Establishing the fishery potential of Lake Nandoni in the Luvuvhu River, Limpopo Province

Report to the

WATER RESEARCH COMMISSION

by

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EXECUTIVE SUMMARY

BACKGROUND

It is often stated that inland fisheries can provide an essential contribution to local and regional economies as well as sustain livelihoods. In Sri Lanka irrigation reservoirs are used for inland fisheries and yields contribute a large portion of the total fish production of the country. Throughout Africa natural and artificial inland water bodies are regarded valuable and integral part of the lives of many people and estimates in West and Central Africa show that fisheries provide livelihoods to full time fishers and yield annual catches in excess of half a million tons. Inland fisheries, and their contribution to the food security, are important in Africa as the harvesting of fish from the reservoirs provides food for rural communities. South Africa is an arid country that depends on man-made reservoirs for the water supply. These reservoirs potentially contain fish that can be utilized as a source food but historically these fish resources were not considered as a source of protein and as such are not commercially harvested.

To determine whether fish can be harvested, or a fishery industry be established, an assessment should be done which must determine the status of the resource and establish safe levels for sustainable exploitation. In such an assessment it should be investigated how the fish population would respond to harvest. This would include determining the fish biomass and the fisheries potential and would include establishing the catch per unit effort and size selectivity of the gear to be used. In addition biological data of the involved fish species, which include feeding and reproduction, are regarded as important and should be collected.

RATIONALE

Based on its size and geographical position the Nandoni Dam is ideally situated to allow for both commercial harvesting and aquaculture. For sustainable utilization these activities should be well managed and the management should be based on a fisheries management plan. Such a fisheries management plan must be based on sound knowledge of the fishery potential of the impoundment which in turn hinges on knowledge of the dynamics of the fish community. The knowledge should include an investigation of the composition of the fish community, the production potential, the basic biology of the major fish species in the impoundment as well as an in depth limnological investigation of the impoundment. The fisheries potential of the impoundment, as well as problems associated with a lack of a proper researched management plan was recognised the Limpopo Department of Economic Development Environment and Tourism (LEDET) who requested and supported the intended research.

OBJECTIVES AND AIMS

The objective of the project was to determine the fisheries potential of Lake Nandoni. To obtain the objectives the aim of this project was to gather data on the aspects regarding the biological,

ecological and physical aspects listed above so that this could be used as guideline for a management plan for inland fisheries.

METHODOLOGY

Study sites were selected in the main body of the impoundment, at the inflow into the impoundment and upstream in the rivers that flow into the impoundment. The sites in the impoundment were used to investigate the limnology, establish the water quality and collect samples of fish as well as zoo- and phytoplankton. Surveys were conducted monthly for a year which, was followed up by three independent surveys, starting in September 2009 and ending in June 2011.

To investigate the limnology selected physico-chemical parameters were recorded *in situ* at the sites in the impoundment. These included dissolved oxygen, electrical conductivity, total dissolved substances, pH and temperature. One site in particular at the deepest point in the impoundment sampling was done at one meter intervals to establish whether stratification and overturn occurred.

At the other sites, with the exception of the deepwater site, and at the inflow sites zoo- and phytoplankton samples were collected. The phytoplankton samples were used to determine the chlorophyll-a concentration, and therefore primary productivity, and to determine the biodiversity up to species level. Only the major taxa of zooplankton were identified.

Water samples were collected at all the sites and analysed in the laboratory to determine nutrient concentrations.

Fish sampling was done at the sites on the impoundment, using fleets of experimental gill nets, traps and electro-fishing. From the collected data the biodiversity, population structure, catch per unit effort and potential yield was determined. Specimens, in particular of the dominant species were retained to investigate their reproductive and feeding biology. Parasites for identification were collected from these specimens and the health status of the fish determined.

RESULTS AND DISCUSSION

Lake Nandoni at this point in time provides excellent habitat for fish. Not only are most of the water quality characteristics within anticipated parameters but the upper levels of the water throughout the main body of the impoundment is sufficiently oxygenated. The fact that the observed oxygen and temperature stratification was followed by turnover, and mixing of the hypo- and epilimnion, can lead to proper distribution of nutrients the water body. This in turn can lead to sustainable production. There are however reasons for concern. The concern is mostly with regard to the levels of pollution, in the form of nutrients and in particular the phosphates, recorded at the inflow sites. At these sites conditions typical of eutrophy, such as supersaturated oxygen levels and high algal densities, were recorded. If the level of pollution, and in particular the Mvudi River, is not controlled there is a reason to believe that this impoundment will become one of the eutrophic impoundments of South Africa.

Phytoplankton abundance and species composition changes as a function of ratios of supplied nutrients; low N:P ratios favour the development of cyanobacterial growth. This ratio in Lake Nandoni was very low (<5), because of the high phosphorus concentrations in particular at the inflow sites, and is probably the causal factors leading to the observed phytoplankton bloom.

Fish catches were dominated by *Schilbe intermedius, Labeobarbus marequensis* and *Oreochromis mossambicus* of which the latter is the species targeted by local fishermen. The population structure of the dominant species was natural with both juveniles and adults present. Due to the small sample size of *L. marequensis* the reproductive strategy could not be studied in detail but results obtained with the other two species supplied data regarding their breeding, which in essence is similar to what is described in the literature. Results show that the potential yield of the impoundment is higher than similar water bodies in adjacent areas and suggest that a sustainable harvest should be in the region of 26 $kg.ha^{-1}$. The results obtained regarding net selectivity is of interest as it supplies an indication of the nets sizes that can be employed successfully. The overall condition and health of the fish was good and no obvious external signs or blood parameters indicated that the fish are stressed. With the exception of *Contracaecum* larvae from *C. gariepinus* none of the parasites were recorded in excessive numbers. The digenean larvae recorded are of zoonotic importance and have the potential to develop in humans.

RECOMMENDATIONS FOR A FUTURE MANAGEMENT STRATEGY

Based on the findings of the report the deteriorating water quality and the possibility of eutrophication were identified as threats. In addition uncontrolled harvesting of fish was pointed out as a contributing factor that could lead to the collapse of a proposed fishery

Recommendations for a management plan included setting clearly formulated and communicated aims by the lead department; ensuring the “buy-in” of affected parties; stakeholder involvement and the setting of prescribed quotas and in particular the enforcement thereof. The water quality issue was pointed out showing that water quality monitoring and plans for corrective actions should form part of any management plan. Because this project did not investigate the socio-economic aspects it is therefore recommended that research in this regard is carried out prior to any projects being initiated.

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1 INTRODUCTION

1.1 Background and problem statement

The Luvuvhu River Catchment forms part of the larger Limpopo River System that together with the Letaba River Catchment forms Water Management Area (WMA) 2. The Luvuvhu River Catchment, with an estimated surface area of 5 941 km^2, extends for 250 km from 20 km east of the town of Louis Trichardt in a north-easterly direction to Pafuri in the Kruger National Park (KNP) (State of the Rivers Report, 2001). The catchment is bisected along its longer east-west axis by the Soutpansberg mountain range where the majority of the tributaries of the Luvuvhu River, which include the Lutanandwa, Dzindi and Mutshundudi, originate on its southern slopes (Figure 1.1). Rainfall in the catchment varies considerably with one portion of the catchment between the towns of Louis Trichardt and Thohoyandou, receiving a mean annual precipitation (MAP) in excess of 1 200 mm while most of the remainder of the catchment, where the headwaters of the Lutanandwa, Barotta, Dzondo, Dzindi and Mutshundudi rivers are situated, receives between 500 and 1000 mm per year (Pullen in DWAF, 1997). These tributaries contribute 73% of the natural run-off that enters the Luvuvhu River. In the arid areas in the extreme east and the west of the catchment rainfall is less than 500 mm per annum.

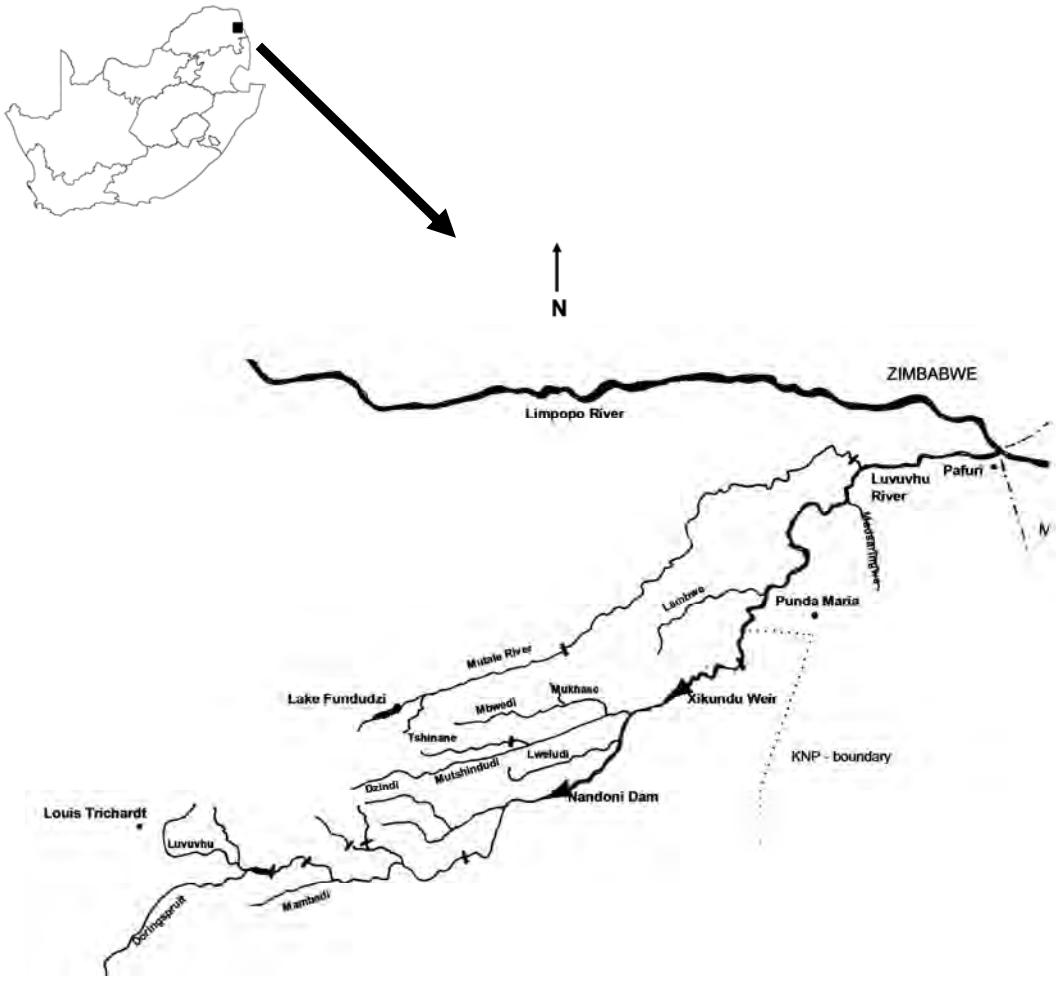

Figure 1.1: Sketch map of the Luvuvhu River and its major tributaries. (Adapted from DWAF, 1997).

The Luvuvhu River is a geomorphologically diverse system with a variety of alluvial and bedrock channel types occurring along its length. The upper reaches are steep and narrow and dominated by cobble riffles and occasional pools with a few bedrock rapids while in the lower reaches rapids are rare and the pools have sand and mud substrates (Fouché, 2009). The river and its tributaries flow through five Level II eco-regions that form part of the Lowveld, Central Highlands and Limpopo Plain and this adds to the diversity of the river (State of the Rivers Report, 2001).

Historic data shows that in general the water quality of the Luvuvhu River is regarded as "good" with electrical conductivity that ranges from 13 to 16 mSm^{-1} because of low dissolved substances (DWAF, 1990) O'Keeffe et al. (in DWAF, 1997) stated that nutrient concentrations were low and that the determinants of water quality are dominated by total alkalinity and sodium, chloride and to some extent calcium concentrations. Table 1.1 shows that dissolved salt and sodium concentration as well as alkalinity increases downstream. Although the Luvuvhu River has always been a river with high silt loads, the increased levels of sedimentation, caused by badly planned farming practices, is reason for concern (State of the Rivers Report, 2001).

Table 1.1: Physico-chemical parameters recorded in the Luvuvhu River (Adapted from DWAF, 1990).

Parameters	Middle reaches	Lower reaches
pH range	5.9-7.8	6.0-8.2
Maximum TDS (mgL^{-1})	90	167
Maximum sodium concentration (mgL^{-1})	11.5	16.5
Maximum total alkalinity (mgL^{-1})	61	83

Table 1.2 shows that 23 species, that belong to nine families, make up the extent of the fish biodiversity in the reach of the Luvuvhu River where the Nandoni Dam has been constructed.

Economic activity within the Luvuvhu-Letaba WMA is characterized by irrigation, afforestation, tourism and informal farming. Over 90 per cent of the WMA's population of about 1.5 million lives in rural communities and based on 1995 surveys (DWAF, 1997) just over 0.51 million resides within the Luvuvhu River catchment. Human impact on the river prior to 1910 was limited with no exotic afforestation, irrigation or dam construction (DWAF, 1997). Afforestation commenced in the upper basin area in 1911 and extended to the areas around Thohoyandou in 1950. The first dam built, the Albasini Dam, was completed in 1952 and the amount of water used for irrigation, previously drawn from run-of-river weirs, increased dramatically (DWAF, 1990). Currently the river and its tributaries are highly fragmented with six dams and ten gauging weirs. A change in run-off in the middle reach has been recorded for the ninety year period from 1900 to 1990, with run-off decreasing from *ca.* 389 million m^3 per annum to 308 million m^3 per annum in (DWAF, 1990). Historically flow in the Luvuvhu River never ceased but in recent times cessation of flow for periods during the year has occurred with the first record in 1946 (Moore et al., 1991). Projections regarding yield, based on 1995 data, showed that as early as 2000 no surplus yield would be available in the catchment and that an over-commitment of resources is occurring with a negative balance to the extent of 6 million m^3a^{-1} (DWAF,

1997). In the same report it is stated that these deficits will be relieved once the new dam at Nandoni is commissioned.

Table 1.2: The fish biodiversity of the reach of the Luvuvhu River where Nandoni Dam has been constructed.

Families	Scientific name	English common name
Anguillidae	*Anguilla mossambica*	Longfin Eel
Amphiliidae	*Amphilius uranoscopus*	Mountain Catfish
Mochokidae	*Chiloglanis paratus*	Sawfin Suckermouth
	Chiloglanis pretoriae	Shortspine Suckermouth
	Synodontis zambesensis	Brown Squeaker
Clariidae	*Clarias gariepinus*	Sharptooth Catfish
Cyprinidae	*Labeobarbus marequensis*	Lowveld Largescale Yellowfish
	Labeo cylindricus	Redeye Labeo
	Labeo molybdinus	Leaden Labeo
	Labeo rosae	Rednose Labeo
	Barbus paludinosus	Straightfin Barb
	Barbus trimaculatus	Threespot Barb
	Barbus unitaeniatus	Longbeard Barb
	Barbus viviparus	Bowstripe Barb
	Mesobola brevianalis	River Sardine
Mormyridae	*Marcusenius macrolepidotus*	Bulldog
	Petrocephalus wesselsi	Southern Churchill
Cichlidae	*Oreochromis mossambicus*	Mozambique tilapia
	Pseudocrenilabrus philander	Southern Mouthbrooder
	Tilapia rendalli	Redbreast Tilapia
	Tilapia sparmanni	Banded Tilapia
Schilbeidae	*Schilbe intermedius*	Butter Catfish
Alestidae	*Micralestes acutidens*	Silver Robber

The Nandoni Dam, which lies 16 km southeast of Thohoyandou, is part of the Luvuvhu River Government Water Scheme (LWGS) and the dam wall consists of a 38 m high composite concrete spillway section with earth flanks and at full supply level (FSL) the surface area of Lake Nandoni will be 1650ha with a gross storage capacity of 164 million m^3 (DWAF, 2001). The LWGS includes of two water treatment plants, pumping stations and bulk water distribution pipelines. The scheme is designed to supply water for domestic use, irrigation and forestry. As part of the normal progression stages of impoundments are concerned the development consists of three early stages. The first stage is the “filling phase”, this is followed by the “stabilizing phase” and then by the “maturing phase”. During the first phase the fish population in the impoundment is as yet not affected as the impoundment still functions a river. In the second phase the dam is filled and starts functioning as a lentic water body. During this phase the productivity, and in particular fish production, increases dramatically. In the third phase the impoundment reaches a more mature stage and production drops to sustainable levels. Lake Nandoni started filling in 2004 and at this point in time it is probably already in the early phases of the third or maturing phase.

However, relatively high levels of productivity are often observed in newly impounded reservoirs. This phenomenon has been termed trophic upsurge and is thought to be caused by the leaching of phosphorous from flooded soils and through phosphorous releases by the decomposition of flooded

vegetation and soil organic matter. New reservoirs typically go through an early period of high fish production soon after they are filled and then decline to a much lower level of productivity. This high initial productivity is due to flooding of terrestrial plants and nutrient rich soil. It is followed by a decline in basic fertility as nutrients are lost by outflow of the nutrient-rich hypolimnetic water and by sedimentation (Holz et al., 1997).

According to Smith et al. (2005) inland fisheries can provide an essential contribution to local and regional economies as well as sustain livelihoods. In Sri Lanka, a country that is devoid of natural lakes and has no riverine commercial fisheries, irrigation reservoirs are used for inland fisheries and yields 20% of the total fish production of the country. Throughout Africa extensive inland waterbodies, both natural and artificial, occur which are seen as a valuable and integral part of the lives of many people (Weyl et al., 2007). A recent estimate of employment and income for seven river basins in West and Central Africa showed that fisheries provide livelihoods to more than 227,000 full time fishers and yield an annual catch of *ca* 570,000 tons (www.nepad.org/foodsecurity/fisheries). The importance of inland fisheries, and in particular their contribution to the food security is underpinned by Ellender et al. (2010). In Africa the harvesting of fish from the reservoirs is an important food source for rural communities, particularly those living close to the water bodies (Kapetsky et al., 1984).

South Africa is an arid country and depends on man-made reservoirs that dominate the landscape (Allanson et al*.,* 1990). A major portion of the annual runoff (Uys, 1996) is captured and stored to supply water for human water use, industries, and irrigation (Rouhani, 2004). Because of increased habitat availability these reservoirs contain large numbers of fish that can be used as a source food (Hamman, 1981). Historically the fish resources in state-owned dams in South Africa were not considered as a source of protein and as such are not commercially harvested. This despite the fact that it is often accepted that the estimated harvestable yield of fish could be as much as 200 kg per ha per year, depending on factors such as water quality, primary productivity, depth, shape of impoundment, fish species present, fishery pressure and other limnological aspects (Gaigher, 1971).

A major component of fishery assessment is to determine the status of the resource and to establish safe levels for sustainable exploitation (King 1995). Catch and effort surveys give a good indication of the source and can subsequently also be used to determine how the fish population responds to harvest (Reid and Montgomery, 2005). The species and size composition of anglers catches can reflect what impact angling has on the exploited population (Weyl et al., 2007). Traditionally commercial and subsistence fishing have often been contributing factors in the collapse of a large number of inland fisheries (Cooke and Cowx, 2006; Allen et al., 2005). In Africa factors such as the lack of a fishing history in communities, the absence of species with a high fisheries potential as well as inadequate fisheries policies can result in the depletion of fish stocks in reservoirs (Weyl et al., 2007). Fishery surveys of South African reservoirs have focused on estimating fish biomass and the fisheries potential of a variety of inland reservoirs (Ellender, 2008). In these surveys the main aim was

to determine the status of the resource and to establish safe levels for sustainable exploitation (King, 1995). Methods such the catch per unit effort and size selectivity of the gear used provide useful information for future management (Naesje et al*.,* 2004) and conservation of species (Ellender, 2008). Length and weight data provide statistics that form the cornerstones in fishery research and management where the number and size of fish available in a population can also be used to determine its potential for recreational, subsistence or commercial fishery (Naesje et al., 2004).

Based on its size and geographical position Lake Nandoni is ideally situated to allow for both commercial harvesting of the fish species present as well as for aquaculture. Such activities should however be well managed and *in lieu* of that, a fisheries management plan should be drawn up. Planning and the establishment of a fisheries management plan must be based on sound knowledge of the fishery potential of the impoundment. This can only take place if enough is known of the dynamics of the fish community in the impoundment. The knowledge gained should include aspects such as: The composition of the fish community, production potential, changes in fish community structure with development of the impoundment into more mature stages after inception, basic biology of the major fish species in the impoundment, basic physical and chemical and biological processes in the impoundment and the ways they affect the fish production potential as well as the effects of sewage plant effluents released into the impoundment on the productivity of the impoundment and quality of the fish. This fisheries potential of the impoundment, as well as problems associated with a lack of a proper researched management plan was recognised by Mr MK Angliss, the Specialist Aquatic Scientist of the Limpopo Department of Economic Development Environment and Tourism (LEDET) at the time, who then requested and supported the intended research.

The aim of this project was to gather data on aspects regarding the biological, ecological and physical listed above so that this could be used as guideline for a management plan for inland fisheries at the Lake Nandoni. The aim was then divided into the following objectives:

a) To investigate the limnology of the impoundment.
b) To determine the primary production and secondary of the impoundment.
c) To determine the potential productivity of the impoundment
d) To determine the contribution of the rivers that feed into the impoundment.

The limnology of the impoundment was investigated by establishing the physico-chemical conditions of the impoundment and determining whether stratification occurs. The primary production was investigated by establishing the phytoplanktonic biodiversity, community structure and seasonal variation. In addition the relationship of the above to physico-chemical aspects of the water was established. Secondary production was investigated by establishing the zooplankton biodiversity, community structure and the seasonal variation in these communities. The potential productivity of the impoundment was investigated by establishing fish diversity and community structure. In addition the biology of selected fish species, including aspects such as condition factor, growth, breeding and feeding. As part of this component the potential yield, the catch per unit effort and net selectivity was

determined. The contribution of the rivers that feed into the impoundment was investigated in respect of their nutrient and sediment loads and other physico-chemical aspects that could potentially lead to pollution.

1.2 Site selection, site description and a summary of the surveys

1.2.1 Site selection

At the onset of the project sixteen potential sites were identified. One site was in close proximity to the dam wall, four of the sites were situated in deeper water, four in shallow water, three at the inflow of the rivers, one at the outflow and three sites upstream in each of the three rivers. During the first survey of the impoundment, that took place from the 31st of August to the 4th of September 2009, the suitability of these sites was investigated. The location of the sites selected finally is shown in Figure 1.2 and Table 1.3.

Sites 2, 3, 4 and 5 are fish sampling sites and are not fixed points but rather refer to the actual deep water areas within the bays. Because of the water depth these sites can be regarded as limnetic. Sites 6, 7 and 9, which were earmarked for fish sampling, are in the shallow water areas of these bays and are regarded littoral sites. The placement of littoral sites in proximity to the limnetic sites was to improve logistics and assist with security. Site 8 these was in proximity to site 4 but due to security reasons and lack of suitable habitat was discarded early in the project. For security reasons sites 2 and 4 were situated in view of the field laboratory. Site 3 is quite a distance away from settlements and was therefore regarded as safe. Site 5 is close to an area that is under control of Madzhivhandila Agricultural College. This latter decision proved to be incorrect as the majority of illegal fishermen used area around the college as a launching area in the period from March to June 2011 when illegal activities escalated. Although four inlet sites were originally selected for limnological surveys with site 10 in the Mvudi River, site 11 in the Dzindi River, site 12 in the Luvuvhu River and site 13 at the confluence of the Mvudi and Dzindi rivers it was later decided to discard site 13. Due to the high concentration of illegal nets in the area, and associated security risk, no fish sampling sites could be placed upstream of site 3. The river sites, sites 14 to 16, were selected during a field trip and their placement is shown in table 1.2. These sites were selected to represent the river proper in order to determine the quality of the inflow water. Site 17 is downstream of the outflow out of the dam wall.

1.2.2 Site descriptions

A brief description that indicates the availability of fish habitat and general conditions, of each of the selected sites is provided in table 1.4.

1.2.3 The surveys conducted.

As shown in table 1.5 the sites were surveyed nineteen times during the period September 2009 to June 2011. Except for the December 2009 survey which could not be fully surveyed due to logistic problems, all intended collections and sampling were carried out during the rest of the surveys. In

addition, because of net tampering, no fish surveys with the experimental fleets of nets were done at sites 3 and 5 during April and June 2011 but netting was shifted to two new sites namely the deeper water at site 6 and a site in the bay west of site 2 for this two surveys.

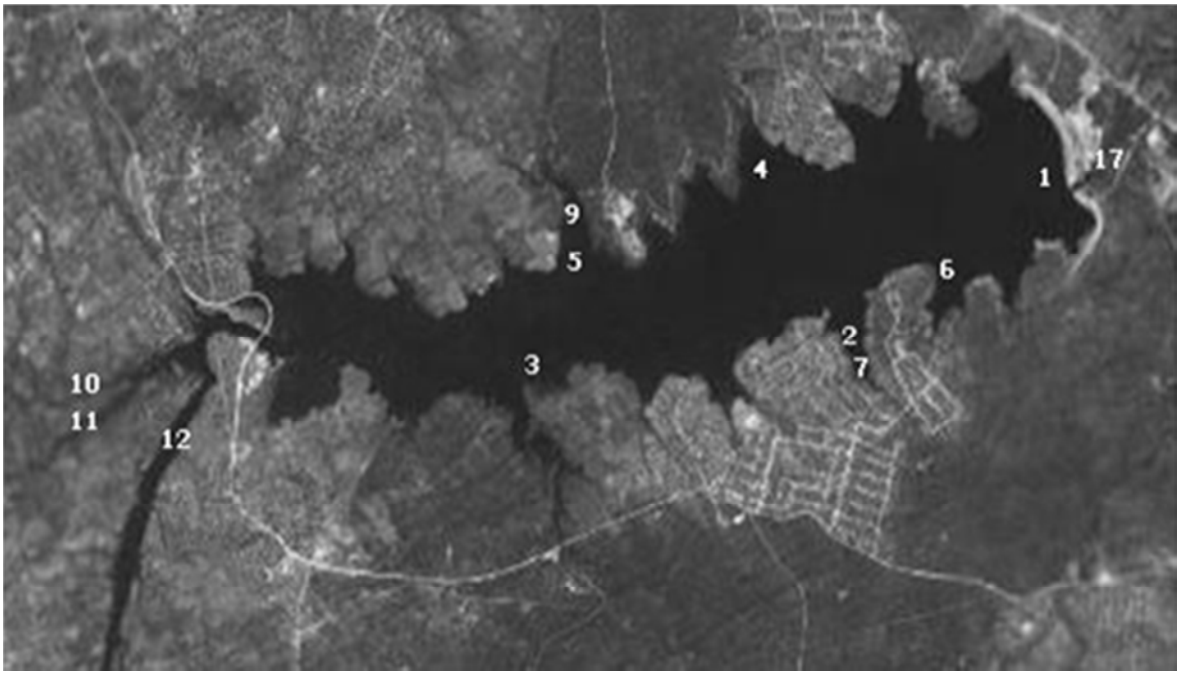

Figure 1.2: The selected sites in Lake Nandoni. Site 1: Deep water limnology, Sites 2, 3, 4 and 5: Limnetic sites, Sites 6, 7 and 9: Littoral sites, Sites 10, 11 and 12: Inlet river sites, Site 17: Outlet site.

Table 1.3: The selected rivers sites.

Site number	River name	Altitude (m.a.s.l)	Coordinates			
			South		East	
			Degrees	Minutes	Degrees	Minutes
14	Mvudi	505.54	23	00.208	30	29.266
15	Dzindi	511.33	23	00.663	30	28.694
16	Luvuvhu	540.14	23	05.080	30	28.232

Table 1.4: Brief descriptions of the selected sites in Lake Nandoni.

Site number	Brief description of site	Function of the site
1	The site is situated at the safety cable close to the dam wall and the water depth is *ca* 38 m.	Deep water limnology.
2	The site is situated in the first bay on the southern shore west of the camp. The depth varies between 4 and 5 m. Based on the surrounding littoral zone the substrate is mud. There are no big trees. A small stream opens into the bay.	Full survey
3	The site is situated on the southern shore west of the camp, upstream of site 2. Large dead trees are abundant and the substrate is mud and sediment. When the impoundment is full the littoral zone of this site consists of an extended shallow area with *Dichrostachys cinerea* and tall grasses. The average depth at the netting site is 6 to 8 m	Full survey
4	This site is on the northern shore of the impoundment opposite the camp. Large dead trees and shrubs are abundant and boulders occur in the substrate. The depth where netting is done varies from 4 to10 m.	Full survey
5	This site is in the bay west of the agricultural college. It is in the inundated river bed with large dead trees and boulders that forms a small "island". Water depth varies between 4 and 8 m.	Full survey
6	This site is situated in the first bay east of the camp. Water depth is shallow 0.5 to 2 m. The site has a well-developed littoral zone when the impoundment is full and boulders and cobbles provide habitat for fish.	Full survey
7	This site is in the shore area of site 2. Although there is a well-developed littoral zone at high water levels, the site does not provide structure in the form of boulders, etc. The depth at the site varies from 0.5 to1 m.	Full survey
9	This site is in the shore area of site 5. There is a well-developed littoral zone with an abundance of structure in the form of dead shrubs and trees.	Full survey
10	The site is where the Mvudi River enters the impoundment. The depth varies from 2-4 m. It has a well-developed littoral zone and a few dead trees.	Water quality
11	The site is where the Dzindi River enters the impoundment. The depth varies from 2-4 m.	Water quality
12	The site is in the impoundment but as high up in the Luvuvhu River as possible. The depth varies from 2-6 m.	Water quality
17	This site is at the outlet of the dam and was selected to sample the quality of the water that enters the Luvuvhu River.	Water quality

Table 1.5: Summary of the surveys done at Lake Nandoni in the period September 2009 to June 2011. The term "full surveys" include fish collections (littoral and limnetic sites), *in situ* water quality, water samples collected, phyto- and zooplankton collections and deep water limnology. "Fish dissected" refers to samples from fish.

	Surveys on the lake		Actions/protocols carried out during the survey	River surveys
Survey number	**Date commenced**	**Date ended**		**Date**
2009				
1	31/8	1/9	Pilot survey and site selection	10/9
2	19/10	21/10	Full survey + Fish dissected	22/10
3	11/11	13/11	Full survey + Fish dissected	17/11
4	4/12	4/12	In situ water quality, Water chemistry, zoo- and phytoplankton	8/12
2010				
5	11/1	14/1	Full survey + Fish dissected	12/1
6	9/2	12/2	Full survey + Fish dissected	11/2
7	9/3	12/3	Full survey + Fish dissected	11/3
8	6/4	8/4	Full survey + Fish dissected	8/4
9	17/5	19/5	Full survey + Fish dissected	19/5
10	8/6	10/6	Full survey + Fish dissected	9/6
11	13/7	15/7	Full survey + Fish dissected	15/7
12	10/8	12/8	Full survey + Fish dissected	11/8
13	14/9	16/9	Full survey + Fish dissected	15/9
14	19/10	21/10	Full survey + Fish dissected	19/10
15	7/11	9/11	Full survey + Fish dissected	8/11
16	29/11	1/12	Full survey + Fish dissected	30/11
2011				
17	1/3	3/3	Full survey + Fish dissected	3/3
18	12/4	14/4	Full survey + Fish dissected	14/4
19	20/6	22/6	Full survey + Fish dissected	22/6

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2 THE ABIOTIC COMPONENT

Biological communities consist of a number of interacting species and the actual species that make up the community are *inter alia* determined by water quality and available biotopes. Aquatic communities are influenced by natural factors which form part of a complex ecosystem. In lentic environments these factors include both chemical constituents and physical attributes. While the physical attributes consists of aspects such as temperature and turbidity, the chemical constituents consist of pH, electrical conductivity (EC), total dissolved substances (TDS), dissolved oxygen (DO) and enriching aspects such as nutrients and organic substances (Dallas and Day, 2004). Aquatic ecosystems are often the recipients of effluents that can lead to changes in the physico-chemical conditions which can be detrimental to the biotic community. In addition lentic water bodies can undergo seasonal changes which consist of the establishment of layers or strata, in a process known as stratification (Davies and Day, 1999). This occurs during the warmer months and is often followed by a period when the strata disappear, known as overturn, and the whole water column mixes. Although the formed strata are traditionally seen as layers of differing temperatures with the warmer epilimnion at the top and the colder hypolimnion in the deeper water separated by a layer of sudden temperature change, the metalimnion. The layering also applies to aspects such as dissolved oxygen. Since both stratification and overturn influences the composition of the biotic community and because not all lentic water bodies undergo stratification it is important to determine whether this occurs in the resource under investigation.

2.1 The limnology of the impoundment

2.1.1 The aims

The aims of this component of the project were to establish the physico-chemical conditions of the impoundment as well as establish whether a pattern of stratification regarding temperature, oxygen, and water chemistry did establish and whether it persisted or if turnover occurred.

2.1.2 Materials and methods

Surveys were conducted monthly in the period from October 2009 to December 2010 and again in March, April and June 2011 and the following sampling protocols were applied:

i) *In situ* water quality assessment of physico-chemical conditions

The total dissolved substances (TDS), pH, temperature, dissolved oxygen (DO) and electrical conductivity (EC) were measured just below the surface with handheld Eutech Cyberscan meters at the sites in the impoundment, sites 1 to 7 and 9, as well as the inflow sites, sites 10, 11 and 12. At each site Secchi disc readings were taken and the depth determined with a Lowrance X135 fish finder.

ii) Stratification assessment

At site 1, which is at the deepest point of the impoundment, the oxygen profile was determined at 1 m intervals using a handheld Hannah oxygen meter fitted with a 20 m cable. This is referred to as the

"direct" method. In addition dissolved oxygen, temperature, pH, conductivity and TDS were determined with handheld Eutech Cyberscan meters in water samples collected at 1 m depth intervals with a van Dorn sampler at sites 1, 2 3, 4 and 5. This method is referred to as the "indirect" method in this report. It should be noted that all the surveys were done at the same point. At site 1 this was achieved by anchoring the boat to a marked buoy in the cable stretched over the width of the water body while at the other sites the boat was tied to structures such as a tree.

2.1.3 Results

The results recorded at the sites are shown in appendices 2.1a to 2.1e. These results shows that the dissolved oxygen data at site 1 obtained with the two methods, were similar and that the differences were statistically not significant ($p = 0.05$). With regard to oxygen concentration as a quality criterion for the protection of aquatic life, and fish in particular, Kempster et al. (1980) indicated that at oxygen concentrations below 4 mgL^{-1} organisms would be under stress and while at 5 mgL^{-1} no stress would occur. To an extent this is supported by Dallas and Day (2004). With the value of 5 mgL^{-1} regarded as a cut-off point all the lower values are shaded in appendices 2.1a to e. This illustrates that, with the exception of the direct readings in May and June 2010, sufficient oxygen concentrations were present in what can be regarded as the limnetic zone (Figure 2.1). The depths at which sufficient oxygen concentrations showed what can be regarded as seasonal trends. For example from October to December 2009 concentrations higher than 5 mgL^{-1} were recorded in the upper layer to a depth of at least 6 m while in January 2010 it was only up to 5 m. In the period March to June 2010 the depth extended to 8 m in March and April but in May and June it was at 4 m. However in some months, such as February 2010, the dissolved oxygen concentrations did constitute a distinct layering with a well oxygenated upper layer of about 5 m, followed by a transitional zone, *i.e.* sharp drop in oxygen concentration between 5 and 10 m, and finally very low oxygen concentrations below 10 m (Figure 2.1).

A trend similar to site 1 where the dissolved oxygen concentration of the limnetic zone was high and normally within accepted levels was observed sites 2 to 5 but not at the inflow sites, sites 10, 11 and 12 (Appendices 2.3 b and c). Although it is in particular sites 10 and 11 that are of concern because of extremely high oxygen concentrations and super-saturation, exceeding 100%, there are also instances, such as for example June and July 2010 and September to November 2010, when values higher than 100% were recorded at site 12 in the Luvuvhu River.

The dissolved oxygen saturation of the surface water at sites 1 to 5 were usually high, ranging between 96 and 103%, but significantly higher and usually supersaturated ranging at the inflow sites, sites 10 to 12. Figure 2.3 shows that the dissolved oxygen concentrations at sites 1 to 5 were similar while at sites 10, 11 and 12 it was higher. Statistical analyses of these results show that while the differences between sites 1-5 were not significant the values obtained at sites 10, 11 and 12 was significantly different ($p = 0.05$) from the first five sites.

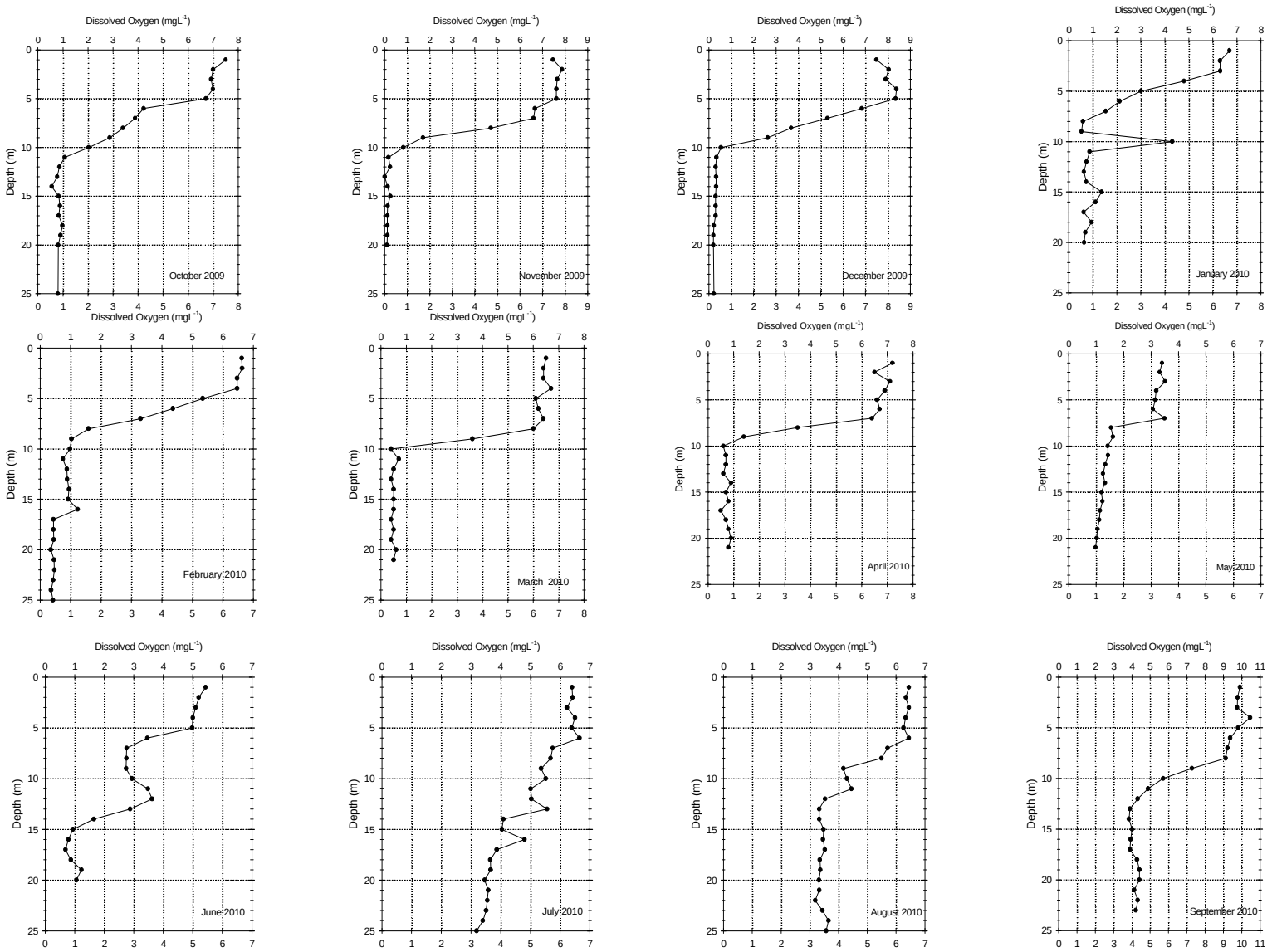

Figure 2.1: The dissolved oxygen concentration (mgL^{-1}) recorded at 1 m intervals at site 1 in Lake Nandoni during the period October 2009 to September 2010.

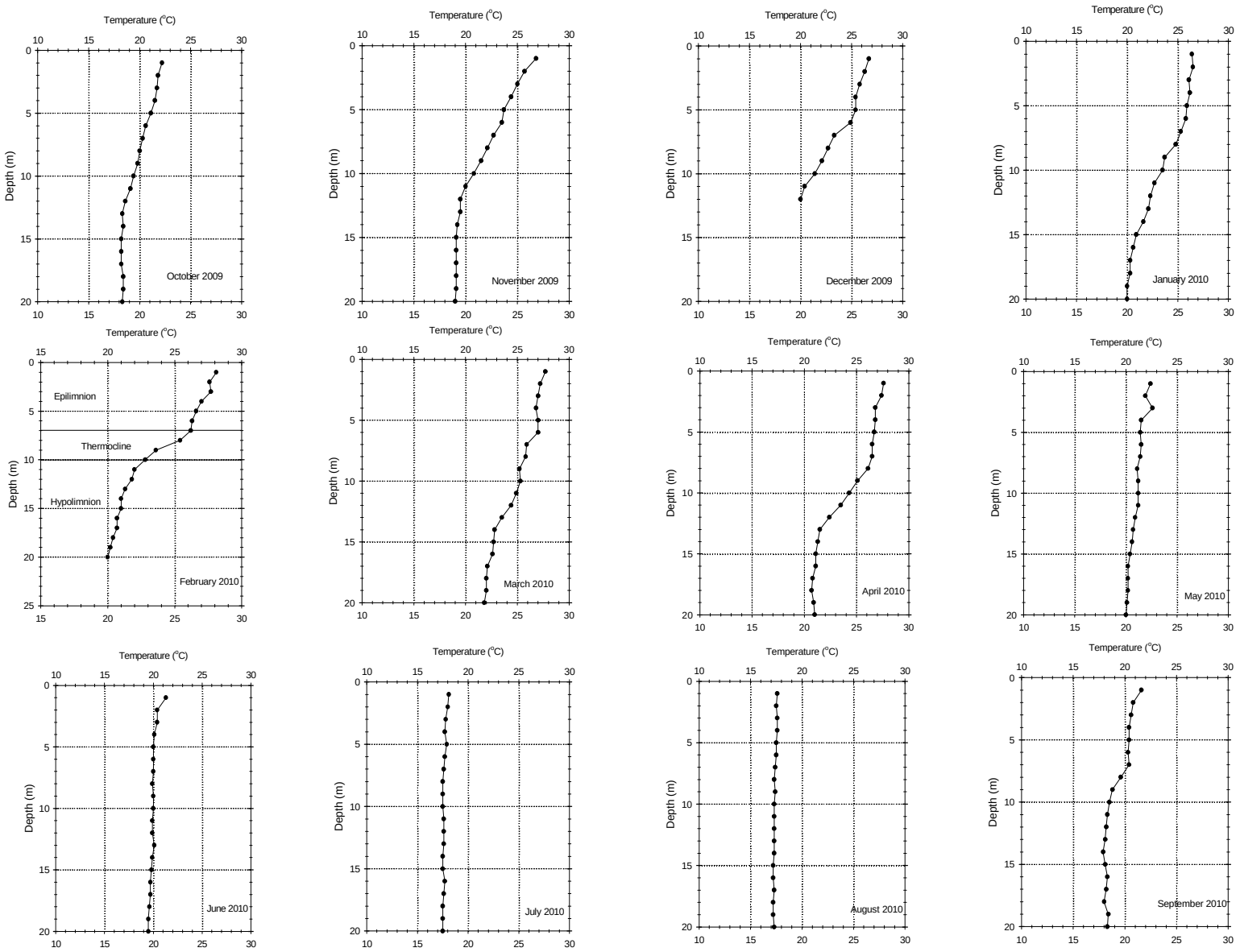

Figure 2.2: Water temperature recorded at 1 m intervals at site 1 in Lake Nandoni during the period October 2009 to September 2010.

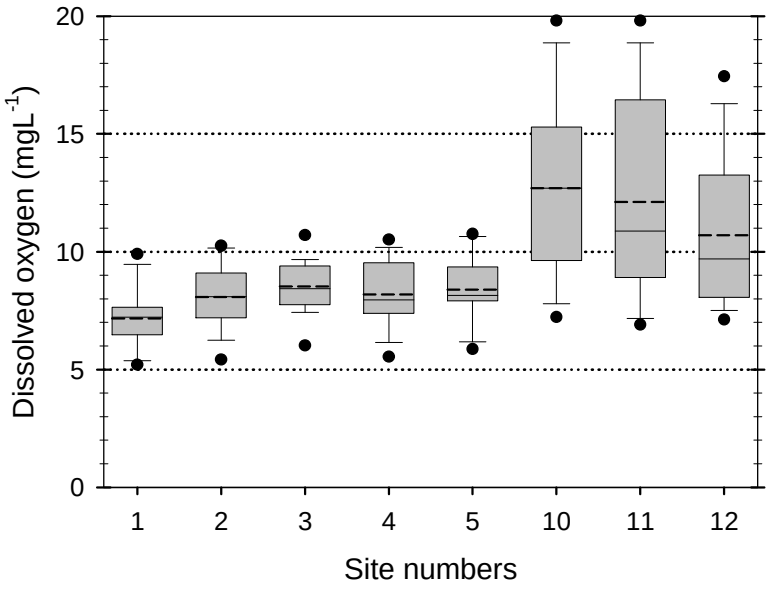

Figure 2.3: Box and whisker plot of the dissolved oxygen concentration (mgL^{-1}) of the surface water at sites 1 to 5 and 10 to 12 in Lake Nandoni measured in the period September 2009 to April 2011 (Dashed line: mean value, solid line: median value).

