Management of a shallow estuarine lake for recreation and as a fish nursery: Zandvlei, Cape Town, South Africa

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Abstract

The estuarine Zandvlei lake is an important regional recreation resource in the SW Cape, South Africa. It is also an important nursery for migrant juvenile marine fish species in the False Bay area. Extensive urbanisation in the catchment, and the regulation of lake water levels, have brought about changes to the water chemistry, hydrology and biota of the system. These perturbations have compromised the fish-nursery role of the estuary and pose water quality-related health and aesthetic threats to the sustained recreational use of the lake system. Optimisation of the existing management practices should be directed towards enhancing water quality and the user-orientated roles of the lake. These include:

- effective stormwater and river management in the catchment to reduce bacteriological and nutrient loading;
- containing peak runoff flows;
- manipulation of the outlet channel to maximise seawater intrusion and allow access for migrant marine fish in early summer;
- control of the macrophyte standing stock to ensure that its vital role is unimpaired; and
- improved education of both users and managers.

Introduction

Zandvlei, an estuarine lake which is the focus of an intensively utilised regional recreation area (Cape Town City Council, 1988; Thornton et al., 1989), is situated on the northwest shore of False Bay, Cape Town. The lake is 2.6 km long, 0.5 km at its widest point and has a maximum depth of approximately 2 m (Harding, 1994). The 93 km² catchment, which is under the jurisdiction of 3 authorities, consists mainly of residential development, but also has areas of viticulture, agriculture, forestry and undeveloped land (Fig. 1). The lake level is artificially maintained with a weir, and the mouth remains closed in summer through the natural formation of a beach sandbar.

During the last 60 years, major man-made changes have occurred in and around the Zandvlei estuary. Modifications to the estuary include a promenade and road bridge which were built over the mouth, and a rubble weir near the mouth which was constructed to control water levels. In 1948, 1950 and during the early 1960s the lake was dredged, and during the mid 1970s the Marina da Gama housing scheme was constructed on the eastern shore (Begg, 1975).

Extensive urbanisation, with a concomitant increase in impervious surface area, has occurred in the Zandvlei catchment. This has resulted in increased runoff and nutrient loading via the influent rivers (Harding, 1994). Together with the raising of the lake's water level, which has reduced the degree of sea water intrusion during late winter and early summer, these urban impacts have caused changes in the water quality (Harding, 1993; 1994), ecological functioning (Stewart and Davies, 1986; Davies et al., 1989; Quick and Bennett, 1989; Dick, 1992; Harding, 1994) and recreational use (Thornton et al., 1989; Harding, 1993) of the lake.

The aims of this paper are to describe the key aspects pertaining to the hydraulic, water quality and biotic characteristics of the lake and its influent rivers, as they affect the recreational use of the lake and its role as a fish nursery for False Bay. This knowledge will be directed towards the optimal management of the lake and its catchment.

Description of the Zandvlei system

Hydrology

Zandvlei's water level is artificially controlled by means of a rubble weir (crest height 0.8 m above mean sea level) situated in the outlet channel. Typical mean annual lake water levels are 0.83 m above mean sea level (AMSL) in winter and 0.92 m AMSL in summer. The bed of the main water body is 0.48 m below MSL (BMSL), the marina canal base is 0.92 m BMSL, and the outlet channel is 0.06 m AMSL.

The mouth of the outlet channel is open to the sea during the winter months, and closes naturally with the formation of a sandbar towards the end of the winter rainfall season. The closure coincides with a seasonal change in the region's prevailing winds from northwesterly to southerly. Mechanical opening of the mouth is occasionally required to allow egress of stormwater and prevent flooding of residential properties in the marina.

Mean annual freshwater inflow to Zandvlei during 1983 to 1987 was estimated using continuous lake level records and data from a calibrated weir in the Sand River subcatchment to be 10^6 $m^3 \cdot a^{-1}$ (unpublished information, Scientific Services Branch, Cape Town City Council). The relative contributions of the individual rivers to the total flow were: Keysers River 45%, Sand River 43% and the Westlake River 12% (Harding, 1994). The total volume of Zandvlei (including the Marina and the outlet channel has been estimated to be 1.33×10^6 m^3 (Harding, 1994).

An extensive system of floodwater detention ponds has been constructed upstream of the lake to reduce the risk of flooding in the lower reaches of the system. In addition, upgrading of the Zandvlei mouth to facilitate more rapid outflow of water has been proposed by the Cape Town City Council as the final part of this flood control programme.

