Dynamics of phytoplankton and phytobenthos in Lake Loskop (South Africa) and in irrigation channels

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Abstract: The relationships between water quality and the phytoplankton community within Lake Loskop and irrigation channels downstream were studied over a period of one year from April 2009 to March 2010. The phytoplankton assemblage in Lake Loskop during this sampling period was dominated by the phytoplankton *Ceratium hirundinella*, with the highest biovolume of 12.1 mm^3 l^{-1} recorded in late summer during January 2010. From the data generated the algae assemblage showed a clear trend in the two channels during the study period and also among sampling stations. The filamentous macroalgae *Cladophora glomerata* dominated the phytobenthos of the two irrigation channels during the whole sampling period. However, a much higher biovolumes (8.5; 6.3 mm^3 l^{-1}) of *Cladophora glomerata* and total phosphates were observed in the long and short irrigation channels during lake overturn in the months of March and September, while much lower average biovolumes (2.4; 1.5 mm^3 l^{-1}) were recorded during the summer months. The dominance of the water column phytoplankton assemblage in the two irrigation channels by *Ceratium hirundinella*, *Fragillaria crotonesis*, *Closteruim stellenboschense* and *Closteruim polystictum* during autumn and spring was in relationship with the observed lake overturn. Withdrawal of irrigation water from the upper-hypolimnia during this two

time periods did contained and transport phytoplankton species in the irrigation channels usually occurring in the epilimnon zone of Lake Loskop. This phenomina resulted in these species to become dominant during autum in the water column of the two irrigation channels downstream of Lake Loskop. The phytoplankton assemblage data generated from this study can be use for management and control of nuisance macroalgae like *Cladophora glomerata* in irrigation channels.

Key words: Phytoplankton seasonal succession, macroalgae *Cladophora glomerata*, lake over turn, irrigation channels

Introduction

In the upper Oliphant's River catchment, which is the main supplier of water to Lake Loskop, acid mine drainage, sewage pollution and agriculture activities are the driving sources of anthropogenic stressors on the aquatic environment (Driescher 2007). Over the past fifteen years Lake Loskop has had a history of isolated incidents of fish mortality (Oberholster et al. 2010). These incidents has escalated during the past five years and are linked with crocodile mortalities and a population decline from ± 80 animals to a total of 6 in 2008 (Oberholster et al. 2010). Crocodile mortalities in Lake Loskop during this period of time were associated with pansteatitis, which was cause by chronic intake of rancid and decaying fish tissue (Paton 2008). Although an earlier study conducted by Kotze et al. (1999) on bioaccumulation of metals in different fish species of Lake Loskop and Oberholster et al. (2010) on the phytoplankton community structure of this impoundment, little is known about the influence of the water quality of Lake Loskop on the second largest irrigation scheme in South Africa downstream of the Lake. The irrigation scheme that consisted of concrete irrigation

channels of ± 480 km, present serious weed problems caused by the establishment of filamentous macroalgae during certain periods of the year. These filamentous macroalgae decrease the carrying capacity of the channels, while detached algae continuously drift down the sediment channels, clogging the control gates and crop sprayers (Joska & Bolton 1996; Ferreira et al. 1999). In South Africa macroalgae especially *Cladophora glomerata* is a significant problem in irrigation channels and potable water systems. Previous investigations in South Africa were mainly of taxonomic nature and studies on ecological interaction with environmental variables e.g. water chemistry and temperature is virtually non-existent (Joska & Bolton 1996). The objective of this study were to link physical chemical water variables and phytoplankton assemblage in Lake Loskop with physical chemical water variables and taxonomic diversity and distribution of phytoplankton assemblage in the two irrigation channels downstream of the lake. The study was undertaken over a period of one year from April 2009 to March 2010 to capture all the impacts of possible seepage of acid mine drainage from mines and untreated sewage inflow in the upper catchment of Lake Loskop on the water quality and phytoplankton community structure in the irrigation channels of the irrigation scheme downstream of Lake Loskop.

Materials and methods

Study area

Loskop Dam (25º 26' 57. 05" S 29º 19' 44. 36 E) is situated in the Mpumalanga province of South Africa and is fed by the Oliphant's River. Building of Loskop Dam commenced in the mid 1930's and was completed in the early 1940's to supply water for the agriculture sector. The mean annual precipitation for this area is 683 mm, and

the mean annual runoff is 10 780 Mm^3 (Midgley et al. 1994). Water pollution in the upper Oliphant's River is acid mine drainage of a number of abandoned coal mines and the release of untreated sewages from municipal sewage works upstream in the region of Lake Loskop. The Loskop irrigation scheme which is downstream of Lake Loskop is the second biggest irrigation area in South Africa and was constructed between 1933 and 1940. The irrigation scheme has an irrigation area of 25 600 ha and a total of ± 480 km of irrigation channels (Loskop Irrigation Board 2010). The water supply for the irrigation scheme is abstracted from the upper-hypolimnia of Lake Loskop and is conducted to crops through the use of two concrete channels. The distance of these two channels is approximately ± 46 km (short channel) and ± 330 km (long channel). The dominant crops in the irrigation area are maize, citrus, grapes and wheat.

Selection of the sampling sites

Water samples were taken from a total of eleven sampling sites which include one sampling site in Lake Loskop near the Dam wall and ten sampling sites in the two irrigation channels downstream from the dam wall (on the left bank six sites in the long channel and on the right bank four sites in the short channel) (**Table 1, Fig 1**). The sampling sites were selected in such a way as to cover both channels (long and short channel) up to the first ± 45 km downstream from the dam wall to determine the influence of water quality of Lake Loskop on the phytoplankton assemblage within these two channels.

