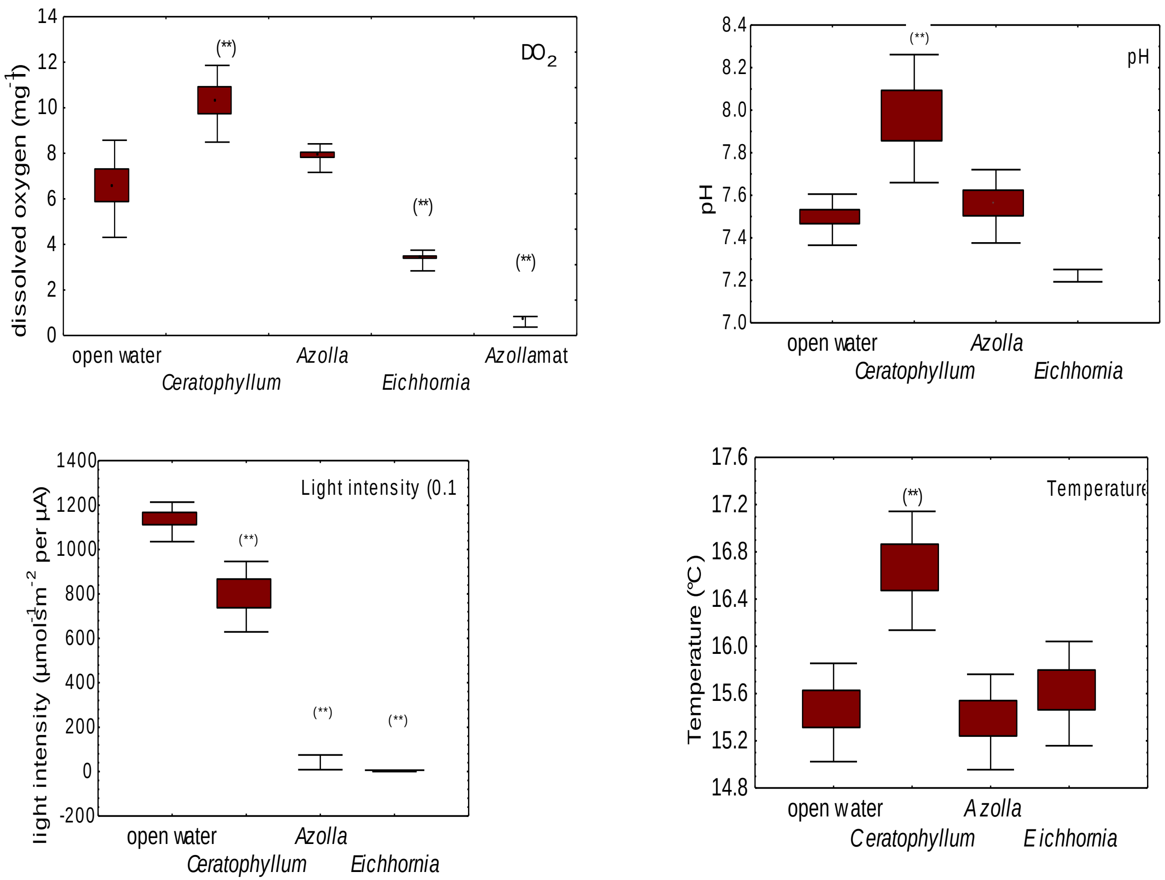

Figure 4: The effect of pure stands of Ceratophyllum, Azolla, and Eichhornia have on dissolved oxygen, pH, light intensity, and temperature of the water. (**)=Significant difference from open water (Anova $p<0.01$). box=standard error, whisker=standard deviation, n=6.