The daytime surface water temperatures measured at site 1 (Appendices 2.2 a to e) were relatively high and ranged between 17.3 and 31.3 ºC. Nevertheless the summer temperature depth profiles in Lake Nandoni indicate that in February 2010 a situation that could be regarded as thermal stratification was observed (Figure 2.2). This stratification was preceded by a period commencing in November 2009 during which the temperature gradually decreased with depth but where there was no distinct thermocline as observed in February. After February a thermocline was not observed and small differences between surface and bottom temperatures were recorded. From May to August water temperatures were similar throughout the water column (isothermal) indicating that the water-column was probably fully mixed and that overturn had occurred in April.

With regard to the other parameters measured at site 1 the pH, electrical conductivity and total dissolved substances (TDS) remained reasonably constant throughout the water column (Appendix 2.2). The TDS values did however show a typical depth profile in certain months such as in February 2010 (Figure 2.4).

Appendices 2.3a, b and c show the *in situ* physico-chemical parameters measured at sites 2-5 and 10, 11 and 12. These results show that the pH readings at the four sites in the impoundment are more or less similar but that the readings at the inflow sites, sites 10, 11 and 12 are higher in a number of instances. This pattern is repeated in the case of the electrical conductivity, where notice should be taken of the high values recorded in readings in October, November and December of both 2009 and 2010 at the inflow sites. Again it is in particular sites 10 and 11 that are of concern. The same applies to the total dissolved substances in October, November and December 2009. These high values could be indicative of pollution that is taking place upstream in the rivers.

The situation reported above is mirrored by the Secchi disc readings obtained at these seven sites (Figures 2.5 and 2.6). These results show that, as can be expected, the water at the sites in the impoundment to be less turbid than the three inflow sites. The readings of less than 0.5 m for most of the surveys at the inflow sites not only underpins the high degree of pollution reflected by the other physico-chemical aspects, such as TDS and conductivity, but can be the result of an excessive algal growth that could be related to high nutrient loads. These results must be compared with the *in situ* results obtained at the river sites.

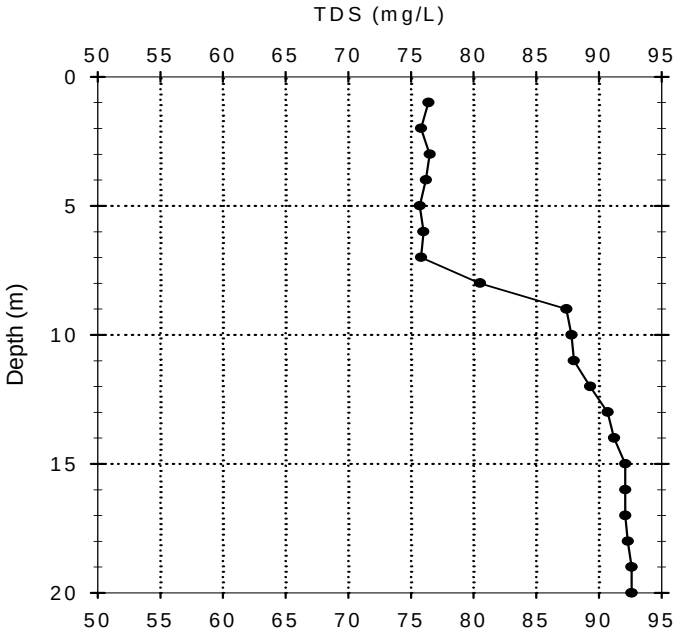

Figure 2.4: A Typical summer Total Dissolved Substance (TDS) depth profile as observed in February 2010 at site 1 in Lake Nandoni.

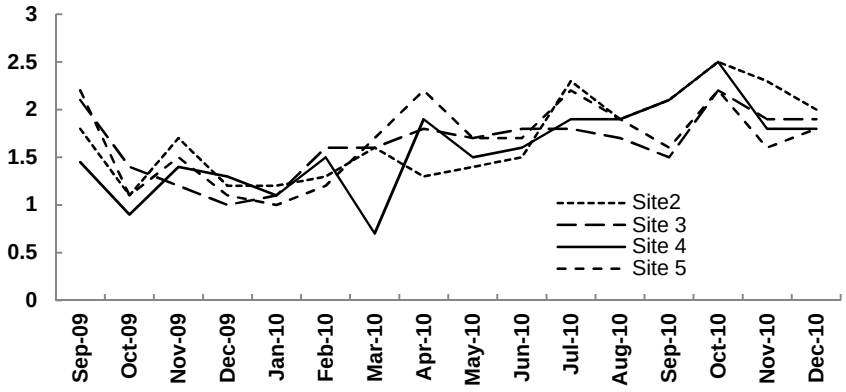

Figure 2.5: Secchi disc readings (m) at sites 2, 3, 4 and 5, 10 in Lake Nandoni recorded during the period September 2009 to December 2010.

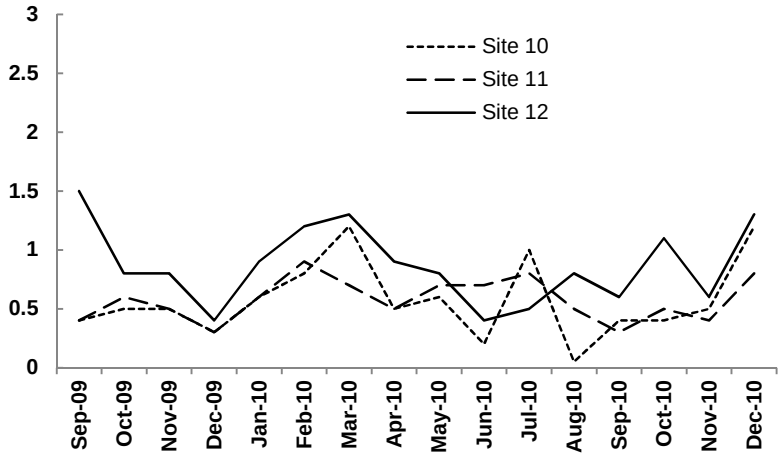

Figure 2.6: Secchi disc readings (m) at the inflow sites (10, 11 and 12) in Lake Nandoni recorded during the period September 2009 to December 2010.

2.1.4 Discussion

The radiant energy that is absorbed by the water is converted into heat energy, and this is stratified in the water-column, being greatest at the surface. This heating is among the most fundamental features of the aquatic environment (Wetzel, 2001). The surface water temperatures in the impoundment were relatively high but nevertheless the summer temperature depth profiles indicate only one typical thermal stratification during the study period in February 2010 with a gradual temperature decrease with depth during the majority of the months. During June, July and August 2010 the temperatures were the same throughout the water column which indicate that the water-column was probably fully mixed.

However, the dissolved oxygen (DO) shows distinct layering with a well oxygenated upper layer of about 5 m, followed by a transitional zone, *i.e.* the sharp drop in oxygen concentration between 5 and 10 m, and finally very low oxygen concentrations in depths below 10 m. The high oxygen in the surface layer is ascribed to photosynthesis by algae and gas exchange with the atmosphere and well mixed condition in the upper 5 m. The low oxygen in what can be referred to as the hypolimnion, *i.e.* deeper than 10 m, is ascribed to high rates of decomposition of organic material and poor mixing conditions (Wetzel, 2001).

Oxygen is essential for all forms of aquatic life, including those organisms responsible for the self-purification processes in natural waters. In unpolluted surface waters, dissolved oxygen concentrations are usually close to saturation. Dissolved oxygen concentrations lower than 4 mgL^{-1} which constitutes hypoxia, is physiological stressful for fish and invertebrates (Dallas and Day, 2004). Depletion of oxygen in bottom waters of lakes and the onset of anoxia results in the re-mobilisation of phosphorus and other elements from lake sediments.

The pH of an aquatic ecosystem is important because it is closely linked to biological productivity. Although the tolerance of individual species varies, pH values between 6.5 and 8.5 usually indicate good water quality and this range is typical of most major drainage basins of the world (Kempster et al.,

1980). The pH values in the surface water in the impoundment ranged between 6.75 and 9.67. The pH values were higher at the inflow, sites 10-12, but decrease with increasing depth. The high pH values in the surface water are probably due to high photosynthetic activity by phytoplankton consisting of microscopic free-floating algae. Phytoplankton assimilates carbon dioxide that lowers the carbonic acid and consequently increases the pH values. The relatively low pH values in the bottom layers are ascribed to decomposition (respiration) of organic matter that release CO_2 and formation of carbonic acid that result in lower pH values.

Salinity is an indication of the concentration of dissolved salts in a body of water. In the impoundment the total dissolved substance (TDS) concentrations were low in the surface waters (70 ± 10 mgL^{-1}) and comparable with unpolluted systems, however, the TDS increase considerably below a depth of 7 m. The high TDS in the lower layers is ascribed to mineralisation of organic matter and a build-up of salts because of poor mixing. However, TDS concentration less than 195 mgL^{-1} is generally considered to be ideal for all the major uses of water. The fitness for use or level of protection are usually categorised as follows: ideal, acceptable, tolerable, and unacceptable. It should be noted at this point that the sewage works that services the town of Thohoyandou is less than 2 km upstream of the survey site in the Mvudi River.

2.2 The nutrient status of the water in the impoundment, inflow sites and the inflow rivers

As stated before, nutrients are regarded factors that can influence biotic communities and in an impoundment situated within a developing area the input of nutrients could potentially be high. It is there important that the nutrient status of the impoundment be determined and to compare the sites within the main body of the impoundment to sites closer to the inflow. Since the lake is still relatively young, this data could be used both as baseline data and data regarding the input into the water body.

2.2.1 Aims

The aim of this component is therefore to investigate the nutrient status of the water in the impoundment and at the inflow sites. In addition the input of the three rivers flowing into the impoundment was also determined.

2.2.2 Materials and methods

Water samples were collected during the surveys at sites in the impoundment, sites 1 to 5, and the inflow sites, sites 10, 11 and 12 by scooping water with a 5 L plastic bucket just below the surface. Subsamples were then transferred to pre-cleaned 500 ml plastic bottles, refrigerated and transported to the laboratory. At river sites, sites 13, 14 and 15, water was collected directly in pre-cleaned 500 ml plastic bottles, refrigerated and transported to the laboratory. The *in situ* physico-chemical parameters determined at all the sites included measurements of TDS, pH and electrical conductivity using handheld Eutech Cyberscan meters. The river sites were monitored for the same period and at the same frequency as the as surveys in the impoundment (Table 1.4).

In the laboratory a Merck Pharo spectrophotometer and associated kits were used to determine the concentrations of PO_4-P, NO_3-N, NO_2-N and NH_4. The turbidity of each sample was determined with a Novasina turbidity meter using double distilled water as a standard while the total suspended solids were determined from the mass increase resulting from the filtration of a 250 ml subsample of water through a pre-weighed 45 µm membrane.

2.2.3 Results

The sites in the impoundment and the inflow sites

The results of the chemical analyses are shown in appendices 2.5 a to d, while the turbidity and total suspended concentrations are shown in appendices 2.6 a to c.

The average ammonium nitrogen (NH_4-N) concentrations in Lake Nandoni (site 1-5) were high and ranged between 0.153 and 0.225 mgL^{-1}, which is in the tolerable range (0.15-0.25 mgL^{-1}) (Dallas and Day, 2004). However, the ammonium concentrations at the inflow sites (10-12) were higher and ranged between 0.321 and 0.366 mgL^{-1} that is in the unacceptable range, *i.e.* >0.25 mgL^{-1} (Dallas and Day, 2004) (Figure 2.7).

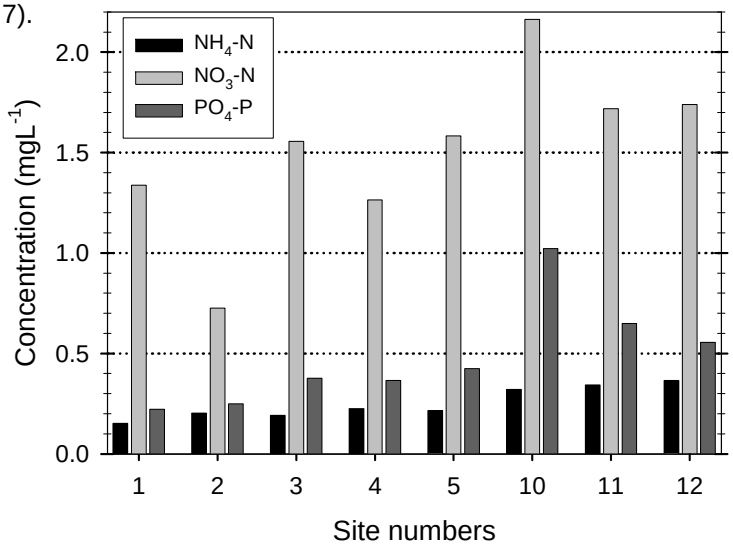

Figure 2.7: Average concentrations (mgL^{-1}) of ammonium (NH_4-N), nitrate (including nitrite; NO_3-N) and phosphate (PO_4-P) at different sampling sites in Lake Nandoni during study period (September 2009 – December 2010).

The average nitrate (NO_3-N) concentrations (including nitrite) in the impoundment were moderately high and ranged between 0.726 to 1.584 mgL^{-1}, but were still in the acceptable range (>0.5; <1.50 mgL^{-1}). However, concentrations at the inflow sites were significantly higher (p= 0.05) and although they ranged from 1.718 to 2.163 mgL^{-1} these values were still within what is regarded as the tolerable range (>1.50; < 2.5 mgL^{-1}).

The phosphate (PO_4-P) concentrations in Lake Nandoni and inflows were very high and ranged between 0.223 and 0.426 mgL^{-1} and note should be taken of the high concentration (av. 1.023 mgL^{-1}) at inflow site 10. These concentrations are in the unacceptable range as it exceeds 0.125 mgL^{-1}.

The TSS values recorded in the surface water were relatively low with mean values that ranged between 8.5 and 9.8 mgL^{-1} while in the case of the inflow sites the mean TSS values ranged between 17.7 and 22.3 mgL^{-1} (Figure 2.8).

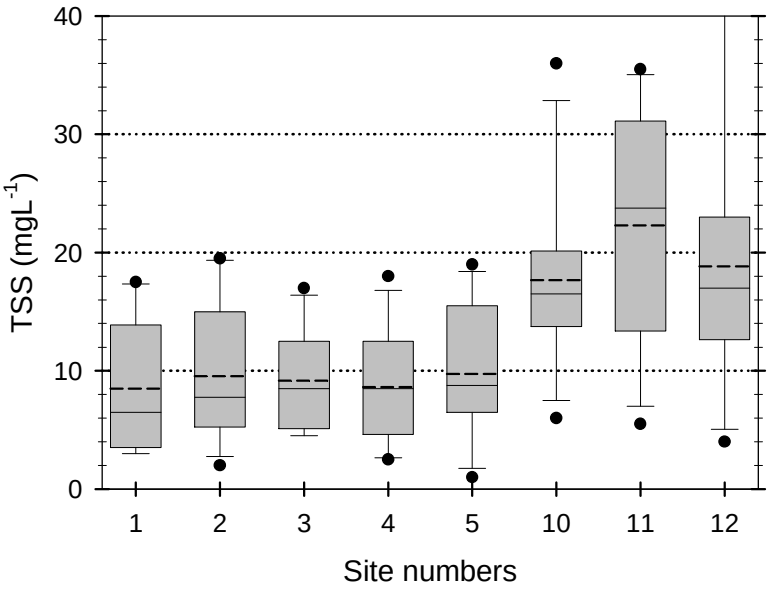

Figure 2.8: Box and whisker plot of Total Suspended Solids (TSS, mgL^{-1}) at different sampling sites for the study period September 2009 to December 2010. (Dashed line: mean value; solid line: median value).

The river sites

The *in situ* results recorded at the river sites are shown in appendices 2.7 a to c. It is in particular the oxygen readings at site 13, which is in the Mvudi River a few hundred meters downstream of the Thohoyandou sewage works that should be noted. This is a typical of an oxygen slump that is often associated with sites downstream of sewage sites. The same applies to both the electrical conductivity and TDS values at this site. These results are to large extent supported by the results of the chemical analyses shown in table 2.1.

Table 2.1 shows that in all three rivers high levels of phosphate were recorded in particular during September to December 2010. In the case of the Mvudi River the nitrogen bearing components were also high during these months.

Table 2.1: Chemical analyses of the water samples collected at sites 13-14 during the period September to December 2009 and February to December 2010. ("Grass" refers to a site upstream of site 13).

Site name and number	Date	Ammonium (mgL^{-1})	Nitrite (mgL^{-1})	Nitrate (mgL^{-1})	Phosphate (mgL^{-1})
GRASS	October 09	0.3	0.21	0.8	1.37
	December 09	0.07	0.06	1.7	0.49
MVUDI (13)	September	0.23	0.05	2.6	0.25
	October	3.32	0.89	2.7	2.95
	November	2.59	0.88	5.4	1.73
	December	0.35	0.18	2.7	1.25
	February	0.9	0.23	2.1	1.11
	March	1.41	0.31	1.6	0.71
	April	0.26	0.1	0.9	0.07
	May	0.11	0.11	0.9	0.18
	June	0.81	0.12	1	0.87
	July	0.96	0.08	1.1	0.88
	August	1.47	0.14	1.9	0.74
	September	1.53	0.21	4.2	1.05
	October	0.23	1	1.1	5.34
	November	3.05	0.19	5.3	4.31
	December	0.1	0.18	3.0	1.23
DZINDI (14)	September	0.21	0.23	3.7	0.95
	October	0.15	0.06	0.3	0.27
	November	0.11	0.06	0.8	0.17
	December	0.17	0.07	2.1	0.38
	February	0.28	0.05	0.8	0.3
	March	0.2	0.21	1.6	1.17
	April	0.82	0.29	1.3	0.81
	May	0.22	0.07	0.8	0.13
	June	0.09	0.05	0.5	0.11
	July	0.31	0.07	1.4	0.5
	August	0.1	0.06	1.1	0.2
	September	0.09	0.06	5.1	0.72
	October	0.06	0.06	2.4	2.27
	November	0.44	0.09	2.4	3.52
	December	0.15	0.05	4.2	3.97
HASANI (15)	September	0.21	0.04	0.4	0.18
	October	0.09	0.05	1.3	0.54
	November	0.11	0.05	2.9	0.26
	December	0.22	0.05	0.5	0.2
	February	0.16	0.07	1.2	0.85
	March	0.17	0.12	0.9	0.14
	April	0.18	0.08	0.7	0.78

Site name and number	Date	Ammonium (mgL^{-1})	Nitrite (mgL^{-1})	Nitrate (mgL^{-1})	Phosphate (mgL^{-1})
	May	0.2	0.06	0.7	0.32
	June	0.09	0.07	0.4	0.32
	July	0.67	0.06	1.5	0.23
	August	0.16	0.14	1.0	0.19
	September	0.09	0.06	5.1	0.72
	October	0.11	0.05	4.6	2.78
	November	0.48	0.13	4.2	4.5
	December	0.1	0.05	4.7	4.93

2.2.4 Discussion

Nutrients are elements essential to life. Inorganic nutrients provide the chemical constituents on which the entire food web is based. However, nutrient enrichment or eutrophication, caused by excessive inputs of phosphorus (P) and nitrogen (N), is an important threat to the water quality of aquatic systems world-wide (UNEP-GEMS, 2006). Increased rates of primary production typical of eutrophic ecosystems are often manifested by excessive growth of algae and the depletion of oxygen, which can result in the death of fish and other animals. Nutrient enrichment can also increase the abundance of cyanobacteria (blue-green algae) which can produce toxins. Mass mortality and anoxia are the ultimate stage of eutrophication.

Ammonia (NH_3) arises mainly from the breakdown of nitrogenous organic matter in the system. Ammonium (NH_4) is a common pollutant and one of the nutrients that contribute to eutrophication (DWAF, 2009). Ammonia is also toxic to many organisms, especially fish.

Although the phosphate (PO_4-P) concentrations in impoundment and inflows were high they were still in general within the accepted range of > 0.125 mgL^{-1}. The exceptional high concentration at inflow site 10 indicates serious pollution in the Mvudi River that could lead to eutrophic conditions, or nutrient over-enrichment, in the impoundment. Organic matter from aquatic algae and macrophytes contains nitrogen (N) and phosphorus (P) in approximately the mass ratio of 7N:1P, which is also referred to as the Redfield Ratio (Wetzel, 2001). This implies that at an N:P ratio of less than 7 in the environment, N could be limiting and at an N:P greater than 7, P could be limiting to algal or macrophyte growth. Waters unimpacted by human influence usually have an N:P ratio greater than 25:1, while most impacted (*i.e.* eutrophic or hypertrophic) system have an N:P ratio of less than 10:1. The N:P ratios in Lake Nandoni were generally low and averages ranged between 3.7 and 6.7 in the impoundment and were even lower (av. 2.4-3.8) at the inflow sites. The low N:P ratios indicate that nitrogen could be the limiting factor for algal growth and could probably lead to high concentrations of cyanobacteria and dinoflagellate (*Ceratium* sp.) in Lake Nandoni. Phytoplankton abundance and species composition changes as a function of ratios of supplied nutrients; low N:P ratios favour the development of cyanobacterial and dinoflagellate growth. Phosphorus and nitrogen are considered to be the primary drivers of eutrophication of aquatic ecosystems, where increased nutrient concentrations lead to

increased primary productivity and algal blooms. The sources of nutrient pollution into Lake Nandoni should be identified. Causes of nutrient over-enrichment or eutrophication of aquatic ecosystems can be attributed to agriculture, urbanization, forestry, impoundments, and industrial effluents (UNEP-GEMS, 2006). However, Municipal wastewater effluent and unsewered informal human settlements are the principal contributor to the eutrophication and degradation of aquatic system in South Africa (DWAF, 2009). Municipal wastewater effluent is also one of the impacts that is the easiest to mitigate because they are easily identified, measured, and susceptible to control by policies and regulation.

The type and concentration of suspended matter controls the turbidity and transparency of the water. Suspended matter consists of silt, clay, fine particles of organic and inorganic matter, soluble organic compounds, plankton and other microscopic organisms. The TSS is a measure of the amount of material suspended in water. Turbidity on the other hand refers to water clarity and an important feature of many South African reservoirs is the high turbidity caused by the presence of suspended silt. The relatively low TSS in the surface water of Lake Nandoni is comparable to a clear water system like Lake Katse (Roos, 2000). The most common natural TSS concentration in rivers world-wide is approximately 150 mgL^{-1}. The low TSS concentration in Lake Nandoni resulted in deep light penetration with Secchi disc readings that ranged between 1 and 2.5 m, resulting in favourable underwater light climate for algal growth. Water bodies that have high transparency values are often regarded to have good water quality.

2.3 Sediments

In lentic water bodies the reduction in water velocity leads to sedimentation of the particles that were in suspension while the water was in motion. These particles then form the benthic layer where the inorganic material contributes to provision of physical habitat for the benthos.

2.3.1 Aims

At the onset of this project the question was asked whether the structure of the benthic zone is uniform throughout the impoundment and whether this is reflected by the composition of the zoobenthos. The aim of this component of the project was to compare the structure of the benthic sediments at the sites and this data could then consequently be related to the zoobenthos diversity.

2.3.2 Materials and methods

Sediment samples were collected from sites 2 to 5 and sites 10 to 12 with an Eckman bottom grab that was lowered from a boat. The collected substrate was poured into a plastic sample bag and transported to the laboratory for further analysis. In the laboratory the plastic bags were cut open and the sediment emptied into a pre-weighed glass beaker **(**Brower et al*.,* 1990; Vivier and Cyrus, 1999). The sediments were allowed to settle after which the liquid was decanted. The mass of the remaining sediment was determined on a chemical balance in grams to the second decimal. A small, *ca* 10 ml, sub-sample was removed and weighed on a pre-weighed glass Petri dish to determine the wet mass of the sediment. The Petri dish was then left in an oven at 60 ºC until the sub-sample was completely dry

and the mass of the dry sediment determined. This was later used to determine the dry mass of the total sample. The remaining wet sample was then sieved, using a stream of tap water to assist the process, through a series of sieves with 2000 µm, 500 µm and 355 µm mesh sizes respectively. The "trapped" matter collected by each mesh size was collected and dried at 60^{o}C to a constant weight when the dry weight was determined.

2.3.2 Results

Table 2.2 shows that at sites 2 and 3 the sediment was dominated by particles larger than 2000 µm while at sites 4 and 5 the particles were smaller and particles larger than 355 µm dominated. The inflow sites, sites 10 to 12, did not only have less debris than the other sites but the material making up the sediment is finer because it is dominated by material of a grain size smaller than 500 µm.

2.3.4 Discussion

The results have shown that the composition of the benthic zones at the investigated sites is not the same. There was a clear distinction between sites 2, 3 and 4, which are deepwater sites, and the sites at the inflow, sites 10, 11 and 12. Where the inflow sites the sediments had more fine material, with a diameter less than 355 µm, the sediments at the deepwater sites were coarser, with diameters exceeding 355 µm. The inflow site with the most "coarse" material was site 10 where *ca* 11% of the material had a diameter of more than 355 µm. In comparison the percentage of coarse material at sites 2, 3 and 4 was more than double the fine material and ranged between *ca* 27% and 43% at sites 2 and 4 respectively. Site 5 differed from the other deepwater sites and had a substrate composition that is similar to that of the inflow sites. The reason for this could most possibly be that site 5 is situated in an old river bed (Table 1.4) where at times there could still be flow.

Table 2.2: An analysis of the particle size of the debris collected from the sediment samples collected at sites 2-5 in Lake Nandoni during the period April to August 2010.

Site No.	Month	Wet mass of collected sample (g)	Wet mass of sieved sub sample (g)	Dry mass of sieved sub sample (g)	Dry mass collected with different sieve sizes (g)				Mass of debris as % of dry mass		
					2000 µm	500 µm	355 µm	Total mass of debris	2000 µm	500 µm	355 µm
2	April	201.65	174.85	82.66	12.73	10.3	5.61	28.64	15.4	12.46	6.79
	May	427.24	398.9	66.15	7.61	8.93	5.22	21.76	11.5	13.5	7.89
	June	325.6	304.55	142.94	7.98	18.52	10.4	36.9	5.58	12.96	7.28
	July	286.49	262.84	175.37	9.89	23.4	13.08	46.37	5.64	13.34	7.46
	August	63.18	63.18	28.04			5.44	5.44	0	0	19.4
								Average	**7.62**	**10.45**	**9.76**
3	April	50.91	50.91	23.97			3.85	13.85	0	0	16.06
	May	207.38	183.31	101.14	26.7	19.35	7.25	53.3	26.4	19.13	7.17
	June	28.0	28.0	18.16			2.81	2.81	0	0	15.53
	July	170.44	151.74	40.09	9.54	10.57	5.69	25.8	23.8	26.37	14.19
	August	106	88.29	52.69	12.01	6.8	2	20.81	22.79	12.9	3.8
								Average	**13.44**	**11.48**	**11.35**
4	April	26.81	26.81	7.75			1.95	1.95	0	0	25.18
	May	34.29	34.29	9.91			6.61	8.61	0	0	66.72
	June	81.95	73.2	15.31	3.28	2.08		5.36	21.42	13.59	0
	July	231.04	206.8	76.27	6.92	7.53	6.53	20.98	9.07	9.87	8.56
	August	43.99	43.99	12.71	4.91	2.62		7.53	38.62	20.62	0
								Average	**13.82**	**8.82**	**20.09**
5	April	206.4	182.3	85.17					0	0	0
	May	172.45	156.66	49.31		3.49	1.83	5.32	0	7.08	3.71
	June	181.22	157.81	78.74	5.7	9.5	3.98	19.18	7.24	12.07	5.05
	July	320.29	293.5	88.96		11.73	5.36	17.09	0	13.19	6.03
	August	119.66	101.39	15.21			4.12	4.12	0	0	27.1
								Average	**1.45**	**6.47**	**8.38**

Table 2.2 (cont.): An analyses of the particle size of the debris collected from the sediment samples collected at sites 10-12 in Lake Nandoni during the period April to August 2010.

Site No.	Month	Wet mass of collected sample (g)	Wet mass of sieved sub sample (g)	Dry mass of sieved sub sample (g)	Dry mass collected with different sieve sizes (g)				Mass of debris as % of dry mass		
					2000 µm	500 µm	355 µm	Total mass of debris	2000 µm	500 µm	355 µm
	April	294.26	259.99	126.62	6.77	8.06	3.07	17.9	5.35	6.37	2.42
	May	460.82	425.75	202.9809	4.7	6.78	5.4	16.88	2.32	3.34	2.66
	June	396.37	371.41	137.4931	7.75	7.63	5.39	20.77	5.64	5.55	3.92
	July	123.31	115.84	30.70458			2.03	2.03	0	0	6.61
10	August	364.54	333.27	153.5792	2.3	7.9	6.91	17.11	1.5	5.14	4.5
								Average	**2.96**	**4.08**	**4.02**
	April	395.99	362.84	137.912	1.7	4.81	3.05	9.56	1.23	3.49	2.21
	May	465.34	439.24	167.618		2.36	1.81	4.17	0	1.41	1.08
	June	424.16	404.3	96.90171	2.73	5.38	3.18	11.29	2.82	5.55	3.28
	July	523.47	495.35	216.4954	2.46	3.95	2.69	9.1	1.14	1.82	1.24
11	August	447.21	412.65	217.3099	7.71	13.75	6.56	28.02	3.55	6.33	3.02
								Average	**1.75**	**3.72**	**2.17**
	April	534.73	502.28	188.0648		3.54	3.04	6.58	0	1.88	1.62
	May	188.09	167.07	42.04569	4.62	4.02	3.14	11.78	10.99	9.56	7.47
	June	486.5	465.2	267.9814				0	0	0	0
	July	457.37	428.76	106.7029	4	6.09		10.09	3.75	5.71	0
12	August	374.64	342.67	101.3969	5.04	6.62		11.66	4.97	6.53	0
								Average	**3.94**	**4.74**	**1.82**

2.4 Conclusion

In conclusion it can be stated that Lake Nandoni at this point in time provides excellent habitat for fish. Not only are the water quality parameters within excepted parameters but the upper levels of the water throughout the main body of the impoundment is sufficiently oxygenated. The fact that the observed oxygen and temperature stratification was followed by turnover, mixing of the hypo- and epilimnion, in September, can lead to proper distribution of nutrients throughout the water column. This in turn can lead to sustainable production. There are however reasons for concern. The concern is mostly with regard to the levels of pollution, in the form of nutrients and in particular the phosphates, recorded at the inflow sites. At these sites conditions typical of eutrophic ecosystems, such as supersaturated oxygen levels and high algal densities, has been recorded. If the level of pollution, and in particular the Mvudi River, is not controlled there is a reason to believe that this impoundment will become one of the eutrophic impoundments of South Africa.

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3 THE BIOTIC COMPONENT

As indicated in chapter 2 data regarding the biological components and processes are needed to draw up a guideline for a management plan for inland fisheries. This data *inter alia* includes aspects such as primary and secondary production as reflected by the phytotoplankton and zooplankton or zoobenthos biodiversity respectively. In addition the potential productivity can be established by investigating fish diversity and community structure as well as biological aspects such as the condition factor, growth, breeding and feeding. In the process of gathering fish data the potential yield, catch per unit effort and net selectivity can be determined for use in the management plan.

3.1 Macrobenthos

3.1.1 Introduction

By far the greatest area of the floor of a lentic water body is where the water column is too deep for light to penetrate and therefore for photosynthesis to occur. In addition this region is oxygen deprived and usually anoxic. This region is referred as the benthic zone and the majority of the organisms that occur here are animal-like and form part of the benthos (Payne, 1986; Barnes and Mann, 1995). Benthic animals make their living in two ways. The infauna burrows into the sediments and feed on those sediments while the epifauna live on the surface of the sediment particles. In general benthos is dependent on the “rain” of organic matter from above for their energy supply, but a small proportion of the benthic organisms do however utilize on chemolithotrophic processes. The benthos can further be subdivided according to size and habitat. The first group is the macrobenthos, which is normally visible to the naked eye, followed by the intermediately sized meibenthos and the microscopic microbenthos. Where the macrobenthos tend to burrow, the meibenthos live among the sediment grains and the microbenthos lives on the surface of the grains. The macrobenthos is often dominated by the larval stages of insects, the annelids (and in particular the Oligochaeta), the ostracod crustaceans and molluscs. The meiobenthos is dominated by nematodes and by small crustaceans known as harpaticoid copepods. The microbenthos is dominated by bacteria, fungi and protozoans.

3.1.2 Aims

As stated earlier the question was asked whether the zoobenthos could be related to sediment particle size. The aim of this component of the project was to identify the macrobenthos diversity at the selected sites and relate this to the benthic sediments.

3.1.3 Materials and methods

Sediment samples were collected during the period April to August 2010 from sites 2 to 5 and sites 10 to 12 with an Eckman bottom grab that was lowered from a boat. The collected substrate was poured into a plastic sample bag, preserved by immediately adding 10% formalin and transported to the laboratory for further analysis. The wet sample was washed through a series of sieves with 2000 µm, 500 µm and 355 µm mesh sizes respectively and the matter collected by each mesh size was

transferred to a marked sample bottle and preserved with 10% formalin. The content of each sample bottle was emptied into a Petri dish, viewed at 10X magnification using a dissecting light and all organisms were handpicked with forceps. The organisms were then identified at 30X magnification using a Kyowa dissecting microscope. Because of the large number of phyla expected to occur it was decided not to identify the organisms up to species level. The molluscans and macroinvertebrates were identified up to family level whereas the annelids were identified to class level using the keys provided in Day and De Moor (2002) and Gerber and Gabriel (2002).

3.1.4 Results

Figures 3.1 and 3.2 show the biodiversity of the macrobenthos at the sites. It should be noted that the same groups of zoobenthos, namely Mollusca, Annelida and macro-invertebrates, were recorded at sites 2, 3 and 4 but at different ratios with Mollusca dominating at site 2 and macro-invertebrates at site 4 with no dominant group at site 3. At site 5 no Mollusca were recorded which is very similar to the situation observed at the inflow sites, sites 10 to 12. At the inflow sites the ratio of the groups present differed with macro-invertebrates dominating at sites 11 and 12 and no domination at site 10.

The total diversity consisted of two families of the phylum Mollusca, two classes of the phylum Annelida and six families of macro-invertebrates (Table 3.1). The similarity between the inflow sites, sites 10, 11 and 12, regarding both the annelid and the macro-invertebrate composition should be noted. Table 3.1 shows that with the exception of the Ceratopogonidae and Tipulidae recorded at site 11 the same taxa were recorded at the three sites. The diversity at site 5 should be noted as it appears to be similar to the diversity of the inflow sites. Table 3.1 gives an indication of the high numbers of Oligochaeta and Chaoboridae at the inflow sites.

Table 3.1: The total number per taxon and sensitivity rating of the organisms collected between April and August 2010 in the benthic zone of sites at Lake Nandoni.

	Mollusca		Annelida		Macro-invertebrates					
Site No.	**Thari-dae**	**Corbicu-lidae**	**Hiru-dinea**	**Oligo-chaeta**	**Culici-dae**	**Polymi-tarcyidae**	**Chaobor-idae**	**Chirono-midae**	**Ceratopo-gonidae**	**Tipuli-dae**
2	50		13	1			12	2		
3		1	1			1				
4	3		8	3	1		4			
5			2	1			15	12		
10			23	66	4		75	4		
11			5	114	6		97	47	4	2
12			1	6	2		87	31		
Total	53	1	53	191	13	1	290	96	4	2

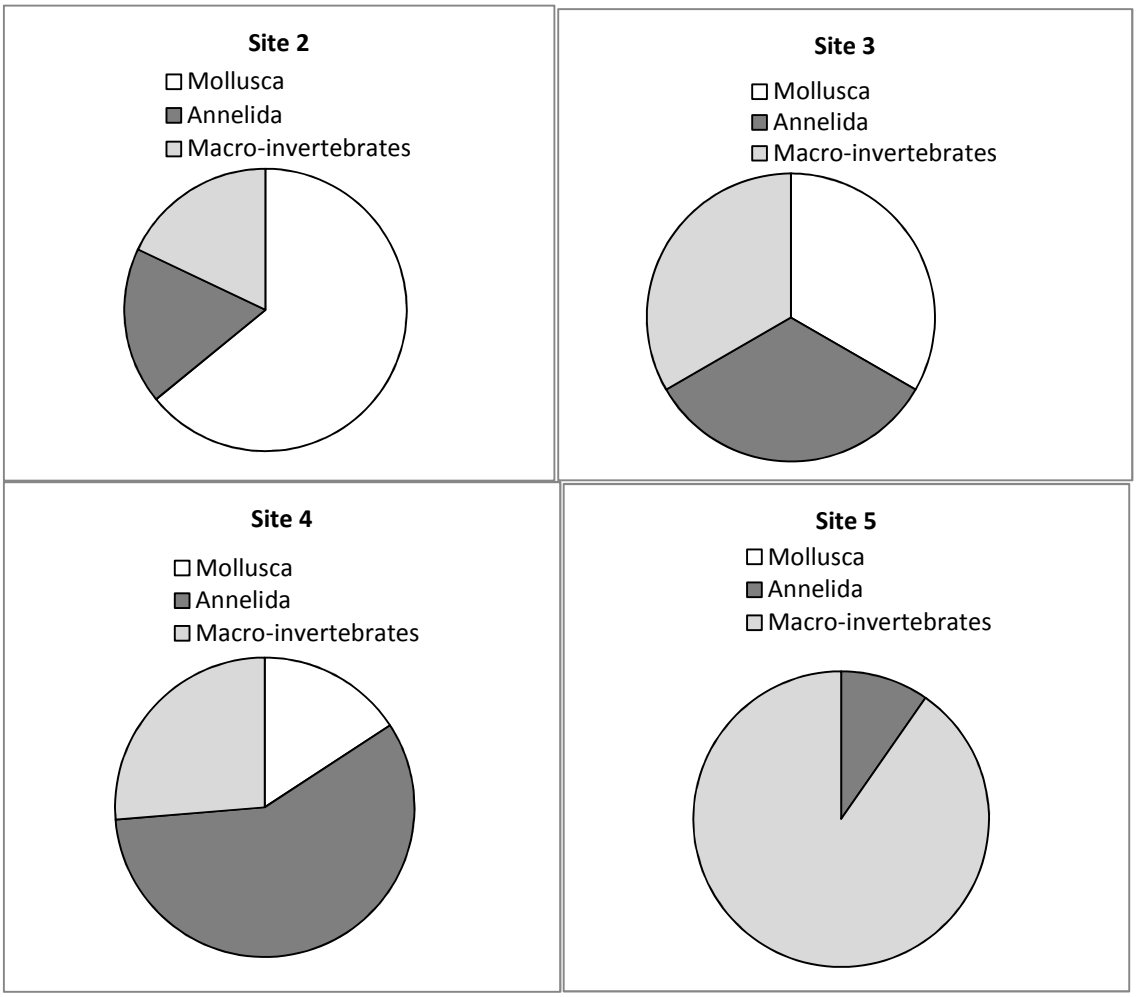

Figure 3.1: The observed zoobenthos biodiversity in the sediments collected at sites 2, 3, 4 and 5 in Lake Nandoni during the period April to August 2010.

3.1.5 Discussion

When the macrobenthos diversity was investigated the diversity at sites 2, 3 and 4 was different from the inflow sites with specimens of molluscans, annelids and macro-invertebrates recorded at the former but only annelids and macro-invertebrates at the latter group. Again, as was the case with the particle size, the diversity at deepwater, site 5, was different from that observed at sites 2, 3 and 4 but similar to that observed at the inflow sites. The absence of the molluscans at the sites with less fine material should be noted. Specimens of a total of eleven taxa were recorded during the survey. The biodiversity at the inflow sites were the highest with eight taxa recorded at site. The composition of the taxa recorded at site 5 was again similar with the diversity recorded at the inflow sites (Vivier and Cyrus, 1999; Saayman and Schoonbee, 1991). It does therefore seem that the observed biodiversity correlates to the substrate composition. To some extent the statistical analyses support these findings with the best correlation recorded at the sites 5 and 12.

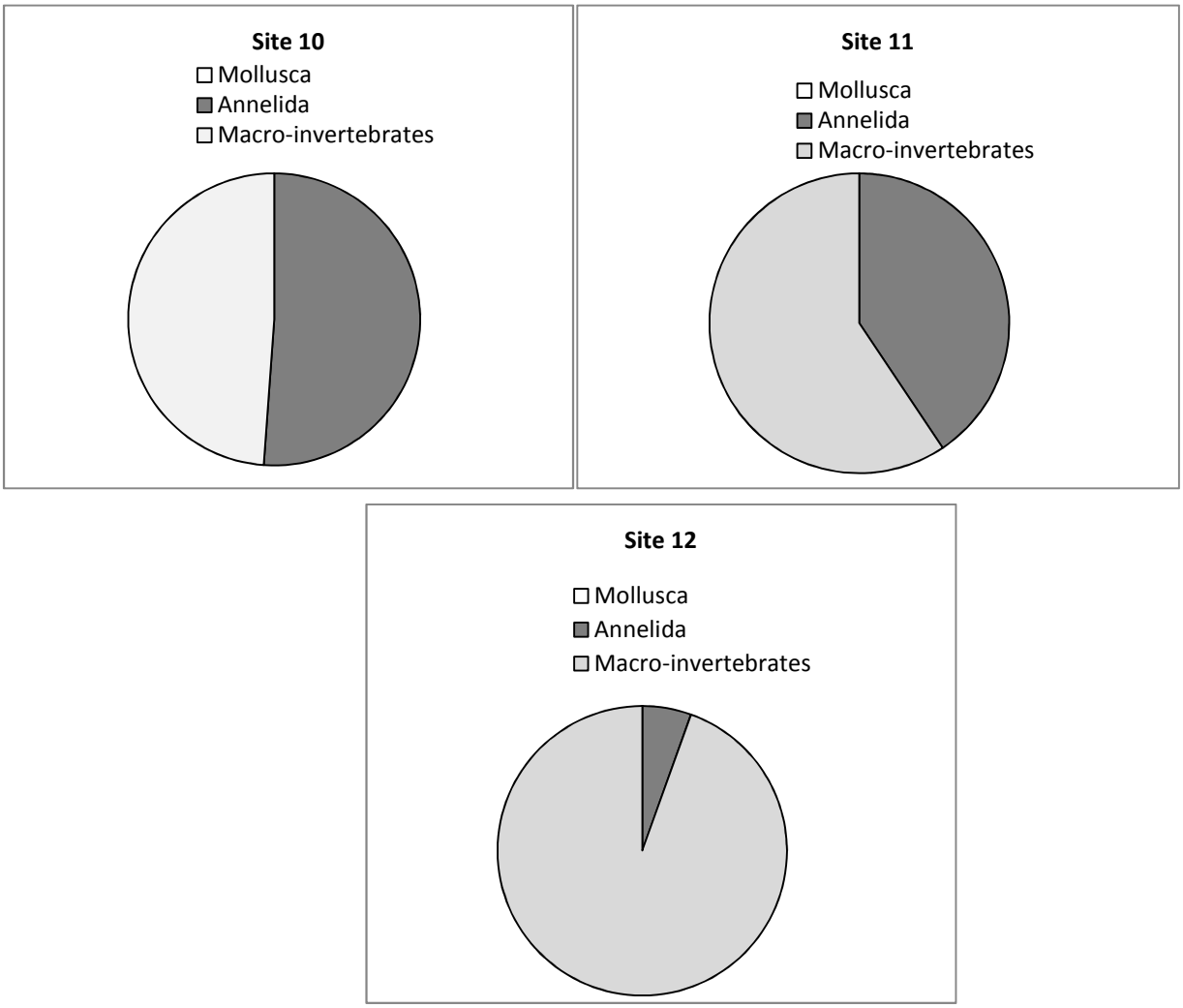

Figure 3.2: The observed zoobenthos biodiversity in the sediments collected at sites 10, 11 and 12 in Lake Nandoni during the period April to August 2010.

3.2 Phytoplankton

3.2.1 Introduction

Although the microflora forms a major component of the production aspect in freshwater ecosystems, it is often one of the neglected aspects in the study of man-made lakes. It was therefore decided to investigate the situation at Lake Nandoni. Determining chlorophyll-concentrations in aquatic systems is regarded as a routine monitoring method to quantify phytoplankton biomass (Trees *et al*. 1985). The aims of this component of this component of the study were to establish: a) the biodiversity and community structure of the phytoplankton in the impoundment, b) the seasonal variation in these communities and c) the relationship of the above to physico-chemical aspects of the water.

3.2.2 Materials and methods

Samples were collected in September, October and December 2009 and again in January to September 2010. The collection of samples was done at sites 1 to 5 and 10 to 12. Integrated water samples were collected at site 1 using a 5 m length of weighted 25 mm hosepipe. The following sub-samples were then taken:

i) A 250 ml sub-sample was filtered through Whatman 45 µm filter paper and the filter paper preserved in 10 ml 95% ethanol. These samples were intended or *chlorophyll-a* determination

ii) During December 2009 and February to September 2010 a 50 mL sub-sample was preserved with 10% formalin. These samples were then submitted to the Botany Department of the Northwest University to determine the phytoplankton diversity and abundance.

Prior to sample preparation the preserved 50 mL subsamples were shaken to suspend the algae uniformly through the water. The gas vacuoles of cyanobacteria were then pressure-deflated using a specially-designed mechanical hammer that exerts a pressure of 49.5 kPa on the sample. Depending on the concentration of algae, 0.5-5 ml of water was pipetted into sedimentation tubes with diameters of 16.5 mm. The sedimentation tubes were then filled with distilled water and covered with circular glass cover slips and left for a period of at least two days in a desiccator to allow the algal cells to settle and to avoid evaporation of water from the sedimentation tubes. Settling times of one centimetre length per day of the sedimentation tubes were allowed.

After the settling period, all algal cells were counted with an inverted light microscope, supplied with a Whipple grid, using the technique described by Utermöhl (1931, 1958) and modified by Lund et al. (1958). The glass bottoms of the sedimentation tubes were examined in strips, while counting all algal cells inside the grid. The original sub-sample volume transferred to the sedimentation tube and the number of strips counted in the sedimentation tubes were used to calculate the concentration of individual phytoplankton genera and species as cells per millilitre (cells mL^{-1}).
The phytoplankton counts were used to determine:

- the total algal concentration in each sample,
- the concentration of individual algal classes, genera and species present in each sample,
- the number of genera and species present in each sample and
- the dominant genus or species at a given time.