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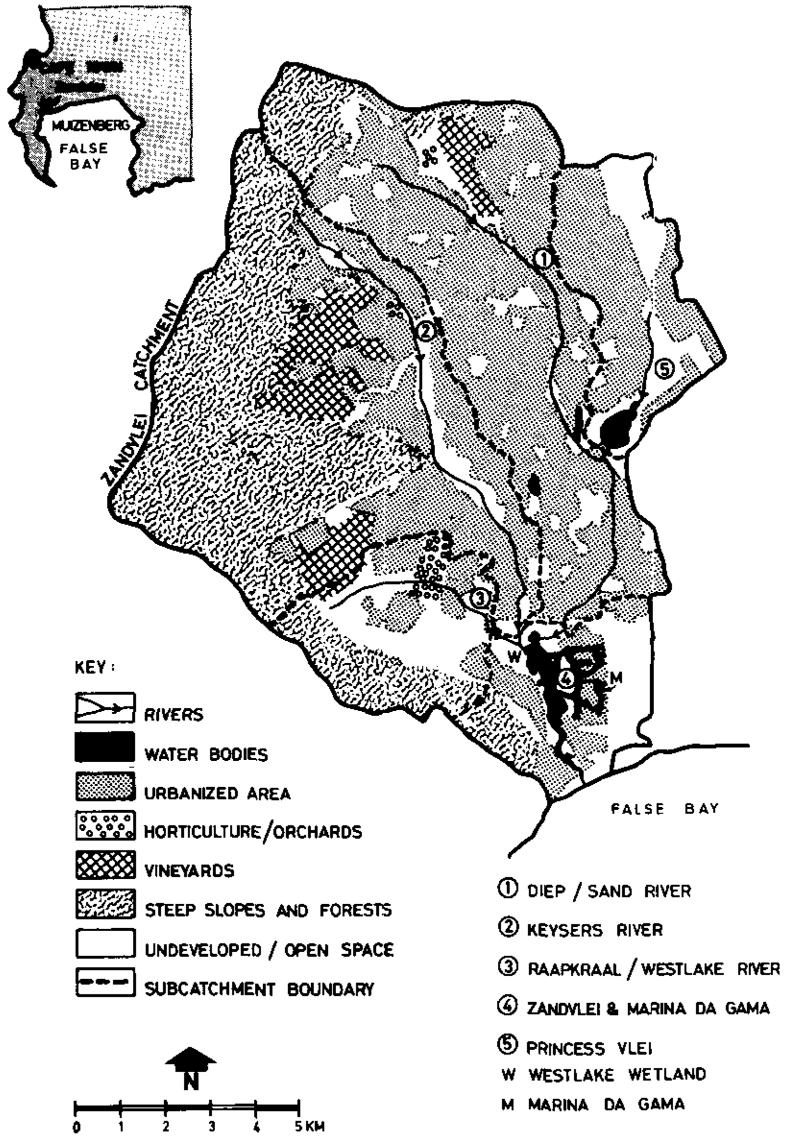

Figure 1
Zandvlei and catchment showing major subcatchments and land use. Zandvlei has 3 components, the main body of the lake with a water surface area (wsa) of 56 ha; a man-made marina, with cement-lined walls, adjacent to the eastern shore (wsa 31 ha); and a narrow outlet channel of 1 km in length (wsa 9 ha). In addition there is a wetland area of 34 ha to the northwest of the lake.

Water quality

Influent rivers

Physico-chemical and bacteriological data for the rivers during the period July 1992 to June 1993 are summarised in Table 1. The main sources of both nutrients and bacteria are urban runoff, sporadic sewer and sewer pump station overflows, and seepage from septic tanks (Ninham Shand, 1993). In addition, runoff from viticulture and market gardening areas in the catchment contributes to nutrient loading (Ninham Shand, 1993).

A 13-year data analysis by Harding (1994) for the period 1978 to 1991 showed that concentrations of particulate phosphorus decreased in all 3 rivers, while significant increases in the levels of biologically-available phosphorus were measured in the Sand and Keysers Rivers. Harding also reported an increase in biologically-available nitrate-nitrogen (in the Keysers and Westlake Rivers). Harding (1994) estimated flow-weighted mean annual concentrations of total nitrogen and phosphorus, respectively, entering Zandvlei (1978 to 1991) to be 2.50 and 0.12 mg·ℓ⁻¹. In terms of total inflow, these concentrations represent mean annual nitrogen and phosphorus loads, respectively, to the lake of 55 and 2.6 tonnes.