Phytoplankton sampling in Lake Loskop

Duplicate water samples for analysis of the phytoplankton population structure were collected from the water column at sampling site 11 in Lake Loskop during the 12 monthly sampling trips from April to March 2010. A random sampling procedure was followed at site 11 during each sampling trip to reduce hydrobiological variability. The duplicate water samples were collected at the lake surface and at 0.5 metre intervals down to a depth of 2 metres using a 6-litre capacity Von Dorn sampler. Samples from each depth were pooled to form two 5-litre integrated samples. One of the 5-litre integrated samples was preserved in the field by addition of acidic Lugol's solution to a final concentration of 0.7 %, followed after one hour by the addition of buffered formaldehyde to a final concentration of 2.5 %, while the other integrated sample was kept for chlorophyll *a* and chemical analyses The integrated water samples were kept cool and in the dark during the 3-h period of transfer from the field to the laboratory.

All algal identifications were made with a compound microscope at 1250 x magnification (Van Vuuren et al. 2006; Taylor et al. 2007). Strip counts were made until at least 100 individuals of each of the dominant phytoplankton species had been counted (American Public Health Association 1992). Diatoms were identified after clearing in acid persulfate. Algal abundance in the samples was evaluated by counting the presence of each species (as cells in a filament or equal number of individual cells), and the individual species were grouped into major algal groups (Lund et al. 1958; Willen 1991). Algal biovolume was calculated by measuring the corresponding dimensions using the geometric formulae given by Willen (1976).

Phytoplankton species composition throughout the whole text refers to biomass, measured as cell volume.

Phytoplankton and sampling in the irrigation channels

Every six weeks over a period of one year data was gathered, to assess phytoplankton and phytobenthos abundance and water chemistry of the two irrigation channels. Attached algae were removed (area of 10 cm^2 area) from the concrete sides of the two irrigation channels at each selected sampling site by using a blade scraper after which the material was resuspended in 200 ml deionised water. An aliquot of 50 ml was fixed with formaldehyde at a final concentration of 4 % (v/v) for microscopic examination Diatoms were identified after clearing in acid persulfate. A total of 100 ml of each of the samples were sedimented in a chamber and were analyzed under an inverted microscope using the strip-count method (American Public Health Association 1992). Algal abundance in the samples was evaluated by counting the presence of each species (as cells in a filament or equal number of individual cells). The water column at a depth of ± 1 meter of each irrigation channel at each sampling site was sampled using a 6-litre capacity Von Dorn sampler for water column phytoplankton and chemical analyses. Due to the strong flow in the irrigation channels it was very difficult using the Von Dorn sampler to determine the precise depth of the sampling.

The Berger-Parker dominance index (Berger & Parker 1970) was used to measure the evenness or dominance of phytoplankton and phytobenthos at each sampling site:

$$D = N_{max}/N \qquad \text{Eqn 1}$$

Where N_{max} = the number of individuals of the most abundant species present in each sample, and N = the total number of individuals collected at each site. Equilibrial phytoplankton species (*sensu* Naselli-Flores 2003) in the main basin (site 11) and at all other sites in the two irrigation channels were determined over the study period of 12 months.

The following criteria of Naselli-Flores (2003) were used: (1) 1, 2 or 3 species of phytoplankton contribute more than 80% of the total biomass; (2) their existence or coexistence persists for more than 1-2 weeks; and (3) during this period, total phytoplankton biomass does not increase significantly.

Physical and chemical parameters of Lake Loskop and the two cement channels

On each of the field visits, dissolved oxygen, water temperature, pH and electrical conductivity values were measured of the water collected with the Von Dorn sampler in the two irrigation channels and the sampling site in Lake Loskop, using a Hach sension^{TM} 156 portable multiparameter (Loveland, USA). All water samples of the 11 different sampling sites were filtered through 0.45 µm pore size Whatman GF/filters and stored in polyethylene bottles that had been pre-rinsed with dilute sulfuric acid (to pH 2.0) for analysis of dissolved nutrients. All analyses were carried out according to standard methods (USEPA 1983; APHA, AWWA & WPCF 1992). Concentrations of total nitrogen (TN) and total phosphorus (TP) were determined with the persulphate digestion technique. Nitrate concentrations were determined on an autoanalyzer with the cadmium reduction method, while soluble reactive phosphorus concentrations were determined by the ascorbic acid method (APHA, AWWA & WPCF 1992).

Sulphate concentrations were analyzed turbidimetrically, while alkalinity concentrations were analyzed by titrimetry following the method of USEPA (1983).

Chlorophyll a analyses as indicator of phytoplankton biomass

Chlorophyll *a* concentrations as indicator of phytoplankton biomass were determined by filtering the collected water of each site through a 45 µm Whatman filter using a hand filter pump in the field. Chlorophyll was extracted from the filters with 80 % acetone at 4 ºC. The chl *a* content of each sample was determined spectrophotometrically at 664 nm wavelengths according to the method of Porra et al. (1989).

Statistic analysis

All data were recorded on standard Excel spreadsheets for subsequent processing and the statistical analysis was conducted using the SYSTAT ® 7.0.1 software package (SYSTAT 1997). Statistical differences were analyzed calculating Pearson correlation and a *t* test using the Sigma Plot (Jandel Scientific) program. Values of $p \leq 0.05$ were regarded as significant in the study.