In the laboratory the chlorophyll-a concentration in the 250 ml samples in ii) above was determined spectrophotometrically from hot ethanol (95%) extracts according to the method of Sartory (Swanepoel *et al.*, 2008). The sample was filtered through a GF/C filter, boiled at 78°C for five minutes in 10 ml 95% ethanol, and then cooled in the dark. Absorbance of the extracted chlorophyll-a was read with a Labomed Spectro 22RS spectrophotometer at a wavelength of 665 nm. Three drops (*ca* 100 µl) of 0.1N HCl were then added directly to the cuvette, which was inverted once to mix the extract, and the absorbance was read again after approximately three minutes. Background absorbance was read at 750 nm and subtracted from the readings obtained at 665 nm. The calculation was done using the formula:

$$\textit{Chlorophyll-a} \text{ in extract } (\mu gL^{-1}) = (A_{665} - A_{665a}) \times 28.66$$

Where:A_{665} = absorbency of ethanol extract at 665nm before it was acidified minus absorbency at 750nm.

A_{665a} = absorbency of the acidified ethanol extract at 665nm minus the absorbency at 750nm.

The concentration of chlorophyll-*a* in the original sample was calculated as:

$$\text{Concentration } (\mu gL^{-1}) = \frac{\text{Concentration of the extract X 10 ml (extract volume)}}{\text{Volume of sample in litre}}$$

To establish correlation between nutrients contents and *Chlorophyll-a* scatter graphs were plotted, and a trendline for which the Pearson correlation coefficient was determined, fitted (Millar, 2001).

3.2.3 Results

The chlorophyll-*a* concentrations shows that the highest concentrations were recorded at the inflow sites, sites 10, 11 and 12, where the highest concentrations were recorded in June 2010 (Table 3.2). This table also shows that in general the concentrations did increase over time at these sites. The high values recorded at the inflow sites are indicative of possible upstream pollution. The highest of concentration chlorophyll-*a* level was observed at sites 10 to 12 where the peak concentrations were: 74.5 μgL^{-1} at site 11 in June, 57.3 μgL^{-1} at site 10 in August, and 45.9 μgL^{-1} at site 12 in June. At sites 1 to 5, in the impoundment, the concentrations were low and ranged between 1.2 and 10.3 μgL^{-1} during the survey. The observed phytoplankton diversity and abundance is shown in appendices 3.1 a to h.

Table 3.2: Chlorophyll-*a* concentrations (μgL^{-1}) recorded at sites 1-12 during the period September 2009 to August 2010 in Lake Nandoni.

	Chlorophyll-a (μgL^{-1})									
	2009			2010						
Site number	September	October	December	January	February	April	May	June	July	August
1	2.3	2.3	1.2	0.6	1.2	4.6	1.2	1.2	4.9	2.3
2	2.3	8.0	5.7	1.2	3.4	3.4	3.4	2.3	5.7	2.9
3	2.4	5.6	3.5	2.3	3.5	2.3	5.8	1.2	5.5	3.3
4	10.3	6.2	4.6	3.0	3.5	5.7	5.7	9.2	5.7	2.2
5	5.7	3.4	5.7	1.2	5.7	3.4	8.0	5.7	5.7	4.4
10	1.2	11.0	8.0	6.9	9.1	10.3	12.6	25.2	11.5	57.3
11	3.2	13.8	6.9	8.0	17.2	11.5	14.9	74.5	33.0	18.9
12	24.1	12.6	8.0	5.7	12.4	17.2	28.7	45.9	2.9	7.5

Note: Due to breakages during transport the samples collected in March 2010 were dried out and could not be analysed.

The growth of planktonic algae in a water body is related to the presence of nutrients (principally nitrates and phosphates), temperature and light (Wetzel, 2001). Therefore, concentrations of chlorophyll-*a* fluctuate seasonally and even daily, or with water depth, depending on environmental conditions. The chlorophyll-*a* concentrations in Lake Nandoni ranged between 0.5 and 74.5 μgL^{-1}, and the average values ranged between 2.2 and 20.2 μgL^{-1}, but were noticeably higher at the inflow river sites (10-12) (Figure 3.2).

However, the results of the calculated relationship between the nutrient and chlorophyll concentrations were not conclusive. Positive relations, with weak correlation, were observed between ammonia and

chlorophyll concentrations at sites 2 and 3, and for nitrite at sites 2, 5 and 11, and for phosphates at site 4. Strong positive correlations (r > 0.5) were however observed for nitrates at sites 4, 5 and 10 and for phosphates at site 2. The general weak correlation between nutrients and algal biomass could be ascribed to the lag-periods of approximately four to eight weeks that exist between high nutrient concentrations and the response of phytoplankton thereto (Roos and Pieterse, 1996).

In freshwater blooms of cyanobacteria (blue-green algae) are prominent symptoms of eutrophication. Cyanobacteria, especially *Pseudanabaena* and *Microcystis* sp, dominated at number of sites on several occasions in Lake Nandoni (Figures 3.6-3.21). For example the algal composition during December 2009, was dominated (70-95%) by Cyanobacteria (Figure 3.5), mainly *Pseudanabaena sp.* and some *Microcystis aeruginosa* cells. However, the cell numbers were only moderate; approximately 1 800 ± 400 cells per ml associated with low Chlorophyll-*a* concentrations; 1-8 μgL^{-1}.

In *Pseudanabaena sp.* the dark green to blue-green trichome, that is 1-3 µm in diameter, is single and does not form a thallus. Their barrel-shaped, with rounded or oval ends, cylindrical cells are longer than broad (2-4 µm long) have conspicuous constrictions at cross-walls (Figure 3.4).

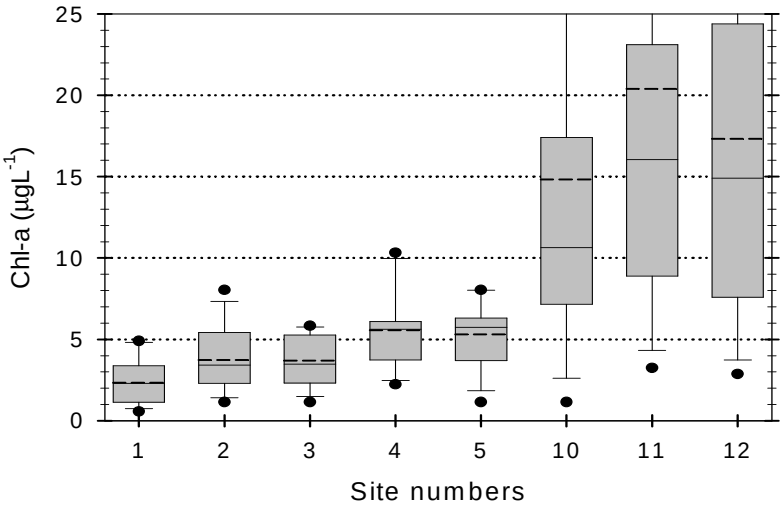

Figure 3.3: Box and whisker plot of algal biomass as chlorophyll-*a* concentration (μgL^{-1}) in surface water at different sampling sites for the study period September 2009 to April 2011. (Dashed line: mean value; solid line: median value).

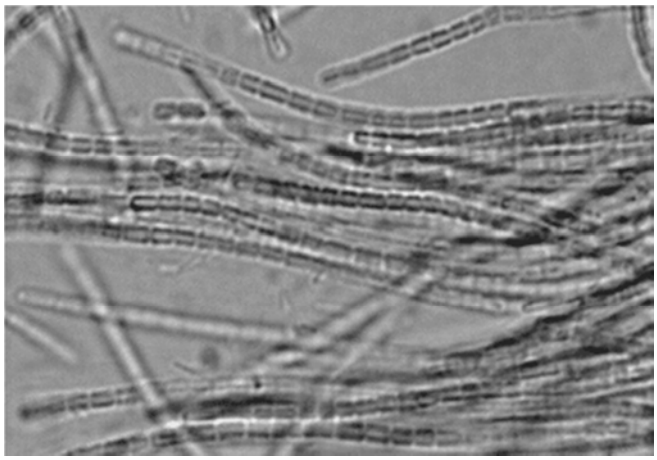

Figure 3.4: Micrograph of the cyanobacteria, *Pseudanabaena sp*.

Another important algal species encountered in Lake Nandoni, was *Ceratium hirundinella*. Whittington *et al.* (2000) described *C. hirundinella* as a ubiquitous relatively large and slow-growing species characteristically found during late summer in water bodies with a warm stable epilimnion and low nutrient concentrations. The *Ceratium* cells are 80-400 µm in length and strongly compressed dorsoventrally. The apical horn is long and narrow with a blunt tip while the slightly diverging antapical horns are straight with pointed, closed tips. A third antapical horn can be present (Figure 3.5). *C. hirundinella* can occur in short chains and is known to have a wide salinity tolerance.

Seasonal (temporal) changes in phytoplankton composition are illustrated in Figures 3.5 to 3.12. At sampling site 1, the algal composition was dominated by blue-green algae (cyanobacteria) and diatoms (Bacillariophyceae). (Figure 3.6). The algal composition at site 2 was usually a mixture of blue-green, diatoms and green algae (Fig. 3.7). At site 3, the composition change gradually from cyanobacteria during summer to diatoms during winter and spring (Fig. 3.8).

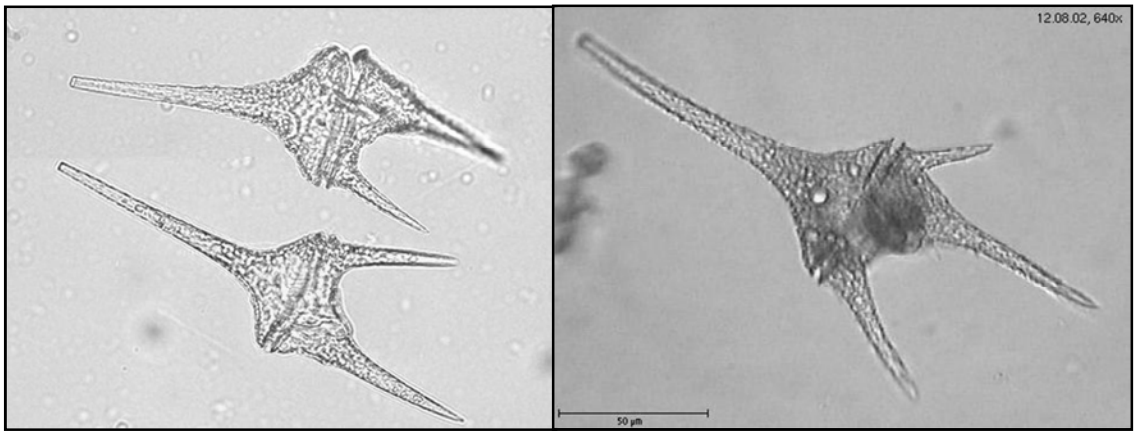

Figure 3.5: Micrograph of *Ceratium hirundinella.*

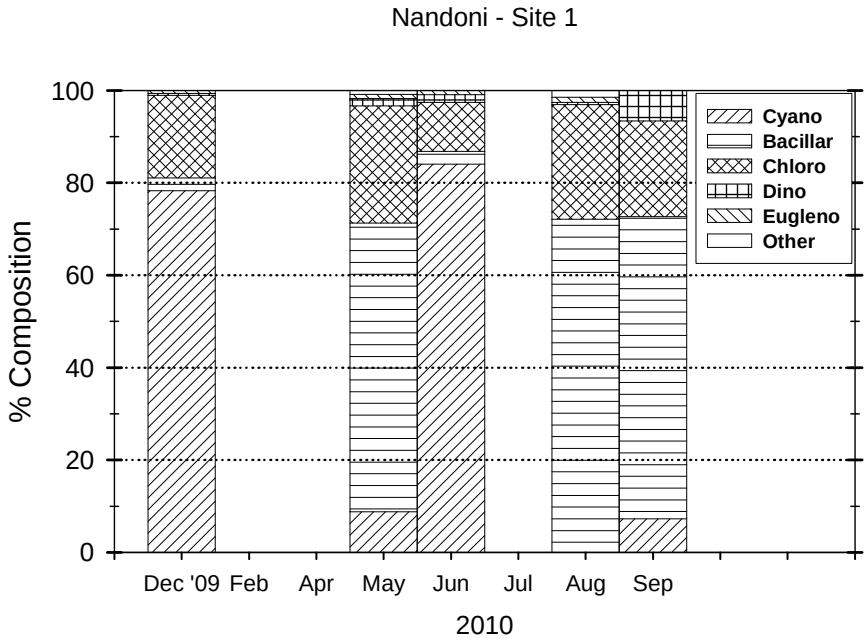

Figure 3.6: Stack bar of algal composition (%) in Lake Nandoni at Site 1 during the study period (December 2009 – September 2010); (Cyano = Total Cyanophyceae; Bacillar = Bacillariophyceae; Chloro = Chlorophyceae Dino = Dinophyceae; Eugleno = Euglenophyceae).

The algal composition at site 4 was very dynamic, with a different dominant group during each sampling, *i.e.* cyanobacteria, followed by euglenoids, back to cyanobacteria, then green algae and finally diatoms (Fig. 3.9). Site 5 is apparently in a transitional zone with an algal composition that is influenced by the inflowing river sites and the impoundment (Fig. 3.10).

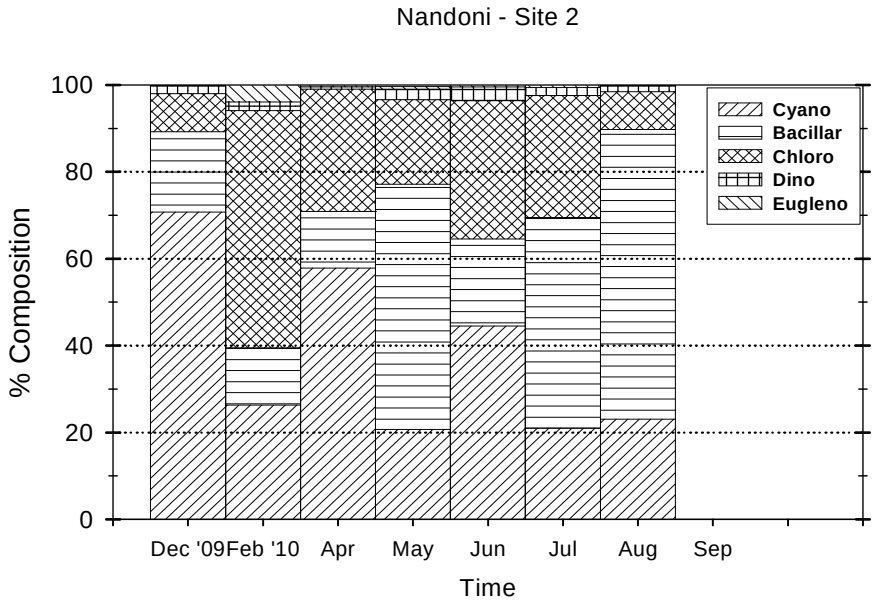

Figure 3.7: Stack bar of algal composition (%) in Lake Nandoni at Site 2 during the study period (December 2009 – September 2010); (Cyano = Total Cyanophyceae; Bacillar = Bacillariophyceae; Chloro = Chlorophyceae; Dino = Dinophyceae; Eugleno = Euglenophyceae).

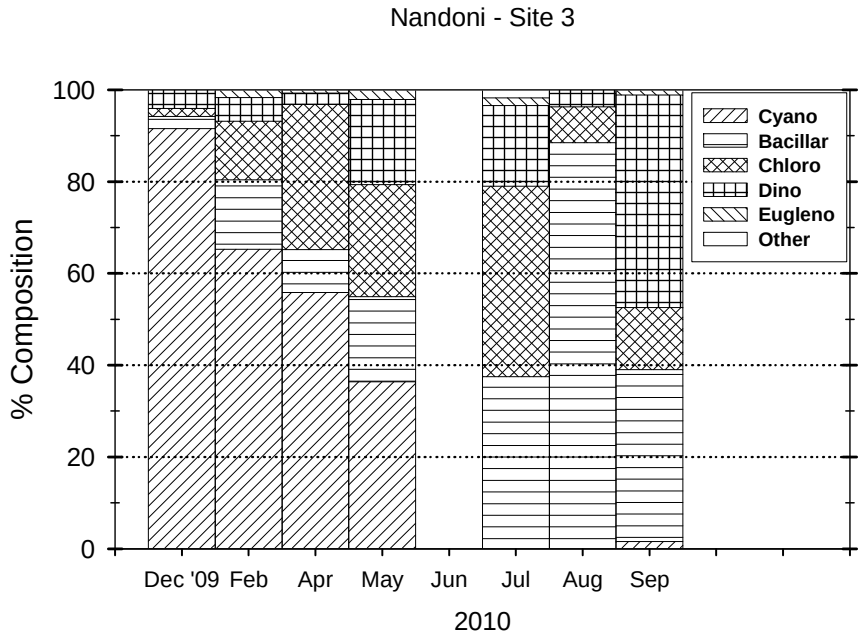

Figure 3.8: Stack bar of algal composition (%) in Lake Nandoni at Site 3 during the study period (December 2009 – September 2010); (Cyano = Total Cyanophyceae; Bacillar = Bacillariophyceae; Chloro = Chlorophyceae;Dino = Dinophyceae; Eugleno = Euglenophyceae).

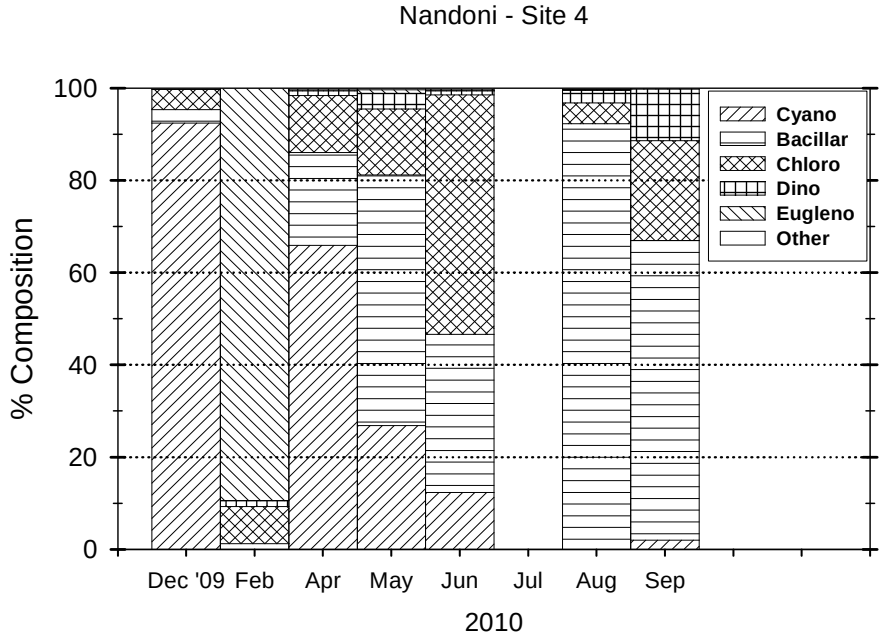

Figure 3.9: Stack bar of algal composition (%) in Lake Nandoni at Site 4 during the study period (December 2009 – September 2010); (Cyano = Total Cyanophyceae; Bacillar = Bacillariophyceae; Chloro = Chlorophyceae; Dino = Dinophyceae; Eugleno = Euglenophyceae).

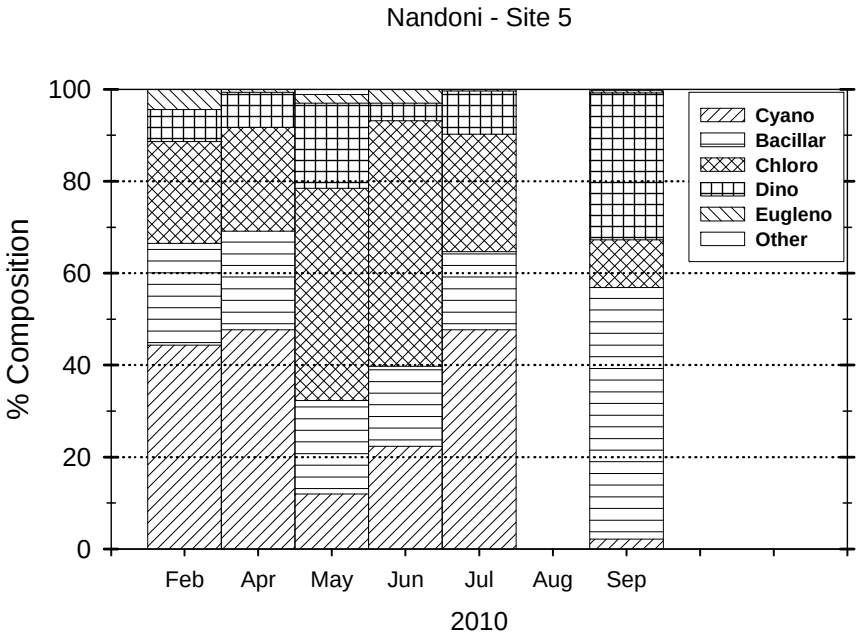

Figure 3.10: Stack bar of algal composition (%) in Lake Nandoni at Site 5 during the study period (December 2009 – September 2010); (Cyano = Total Cyanophyceae; Bacillar = Bacillariophyceae; Chloro = Chlorophyceae; Dino = Dinophyceae; Eugleno = Euglenophyceae).

The seasonal succession at Sites 10, 11, and 12, at the (inflowing rivers, differ considerably from sites in the impoundment, but follow the same pattern mutually, *i.e.* cyanobacteria during the summer (December to April), followed by dominance by dinoflagellates during the winter-spring months (May to September) (Figures 3.11-3.13).

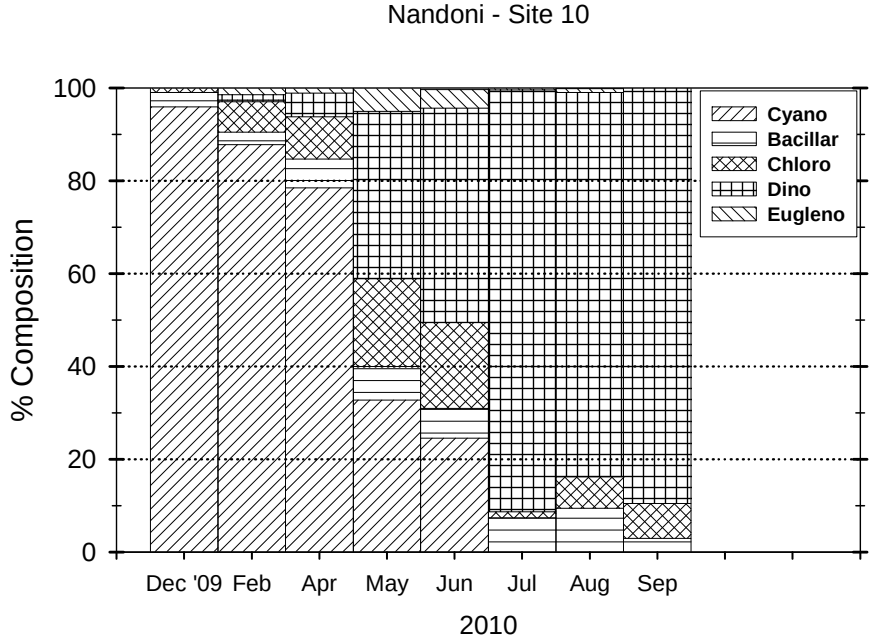

Figure 3.11: Stack bar of algal composition (%) in Lake Nandoni at Site 10 during the study period (December 2009 – September 2010); (Cyano = Total Cyanophyceae; Bacillar = Bacillariophyceae; Chloro = Chlorophyceae; Dino = Dinophyceae; Eugleno = Euglenophyceae).

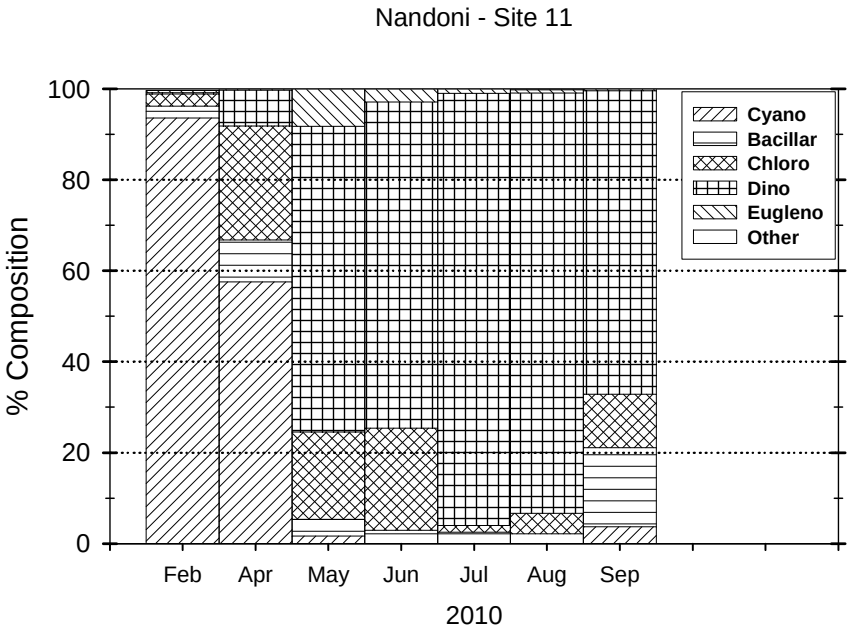

Figure 3.12: Stack bar of algal composition (%) in Lake Nandoni at Site 11 during the study period (December 2009 – September 2010); (Cyano = Total Cyanophyceae; Bacillar = Bacillariophyceae; Chloro = Chlorophyceae; Dino = Dinophyceae; Eugleno = Euglenophyceae).

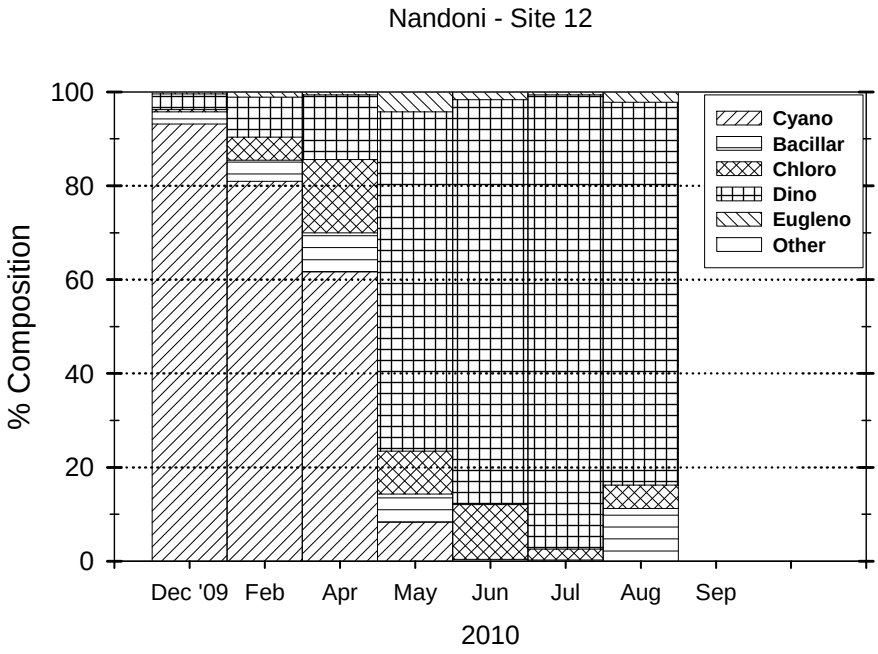

Figure 3.13: Stack bar of algal composition (%) in Lake Nandoni at Site 12 during the study period (December 2009 – September 2010); (Cyano = Total Cyanophyceae; Bacillar = Bacillariophyceae; Chloro = Chlorophyceae; Dino = Dinophyceae; Eugleno = Euglenophyceae).

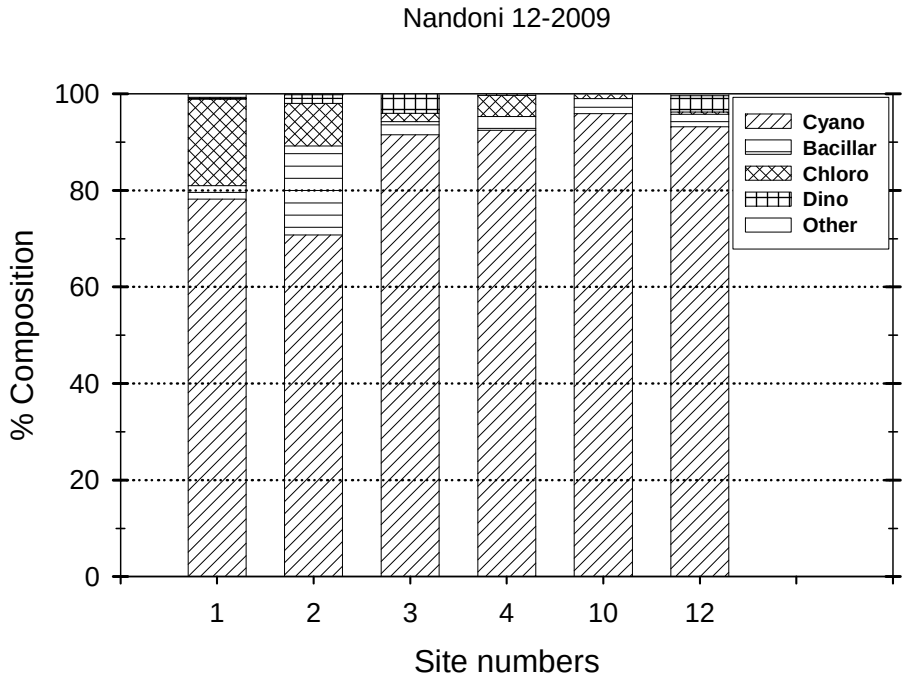

Figure 3.14: Stack bar of algal composition (%) in Lake Nandoni during December 2009 at different sampling sites.(Cyano = Total Cyanophyceae; Bacillario = Bacillariophyceae; Chloro = Chlorophyceae; Dino = Dinophyceae).

The spatial algal composition during December 2009 was more or less the same at the different sites (Figure 3.14), but the cell numbers and chlorophyll-*a* concentration at site 11 and 12 increased significantly to 3 963 cells per ml and 15 μgL^{-1} respectively. During February 2010, the algal composition in the impoundment (sites 1, 2, and 3), shift from cyanobacteria to the Chlorophyceae (green algae) with an isolated dominance of Euglenophyceae at sampling site 4 – dominated by *Trachelomonas volvocina* (Fig. 3.15).

The algal composition in Lake Nandoni during April 2010 was again dominated (50-78%) by Cyanobacteria (*Pseudanabaena sp.* and *Microcystis aeruginosa*) (Figure 3.16). However, the composition changed significantly during May, with a shift towards Bacillariophyceae (diatoms; *Fragilaria ulna*) in the impoundment, and towards Dinophyceae (dinoflagellate, *C. hirundinella)* at the inflow sites (10, 11 and 12) (Figure 3.17).

During June, the chorophylll-*a* concentrations at the inflow (sites 11 and 12) were very high (av. 60 μgL^{-1}) associated with high cell numbers (av. 3 716 cells per ml). During July 2010, the inflow sites (10, 11, and 12) were totally dominated (90-96%) by *C. hirundinella*, with very high cell numbers (5127 cell/mL) at site 12. The algal composition in the impoundment, however, starts to shift towards the diatoms (Figure 3. 18).

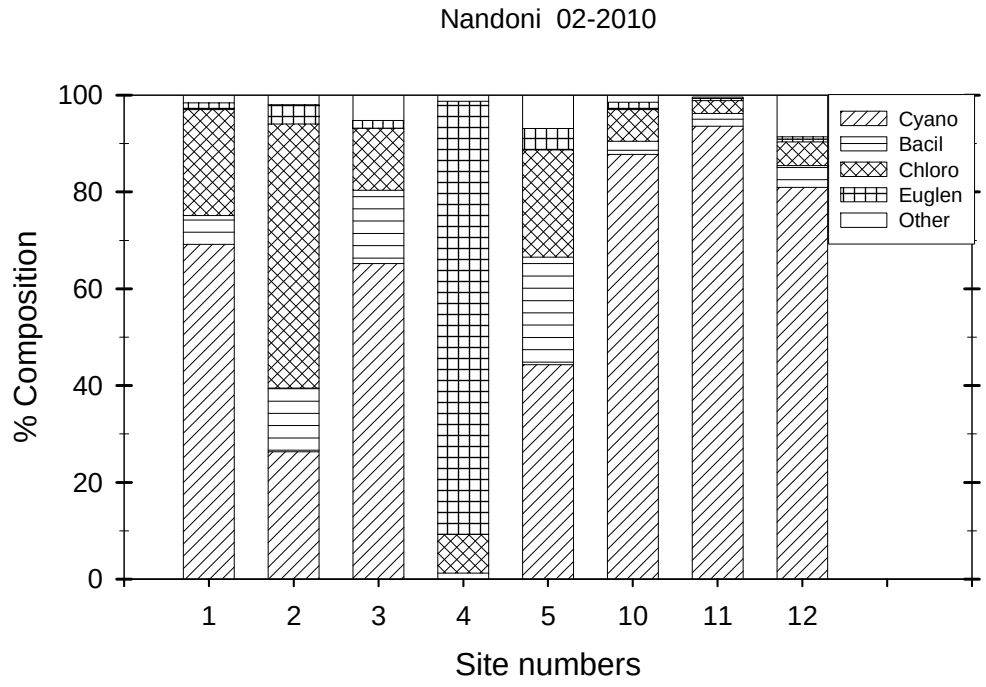

Figure 3.15: Stack bar of algal composition (%) in Lake Nandoni during February 2010 at different sampling sites. (Cyano = Total Cyanophyceae; Bacil = Bacillariophyceae; Chloro = Chlorophyceae; Eugleno = Euglenophyceae).

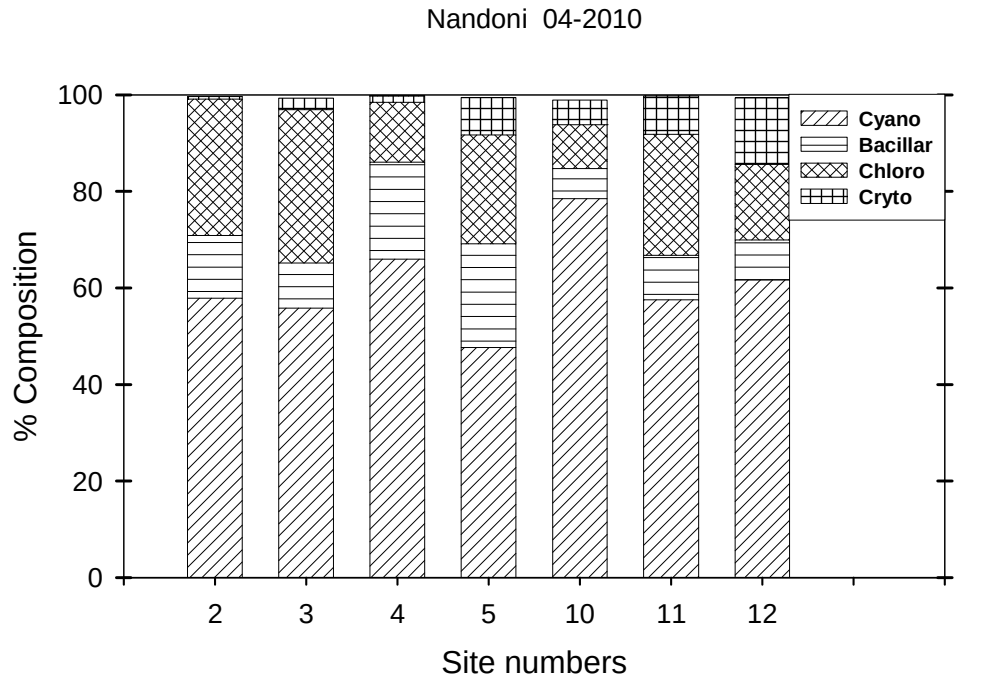

Figure 3.16: Stack bar of algal composition (%) in Lake Nandoni during April 2010 at different sampling sites. (Cyano = Total Cyanophyceae; Bacillario = Bacillariophyceae; Chloro = Chlorophyceae; Crypto = Chrysophyta).

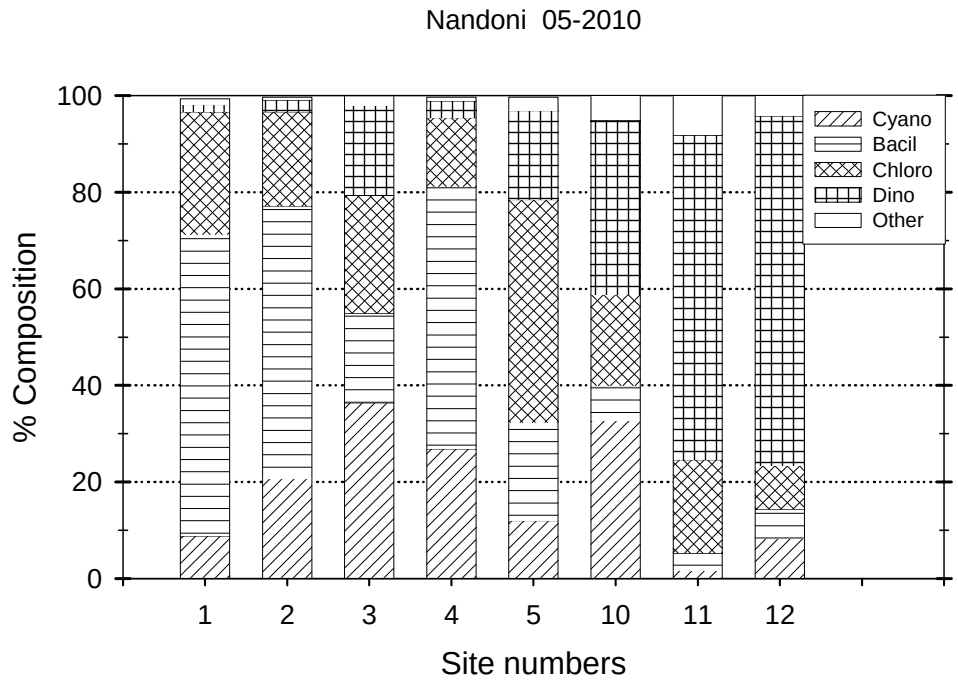

Figure 3.17: Stack bar of algal composition (%) in Lake Nandoni during May 2010 at different sampling sites. (Cyano = Total Cyanophyceae; Bacillario = Bacillariophyceae; Chloro = Chlorophyceae; Dino = Dinophyceae).

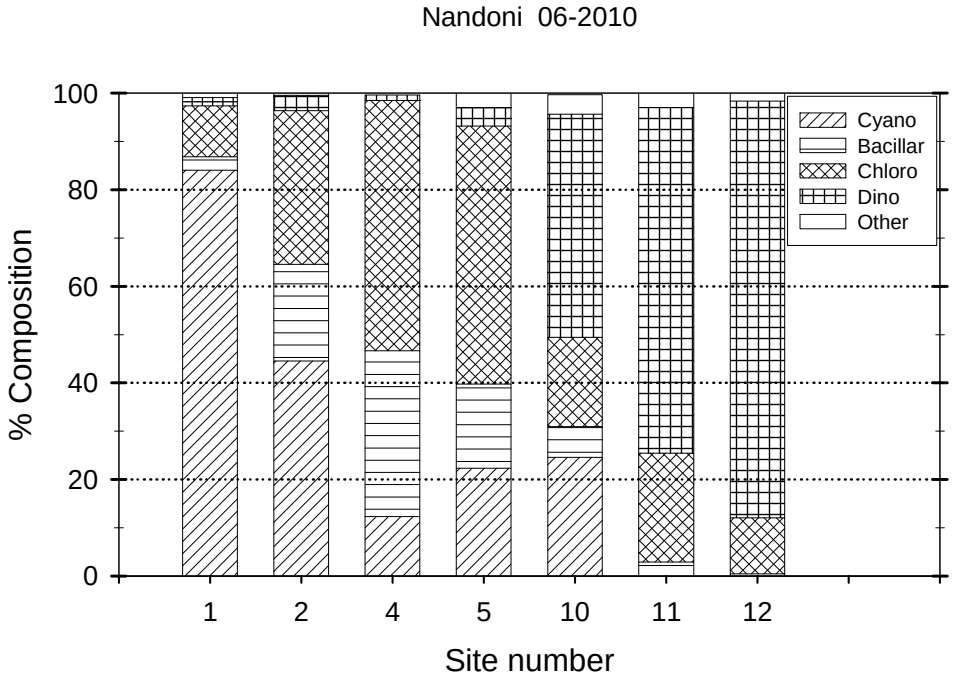

Figure 3.18: Stack bar of algal composition (%) in Lake Nandoni during June 2010 at different sampling sites. (Cyano = Total Cyanophyceae; Bacillario = Bacillariophyceae; Chloro = Chlorophyceae; Dino = Dinophyceae).

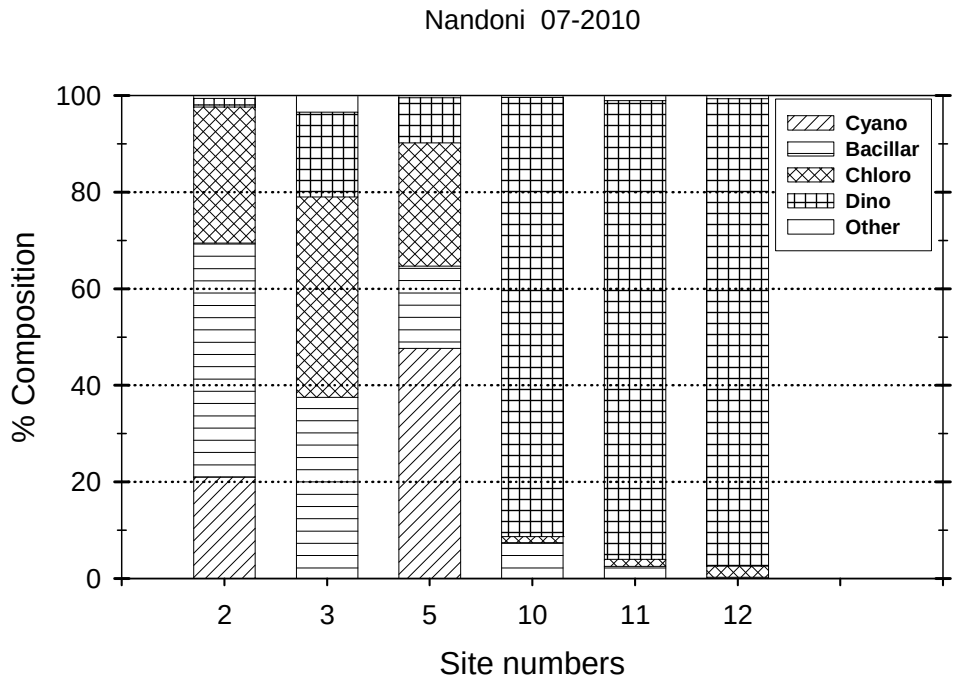

Figure 3.19: Stack bar of algal composition (%) in Lake Nandoni during July 2010 at different sampling sites. (Cyano Total Cyanophyceae; Bacillario = Bacillariophyceae; Chloro = Chlorophyceae; Dino = Dinophyceae).

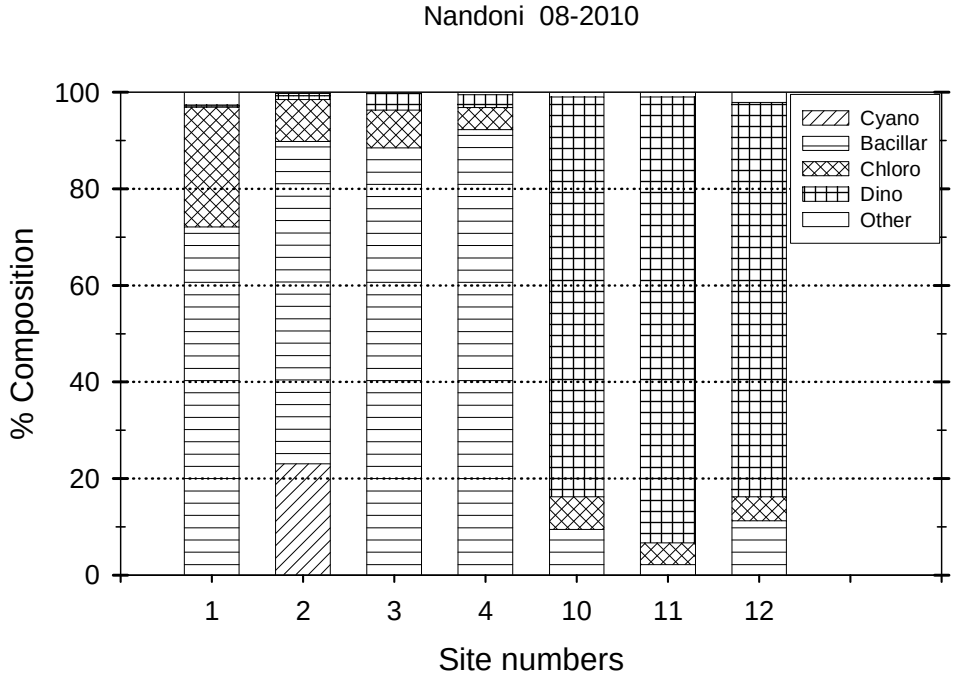

Figure 3.20: Stack bar of algal composition (%) in Lake Nandoni during July 2010 at different sampling sites. (Cyano = Total Cyanophyceae; Bacillario = Bacillariophyceae; Chloro = Chlorophyceae; Dino = Dinophyceae).