Zandvlei

Physico-chemical and bacteriological information for Zandvlei during 1992 to 1993 are given in Table 1. Salient information from Harding's (1994) analysis is summarised below: a noticeable decrease in ambient lake-salinity levels occurred between 1978 and 1991. The mean of 12 mg·ℓ⁻¹ in 1978 decreased to <3 mg·ℓ⁻¹ in 1991. However, salinities increased again during 1992/93 in response to manual and mechanical manipulation of the beach sandbar to allow tidal ingress to the lake (Harding, 1994). Associated with the decrease in salinity, a marked increase in phytoplankton numbers (and hence chlorophyll *a*) was recorded during the second half of 1991. More typical [lower] chlorophyll *a* concentrations were restored following the increase in salinity.

Mean annual concentrations (for the whole lake) of total-ammonia- and nitrate plus nitrite-nitrogen were 1.6, 0.10 and 0.16 mg·ℓ⁻¹, respectively, with total- and ammonia-nitrogen concentrations showing a downward trend between 1985 and 1991. Mean annual total, total soluble and orthophosphate concentrations, respectively, were 0.081, 0.020 and 0.011 mg·ℓ⁻¹. In recent years (1978 to 1991) there has been an increase in the concentration of total and soluble phosphorus, with increases of 0.074 to 0.095 mg·ℓ⁻¹ and from 0.017 to 0.038 mg·ℓ⁻¹ (Harding,

TABLE 1
WATER QUALITY IN ZANDVLEI AND INFLUENT RIVERS DURING 1992/93 (n = 25)

Sampling point			Sand River	Keysers River	Westlake River	Zandvlei*[1]
Temperature	°C	Mean	17.9	15.4	16.2	18.0
		Min	12.4	10.5	12.0	12.0
		Max	22.9	21.6	20.5	22.5
Oxygen saturation	%	Mean	92	66	36	97
		Min	59	43	9	63
		Max	148	95	86	146
pH value		Mean	7.8	7.5	7.1	8.3
		Min	6.7	7.0	6.5	7.1
		Max	8.4	8.1	7.7	9.0
Organic nitrogen	$mg \cdot \ell^{-1}$	Mean	0.8	0.4	0.6	0.8
		Min	0.3	0.1	0.2	0.3
		Max	1.5	0.8	1.6	2.2
Ammonia as N	$mg \cdot \ell^{-1}$	Mean	0.06	0.06	0.06	0.04
		Min	<0.01	0.01	0.02	<0.01
		Max	0.52	0.41	0.55	0.23
Total phosphorus		Mean	0.135	0.077	0.087	0.082
as P	$mg \cdot \ell^{-1}$	Min	0.039	0.027	0.026	0.033
		Max	0.286	0.243	0.313	0.216
Reactive phosphorus		Mean	0.044	0.019	0.021	0.011
dissolved as P	$mg \cdot \ell^{-1}$	Min	0.004	0.007	0.005	0.001
		Max	0.158	0.052	0.178	0.050
Faecal coliforms/100 mℓ		50%	600	260	30	3
percentiles		80%	920	540	390	280
		90%	1500	720	2000	330

*[1] chlorophyll *a* corrected for phaeophytin mean 39 $\mu g \cdot \ell^{-1}$ (range 3 to 210); salinity mean 3 $mg \cdot \ell^{-1}$ (range <1 to 14); secchi transparency mean 400 mm (range 10 to 1050).
Source: Cape Town City Council (1993).

1994). No distinct seasonality can be attributed to concentrations of nitrogen and phosphorus in Zandvlei. Zandvlei is regarded as eutrophic in terms of the open boundary classification of the OECD (1982) and the chlorophyll *a* trophic status classification developed by Walmsley (1984).

As a result of strong prevailing winds parallel to the longest axis of the lake, the lake and outlet channel are almost continuously well mixed and oxygenated. The marina canals are more sheltered, and are deeper than the main lake body. Hence they are not as well mixed as the lake, and the bottom waters of the canals occasionally become anoxic during calm conditions.

Faecal pollution, as measured using the faecal coliform indicator and expressed as faecal coliforms per 100 mℓ of lake water is given in Table 1. The implications of these for contact recreation in the lake are discussed in detail later in the paper.

Siltation and littering

Siltation in the lake is caused by sediments arising from marine and land sources. A 7 000 m^3 delta of riverine silt has formed at the point of entry of the Sand River into the north of Zandvlei. Intrusion of marine sediments causes siltation in the outlet channel which obstructs in- and outflowing water (these sediments are dredged periodically).

Litter accumulation occurs in the lower reaches of the Sand River, and therefore, trash racks have been positioned in the river course upstream of Zandvlei to intercept solid wastes before they enter the lake. Although these racks are cleaned regularly by the local authorities some litter is still transported into Zandvlei during conditions of high [storm] flows.