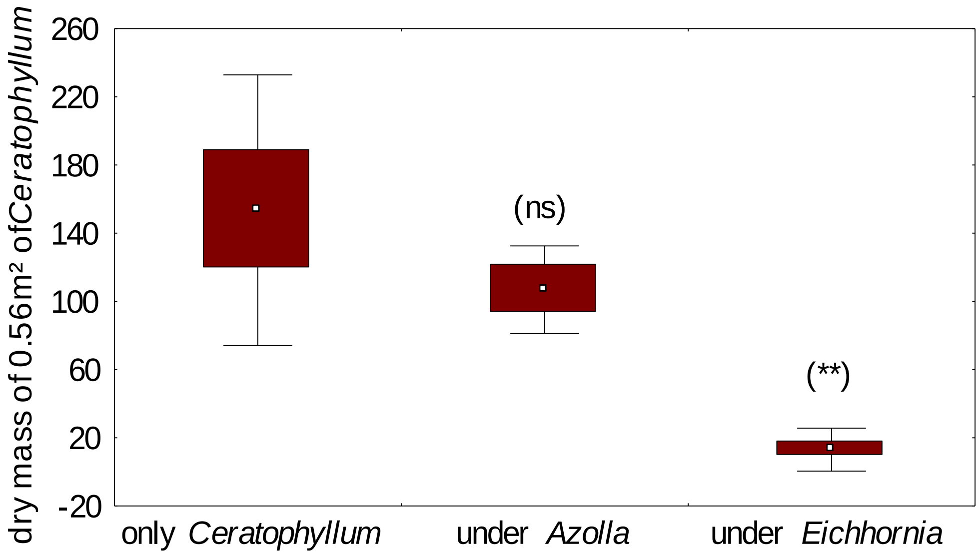

Figure 5: The effect that floating mats of *Azolla* and *Eichhornia* have on the biomass of submerged *Ceratophyllum*. Box=std error whisker=std deviation, 6 replicates. significant differences indicated (** $p<0.01$)