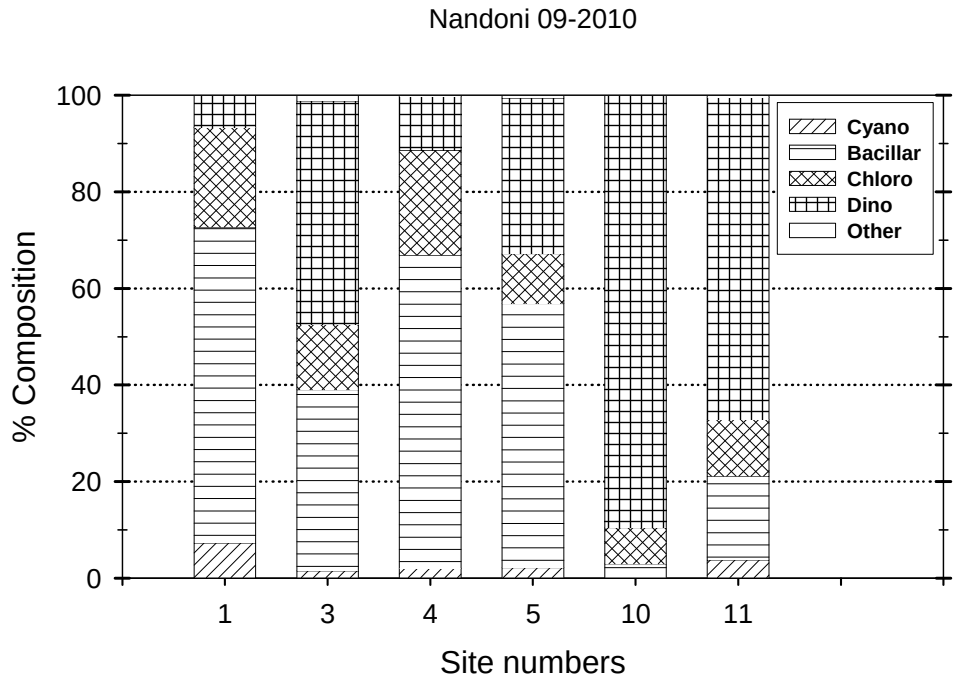

Figure 3.21: Stack bar of algal composition (%) in Lake Nandoni during July 2010 at different sampling sites. (Cyano = Total Cyanophyceae; Bacillario = Bacillariophyceae; Chloro = Chlorophyceae; Dino = Dinophyceae).

In Lake Nandoni (sites 1- 5), the algal composition during August 2010 was dominated (66-92%) by diatoms (*Fragilaria ulna).* The total cell numbers were also high (4 000 ± 2 000 cells per ml) (Figure 3.19).

During September 2010, *C. hirundinella* was still dominating at the inflow sites (10 and 11) and start to increase in the impoundment. However, diatoms were still dominating and cyanobacteria reappear again, but the cell numbers were relatively low (1 500 ± 500 cells per ml) (Figure 3.21).

3.2.4 Discussion

Lakes and rivers have two major sources of organic carbon, first an autochthonous input from photosynthetic organisms (like algae) within the aquatic system, and secondly allochtonous organic carbon transported into the lake or river. Planktonic autotrophs are essential to the function of pelagic (open water) ecosystems (Horne and Goldman, 1994).

Phytoplankton consists of an assemblage of microscopic photosynthetic organisms, having no or limited powers of locomotion; they are therefore free-floating and subject to distribution by water movements. Phytoplankton is lost from the epilimnion of aquatic ecosystems via three major pathways: (i) grazing by zooplankton (ii) sedimentation to the hypolimnion and (iii) lysis of phytoplanktonic cells is now perceived to be an important loss process.

High concentrations of the dinoflagellate (*C. hirundinella*) occurred in Lake Nandoni, but especially at the inflow sites. An expansive literature reviewed attests that blooms of dinoflagellates (*Ceratium* and *Peridinium* species) have become widespread and prominent in many lentic freshwaters, while coastal marine environments have experienced similar blooms ("red tides") especially in the past three decades (Reynolds, 2006). Under these low-turbulence conditions, its ability to undertake significant diel vertical migrations apparently enables its optimal exploitation of light and nutrients which are the two essential resources whose availability contrasts directly in the vertical dimension during stratification.

Notwithstanding its putative advantage at low nutrient levels (Whittington et al., 2000), *Ceratium* occurs in as a component of late-summer phytoplankton associations in oligotrophic, mesotrophic and eutrophic (but not hypertrophic) temperate waters (Reynolds, 1996). In South Africa, *Ceratium* blooms have been recorded in 17 of 57 reservoirs, and were perceived as being 'serious' in 9 (Hart and Wragg, 2009). Among these reservoirs, blooms occurred in all seasons and across the trophic status range. Although most common in mesotrophic waters with total chlorophyll levels below 15 μgL^{-1}, *Ceratium* blooms occurred in several waters of very high nutrient status, most prominently in the hyper-eutrophic Hartbeespoort Dam. Here, *Ceratium* was recorded for the first time in 1999 as a sudden-onset bloom that generated average chlorophyll levels of up to 600 μgL^{-1} in the upper (0 to 5 m) stratum (Van Ginkel *et al.*, 2001), equivalent to cell densities of around 13 500 cells per ml. A subsequent rule-based model developed by Van Ginkel *et al.* (2007) to predict *Ceratium* abundance in various hyper-trophic reservoirs in South Africa relies on prevailing nutrient concentrations (either TN and TP or SRP) as input drivers, further inferring nutrient enrichment as a causal/contributory factor underlying bloom occurrence.

Ceratium is recognised as a problem alga on 2 counts; it imparts taste and odour to potable water, and clogs water purification filters. The sudden onset of blooms recorded in 7 reservoirs and described in detail for Hartbeespoort Dam (Van Ginkel *et al.*, 2001), is accordingly very significant in terms of water quality management. But it is also commensurately intriguing from a purely ecological perspective. Ecosystems often respond abruptly to gradual changes in forcing variables, and can exhibit unexpected discontinuous shifts to an alternative state as the ecosystem exceeds a threshold in one or more of its key variables or processes. Underlying ecological thresholds define conditions beyond which an abrupt change in a quality, property, or phenomenon of the ecosystem may occur. Such changes, commonly human-induced, can lead to sudden, unexpected switches to 'new' alternative ecological states, which are commonly less desirable with respect to ecological services valued by society. The identification of such ecological thresholds promises to reveal much about mechanistic functioning of community processes and also has direct implications for resource management (Hart and Wragg, 2009).

The extensive re-structuring of plankton communities (both autotroph and zooplankton components) associated with emergent blooms of *Ceratium* can be broadly likened to a change of state, which, while perhaps 'unstable', is otherwise loosely analogous to switches between hydrophyte- and algal-

dominated shallow lakes. Hart and Wragg (2009) describe the sudden appearance of *Ceratium* at bloom densities in Albert Falls Dam (plausibly reflecting the transcendence of an ecological threshold) and attempt to evaluate the likely causality and ecosystem consequences of this 'new dimension' in an 'old' (mature) reservoir of paramount strategic importance in a water-scarce nation.

The presence of certain algal species has long been used to classify aquatic ecosystems according to the degree of impact from organic enrichment (e.g. insufficiently or untreated wastewater). Various lists of taxa indicative of different degrees of impact have been compiled based on available information on species tolerances to this form of pollution and phytoplankton indicators of trophic status.

In oligotrophic lakes, a large number of algal species are present, usually in excess of 50, and it is mostly desmids and diatoms, but with very few cells of each species and the therefore total standing crop is low. In Lake Nandoni a total of 15-20 phytoplankton taxa were usually recorded.

Predicting responses of ecosystems to perturbation is among the greatest challenges to ecology. Phytoplankton development in aquatic ecosystems is under the control of various meteorological, hydrological, chemical and biological factors. A concept that holds the key to phytoplankton responses is that of limiting factors. Any condition that approach or exceeds the limit of tolerance for the organism or group in question may be said to be a limiting factor. The limiting factor concept implies that the numbers of a particular organism and its presence or absence are controlled by a deficiency or an excess of chemical constituents and changes in physical variables. Therefore, the growth rate of phytoplankton in water is restricted by that variable with the least favourable demand to supply ratio. One well-known seasonal shift in limiting factors is the transition from limitation by physical factors in winter to nutrient limitation in late spring and summer.

Eutrophication is the process of nutrient enrichment, in particular nitrogen and phosphorus, of waters which result in the stimulation of increased production (or growth) of algae and macrophytes. Human sewage, industrial effluents, and agricultural nutrients have been ranked as the most severe and widespread sources of pollution causing eutrophication. Nutrient over-enrichment continues to be one of the leading causes of water quality impairment worldwide. As early as in 1994, the USA National Water Quality Inventory Report to Congress, cites nutrients, nitrogen and phosphorous, as one of the leading causes of water quality impairment in their rivers, lakes, and estuaries. Although nutrients are essential to the health of aquatic ecosystems, excessive nutrient loadings can result in the growth of aquatic weeds and algae, leading to oxygen depletion, increased fish and macro-invertebrate mortality, and other water quality and habitat impairments. The impacts are ecological, social and economical.

Phytoplankton is sensitive to changes in water quality and, in particular, responds rapidly and predictably to nutrient enrichment in lakes and the observation that phytoplankton biomass increases with higher phosphorus concentrations in lake water has been part of limnological theory for decades (Horne and Goldman, 1994). The widespread belief that phosphate limitation is nearly universal in

lakes has partly grown out of the convincing nature of whole lake eutrophication studies, but probably is even more attributable to correlation analysis. Analyses of regional and global data sets have shown a statistically significant correlation between chlorophyll-*a* and TP concentration. The consistency of this finding argues strongly for a major role for P in constraining algal biomass in lakes (Horne and Goldman, 1994).

The occurrence of cyanobacteria at high concentrations restricts the use of the water for drinking water, irrigation, and recreation. Harmful algal blooms are dangerous for animal and human drinking water resources due to the release of toxins. Thus, impairment of water quality due to the eutrophication can lead to health-related problems and result in economic losses.

A major problem for reservoirs, and a driving force behind much of their management, is the biological outcome of eutrophication, particularly as manifested in the enhanced phytoplankton growth. The resultant phytoplankton population densities cause problems for recreational users, for treatment processes in drinking water supply, and directly to consumers. Users may be merely reluctant to use the water because of its taste and odour but, at worst, they may experience a toxic effect. It is usually specific algal species, especially cyanobacteria, which are responsible for water quality problems in water treatment plant.

Phytoplankton succession is changed by eutrophication and can cause a shift from a community dominated by 'good' species to a community dominated by 'bad' algae. Diatoms, especially centric diatoms, are generally regarded as beneficial while dinoflagellates and blue-green algae are often toxic or in some way (size, taste, etc.) inedible for zooplankton. The total phosphorous (TP) concentration levels are usually strongly associated with trophic conditions in the aquatic system and cyanobacteria (blue-green algae) show a conspicuous stepped increase with an increase in TP concentration.

In all likelihood, the sudden appearance of dinoflagellate blooms reported in Albert Falls Dam is attributable to surpassing an ecological threshold, in this case, namely, that of prevailing nutrient concentration. While the data available do not permit an identification of the actual threshold level involved, exponential enrichment of Albert Falls with P manifests clearly and inescapably as a causal factor for the ecological 'switch' observed here (Hart and Wragg, 2009). The emergence of *Ceratium* at bloom densities results in a variety of undesirable consequences, ranging from its nuisance value in clogging water purification filters through to its various impacts on affected aquatic ecosystems. With regard to the latter, the observed re-structuring of zooplankton composition accompanying or associated with its appearance at high densities is highly undesirable in terms of sustaining ecological services beneficial to humans.

Based on the above identification of sharply rising TP concentrations in inflow waters, with associated lower N:P ratios as contributory or causal factors leading to bloom formations of this dinoflagellate, and the inference that this change in nutrient stoichiometry arises from increasing P loading from the local WWT plant, it seems certain that bloom formation can be reduced, if not avoided, by improved

compliance with WWT effluent standards and associated release management (Hart and Wragg, 2009). Operational deficiencies in WWT plant management and quality control have been widely publicised as a national problem in the Green Drop Report (DWA, 2011).

Phytoplankton abundance and species composition changes as a function of ratios of supplied nutrients; low N:P ratios favour the development of cyanobacterial growth. The N:P ratios in Lake Nandoni was very low (<5), because of the high phosphorus concentrations (especially at the inflow sites), and is probably the causal factors leading to bloom formations of the dinoflagellate, *C. hirundinella*.

3.3 Zooplankton

3.3.1 Introduction

Zooplankton consists mostly of organisms from the unicellular Protozoa that do not contain chlorophyll, the Rotifera and the Crustaceans. Although the latter group is dominated by the Cladocera and Copepoda, some Ostracoda and Acari are sometimes observed. Members of the Anacostraca, such as *Artemia,* or brine shrimp, can also form part of the group. Zooplankton does not, like phytoplankton, have to stay in the euphotic zone but do need to move to areas of phytoplankton abundance for grazing. Because many of the zooplankton are motile, stratification (where they are found in different layers or depth of the water) is often observed with distinct diurnal and seasonal differences. Although most of the zooplankton feed on organic material, either phytoplankton or detritus, the size of the particles that they feed on are related to their own size.

3.3.2 Aims

The aims of this component aims were to establish the biodiversity and community structure of the zooplankton in the impoundment and the seasonal variation in these communities.

3.3.3 Materials and methods

Samples were collected at all the sites where fish were collected, where lake stratification was determined and where the physico-chemical aspects were determined and this included sites 1 to 5 and 10 and 12. Samples were collected monthly in the period from September 2009 to September 2010. Samples were collected by vertically hauling a 60µ mesh plankton net (Hart, 1999) from the substrate level to the surface. A sub-sample was then preserved in 90% ethanol. In the laboratory the volume of the sample was determined with a measuring cylinder, returned to the container and mixed well. A sub-sample of 1 mL was removed with micropipette and placed in a zooplankton counting chamber. Using a Kyowa dissecting microscope, at 30 X magnification, the biota were identified and counted (Hart 1999). Schoeman (1986) indicated that three main groups of zooplankton could be identified in South African impoundments namely the Rotifera and two subclasses of Crustacea namely the Cladocera and Copepoda. The copepods in turn can be subdivided into Calanoida and Cyclopoida. These taxa were identified at the hand of the keys supplied in De Moor et al (1999 a and b).

Abundance values, reported as individuals per 100 mL, were calculated assuming 100% net sampling efficiency. The average and standard deviation of the data of each site and season was statistically determined and an unpaired t-test for normal data was applied to establish whether temporal, or seasonal, differences did occur and whether the diversity at sites were significantly different.

3.3.4 Results

The results obtained are shown in Appendices 3.2 and 3.3. Table 3.3 and Figure 3.21 show that the sites in the main body of water, sites 1 to 5, were dominated by copepods while the inflow sites, sites 10 to 12, were dominated by cladocera. The lowest total counts and averages of both Cladocera and Copepoda were recorded at the deepwater site, site 1, while the highest number of cladocera occurred at the inflow sites (Table 3.3). Results of an unpaired t-test showed that with regard to the Cladocera sites 1 to 5 were significantly ($p = 0.05$) different from sites 10 to 12 but not with regard to the Copepoda. The data in the appendices show that Calanoid copepods dominated the Cyclopoids at all the sites.

Table 3.3: A summary of the total and average number of Cladocera and Copepoda individuals counted per 100 mL of water at selected sites in Lake Nandoni during the period October 2009 to September 2010. (Standard deviation is shown in parenthesis)

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Site number	Cladocera abundance		Copepod abundance	
	Count	Average and SD	Count	Average and SD
1	159	13.25 (15.4)	650	54.75 (32.1)
2	441	36.75 (35.8)	894	74.5 (35.9)
3	668	55.66 (87.8)	738	65.25 (44.5)
4	672	56.0 (92.70)	843	70.25 (52.1)
5	425	35.42 (37.0)	712	59.33 (45.5)
10	702	58.51 (57.5)	616	51.33 (56.8)
11	881	73.41 (201.2)	724	60.33 (64.1)
12	918	76.5 (85.2)	817	68.08 (35.3)

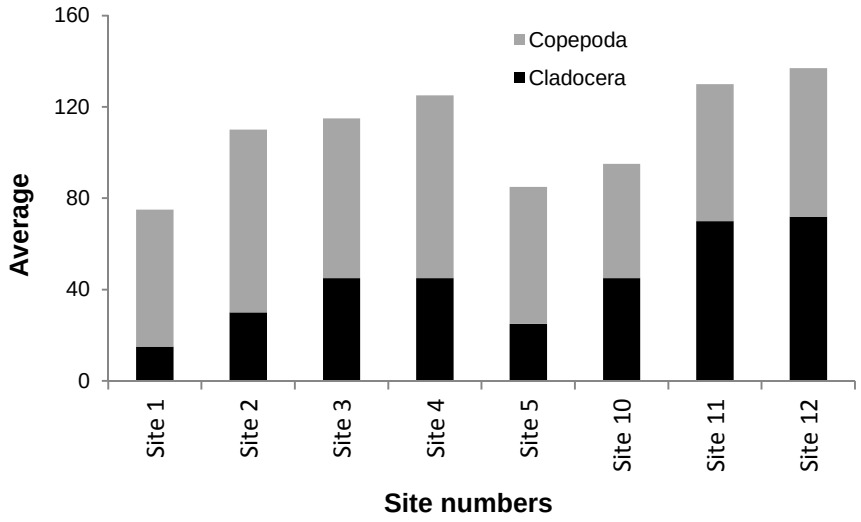

Figure 3.22: The average number of Cladocera and Copepoda individuals counted per 100 mL of water at selected sites in Lake Nandoni during the period October 2009 to September 2010.

To determine whether seasonal variation in zooplankton abundance existed the data of various months were combined based on similarity in water temperature. June, July and August, where the temperatures were lower than 21^{o}C, were combined to form the Winter season, September and October where the temperatures were above 25^{o}C, as Spring, November to March where the temperatures were above 28^{o}C, as Summer and April and May where the temperatures were above 22^{o}C but below 25^{o}C, as Autumn. In addition the data of the sites were pooled. Figure 3.23 shows that the average abundances were the lowest in spring and summer, followed by an increase in autumn with the highest averages recorded in winter. Statistical analysis, using ANOVA, showed that the difference between summer and winter were significantly different at p = 0.05.

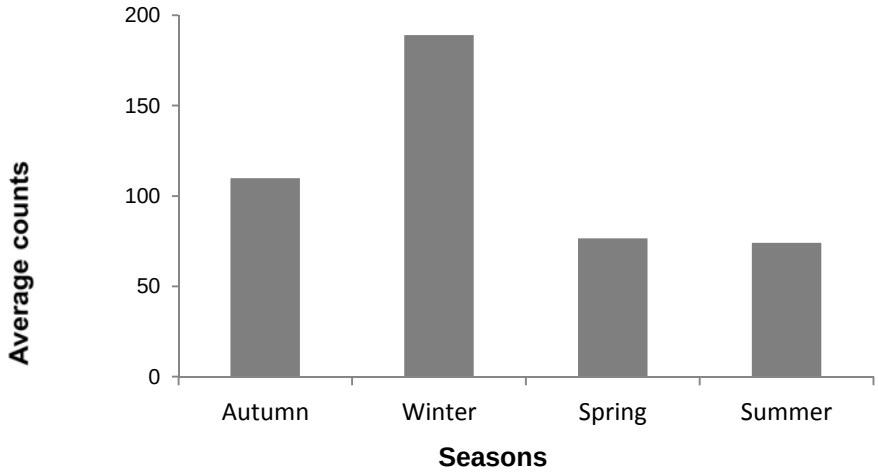

Figure 3.23: The average number of Cladocera and Copepoda individuals counted per 100 mL of water during the four seasons in Lake Nandoni during the period October 2009 to September 2010.

Although the majority of the results showed a weak correlation between chlorophyll concentration and zooplankton count, four of these sites, namely sites 2, 5, 11 and 12 showed a positive relationship with a strong correlation observed at site 12.

3.3.5 Discussion

Distinct seasonal patterns were observed with zooplankton counts the highest in Autumn and Winter as was found in mesotrophic by Gong et al. (2000). On a spatial scale a higher density was observed in the river sites which seemingly correlates with the high nutrient levels, and consequently high chlorophyll counts, at these sites. Statistical analyses however indicated a weak relation between both phytoplankton (chlorophyll-a) and zooplankton composition at the majority of the sites. An increase in phytoplankton commonly stimulates zooplankton production, but the grazing effect of the latter can lead to a predominantly inverse relation (Harvey et al., 1935). The resulting statistical picture is confused because of lag periods and nonlinearities in the relation (Steele, 1961). Feeding experiments (Marshall and Orr, 1955) have shown that most zooplankton will filter a constant amount of water in unit time irrespective of food concentration**.** The weak relation between phytoplankton and zooplankton is simply defined as low assimilated materials in excess of zooplankton growth requirements that lead to slow return of nutrients to the water in forms suitable for further phytoplankton growth. Excretion of phosphate and ammonia has received particular attention (Marshall and Orr, 1961) since these are important nutrients limiting phytoplankton growth. This is an indication that zooplankton are important in the cycling of these elements.

3.4 Fish

Currently the dam is in its maturing phase and the increased production that commenced in the initial two phases of the dam's existence, should now peak and drop to sustainable levels with the normally expected fluctuations. The aims of this component were *inter alia* to establish the present fish community structure, to determine the structure and function of fish populations which include aspects such as the condition factor, growth, breeding (physiological preparation for breeding, fecundity, length at sexual maturity, breeding seasons), feeding habits and general health.

3.4.1 The community structure of fish

Materials and methods

i) Sampling of fish

Fish were collected at the four selected limnetic sites, sites 2 to 5, once per month using fleets of multifilament experimental gill nets each consisting of a series of five individual nets, each 30 m long and 1,8 m deep, with the following stretched mesh sizes: 28, 45, 73, 93 and 118 mm. Initially, during the September 2009 survey the nets were set during day-time but due to the extremely low number of specimens collected, it was decided to adapt and from October 2009 the nets were left overnight. The nets were top set at each site during late afternoon, after 15h00. Clearing of the nets were done early the next morning. When clearing the nets the specimens were identified using the key provided in Skelton (2001). The mesh size from which each specimen was removed was recorded for the calculation of net selectivity. On site the body length of all the fish caught was measured in millimetre on a measuring board and the mass in gram on an electronic balance. Selected specimens, representative of the size classes of each species, were retained, kept alive and taken to a field laboratory for dissection. Prior to dissection, the ecto-parasites were removed and preserved. The endo-parasites were removed during dissection. After the abdominal cavity had been opened the gonadal development (De Villiers, 1991) and fat deposition (Nikolsky, 1963) was visually examined and scored. Both gonads and intestines were dissected out, preserved in 10% formalin for laboratory investigation of gonad development and fecundity determinations as well as gut content analyses.

At the littoral sites fish were collected using minnow traps, seine nets, cast nets and electro-fishing. In addition a composite gill net with 5 m sections with 16, 28, 48, 57, 73 and 93 mm stretched mesh sizes were set at each site at 15h00 and left until the next morning. The minnow traps were baited with commercial angling bait and set and collected at the same time as the gill nets. Shallow areas were seine netted with a 10 m seine net where snags allowed. Electro-fishing, using a Samus 10G fish shocker, was done among the littoral vegetation and rocky areas along the shore. All the specimens collected were weighed and the fork length or total length measured. Selected specimens, representative of the size classes of each species, were retained for laboratory investigation.

ii) Fish biodiversity, population structure and seasonal differences.

Fish numbers and lengths of the specimens collected during the whole survey were used to establish population structure and biodiversity while the monthly data was used to determine seasonality.

Results

As was shown Figure 1.4 fish were collected during the monthly surveys conducted in September to November 2009 and in the surveys from January to December 2010 and again in March, April and June 2011.

i) The diversity and seasonality of fish collected

At the limnetic sites, sites 2 to 5, twelve species were collected in the nets and Figure 3.24 shows that *Schilbe intermedius* was the most abundant at more than 76% of the total catch, followed by *Oreochromis mossambicus,* at close on 20%, and *Labeobarbus marequensis* at close to 3%. A total number of 3039 specimens were collected (Table 3.4) with the largest number of specimens collected at sites 2 and 4. Table 3.4 shows that *S. intermedius* dominated at all the sites. The pattern observed with *L. marequensis,* with the majority of specimens collected at sites 2 and 4, should be noted.

At the littoral sites fourteen species were collected with *S. intermedius* dominating (Table 3.5) as was the case in at the limnetic sites. While no specimens of *Synodontis zambezensis* were found, a single *Petrocephalus wesselsi* specimen and a large number of silver robbers, *Micralestes acutidens*, were collected. The presence of the two eel specimens at site 6 should be noted. When the data of all the sites are combined the pattern does not change (Figure 3.25) with *S. intermedius* still the most dominant.

Table 3.4: The numbers of fish collected at sites 2, 3, 4 and 5 at Lake Nandoni during the period September 2009 to April 2011.

Species		Site 2	Site 3	Site 4	Site 5	Total
Barbus trimaculatus	Threespot Barb	3	4	4	4	15
Barbus viviparus	Bowstripe Barb	2	6	1	6	15
Clarias gariepinus	Sharptooth Catfish	12	2	4	2	20
Labeo cylindricus	Redeye Labeo	5	2	2	2	11
Labeo molybdinus	Leaden Labeo	0	3	0	3	86
Labeobarbus marequensis	Lowveld Largescale Yellowfish	42	9	27	8	6
Marcusenius macrolepidotus	Bulldog	13	3	6	3	25
Micropterus salmoides	Largemouth Bass	7	5	1	5	18
Oreochromis mossambicus	Mozambique Tilapia	147	188	62	187	584
Schilbe intermedius	Butter Catfish	686	410	732	410	2238
Synodontis zambezensis	Brown Squeaker	0	0	1	0	1
Tilapia rendalli	Redbreast tilapia	6	6	2	6	20
Total no of fish collected		923	638	842	636	3039

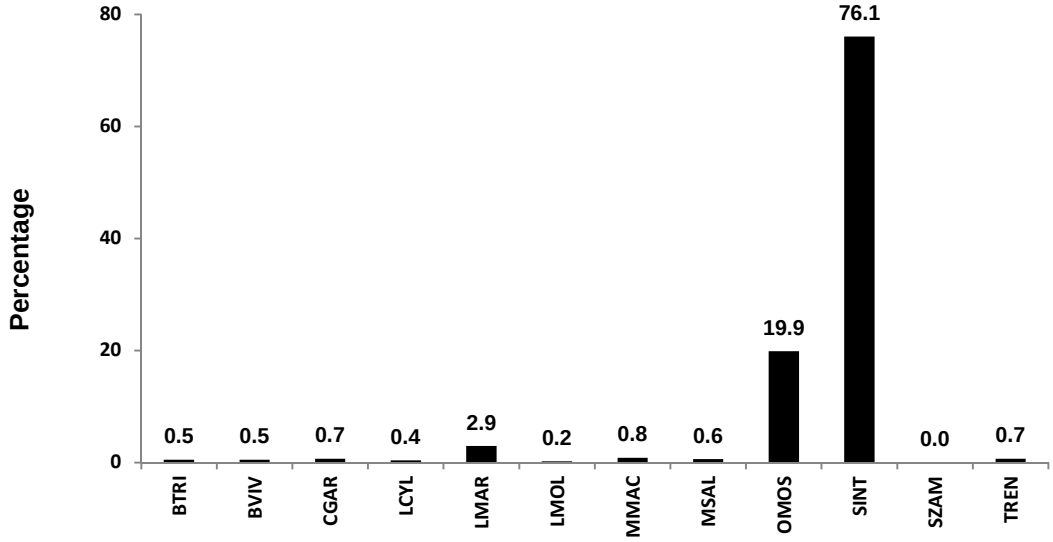

Figure 3.24: The numbers of fish, presented as a percentage of the total number, collected at sites 2, 3, 4 and 5 in Lake Nadoni during the period September 2009 to June 2011. (BTRI: *Barbus trimaculatus*, BVIV: *Barbus viviparus,* CGAR: *Clarias gariepinus,* LMAR: *Labeobarbus marequensis,* LCYL: *Labeo cylindricus,* LMOL: *Labeo molybdinus,* MSAL: *Micropterus salmoides*, OMOS: *Oreochromis mossambicus,* SINT:*Schilbe intermedius,* SZAM*: Synodontis zambezensis,* TREN: *Tilapia rendalli).*

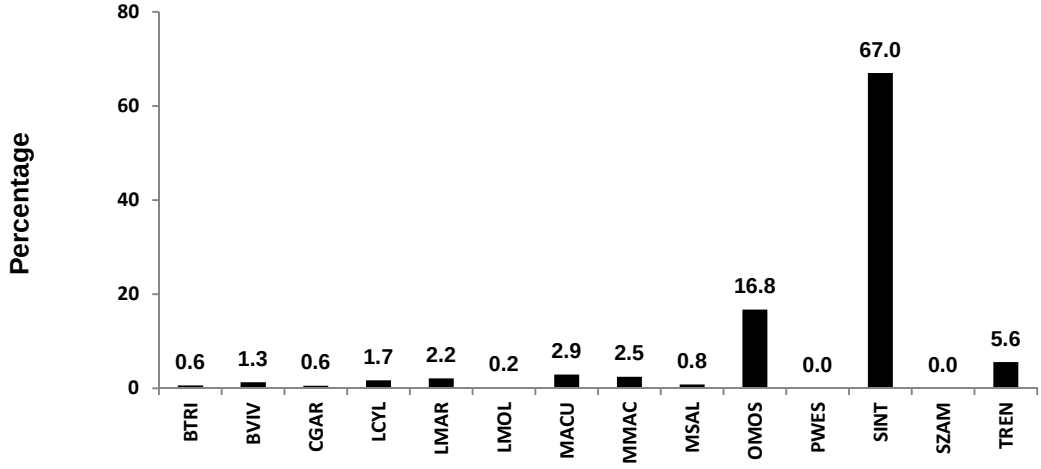

Figure 3.25: The numbers of fish, presented as a percentage of the total number collected at sites 2, 3, 4, 5, 6, 7 and 9 in Lake Nadoni during the period September 2009 to 2010. (BTRI: *Barbus trimaculatus*, BVIV: *Barbus viviparus,* CGAR: *Clarias gariepinus,* LMAR: *Labeobarbus marequensis,* LCYL: *Labeo cylindricus,* LMOL: *Labeo molybdinus, MACU: Micralestes acutidens, MMAC : Marcusenius macrolepidotis,* MSAL: *Micropterus salmoides*, OMOS: *Oreochromis mossambicus, PWES:petrocephalus wesselsi,* SINT:*Schilbe intermedius,* SZAM*: Synodontis zambezensis,* TREN: *Tilapia rendalli)*

Table 3.5: The number of fish collected at sites 6, 7 and 9 at Lake Nandoni during the period September 2009 to April 2011.

Species		Site 6	Site 7	Site 9	Total
Anguilla mossambica	Longfin eel	2	0	0	0
Barbus trimaculatus	Threespot Barb	5	4	1	10
Barbus viviparus	Bowstripe Barb	10	28	2	40
Clarius gariepinus	Sharptooth Catfish	2	1	1	4
Labeo cylindricus	Redeye Labeo	21	14	26	61
Labeo molybdinus	Leaden Labeo	2	2	0	4
Labeobarbus marequensis	Lowveld Largescale Yellowfish	1	1	1	3
Marcusenius macrolepidotus	Bulldog	52	23	2	77
Micralestes acutidens	Silver Robber	74	44	3	121
Micropterus salmoides	Largemouth Bass	6	4	7	17
Oreochromis mossambicus	Mozambique Tilapia	28	49	30	107
Petrocephalus wesselsi	Southern Churchill	0	1	0	1
Schilbe intermedius	Butter Catfish	259	187	80	526
Tilapia rendalli	Redbreast Tilapia	83	36	93	212
Total no of fish collected		543	394	246	1183

Table 3.6 shows the seasonal trends observed regarding the number of fish over the period of sampling. With regard to *S. intermedius* peaks in the numbers were observed during November 2009 and January and April 2010 respectively with the highest number in the latter month. The numbers of *O. mossambicus* were high during October to February followed by a steady decline. In the case of *L. marequensis* the highest number was observed during October and it is postulated that this coincided with increased breeding activity.

Table 3.6: Seasonal trends observed in the number of fish collected in the gill nets at sites 2, 3, 4 and 5 at Lake Nandoni during the period October 2009 to December 2010.

	2010													
Species	**Oct**	**Nov**	**Jan**	**Feb**	**Mrch**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
Barbus trimaculatus	1	6												
Barbus viviparus	1	7										1	1	
Clarias gariepinus	2	1			3	7		2				1		
Labeo cylindricus		1		1	1			3	2		1			
Labeobarbus marequensis	32	17	7		2		2	5		3	1			
Labeo molybdinus	1		1		3						2			
Marcusenius macrolepidotus	2	7	1					6				2		
Micropterus salmoides	1	2	1	2	1	1					1			
Oreochromis mossambicus	101	80	50	95	41	26	11	16	3	8	37	8	4	3
Schilbe intermedius	156	248	262	107	175	654	68	36	11	16	34	61	75	102
Synodontis zambezensis	1	1												
Tilapia rendalli		1	1	3	1	2		2			1		1	

Table 3.7: The biomass of the fish species collected in the gill nets at sites 2, 3, 4 and 5 at Lake Nandoni during the period September 2009 to December 2010.

Species	Total mass (kg)	Average mass (kg)	Standard deviation
Barbus trimaculatus	0.101	0.014	0.0023
Barbus viviparus	0.163	0.012	0.0036
Clarias gariepinus	29.386	1.633	0.8395
Labeobarbus marequensis	44.787	0.509	0.2984
Labeo cylindricus	1.015	0.092	0.0397
Labeo molybdinus	0.497	0.124	0.0277
Marcusenius macrolepidotus	2.639	0.078	0.0423
Micropterus salmoides	2.155	0.154	0.1836
Oreochromis mossambicus	156.414	0.288	0.1365
Schilbe intermedius	317.043	0.142	0.0691
Synodontis zambezensis	0.431	0.216	0.0601
Tilapia rendalli	3.639	0.192	0.1062

Table 3.7 shows that although three times more *S. intermedius* than *O. mossambicus* was collected in the gill nets during the period September 2009 to December 2010 the mass of the former was slightly more than double. This would imply that on average the *O. mossambicus* specimens were larger. This is important to note as this species makes up the major catch of local fishermen (Gaigher et al., 2001).

ii) The population structure of selected fish species at the sites.

The population structure, reflected by the percentage frequency of occurrence of the body length classes, of the three dominating species, is shown in Figures 3.26 to 3.28. Descriptive statistical analyses showed that most specimens of *O. mossambicus* collected had lengths that ranged between 200 and 290 mm. Figures 3.29 to 3.31 show the length mass relation of the three dominant species. The fitted trendlines and the associated equations in these figures show that the length-mass relationship of the species is similar as observed in other impoundments (Nicolaai, 2007) and the mainstream of the river (Fouche, 2009). From this relationship it can be deduced that *O. mossambicus* in the 200-290 mm fork length range has an average body mass of *ca* 300 g. In the case of *S. intermedius* the highest frequencies were recorded in the 180 to 270 mm range while in *L. marequensis* it was in the 240-260 and 290-300 mm range (Figure 3.31). This would imply average masses of 200- 300 g and more than 300 g in *S. intermedius* and *L. marequensis* respectively (Figures 3.29 and 3.30).

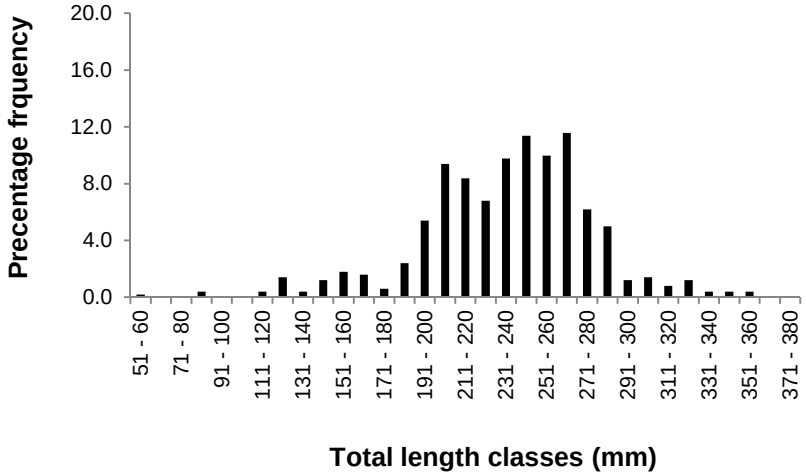

Figure 3.26: Population structure of *Oreochromis mossambicus* collected during the period September 2009 to April 2011 in Lake Nandoni.

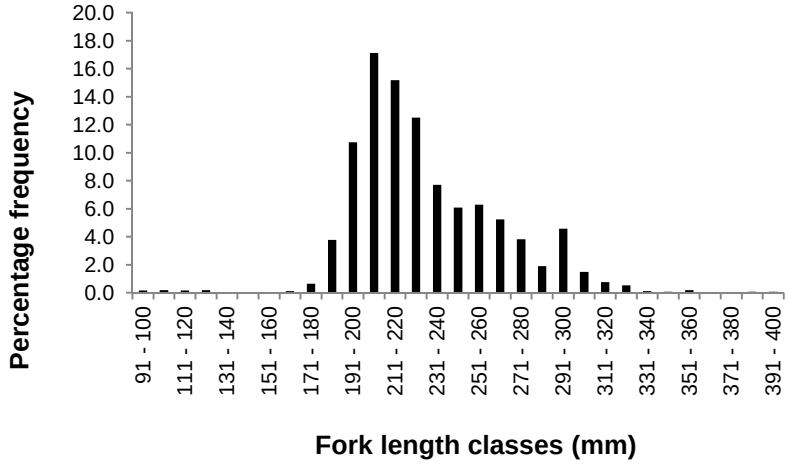

Figure 3.27: Population structure of *Schilbe intermedius* collected during the period September 2009 to April 2011 in Lake Nandoni.

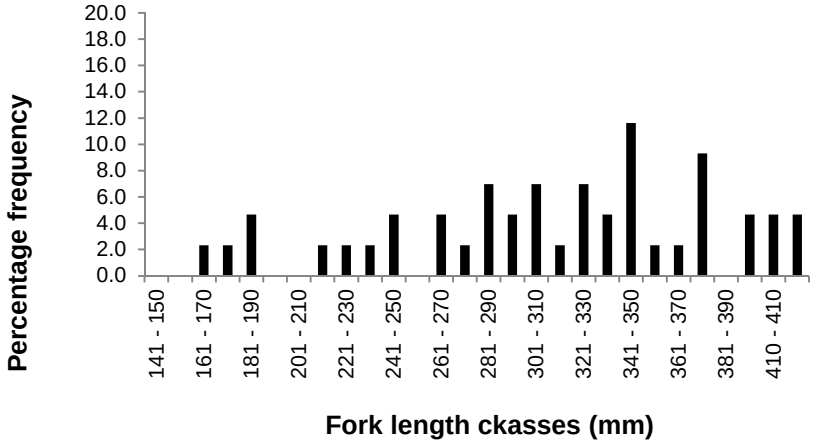

Figure 3.28: Population structure of *Labeobarbus marequensis* collected during the period September 2009 to April 2011 in Lake Nandoni.

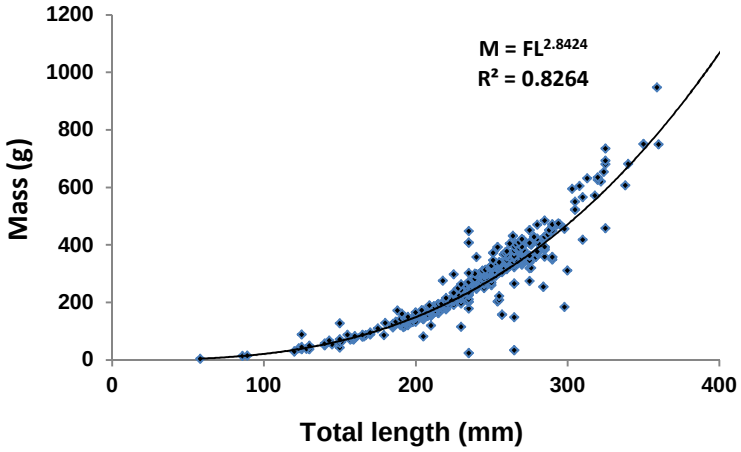

Figure 3.29: The length mass relationship observed in *Oreochromis mossambicus* collected in Lake Nandoni during the period September 2009 to April 2011.

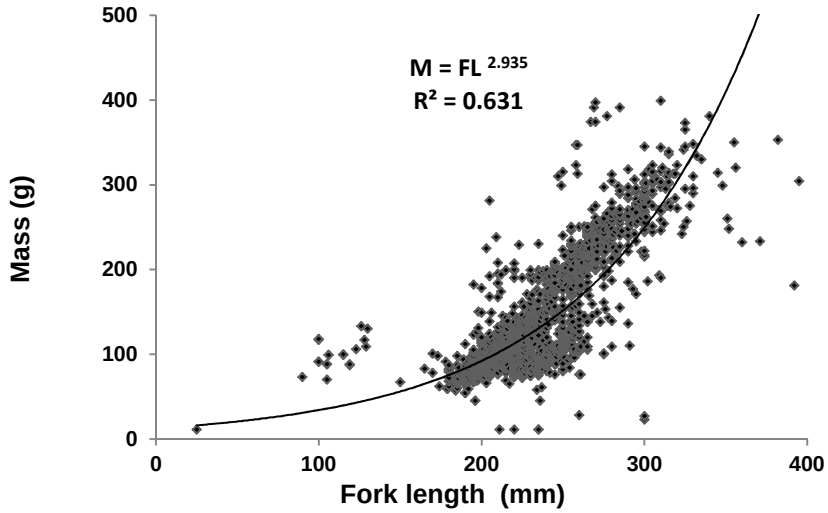

Figure 3.30: The length mass relationship observed in *Schilbe intermedius* collected in Lake Nandoni during the period October 2009 to April 2011.

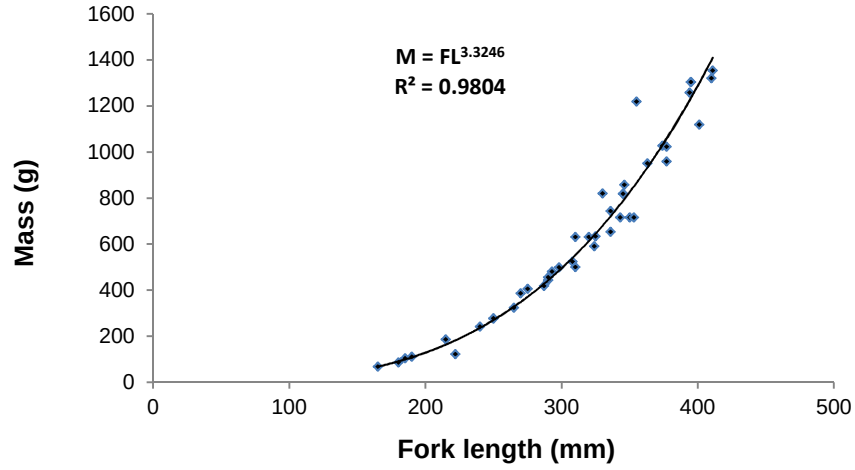

Figure 3.31: The length mass relationship observed in *Labeobarbus marequensis* collected in Lake Nandoni during the period September 2009 to April 2011.

Discussion

The observed population structure of the three dominant species indicates that both adults and juveniles (Skelton, 2001) are present at all the sites showing that breeding does occur throughout the dam. The authors are however of the opinion that a lack of fish data at the inflow sites, sites 10, 11 and 12, is a shortcoming of this project. These sites are traditionally regarded as the best breeding areas, in particular for species such as *L. marequensis* where flow is required (Fouché, 2009). The study also showed that certain size groups were dominant and it is suggested when harvesting is done that it should be done from these groups. The length-mass relationships recorded in this study are similar to what is observed in the natural environment (Fouché, 2009; Nicolai, 2009).

3.4.2 The reproductive and feeding biology of selected fish species.

3.4.2.1 Reproductive biology

Introduction

In the process of preparing for spawning the gonads, and in particular the gametes within them, grow and mature up to a point where the gametes are ready to be released for fertilization. The maturing process is cyclic and a continuum but with repeating steps in which the gametes start to develop, then grow in size after which they are discarded (Nikolsky, 1963). This process is repeated between spawning events and the length of time between spawning events varies between species. Although the maturing process is continuous, various stages in the process have been identified and described (Nikolsky, 1963). A number of systems, such as the one proposed by Nikolsky (1963), have been developed to describe the stages which represent the state of the gonads in general terms. It is also possible to deduce the breeding season by visually classifying the gonadal development. The gonadosomatic index (GSI) is a formula which expresses the gonad mass in relation to the total fish mass as a percentage. This index can be used to determine when a fish is ready to spawn and to predict the time period during which a certain fish species is likely to reproduce (Saayman and Schoonbee, 1991). In order to prepare for spawning, energy needs to be stored, with the result that the condition of the fish, which is a weigh to body length ratio, increases (Nikolsky 1963). When calculated the condition factor of a fish describes the wellbeing of a fish and works on the assumption that heavier fish of a given length are in better condition for breeding (Abowei et al. 2009).

Materials and methods

At the field laboratory, each specimen selected specimens were re-weighed to the nearest milligram, and the body length measured on a measuring board, to the nearest millimetre. Each specimen was dissected with an incision along the mid-ventral line from just anterior of the anal opening through the pelvic and pectoral girdles to posterior of the branchiostomal membrane (Willers, 1991). After dissection the fat deposition was visually assessed using the scale (Table 3.8) suggested by Nikolsky (1963) and the gonad development rated (Table 3.9). Both gonads were then carefully removed and preserved in 10% formalin for further analysis.

Table 3.8: The scale of fat deposition (Adapted from Nikolsky, 1963).

Fat content scale	Description of the visual appearance
Unit 0	No fat present.
Unit 1	Thin cord-like strips/globules of fat appearing between the segments/folds of the intestines.
Unit 2	Strips start joining to form dense fat.
Unit 3	Strips that have joined started "growing over" the intestines. Intestines are being covered by fat.
Unit 4	Intestines almost completely covered by fat. No gaps seen.
Unit 5	Intestines completely covered by fat. No gaps seen.

Table 3.9: The gonadal maturity classes of fish (Adapted from De Villiers, 1991).

Maturity classes		Description
1	Latent (Developing)	Sexual organs small, both ovaries and testes are white, no eggs visible
2	Maturing	Size increase in both male and female, colour changes to cream; eggs visible. Eggs are of various sizes.
3	Mature	Size increase in both male and female. Testes appear swollen and are cream in colour. Ovaries increase dramatically and occupy large amount or volume abdominal cavity. Large eggs are visible.
4	Spent	A marginal size decrease in testis, but still cream in colour, ovaries decrease in size of eggs.