Biotic characteristics of rivers and Westlake Wetland

A detailed description of the biota of the influent rivers and the Westlake wetland is beyond the scope of this paper. However, a knowledge of the dominant aquatic and emergent vegetation is of importance, particularly as they affect river hydrology and the maintenance of chemical [nutrient] and bacteriological water quality (see management section for details). The riparian vegetation along lower and middle reaches of both the Keysers and Westlake rivers is dominated by bulrushes (*Typha capensis*), and Kikuyu grassland (*Penisitum clandestinum*), with patches of Kaapseriet (*Phragmites* spp.) and thickets of acacia (*Acacia* spp.). The upper reaches are lined by mountain fynbos and areas of viticulture. Much of the Diep/Sand River is canalised and, apart from attached macroalgae, there is no macrophyte growth.

In the Keysers River, parrot's feather (*Myriophyllum aquaticum*) and water hornwort (*Ceratophyllum demersum*) form hydraulically-occlusive growths in the middle reaches of the river. Water hyacinth (*Eichornia crassipes*) and waterfern (*Azolla filiculoides*) also occur in this stretch of river. Dense growths of parrot's feather choke the Westlake River where it enters the Westlake wetland. Regular mechanical removal of these plants is undertaken by the local authorities to maintain the hydraulic integrity of the system.

The dominant semi-aquatic macrophyte plant species in the Westlake wetland are bulrushes, Kaapseriet and reeds (*Scirpus* spp.) (Azorin, 1988; Ninham Shand, 1993). Open waters within the wetland are dominated by dense growths of water hornwort, with pockets of water hyacinth and waterfern.

The role of *Potamogeton pectinatus* (pondweed), and macrophyte-phytoplankton dynamics in Zandvlei

In common with other similar lakes (Howard-Williams and Allanson, 1981; Taylor, 1983; Bally et al., 1985), the macrophyte *Potamogeton pectinatus* (pondweed) and, in the case of Zandvlei (Stewart and Davies, 1986; Davies et al., 1989), the associated filter feeding polychaete *Ficopomatus enigmaticus*, are considered to be the essential biotic component responsible for the maintenance of good water quality (Harding, 1994). Pondweed is a submerged rooted hydrophyte with thread-like leaves. It forms dense beds which restrict boating and other water-recreation pursuits, while providing a substratum for the attachment of nuisance algae such as *Enteromorpha intestinalis* and *Cladophora* spp. In Zandvlei, the pondweed is maintained at a depth which does not impede boating activities in the lake and marina canals, by means of a floating mechanical harvester.

The pondweed plays a vital role in the functioning of the lake ecosystem. It increases water clarity by reducing sediment resuspension caused by wind, fauna and recreational activities, oxygenates the water column, removes nutrients from the water and bottom substratum, provides refuges and feeding areas for juvenile fish and other aquatic fauna, and forms a substratum for the filter feeding polychaetes (Timms and Moss, 1984; Davies et al., 1989; Van Donk et al., 1989; Meijer et al., 1990; Moss, 1992; Reynolds, 1992). Davies et al. (1989) estimated that approximately half the polychaete biomass in the Marina occurred on pondweed and the remainder on the canal walls. They emphasised the important role that this organism plays in the maintenance of water quality in the system through filtration.

Harding (1994) has reported on a recent collapse of the *Potamogeton* standing stock of Zandvlei. The reasons for this have not been conclusively established, but may be related to increased water depths, decreased salinity and/or a natural change from a clear water, macrophyte-dominated condition to an alternative, phytoplankton-dominated equilibrium state (Blindow et al., 1993; Scheffer et al., 1993). In Zandvlei the cause and effect pathway of reduced salinity > increased phytoplankton > reduced light > macrophyte decline did not occur (Harding, 1994).

There is increasing evidence that shallow lakes may possess 2 alternative stable states, one dominated by macrophytes and the other a turbid state dominated by phytoplankton (Scheffer et al., 1993). Typically, low-nutrient situations are characterised by macrophyte dominance and eutrophic lakes by the turbid state, separated by a range of intermediate states where either of the 2 alternative equilibria may exist (Scheffer et al., 1993). In shallow lakes of homogenous depth [such as Zandvlei], changes in the water depth may initiate the switch from macrophyte to algal dominance (Scheffer et al., 1993; Blindow et al., 1993). Changes in water depth have been shown to be the most common causes of such changes in Swedish lakes (Blindow et al., 1993), with reduction in water level a possible inducement to a return from a phytoplankton- to a macrophyte-dominated state (Scheffer et al., 1993). The operating water level in Zandvlei was raised progressively between 1978 and 1992 by approximately 0.12 m (Harding, 1994) and this may have had some effect in reducing light availability for the submerged plant population. Zeekoevlei, a shallow and hypertrophic lake adjacent to Zandvlei (see Harding, 1992) was reported as having alternate macrophyte- (*Potamogeton*) and phytoplankton- (cyanobacteria) dominated states (Stephens, 1929; Harrison, 1962) prior to water level increases brought about by the construction of a weir.