Results

Phytoplankton seasonal succession in Loskop Dam

The phytoplankton assemblage in Loskop Dam was dominated (Berger & Parker Index, 0.424) throughout the sampling period by the Dinophyceae *Ceratium hirundinella* (Müller), with the highest biovolume of 12.1 mm^3 l^{-1} recorded in late summer during January 2010. Amongst the lesser contributors in the phytoplankton assemblage were *Peridinium bipes* (Ehrenberg) (biovolume, 1.2 mm^3 l^{-1}) and the

diatoms *Fragilaria crotonesis* (Ehrenberg) (biovolume, 3.0 $mm^3 l^{-1}$) and *Asterionella formosa* (Hassal) (biovolume, 1.1 $mm^3 l^{-1}$) which were the dominant diatom species from March to the beginning of October. In autumn (March and April) phytoplankton assemblage mainly composed of *Ceratium hirundinella* (Müller) and the filamentous conjugatophyceae *Staurastrum anatinum* (Meyer *ex* Ralfs), *Closterium stellenboschense* (Nov.), and *Closterium polystictum* (Ehrenberg). The cyanobacteria *Microcystis aeruginosa* (Kütz) and *Microcystis flos-aquae* (Wittrock) occurred in low biovolumes (3.2 and 1.0 $mm^3 l^{-1}$) during the summer season of 2009.

Phytoplankton seasonal succession in irrigation channels

From the data generated the algae assemblage in the two channels showed a clear trend during the study period and also among sampling stations (**Table 2; Fig 2**). The dominant (Berger & Parker Index, 0.381; 0.312) phytoplankton species *Synedra ulna* (Kütz) occurring in the water column during the 6-weekly sampling intervals at all sampling stations in both the irrigation channels — except for the months March and September. This cosmopolitan species is normally found in the benthos of lakes and rivers but is easily suspended in the plankton due to its relatively large surface (Table 2) During the autumn (March) and fall (September) sampling period the water columns' phytoplankton assemblage of the two channels were dominated by the Dinophyceae *Ceratium hirundinella* (Müller), the Bacillariophyceae species *Fragillaria crotonesis* (Ehrenberg) and the Chlorophyceae species *Closterium stellenboschense* (Nov.), *Closterium polystictum* (Ehrenberg) and *Cosmarium pseudopraemorsium* (Nitzsch *ex* Ralfs). The filamentous macroalgae *Cladophora glomerata* (Kütz) dominated (Berger & Parker Index, 0.478, 0.397, 0.451 and 0.462)

the phytobenthos of sampling stations 3, 4, 5 and 8 during the whole sampling period. However, a much higher biovolume (8.5; 6.3 $mm^3 l^{-1}$) of this species was observed in the long and short channels during the months of March and September, while lower average biovolumes (2.4; 1.5 $mm^3 l^{-1}$) were recorded during the summer months at these sites. The filamentous macroalgae *Oedogonium crassum* (Link) also occurred within the *Cladophora glomerata* benthic mats at sites 5 and 9 during the winter months but at much lower biovolumes (1.3 $mm^3 l^{-1}$; 2.0 $mm^3 l^{-1}$). The benthic algal assemblage at sites 1 and 7 that were within the first 5 km distance downstream of the dam wall reflects physiogenomic forms of commonly occurring and abundant species. Moreover, the occurrence of *Nitzchia frustulum* (Kütz) and *Synedra ulna* (Kütz) emphasize species which were both abundant and cosmopolitan in their distribution (Table 1.). At a distance of 20 km downstream of the dam wall the biovolumes (2.2; 1.3 $mm^3 l^{-1}$) of the epiphytic prostrate, monoraphid diatom species *Cocconeis pediculus* (Ehrenberg) attached to *Cladophora glomerata* mats were much higher in both the long and short channels in comparison to the biovolumes (5.1; 3.3 $mm^3 l^{-1}$) detected on *Cladophora glomerata* branches within the first 5 km downstream of the dam wall during winter. Microscopic analyses reveal that the angle of *Cladophora glomerata* branches from the main axis were much smaller at sampling stations 1 and 7, than observed at sampling stations 3, 4, 8 and 9.

The centric diatom assemblage at all sampling stations throughout the study period were dominated by *Melosira varians* (Agardh) (average Berger & Parker Index, 0.312 for all sites in both channels) and *Cyclotella meneghiniana* (Kütz) (average Berger & Parker Index, 0.248 for all sites in both channels). Both these two species are also good indicators of eutrophication (Taylor et al. 2007). The dominance and average

total biovolume of *Ceratium hirundinella* measured at site 11 was more than 80 % of the total phytoplankton assemblage of this studied site for the whole duration of this study period, indicating that it was an 'equilibrial species' according to Naselli-Flores (2003) (Table 1). The equilibrial phytobenthos species in fall and autumn in the two irrigation channels downstream of Lake Loskop was *Cladophora glomerata* while *Closterium stellenboschense* was the equilibrial Chlorophyceae species in the water column of the two irrigation channels.

Chlorophyll and physicochemical measurement

Although the physical-chemical characteristics of the water at all 11 sampling sites were carried out on a 6-weekly bases only the data of March 2010 are presented in Table 3 — for convenience, since this was the time period when the highest phytoplankton and *Cladophora glomerata* biomass was observed within the two irrigation channels. The highest Chlorophyll *a* concentrations for phytoplankton (32 and 30 μg l^{-1}) in the water column which include drifting detached filaments of *Cladophora glomerata* were measured during March 2010 (in both the long and short irrigation channels), and correlated positively ($r = 0.979$; $p \leq 0.05$) with the high total phosphate (458 μg l^{-1} and 403 μg l^{-1}) measured in the two channels. Records of conductivity at all sampling stations ranged between 290-330 μScm^{-1}, with the highest measured in March at sampling station 7 and the lowest at sampling station 1 in June 2009 (**Table 3**). Surface water temperature in the two channels range from 13.7 ºC in July (mid winter) to a maximum of 25.1 ºC in February (late summer). The decrease in average biovolumes (2.4; 1.5 mm^3 l^{-1}) of *Cladophora glomerata* recorded during the summer months in both the long and short irrigation channels correlated negatively ($r = -0.859$; $p \leq 0.03$) with the average surface temperature of 24.7 ºC