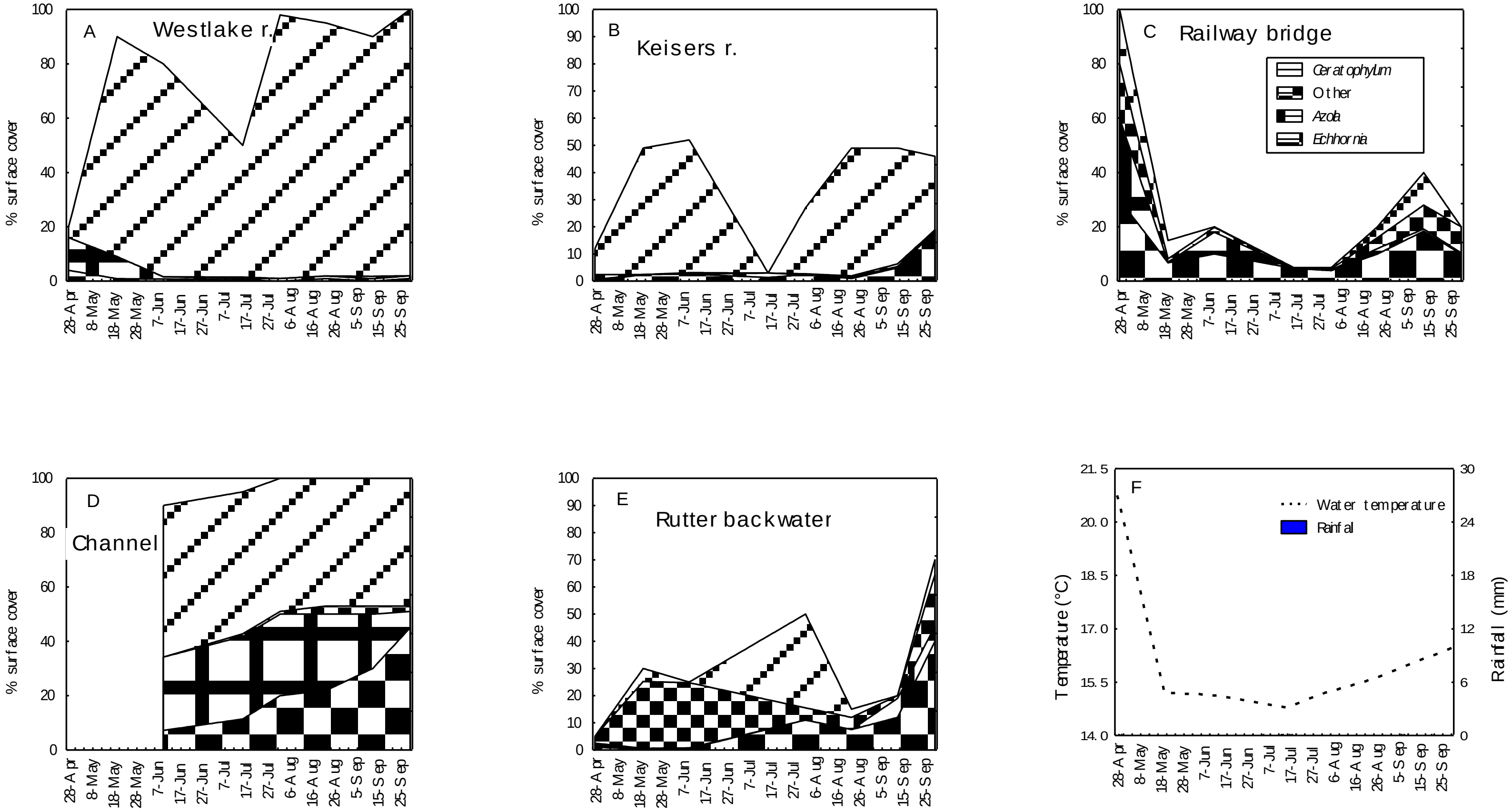

Figure 6, A-E: Relative cover of the major weeds at 5 sampling sites (figure 2) on the Westlake wetland from 28 April-30 September 1998, F: Rainfall and water temperature over the same time period. Rainfall values from Cape Town International meteorological office.