Anticipated increases in nutrient loading from the progressively developing Zandvlei catchment will push the system toward the phytoplankton-dominated state (Blindow et al., 1993; Scheffer et al., 1993). As the restoration of phytoplankton- (particularly cyanobacteria) dominated shallow eutrophic systems is particularly difficult, every effort should be made to prevent such a condition occurring in Zandvlei. A further concern is that Zandvlei is situated in a region having near-continuous and high mean wind speeds (Harding, unpublished data) and angiosperms such as *Potamogeton* are considered unsuited to shallow, wind-exposed lakes (Blindow et al., 1993). Wind-induced resuspension of the now unstabilised sediments will reduce light penetration further and make any recolonisation of the open waters of the lake by *Potamogeton* more difficult.

Role of Zandvlei as a fish nursery area

Estuaries are important nursery areas for many marine fish species (Wallace et al., 1984; Wallace and Van der Elst, 1975). According to Morant and Grindley (1982), Quick and Bennett (1989), and Morant (1991), Zandvlei (= the Sand River estuary) should be regarded as the only False Bay estuary of real significance as a fish nursery. Harrison et al. (1994) reported that the estuary had the highest biological health index of all the estuarine systems in False Bay.

The species of fish associated with South African estuaries have been classified by Wallace et al. (1984) into 3 broad categories:

- resident species which complete their life cycles in estuaries;
- marine migrants which spawn at sea, their larvae undergoing early stages of development in the marine environment before moving into estuaries as juveniles, where they remain for varying lengths of time; and
- freshwater species.

Fish population surveys conducted in Zandvlei by Bourgeouise (1948), Begg (1976), Gaigher and Thorne (1979) and Quick and Bennett (1989) recorded a total of 27 species, and included representatives of all the above-mentioned categories (Table 2). Four of the fish species recorded in Zandvlei during the period 1948 to 1989 (white steenbras *Lithognathus lithognathus*, flathead mullet *Mugil cephalus*, leervis *Lichia amia* and Cape stumpnose *Rhabdosargus holubi*) are heavily reliant on estuaries during their juvenile phase (Wallace et al., 1984). These species spawn at sea mainly during winter or spring, and their juveniles are then recruited into the estuaries during the spring and summer, approximately 1 to 2 months after spawning (Whitfield and Kok, 1992). Zandvlei is at the fringe of the distribution of Cape stumpnose (Van der Elst, 1981) and they have only been caught infrequently and in low numbers in Zandvlei (Quick and Bennett, 1989).

The nursery role of Zandvlei for white steenbras in False Bay is of particular concern because catches have declined by

TABLE 2
CHECKLIST OF FISH SPECIES RECORDED FROM ZANDVLEI DURING VARIOUS SURVEYS CONDUCTED BETWEEN 1948 AND 1989

	Common Name	Reference*					
Marine migrants							
Liza richardsoni	southern mullet	1	2	3	4	5	6
Mugil cephalus	flathead mullet	1	2	3	4	5	6
Pomatomus saltatrix	elf	1	2	3			
Lichia amia	leervis	1	2	3	4	5	6
Rhabdosargus globiceps	white stumpnose	1	2	3			6
Rhabdosargus holubi	Cape stumpnose	1					
Amblyrhyncotes honkenii	evil eyed puffer			3			6
Lithognathus lithognathus	white steenbras		2	3	4	5	
Diplodus sargus capensis	blacktail		2				
Argyrosomus hololepidotus	kob		2				
Monodactylus falciformis	Cape moony			3			
Iso natalensis	surf sardine			3			
Solea bleekeri	blackhand sole	1					
Heteromycteris capensis	Cape sole	1		3			6
Residents							
Psammogobius knysnaensis	Knysna sand goby	1		3	4	5	6
Atherina breviceps	silverside	1		3	4	5	
Gilchristella aestuaria	estuarine round herring	1		3			
Caffrogobius multifasciatus	banded goby	1					
Clinus superciliosus	klipfish			3			
Syngnathus acus	pipe fish			3			
Caffrogobius nudiceps	barehead goby			3			
Freshwater species							
Cyprinus carpio	carp (exotic)	1	2	3	4		
Oreochromis mossambicus	Mozambique bream (exotic)	1	2	3	4		
Gambusia affinis	mosquito fish (exotic)	1					
Clarias gariepinus	sharptooth catfish (exotic)	1					
Galaxias punctifer	Cape galaxias			3			6
Sandelia capensis	Cape kurper			3			
Micropterus salmoides	black bass (exotic)			3			