during these months. In contrast with the higher average pH of 8.9 measured in Lake Loskop at site 11, the average pH of the two irrigation channels range between 6.6 and 6.8 throughout the study. During March (beginning of autumn) a much higher average concentration of total phosphate (458 μg l^{-1} and 403 μg l^{-1}) was measured at sampling sites 1 and 7 in the two irrigation channels (nearest to the dam wall) in comparison with the surface water at sampling site 11 (347 μg l^{-1}) in the lake (**Table 3**). Furthermore, a strong positive correlation exist ($r = 0.943$; $p \leq 0.05$) between the higher total phosphate (458 μg l^{-1} ; 403 μg l^{-1}) concentration in the long and short irrigation channels measured in March and the increase in biovolume (8.5; 6.3 mm^3 l^{-1}) of *Cladophora glomerata* in the long and short channels. Throughout the study of 12 months the average concentrations of silica measured in the long and short irrigation channels (4.7 mg l^{-1} ; 4.8 mg l^{-1}) were higher in comparison to concentrations recorded at sampling site 11 (2.2 mg l^{-1}) in Lake Loskop. The dominance (Berger & Parker Index, 0.381; 0.312) of *Synedra ulna* in the water column throughout the study — except for the months March and September — correlated positively ($r = 0.823$; $p \leq 0.04$) with the average concentrations of silica measured in the long and short irrigation channels (4.7 mg l^{-1} ; 4.8 mg l^{-1}) during that sampling period (**Tables 2 & 3**).

Discussion

Frequency of disturbance and water velocity are primary hydrologic variables influencing species richness and diversity (Clausen & Biggs 1997). The resistance of benthic algae to detachment by flooding is conferred by low vertical profile, strong adhesion or cohesive assemblage physiognomy (Hoagland et al. 1982). Tightly

adherent, prostrate taxa like *Cocconeis* and small *Navicula* as well as basal cells of heterotrichous chlorophytes typically dominate benthic algal assemblages at sampling stations with high flows. The high biomass of *Cocconeis* diatoms observed during the study period can be related to this species association with *Cladophora glomerata* mats, since *Cladophora glomerata* mats benefit epiphytic diatoms by providing attachment space and refuge from high flow (Moore 1976).

Although solitary centric diatoms and pinnate diatoms dominated the water column diatom populations in both channels from a distance of 20 km downstream of the dam wall, the centric diatom *Melosira* sp. dominated the water column within the first 5 km downstream of the dam wall. This phenomenon is in accordance with a literature reports by Lund (1966) that *Melosira* filaments sink to the bottom when turbulence becomes to low to keep them in suspension (Lund 1966). The increase in biomass of *Melosira varians* during the winter months in the two irrigation channels can possibly be correlated to lower surface water temperatures measured over this period. This observation is concurrent with an earlier study conducted by Peterson & Stevenson (1989) on the Ohio River and six Kentucky tributaries which indicated that the abundance of the diatom *Melosira varians* correlated positively with lower surface water temperatures.

The decline in biomass by *Cladophora glomerata* during the summer months in both channels can possibly be related to temperature and low nutrients. According to Wong et al. (1978), the *Cladophora* die-off in mid summer could be caused by an inability to maintain dominance above 23.5 ºC. Furthermore, laboratory experiments conducted by Graham et al. (1982) on *Cladophora* indicated that the net photosynthetic O_2

production decreased above 25 ºC, establishing a clear correlation between temperature and midsummer biomass decline. According to Muller (1983) low nutrients associated with higher temperature may partially explain midsummer decline of *Cladophora* biomass in rivers. The increased branching of *Cladophora* observed in this study, in both channels within the first 10 km downstream of the dam wall, can possibly be linked to hydrodynamic factors, since the slope and current velocity of both channels are higher for the first couple of kilometres. This observation is concurrent with earlier studies by Parodi & Caceres (1991) who reported that *Cladophora* branching may increase with increase in water velocity, while Whitton (1975) observed that the angle of *Cladophora* branches from the main axis decreases with increased current.

The dominance of the water column phytoplankton assemblage in the two irrigation channels by the Dinophyceae *Ceratium hirundinella*, the Bacillariophyceae species *Fragillaria crotonesis* and the chlorophycea species *Closterium* during the autumn (March) and fall (September) sampling period can possibly be related to temperature induced mixing (lake overturn) causing the vertical warm and cold water zones in the dam to mix due to changes in net heat input. The increase in mixing depth may induce similar temperature and chemical conditions from top to bottom (Wetzel 1983). Withdrawal of irrigation water from the upper-hypolimnia during this period may have contained and transport phytoplankton species usually occurring in the epilimnon zone causing the dominance of *Ceratium hirundinella*, *Fragillaria crotonesis*, *Closterium stellenboschense* and *Closterium polystictum* in the water column of the two irrigation channels. Furthermore, *Ceratium hirundinell* is known to be absent in systems with high flushing rates and unstratified water columns (Sommer

et al. 1986) and therefore it is unlikely that this species will occurred under natural conditions in elevated numbers in the two irrigation channels with high flows. The higher biomass of *Cladophora glomerata* observed during late March and September can also be related to the dam overturn. During these sampling periods the total phosphate measured in the epilimnon zone of the lake (site 11) was much less than the measured total phosphate in the two irrigation channels within the first 5 km downstream of the dam wall.