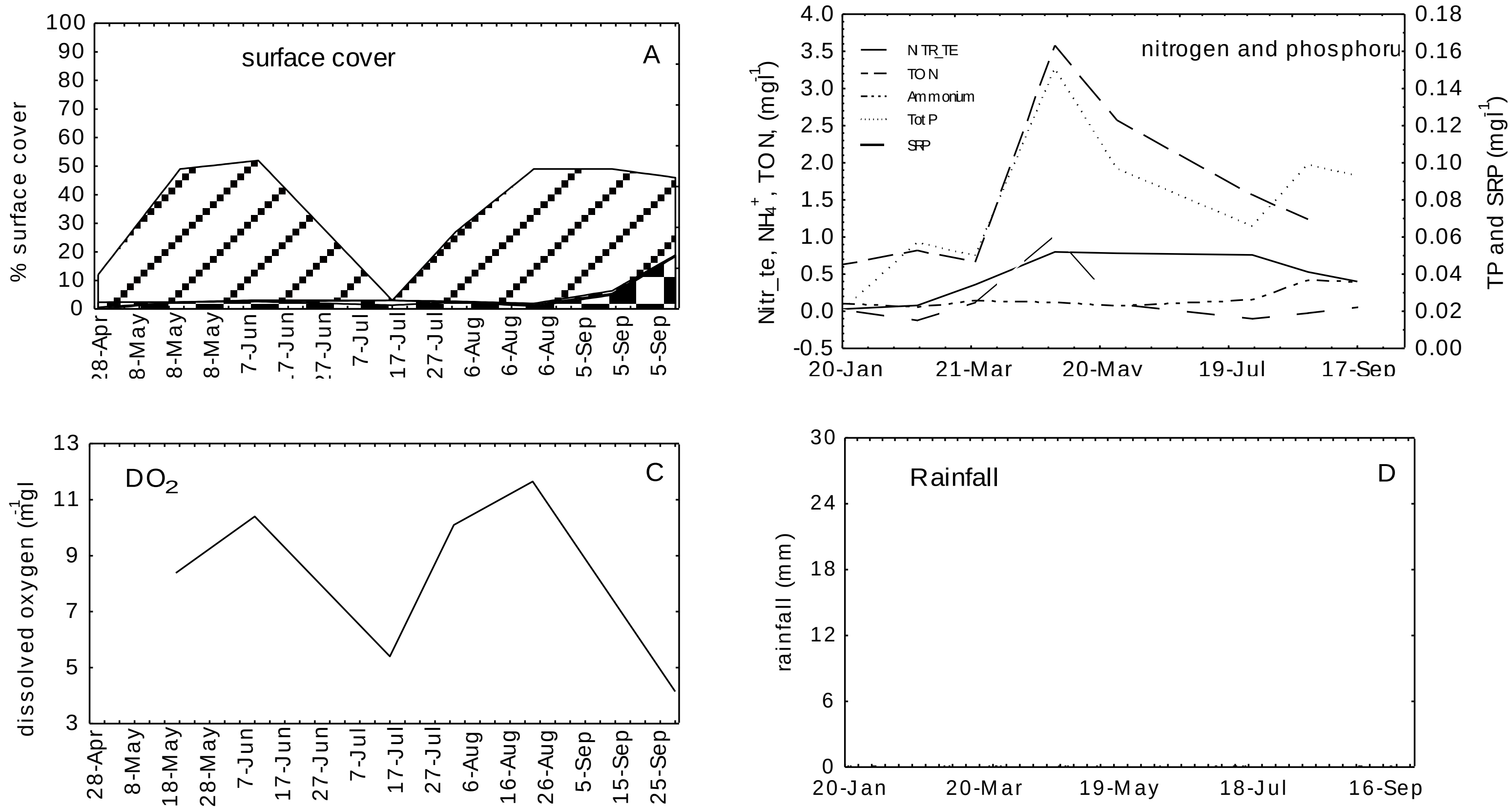

Figure 7: Nutrient (B) and dissolved oxygen (C) data for the Keisers river site in relation to aquatic vegetation cover (A) and rainfall (D) during 1998. (Nutrient data from Scientific Services CMC, rainfall data from Cape Town International meteorological office)

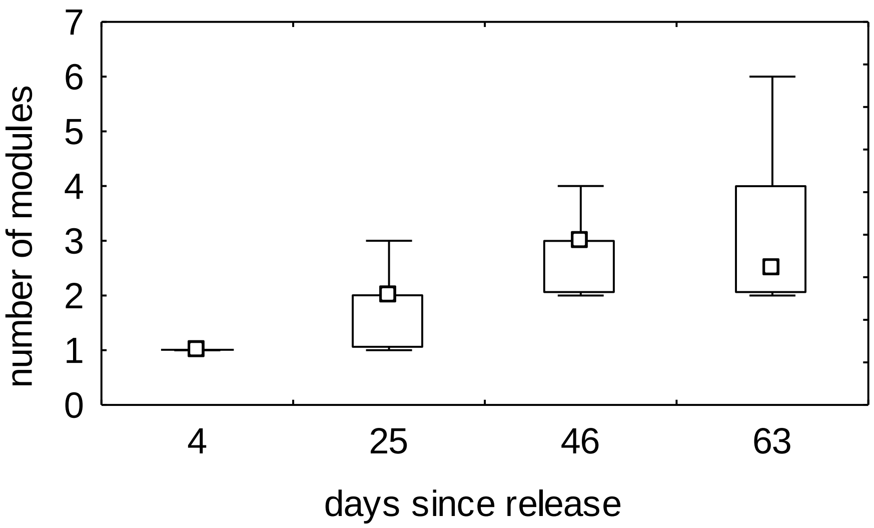

Figure 8: Increase in number of modules in tagged Eichhornia individuals with time. (median, max. and min. values. n ranges from 80 to 30)