* 1. Quick and Bennett (1989) 2. Gaigher & Thorne (1979) 3. Begg (1976) 4. Shelton (1975) 5. Muir (1974) 6. Bourgeouise (1948)

approximately 90% since the mid-1970s (Bennett, 1993a). This is probably the direct result of the sensitivity of this species to human activities (Bennett, 1993a;b). Small juveniles are extremely vulnerable to anthropogenic impacts on estuaries, and larger juveniles and sub-adults are confined to the surf zone, which exposes them to exploitation by fishermen. Adults are also vulnerable to over-exploitation because individuals are large and relatively old at maturation, and because they form predictable aggregations (Bennett, 1993a;b). Zandvlei should be regarded as one of the main nursery grounds for 0+ juvenile white steenbras in False Bay. Post-estuarine juveniles are semi-resident in the surf zone of sandy and mixed shores until they attain maturity (Bennett, 1993b), suggesting that recruitment from estuaries adjacent to False Bay (e.g. Palmiet, Kleinmond and Bot) is likely to be minimal.

Zandvlei should also be regarded as an important nursery area for both leervis and flathead mullet, as both species are described as being highly dependent on estuaries during their juvenile phase (Wallace et al., 1984). Long-term catch data are not available for either species but both are regarded as components of the local fishery. Flathead mullet are occasionally caught in low numbers by the shore-based seine fishermen (Bennett, 1993c) and leervis are an important recreational angling fish (Van der Elst and Adkin, 1991). It should be noted that some juvenile leervis may be recruited from elsewhere along the South African coastline as the migratory patterns for juveniles are not known.

Elf (*Pomatomus saltatrix*), white stumpnose (*Rhabdosargus globiceps*) and southern mullet (*Liza richardsonii*) are categorised by Wallace et al. (1984) as species whose juveniles occur mainly at sea but which are also reasonably abundant in estuaries. Southern mullet juveniles occur in Zandvlei in very large numbers. A comparison of seine hauls in Zandvlei by Quick and Bennett

(1989) with those made by Bennett (1989) in the surf zone of False Bay showed 2 157 and 390 southern mullet juveniles per haul, respectively. Although juvenile southern mullet also occur in the sea, Zandvlei should thus be regarded as a valuable nursery area. On the other hand, Zandvlei is of limited value to white stumpnose. Seine hauls by Bennett (1989) and Quick and Bennett (1989) indicated that juveniles of this species are present in higher densities in the surf zone of False Bay.

The fish which are of recreational value in Zandvlei and of importance in the False Bay fishery are all marine migrants. Therefore, in order to improve the recreational fishing and to enhance the nursery role of Zandvlei it is necessary to make the estuary more accessible to the juveniles of this group of fish during September to the end of November (the period when the mouth would naturally remain open as a result of winter rains) i.e. through a portion of their spring/summer recruitment period. In addition, shallow, vegetated (e.g. pondweed) areas should be maintained in the lake, as these provide warmer water, food and protection from predation for juveniles. Finally, the salinity levels should not be allowed to fall below 3 $mg \cdot \ell^{-1}$ as this will result in large-scale mortalities of many marine migrant species during winter (Bennett, 1985).

Role of Zandvlei for recreation

According to a study by the City of Cape Town (1988) and Thornton et al. (1989), Zandvlei is an important regional recreational resort with peak daily attendance figures of 2 000 to 3 000 people, some 40% of whom reside outside the Cape Town municipal area. There is a marked seasonality to the recreational use of the lake, with a strong bias towards the summer months.

The main activities in Zandvlei and its immediate environs (City of Cape Town, 1988) are barbecuing (29% of users), boardsailing (24%), picnicking (18%) and walking (12%). Other uses include yachting, canoeing, angling and bird watching. These uses of the lake require (for aesthetic and practical reasons) that the water level be maintained at the current water depth of approximately 1.3 m. In addition, managers need to ensure that the visual aesthetics of the lake and its surrounds are of a high standard, and that the water quality complies with international and South African guidelines (Lusher, 1984; Water Research Commission, in prep.). Generally, the users polled in the above survey were satisfied with water quality, with 60% of respondents regarding Zandvlei as a clean water lake (Thornton et al., 1989). Water quality concerns reported by users of Zandvlei were primarily related to visual aesthetics, and included water weeds (40% of respondents), litter (22%), shallowness (18%), odour of water (18%) and accumulated sediments (16%) (Thornton et al., 1989).