The importance of overturn events is magnified in reservoirs that release water for irrigation from the middle or bottom of the water column, since advective circulation allows hypolimnetic phosphate to exit the reservoir without entering the photic zone when recycling of nutrients during lake overturn does not bring it to surface waters (Matzinger et al. 2007). These increase concentrations of phosphate measured in the irrigation channels may have been one of the main drivers that stimulated the increase in biomass of *Cladophora glomerata*. In literature, the most commonly published observation is that an increase in *Cladophora* biomass or production in freshwater is stimulated by phosphorus additions (Jackson 1988; Painter & Jackson 1989). In a previous study by Auer & Canale (1982) they determined that the half-saturation phosphate uptake constants by *Cladophora glomerata* was in the range of 50-250 μg P l^{-1}, while slightly lower half-saturation uptake constants of 15-86 μg P l^{-1} were reported for the same species by Lohman & Priscu (1992).

However, the poor relationship between phytoplankton density and the decrease of total phosphate concentrations measured at irrigation channel sites 30 to 40 km downstream of the dam wall may have been due to the exsistence of a nutrient-

depletion gradient between these sites and sites 10 km downstream of the dam wall. Lakshminarayana (1965) reported in his study that nutrients in rivers can decrease with phytoplankton density. Therefore we suggest that, the increase in phytoplankton densities measured at sites which were allocated 10 km in distance away from the dam wall, could have sequestered nutrients and decreased nutrient concentrations as they settled or were transported downstream.

The differences in pH values between site 11 and the much lower pH values measured at all sites in both irrigation channels through out the study can be linked to a bloom of *Ceratium hirundinella* that excist in the epilimnion (site 11) during the whole sampling period with a high average biovolume of 13 mm^3 l^{-1}. The high photosynthetic rate of these dinoflagellate species can lower the dissolved CO_2 in the water causing a raise in pH (Kalff 2002). The increase in silica concentrations measured in the two irrigation channels in comparison with sampling site 11 can be related to the all year round bloom of *Ceratium hirundinella* which significantly reduced silica since this element is a major constituent of the phytoplankton *Ceratium's* cell walls (Sigee et al., 1999).

Conclusion

It was evident from our study that the poor water quality of Lake Loskop which contain high concentrations of phosphates stimulate the growth of the nuisance algal *Cladophora glomerata* in the irrigation channels downstream. The possible management practices of *Cladophora glomerata* can be divided in twee categories namely direct control by removing the algae over the short term during lake over turn

periods and secondly the initiation of a long term nutrient management program in the watershed.

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Figure legends

Figure 1. Map of Lake Loskop and the two irrigation channels, showing the location of the 11 sampling sites, and the position of inflowing Olifants River. Inset shows the location of the map area in South Africa.

Figure 2. Seasonal succession of phytoplankton Classes in the irrigation channels downstream from Lake Loskop.

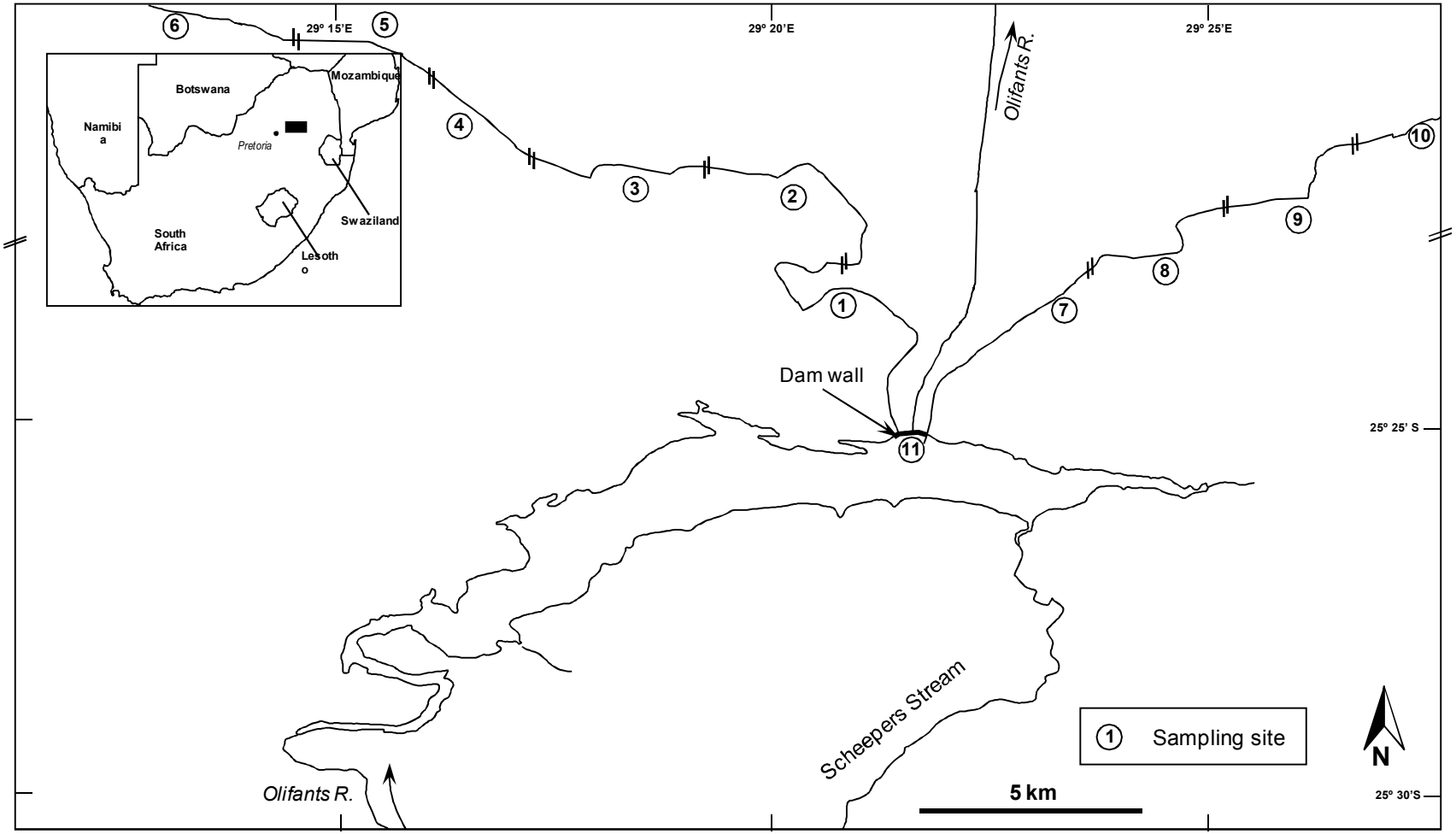
29° 15'E
29° 20'E
29° 25'E
25° 25' S
25° 30'S
Olifants R.
Botswana
Mozambique
Namibia
Pretoria
Swaziland
South Africa
Lesotho
Dam wall
Scheepers Stream
Olifants R.
1 Sampling site
N
5 km