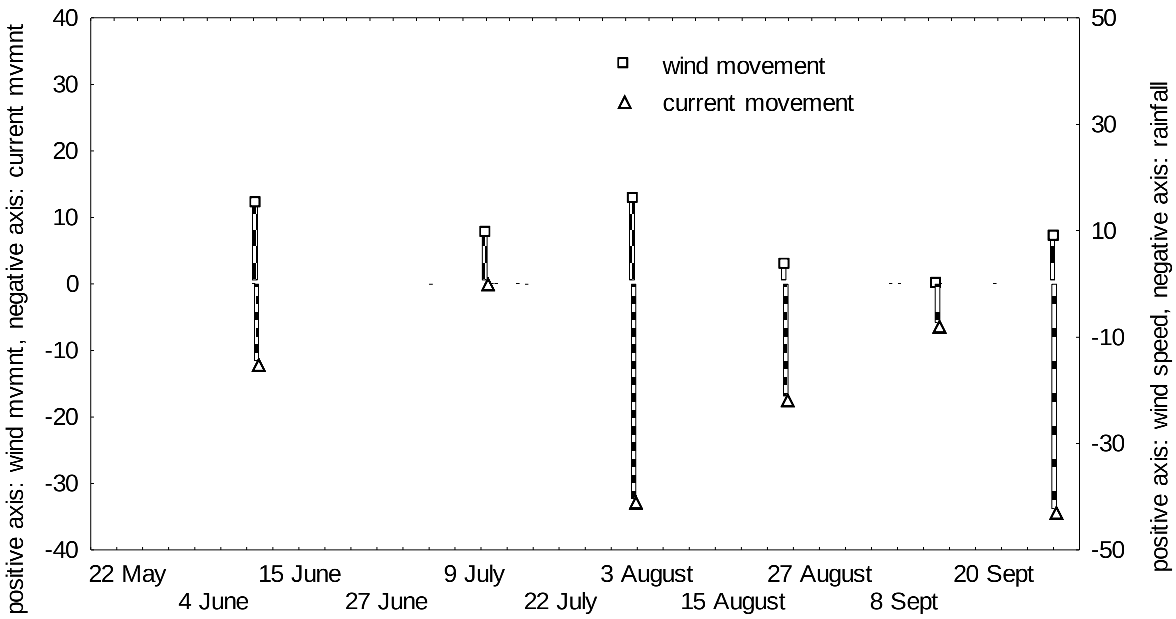

Figure 10: An indication of the causes of movement of tagged *Eichhornia* individuals over the period June-September 1998 at Westlake.

Wind and current data from Cape Town International meteorological office- amount of movement calculated from the total number of plants which moved since last sampling event.

4: DISCUSSION

4.1 Effects of the aquatic plants on the Westlake wetland

In the introduction five factors were identified to judge the nuisance value of aquatic weeds and their effect on a wetland:

1. public perception
2. hinderance of human activities
3. effect on stream flow
4. effect on water quality
5. effect on the ecosystem

4.1.1 Public perception, hinderance of activities, and stream flow

From these three perspectives *Eichhornia* has much more of an effect than the other two major weeds. The public is much more vocal about it because it is more notorious and also because it prevents use of the wetland for canoeing and fishing when it has grown into impenetrable mats. Neither *Ceratophyllum* nor *Azolla* directly hinder human use of the wetland in this way.

Azolla, with its finely divided floating growth form has no effect on stream flow (Van der Zweerde 1990). There is no information on how much *Ceratophyllum* hinders water flow but it is not a rooted plant (Sculthorpe 1967) and Figure 6 suggests that it is washed out of the system very quickly with winter rain. *Eichhornia* however, has been reported to decrease streamflow by 40-95% (Gopal 1987) and this is the major reason it is cleared from the river channels each year.

4.1.2 Water quality and ecosystem effects

The effects of the submerged (*Ceratophyllum)* and the floating (*Eichhornia and Azolla)* plants on water quality and ecosystem function are quite different. As a submerged plant *Ceratophyllum* increases temperature, dissolved oxygen and pH of the water body (Figure 4 and Musil et al 1976). It is also probable that it functions as a refuge for juvenile aquatic animals and as a substrate for various invertebrates and filter-feeders in the same way that *Potamogeton pectinatus*, another submerged plant, has been shown to do in Zandvlei itself (Davies 1982, Carpenter and Lodge 1986)

While the floating plants *Eichhornia* and *Azolla* both decrease light penetration to levels unsuitable for photosynthesis a few centimeters below the surface (Figure 3), they affect other physical properties of the water in the wetland to different degrees (Figure 4). This is presumably due to the small, finely divided structure of *Azolla* - the mats can be disturbed by wind and broken up by the submerged plants growing underneath and it does not form a permanent, impenetrable barrier on the surface of the main wetland. Thus while it might temporarily block out the light to the submerged plants underneath, in the long term submerged plants seem able to survive and grow under the *Azolla* mats (Figure 5). That photosynthesis is inhibited to some extent however, is clear from the dissolved oxygen values which are lower than in pure *Ceratophyllum* stands (Figure 4).

However, in the shallower, less disturbed backwaters of the wetland *Azolla* achieves thick, permanent surface cover. Under these mats oxygen concentration is as low as 0.2mg l^{-1} (Figure 4) and no other plants grow.