In the laboratory the mass of the preserved gonads was determined and a sub-sample, of *ca* 5 mm x 5 mm, sectioned out. The mass of the sub-sample was then determined to the nearest milligram. The sub-sample was placed in a vial containing distilled water and vigorously shaken to separate the oocytes and the connective tissue (Gaigher, 1976). The excessive connective tissue was then physically removed with tweezers and by repeated filling and decanting with water. After separation all the liquid was decanted and 1 mL distilled water added to the sample. The sample was thoroughly stirred and a 0,2 mL sub-sample was removed with a micro-pipette and transferred to a counting chamber (Gaigher, 1976). The counting chamber consisted of a Petri dish with a transparent grid of 1 mm^2 squares attached to the exterior surface of the floor. All primary oocytes, oocytes with yolked nuclei and fully yolked oocytes were counted with the aid of a Kyowa dissecting microscope at 10X and 30 X magnifications. Standard cell enumeration protocols, as described by Baker and Silverton (1980) for counts on calibrated chambers were applied. The number of oocytes in the 0,2 mL sub-sample was then calculated as follows:

$$\text{Average number of oocytes per block} = \frac{\text{Total number counted}}{\text{Number of blocks counted}}$$

This average was multiplied by the number of grid blocks covered by the sub-sample and the average was used to calculate the number of oocytes in the sub-sample of the gonads (Ts). The total number of oocytes (T_o) in the ovaries was calculated using the formula adapted from Mulder (1971):

$$To = \frac{Ts}{B} X A$$

Where: T_o is the total number of oocytes in gonad, T_s the number of oocytes in sub-sample, *A* the mass of both gonads and *B* the mass of sub-sample.

A second sub-sample of 0,1 mL was extracted, placed on a microscope slide and the diameter of the oocytes measured with a calibrated ocular micrometer at 400X magnification on a Nikon light microscope. In each sample, a minimum of 50 oocytes were measured to the nearest 0,001 mm. After measuring, the oocytes were grouped into 0,125 mm size categories. There is no definition of fecundity that is acceptable in all circumstances (Cambray, 1992) and often the term fecundity reflects the number of eggs per spawning. However determining the number eggs per spawning is not practical under field conditions. Because of this difficulty fecundity is often measured as the number of eggs present in the ovary immediately before spawning and in this study this was done by counting yolked oocytes in the 0,1 mL sub-sample of the ovary and then calculating the total number (Nikolsky, 1963; Cambray, 1992). From these counts the relative fecundity was calculated by relating the oocyte count to the mass of the fish (de Villiers, 1991).

The data regarding body mass, fork length and gonad mass was used to calculate the Condition Factor (CF), Gonadosomatic index (GSI) and the Maturity Coefficient (MC). The condition of the fish was established by calculating the body mass to body length ratio as a percentage using the formula proposed by Nikolsky (1963), followed by calculation of the average condition factor.

$$CF = \frac{\text{Fish mass (g)}}{\text{Fork length (cm)}} \times 100$$

The GSI was calculated using the equation below. Thereafter, an average GSI was then calculated for all the specimens collected on the same collection date (Glazier and Taber, 1980).

$$GSI = \frac{\text{Gonad mass (g)}}{\text{Total mass (g)}} \times 100$$

The maturity coefficient was calculated using the formula below (Gaigher, 1976). The average maturity coefficient was then calculated for all the specimens collected on the same collection date.

$$MC = \frac{\text{Gonad mass (g)}}{\text{Fork length (cm)}^3} \times 10^4$$

Results

Because of the fact that *S. intermedius* is the most numerous species a large number of specimens were available for analyses and a detailed investigation was possible. The number *O. mossambicus* specimens were lower but the results could still be regarded as representative. In the case of *L. marequensis* only a few specimens were retained which reduces the confidence in the results.

A) *Schilbe intermedius*

i) The observed fat deposition classes.

Table 3.10 shows the percentage of *S. intermedius* specimens of which the fat deposition was visually rated into the five fat deposition units. Although no distinct pattern of increase is observed from January onwards, the high percentage of specimens in the recorded in April and May in the two classes with the

most fat deposition should be noted. These high values are a clear indication that sufficient energy storage was occurring.

Table 3.10: The percentage of *Schilbe intermedius* specimens in each of the visually assessed fat deposition units, collected during the November 2009 to August 2010 surveys in Lake Nandoni.

				Percentage of specimens in visual fat deposition classes					
Month	**Number of specimens**	**Minimum FL size (mm)**	**Maximum FL size (mm)**	**Unit 0**	**Unit 1**	**Unit 2**	**Unit 3**	**Unit 4**	**Unit 5**
November 2009	7	250	318	0.0	14.3	42.9	42.9	0.0	0.0
January 2010	13	208	305	15.4	30.8	15.4	23.1	0.0	15.4
February 2010	13	20	311	0.0	15.4	23.1	38.5	23.1	0.0
March 2010	19	194	342	0.0	52.6	5.3	42.1	0.0	0.0
April 2010	28	193	340	14.3	7.1	21.4	35.7	14.3	7.1
May 2010	22	195	330	0.0	31.8	27.3	31.8	4.5	4.5
June 2010	21	187	220	4.8	47.6	23.8	19.0	4.8	0.0
July 2010	11	186	290	0.0	9.1	36.4	54.5	0.0	0.0
August 2010	18	184	317	5.6	27.8	16.7	38.9	5.6	5.6

During the November 2009 and January 2010 surveys there were no male specimens evaluated. Figure 3.32 shows the average condition factor of male and females for the surveyed months and shows that the condition factor of females is at its highest level during March and April, followed by a decrease during May. This suggests that preparation for breeding commences in February, increasing in March and April and decreasing in May. In the males the increase in condition factor was at its highest level earlier than in the case of the females. Because these findings do not coincide with the fat deposition it can be postulated that the condition of the fish can only be partly attributed to fat deposition.

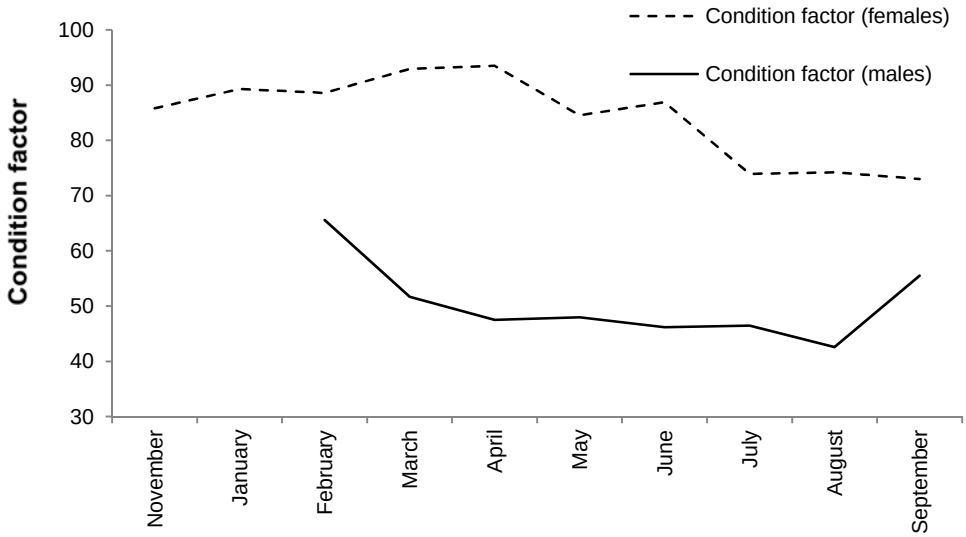

Fig 3.32: The average Condition Factor values of male and female *Schilbe intermedius* collected during the November 2009 to August 2010 surveys in Lake Nandoni.

ii) Gonadal development

Figure 3.33 shows that the gonadosomatic index (GSI) and maturity coefficient (MC) both reached a peak in March and rapidly decreased rapidly during April. The visual gonad maturity reached its highest level during February, followed by a steep decrease from March to May. Because of the subjective manner in which the gonads are visually classified the confidence level in this latter aspect is low and the results should be treated as such.

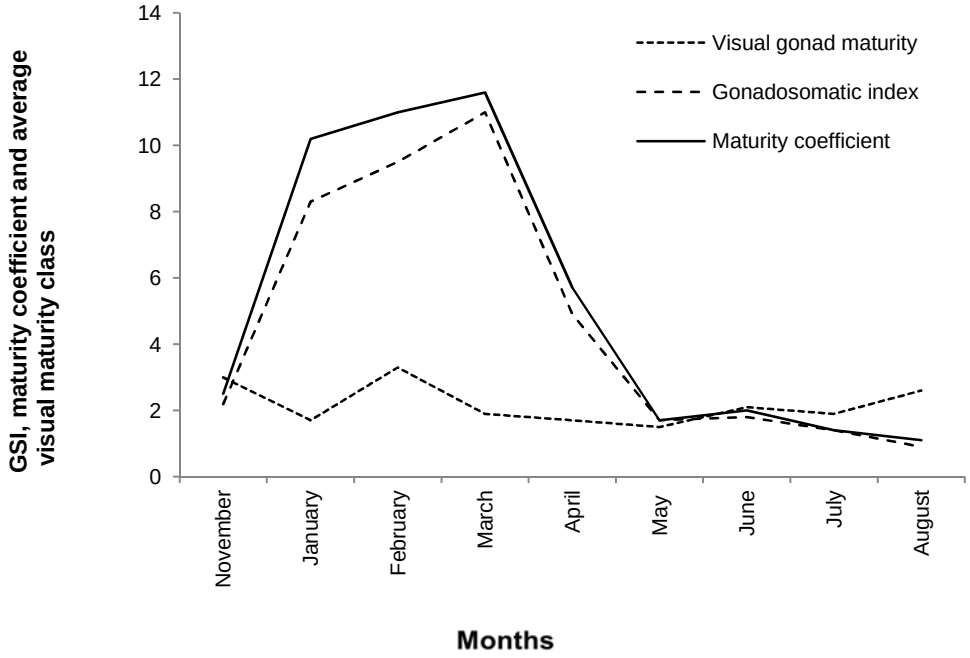

Figure 3.33: The GSI and Maturity Coefficient scores and gonad maturity class, as visually observed, of female *Schilbe intermedius* sampled during surveys conducted from November 2009 to August 2010 in Lake Nandoni.

Table 3.11 shows the average GSI in each of six fork length classes for the three months with the highest GSI averages observed namely January, February and March. The specimens in the 261 to 280 mm fork length class show the highest overall GSI values for the three months. This class has the highest GSI value for the months of February and March, suggesting that fish within this class are the ones which are ready to breed.

Table 3.11: Average GSI of female *Schilbe intermedius* in six fork length classes collected in Lake Nandoni for the months with the highest GSI. (N= no specimens in the fork length class were evaluated).

	Fork length class (mm)					
Month	**221-240**	**241-260**	**261-280**	**281-300**	**301-320**	**321-340**
January	N	8.3	6.8	5.5	7.9	N
February	8.0	N	10.4	9.3	8.1	N
March	N	11.5	12.1	10.8	N	11.0

iii) Oocyte stages and size.

Oocyte diameters ranged from a minimum of 0.0625 mm to a maximum of 1.250 mm. In oocytes smaller than 0.5 mm in diameter, the pre-vitellogenic oocytes (de Villiers 1991), there was no evidence of yolk formation and the nucleus was still clearly visible. These oocytes were referred to as the "primary development oocytes". The ooplasm of oocytes with diameters between 0.5 and 0.75 mm appeared grainy as a result of yolk formation and oocytes with a diameter larger than 0.75 mm were fully yolked with no visible nucleus. These oocytes are referred "maturing" and "matured" oocytes respectively. Figure 3.34 shows the percentage distribution of oocyte diameters sizes, when grouped into the three maturity classes in the six fork length classes of largest specimens of *S. intermedius*. Primary development oocytes were present in all the classes with specimens in the 221-240 mm fork length class having the highest percentage. As the fork length class increased, there was also an increase in the percentage of maturing and mature oocytes. The exception is the 301-320 mm fork length class. Specimens in the 321-340 mm fork length class have the highest percentage of large oocytes. This suggests that the ova of larger fish contain higher numbers of oocytes which are ready for fertilization.

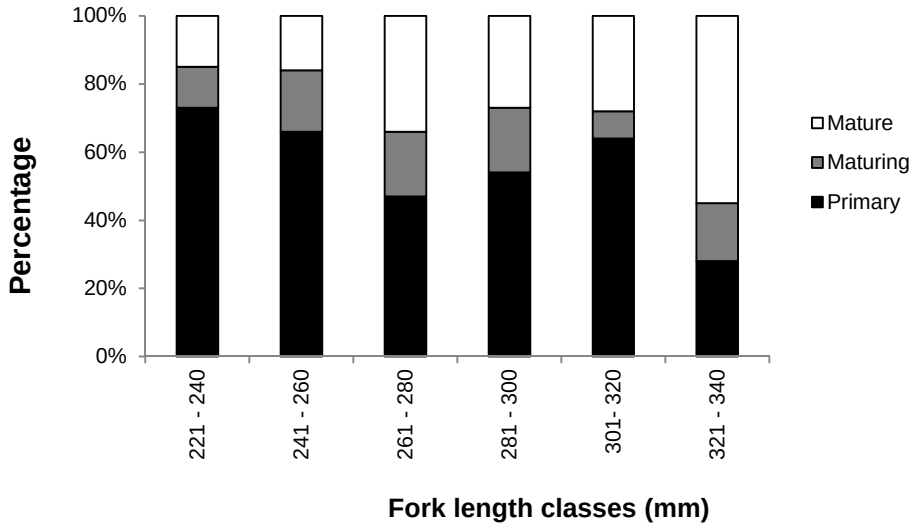

Figure 3.34: Percentage distribution within the three classes of oocytes development observed in female *Schilbe intermedius* specimens.

iv) The number of oocytes and fecundity.

Table 3.12 shows the number of mature oocytes counted in 14 female specimens with fork lengths longer than 250 mm collected in the two months, February and March, during which the average GSI values peaked as shown in Table 3.11. According to Table 3.12 the fecundity ranged from 2224 to 9078 mature oocytes with an average in excess of 5000 mature oocytes.

The average relative fecundity of the fish was found to be 20.3 mature oocytes per gram of body mass (Table 3.12) and when the number of mature oocytes and relative fecundity of similar sized females collected in April 2010 is calculated the average number of mature oocytes is only 531 and the average relative fecundity decreases to 2 (Table 3.13).

Table 3.12: The number of mature oocytes and the relative fecundity of *Schilbe intermedius* females with fork lengths in excess of 250 mm collected in February and March 2010 in Lake Nandoni.

	Oocyte sizes (mm)						
Fish mass (g)	**to .875**	**to 1.00**	**to 1.125**	**to 1.250**	**Mature oocytes as a percentage of total oocytes**	**Number of mature oocytes**	**Relative fecundity**
217.6	11	11	6	0	52	4297	19.7
194.0	17	12	4	0	61	5886	30.3
206.3	6	10	4	1	40	5143	24.9
219.0	1	8	25	3	64	4595	21
229.4	4	22	3	0	54	4563	19.9
233.0	8	15	6	1	58	7542	32.4
235.1	12	23	10	3	89	2534	10.8
255.0	8	19	8	3	67	9078	35.6
284.6	8	12	7	5	56	3201	11.2
285.1	6	15	4	0	45	6168	21.6
289.8	10	20	12	1	84	2612	9
290.1	3	22	11	6	82	2224	7.7
306.1	12	20	2	1	61	2356	7.7
306.1	9	13	5	1	48	4576	15
319.8	6	20	9	2	71	5757	18
		Averages				**5038**	**20.3**

B) *Oreochromis mossambicus*

The sample size for this component of the report consisted of 51 female and 37 male specimens. Table 3.14 shows that the average fork lengths of females ranged from 163.5 to 329 mm and the mass from 82.5 to 655 g while the males ranged from a length of 237 to 285 mm and a mass from 220 to 445 g.

Table 3.13: Number of mature oocytes and relative fecundity of *Schilbe intermedius* females with fork lengths in excess of 250 mm collected in April 2010 in Lake Nandoni.

	Oocyte sizes (mm)						
Fish mass (g)	**0 to 0.875**	**to 1.00**	**to 1.125**	**to 1.250**	**Mature oocytes as a percentage of total oocytes**	**Number of mature oocytes**	**Relative fecundity**
258.1	2	8	8	2	39	433	2
271.8	17	19	2		72	535	2
273.8	4	13	9		47	790	3
299.9			3	2	9	78	0
303.8	7	15	9		57	937	3
324.2	5	5	7	2	36	1028	3
326.6	3	6	8	2	33	982	3
		Averages				**531**	**2**

Table 3.14: Monthly average length (mm) and mass (g) of male and female *Oreochromis mossambicus* collected in Lake Nandoni in the period November 2009 to December 2010.

	Males			Females		
Month	Number of fish	Average fork length (mm)	Average mass (g)	Number of fish	Average fork length (mm)	Average mass (g)
November 2009	3	259.0	304.5			
January 2010	7	254.0	326	5	276.5	455
February 2010	10	282.0	453.5	2	255	319.5
March 2010	5	237.0	220	1	274	401
April 2010	3	263.5	302	3	260.5	323
May 2010				4	163.5	82.5
June 2010				1	230	219
July 2010	4	248.5	356	2	284	475
August 2010	2	275.5	445.5	2	224.5	232
September 2010	8	276.5	427	8	277.5	437.5
October 2010	5	272.5	354.5	4	262	357
November 2010	2	251.0	319	2	247.5	301
December 2010	2	285.5	362	3	329	685

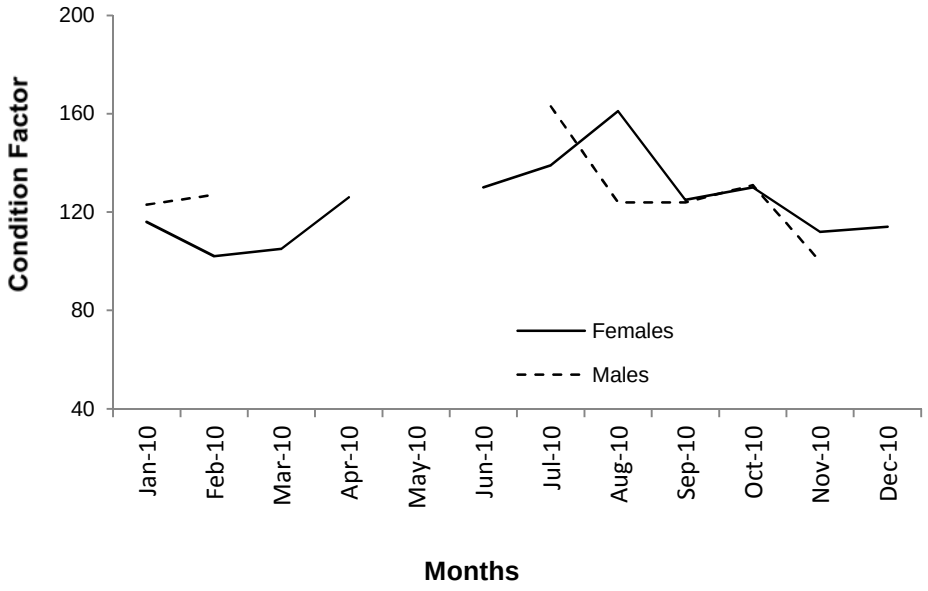

Figure 3.35: Average Condition Factor recorded for male and female *Oreochromis mossambicus* collected in Lake Nandoni in the period January to December 2010.

The calculated condition factors of females peaked in August and males in September and October. These peaks actually coincide quite well with the observed visually classified gonadal development classes shown in table 3.22. Mature oocytes were observed during the months January and February and again from August to October.

Table 3.15: The observed visual gonadal maturity classes expressed as a percentage of Oreochromis *mossambicus* collected in Lake Nandoni in the period November 2009 to December 2010.

Gonad maturity class	Nov. 2009	Jan. 2010	Feb. 2010	Mar. 2010	Apr. 2010	Jul. 2010	Aug. 2010	Sept. 2010	Oct. 2010	Nov. 2010	Dec. 2010
Developing					67					50	
Maturing		43		100	33	100		50	20		50
Mature		57	50				100	50	80		50
Spent	100		50								

The laboratory analysis of gonadal development shows that the average gonadosomatic index (GSI) scores of female *O. mossambicus* reached a peak in January 2010 and rapidly decreased towards March and again peaked in August followed by a distinct decline in September (Figure 3.36). The same pattern was observed in the average monthly maturity coefficient.

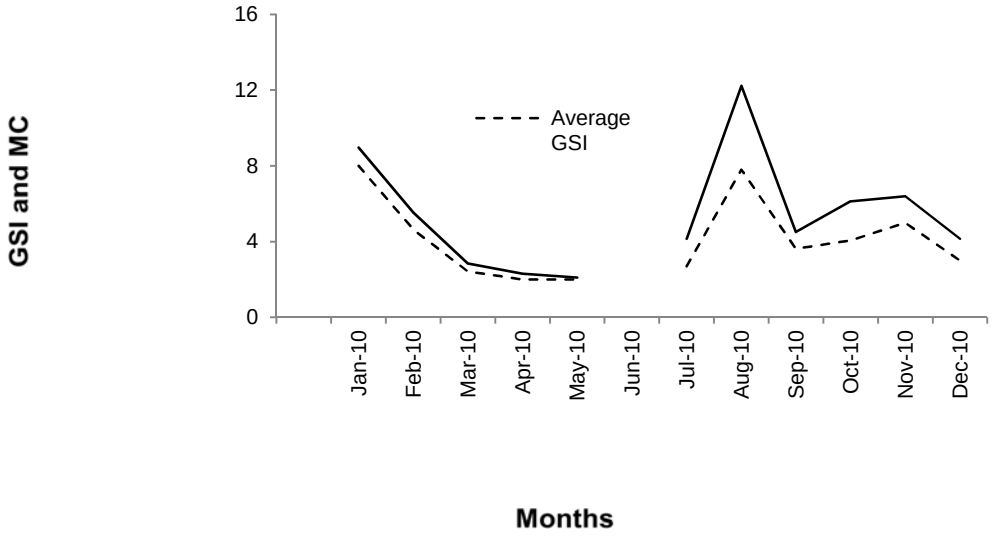

Figure 3.36: The average gonadosomatic index (GSI) and Maturity Coefficient (MC) scores of female *Oreochromis mossambicus* collected in Lake Nandoni in the period November 2009 to December 2010

Oocyte size and fecundity

The oocyte diameter of *O. mossambicus* ranged from a minimum of 0.0633 mm to a maximum of 3.9 mm. Table 3.16 shows the monthly averages of total number of counted oocytes as well as the fecundity and relative fecundity of female *O. mossambicus.*

Table 3.16: Average total number of oocytes, average fecundity and average relative fecundity of female *Oreochromis mossambicus* collected in Lake Nandoni in the period November 2009 to December 2010.

Month	Average of total number of oocytes	Average fecundity (Based on maturing and mature oocytes)	Average relative fecundity
November 2009	328722	2864	8.8
January 2010	69703	2930	11
February 2010	57870	1918	5
March 2010	6763	3578	11
April 2010	13354	3895	13.6
July 2010	12033	2667	9
August 2010	6979	644	1.4
September 2010	12239	1652	4
October 2010	21559	1217	3
November 2010	20943	1206	4.8
December 2010	46026	4165	1.5
Average	54199.18	2430.55	6.65

C) *Labeobarbus marequensis*

Table 3.17 shows that only 23 specimens of *L. marequensis* formed part of this investigation with the fork lengths of females ranging from 300 to 315 mm and males ranged from 164 to 320 mm. Because of the small sample size Figure 3.37 does not provide conclusive results regarding the condition factor but does show that the condition factor of both females and males increased towards the later part of the year from June onwards. Although table 3.18 shows that all the gonads observed in January and August were classified as mature, indicating that spawning could occur in the following months, cognizance of the small number of specimens should be taken. In addition it should also be noted that all the investigated gonads in November were classified as spent, indicating that a spawning event had taken place in the preceding months. That being said, the indication is that the spawning events and their timing concurs with findings of Fouché (2009) who showed that spawning occurs in September in the Luvuvhu River.

Table 3.17: Average fork length (mm) and mass (g) of *Labeobarbus marequensis* collected in the Lake Nandoni in the period November 2009 to December 2010.

	Females			Males		
Month	Number of specimens	Average Fork length (mm)	Average Mass (g)	Number of specimens	Average Fork length (mm)	Average Mass (g)
Nov-09	1	300	502	3	234.5	282
Jan-10	1	352	723	6	301.5	586.5
May-10	2	372.5	1358	2	283.5	417
Jun-10	2	388	1195	1	310	631
Aug-10	2	352.5	1089	3	334	682.5

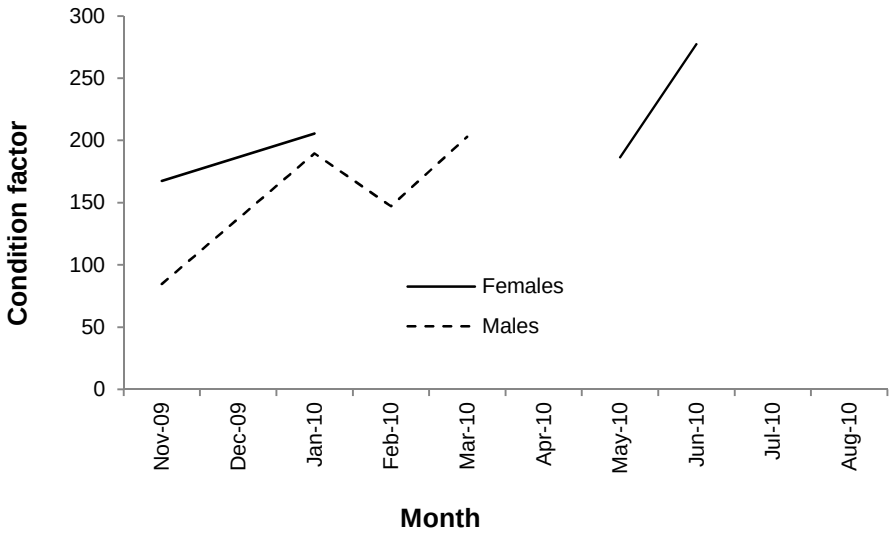

Figure 3.37: Average monthly condition factor of male and female *Labeobarbus marequensis* collected in Lake Nandoni in the period November 2009 to December 2010.

Table 3.18: The observed gonadal maturity classes expressed as a percentage of Labeobarbus *marequensis* collected in the Lake Nandoni in the period November 2009 to December 2010.

Gonad maturity class	Nov. 2009	Jan. 2010	May. 2010	Jun. 2010	Aug. 2010
Developing			50	50	
Maturing			50	50	
Mature		100			100
Spent	100				

3.4.4.2 Feeding biology

Introduction

As stated earlier in this report the sustainability of a fishery depends on the management of the impoundment which in turn hinges on aspects such as knowledge of the biology of the organisms occupying the resource (Weyl et al*.,* 2007) and feeding is an important aspect. Analyses of the stomach contents can be used to establish what the fish feed on for survival and their adaptation to the environment. This will also provide information on the fish life history with regards to their diet and the role it plays in different species.

Five species were selected for this component of the study. This consisted of the three dominant species, namely *S. intermedius, O. mossambicus* and *L. marequensis, and Marcusenius macrolepidotus* also occur in the dam and form part of the catch of local fishermen as well as *Tilapia rendalli* which form a large component of the fish diversity in the littoral sites.

Based on the changed habitat resulting because of the construction of Nandoni Dam a question regarding the diet of these species arose. It was hypothesized that the diets or food preference of the

species found in the impoundment is different from what is observed in their natural habitats and that they have adapted to their new environment. The aims of this study were to determine the diets and food preference of *S. intermedius*, *L. marequensis*, *O*. *mossambicus T. rendalli* and *M. macrolepidotus* through an investigation of their stomach content.

Materials and methods

Fish specimens collected, identified, weighed and measured at the limnetic and littoral sites were used. Each specimen was dissected open at the field laboratory to expose the viscera and the intestines were then removed. The stomach or pseudogaster of each specimen was removed and placed in a vial, supplied with a label with the species name and date of collection and preserved in 10% formalin.

In the laboratory the preserved stomachs were held up against a strong light source to visually estimate and classify the stomach fullness as empty, less than ¼, ¼, ½, ¾, or completely full (Bowen, 1976). Where size permitted the volume of the contents was determined using the water displacement method described by Göldner (1964). In this method the stomach and the contents were placed in a measuring cylinder that was filled to capacity, the displaced water collected and the volume determined.

Each stomach was dissected open, the contents removed and preserved in 4% formalin for stomach content analyses. When the stomach contents was analysed the excess formalin was drained from the stomach contents after which the stomach content was decanted onto a counting chamber. The counting chamber consisted of a Petri dish with a transparent grid of 1 mm^2 squares attached to the exterior surface of the Petri dish floor (Gaigher, 1976). The contents were then viewed at 10 and 30 X magnification using a Kyowa dissecting microscope. Where possible individual food items were identified to the lowest taxon (Marriott et al., 1997) and divided into predetermined taxonomic groups (Gaigher and Fourie, 1984). When necessary, a Nikon light microscope was used to identify microscopic food particles at a 100 X magnification.

The percentage by volume of food items was estimated by counting the number of grid blocks covered by the food item and expressing this as a percentage of the total number of blocks covered by the sample (Marriott et al., 1997). As suggested by Charalambos and Economidis (1989) the percentage frequency of occurrence and percentage contribution of each component to the content was calculated. To determine the percentage frequency of occurrence of each component the individual food items were sorted and the number of the stomachs in which it occurred was expressed as a percentage of the total number of stomachs of the specific species investigated (Gaigher, 1969; Windell, 1971). Where prey items could be identified an adapted format of the Index of Relative Importance (IRI) proposed in Marriot et al. (1997) was calculated for each prey item according to the proposed method of Hyslop in Marriott et al. (1997) using the formula:

$$IRI = \frac{(\%N + \%V) \times (\%\ FO)}{100}$$

Where: % N is the number of individuals of each prey item expressed as a percentage of the total number of prey items observed in a specific stomach,

% V is the visual estimates of percentage volume and

% FO is the percentage frequency of occurrence or in other words in how many stomachs it occurs.

Results

The stomach content of 130 specimens were analysed and Appendix 3.4 shows numbers and size distribution of each of the five species from which these stomachs originated. *Schilbe intermedius* was the most numerous, contributing 69.2% of the total number, followed by *O. mossambicus, T. rendalli, L. marequensis* and *M. macrolepidotus* at 11.5%, 7.7%, 6.2% and 5.4% respectively. Specimen body lengths of *S. intermedius* ranged from 113 to 410 mm and Appendix 3.4 shows that with the exception of *T. rendalli,* all the specimens of the other species were longer than 170 mm. Of stomachs that was investigated 90% contained food but the amount of food in the stomachs varied and Table 3.19 shows the estimated stomach fullness of the different fish species.

Table 3.20 shows the measured volume of food in the stomachs determined by the water displacement method. On average the largest stomach content volumes were observed in *S. intermedius* and *L. marequensis* while the smallest volumes were observed in *T. rendalli.*

Table 3.19: The estimated stomach fullness of the stomachs containing food of fish collected in Lake Nandoni.

Species	Number	Estimated stomach fullness				
		Empty	¼	½	¾	Full
Oreochromis mossambicus	15	6	4	0	0	5
Labeobarbus marequensis	8	3	1	0	0	4
Schilbe intermedius	90	3	5	7	10	65
Tilapia rendalli	10	1		1	1	7
Marcusenius macrolepidotus	7	0	0	0	0	7

Table 3.20: Measured volume of the stomach contents of fish species collected in Lake Nandoni (SD = standard deviation).

Species	Stomach volume (mL)			
	Number	Min	Max	Average (SD)
Oreochromis mossambicus	15	0.1	3.3	1.09 (1.13)
Labeobarbus marequensis	8	0.2	4.9	1.71 (1.64)
Schilbe intermedius	90	0.2	9.8	1.77 (1.73)
Tilapia rendalli	10	0.3	1.5	0.89 (0.35)
Marcusenius macrolepidotus	7	0.9	3.2	2.06 (0.92)

The composition of the stomach contents is shown in appendix 3.5. The lowest diversity was observed in the stomachs of *L. marequensis* where only algae were found in the stomachs. From these results it would appear that although both *S. intermedius* and *M. macrolepidotis* are carnivorous the stomach contents of the latter species contained organisms, such as the annelids, that are benthic in origin. None of these benthic organisms were observed in the stomach contents of *S. intermedius.*

In order to calculate the food preference of the species the percentage frequency of occurrence of each food item, as suggested by Charalambos and Economidis (1989), was calculated and these results are shown in Figure 3.38. Because the stomach contents of *L. marequensis* showed no variety at all the frequency of occurrence was not calculated. The Index of Relative Importance (IRI) scores shown in Table 3.21 is noteworthy as it combines the data reported in the previous tables and underpins the findings already stated. Although these findings clearly show that *O. mossambicus* is an algivore and *T. rendalli* a herbivore it is the composition of the diets, and in particular the higher IRI values, of the two insectivores that should be noted. Because of the large sample size of *S. intermedius* it allowed further investigation of the stomach contents of the different size classes. Appendix 3.6 shows that as the fish increased in size the variety of food items not only increased but the variation in contents changed.

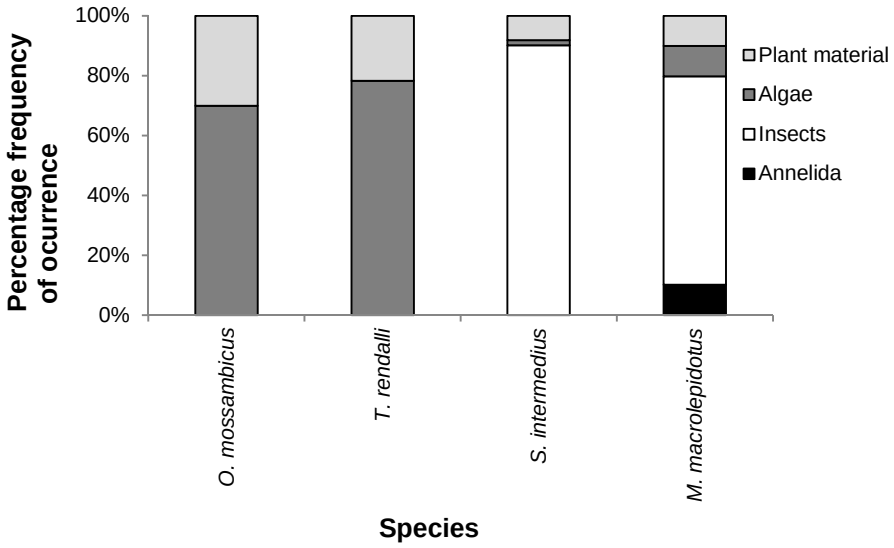

Figure 3.38: The percentage frequency of occurrence of the food item groups observed in the stomach contents of four selected fish species in Lake Nandoni.

Discussion

Basic life processes of an organism such as growth, development and reproduction, all take place at the expense of the energy which enters the organism in the form of food (Nikolsky, 1963). This makes feeding one of the most important aspects of an organism. Fish feed on a variety of food sources using different strategies ranging from sieving phytoplankton, grazing algae to preying on insects and even other fish (Eccles, 1986). In addition, the size and the systematic position of the food that organisms consume are extremely variable and the range in fish is greater than for other groups of vertebrates (Nikolsky, 1963). Aquatic insects and other benthic invertebrates are stable food sources and are consumed by virtually all South African fish species at least during certain stages of their lives or times of the year (Eccles, 1986). Species are adapted to feeding on a particular food source using its sensory organs to seek out the food, the buccal cavity to seize it and the intestines to digest it. Often, the adaptation to feeding on a particular diet does not remain constant throughout the life of the fish and it changes as the fish grows (Nikolsky, 1963). Fish can be classified according to the food they consume and the following feeding groups are often recognized: a) Euryphagic fish that feed on a variety of

foods, b) stenophagic fish that feed on a few different types of food and c) monophagic fish that feed on only a single type of food. Feeding behaviour is also a species specific characteristic, "which becomes formulated during its evolution" (Nikolsky, 1963).

Table 3.21: The Index of Relative Importance scores of food items in the stomachs of the four selected fish species occurring in Lake Nandoni. (Percentage volume: %V, percentage number: %N and percentage frequency of occurrence: %FO).

	Oreochromis mossambicus			***Tilapia redalli***			***Schilbe intermedius***			***Marcusenius macroplepidotis***		
Food item	**%V**	**% N**	**IRI**	**%V**	**%N**	**IRI**	**%V**	**%N**	**IRI**	**%V**	**%N**	**IRI**
Algae	55.9	80.0	72.5	23.8	32.0	50.2	0.3	0.2	0.0	1.4	1.6	1.3
Insects												
Coleoptera							1.4	1.2	0.1			
Ceratopogonidae										0.8	1.6	1.1
Chaoboridae (larvae)				0.8	1.1	0.4	28.4	36.6	41.9	14.1	18.4	27.8
Chaoboridae (pupae)							2.0	3.6	0.8			
Chironomidae										10.5	14.1	21.1
Baetidae							7.0	4.3	1.9			
Polymitarcyidae							31.1	32.5	30.4	10.1	7.0	9.8
Libelludae										4.7	1.1	0.8
Pyralidae							11.9	2.9	2.5			
Ecnomidae										2.5	4.9	3.2
Philopotamidae										11.8	13.0	24.8
Trichopera(pupae)							2.4	1.1	0.2	22.8	9.2	22.9
Diptera							2.3	4.7	0.9			
Formicidae							0.5	0.8	0.1			
Orthoptera							5.4	4.0	1.0			
Crustacea	3.5	2.3	0.8									
Mollusca				10.5	10.1	4.1						
Hirudinia										5.8	3.8	2.7
Oligochaeta										0.9	3.8	2.0
Fish							1.0	0.8	0.0			
Araneae							0.1	0.1	0.0			
Plant material	4.9	3.1	2.5	48.4	50.6	89.0	5.8	6.2	2.1	6.6	8.6	8.7
Seeds										0.1	0.5	0.1
Unidentifiable material				4.5	0.6	0.5						

According to Skelton (2001) *S. intermedius* feeds on a wide variety of food including fish, insects, shrimps, snails, plant seeds and fruit (Skelton, 2001; Nicolaai, 2009). On the other hand *O. mossambicus* is an omnivore that feeds on algae and detritus, but larger individuals have been found to take insects and other invertebrates (Skelton, 2001). However, Bowen (1979) and Bruton and Bollt (1975) found diatoms to play an important role in the nutrition of the species. De Silva et al. (1984) found that *O. mossambicus* populations in different lakes differed markedly with regard to their diets, ranging from almost exclusively detritivorous, to primarily herbivorous and even primarily carnivorous. *L. marequensis* is regarded as omnivorous (Crass, 1964; Pienaar, 1978; Skelton, 2001) list a wide variety of food items in their diets which include algae, plant detritus, aquatic insect larvae, small fish, snails, freshwater mussels, beetles and ants. Fouché (2009) however, found that the primary food source is algae. *Marcusenius macrolepidotus* is classified as insectivorous and feeds on a wide range of benthic invertebrates, especially midge and mayfly larvae as well as pupae taken from the bottom and off plant stems from the bottom or on vegetation (Skelton, 2001). *Tilapia rendalli* feed mainly on

water plants and algae but are also known to take aquatic invertebrates and even small fish (Skelton, 2001).

3.4.3 Fish productivity

3.4.3.1 Catch per unit effort

Catch per unit effort (CPUE) is calculated as the number or biomass of fish collected by a net or set of nets during a period of time. Traditionally nets are set overnight and the CPUE is reported as the catch (number or biomass) per net length per night (Richardson et al., 2009; Ellender et al., 2010). However in this project the time the net was set and the time the fish removed was recorded and the CPUE is reported as mass net^{-1} $hour^{-1}$.

Materials and methods

For this report the CPUE was calculated for the three dominant species and for the whole fleet of nets. For the final report the CPUE for each mesh size will be calculated.

Results

Figure 3.39 shows the results obtained over the period September 2009 to December 2010 and although there were periodical increases in the numbers, such as *O. mossambicus* in February and September 2010 and *S. intermedius* in April and November 2010 a general decrease in the CPUE was observed during the survey period.

3.4.3.2 Net selectivity

With regard to net selectivity the results (Table 3.22) show distinct differences between the three dominant species. In the nets with smaller mesh sizes, ranging from 28 to 73 mm the catches were dominated by *S. intermedius* while in nets with larger mesh sizes that ranged from 73 to 118 mm the dominant species was *O. mossambicus*. *Labeobarbus marequensis* did not dominate in any of the mesh sizes but formed a large proportion of the catch in the 118 mm mesh size.

Figures 3.37 to 3.39 show that in all three dominant species the length frequency distribution shifts towards the right with increasing mesh size. The distribution of length groups in the 28 mm, in the case of *S. intermedius*, and 45 mm mesh in the cases of the other two species is distinctly polymodal. This in particular evident in the case of *O. mossambicus* in the 45 mm mesh. In the case of the other mesh size the length groups approximate a normal distribution. It is important to note that there are overlaps in the dominant lengths of *S. intermedius* in the two smaller mesh sizes and again in the two larger net sizes. To an extent that applies to *L. marequensis* with regard to the 48 and 73 mm mesh size. The distinct lack of lack of overlap in the case of *O. mossambicus* in the 73, 93 and 118 mm mesh size should be noted as this is the species preferred by local fishers.

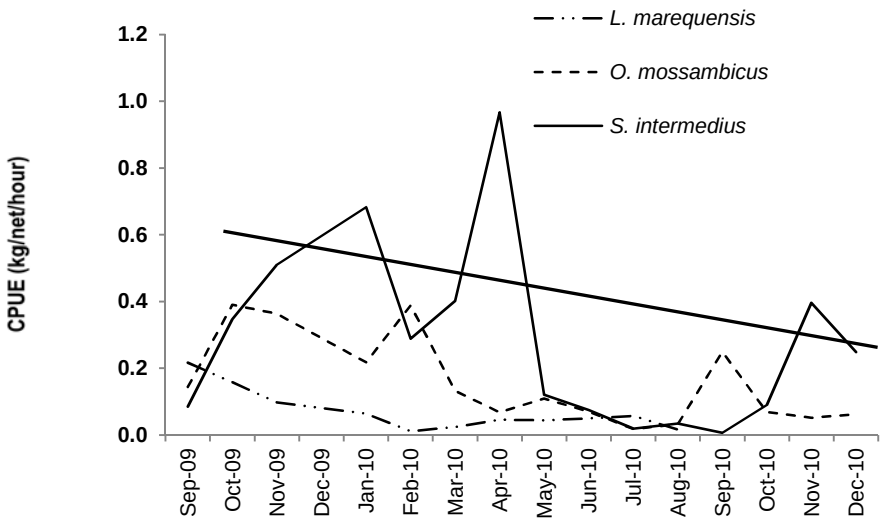

Figure 3.39: Mean monthly catch per unit effort (CPUE) for the three dominant species collected in Lake Nandoni during the period September 2009 to December 2010. The decrease in CPUE is illustrated by solid trend line.

Table 3.22: The percentage catches per species in the 25, 45 mm, 73, 93 and 118 mm gill nets used at sites 2, 3, 4 and 5 in Lake Nandoni during the period September 2009 and December 2010.

	Stretched mesh size (mm)				
Species	**28**	**45**	**73**	**93**	**118**
Barbus trimaculatus	7.64				
Barbus viviparus	13.19				
Clarias gariepinus			0.31	2.33	18.97
Labeobarbus marequensis	0.69	0.85	5.99	7.64	17.24
Labeo cylindricus	0.69	0.57			
Labeo molybdinus		0.34			
Marcusenius macrolepidotus	2.08	1.25			
Micropterus salmoides	0.69	0.51		0.66	3.45
Oreochromis mossambicus		0.40	41.94	86.38	58.62
Schilbe intermedius	74.31	96.01	50.08		1.72
Synodontis zambezensis			0.15		
Tilapia rendalli		0.06	1.54	2.99	

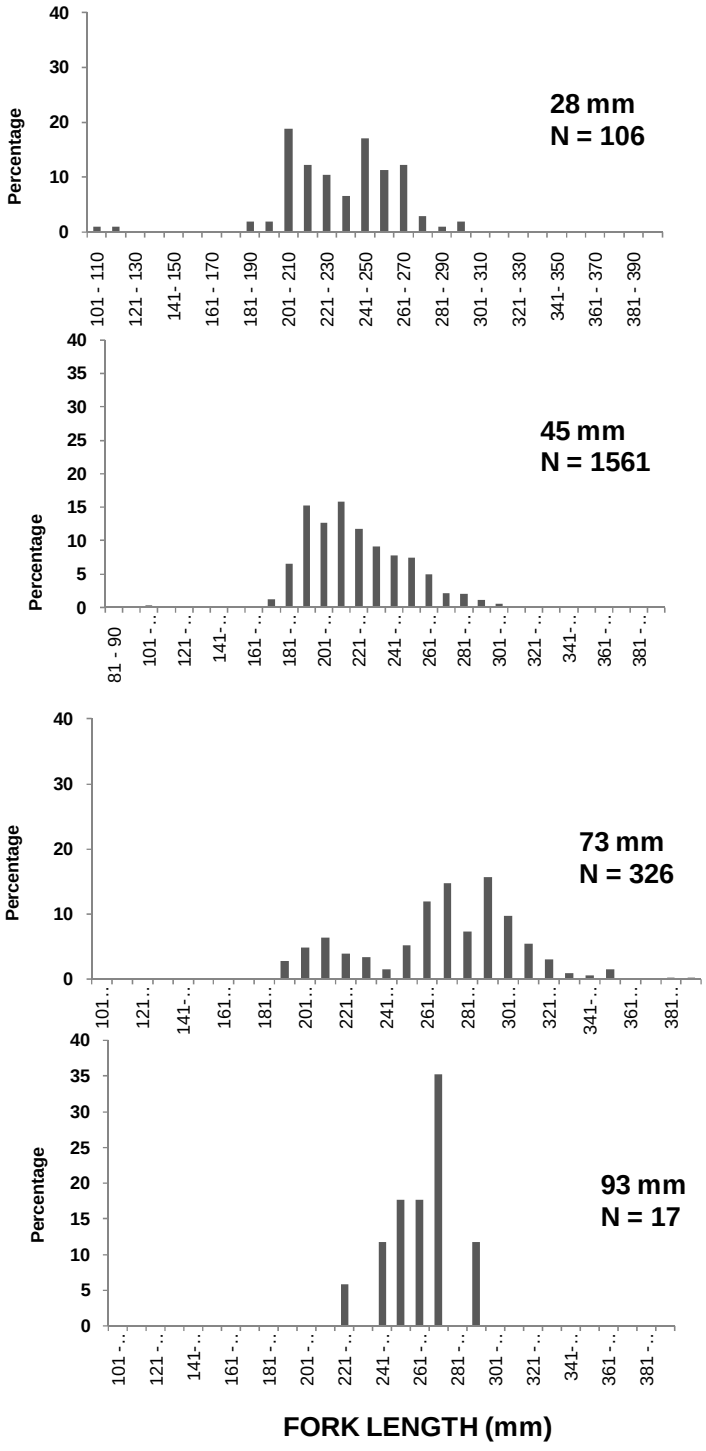

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Figure 3.40: Percentage length frequency distribution of *Schilbe. intermedius* sampled from Lake Nandoni at sites 2, 3, 4 and 5 during the period September 2009 to December 2010.