Figure 1

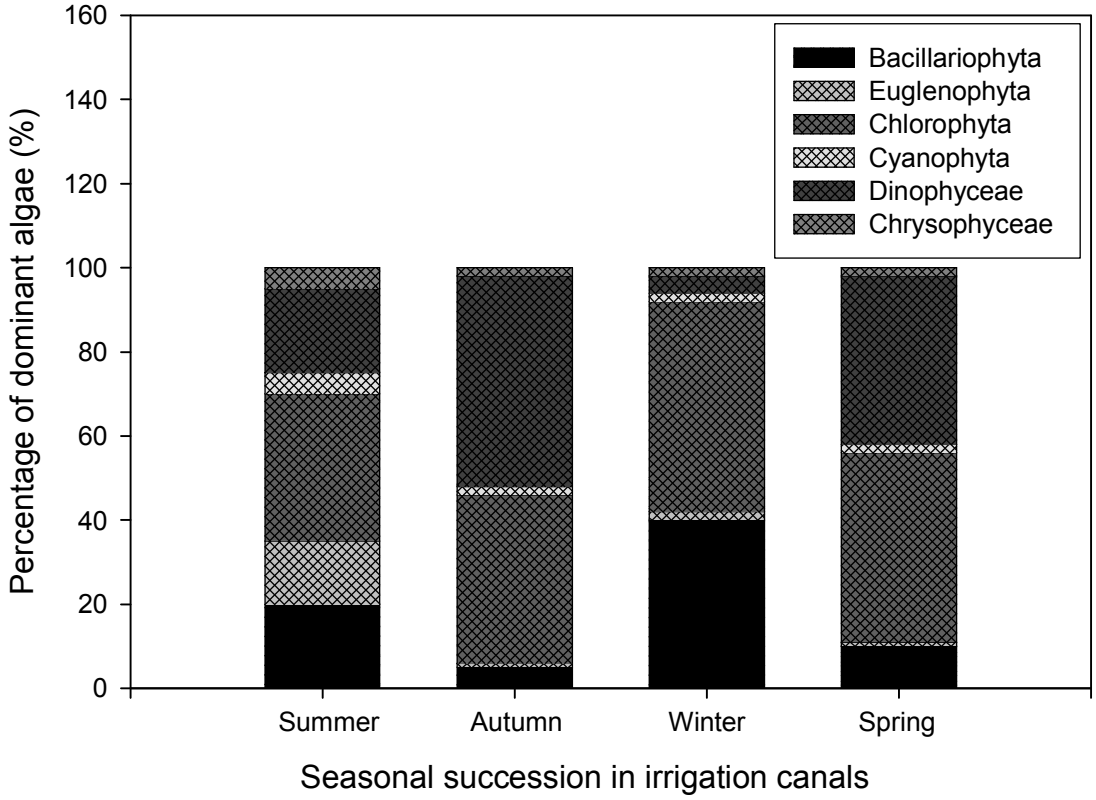
160
140
120
100
80
60
40
20
0
Percentage of dominant algae (%)
Bacillariophyta
Euglenophyta
Chlorophyta
Cyanophyta
Dinophyceae
Chrysophyceae
Summer
Autumn
Winter
Spring
Seasonal succession in irrigation canals

Figure 2

Table 1: Description of sampling sites, coordinates and dominant algal species and average bio volume at each sampling site over a period of one year.