Mats of *Eichhornia* are much more permanent and effectively block diffusion of oxygen (Figure 4). The reduced amount of *Ceratophyllum* found growing under the *Eichhornia* mats (Figure 5) indicates that this environment is much less suitable for submerged plants and the low dissolved oxygen measurements (Figure 4) mean that this is likely to hold true for all aquatic organisms.

The effects of floating plants can thus be said to be proportional to the amount of movement shown by the plants: only when these floating mats become permanent do their effects on water quality and aquatic organisms become significant. *Azolla* is highly mobile and only really proliferates in shallow standing water (Wagner 1997). On the wetland it only covered the surface completely for short periods of time before being blown elsewhere by the wind. *Eichhornia* can also be very mobile (Figure 9) but eventually forms permanent floating mats or sudds.

If we consider the effect of the weeds in relation to the actual biomass present the *Azolla* becomes more significant. The same surface area will be completely covered by about one tenth of the amount of *Azolla* as of *Eichhornia* (Table 3) but it has about one third of the effect on dissolved oxygen, pH, and biomass of *Ceratophyllum* as *Eichhornia*.

4.2 Conditions promoting growth

4.2.1 Seasonal controls of weed growth

The aquatic plants were monitored for five months (April-September 1998) and so there is detailed information available for aquatic plant growth only from late autumn to early spring.

However, it becomes clear that on a seasonal scale, distribution and growth of aquatic plants is controlled by temperature and stream flow.

Plants of the three species have different temperature requirements and this is displayed in their interactions on the wetland (Figure 6). *Eichhornia*'s optimum temperature for growth is 25-27°C (Gobal 1987), *Azolla*'s is slightly less (18-28°C, Wagner 1997) and *Ceratophyllum* displays high growth rates at quite low temperatures (10-15°C in some northern temperate lakes- Best and Visser 1987). It is also possible that, being partially rooted, *Ceratophyllum* is more resistant to fast currents than are the other two weeds. Thus during the winter period of study *Ceratophyllum* was the major weed.

In the three sites on the river (Westlake, Keisers, Railway- Figure 2), which have high stream flows during winter *Ceratophyllum,* is dominant (Figure 6). It re-colonises any gap made by mechanical clearing or winter floods very quickly. The colonising abilities of *Ceratophyllum* have been noted in other studies on plant re-growth (Howard-Williams, Schwarts and Reid 1996). However *Eichhornia* was starting to take over on the surface during the last few weeks of monitoring. (This was accompanied by a concurrent decrease in dissolved oxygen concentrations as would be expected- Figure 7).

In comparison, the site in the channel displays the succession of plants unaffected by winter flooding: the initial coloniser *Ceratophyllum* is covered by a surface film of *Azolla* quite quickly, but over time the *Eichhornia* becomes the more dominant of the floating weeds. This is probably due to a combination of the effect of increasing temperatures and the better long term competitive ability of *Eichhornia* (DeSilva et al (1984) in Gopal 1987). The site on the Rutter backwater was very variable both in species composition and in amount of cover. This reflects the information shown in Figure 9, that wind has an effect on the distribution of the aquatic plants at this site.

Growth of the *Eichhornia* plants appeared to be linear (Figure 5), rather than exponential as was expected. This could be because the sampling method was underestimating their growth by not taking broken off modules into account. However the maximum number of modules that the unimodular tagged plants grew over 63 days indicates that the time taken for *Eichhornia* to double in size is about 20days and while the most rapid doubling time recorded is 6 days, this value is in accord with other records for similar natural systems (Gobal 1987).

4.2.2 Long term control of weed growth

It is less easy to track the conditions that promote the aquatic weed growth over longer periods of time. Plates 1 and 2 show the wetland in 1980 and in 1998. In the 1998 photograph the channels and Rutter backwater had already been cleared of weeds, but the extent of the weed growth is visible in the two rivers. The weeds have clearly increased since 1980 and it has been suggested that this is due to increased nutrient concentrations in the system (*Azolla,* *Ceratophyllum* and *Eichhornia* all show increased growth rates with increasing nitrogen and phosphorus concentrations of up to 10-20mg l^{-1}, Gobal 1987, Wagner 1997, and Boyd 1978).