Harding (1993) assessed Zandvlei's bacteriological water quality in terms of the European and South African Guidelines (European Community, 1976; Lusher, 1984). Faecal coliforms (fc) in the influent rivers during the past 5 years have ranged from 500 to 11 000 coliforms per 100 $m\ell$ (80 percentile). Levels of faecal coliforms in the lake are also high, and there is only marginal compliance with the European Community (80 percentile) guideline during the summer months (Harding, 1993).

Management priorities

Three interrelated components of the Zandvlei system need to be well managed in order to conserve or to enhance the water quality, and to support the recreational and fish nursery roles of the lake. These are the stormwater and rivers flowing into the lake, pondweed harvesting, and the manipulation of the mouth sand bar to facilitate sea-water intrusion to the lake.

Stormwater and river management

The primary, development-related, management concerns which impact on the water quality of rivers flowing into Zandvlei are increased volumes of runoff and increased loading of nutrients and bacteria/viruses. Indicator faecal coliform bacteria already exceed established guideline limits for contact recreation (Harding, 1993).

Measures which can be taken by authorities and developers to reduce runoff volume, and improve the nutrient and bacteriological quality of stormwater runoff have been described in detail in Field et al. (1993), Moshiri (1993) US Environmental Protection Agency (1992), Aalderlink et al. (1990), Ellis (1989) and Novotny and Chesters (1981). These methods focus primarily on 6 aspects of catchment management:

- improved operation, maintenance and design of stormwater and waste-water infrastructure;
- improved street sweeping operations;
- improved infiltration in the catchment by using porous surfaces wherever possible, and detaining stormwater runoff on site;
- improved "treatment' of stormwater runoff by natural processes by detaining runoff on grassed or other surfaces during storm runoff conditions (this also results in decreased flood peaks);
- effective use of natural or constructed wetlands for improving water quality - in particular, this might apply to the Westlake wetland; and
- effective use of zoning controls to maintain the integrity of the riparian zone, encourage the methods discussed above for improving stormwater management, and discourage inappropriate development which will have major negative impacts on water quality and increase runoff volumes.

There is a need for a co-ordinated policy on stormwater management which takes the above concerns into account, and involves all the authorities (Cape Town City Council, Western Cape Regional Services Council, and the State) in the catchment.

Pondweed (*Potamogeton pectinatus*) management

Subsequent to the pondweed collapse described earlier in this paper, there is still no sign of any significant recovery of pondweed in Zandvlei, although there is some evidence of limited regrowth in isolated reaches of the lake and the marina. Therefore, a priority management concern is to facilitate the return of the macrophyte. A variety of ecological and environmental forcing-factors influence the growth and survival of aquatic plants (Mitchell, 1974), complicating the formulation of appropriate management directives. In the case of pondweed these include salinity, depth, nutrient availability and phytoplankton population density. The brackish/estuarine conditions in Zandvlei favour the growth of pondweed (rather than phytoplankton), and therefore careful attention to the control of salinity (see below) in the lake should facilitate its re-establishment in Zandvlei. Re-seeding of the lake should occur readily from *Potamogeton* standing stocks in the rivers and lakes in the Zandvlei catchment area, as well as from plants and winterbuds already present in the lake and sediments, respectively. Depth also plays a major role in pondweed population dynamics, with shallower depths tending to promote *Potamogeton* growth (Blindow et al., 1993; Scheffer et al., 1993).

Once the pondweed population begins to re-establish itself there exists a need for regular biomass surveys to monitor any spatial and temporal recovery that occurs, inclusive of sampling of the sediments for overwintering buds of *Potamogeton*, and the routine observance of factors such as wildfowl numbers which are closely correlated with the occurrence of submerged vegetation (Blindow et al., 1993). If and when re-establishment does occur, management of harvesting should be closely linked to surveys of the macrophyte biomass and growth cycles, and not be allowed to operate in crisis response fashion to complaints from water users and residents. The latter should be integrated into a management education programme which stresses the interactive value of each of the components of the ecosystem. A further concern, according to unpublished information (Scientific Services Branch, Cape Town City Council), is that if harvested pondweed is left on the edge of the lake, nutrients contained in the pondweed leach back into the lake waters. To minimise this potential source of nutrient loading, every effort should be made to expedite the removal of the nutrient-containing pondweed from the vicinity of the lake after harvesting.

Management of the intrusion of seawater

The key management objective for enhancing the nursery role of the estuary for marine migrants is to keep the mouth of the lake open during high spring-tide events for the duration of October and November (the winter rainfall regime precludes keeping the mouth open for a longer period). The lake would then be available to marine migrants during an important portion of their recruitment period. In addition, this would maintain salinity concentrations at levels which give pondweed a competitive advantage over the phytoplankton in the estuary, and also above levels which might stress marine migrants (Bennett, 1985). A useful spinoff of increased salinities is that the alien freshwater fish Carp (*Cyprinus carpio*) which has been recorded in relatively large numbers in the lake (Gaigher and Thorne, 1979; Quick and Bennett, 1989), and which is known to increase turbidity by its benthic feeding methods (Gophen, 1990a;b), will be restricted to the north of the lake.