Sampling Site	Sampling site description	Coordinates	Dominant algal species	Biovolumn
1	Channel (± 5 km from Loskop Dam wall — long channel)	25°21'29.2" 29°21'18.03"	*Synedra ulna*	4.6 $mm^3 l^{-1}$
2	Channel (± 10 km from Loskop Dam wall — long channel)	25°10'44.4" 29°20'48.07"	*Synedra ulna*	4.1 $mm^3 l^{-1}$
3	Channel (± 24 km from Loskop Dam wall — long channel)	25°15'24.4" 29°24'40.8"	*Cladophora glomerata*	5.7 $mm^3 l^{-1}$
4	Channel (± 30 km from Loskop Dam wall — long channel)	25°14'33.4" 29°24'49.8"	*Cladophora glomerata*	6.2 $mm^3 l^{-1}$
5	Channel (± 35 km from Loskop Dam wall — long channel)	25°14'15.2" 29°24'17.9"	*Cladophora glomerata*	7.6 $mm^3 l^{-1}$
6	Channel (± 40 km from Loskop Dam wall — long channel)	25°04'05.22" 29°14'44.11"	*Cladophora glomerata*	7.1 $mm^3 l^{-1}$
7	Channel (± 5 km from Loskop Dam wall — short channel)	25°13'59.7" 29°29'35.6"	*Cladophora glomerata*	7.8 $mm^3 l^{-1}$
8	Channel (± 10 km from Loskop Dam wall — short channel)	25°19'26.7" 29°25'22.9"	*Cladophora glomerata*	7.5 $mm^3 l^{-1}$
9	Channel (± 20 km from Loskop Dam wall — short channel)	25°23'15.6" 29°29'35.6"	*Cocconeis pediculus*	4.9 $mm^3 l^{-1}$
10	Channel (± 40 km from Loskop Dam wall — short channel)	25°16'23.3" 29°26'18.3"	*Cocconeis pediculus*	5.2 $mm^3 l^{-1}$
11	Loskop Dam near the dam wall	25°26'03.3" 29°22'25.7"	*Ceratium hirundinella*	12.1 $mm^3 l^{-1}$

Tabel 2. Composition of the phytoplankton community in the long, short irrigation channels and Lake Loskop. Sampled from April 2009 to March 2010 (+ = rare, + + =scarce, + + + = common, + + + + = abundant, + + + + + = predominant) The relative abundance of each phytoplankton taxa was grouped into : 1 = ≤ 50 (rare) 2 = 51- 250 (scarce), 3 = 251-1000 (common), 4 = 1001-5000 (abundant), 5 = 5001-25 000 (predominant) cells l^{-1}.

Division	Major species	Pelagic (P)or benthic (B) algal species	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10	Site 11
Chrysophyta													
Chrysophyceae	*Dinobryon divergense*	P	+ +	+ +	+	+	+	+	+ +	+	+	+	+
Bacillariophyceae	*Cocconeis pediculus*	B	+ +	+ +	+ + + +	+ + + +	+ + + +	+ + + +	+ +	+ + +	+ + +	+ + + +	
	Craticula cuspidata	P	+	+ +	+ +	+ +	+ +	+ +	+	+	+ +	+ +	
	Cyclotella meneghiniana	P	+ +	+ + +	+ + +	+ + +	+ + +	+ + +	+ +	+ + +	+ + +	+ + +	+
	Diatoma vulgaris	P	+ +	+ + +	+ + +	+ + +	+ + +	+ + +	+ + +	+ + +	+ + +	+ + +	+
	Flagilaria ulna	B	+ +	+ +	+ + +	+ + +	+ + +	+ + +	+ +	+ + +	+ + +	+ + +	+
	Flagilaria crotonesis	P	+ + +	+	+	+	+	+	+ + +	+	+	+	+ + +
	Nitzschia intermedia	P	+ + +	+ + +	+ + +	+ + +	+ + +	+ + +	+ + +	+ + +	+ + +	+ + +	+
	Nitzschia umbonata	P	+ +	+ +	+ +	+ +	+ +	+ +	+ + +	+ +	+ +	+ +	
	Nitzschia pura	P	+ +	+ +	+ +	+ +	+ +	+ +	+ +	+ +	+ +	+ +	
	Gyrosigma rautenbachiae	B	+ +	+ + +	+ + +	+ +	+ +	+ +	+ + +	+ + +	+ +	+ +	+ +
	Pinnularia viridiformis	B	+ + +	+ + +	+ + +	+ + +	+ + +	+ + +	+ + +	+ + +	+ + +	+ + +	+
	Pinnularia subcapitata	B	+	+	+	+		+	+	+	+	+	
	Surirella ovalis	P	+ +	+ +	+ +	+	+ +	+ +	+	+ +	+	+ +	
	Synedra ulna	B	+ + +	+ + +	+ + +	+ + +	+ + + +	+ + +	+ + + +	+ + +	+ + +	+ + +	+ +
	Melosira varians	B	+ + + +	+ + + +	+ + + +	+ + + +	+ + +	+ + +	+ + + +	+ + +	+ + +	+ + +	+ + +
	Stephanodicus hantzchii	P	+	+ +	+ +	+	+	+ +	+	+	+ +	+	+
	Eunotia formica	P	+ +	+	+	+	+	+	+	+	+	+	+
	Asterionella Formosa	P	+ +	+	+	+	+	+	+	+	+	+	+ + +
Pyrrhophyta													
Dinophyceae	*Peridinium bipes*	P	+ +	+	+	+	+	+	+ +	+	+	+	+ + +
	Ceratium hirundinella	P	+ + +	+ +	+	+	+		+ + +	+ +	+	+	+ + + + +
Chlorophyta													

Conjugatophyceae	*Closterium polystictum*	P	+ ++	+ ++	+ ++	+ ++	+ ++	+ ++	+ ++	+ ++	+ ++	+ ++	+ ++
	Closterium stellenboschense	P	+ +	+ ++	+ +	+ ++	+ ++	+ +	+ +	+ ++	+ ++	+ ++	+
	Spondylosium secedens.	P	+	+				+	+	+			
	Cosmarium pseudopraemorsium	P	+	+		+	+			+	+		+ ++++
Chlorophyceae (Cladophorales)	*Cladophora glomerata*	B	+ ++++	+ ++++	+ +++	+ ++++	+ +++	+ +++	+ ++++	+ +++	+ ++	+ ++	
Chlorophyceae (Oedogoniales)	*Oedogonium crassum*	B	+ +	+ +	+	+ ++	+	+	+	+ +	+	+ +	
Chlorophyceae (Chlorococcales)	*Scenedesmus armatus*	P	+ +	+ +	+ +	+		+	+ +	+	+	+	+ +
	Oocystis rupestris	P	+	+	+	+		+	+	+			+ +
	Staurastrum anatinum	P	+	+	+ +	+ +	+	+	+ +	+	+	+	+ +
Euglenophyta													
Euglenophyceae	*Trachelomonas intermedia*	P	+ +	+ +	+	+	+	+	+	+	+	+	+ +
	Phacus pleuronectes	P		+		+				+	+	+	+
Cyanophyta													
Oscillatoriaceae	*Oscillatoria limosa*	P	+ +	+	+	+ +	+ +	+	+	+	+	+	+