Harding (1994) states that nutrients in this system have increased but the data updated to 1998 do not support this (Table 1). While total phosphorus and SRP have increased in the vlei itself, the concentrations coming in from the two rivers are less now than they were fifteen years ago. Nitrate, nitrite and ammonium concentrations have also generally decreased. Nutrient concentrations in the Rutter backwater are always less than in the two rivers. These concentrations are about 10x higher than other more pristine Western Cape river systems, however (Harding 1994), and it is therefore likely that the nutrient loading is playing a part in the weed growth.

It is important to remember the seasonality of the system: Figure 7 shows how nutrient concentrations rise to about 7 times their summer values just after the first winter rains (when the amount of aquatic weeds in the system is at its lowest). Estimates of the amount of nutrients available to the plants based on annual averages are therefore exagerated.

Conductivity has decreased significantly since the weeds first appeared in the rivers. This is probably because the height of the wier from Zandvlei to the sea was raised during this time (Harding 1994). During spring tides salinity changes at the vlei mouth can affect conditions in the inflowing rivers. Increased salinity has been shown to affect growth of *Eichhornia* and other aquatic plants quite significantly (Table 4). It is very possible that the lower salinities in the wetland over the last few years (Table 5) are playing a part in the proliferation of the weeds in the system. While salinity does increase with depth in still waters this would not invalidate the comparative decrease shown in Table 1. Also, the amount of mixing in the vlei (and presumaby on the wetland as well) mean that surface measures give a good representation of the salinity levels experienced by the plants (Harding 1994).

Table 4: Critical salinity levels (g l^{-1}) for three aquatic weeds (data from Haller et al 1974)

	no effect on growth	toxic concentration
Eichhornia crassipes	<0.83	2.5
Hydrilla verticiliata *	<3.33	10
Azolla filiculoides	growth decreases as salinity increases	

* There is no information for *Ceratophyllum demersum,* but *Hydrilla verticiliata* is a submerged weed of similar growth habits (Van Haller and Bowes 1976)

Table 5: Conductivity values from Table 1 (mS m^{-1}) converted to salinity values (g l^{-1})

	Inflowing rivers	Rutter backwater	Vlei surface	Vlei Bottom
1978-1982	1.06	~	8.6	9.9
1993-1998	0.31	2.18	5.7	7.2

Conversion: 1mS m^{-1} = aproximately 6/1000 g l^{-1}

The salinity in the Rutter backwater is quite high even at present (Table 5) and it is possible that this is a reason why it remains open during the summer when the rest of the wetland is clogged with weeds.

Other things which could possibly affect weed growth are wind, which causes a fair amount of disturbance to the weeds in the open backwater areas (Figure 9), and herbivory. *Ceratophyllum* is heavily eaten by red-knobbed coots (*Fulica atra)* (pers. obs. and Van Donk & Otte 1996) and it is possible that herbivory is controlling the amount of C*eratophyllum* on the wetland to some extent.

4.3: Managing the weeds on the Westlake wetland

The negative effects of the aquatic weeds on the functioning of the wetland are enough to warrant some form of control. *Eichhornia* in particular has a marked effect on the water quality as well as interfering with human activities.

4.3.1 Present control programme

Table 2 gives the costs of the present methods of clearance of the aquatic weeds. The combined cost of the mechanical and manual removal this year is thus estimated to be about

R56 000. Various uses for the 2 000 tonnes of cleared weed are being experimented with: mulch for soil, compost, and pig feed, but it is not clear how successful this is (Dean Ferriera, Cape Nature Conservation).

Table 2: Breakdown of the available information on the costs of removal of aquatic weeds from Westlake

	costs of mechanical removal (rands)	*costs of manual removal (rands)*	*approximate amount removed (kg)*
1998	-	45 000	2 $x10^6$
avg. of last 5 years	10 581	-	-

Figures from South Peninsula Municipality: Nature Conservation and Southfield Road Branch

Because the weeds have not yet achieved maximum seasonal growth we are unable to assess how much more effective a combination of intensive manual clearing and mechanical removal is compared with simple mechanical removal. However, manual removal triples the cost of the clearing process, and it is unlikely that its effects will be significant enough to obviate the need for mechanical clearing again next year.

The present time of clearing is in March/April before the winter rains. This is to reduce the hydraulic resistance in the rivers for winter flooding. The *Eichhornia* is sensitive to cold and high flow rates (Gobal 1987), so this is the most effective time to clear the weeds, because it will keep the system open for longest. *Eichhornia* has only started to grow back in a way that interferes with use of the wetland after 6 months (Figure 6).