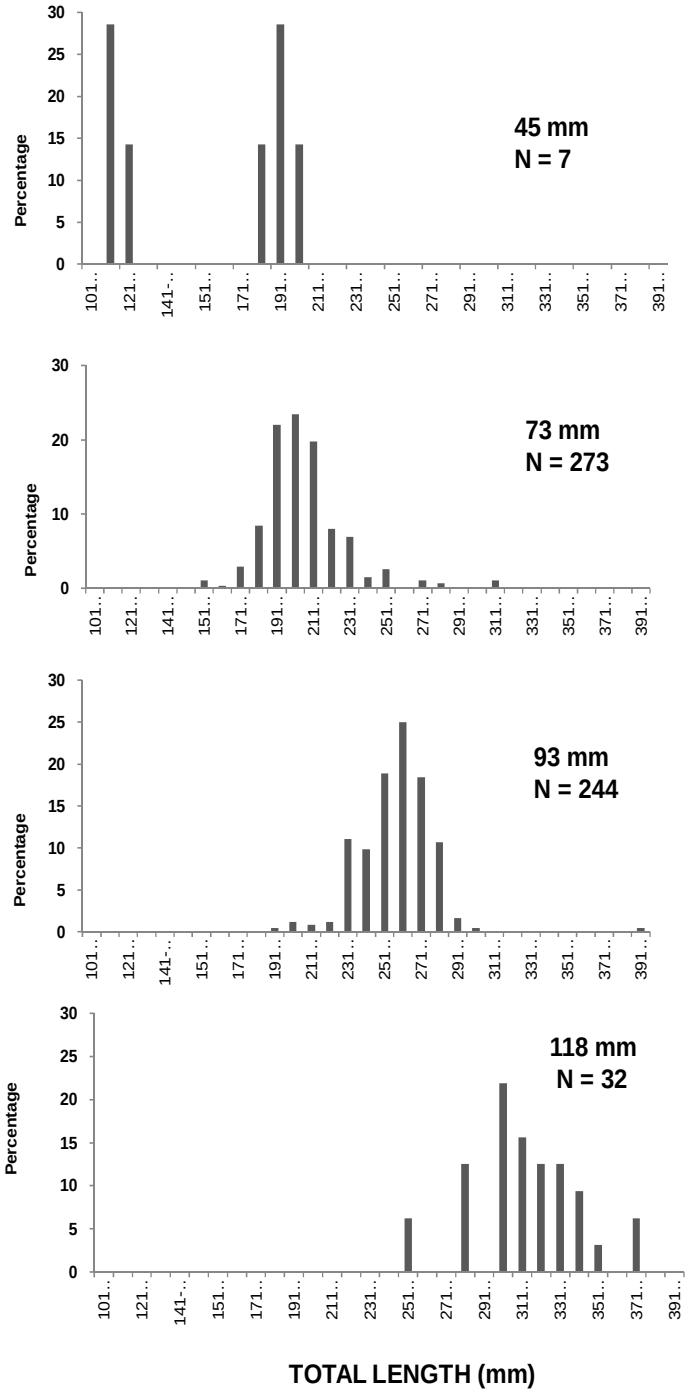

Figure 3.41: Percentage length frequency distribution of *Oreochromis mossambicus* sampled from Lake Nandoni at sites 2, 3, 4 and 5 during the period September 2009 to December 2010.

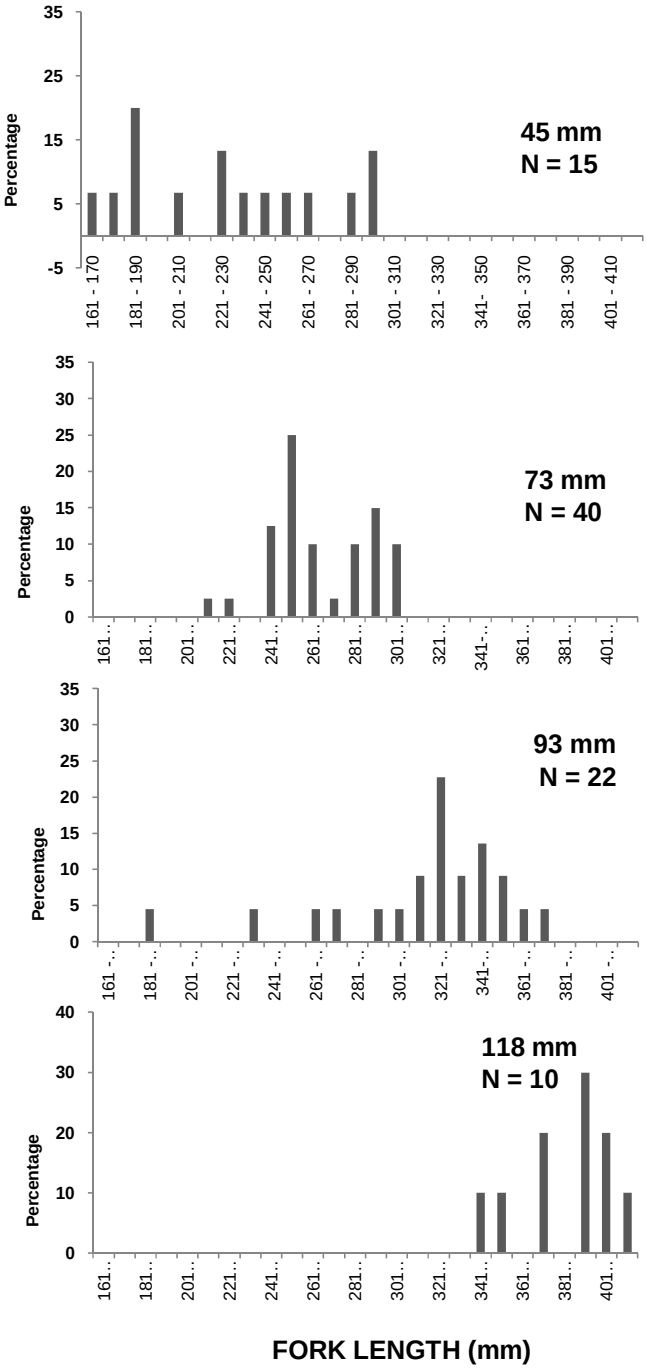

Figure 3.42: Percentage length frequency distribution of *Labeobarbus marequensis* sampled from Lake Nandoni at sites 2, 3, 4 and 5 during the period September 2009 to December 2010.

3.4.3.3 Potential yield

Materials and methods

Various morpho-edaphic models are used to determine potential productivity of fish resources with the models of Ryder (1982) and Schlesinger and Regier (1982) being used the most often. In addition Marshall and Maes (1994) used an adapted model to suit smaller freshwater impoundments. Ryder (1982) first calculated the morpho-edaphic index (MEI) as MEI = EC/AD where EC is conductivity (μScm^{-1}) and AD is average depth (m). The yield (Y) in kg ha^{-1} y^{-1} was then calculated using the formula $Y = 14.3136 *(MEI)^{0.4681.}$ Marshall and Maes (1994) adapted this model and calculated yield as $Y = 23.231 \times (EC/AD)^{0.447}$. Richardson et al. (2009) in turn used the temperature adapted MEI model of Schlesinger and Regier (1982) where Y is calculated using the formula $Y = 10.^{044T + 0.482log10\ TDS/AD + 0.021}$ where TDS is the total dissolved solids (mgL^{-1}) and T the average temperature (^{o}C). For comparative reasons all three models was used to estimate the potential yield. In order to calculate the potential yield the mean electrical conductivity, total dissolved solids and temperature as well as standard deviation was calculated and these results are shown in Appendix 3.7.

Results

The estimated potential yield (Table 3.23) ranged between 26.5 and 87.8 kg ha^{-1} y^{-1} and to remain precautionary the lower, but conservative, estimate of 26, 5 kg ha^{-1} y^{-1} as per the method of Schlesinger and Regier (1982) is regarded as more appropriate. It should be noted that the yield is higher than the 36 kg ha^{-1} y^{-1} of Tzaneen Dam as calculated by Nicolaai (2009).

Table 3.23: Calculated potential yield of Lake Nandoni, based on the mean physico- chemical parameters.

Morpho-edaphic model applied	Potential yield (kg ha^{-1} y^{-1})
Ryder (1965) as used by Nicolaai (2008)	57.4
Marshall and Maes (1994)	87.8
Schlesinger and Regier (1982)	26.5

Discussion

The data generated in this section of the report is important when management plans have to be developed for Lake Nandoni. This refers not only to the amount of fish that can be harvested but also to the net sizes that should be used in such operations. Both Table 3.22 and Figure 3.41 show that with regard to *O. mossambicus,* which is regarded as the preferred catch of local fishermen, the use of nets with stretched mesh sizes of 73 and 93 mm will successfully harvest the most abundant size group of the species while at the same time smaller specimens and specimens in excess of 300 mm, which can be regarded as the most productive cohort, will not be trapped. This will allow smaller specimens to grow up while the larger specimens can contribute reproductively. Although lower numbers of L. marequensis is present and they do not form part of the preferred angling species similar mesh sizes will target the young reproductive females in particular (Fouche 2009) and the species could be under threat. In the case of this species it should be considered to use mesh sizes larger than 118 mm.

3.5 Fish health and fish parasites

3.5.1 Introduction

Several approaches can be followed to monitor contaminants in aquatic ecosystems. Chemical analysis and measuring physical variables of water give very accurate measures of the amounts of individual substances in the water, but are expensive and only accurate at the time of sampling. Biological monitoring, on the other hand, provides a 'bigger picture' of both the past and the present conditions in an aquatic ecosystem. This is because the organisms that are living in the ecosystem must have been able to survive whatever conditions the system has been subjected to in the recent past (Davies and Day, 1998) and the integrity or health of the biota provides a direct and integrated measure of the health of the ecosystem as a whole.

Organisms in aquatic environments are considered biologically sensitive and respond to changes that occur in the water. The biotic integrity of an ecological system is therefore reflected in the health of its fauna. Changes occurring in fish populations due to chemical stress are manifestations of biochemical, histological and physical alterations, and can give a relatively rapid indication of how environmental conditions affect fish populations. Fish health (with accurate histopathological assessments) may thus reflect, and give a good indication of the health status of a specific aquatic ecosystem (Van Dyk et al., 2009). To manage healthy fish populations, it is necessary to identify early warning signs of damage on cellular level, before physiological and behavioral processes are affected (Van Dyk, 2003).

The Health Assessment Index (HAI), used in biological monitoring during this study, was developed in the United States of America as a necropsy-based condition assessment by Goede and Barton (1990) and was further quantified by Adams et al. (1993). This approach is based on the assumption that if fishes are in a good condition (physiologically), the vital organs and other easily observed body structures will also be in a good condition. The fish that have been exposed to various environmental stressors for extended periods of time will have changes in organ appearances and morphology, or blood chemistry. Thus, deviations from normal are generally considered indicative of some type of existing or developing problem within the population (Adams et al., 1993).

The HAI was introduced and tested in South Africa in the Olifants River (Avenant-Oldewage *et al*., 1995), the Vaal River System (Crafford, 2000; Groenewald, 2000; Bertasso, 2004; Crafford and Avenant-Oldewage, 2009), the lower reaches of the Ga-Selati River (Jooste et al., 2004), a comparable study between two industrial and two mine sites at Phalaborwa (Ramollo, 2008) and in the Limpopo and Olifants River systems (Madanire-Moyo et al., 2012b). The HAI is a quantitative index that allows statistical comparison between different water bodies and it gives a rapid indication of the health status of a selected environment. This method is based on scores, with higher scores indicating the more polluted sites and lower scores the less polluted sites (Avenant-Oldewage, 2004). Although the exact cause of pollution cannot be assessed, the HAI is useful in assessing first level problems in the health profile of fishes (Heath et al., 2004).

The HAI is thus based on the assumption that the normal appearance of internal vital organs, blood parameters and external aspects indicate that a fish population is in equilibrium with its environment. Any unnaturally high concentration of contaminants in an aquatic ecosystem may pose a direct threat to the health of fish by disrupting important metabolic pathways. Together with changes at a chemical and biochemical level, structural changes will also occur that may significantly transform the normal functioning of a particular tissue type or an organ (Roberts, 2001). Schmidt-Posthaus et al. (2001) recorded degenerative and inflammatory reactions in several organs especially the gills, liver and kidney of fish exposed to polluted water and concluded that there will be clear indications, and even visible signs, in fishes if they have been challenged by an unacceptable environment.

It is therefore clear that the water quality of an ecosystem has an effect on the organisms living in it. Organisms living in water over an extended period provide a more sensitive and reliable measure of the biological suitability of conditions than do physical and chemical measurements. Monitoring of the biota is therefore a sensitive and sensible way of determining the effects of pollutants, especially the effects of chronic (continuous, low-level) exposure.

Fish parasites

Parasites are organisms that live in close association with another organism (the host). Most fishes in an aquatic ecosystem have of a range of ecto- and endoparasites, and the parasites form an integral part of the ecosystem. Parasites usually exist in equilibrium with their hosts as a survival strategy. But, in instances where the hosts are overcrowded or stressed, parasitic diseases can spread very rapidly with high pathogenisity and may cause gross mortalities while threatening abundance and diversity of indigenous fish species. This is usually not the case in their natural environment, unless the aquatic system is disturbed by human interference, e.g. pollution, which can alter the natural distribution of parasite communities and infracommunities (Bush et al., 2001).

Parasites may affect host biology in numerous ways, be it behaviourally, physiologically, morphologically or reproductively (Marcogliese, 2004). Oldewage (1985) reported that increased infestation rates could result from environmental conditions, predation and emaciation as a result of insufficient food, causing a decline in physiological proficiency and thus also of immunological tolerance. Paperna (1996) referred to fish parasitology as an indispensable tool in aquatic health studies and a basic understanding of the biology of parasites as essential for instituting mechanism control.

Fish can serve as definitive (the host in which a parasite reaches sexual maturity and reproduce), intermediate or paratenic (transport) host in the life cycle of many species of protozoan and metazoan parasites. In intermediate hosts, the parasites may develop and reproduce asexually but does not reach sexual maturity while paratenic host are important or necessary for completion of the life cycle of the parasite. Some parasites (e.g. monogeneans) have direct life cycles, and do not need an intermediate host to complete their life cycle. These infections can spread directly from one fish to another by direct contact.

Parasites with an indirect life cycle have eggs or larvae that are excreted into the water and, during development, immature stages pass through at least two different types of organisms, one of which may be a fish. Parasites with indirect life cycles include the digeneans, nematodes, cestodes, acanthocephalans and pentastomids. The life cycles of some parasites are thus so complex, involving more than one intermediate host, including fish, that the study of all stages enables one to understand the dynamics of aquatic ecosystems as a whole (Hoffman, 1976).

The relationship between pollution and parasitism in fish, and the potential role of parasites as water quality indicators and as a bio-monitoring tool have received increasing attention during the last decade (Avenant-Oldewage, 1998; Crafford and Avenant-Oldewage, 2001; Sures, 2004; Jooste et al., 2005, Luus-Powell et al., 2005; Madanire-Moyo et al., 2012a). Fish parasites can be used as indicators of water quality, because of the variety of ways in which they respond to anthropogenic pollution. Pollution can increase parasitism if the host defense mechanisms are negatively affected, thereby increasing host susceptibility (Sures, 2006). Conversely, pollution can also decrease parasitism if the parasites are more susceptible to a particular pollutant than the host, or pollution levels eliminate the suitable intermediate host. The presence or absence of parasites can thus also reflect environmental conditions and possibly environmental health.

Ectoparasites, for instance, are more in direct contact with water; if they are sensitive to a pollutant, there will be less ectoparasites than endoparasites in a polluted ecosystem, while the converse is also true (Avenant-Oldewage, 2001). Endoparasitic infections may give an indication of the quality of the water since they generally increase in abundance and diversity in more polluted waters (Poulin, 1997; Avenant-Oldewage, 2001). On the other hand, parasites diversity seems to be affected by pollution with a decline in diversity in more polluted systems (depending on the type of pollution). Thus, the relative abundance of endoparasites and ectoparasites of fish in a particular aquatic ecosystem can be used as an indicator of environmental stress. Fish parasitology is therefore an indispensable tool in aquatic health studies and a basic understanding of the biology of the parasites is essential for the use of parasites as a biomonitoring tool and for instituting mechanisms of control.

Rather than only monitoring physical and chemical parameters in water, parasitic indicators could be more economical and sensitive monitors of environmental deterioration. Therefore, analysis of a host's parasites offers a reliable and economical indication of environmental health and provides valuable information about the health of the surrounding environments. When the HAI is thus supplemented by a Parasite Index (PI), the value of the HAI can only be enhanced.

In the original HAI of Adams et al. (1993), parasites were regarded as an indication of bad fish condition and therefore only their presence or absence was recorded. Marx (1996) and Luus-Powell (1997) conducted studies on the interrelationship between fish health and parasitism to determine whether endo- and ectoparasites should be used as separate entities in the HAI. Crafford (2000) assessed the use of four parasite indices, namely (a) the original Parasite Index (distinguishing between the presence and absence of parasites) by Adams et al. (1993), (b) Inserted Parasite Index

(distinguishing between the presence and absence of endo- and ectoparasites), (c) Refined Parasite Index (distinguishing between the number of endo- and ectoparasites and (d) the Inverted Parasite Index. Crafford and Avenant-Oldewage (2009) found that the Inverted parasite index (IPI) more accurately reflected the HAI values obtained in the Vaal Dam and Vaal Barrage. For this reason, the evaluation of endo- and ectoparasites was successfully incorporated in the HAI.

According to Jooste et al. (2004), the PI is a useful bio-monitoring tool that gives a reliable indication of water quality. In addition, it is assumed that a count of 10 to 20 ectoparasites can be expected in good quality water, but the count will drop drastically to two, one or even zero if the water quality is poor. The Parasite Index was developed as a separate Index, but interpreted in conjunction with the HAI (Jooste et al., 2004; Luus-Powell et al., 2005). The PI used during this study differs slightly in the numerical scoring than the one used by Crafford and Avenant-Oldewage (2009). Only the PI was used during this study.

3.5.2 Materials and Methods

Field procedures

Collection and dissection of hosts

Surveys were undertaken at Nandoni Dam from September 2009 to June 2011 for health and parasitological work. Fish were selected for a detailed parasitic study and all deformities and anomalies were recorded using the HAI criteria (Table 3.23). Gill nets of different mesh sizes were used to collect the fish. The selected fish was kept in large holding tanks. Fish was placed on polypropylene dissecting boards, sacrificed by severing the spinal cord and dissected to examine all internal organs and tissues for the presence of parasites, as well as determining the HAI.

Health Assessment Index

One fish was selected at a time to determine the HAI and PI. Blood collection was done as quickly as possible before the fish dies. Blood was drawn and capillary tubes were filled with blood and plugged at one end using commercial Critoseal clay. The haematocrit value was read and recorded after centrifugation of capillary tubes for five minutes.

The fish was examined externally by using the revised HAI method (Heath et al., 2004; Jooste et al., 2004; Table 3.24) and recorded on a HAI data sheet. As mentioned earlier, fish was sacrificed prior to dissection by severing the spinal cord. The fish was dissected and all internal organs assessed with the help of a colour chart developed by Watson (2001) and values were assigned to each organ as indicated in the revised HAI table (Table 3.24).

Table 3.24: Fish health variables with assigned characters showing the norm and deviation from the norm in the necropsy-based system (adapted from Adams et al. 1993 and Jooste et al. 2004).

Variables	Variable condition	Original field designation	Substituted value for the HAI
External variables			
Length	Total length in millimetres	mm	-
Weight	Weight in gram	g	-
Eyes	Normal	N	0
	Exopthalmia (E)	E1/E2	30
	Haemorrhagic (H)	H1/H2	30
	Blind (B)	B1/B2	30
	Missing (M)	M1/M2	30
	Other	OT	30
Fins[b]	No active erosion or previous erosion healed over	0	0
	Mild active erosion with no bleeding. >10 parasite cysts	1	10
	Severe active erosion with haemorrhage / secondary infection. > 50 parasite cysts	2	20
Skin[b]	Normal, no aberrations	0	0
	Mild skin aberrations. >10 parasite cysts	1	10
	Moderate skin aberrations. >50 parasite cysts	2	20
	Severe skin aberrations	3	30
Opercules	Normal/no shortening	0	0
	Mild/slight shortening	1	10
	Severe shortening	2	20
Gills	Normal	N	0
	Frayed	F	30
	Clubbed	C	30
	Marginate	M	30
	Pale	P	30
	Other	OT	30
Pseudobranch	Normal	N	0
	Swollen	S	30
	Lithic	L	30
	Swollen and lithic	P	30
	Inflamed	I	30
	Other	OT	30
Thymus[a]	No haemorrhage	0	0
	Mild haemorrhage	1	10
	Moderate haemorrhage	2	20
	Severe haemorrhage	3	30
Internal variables (necropsy)			
Variables	Variable condition	Original field designation	Substituted value for the HAI
Mesenteric fat	(Internal body fat expressed with regard to amount present)		
	None	0	-
	Little, where less than 50% of each cecum is covered	1	-
	50% of each cecum is covered	2	-
	More than 50% of each cecum is covered	3	-
	Cecae are completely covered by large amount of fat	4	-
Spleen	Black	B	0
	Red	R	0
	Granular	G	0
	Nodular	NO	30
	Enlarge	E	30
	Other	OT	30
Hindgut	Normal, no inflammation or reddening	0	0
	Slight inflammation or reddening	1	10
	Moderate inflammation or reddening	2	20
	Severe inflammation or reddening	3	30
Kidney	Normal	N	0
	Swollen	S	30
	Mottled	M	30
	Granular	G	30
	Urolithic	U	30
	Other	OT	30

Variables	Variable condition	Original field designation	Substituted value for the HAI
Liver	Red	A	0
	Light red	B	30
	"Fatty" liver, "coffee with cream" colour	C	30
	Nodules in liver	D	30
	Focal discolouration	E	30
	General discolouration	F	30
	Other	OT	30
Bile[a]	Yellow or straw colour, bladder empty or partially full	0	-
	Yellow or straw colour, bladder full, distended	1	-
	Light green to "grass" green	2	-
	Dark green to dark blue-green	3	-
Blood (haematocrit)	Normal range	30-45%	0
	Above normal range	>45%	10
	Below normal range	19-29%	20
	Below normal range	<18%	30
Parasites	No observed parasites	0	0
	Few observed parasites	1	10
Endoparasites[b]	No observed endoparasites	0	0
	Observed endoparasites < 100	0	10
	101 -1000	1	20
	> 1000	3	30
Ectoparasites[b]	No observed ectoparasites	0	0
	Observed ectoparasites 1-10	1	10
	11-20	2	20
	> 20	3	30

a – no values were assigned to these parameters in the original HAI
b – refinement of the HAI

Parasites

As soon as the fish was removed from the gill nets, macroscopic examinations were done on the boat for mobile ectoparasites. Mobile ectoparasites found were recorded and kept in small glass containers filled with water from the site for further processing in the field laboratory. Skin smears were made and scrutinized for parasites.

The different organs, e.g. eyes, gut (alimentary canal and associated organs), swim bladder (if present) and urinary bladder were placed in separate petri-dishes containing saline solution and examined for endoparasites with the aid of a stereomicroscope (gills were placed in water from the site). The muscles were thoroughly scrutinized for encysted parasites.

Monogeneans were fixed and preserved in 70% ethanol or mounted in a small amount of glycerin jelly or Glycerine ammonium Picrate (GAP). The preparation was sealed with clear nail vanish. Digeneans were fixed in hot (± 70°C) alcohol formalin-acetic acid (AFA) for 15 minutes and stored in 70% ethanol. Cestodes from the intestinal tract and liver were swirled in saline until they were relaxed, fixed in buffered formalin or preserved in 70% ethanol. Nematodes were fixed in glacial acetic acid and preserved in 70% ethanol.

Laboratory procedures

Calculation of the Health Assessment Index

Original field designations of all variables from the necropsy-based system were substituted with comparable numerical values into the HAI (Heath et al., 2004; Jooste et al., 2004). All the variables of

the HAI were represented by a value ranging from 0-30, depending on the condition of the organs, etc. tested, with normal conditions indicated by 0. To calculate the index value for each fish within a sample, numerical values for all variables are summed. By adding all individual fish health index values and dividing it by the total number of fish examined, the HAI for a sample population was calculated.

Parasites and the Parasite Index

Preparation of whole mounts and identification of different parasites were done in the laboratory where specimens were stained either with Horen`s Trichrome™ or Aceto Carmine™ solution. Parasites were cleared in lactophenol or clove oil for 10 minutes or overnight if necessary. Specimens were mounted on pre-cleaned glass slides with Canada balsam™ or Entellan™ and labelled. Nematodes were cleared with lactophenol and mounted without staining (temporary mounts). All parasites were micrographed with the aid of a stereomicroscope with an Olympus digital camera adapter and an Olympus digital camera (C50-50 Zoom). Parasites were identified to species level where possible.

As mentioned earlier, contaminants have different influences on ecto- and endoparasites and therefore these were incorporated as separate variables in the HAI tested in South Africa (Marx, 1996; Robinson, 1996; Luus-Powell, 1997; Watson, 2001). Endoparasites are usually much higher in numbers than ectoparasites and more than, e.g. 1 000 trematode cysts or nematode larvae can be observed in a single host. Therefore endo- and ectoparasites were categorized as presented in Table 3.23.

Ecological terms used in infestation statistics

A variety of terms are used by parasitologists to describe the number of parasites in a host or the number of infected hosts in a sample. Examples of such terms are parasite burden; parasite load; level or extent of infection; degree of infection or infection rate. The terminology as suggested by Bush et al. (2001) was used during this study and includes prevalence (expressed in percentage), mean intensity and mean abundance where:

Prevalence = number of infested individuals of a host species divided by the number of hosts examined, expressed in percentage.

Mean Intensity = total number of a particular parasite species divided by the number of infested hosts.

Mean Abundance = total number of particular parasite species divided by the total number of hosts in a sample.

3.5.3 Results and concluding remarks

The health status of fish was determined during eleven surveys (from September 2009 to June 2011) with the aid of the HAI and PI (data was collectively used from different year's seasons).

Health of fish

The HAI was calculated by assigning numerical ratings to the values given in the health condition profile to the pseudobranches, thymus, eyes, gills, spleen, hindgut, kidneys, liver, opercules, and fins.

A rating of 0 is given for normal values, 10 for mild abnormalities, 20 for moderate, and 30 for severe (Table 3.23). The sum total of values awarded being the index value for the fish and the mean calculated for all fish in the sample being the index value for that locality. A higher HAI represents a higher incidence and severity of abnormalities. An elevated HAI has been linked to contaminant exposure and associated decreased growth and condition in other studies (Adams et al., 1993; Crafford and Avenant-Oldewage, 2009).

Furthermore, this protocol was developed to be a rapid assessment, but each individual fish was also surveyed extensively for the presence of parasites. Crafford (2000) also stated that some ectoparasites might be negatively affected by poor water quality (e.g. *Lamproglena* sp., *Achtheress percarum*, *Ergasilus sieboldi*, *Gyrodactylus* sp.), while others may be favoured or unaffected (Trichodinid ciliates, *Argulus* sp.). Crafford (2000) furthermore concluded that total parasite numbers (endo- and ectoparasites) could distinguish between two sites with differing water quality in the Vaal River.

The HAI scores were relatively low for all fish species tested at Nandoni Dam, except for *Labeobarbus marequensis* during spring (Table 3.25). Higher HAI values were recorded for most fish species during the spring and summer seasons. This is in contrast with results from a study done by Madanire-Moyo et al. (2012b), where higher HAI values were recorded for the autumn and winter months. Compared with results from the latter study, the HAI for *Clarias gariepinus* was low at Nandoni dam (a value of 93 was recorded for *C. gariepinus* at a polluted site; Madanire-Moyo et al., 2012b). A population HAI value of 87.8 was recorded for *C. gariepinus* in the Vaal River System (Crafford and Avenant-Oldewage, 2009).

Table 3.25: The Health Assessment Index for different fish species from Nandoni Dam from September 2009 to June 2011.

Fish species	Spring	Summer	Autumn	Winter
Clarias gariepinus	43 (n=3)	22 (n=5)	29 (n=9)	20 (n=3)
Labeobarbus marequensis	75 (n=2)	36 (n=10)	-	37 (n=7)
Micropterus salmoides	46 (n=7)	38 (n=4)	26 (n=8)	14 (n=5)
Oreochromis mossambicus	47 (n=13)	41 (n=23)	35 (n=13)	33 (n=15)
Schilbe intermedius	56 (n=15)	53 (n=34)	43 (n=20)	39 (n=20)

External variables

Skin and fins – No skin lesions or epidermal tumors and abnormal colour were observed during this study. No fish exhibited fin damage, frayed, split, or eroded fins, forked or short fins. However, small abrasions were noted from the skin, particularly where the parasite *Dolops ranarum* was found. There was, however, no secondary infection and a value of zero was given to the skin of *Clarias gariepinus*. Thus, for skin and fins, a value of zero was recorded for all the surveys, indicating a normal appearance with no aberrations. Eyes – A value of zero was recorded for eyes during all the surveys, except during November 2009 when a value of 30 was recorded for the eye of *Oreochromis mossambicus*. The one eye appeared opaque (Figure 3.43A), possibly due to parasitic infection. Opercula – No abnormal conditions were recorded for opercula during this study. They appeared normal with no shortening of the opercula. Gills – Abnormal gills were recorded for *Labeobarbus*

marequensis during one survey. Some gills appeared pale and some filaments were completely white, indicating dead cells (Figure 3.43B). Some of the gills showed swelling of the tips of the gill lamellae. These gills appeared bulbous with light, discoloured margins along the distal ends or tips of the lamellae or filaments, often associated with 'clubbing' (Figure 3.43C). A value of 30 was awarded to these abnormalities. One specimen (12.5%) of *Micropterus salmoides* had gills that were rotten with sessile protozoa present (Figure 3.43D). Digenean cysts were found on the gills of some specimens of *O*. *mossambicus* (Figure 3.45B). The rest of the fish had normal gills.

Internal variables

Liver – Discolouration indicating abnormal conditions in the liver were seen in some of the fish during all surveys. The value for liver ranged from zero to 30 during all surveys, indicating light red, 'fatty' as well as discoloured liver. Certain liver lesions are thought to be induced by contaminants and thus are useful indicators of contaminant exposure (Roberts, 2001). Spleen – A value of zero was awarded to the spleen throughout the study period, meaning that no abnormalities were observed for this organ during all surveys. Spleen with black, red and glandular conditions were considered as normal. Kidney – No anomalies of the kidneys were observed during the present study. Bile – the bile of the fish varied between species and was assigned one, two or three numerical values based on the colours observed. It exhibited the following colours; dark blue to green, yellow or straw colour, bladder full and distended. This colour changes could be due to prolong time spent in the nets before collection. Bile colour changes from straw-yellow in fish that have fed within the previous couple of days to blue green in fish which have not eaten for a couple of days. A complete empty gall bladder indicates that the fish have probably eaten within the past few hours. However, bile colour was not used in the original HAI; therefore, they were excluded in the present analysis. Haematocrit – the normal haematocrit range for fish is between 30 to 45%, however the haematocrit recorded for the fish from Nandoni Dam was between 19 and 51%. The lowest values were recorded for *O*. *mossambicus*, and the highest for *Labeobarbus marequensis.* Mesenteric fat **–** the internal body fat, expressed with regard to amount present, was indicated for all surveys, ranging from zero to 4 (Table 3.23). In the original HAI, mesenteric fat was not assigned values because of their response to environmental factors (Adams et al., 1993) and therefore this variable was excluded during this study. Hind gut – Conditions of the hindgut were recorded as normal and no inflammation was detected during this study. Pseudobranch – Little is known about the physiological response of the fish pseudobranch to environmental stressors. Goede and Barton (1990) suggest the swelling of pseudobranches may indicate a change in the partial pressure of oxygen and carbon dioxide. Increases in salinity levels may also cause pseudobranchial cell disruption. The pseudobranch of *C. gariepinus* appeared normal during all surveys.

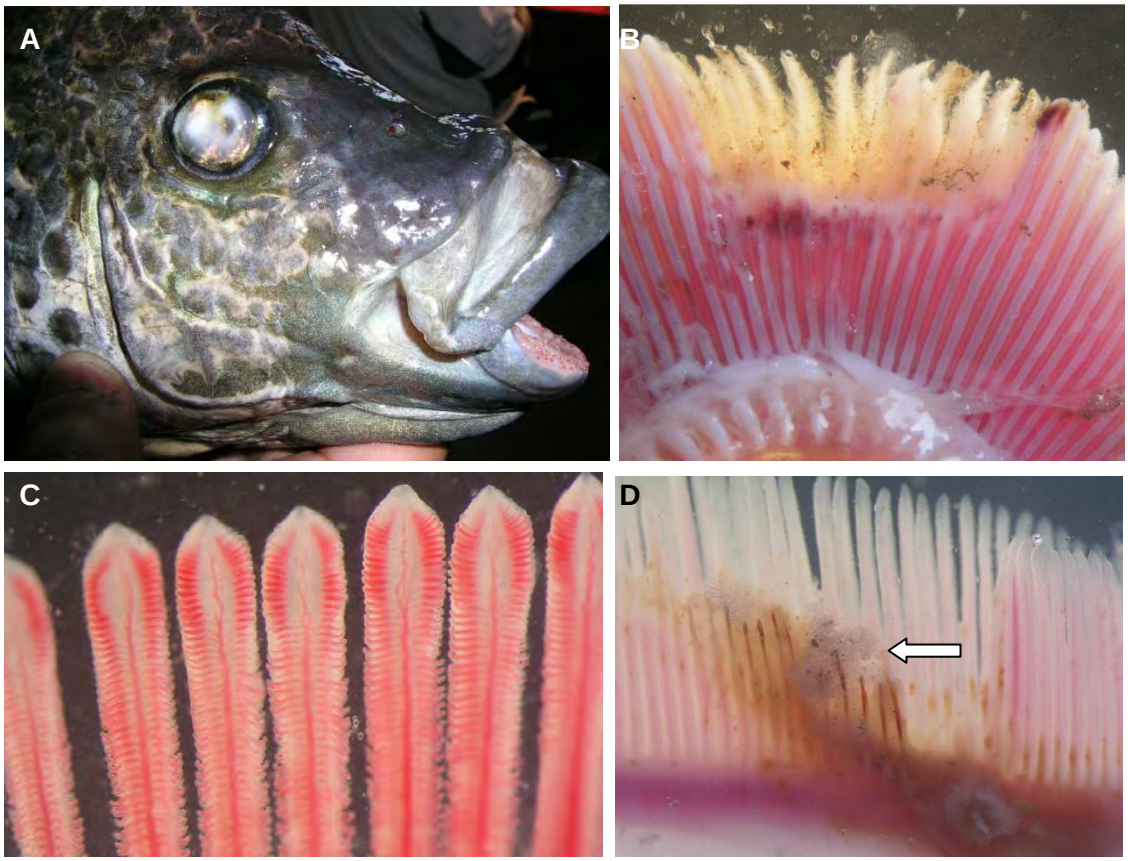

Figure 3.43: Condition (health) of fish a Lake Nandoni A. Opaque eye of *Oreochromi mossambicus*. B. Pale gills of *Labeobarbus marequensis*. C. Gills of *Labeobarbus marequensis* showing swelling of the tips of the gill lamellae. D. Gills of *Micropterus salmoides* showing rotten filaments with sessile protozoa (arrowed).

Parasite species composition

Several parasites (adult as well as larva forms) were recorded for the different fish species from the Nandoni Dam (Table 3.26). A total of 19 parasites species (7 monogeneans, 5 digeneans, 2 nematodes, 1 cestode, 1 branchiuran and 3 copepods) was found in the 214 fish collected during eleven surveys. Nine of the 16 species were found as adult stages infecting the skin, gills and the digestive tract. Fish in the dam are potential intermediate hosts for at least seven parasite species whose life cycles are completed when fishes are eaten, mostly by fish-eating birds (Table 3.26).

Infestation statistics

The parasite data was combined for the different seasons and the infestation statistics are presented in Tables 3.26-3.30.

Table 3.26: Metazoan parasites recovered from fish hosts at Nandoni Dam from September 2009 to June 2011.

Parasite species	Stage	Location	Definitive hosts
Monogenea			
Cichlidogyrus sp.	Adult	Gills	Fish
Gyrodactylus sp. A	Adult	Gills	Fish
Gyrodactulus sp. B	Adult	Gills	Fish
Macrogyrodactylus sp.	Adult	Gills	Fish
Schilbetrema sp.	Adult	Gills	Fish
Quadriacanthus sp.	Adult	Gills	Fish
Dactylogyrus spinicirrus	Adult	Gills	Fish
Digenea			
Diplostomum sp.	Larva	Brain and eye	Piscivorous birds
Unidentified sp. (cysts)	Larva	Gills	Probably piscivorous birds
Unidentified sp. (cysts)	Larva	Body cavity	Probably piscivorous birds
Euclinostomum sp.	Larva	Muscle	Piscivorous birds
Clinostomum sp.	Larva	Body cavity	Piscivorous birds
Cestoda			
Gryporynchid cestode	Larva	Intestine layer	Piscivorous birds
Nematoda			
Contracaecum sp.	Larva	Body cavity	Piscivorous birds
Paracamallanus sp.	Adult	Intestine	Fish
Copepoda			
Lernaea cyprinacea	Adult	Fins/Skin	Fish
Ergasilus sp.	Adult	Gills	Fish
Lamproglena clariae	Adult	Gills	Fish
Branchiuria			
Dolops ranarum	Adult	Skin, mouth, gills	Fish

Table 3.27: Infestation statistics of metazoan parasites recorded from *Clarias gariepinus* at Lake Nandoni during from September 2009 to June 2011.

Host/Parasite	Location	Infestation Statistics	Spring	Summer	Autumn	Winter
Clarias gariepinus						
Quadriacanthus sp.	Gills	MA	1.3	4.0	4.9	1.7
		MI	2.0	6.7	6.3	2.5
		P (%)	66.7	60.0	77.8	66.7
Macrogyrodactylus sp.	Gills	MA	1.0	1.2	1.9	1.0
		MI	3.0	3.0	3.4	1.5
		P (%)	33.3	40.0	55.6	66.7
Clinostomum sp.	Body cavity	MA	0	0	0.22	0
		MI	0	0	22.2	0
		P (%)	0	0	1	0
Contracaecum sp.	Body cavity	MA	60.0	27.2	29.1	65.0
		MI	60.0	27.2	43.7	97.5
		P (%)	100	100	66.7	66.7
Paracamallanus sp.	Intestine	MA	9.3	7.6	4.7	0.7
		MI	14.0	7.6	2.5	2.0
		P (%)	66.7	100	66.7	33.3
Lamproglena clariae	Gills	MA	0	0.2	0	0
		MI	0	1	0	0
		P (%)	0	20	0	0
Dolops ranarum	Skin	MA	1.7	0.4	0.9	0.3
		MI	2.5	1.0	2.0	1
		P (%)	66.7	40.0	44.4	33.3

Table 3.28: Infestation statistics of metazoan parasites recorded from *Labeobarbus marequensis* at Lake Nandoni during from September 2009 to June 2011.

Host/Parasite	*Location*	Infestation Statistics	Spring	Summer	Autumn	Winter
Labeobarbus marequensis						
Dactylogyrus spinicirrus	Gills	MA	0	0.8	-	1.6
		MI	0	1.6	-	4
		P (%)	0	50.0	-	40.0
Diplostomum sp.	Eye	MA	3.5	1.5	-	0
		MI	3.5	3.8	-	0
		P (%)	100	40	-	0
Digenean cysts	Body cavity	MA	0	26.6	-	52.0
		MI	0	88.7	-	130.0
		P (%)	0	30.0	-	40.0
Contracaecum sp.	Body cavity	MA	0	0.6	-	0
		MI	0	6.0	-	0
		P (%)	0	60.0	-	0
Ergasilus sp.	Gills	MA	0	0.1	-	0
		MI	0	1.0	-	0
		P (%)	0	10.0	-	0
Lernaea cyprinacea	Skin	MA	0.5	0.1	-	0
		MI	1.0	1.0	-	0
		P (%)	50.0	10.0	-	0

MA – mean abundance; MI – mean intensity; P – prevalence, expressed in percentage

Table 3.29: Infestation statistics of metazoan parasites recorded from *Micropterus salmoides* at Lake Nandoni September 2009 to June 2011.

Host/Parasite	***Location***	**Infestation Statistics**	**Spring**	**Summer**	**Autumn**	**Winter**
Micropterus salmoides						
Gyrodactylus sp.	Gills	MA	3.6	1.0	2.0	3.0
		MI	6.3	4.0	4.7	5.0
		P (%)	57.1	25.0	42.9	60.0
Contracaecum sp.	Body cavity	MA	1.9	0.8	0.1	0
		MI	3.3	3.0	1	0
		P (%)	57.1	25.0	14.3	0
Dolops ranarum	Skin	MA	0.1	0.8	0	0
		MI	1.0	3.0	0	0
		P (%)	14.3	25.0	0	0

MA – mean abundance; MI – mean intensity; P – prevalence, expressed in percentage

Table 3.30: Infestation statistics of metazoan parasites recorded from *Oreochromis mossambicus* at Lake Nandoni during from September 2009 to June 2011.

Host/Parasite	***Location***	**Infestation Statistics**	**Spring**	**Summer**	**Autumn**	**Winter**
Oreochromis mossambicus						
Cichlidogyrus sp.	Gills	MA	0.7	1.6	0.9	0.9
		MI	3.0	3.6	2.8	2.3
		P (%)	23.1	43.5	30.8	40.0
Gyrodactylus sp.	Gills	MA	0.5	0.3	0.9	0.3
		MI	1.2	2.3	2.2	1.7
		P (%)	38.5	13.0	38.5	20.0
Digenean cysts	Gills	MA	0.8	0.7	0.4	0.8
		MI	2.5	1.9	1.3	4.0
		P (%)	30.8	39.1	30.8	20.0
Digenean cysts	Skin and fins	MA	0	0.2	0	3.6
		MI	0	8.7	0	6.7
		P (%)	0	2.5	0	54.0
Diplostomum sp.	Eyes	MA	0.1	0.04	0	0
		MI	1	1	0	0
		P (%)	7.7	4.4	0	0
Clinostomum sp.	Body cavity	MA	1.1	0.6	2.1	0.2
		MI	4.7	2.6	3.9	1.5
		P (%)	23.1	21.8	53.9	13.3
Euclinostomum sp.	Muscle	MA	0.1	0.1	0.1	0.1
		MI	1	2	1	1
		P (%)	7.7	4.4	7.7	13.3
Gryporynchid larvae	Intestine layer	MA	1.3	7.6	0	0
		MI	8.5	24.9	0	0
		P (%)	15.4	30.4	0	0
Contracaecum sp.	Body cavity	MA	1.2	0.3	0.5	0
		MI	3.2	1.8	1.5	0
		P (%)	38.5	17.4	30.8	0
Dolops ranarum	Mouth/skin	MA	0	0.2	0	0
		MI	0	1.33	0	0
		P (%)	0	13.0	0	0

MA – mean abundance; MI – mean intensity; P – prevalence, expressed in percentage

Table 3.31: Infestation statistics of metazoan parasites recorded from *Schilbe intermedius* at Lake Nandoni from September 2009 to June 2011.

Host/Parasite	***Location***	**Infestation Statistics**	**Spring**	**Summer**	**Autumn**	**Winter**
Schilbe intermedius						
Schilbetrema sp.	Gills	MA	58.1	72	24.4	14.4
		MI	58.1	72	27.1	16.9
		P (%)	100	100	90	85
Diplostomum sp.	Eye	MA	0	0.03	0	0
		MI	0	1.0	0	0
		P (%)	0	2.9	0	0
Clinostomum sp.	Body cavity	MA	0.3	0.4	0.6	0.2
		MI	1.3	1.5	4.0	1.3
		P (%)	20.0	23.5	15.0	15.0
Contracaecum sp.	Body cavity	MA	17.7	12.1	10.7	13.4
		MI	18.9	18.7	17.8	24.4
		P (%)	93.0	64.7	60.0	55.0
Paracamallanus sp.	Intestine	MA	1.7	4.4	3.2	4.8
		MI	2.9	6.2	4.8	8.7
		P (%)	60.0	70.6	65.0	55.0
Dolops ranarum	Skin	MA	0	0	0	0.1
		MI	0	0	0	1.0
		P (%)	0	0	0	10.0
Unidentified digenean	Swim bladder	MA	0	0	0	1.0
		MI	0	0	0	3.2
		P (%)	0	0	0	30.0

MA – mean abundance; MI – mean intensity; P – prevalence, expressed in percentage

Community structure at infra- and component community levels

The parasites recovered from fishes from Nandoni Dam show different levels of host specificity. Host specificity is more obvious in adult helminthes since larval helminthes tend to be more generalist in their host associations (Pérez-Ponce de Leon et al., 2000). Only *Diplostomum* sp., *Clinostomum* sp., *Paracamallanus* sp., *Contracaecum* sp. and *Dolops ranarum* was associated with more than one fish hosts in this study. This pattern of host specificity follows the pattern observed in helminthes of freshwater fishes in general, where a group of helminthes is typical and often specific for higher taxa of host (e.g. families of fishes) (Dogiel et al., 1961). Less than 40% of the fish parasite population from Nandoni Dam is comprised of larval stages. This suggests that fishes play an important role in the parasite life cycles in this lacustrine ecosystem, mainly those of fish eating birds. Many piscivorous birds were observed at Nandoni Dam which means the life cycle of the parasites can be completed. Future studies may include the helminths of some piscivorous birds in the locality to identify/verify the adult stages in order to identify the larvae to species level.