To achieve this, mechanical manipulation of the mouth sand bar is essential during the early summer (September to the end of November). Eventual deepening of the lake and the possibility of an improved outlet weir construction, will facilitate salinity control, but manual removal of the beach sandbar will remain a necessity. The effectiveness of mouth manipulation on salinity concentrations, and on improving access to marine migrants needs to be monitored.

Conclusion

Zandvlei estuary is an important natural and recreational resource in Cape Town which has become severely regulated during the past 60 years. If the system is not actively managed, water quality degradation will compromise its amenity and natural ecosystem value. The key management measures needed to maintain acceptable water quality and enhance the recreational and fish nursery roles of Zandvlei are shown in Fig. 2, and are summarised below:

- Implement effective stormwater and river management (including ongoing monitoring) in the catchment to reduce bacteriological and nutrient loading and to contain peak runoff volumes using methods well documented in the literature.
- Mechanically manipulate the mouth sand bar (and rubble weir) to optimise sea-water intrusion, thus facilitating adequate salinity levels for the aquatic flora and fauna, and access to marine migrant fish juveniles in early summer (September to end of November).
- Institute a pondweed monitoring and management programme that ensures that the vital multi-faceted role performed by this plant (in particular water quality enhancement and juvenile fish habitat), is unimpaired.
- If pondweed regrowth in Zandvlei has not occurred by the end of the 1994/95 growing season, then the option of reducing the

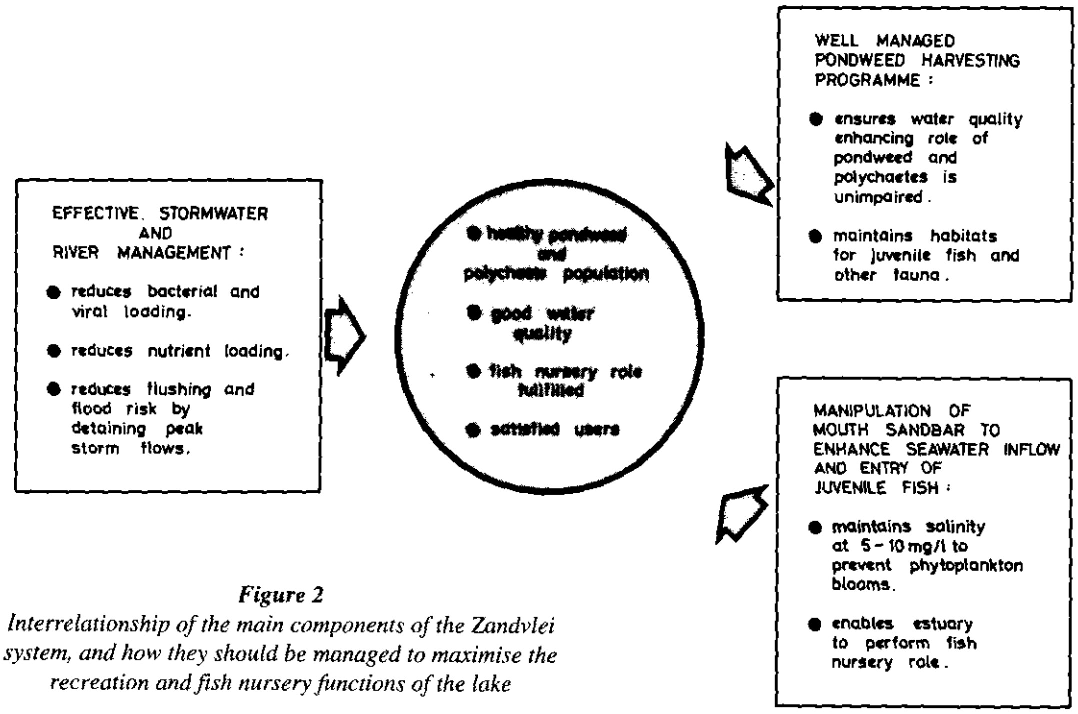

Figure 2

Interrelationship of the main components of the Zandvlei system, and how they should be managed to maximise the recreation and fish nursery functions of the lake water level to the 1978 level (to help facilitate a return to the macrophyte-dominated condition) should be investigated.

- Finally, managers, scientists, users and residents need to be informed and educated about both the functioning of the Zandvlei ecosystem and its role as a regional recreation resource.

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