About 2 000 tonnes of weed were cleared out of the system in 1998 (Dean Ferriera, Cape Nature Conservation). Using the nitrogen and phosphorus dry weight contents reported for *Eichhornia* under similar nutrient conditions (3.12 and 0.36 respectively Musil and Breen 1977 in Gobal 1987) one can estimate the amount of nutrients removed from the system to be about 4 000kg nitrogen and 500kg phosphorus. This is roughly equivalent to other values reported in the literature (Musil and Breen 1985: 15 000kg N for 20ha *Eichhornia*). Using inflow data from Harding (1994), and average Total N and P concentrations of 2.5 and 0.12 mg l^{-1} respectively, one can calculate the mean annual nitrogen and phosphorus loads entering Zandvlei to be 55 000kg and 2 600kg respectively. Thus amount contained in the aquatic weeds is a significant proportion (±10%) of the total nutrients in the system. Other investigations into nitrogen distribution in wetland systems support these calculations: Isirimah et al (1976) in Wetzel (1983) showed that macrophyte vegetation accounted for 10-20% of the nitrogen in the system.

It is important to keep these figures in mind when comparing mechanical removal to other possible control methods. If mechanical removal did not occur the weeds would get washed out into the vlei during the winter rains, increasing the nutrient loading in the already eutrophic system.

4.3.2 Other forms of control

Other possible management options include:

- chemical control, which is very expensive and of which it is difficult to assess the costs to the ecosystem (Murphy and Barrett 1990, Davies and Day 1998)
- biological control, which is being attempted on other river systems of the Western Cape but has not yet proved effective
- increasing the salinity.

4.3.3 Effects of Salinity

Broader management plans for the Zandvlei system include changing the present weir and increasing the salinity levels at certain times of year, (Harding 1994). This would allow for control of the salinity of Westlake at the same time. Assuming that the information on the weeds' resistance to high salinities (Table 4) is correct this would be a very simple, effective way of reducing the growth of the weeds on the wetland. Salinity levels are usually at their highest during the summer (Figure 7) when the weeds exibit maximum growth.

4.4 Conclusions

While it is not easy to be sure of the conditions which have promoted the growth of the weeds on the wetland a study of the long term chemisty data suggests that lowered salinities, in conjunction with high nutrient levels, are a factor. The three major species have different environmental requirements and this does seem to be affecting their rates of regrowth and dominance on the wetland, at least on a seasonal time scale.

Eichhornia is the most problematic of the weeds, both from a human perspecive, and in its effect on the ecosystem. Its notorious competitive abilities are also apparent in the system, where it is seen to be taking over from the other two dominant plants *Ceratophyllum demersum* and *Azolla filiculiodes.* However, it is also the most sensitive to low temperatures and high salinities.

It is unlikely that any control method will eradicate the weeds entirely, nor is this necessarily desirable. Regular harvesting in the form of mechanical control is relatively cheap, and, if the removed weeds are taken away and utilised, it can help to reduce the nutrient loads into the eutrophic vlei.

The present programme of harvesting in autumn is likely to keep the wetland clear for longest because cold winter weather and strong currents inhibit the growth of the weeds. It would also be worth experimenting on the effect of increasing salinities however, as this could also decrease the rate at which the weeds grow back.

Finally this study must be considered in context. Wetland systems, particularly highly modified estuaries like Zandvlei, are very dynamic. The community composition at present is not an indication of any long term trends- *Myriophyllum aquaticum,* for example has been a dominant weed in the system in the past (Dick 1984) but is hardly present at all at the moment. The information on the ecosystem effects and community interactions of the weeds during this study, and the conclusions drawn, must be considered in the context of this variable system.

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7: APPENDIX I

species name	family	common name
Azolla filiculoides Lam.	Azollaceae	
Ceratophyllum demersum L.	Ceratophyllaceae	hornwort/coontail
Eichhornia crassipes Mart.	Pontederiaceae	water hyacinth
Myriophyllum aquaticum	Haloragaceae	parrot's feather
Polyganum setulosum Rich.	Polygalaceae	
Potamogeton pectinatus L.	Potamogetonaceae	
Lemna spp.		