Digeneans have been suggested as the most dominant group parasitising freshwater fishes in tropical latitudes (Salgado-Maldonaldo and Kennedy, 1997). This generalization is not supported in the present

study, where *Diplostomum* sp. ranks second after the nematode, *Contracaecum* sp. The bird digenean, *Diplostomum* is a generalist as a larval stage and the present data indicates its lack of specificity for its second intermediate host (recorded from three different host species). It is also found in about 100 species of fish in other parts of the world (Paperna, 1996). The presence of many larval parasites in fishes from Nandoni Dam indicates the abundance of suitable hosts and favourable conditions for the first intermediate mollusc and copepod hosts of these parasites.

Helminths

Host geographic range is not a major determinant of helminth communities, but species richness is influenced by local availability of parasite species and their possibility of colonization, with infracommunities (the lowest level) as subsets of the component community (Bush et al., 2001). The present data set supports the latter idea in that the richness of the helminth communities depends mainly on the local characteristics of the impoundment and not the richness of the regional pool of parasites for a host species. The helminth communities of fish from Nandoni Dam indicate that there are high levels of species richness and diversity and relatively high abundance of most species, although very low mean intensity levels were recorded for some helminths. The monogeneans recorded during study were from the gills. They include a *Gyrodactylus* sp. and *Cichlidogyrus* sp. from the gills of *O. mossambicus* (Figures 3.44 A, B). *Macrogyrodactylus* sp. was found from *C. gariepinus* with the highest prevalence recoded during winter. *Dactylogyrus spinicirrus* was recorded from the gills of *L. marequensis* during summer and winter only. None of the monogeneans from fish from Nandoni Dam caused visible pathology to the host and very low mean abundance and mean intensity levels were recorded during all surveys (Table 3.30).

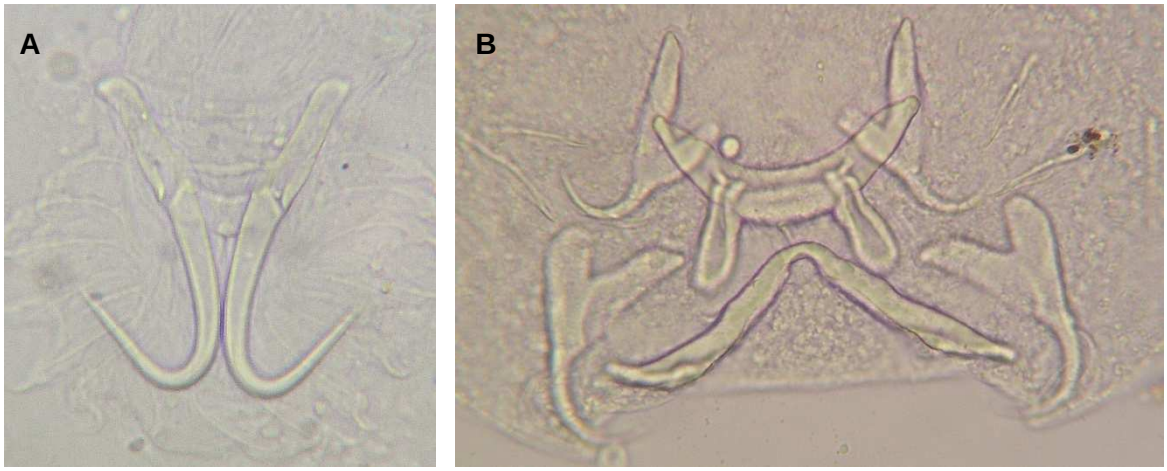

Figure 3.44: Opisthaptoral sclerotised parts of monogeneans. A. *Gyrodactylus* sp. from the gills of *Oreochromis mossambicus*. B. *Cichlidogyrus* sp. from the gills of *Oreochromis mossambicus*.

The digeneans are a diverse group of parasites with respect to both their hosts and their habitats within the host. The life cycle of most digeneans are among the most complex in nature, and are usually linked to the feeding strategy of their definitive hosts. Usually, more than one larval stage is present in the life cycle of digenean parasites. In this study, *Diplostomum* larva (Figure 3.45A) was recorded from

the eye of *L. marequensis*, *O mossambicus* and *S. intermedius*. The larvae from the muscle and gills (Figure 3.44B) were encysted while those in the eye were free-moving. Five different digeneans were present in fishes from Nandoni Dam, and all of these were larva forms. All the larvae were in low numbers except for the cysts (which were digenean larvae) from the body cavity of *L. marequensis* where a mean intensity of 130 was recorded during winter.

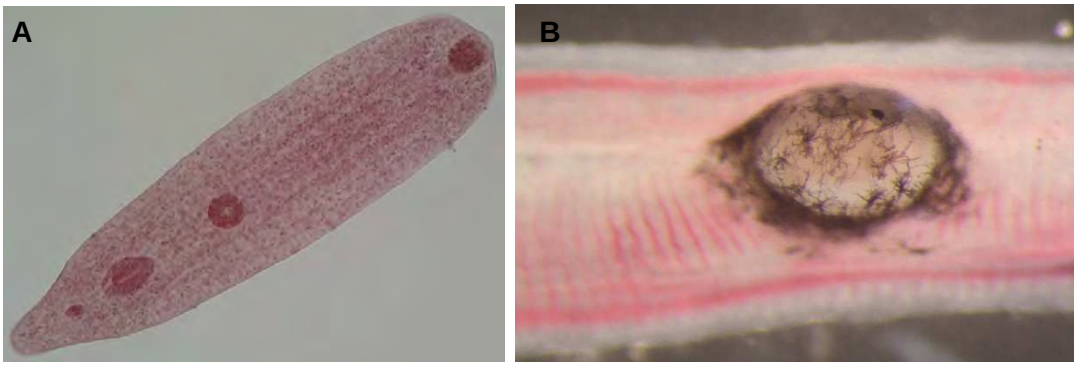

Figure 3.45: Digeneans from fish at Nandoni Dam. A. *Diplostomum* larvae (stained) from the brain and eye. B. Cysts on the gills of *Oreochromis mossambicus*.

The tapeworms (cestodes) infect internal organs of fish. They are parasitic in the intestine of fresh water teleost fishes mainly cyprinid and catfishes, although a few parasitize the coelom of freshwater oligochaetes. The life cycle of cestodes involve more than one intermediate host, including planktonic copepods, molluscs and fish. Piscivorours birds, in which some cestodes develop into adult stages, are important for parasites in that they can disseminate parasite eggs over long distances, making it difficult to control the spread of infections between different catchments. The only cestode recorded during this study is a gryporynchid larvae (encysted) on the outer layer of the intestine of *O. mossambicus* during spring and summer. This cestode larvae have also been reported in the same host from different localities in the Limpopo and Olifants River System (Madanire-Moyo et al., 2012a).

Nematodes (roundworms) are the most significant metazoan parasites associated with human infections; however, most nematodes are free living and found in a wide variety of aquatic and terrestrial habitats. Most species' life cycle involves eggs with several larval stages. The nematodes recorded during this study include *Contracaecum* larvae collected from the body cavity of *C. gariepinus* (Figure 3.46A) with a high mean intensity of 97.5 during winter and adult *Paracamallanus* sp. (Figure 3.46B) recorded from the intestine of the different hosts. Although high numbers of *Contracaecum* were recorded, it did not affect the condition of the host negatively.

Parasitic copepods are the most morphologically diverse of all groups of crustaceans ranging from the characteristics free-living body plan to highly modified forms that shows show no resemblance

to typical copepods (Bush et al., 2001). They parasitize a wide variety of host including cnidarians, annelids, mollusc, arthropod and fishes. Most of the species are marine but some are parasitic on fresh water fishes. They are ectoparasites on the skin and gills of fish.

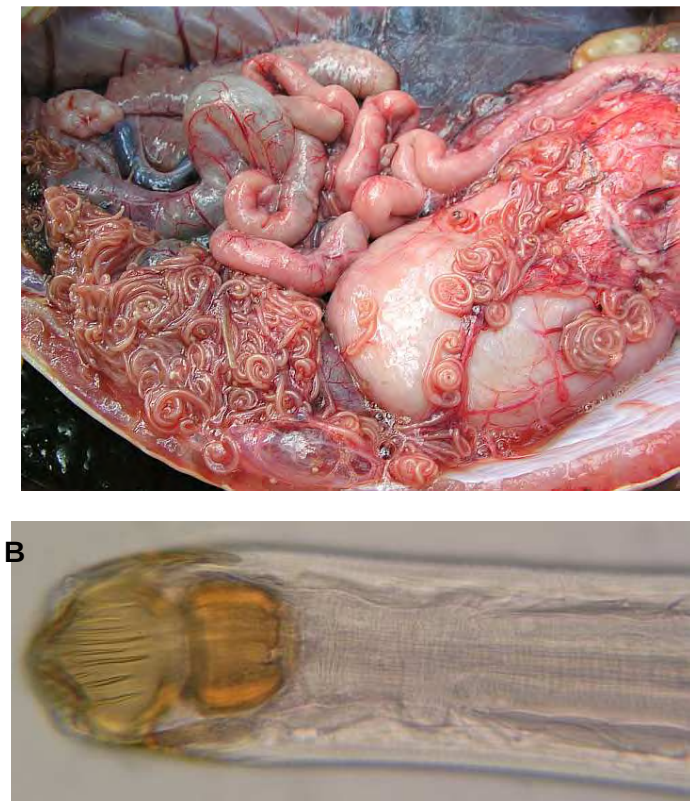

Figure 3.46: Nematodes recorded from fish from Nandoni Dam. A. *Contracaecum* larvae from the body cavity of *Clarias gariepinus*. B. *Paracamallanus* sp. from the intestine of *Schilbe intermedius*.

Three different copepods were recorded from fishes from Nandoni Dam. *Lernaea cyprinacea* (Figure 3.47) was recorded from the skin (scales) of *L. marequensis*. Only females are parasitic and attach to the skin or scales before their final moult, where after they are permanently attached. The adult females feed on blood. A mean intensity of 1 was recorded for *L. cyprinacea* during spring and summer and these low numbers will have no influence on the condition of the host.

Lamproglena clariae was recorded from the gills of *C. gariepinus* with a prevalence of 20% during summer. This copepods was also reported from *C. gariepinus* from Nwanedi-Luphephe dams (Madanire-Moyo et al., 2010). *Ergasilus* sp. was found on the gills of *L. marequensis* with a mean intensity of 1 during summer.

Branchiurans are a relatively small group of crustaceans exclusively parasitic on marine and fresh water fishes, and occasionally amphibians (Bush et al., 2001). They attach to the host with modified maxillules that form suckers in *Argulus* and *Chonopeltis* and hooks in *Dolops*, but they are able to move over the surface of the host. The life cycle of branhiurans may include one to

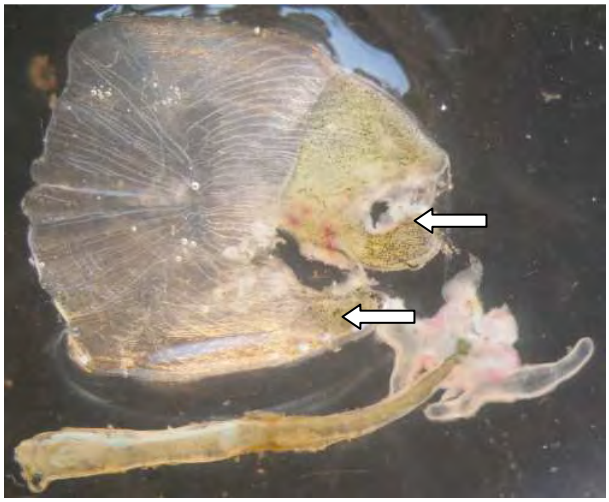

Figure 3.47: *Lernaea cyprinacea* from the skin/scales of *Labeobarbus marequensis* showing the damage caused to scales (arrowed) by the copepod.

many hosts, depending on the species. The only branchiuran recorded during the study is *Dolops ranarum* (Figures 3.48A,B) from the skin of all the host species examined at Nandoni Dam, except for *L. marequensis.*

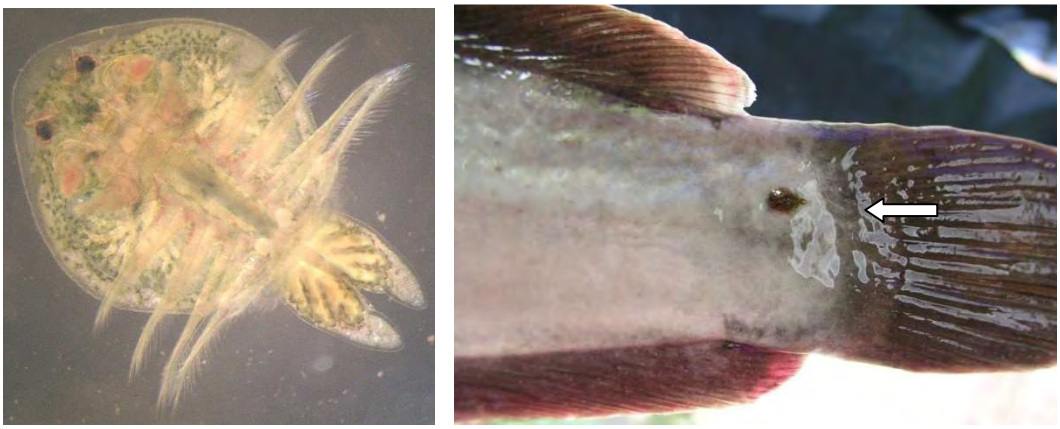

Figure 3.48: Ectoparasites recorded from fish at Nandoni Dam. A. Light micrograph of *Dolops ranarum*. B. *Dolops ranarum* (arrowed) from the skin of *Clarias gariepinus*.

Concluding remarks

The overall condition and health of the fish was good at Nandoni Dam. No obvious external signs or blood parameters indicated that the fish were stressed. None of the parasites from the fishes at Nandoni Dam were recorded in excessive numbers, except for *Contracaecum* larvae from *C. gariepinus*. However, large numbers of this nematode larva is fairly common in freshwater ecosystems. Fish health (including parasite burden) is important as freshwater fish is consumed by humans on a regular basis. The digenean larvae, including *Clinostomum*, *Euclinostomum* and possible the digenean cysts, are of zoonotic importance and these larvae have the potential to develop in humans.

3.6 Reference list

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4 POTENTIAL THREATS

The potential threats to the lake, and in particular to the fisheries potential of the dam, fall into one of the major groups listed below.

4.1 Water quality and the possibility of eutrophication

The results obtained in this project show that at this point water quality is at risk. Average nitrate concentrations in the main body of the dam were moderately high but still within in the acceptable range of 0.5 to 1.50 mgL^{-1}. It is however the quality of the water at the inflow of both the Mvudi (Site 10) and Dzindi (Site 11) rivers that is of concern. Here nitrate concentrations were significantly higher and although still in the tolerable range, the situation could easily deteriorate (Figure 4.1).

The phosphate levels both in the main body of water and at the inflow sites were very high and ranged between 0.223 and 0.426 mgL^{-1} and even the lowest average is within the "unacceptable" range. It is in particular the exceptionally high concentration (av. 1.023 mgL^{-1}) at the inflow of the Mvudi River. This will lead to eutrophic conditions of which signs, such as the high dissolved oxygen readings, were already observed during a number of surveys. The source of this is nutrient pollution was identified as wastewater effluent dumped by the Thohoyandou Sewage Treatment plant that is immediate upstream of the site.

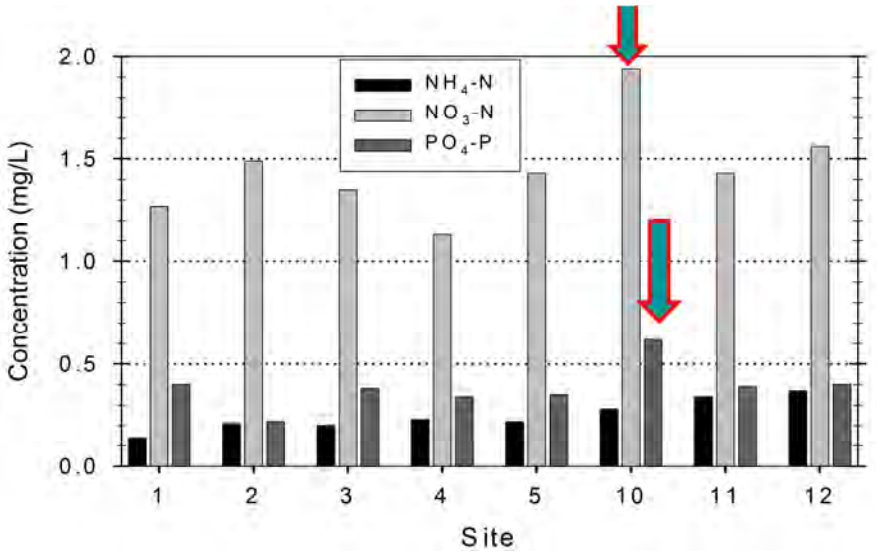

Figure 4.1: An illustration of the high nutrient concentrations recorded at sites 10 and 11 in Lake Nandoni.

In addition solid waste pollution, dominated by plastic containers, was also observed at the Mvudi site. The amount of this pollution was in particular high after rainstorms, which clearly indicates a lack of structure and services within adjacent communities. A continuation of the situation would most surely lead to habitat destruction and fish kills

4.2 Current fishing practices

Commercial and subsistence fishing have often been contributing factors in the collapse of inland fisheries (Allen et al., 2005). At this point there is no official commercial venture on the lake but subsistence fishing is taking place. These operations can rather be regarded as commercial since the catch is sold locally or at the roadside. The majority of the operators work from canoes and set gill nets overnight. At the start of the project gill netting was concentrated in the ringed areas in figure 4.2 A, this however expanded and by February 2010 it included the large ringed area (Figure 4.2 B). By September 2010 it had expanded to the areas shown in figure 4.2 C. The number of "operators", based on the number of camps counted had increased from 20 in September 2009 to more than 50 in September 2010 (pers. obs). Investigations have shown that each camp "harvest" a 20 L bucket filled with *O. mossambicus,* on what is thought to be a daily basis, which they sell. Informal estimates would be that a bucket would contain at least 30 large specimens, or a minimum of 10 kg of fish, and that continuous harvesting could lead to the depletion of the resource. It could be the cause of the downward trend observed in Figure 3.36.

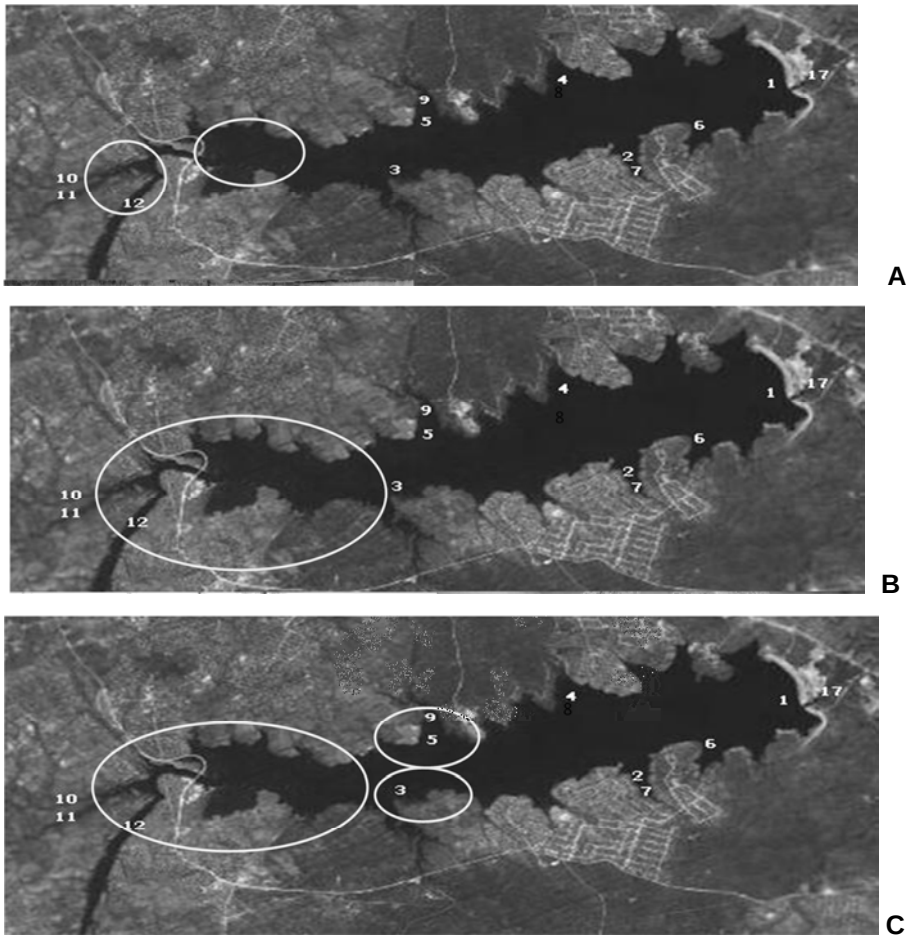

Figure 4.2: The extent of "commercial fishing in Lake Nandoni (A: September 2009, B : February 2010 and C: September 2010)

The gear used by the fisher is also of concern. Nets are made from packing nets and floats are slightly submerged to avoid detection. The mesh size of the nets varies and all size groups are targeted and

remove. Because of the low cost of the material damaged nets are left in the water and pose serious hazards to biota. The nets are also not cleared regularly and this leads to a high death rate. Dead fish is often discarded and has been the source of rumours of fish kills in the dam.

4.3 Lack of control

Although there are control exercises by authorities on the dam these events are sporadic and widely "advertised". Rather than contribute to the knowledge of the fishermen these exercise are marred by officials taking possession of boats and nets and destroying them. This has led to conflict situation between fishermen and recreation anglers.

Drowning in the lake is a common occurrence with more than 20 people having drowned since the closing of the wall. A large number can be attributed to the lack of safety control at the dam.

4.4 Lack of education and community involvement

Currently there are no actions of this nature in place. If however this is done it would ensure that community "buy-in" occurs and as consequence future projects would not be at risk.

4.5 Development

Over the past years a lot of housing development has taken place on the shores of the dam. It is unsure whether these have been approved and whether municipal services are provide. If not this could lead to serious point source pollution which would acerbate the already deteriorating water quality.

4.6 Alien invasive fish

Although it has not been mentioned earlier in this report the majority of what is reported as *O. mossambicus* could in fact be the alien invasive *Oreochromis niloticus*. In fact the physical characteristics of the specimens collected did indicate that they could be hybrids of the two species. A research project, investigation the genetics of specimens collected is currently under way. The first three specimens of Nile tilapia were collected in 1995 in pans associated to the Limpopo River in the Pafuri region of the Kruger National Park and in the Limpopo River at two sites in the region of Mapungubwe (Van der Waal and Bills 2000). Later studies have shown that the species have spread into the tributaries of the Limpopo River with specimens reported in the lower reaches of the Luvuvhu River (State of the Rivers Report, 2001) and in the Nzhelele River within the Maremani Reserve. According to Moralee et al. 2000) and Kleynhans in Van der Waal and Bills (2000) enzyme differences showed that hybridization between *O. niloticus* and the indigenous Mozambique tilapia, *O. mossambicus,* occurs and this may lead to a loss of the genetic integrity of the latter species which is then replaced by hybrid populations. Apart from the threat to the genetic purity of the indigenous

species, the Nile tilapia directly competes with the native Mozambique tilapia for food and breeding habitat and experts are of the opinion that the native species might be outcompeted

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5 RECOMMENDATIONS FOR FUTURE MANAGEMENT

At the onset it should be reiterated that what is stated below does not constitute a management plan but merely contains suggestions that could aid the formulation of such a plan.

As stated earlier in the report the fisheries potential of the dam, as well as problems associated with a lack of a proper researched management plan was recognised by Mr MK Angliss; the Specialist Aquatic Scientist of the Limpopo Department of Economic Development Environment and Tourism (LEDET) at the time who then requested and supported the intended research. The aim of this project was to gather data on the aspects regarding the biological, ecological and physical aspects listed above so that this could be used as guideline for a management plan for inland fisheries at the Nandoni Dam

Since the initial request for this study came from the Provincial Department of Environmental Affairs the very first recommendation is that their aims with the dam should be clearly formulated and communicated. These aims, whether it be conservation or sustainable use of a resource, will be the element that shapes any future management plan.

It should also be borne in mind that a large number of people with vested interests have congregated around the dam. No future management plan can be successful if the “buy-in” of these parties are not ensured.

The current project was aimed at determining the fisheries potential of the dam. From the obtained results it would appear that the dam has potential for commercial fisheries. On the one hand it can be utilized for aquaculture through the use of floating cages while on the other hand commercial fishing by local fisherman can be allowed, but should be controlled.

While this project addressed the limnology and the productivity of the impoundment it was not intended to investigate the socio-economic aspects of any fisheries venture, neither did it look at the social fabric of the impacted and interested parties. It is therefore recommended that research in this regard is carried out prior to any projects being initiated.

Any fisheries undertaking will impact on the communities adjacent to the dam. It is therefore imperative that these communities, and other stakeholders, be involved prior to any action being undertaken. In the process the following questions should be addressed: Who are the stakeholders?, What would be the most effective way to identify and involve stakeholders.? How should the stakeholder involvement process take place for example should it be meetings that involve all stakeholders or should stakeholders be separated according to their needs, e.g. landowners and anglers separately?

The potential yield of the dam has been calculated as part of this project. Although that figure is in essence an estimate of what can be harvested it should be honoured. It should also be borne in mind

that that estimate is based on the total Catch per Unit Effort while the most dominant species, *S. intermedius*, is not harvested at all by local fishermen. The final yield of the dam will therefore have be based on *O. mossambicus*, which is the preferred and targeted species. This will imply that less than 16% of the total yield or 13 kg ha^{-1} of this species would be a safe amount of fish to harvest per annum.

In any conservation exercise control, in the form of prescribed quotas and in particular the enforcement thereof, is of utmost importance. This project has shown that over the period of sampling the numbers of fish had declined and it can be ascribed to the uncontrolled harvesting that is taking place. Over and above quotas in the form of harvested biomass being important, the correct use of the correct fishing gear is cardinal. The results of this project contain the selectivity of the nets used. It is proposed that this is applied in such a way no harm is done to the population structure of the target species. This will ensure that a viable breeding population will be maintained.

In conclusion the water quality issue should be addressed as a matter of urgency. The results of this project has shown that pollution in the Dzindi and Mvudi river catchment existed and that this was reflected by the decline of water quality at the inflow. It is however important to take cognizance of the fact that this decline will extend throughout the dam if no action is taken. It is therefore imperative that water quality monitoring, and plans for corrective actions, should form part of any management plan

6 APPENDICES

Appendix 2.1a: The dissolved oxygen concentration at Site 1 during the period October 2009 to February 2010 in Lake Nandoni. (Indirect refers to the measurement of the collected water samples, Direct refers to direct measurements at 1 m intervals with a Hannah DO meter.)

	October 2009		November 2009		December 2009		January 2010		February 2010	
	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct
Depth measured	DISSOLVED OXYGEN (mgL^{-1})	DISSOLVED OXYGEN (mgL^{-1})	DISSOLVED OXYGEN (mgL^{-1})	DISSOLVED OXYGEN (mgL^{-1})	DISSOLVED OXYGEN (mgL^{-1})	DISSOLVED OXYGEN (mgL^{-1})	DISSOLVED OXYGEN (mgL^{-1})	DISSOLVED OXYGEN (mgL^{-1})	DISSOLVED OXYGEN (mgL^{-1})	DISSOLVED OXYGEN (mgL^{-1})
1	7.5	6.8	7.47	8	7.49	7.4	6.69	7.9	6.62	7.5
2	7	6.8	7.87	8.1	8.03	8.4	6.3	7.7	6.63	6.7
3	6.92	6.7	7.65	8.2	7.9	8.5	6.31	7.4	6.47	6.6
4	6.99	6.5	7.62	7.8	8.38	8.6	4.8	7.2	6.47	6.6
5	6.71	6.3	7.62	6.9	8.34	8.4	3.01	4.1	5.34	6.4
6	4.22	4.3	6.67	5.7	6.84	7.4	2.12	2.2	4.36	5.1
7	3.88	2.9	6.6	3.8	5.3	5.2	1.54	1.6	3.3	4.1
8	3.4	3	4.71	2	3.67	3.7	0.59	0.5	1.59	3
9	2.87	2.1	1.7	0.4	2.63	2.5	0.53	0	1.03	0.8
10	2.03	1.6	0.83	0	0.54	0.3	4.31	-0.03	0.98	0.2
11	1.07	0.5	0.17	-0.2	0.34	0	0.87	-0.04	0.75	0
12	0.86	-0.2	0.24	-0.3	0.30	-0.2	0.74	-0.05	0.88	-0.1
13	0.77	-0.2	0	-0.4	0.32	-0.3	0.63	-0.05	0.89	-0.2
14	0.55	-0.2	0.13	-0.4	0.32	-0.3	0.73	-0.05	0.95	-0.2
15	0.83	-0.2	0.25	-0.4	0.30	-0.3	1.37	-0.05	0.92	-0.4
16	0.88	-0.2	0.13	-0.4	0.30	-0.4	1.12	-0.06	1.23	-0.3
17	0.83	-0.2	0.12	-0.4	0.30	-0.4	0.62	-0.06	0.44	-0.4
18	0.98	-0.2	0.12	-0.6	0.22	-0.5	0.95	-0.06	0.44	-0.4
19	0.90	-0.2	0.12	-0.5	0.20	-0.5	0.69	-0.06	0.45	-0.4
20	0.81	-0.2	0.10	0.5	0.20	-0.5	0.64	-0.06	0.35	-0.4
21									0.46	
22									0.47	
23									0.43	

Appendix 2.1b: The dissolved oxygen concentration at Site 1 during the period March to July 2010 in Lake Nandoni. (Indirect refers to the measurement of the collected water samples, Direct refers to direct measurements at 1 m intervals with a Hannah DO meter.)

	March 2010		April 2010		May 2010		June 2010		July 2010	
	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct
Depth measured	DISSOLVED OXYGEN (mgL^{-1})	DISSOLVED OXYGEN (mgL^{-1})	DISSOLVED OXYGEN (mgL^{-1})	DISSOLVED OXYGEN (mgL^{-1})	DISSOLVED OXYGEN (mgL^{-1})	DISSOLVED OXYGEN (mgL^{-1})	DISSOLVED OXYGEN (mgL^{-1})	DISSOLVED OXYGEN (mgL^{-1})	DISSOLVED OXYGEN (mgL^{-1})	DISSOLVED OXYGEN (mgL^{-1})
1	6.5	6.6	7.3	7.2	5.2	3.4	5.43	4.8	6.4	5.2
2	6.4	6.9	7.3	6.5	5.1	3.31	5.2	3.9	6.42	5.2
3	6.4	7.1	7.4	7.1	5	3.51	5.1	3.4	6.23	5.1
4	6.7	7.1	7.1	6.9	5	3.19	5	3.2	6.5	5.2
5	6.1	7	7	6.6	4.9	3.15	4.98	3	6.39	5.2
6	6.2	6.9	6.8	6.7	4.8	3.07	3.46	3	6.65	5
7	6.4	6.9	6.6	6.4	4.5	3.49	2.76	3	5.75	4.9
8	6	6.6	6.3	3.5	1.9	1.54	2.75	2.8	5.68	4.8
9	3.6	4.6	0.6	1.4	0.4	1.61	2.74	2.3	5.36	4.3
10	0.4	1.1	0.1	0.6	-0	1.42	2.94	2.1	5.52	4.1
11	0.7	0.4	-0	0.7	-0	1.43	3.48	2.3	5.01	3.9
12	0.5	0	-0	0.7	-0	1.33	3.62	2.4	5.03	3.9
13	0.4	-0	-0	0.6	-1	1.25	2.88	2.1	5.56	3.8
14	0.5	-0	-0	0.9	-1	1.32	1.65	0.3	4.09	3.2
15	0.5	-0	-0	0.7	-1	1.19	0.94	0	4.04	3
16	0.5	-0	-0	0.8	-1	1.23	0.79	-0.2	4.8	2.9
17	0.4	-0	-1	0.5	-1	1.14	0.69	-0.3	3.87	2.7
18	0.5	-1	-1	0.7	-1	1.11	0.87	-0.3	3.65	2.4
19	0.4	-1	-1	0.8	-1	1.05	1.23	-0.4	3.66	2.4
20	0.6	-1	-1	0.9	-1	1.02	1.06	-0.4	3.46	2.4
21	0.5			0.8		0.98			3.58	
22									3.55	
23									3.51	
24									3.4	
25							0.73		3.19	

Appendix 2.1c: The dissolved oxygen concentration at Site 1 during the period August to December 2010 in Lake Nandoni. (Indirect refers to the measurement of the collected water samples, Direct refers to direct measurements at 1 m intervals with a Hannah DO meter.)

	August 2010		September 2010		October 2010		November 2010		December 2010	
	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct
Depth measured	DISSOLVED OXYGEN (mgL^{-1})	DISSOLVED OXYGEN (mgL^{-1})	DISSOLVED OXYGEN (mgL^{-1})	DISSOLVED OXYGEN (mgL^{-1})	DISSOLVED OXYGEN (mgL^{-1})	DISSOLVED OXYGEN (mgL^{-1})	DISSOLVED OXYGEN (mgL^{-1})	DISSOLVED OXYGEN (mgL^{-1})	DISSOLVED OXYGEN (mgL^{-1})	DISSOLVED OXYGEN (mgL^{-1})
1	6.44	7.5	9.9	9.5	9.35	7.7	6.73	9.5	7.23	7.4
2	6.34	6.8	9.77	9	8.63	7.6	6.36	8.6	7.40	7.4
3	6.44	6.3	9.75	8.9	8.33	7.6	6.22	8.4	7.14	7.3
4	6.33	6	10.46	8.9	9.29	7.8	6.17	8.2	5.89	7.2
5	6.26	5.8	9.81	8.9	8.94	7.8	6.15	8.0	7.35	6.1
6	6.44	5.7	9.37	8.8	8.60	7.7	5.66	7.6	4.28	5.2
7	5.7	5.6	9.22	8.6	7.95	7.6	5.43	6.8	2.25	4.2
8	5.49	5	9.12	8.6	8.58	7.5	5.13	6.1	2.12	3.9
9	4.17	4.2	7.28	7.4	7.14	7.0	3.97	5.6	0.83	2.6
10	4.29	3.7	5.71	6.2	3.78	5.9	3.23	3.9	0.90	1.8
11	4.45	3.6	4.89	4.9	2.73	2.6	3.11	1.5	0.99	0.2
12	3.53	3.3	4.32	4.1	2.02	0.2	3.75	0.5	0.65	-0.5
13	3.33	2.8	3.89	3.9	1.82	0.3	4.57	0.1	0.69	-0.5
14	3.33	2.6	3.84	3.4	1.75	0.4	4.74	0.1	0.60	-0.6
15	3.48	2.5	4.01	3.2	1.53	0.4	3.93	0.5	0.55	-0.7
16	3.46	2.5	3.93	3	1.65	0.4	3.51	0.1	0.65	-0.7
17	3.52	2.4	3.89	3	1.34	0.5	3.49	0.1	0.72	-0.8
18	3.35	2.3	4.28	2.7	1.25	0.5	3.04	0	0.55	-0.8
19	3.37	2.4	4.41	2.7	1.18	0.5	3.16	0	0.52	-0.8
20	3.32		4.41	2.3	0.76	0.5	2.44	0	0.74	-0.9
21	3.33		4.12		0.78		2.33		0.75	-0.9
22	3.19		4.32		0.60		2.29		0.99	
23	3.44		4.22		0.59		3.01		0.63	
24	3.65				0.64		2.29		0.53	
25	3.57				0.65				0.89	

Appendix 2.1d: The dissolved oxygen concentration at Site 1 during the period March to June 2011 in Lake Nandoni. (Indirect refers to the measurement of the collected water samples, Direct refers to direct measurements at 1 m intervals with a Hannah DO meter.)

	March 2011		April 2011		June 2011	
	Indirect	Direct	Indirect	Direct	Indirect	Direct
Depth measured	DISSOLVED OXYGEN (mgL^{-1})	DISSOLVED OXYGEN (mgL^{-1})	DISSOLVED OXYGEN (mgL^{-1})	DISSOLVED OXYGEN (mgL^{-1})	DISSOLVED OXYGEN (mgL^{-1})	DISSOLVED OXYGEN (mgL^{-1})
1	7.78	9.3	7.86	8.1	5.20	6.3
2	7.75	9.3	7.97	7.9	5.10	5.8
3	5.06	8.4	7.83	7.8	4.77	5.5
4	4.01	5.5	7.63	7.6	4.70	5.3
5	1.69	4.9	7.64	6.7	4.49	5.1
6	1.31	3.0	6.90	6.6	4.48	5.0
7	0.89	2.0	6.87	6.5	4.40	4.9
8	1.99	1.7	6.86	6.5	4.14	4.8
9	1.56	1.5	6.38	2.7	4.25	4.7
10	1.58	1.4	2.79	0.3	4.14	4.7
11	1.55	1.4	0.51	0.2	4.02	4.7
12	0.97	1.4	0.48	0.2	3.93	4.7
13	0.94	1.5	0.27	0.2	4.04	4.7
14	0.94	1.3	0.51	0.4	4.00	4.8
15	0.75	1.1	0.37	0.2	3.93	4.6
16	0.65	1.1	0.70	0.1	3.78	4.6
17	0.70	0.9	0.24	0.5	3.89	4.6
18	0.53	0.6	0.20	0.8	3.93	4.6
19	0.52	0.5	0.20	0.5	3.94	4.6
20	0.45	0.5	0.20	0.5	3.88	4.6
21	0.75		0.20		3.80	
22	0.99		0.20		3.80	
23	0.63		0.10		3.80	
24	0.53		0.10		3.80	
25	0.89				3.80	

Appendix 2.2a: The pH, electrical conductivity, total dissolved salts and temperature readings obtained at 1 m intervals during October 2009 to January 2010 at site 1 Lake Nandoni.

	October 2009				November 2009				December 2009				January 2010			
Depth	pH	Conductivity (μScm^{-1})	Total dissolved salts (mgL^{-1})	Temperature (^oC)	pH	Conductivity (μScm^{-1})	Total dissolved salts (mgL^{-1})	Temperature (^oC)	pH	Conductivity (μScm^{-1})	Total dissolved salts (mgL^{-1})	Temperature (^oC)	pH	Conductivity (μScm^{-1})	Total dissolved salts (mgL^{-1})	Temperature (^oC)
1	7.64	177.8	88.3	22.2	8.07	292	88.9	26.8	8.41	161.5	81.2	26.7	8.6	156.4	78.1	26.4
2	8.2	162.4	81.2	21.8	8.4	176.6	86.3	25.7	8.69	161.2	80.2	26.3	8.59	156	77.9	26.5
3	8.43	162.8	81.4	21.7	8.45	165.3	82.8	25.0	8.69	159	79.7	25.8	8.56	154.9	77.5	26.1
4	8.45	162.6	81.4	21.5	8.46	165.5	82.5	24.4	8.65	159.9	80	25.4	8.47	155.6	77.7	26.2
5	8.25	162.5	81.2	21.1	8.26	165.3	82.6	23.7	8.65	160	79.8	25.4	7.99	154.2	77	25.9
6	7.93	162.8	81.2	20.6	8.07	165.2	82.7	23.5	8.31	162.2	81.4	24.9	7.57	154.6	76.3	25.8
7	7.72	162.6	81.3	20.3	7.91	165	82.4	22.7	7.94	163.8	82	23.3	7.43	152.5	76.3	25.3
8	7.61	162.8	81.2	20.0	7.53	165.7	82.7	22.1	7.91	165.7	82.5	22.7	7.41	160	79.9	24.8
9	7.35	160.5	81.4	19.8	7.26	164.5	82.4	21.5	7.43	163.3	81.8	22.1	7.35	168.5	84.1	23.7
10	7.46	162.7	81.4	19.4	7.25	167.5	83.7	20.8	7.3	168.2	84	21.4	7.4	159.8	79.7	23.5
11	7.38	162.9	81.6	19.1	7.11	168.6	84.2	20.0	7.29	174	81.7	20.4	7.29	172.7	86.3	22.7
12	7.29	164.2	82.1	18.6	7.08	167.5	83.8	19.5	7.13	174.8	87.7	20	7.28	176.3	88	22.3
13	7.26	165	82.6	18.3	7.08	168.6	84.3	19.5					7.19	179.2	89.6	22.1
14	7.35	165.2	82.6	18.4	7.07	169.8	84.7	19.2					7.13	179.8	89.8	21.6
15	7.28	165.7	83.1	18.2	7.06	167.2	85.1	19.1					7.19	180.9	90.6	20.9
16	7.28	165.3	82.7	18.2	7.06	168.1	85.2	19.1					7.18	181.9	91.1	20.6
17	7.31	165.6	82.9	18.2	7.06	167.1	85.2	19.1					7.17	181.9	91.1	20.3
18	7.43	165.6	83.2	18.4	7.05	168.2	85.2	19.1					7.15	180.9	90.3	20.3
19	7.44	165	85.1	18.4	7.01	170.1	85.2	19.1	7.1	175.7	87.8		7.8	154.9	77.8	20
20	7.38	164.1	83.1	18.3	7.16	170.5	85.2	19					7.35	181.7	90.8	20

Appendix 2.2b: The pH, electrical conductivity, total dissolved salts and temperature readings obtained at 1 m intervals during February to May 2010 at site 1 in Lake Nandoni.

	February 2010				March 2010				April 2010				May 2010			
Depth	pH	Conductivity (μScm^{-1})	otal dissolved salts (mgL^{-1})	Temperature (^oC)	pH	Conductivity (μScm^{-1})	otal dissolved salts (mgL^{-1})	Temperature (^oC)	pH	Conductivity (μScm^{-1})	otal dissolved salts (mgL^{-1})	Temperature (^oC)	pH	Conductivity (μScm^{-1})	otal dissolved salts (mgL^{-1})	Temperature (^oC)
1	8.1	152.6	76.4	28.1	7.55	144	72.2	27.7	7.7	151.9	75.7	27.6	6.98	132.5	66.2	22.4
2	8.07	151.8	75.8	27.6	7.79	144	72.9	27.2	7.82	142.9	71.5	27.4	7.22	132.2	66	21.9
3	8.01	153	76.5	27.7	7.82	145.4	72.8	27	7.93	140.2	70.1	26.8	7.28	132.1	65.9	22.6
4	8	152.3	76.2	27	7.85	143.1	71.6	26.8	7.95	139.6	69.8	26.8	7.29	132	65.9	21.5
5	7.83	151.6	75.7	26.6	7.83	144.3	72.3	27	7.88	139.6	69.9	26.7	7.29	132.1	66	21.4
6	7.74	151.7	76	26.3	7.88	143.5	71.9	27	7.89	139.3	69.7	26.5	7.26	132.1	66.1	21.5
7	7.59	151.4	75.8	26.2	7.86	144.6	72.5	25.9	7.9	140.5	70.3	26.5	7.23	132.2	66	21.4
8	7.56	161	80.5	25.4	7.82	134.9	67.6	25.8	7.53	143.4	71.7	26.1	6.99	142.7	71.5	21.1
9	7.53	174.8	87.4	23.6	7.66	147.4	74	25.2	7.25	152.4	76.2	25.1	7	142.5	71.4	21.2
10	7.33	175.6	87.8	22.8	7.23	177.3	88.7	25.3	7.27	162.6	81.5	24.3	6.99	144.7	72.4	21.2
11	7.28	176.3	88	22	7.3	175.7	87.7	24.9	7.23	176.3	88.2	23.5	6.95	159.8	80	21.2
12	7.23	179.4	89.3	21.8	7.28	183.1	91.6	24.4	7.17	185.7	93	22.4	6.93	181.5	90.8	20.9
13	7.28	181.1	90.7	21.3	7.15	186.9	93.5	23.5	7.08	189.9	95.1	21.5	6.85	189.9	95.9	20.7
14	7.25	182.4	91.2	21	7.16	186	93.3	22.8	7.08	189.4	94.7	21.3	6.87	192	96	20.6
15	7.2	184.4	92.1	21	7.03	187.1	93.8	22.7	7.07	191.3	95.9	21.1	6.88	193.2	96.6	20.4
16	7.23	184.8	92.1	20.7	7	188.1	94.4	22.6	7.03	191.9	96.2	21.1	6.87	193.1	96.5	20.2
17	7.16	184.5	92.1	20.7	6.95	188.8	94.4	22.1	7.02	192	96.3	20.8	6.89	194.8	97.2	20.2
18	7.16	184.9	92.3	20.4	6.93	190.4	95.5	22.0	7.02	191	95.6	20.7	6.86	197.5	98.5	20.2
19	7.13	185.4	92.6	20.2	6.93	190.3	95.5	22.0	7.06	191.4	95.8	20.9	6.86	196.9	98.2	20.1
20	7.12	185.5	92.6	20	6.92	190.2	95.4	21.8	7.01	191.7	95.9	21	6.87	198.2	98.9	20

Appendix 2.2c: The pH, electrical conductivity, total dissolved salts and temperature readings obtained at 1 m intervals during June to September 2010 at site 1 in Lake Nandoni.