Table 3. Comparison of the average physical, chemical and biological characteristics recorded after random sampling at each of the eleven sampling sites which include Lake Loskop and both the short and long irrigation channels over a period of 1 year. (n = 9).

Characteristic (and units)	Sampling Sites										
	1*	2*	3*	4*	5*	6*	7†	8†	9†	10†	11†
Electrical Conductivity (µS.cm^{-1} @ 25 °C)	363 ± (16)	359 ± (10)	342 ± (13)	340 ± (9)	334 ± (11)	331 ± (19)	359 ± (20)	341 ± (11)	338 ± (18)	311 ± (9)	411 ± (31)
pH (Negative Log [H^+] @ 25 °C)	6.5 ± (0.6)	6.7 ± (0.)	6.9 ± (0.4)	6.9 ± (0.2)	6.9 ± (0.3)	6.9 ± (0.3)	6.4 ± (0.6)	6.5 ± (0.2)	6.5 ± (0.3)	6.7 ± (0.5)	8.6 ± (4)
Dissolved Oxygen (mg O_2.liter^{-1})	4.1± (0.3)	4.7± (1.1)	5.4± (1.7)	6.1± (1.2)	6.7± (1.1)	6.9± (1.8)	4.3± (1.1)	5.1± (2.6)	6.6± (1.3)	7.9± (1.7)	9.01± (2.1)
Sodium (mg Na.liter^{-1})	19 ± (3)	17 ± (2)	20 ± (1)	18 ± (2)	19 ± (3)	19 ± (3)	19 ± (4)	18 ± (3)	17 ± (3)	18 ± (2)	25 ± (6)
Potassium (mg K.liter^{-1})	4.2 ± (0.5)	4.3 ± (0.2)	4.7 ± (0.6)	4.1 ± (0.1)	4.5 ± (0.2)	4.2 ± (0.3)	4.4 ± (0.2)	4.1 ± (0.2)	4.3 ± (0.2)	4.2 ± (0.3)	4.4 ± (0.2)
Calcium (mg Ca.liter^{-1})	29 ± (3)	27 ± (4)	26 ± (4)	24 ± (3)	27 ± (3)	23 ± (3)	28 ± (3)	27 ± (4)	25 ± (2)	24 ± (1)	27 ± (3)
Magnesium (mg Mg.liter^{-1})	20 ± (3)	19 ± (4)	18 ± (2)	18 ± (4)	18 ± (4)	16 ± (4)	19 ± (3)	18 ± (1)	19 ± (2)	19 ± (2)	21 ± (4)
Chloride (mg Cl.liter^{-1})	16 ± (4)	13 ± (3)	13 ± (3)	14 ± (1)	14 ± (3)	15 ± (2)	16 ± (4)	15 ± (1)	13 ± (2)	12 ± (4)	19 ± (5)
Sulfate (mg SO_4.liter^{-1})	267 ± (42)	167 ± (18)	142 ± (11)	126 ± (10)	111 ± (14)	110 ± (24)	273 ± (67)	210 ± (21)	132 ± (10)	110 ± (9)	183 ± (47)
Total Alkalinity (as mg $CaCO_3$.liter^{-1})	69 ± (3)	68 ± (4)	68 ± (1)	64 ± (5)	63 ± (4)	63 ± (2)	72 ± (8)	68 ± (3)	65 ± ()	63 ± (2)	79 ± (11)
Silica (mg Si.liter^{-1})	5.3 ± (0.4)	5.1 ± (0.8)	5.5 ± (0.9)	4.8± (0.9)	5.4 ± (0.6)	5.8 ± (0.7)	5.6 ± (0.7)	5.1 ± (0.3)	4.8 ± (0.3)	4.9 ± (0.7)	2.3 ± (0.9)
Total phosphate (µg P.liter^{-1})	431 ± (71)	481 ± (53)	361 ± (35)	349 ± (29)	279 ± (24)	164 ± (18)	55 ± (87)	459 ± (72)	410 ± (58)	321 ± (33)	390 ± (23)
Total nitrogen (µg N.liter^{-1})	9573 ± (322)	9319 ± (253)	6751 ± (211)	4901 ± (231)	4632 ± (219)	4200 ± (181)	8979 ± (397)	7651 ± 317)	6433 ± (284)	5322± (221)	7231 ± (309)
Chlorophyll *a* (µg.liter^{-1})	29± (11)	34± (9)	28± (3)	23± (8)	19± (6)	25± (7)	32± (4)	23± (9)	27± (5)	14± (3)	119± (33)
Temperature (C°)	16.3 ± (0.4)	17.7 ± (0.5)	17.9 ± (0.3)	18.3 ± (0.4)	19.6 ± (0.6)	19.3 ± (0.3)	16.3 ± (0.2)	17.5 ± (0.4)	18.2 ± (0.7)	18.7.0 ± (0.3)	25.1.1 ± (0.3)

- Long irrigation channel
† Short irrigation channel