	June 2010				July 2010				August 2010				September 2010			
Depth	pH	Conductivity (μScm^{-1})	otal dissolved salts (mgL^{-1})	Temperature (^oC)	pH	Conductivity (μScm^{-1})	otal dissolved salts (mgL^{-1})	Temperature (^oC)	pH	Conductivity (μScm^{-1})	otal dissolved salts (mgL^{-1})	Temperature (^oC)	pH	Conductivity (μScm^{-1})	otal dissolved salts (mgL^{-1})	Temperature (^oC)
1	6.95	143	71.4	21.3	7.46	135.5	69.3	18.1	7.33	139.3	69.4	17.6	8.99	139.9	69.7	21.6
2	6.9	142.1	71.1	20.4	7.46	139.6	69.9	18	7.44	133.7	69.5	17.5	9.11	138.9	69.3	20.8
3	7.1	140.9	70.5	20.4	7.42	138.7	69.3	17.8	7.47	129.1	64.6	17.6	9.04	139.1	69.4	20.6
4	7.2	141.8	70.9	20.1	7.55	139.2	69.5	17.7	7.46	126.7	63.4	17.6	9.08	138.7	69.3	20.4
5	7.21	141.2	70.6	20	7.47	139.2	69.5	17.9	7.49	137.2	68.7	17.5	9.02	139.3	69.6	20.4
6	7.21	140.5	70.3	20	7.49	139	69.2	17.7	7.42	138.8	69.4	17.5	8.98	139.1	69.4	20.3
7	7.21	141.2	70.6	20	7.25	138.5	69.1	17.6	7.38	133.5	66.8	17.4	8.96	139.7	69.7	20.4
8	7.21	143.1	71.6	19.9	7.12	138.5	69.1	17.5	7.35	130.7	65.5	17.3	8.39	141.1	70.3	19.6
9	7.14	143.2	71.6	20	7.29	137.9	69	17.5	7.18	138.9	69.3	17.4	7.86	140.9	70.5	18.8
10	7.17	142.3	71.1	20	7.34	138	68.9	17.5	7.28	131.9	66.2	17.3	7.64	141	70.6	18.5
11	7.03	139.8	69.9	19.9	7.21	137.7	68.6	17.6	7.25	140.5	70.1	17.3	7.58	142.2	70.9	18.3
12	6.89	140.9	70.5	19.9	7.3	137.9	68.7	17.6	7.1	135	67.5	17.3	7.5	141.6	70.6	18.2
13	7.2	147.8	73.9	20.1	7.29	137.3	68.5	17.6	7.18	133.7	66.8	17.3	7.44	141.8	70.9	18.1
14	6.79	148.5	74.3	19.9	7.26	137.3	68.5	17.5	7.26	139.4	69.9	17.3	7.43	141.6	70.7	17.9
15	7	159.3	79.6	19.8	7.15	137.4	68.5	17.5	7.25	139.4	69.6	17.2	7.42	141.3	70.4	18.1
16	6.96	190.4	95.2	19.7	7.29	138	68.7	17.7	7.23	139.2	69.4	17.2	7.44	141.4	70.6	18.3
17	6.8	216	107	19.7	7.23	137.1	68.8	17.6	7.25	139.1	69.4	17.3	7.47	140.8	70.4	18.2
18	6.9	215	107	19.6	7.19	137.1	68.6	17.5	7.25	139	69.3	17.2	7.51	140.7	70.4	18
19	7.1	215	108	19.5	7.15	137.2	68.4	17.5	7.16	139.2	69.4	17.2	7.45	142.5	70.1	18.4
20	7	216	107	19.5	7.25	137	68.5	17.5	7.27	139.2	69.5	17.3	7.45	142.2	70.1	18.3

Appendix 2.2d: The pH, electrical conductivity, total dissolved salts and temperature readings obtained at 1 m intervals during October to December 2010 and March 2011 at site 1 in Lake Nandoni.

	October 2010				November 2010				December 2010				March 2011			
Depth	pH	Conductivity (μScm^{-1})	otal dissolved salts (mgL^{-1})	Temperature (^oC)	pH	Conductivity (μScm^{-1})	otal dissolved salts (mgL^{-1})	Temperature (^oC)	pH	Conductivity (μScm^{-1})	otal dissolved salts (mgL^{-1})	Temperature (^oC)	pH	Conductivity (μScm^{-1})	otal dissolved salts (mgL^{-1})	Temperature (^oC)
1	8.49	138.8	69.5	22.9	8.33	138.0	69.6	24.3	8.05	138.2	69.2	24.0	7.56	115.9	57.8	26.9
2	8.61	139.6	69.6	22.4	8.4	138.0	68.7	24.3	8.11	137.3	68.8	24.4	7.61	116.1	58.0	26.3
3	8.63	139.2	69.6	22.1	8.45	138.4	69.1	24.1	8.09	139.1	69.8	24.1	7.36	115.9	58.0	26.1
4	8.67	139.1	69.5	22.2	8.39	136.9	68.4	24.3	7.72	138.1	69.0	23.6	7.06	115.5	57.7	25.6
5	8.58	139.1	69.5	21.9	8.14	136.3	69.5	23.7	8.16	137.5	68.8	24.1	7.00	114.8	57.4	25.1
6	8.58	139.1	69.6	21.8	7.97	138.5	69.0	23.2	7.64	138.5	69.5	23.3	6.97	113.7	56.8	24.7
7	8.49	139.1	69.5	21.6	7.84	138.7	69.3	23.0	7.15	138.6	69.1	22.8	6.86	112.2	56.1	24.2
8	8.33	139.2	69.6	21.4	7.54	140.3	70.0	22.1	6.94	139.2	69.2	22.6	6.88	113.1	56.5	23.8
9	7.66	141.2	70.7	20.7	7.31	143.0	71.4	20.9	6.87	147.2	74.0	20.8	6.92	115.3	57.6	23.5
10	7.33	138.5	69.3	19.6	7.29	147.0	73.3	19.8	6.84	149.5	74.9	20.2	6.91	127.3	63.5	22.8
11	7.27	142.6	71.4	19.4	7.22	147.5	73.6	19.6	6.80	147.1	73.6	20.8	6.94	159.7	79.7	21.0
12	7.18	144.7	72.3	18.8	7.22	148.1	74.0	19.1	6.90	153.3	76.3	19.4	6.87	160.6	80.3	20.7
13	7.16	133.1	66.4	18.8	7.21	148.9	74.3	19.0	6.77	152.1	76.0	19.0	6.87	164.5	82.3	20.4
14	7.16	144.8	72.4	18.6	7.28	149.5	74.6	18.9	6.75	153.3	76.6	19.6	6.91	169.3	84.7	20.0
15	7.21	145.8	72.9	18.5	7.22	140.1	75.1	18.7	6.75	153.5	76.9	18.9	7.08	168.0	84.3	20.5
16	7.17	146.7	72.9	18.5	7.23	149.4	74.7	19,.1	6.81	152.9	76.9	18.8	6.90	168.9	84.0	19.2
17	7.20	146.6	72.8	18.5	7.28	149.9	74.8	18.8	6.76	153.4	76.6	18.8	6.89	170.0	83.9	19.0
18	7.22	144.9	72.6	18.4	7.26	150.9	75.5	19.0	6.79	153.1	76.6	18.8	6.88	170.0	84.0	19.0
19	7.22	137.7	72.6	18.4	7.22	150.3	75.2	18.8	6.75	150.3	75.2	18.8	6.88	170.0	84.0	18.9
20	7.13	145.3	72.7	18.5	7.22	141.6	69.4	18.6	7.85	137.6	68.9	22.6	6.88	165.4	84.0	18.9

Appendix 2.2e: The pH, electrical conductivity, total dissolved salts and temperature readings obtained at 1 m intervals during April and June 2011 to at site 1 in Lake Nandoni.

	April 2011				June 2011			
Depth	pH	Conductivity (μScm^{-1})	otal dissolved salts (mgL^{-1})	Temperature (^oC)	pH	Conductivity (μScm^{-1})	otal dissolved salts (mgL^{-1})	Temperature (^oC)
1	6.15	162.3	57.5	25.8	6.71	146.0	73.2	21.0
2	7.06	131.3	65.6	25.8	6.75	141.0	70.5	19.7
3	6.90	125.9	63.0	25.7	6.96	140.8	7.5	19.0
4	7.10	117.5	58.8	25.5	6.95	141.7	70.9	18.8
5	7.24	117.5	58.5	25.6	6.72	141.7	70.9	18.6
6	7.37	118.6	59.3	24.8	6.61	143.5	71.9	18.5
7	7.41	117.9	58.9	24.3	6.62	142.1	70.9	18.5
8	7.43	117.9	58.9	24.2	6.8	142.5	71.4	18.4
9	7.51	120.4	60.3	24.0	6.9	143.1	71.6	18.4
10	7.48	128.7	64.4	23.5	6.75	144.3	72.2	18.4
11	7.27	149.3	74.8	22.5	6.8	144.3	72.2	18.5
12	7.08	159.9	80.0	21.7	6.87	145.7	72.9	18.4
13	7.03	168.4	84.2	21.0	6.77	143.8	71.9	18.4
14	7.11	181.4	90.5	20.6	7.01	144.3	72.2	18.4
15	7.13	173.7	86.9	20.8	7.08	143.0	71.6	18.4
16	7.12	158.6	79.3	20.8	6.98	143.5	71.9	18.4
17	7.11	182.8	91.4	20.4	7.09	143.9	72.1	18.4
18	6.15	162.3	57.5	20.8	7.1	147.3	73.3	18.4
19	6.10	162.5	58.0	20.3	6.88	145.9	73.0	18.4
20	6.10	164.0	58.0	20.3	7.04	146.7	73.4	18.4

Appendix 2.3a: The *in situ* parameters measured at 1 m intervals at site 2 during the period from July 2009 to June 2011 in Lake Nandoni.

Site no.	Month	Depth (m)	pH	Electrical conductivity (μScm^{-1})	Temperature (^oC)	Dissolved oxygen (%)	Dissolved oxygen (mgL^{-1})	TDS (ppm)
2	July	1	7.23	142.6	18.1	88.6	8.26	71.3
		2	7.65	140.4	17.9	83.3	8.13	70.3
		4	7.65	140.8	17.8	82.4	7.63	70.3
		6	7.74	140.1	17.8	96.4	9.26	70
	August	1	8.23	140.3	17	93.9	10.25	69.7
		2	8.21	136.6	17.1	102.1	9.56	68.2
		3	8.21	117.2	17.2	98.1	9.52	59.5
		4	7.94	139.2	17.1	73.4	7.08	69.4
		5	8	139.2	17	93.1	8.95	64
	September	1	8.97	141.0	23.1	111.3	9.83	70.5
		2	9.08	139.6	21.7	112.4	10.2	69.5
		3	8.95	139.9	20.8	115.9	9.93	69.9
		4	8.78	141.6	20.3	103.2	9.49	70.6
	October	1	7.65	139.4	24.1	99.9	8.36	67.6
		2	7.99	137.4	23.0	93.5	7.8	68.5
		3	7.84	137.5	22.2	81.3	6.97	68.4
	November	1	8.53	137.5	25.8	84.4	6.97	68.7
		2	8.41	136.6	25.7	86.7	6.95	68.2
	December	1	8.03	140.5	24.8	77.3	6.41	70.2
		2	8.08	137.7	25.0	78.0	6.31	69.1
		3	7.94	137.7	24.3	67.6	5.63	68.9
		4	7.68	136.5	24.2	57.5	5.3	68.3
	March	1	8.38	128.0	25.9	105.7	8.63	64.0
		2	8.38	127.8	26.0	102.8	8.52	63.4
		3	8.20	127.2	25.6	93.5	7.76	63.6
		4	7.95	125.7	25.6	91.7	7.59	62.9
		5	7.0	133.9	23.2	26.7	2.45	66.1
		6	6.41	149.0	22.6	27.6	2.37	74.4
	April	1	7.53	135.5	26.3	75.7	6.01	67.7
		2	7.60	135.7	25.4	71.0	5.94	67.6
		3	7.68	135.6	24.8	82.0	6.49	67.5
		4	7.66	136.1	24.3	69.3	5.78	68.6
	June	1	7.24	156.6	18.6	57.2	5.19	78.3
		2	7.27	156.5	18.5	54.5	4.99	78.3
		3	7.30	156.5	18.4	52.8	4.87	78.3
		4	7.31	156.6	18.4	50.3	4.63	78.3
		5	7.33	157.6	18.3	48.9	4.51	78.7

Appendix 2.3b: The *in situ* parameters measured at 1 m intervals at site 3 during the period from July 2009 to June 2011 in Lake Nandoni.

Site no.	Month	Depth (m)	pH	Electrical conductivity (μScm^{-1})	Temperature (^oC)	Dissolved oxygen (%)	Dissolved oxygen (mgL^{-1})	TDS (ppm)
3	July	1	8.13	139.3	18.2	96.7	8.94	69.7
		2	7.96	140.3	17.9	87.1	8.25	69.8
		3	7.91	139.8	17.8	83.6	8.0	69.7
		4	7.89	140.1	17.7	84	8.01	70.1
		5	7.87	140.2	17.5	84.1	7.89	70.1
	August	1	8.54	139.3	17.4	101.6	9.71	69.6
		2	8.51	139.9	17.4	100.1	9.72	69.7
		3	8.42	140.3	17.5	99.3	8.33	70.1
		4	8.22	128.3	17.4	98.4	8.82	64.5
	September	1	7.3	138.7	22.3	121.8	10.49	69.6
		2	9.4	138.9	21.1	131.3	11.75	69.5
		3	8.75	140.7	20.3	93.4	8.5	70.5
		4	8.43	140.6	19.8	89.3	8.05	70.3
		5	8	141.7	19.4	53.5	4.81	70.7
		6	7.6	142.0	19.3	47.9	6.11	71.4
	October	1	8.84	139.9	24.5	97.4	8.27	69.9
		2	8.85	139.6	24.3	96.3	8.25	69.8
		3	8.93	139.6	24.0	95.8	8.0	69.8
		4	8.98	139.6	23.6	94.6	7.74	69.6
		5	8.82	139.5	22.7	84.8	6.56	69.9
	November	1	8.74	138.6	27.7	98.9	7.96	69.0
		2	8.81	141.7	26.4	95.7	7.57	70.8
		3	8.67	138.2	25.9	85.4	6.85	69.1
		4	8.58	138.3	25.7	77.7	6.33	69.1
		5	8.55	138.2	25.6	82.3	6.74	68.1
	December	1	8.59	144.8	24.9	88.4	7.19	72.1
		2	8.56	153.1	25.1	88.7	7.06	71.4
		3	8.62	144.3	25.2	86.7	6.99	73.2
		4	8.53	146.2	24.9	79.8	6.68	72.9
		5	8.28	145.6	24.8	73.3	6.05	72.5
		6	7.37	143.1	24.1	48.5	4.03	69.5
		7	7.00	142.1	23.0	7.6	0.64	70.9
	March	1	8.55	125.2	28.1	101.3	7.94	62.5
		2	8.55	124.9	27.4	102.1	8.10	62.4
		3	8.45	124.8	26.6	191.5	8.14	62.6
		4	8.19	124.9	26.2	76.7	6.30	62.5
		5	7.85	124.4	26.0	72.5	5.98	62.3
	April	1	8.16	131.6	25.5	88.4	7.09	65.6
		2	8.16	131.5	25.4	86.0	7.00	66.0
		3	8.16	131.5	25.0	85.1	6.78	66.0
		4	8.14	133.1	24.2	69.7	5.73	66.7
		5	8.13	133.2	24.2	68.0	5.60	66.7
		6	8.13	134.0	24.0	68.6	5.56	66.7
		7	8.11	134.0	23.9	66.0	5.43	66.7
	June	1	6.97	159.4	18.7	66.2	5.96	79.8
		2	7.15	155.7	18.7	64.1	5.84	77.8
		3	6.63	155.8	18.6	64.5	5.94	77.7
		4	7.05	154.9	18.5	60.8	5.60	77.6
		5	7.10	154.6	18.4	57.7	5.36	77.2

Appendix 2.3c: The *in situ* parameters measured at 1 m intervals at site 4 during the period from July 2009 to June 2011 in Lake Nandoni.

Site no.	Month	Depth (m)	pH	Electrical conductivity (μScm^{-1})	Temperature (^oC)	Dissolved oxygen (%)	Dissolved oxygen (mgL^{-1})	TDS (ppm)
4	July	1	7.73	139.9	18.1	91.1	8.33	70
		2	7.74	140.2	18.2	90.6	8.55	70.1
		3	7.74	140.3	18.1	85.5	8.31	70
		4	7.74	140.4	18.1	85.7	7.99	70.1
	August	1	8.36	140.7	17.3	103.7	8.29	70.2
		2	8.49	140.2	17.4	100.2	8.63	70
		3	8.5	139.6	17.4	97.6	8.4	69.3
		4	8.49	140	17.5	97.4	8.3	69.9
		5	8.47	127.7	17.5	96.7	7.37	63.9
	September	1	9.28	140.1	22.9	124.2	9.47	70.3
		2	9.38	139	21.6	128.9	11.19	69.5
		3	8.97	139.1	20.2	106.6	9.32	69.6
		4	8.2	140.6	19.2	80.4	7.42	70.0
		5	7.69	142.3	18.5	26	2.3	71.2
	October	1	8.7	139.9	23.8	104.8	8.9	70.1
		2	8.8	139.4	22.8	109.2	9.5	69.7
		3	8.83	139.6	22.6	110.0	9.58	69.8
		4	8.23	140.4	21.4	72.3	6..38	70.3
		5	7.6	144.4	20.8	25.2	2.11	72.3
	November	1	8.52	138.1	28.0	88.4	6.79	69.0
		2	8.66	138.4	26.6	85.6	6.75	69.0
		3	8.67	138.9	25.9	84.5	6.76	69.5
		4	8.47	138.4	25.3	80.0	6.37	67.4
		5	8.09	138.2	24.5	63.6	5.23	69.3
		6	7.8	139.2	23.4	52.8	4.33	69.8
	December	1	8.53	138.8	26.5	83.1	7.69	69.2
		2	8.57	136.9	26.4	82.4	6.40	68.5
		3	8.63	138.7	26.6	82.6	6.91	69.3
		4	8.15	138.8	25.8	74.4	5.53	69.1
	March	1	8.33	124.0	27.5	115.8	9.33	61.9
		2	8.25	123.1	27.5	115.8	9.34	61.9
		3	8.33	131.1	27.5	115.3	9.29	65.4
		4	8.3	122.0	26.8	115.0	8.88	61.0
		5	8.45	121.3	27.4	115.0	9.32	60.6
		6	7.57	119.3	25.2	28.3	2.32	59.7
		7	7.34	117.4	24.3	20.1	1.60	58.9
		8	7.61	120.1	26.6	17.0	0.90	59.9
	April	1	7.25	118.3	25.4	97.3	6.99	59.3
		2	7.31	118.6	24.8	84.8	6.85	59.5
		3	7.41	119.0	24.4	72.4	6.05	59.5
		4	7.41	119.2	24.1	74.0	6.44	59.7
		5	7.41	119.9	24.0	62.4	5.47	60.1
		6	7.39	120.3	23.9	49.6	4.08	60.2
		7	7.29	122.4	23.8	22.1	1.92	61.3
		8	7.19	131.9	23.5	6.5	0.54	66.1
	June	1	7.2	155.2	18.9	71.4	6.53	77.4
		2	7.28	154.3	188.8	75.9	6.98	77.1
		3	7.04	154.4	18.7	66.3	6.07	77.2
		4	7.24	154.0	18.7	66.6	6.11	77.0
		5	7.36	154.2	18.7	69.1	6.36	77.2
		6	7.41	154.5	18.6	64.3	5.89	77.2
		7	7.45	154.1	18.6	62.9	5.78	77.1
		8	7.48	154.1	18.5	67.0	6.21	77.1

Appendix 2.3d: The *in situ* parameters measured at 1 m intervals at site 5 during the period from July 2009 to June 2011 in Lake Nandoni.

Site no.	Month	Depth (m)	pH	Electrical conductivity (μScm^{-1})	Temperature (^oC)	Dissolved oxygen (%)	Dissolved oxygen (mgL^{-1})	TDS (ppm)
5	July	1	8	139.9	18.1	83.6	7.91	69.8
		2	7.93	139.6	17.9	86.3	8.14	69.9
		3	7.94	140	17.8	80.2	7.61	69.9
		4	7.83	140	17.8	81.8	7.81	69.8
	August	1	8.36	139.7	17.7	103.5	9.92	69.9
		2	8.38	140.7	17.8	102.2	9.82	70.4
		3	8.36	139.9	17.8	101.2	9.12	69.9
		4	8.35	138.8	17.8	97.2	8.81	69.5
		5	8.31	139.1	17.8	96.4	8.33	69.5
		6	8.27	139.1	17.8	97.5	8.31	69.5
	September	1	9.62	139.8	24.2	104.1	9.26	69.9
		2	9.7	138.2	24.0	103.2	8.81	69.1
		3	9.33	140.1	21.7	102.6	8.63	69.9
		4	9.69	138.6	23.4	95.3	8.0	69.3
		5	7.95	141.7	19.7	51.1	4.6	71.2
		6	7.52	142.1	18.8	11.0	1.05	70.8
		7	7.31	142.9	18.6	9.7	0.88	71.2
	October	1	8.86	139.7	24.3	103.7	9.08	69.7
		2	9.02	139.7	23.3	95.2	8.29	69.9
		3	8.82	140.4	22.7	93.7	7.70	70.2
		4	8.68	140.4	22.4	90.3	7.65	70.3
		5	8.36	140.6	22.0	82.2	6.73	70.3
	November	1	8.63	139.5	26.8	78.8	6.2	69.8
		2	8.70	138.6	25.9	77.5	6.32	69.4
		3	8.78	138.6	25.8	77.6	6.5	69.2
		4	8.78	138.6	25.6	76.9	6.37	69.4
		5	8.62	131.5	25.5	77.6	6.33	65.5
	December	1	8.74	139.5	25.3	84.5	7.00	70.1
		2	8.81	137.0	25.6	86.8	7.09	68.7
		3	8.54	137.7	25.3	76.1	6.32	68.9
		4	7.58	138.8	24.6	45.0	3.63	69.5
	March	1	8.63	123.3	27.7	109.8	8.56	61.7
		2	8.63	123.3	26.9	107.0	8.53	61.6
		3	8.42	123.2	26.4	96.1	7.74	61.6
		4	8.07	123.2	26.1	85.2	6.95	61.6
	April	1	7.25	118.3	25.4	97.3	6.99	59.3
		2	7.28	118.6	24.8	84.8	6.85	59.5
		3	7.30	119.0	24.4	72.4	6.05	59.5
		4	7.35	119.2	24.1	74.0	6.44	59.7
	June	1	7.1	155.2	18.9	71.4	6.53	77.4
		2	7.0	154.3	188.8	75.9	6.98	77.1
		3	7.0	154.4	18.7	66.3	6.07	77.2
		4	6.9	154.0	18.7	66.6	6.11	77.0

Appendix 2.3e: The *in situ* physico-chemical parameters measured at 1 m intervals at sites 10, 11 and 12 in the period from July to December 2010 in Lake Nandoni.

Site no.	Month	Depth (m)	pH	Electrical conductivity (μScm^{-1})	Temperature (^oC)	Dissolved oxygen (%)	Dissolved oxygen (mgL^{-1})	TDS (ppm)
10	July	1	9.72	138.8	18.4	161.9	14.63	69.5
		2	8.05	181.9	16.5	78.8	7.44	90.9
		3	7.62	198.1	15.9	54.6	5.29	98.4
	August	1	9.08	135.7	17.4	103.1	10.27	68
		2	8.95	139	17.0	94.3	9.03	69.6
		3	7.82	170.8	16.0	71.4	6.92	85.7
	September	1	9.99	153.8	22.9	195.6	17.24	67.9
		2	8.15	199.2	21.1	65.5	6.06	99.2
		3	7.54	245.0	20.1	6.6	0.73	12.3
	October	1	9.91	150.2	26.2	170.5	16.3	75
	November	1	7.53	160.7	26.7	80.4	7.59	75.0
	December	1	9.54	147.1	29.6	160.8	11.66	74.0
		2	9.63	147.3	29.2	160.1	11.78	73.8
11	July	1	9.71	134.4	18.3	166.2	15.2	67.3
		2	9.22	131.3	17.7	119.2	11.89	65.6
		3	9.27	131	17.6	118.6	11.2	65.6
		4	8.28	120.4	16.4	77.1	7.54	60.3
	August	1	8.91	135.2	17	104.6	9.62	67.5
		2	8.82	135.8	17.2	89.9	8.64	67.4
		3	8.59	134.2	17.4	81.4	7.8	66.9
		4	8.15	132.9	17.3	72.3	6.72	66.4
	September	1	9.47	130.2	22.2	92.4	8.12	65.2
		2	9.4	116.5	21.8	102.6	8.83	58.2
	October	1	9.74	146.2	25.9	170.4	16.1	72.9
		2	9.34	139.3	24.2	167.6	14.57	69.7
	November	1	7.91	147.1	25.8	140.6	12.31	73.0
		2	7.87	148.6	26.0	120.4	11.42	74.3
	December	1	9.67	139.5	27.0	166.0	13.53	69.6
		2	9.45	139.7	26.8	167.0	13.44	69.5
12	July	1	8.59	137.7	18.0	88.7	8.43	68.8
		2	8.39	136.5	17.9	76.2	7.14	68.1
		3	7.82	137	17.7	52.7	4.76	68.7
		4	8.1	135.7	17.7	74.1	7.22	67.9
		5	7.63	136.5	17.6	43.3	4.08	68.3
	August	1	8.72	137.2	17.5	99.4	9.79	68.6
		2	8.63	139.4	18.1	88.8	8.48	69.8
		3	8.75	137.3	17.6	86.6	8.22	69.5
	September	1	10.4	146.8	23.3	134.8	12.8	73.3
		2	10.4	147.8	22.2	98.4	9.76	73.7
		3	8.52	138.6	21.0	25.0	2.43	69.4
	October	1	9.44	141.2	24.8	106.1	8.15	70.5
		2	9.63	140.6	24.4	92.3	7.9	70.3
		3	9.63	140.1	23.8	80.1	6.82	70.2
		4	9.58	140.5	23.6	74.1	6.07	70.3
		5	8.82	142.7	23.1	56.1	4.80	71.5
	November	1	9.65	142.0	27.8	139.1	10.46	70.8
		2	8.86	139.5	26.9	112.8	9.09	69.6
		3	7.77	138.0	26.2	51.2	4.58	75.3
		4	8.01	137.3	26.5	59.3	5.23	68.5
		5	7.48	137.5	25.0	18.7	1.37	76.5
	December	1	8.74	141.6	25.7	72.6	6.13	70.9
		2	8.53	143.3	25.4	61.2	4.92	72.1
		3	7.82	142.5	25.1	48.7	4.08	71.2
		4	6.97	142.8	24.6	15.7	1.16	71.5

Appendix 2.4a: The *in situ* parameters measured at the surface at sites 2, 3, 4, 5, 10, 11 and 12 in Lake Nandoni during the period September 2009 to June 2011.

Survey period	Time of survey	Site 2	Site 3	Site 4	Site 5	Time of survey	Site 10	Site 11	Site 12
pH									
Sept	9-10	8.73	8.95	8.73	8.81	13	10.3	10.3	9.32
Oct	13-14	7.33	8.65	8.63	8.7	12	9.41	8.6	9.16
Nov	16-17	8.14	8.24	8.14	8.47	9	8.2	8.3	9
Dec	13-14	8.72	8.49	8.73	9.0	12	8.77	9.63	8.84
Jan	16-17	8.61	8.6	8.28	8.72	12	9.28	9.45	9.37
Feb	16-17	8.29	8.82	8.47	8.24	12	9.12	9.18	9.16
March	14-16	7.44	8.47	8.05	8.62	13	9.75	10.3	9.17
April	14-16	7.66	7.25	7.45	7.71	15	7.95	7.3	7.4
May	14-16	6.75	7.73	6.78	7.17	15	9.02	9.13	8.82
June	14-16	7.01	7.36	7.01	7.43	15	9.78	9.74	9.12
July	14-16	7.23	8.05	7.14	7.81	15	9.63	9.56	9.5
August	14-16	8.22	8.57	8.28	8.12	10	9.04	9.13	8.72
Sept	14-16	8.81	7.3	9.14	9.67	12	9.04	9.56	9.46
Oct	14-16	8.14	8.66	8.62	8.84	12	9.13	9.84	9.36
Nov	14-16	8.27	8.59	8.48	8.48	14	9.46	10.03	9.65
Dec	14-16	7.54	8.3	7.86	8.6	13	9.45	9.38	8.9
March	14-16	8.05	8.44	8.2	8.1				
April	14-16	7.42	8.12	8.0	8.2				
June	14-16	6.72	6.41	6.73	7.01				
Electrical conductivity (μScm^{-1})									
Sept	9-10	158.7	158.3	158.7	159.5	13	156.5	156.5	160.1
Oct	13-14	162.3	163.6	162.9	164.9	12	177.2	173.9	161.7
Nov	16-17	166.3	167.3	165.6	167.4	9	179	179	164
Dec	13-14	157.3	158.6	157.6	158.8	12	146.3	151.5	153.8
Jan	16-17	155.3	155.4	154.5	155.4	12	147.4	146.3	139.7
Feb	16-17	150.9	148.8	152	151.6	12	142.4	142.4	133.7
March	14-16	139.1	138.8	143.1	138.2	13	136.4	153.1	142.7
April	14-16	137.1	134.0	135.4	133.9	15	113.2	114.3	107.0
May	14-16	130.3	129.1	129.9	129.6	15	128.6	128.8	125.3
June	14-16	137.5	135.6	136.4	135.9	15	130.6	130.3	128.2
July	14-16	140.6	139.2	140.4	139.3	15	136.6	135.8	135.8
August	14-16	139.7	139.2	139.6	139.3	10	137.3	135.2	137.2
Sept	14-16	137.7	138.8	137.4	138.7	12	141.0	150.2	149.6
Oct	14-16	138.7	139.5	139.7	138.8	12	150.2	143.1	139.9
Nov	14-16	138.7	138.6	137.8	138.2	14	161.6	145.1	144.0
Dec	14-16	136.4	137.8	137.2	137.2	13	147.2	140.3	139.5
March	14-16	124.6	129.6	119.8	124.8				
April	14-16	132.6	126.9	115.9	123.7				
June	14-16	156.3	150.9	154.3	154.0				

Appendix 2.4b: The *in situ* parameters measured at the surface at sites 2, 3, 4, 5, 10, 11 and 12 in Lake Nandoni during the period September 2009 to June 2011.

Survey period	Time of survey	Site 2	Site 3	Site 4	Site 5	Time of survey	Site 10	Site 11	Site 12
Temperature (^{o}C)									
Sept	9-10	19.2	22.1	19.9	19.9	13	23.0	23.0	23.2
Oct	13-14	22.8	24.7	23.6	22.9	12	27.2	25.7	25.7
Nov	16-17	29.1	27.8	28.4	27.6	9	28.4	27.9	27.2
Dec	13-14	28.01	30.3	28.8	28.8	12	29.9	29.9	30.1
Jan	16-17	27.4	27.4	28.4	27.4	12	28.7	28.5	28.4
Feb	16-17	28.1	30.4	28.9	31.3	12	30.1	29.9	29.3
March	14-16	28.8	29.5	29.5	29.5	13	30.7	30.6	29.4
April	14-16	28.2	29.5	27.9	29.2	15	30.0	29.6	26.1
May	14-16	22.6	24.1	22.3	22.7	15	22.6	22.5	22.5
June	14-16	21.7	20.9	21.5	21.0	15	21.1	20.1	20.0
July	14-16	18.4	18.7	18.3	19.0	15	19.0	19.0	18.6
August	14-16	17.3	17.8	17.3	17.8	10	17.5	17.6	17.5
Sept	14-16	23.8	22.3	23.6	24.2	12	24.2	24.5	22.6
Oct	14-16	24.2	24.7	23.8	24.5	12	26.7	26.7	25.1
Nov	14-16	27.6	28.6	28.2	27.9	14	28.5	29.3	28.7
Dec	14-16	25.0	25.3	27.2	25.7	13	29.6	28.8	27.6
March	14-16	26.6	29.3	27.9	28.7				
April	14-16	26.5	26.6	26.1	26.4				
June	14-16	18.8	19.2	19.0	19.3				
Dissolved oxygen (%)									
Sept	9-10	112.1	117.5	116.5	111.3	13	190.0	190.0	95.3
Oct	13-14	96.4	88.3	102.1	98.4	12	184.7	118.6	98.2
Nov	16-17	106.6	110.1	103.5	101.8	9	160.0	123	95.3
Dec	13-14	116.4	111.2	112.4	130.0	12	120.0	128	160
Jan	16-17	81.1	101.6	79.1	101.6	12	111.3	102.2	108.8
Feb	16-17	96.3	103.3	98.8	101.9	12	109.5	120.4	112.9
March	14-16	87.5	111.3	99.3	111.2	13	172.5	115.3	110.2
April	14-16	88.3	108.0	90.7	97.5	15	96.8	93.6	94.7
May	14-16	77.4	106.9	80.6	98.5	15	116.2	110.8	109.8
June	14-16	62.8	68.4	65.3	74.2	15	187.4	173.6	148.8
July	14-16	89	100.7	93.7	92.4	15	172.7	191.4	148.6
August	14-16	114.6	101.7	109.1	103.4	10	130.1	133.4	99.4
Sept	14-16	101.5	102.8	108.4	111.4	12	150.0	149.2	134.3
Oct	14-16	106.1	101.7	103.1	107.8	12	181.5	172.6	135.0
Nov	14-16	112.3	106.7	91.6	101.6	14	160.5	151.7	140.0
Dec	14-16	87.5	94.6	97.5	94.2	13	160.8	167.8	98.6
March	14-16	104.1	113.2	122.4	119.7				
April	14-16	89.1	104.4	93.4	101.2				
June	14-16	59.4	71.0	78.5	76.4				

Appendix 2.4 c: The *in situ* parameters measured at the surface at sites 2, 3, 4, 5, 10, 11 and 12 in Lake Nandoni during the period September 2009 to June 2011.

Survey period	Time of survey	Site 2	Site 3	Site 4	Site 5	Time of survey	Site 10	Site 11	Site 12
Dissolved Oxygen (mgL^{-1})									
Sept	9-10	10.15	9.4	10.15	10.75	13	19.8	19.8	8.01
Oct	13-14	8.09	7.59	8.65	8.73	12	13.99	8.88	7.67
Nov	16-17	8.09	8.32	7.79	8.02	9	12.7	9	8.23
Dec	13-14	8.21	7.62	8.05	9.34	12	9.55	8.96	10.45
Jan	16-17	6.34	7.98	6.21	7.98	12	8.08	7.28	9.04
Feb	16-17	7.52	7.72	7.6	8.04	12	8.03	9.25	8.7
March	14-16	6.59	8.34	7.6	8.02	13	12.74	9.1	10.92
April	14-16	7.07	7.86	6.81	7.36	15	7.22	6.9	7.12
May	14-16	7.37	8.97	7.04	8.25	15	9.86	8.89	9.6
June	14-16	5.42	6.02	5.54	5.86	15	16.9	18.47	15.79
July	14-16	8.29	9.55	8.87	8.6	15	15.73	17.52	15.41
August	14-16	10.25	10.7	10.51	10.64	10	13.2	13.2	9.79
Sept	14-16	9.96	9.49	9.74	9.4	12	12.6	13.12	13.9
Oct	14-16	8.83	9.39	9.47	8.75	12	18.46	17.92	17.44
Nov	14-16	9.9	9.26	7.91	6.21	14	12.7	12.5	11.3
Dec	14-16	7.5	7.77	8.02	7.75	13	11.6	13.03	7.85
March	14-16	8.51	8.84	9.79	9.48				
April	14-16	7.24	8.52	7.51	8.0				
June	14-16	5.39	6.49	78.5	79.0				
TDS (mgL^{-1})									
Sept	9-10	79.4	79.2	79.5	79.7	13	89.2	85.4	78.0
Oct	13-14	81.2	81.5	82.1	82.4	12	88.2	87.3	80.9
Nov	16-17	82.8	83.7	82.11	83.5	9	88.2	86.4	80.9
Dec	13-14	79.3	78.2	79.1	79.3	12	75.7	75.7	76.5
Jan	16-17	77.6	77.6	76.9	77.6	12	73.6	73.3	69.9
Feb	16-17	75.7	74.5	75.9	75.4	12	71.3	71.2	66.7
March	14-16	69.5	69.3	71.3	69.2	13	68.6	76.5	71.0
April	14-16	68.4	67.1	67.8	66.9	15	56.5	57.2	63.4
May	14-16	65.1	64.6	64.9	64.6	15	64.1	64.2	62.5
June	14-16	68.7	68.4	68.1	67.9	15	65.3	65.2	64.0
July	14-16	70.1	69.6	70.0	69.6	15	67.8	67.7	67.9
August	14-16	69.8	69.6	69.8	69.5	10	68.4	67.7	68.6
Sept	14-16	68.9	69.8	68.9	69.1	12	70.3	74.9	74.4
Oct	14-16	69.3	69.7	69.6	69.6	12	75.0	72.1	69.9
Nov	14-16	68.7	69.2	69.0	69.8	14	74.3	72.6	72.0
Dec	14-16	68.2	68.9	68.4	68.6	13	74.0	70.3	69.5
March	14-16	62.0	64.8	59.4	62.2				
April	14-16	66.5	63.2	58.4	61.7				
June	14-16	78.2	74.3	78.5	74.7				

Appendix 2.5a: Chemical analyses of the water samples collected at sites 1and 2 in Lake Nandoni during the period September 2009 to December 2010 (Concentration in mgL^{-1}).

Site number	Date of survey	Ammonium	Nitrite	Nitrate	Phosphate
1	October 2009	0.22	0.03	0.6	0.2
	November	0.14	0.07	2.3	0.35
	December	0.15	0.07	0.9	0.16
	January 2010	0.1	0.06	1.3	0.18
	February	0.1	0.07	0.4	0.22
	March	0.16	0.08	0.7	0.15
	April	0.1	0.09	1.3	1.38
	May	0.16	0.09	0.8	0.48
	June	0.25	0.06	0.7	0.05
	July	0.17	0.09	0.5	0.49
	August	0.13	0.07	0.8	0.17
	September	0.05	0.05	4.1	0.91
	October	0.43	0.03	0.3	1.07
	November	0.15	0.04	2.9	0.36
	December	0.1	0.04	2.6	0.64
2	September	0.23	0.05	0.5	0.31
	October	0.9	0.22	0.5	0.17
	November	0.09	0.05	1	0.26
	December	0.15	0.03	0.5	0.21
	January	0.25	0.05	0.9	0.18
	February	0.29	0.06	0.5	0.1
	March	0.17	0.04	0.6	0.18
	April	0.1	0.06	1.2	0.21
	May	0.13	0.06	0.7	0.15
	June	0.1	0.08	0.7	0.07
	July	0.14	0.09	0.9	0.46
	August	0.12	0.05	0.5	0.2
	September	0.1	0.06	0.5	0.35
	October	0.23	0.03	0.4	0.13
	November	0.1	0.03	0.9	0.29
	December	0.16	0.05	0.3	0.71

Appendix 2.5b: Chemical analyses of the water samples collected at sites 3 and 4 in Lake Nandoni during the period September 2009 to December 2010 (Concentration in mgL^{-1}).

Site number	Date of survey	Ammonium	Nitrite	Nitrate	Phosphate
3	September	0.13	0.07	1.6	0.17
	October	0.27	0.08	0.5	0.23
	November	0.11	0.05	1.9	0.26
	December	0.12	0.06	1.1	0.1
	January	0.17	0.06	1.4	0.9
	February	0.19	0.06	1.6	1
	March	0.16	0.07	0.8	0.7
	April	0.1	0.07	0.7	0.26
	May	0.12	0.09	1	0.21
	June	0.31	0.05	0.7	0.19
	July	0.35	0.07	0.5	0.52
	August	0.12	0.06	1.1	0.24
	September	0.4	0.05	3.8	0.18
	October	0.12	0.05	1.9	0.3
	November	0.17	0.04	2.7	0.35
	December	0.22	0.07	2.6	0.41
4	September	0.05	0.04	0.5	0.18
	October	0.03	0.04	0.5	0.15
	November	0.17	0.04	0.6	0.25
	December	0.18	0.03	1.6	0.18
	January	0.15	0.05	0.3	0.21
	February	0.18	0.07	0.8	0.57
	March	0.36	0.06	0.8	0.27
	April	0.32	0.23	0.9	0.48
	May	0.15	0.07	0.9	0.25
	June	0.42	0.07	0.7	0.46
	July	0.38	0.1	0.8	0.28
	August	0.43	0.07	1.5	0.19
	September	0.23	0.23	3.7	0.97
	October	0.23	0.03	0.3	0.10
	November	0.16	0.03	2.3	0.21
	December	0.16	0.06	2.8	1.10

Appendix 2.5c: Chemical analyses of the water samples collected at site 5 and 10 in Lake Nandoni during the period September 2009 to December 2010 (Concentration in mgL^{-1}).

Site number	Date of survey	Ammonium	Nitrite	Nitrate	Phosphate
5	September	0.19	0.04	0.9	0.2
	October	0.12	0.04	0.7	0.1
	November	0.43	0.05	0.7	0.24
	December	0.17	0.03	1.5	0.18
	January	0.1	0.04	4.6	0.22
	February	0.06	0.17	0.5	0.41
	March	0.37	0.08	1.2	0.44
	April	0.1	0.06	0.7	0.39
	May	0.37	0.05	1.1	0.15
	June	0.18	0.24	0.5	0.32
	July	0.25	0.07	0.7	0.17
	August	0.16	0.05	1.5	0.33
	September	0.37	0.09	3.0	1.41
	October	0.26	0.04	1.5	0.93
	November	0.16	0.03	2.3	0.21
	December	0.16	0.06	2.8	1.1
10	September	0.27	0.11	3.3	1.09
	October	0.67	0.14	2.0	0.49
	November	0.73	0.15	2.3	0.35
	December	0.17	0.07	1.5	0.25
	January	0.43	0.02	1.7	0.09
	February	0.23	0.07	0.8	0.34
	March	0.14	0.07	1.7	0.52
	April	0.27	0.07	1.2	0.1
	May	0.2	0.08	1.3	0.58
	June	0.17	0.06	1.5	0.4
	July	0.16	0.14	1	0.55
	August	0.13	0.09	1.5	0.12
	September	0.05	0.11	4.3	3.15
	October	0.91	0.09	2.5	2.3
	November	0.35	0.15	2.6	2.65
	December	0.26	0.08	3.9	3.38

Appendix 2.5d: Chemical analyses of the water samples collected at site 5 and 10 in Lake Nandoni during the period September 2009 to December 2010 (Concentration in mgL^{-1}).

Site number	Date of survey	Ammonium	Nitrite	Nitrate	Phosphate
11	September	0.2	0.11	2.2	0.21
	October	0.42	0.12	0.8	0.52
	November	0.23	0.1	2.1	0.41
	December	0.18	0.05	1.3	0.21
	January	0.27	0.09	0.5	0.37
	February	0.06	0.07	0.7	1.15
	March	0.23	0.06	0.4	0.31
	April	0.2	0.06	0.9	0.05
	May	0.16	0.02	0.7	0.11
	June	0.14	0.1	1.3	0.13
	July	0.67	0.08	1.2	0.34
	August	0.54	0.11	0.9	0.45
	September	1.18	0.12	4.5	0.81
	October	0.21	0.05	2.4	1.47
	November	0.66	0.28	2.1	1.95
	December	0.14	0.07	4.0	1.9
12	September	0.19	0.06	0.7	0.19
	October	0.17	0.06	2.2	0.16
	November	0.13	0.05	2.5	0.28
	December	0.13	0.07	2.0	0.13
	January	0.4	0.11	1	0.79
	February	0.36	0.05	0.5	0.65
	March	0.23	0.07	2.4	0.19
	April	0.15	0.07	1	0.81
	May	0.34	0.05	1.2	0.08
	June	0.24	0.1	0.5	0.32
	July	0.57	0.11	0.7	0.74
	August	0.26	0.07	1	0.36
	September	1.6	0.05	3.6	0.55
	October	0.27	0.06		1.74
	November	0.48	0.12	2.2	0.90
	December	0.34	0.06	3.5	0.99

Appendix 2.6a: The turbidity and total suspended solids recorded in the water samples collected at sites 1, 2 and 3 in Lake Nandoni during the period September 2009 to December 2010.

Site number	Date of survey	Total suspended solids (mgL^{-1})	Turbidity (NTU)
1	January	10	8
	February	7	7
	March	17	4
	April	12	3
	May	6	1
	June	14.5	4
	July	5	1
	August	17.5	1.1
	September	3	1
	October	3.5	2
	November	3.5	1
	December	3.0	1
2	January	19	1
	February	19.5	7
	March	6	4
	April	10.5	6
	May	10	4
	June	16.5	4
	July	8.5	2
	August	5	1
	September	7	1
	October	6	1
	November	2.0	3
	December	4.5	1
3	January	15	2
	February	17	2
	March	7.5	3
	April	8.5	2
	May	13	5
	June	5.5	1
	July	11	3
	August	8.5	1
	September	5	3
	October	10	2
	November	4.5	1
	December	4.5	1

Appendix 2.6b: The turbidity and total suspended solids recorded in the water samples collected at sites 4, 5 and 10 in Lake Nandoni during the period September 2009 to December 2010.

Site number	Date of survey	Total suspended solids (mgL^{-1})	Turbidity (NTU)
4	January	18	1
	February	7.5	1
	March	10	1
	April	13	1
	May	11	1
	June	14	2
	July	9.5	4
	August	4.5	2
	September	3	2
	October	2.5	1
	November	5.5	1
	December	5	1
5	January	17	2
	February	19	6
	March	16.5	4
	April	12.5	6
	May	9.5	2
	June	10	3
	July	7	1
	August	3.5	5
	September	6.5	6
	October	1	1
	November	8	0.5
	December	6.5	1
10	January	25.5	3
	February	13.5	5
	March	20.5	6
	April	14.5	4
	May	36	1.2
	June	16.5	2
	July	18.5	5
	August	16.5	8
	September	11	9
	October	14.5	11
	November	19	9
	December	6	1

Appendix 2.6c: The turbidity and total suspended solids recorded in the water samples collected at sites 11 and 12 in the Lake Nandoni during the period September 2009 to December 2010.

Site number	Date of survey	Total suspended solids (mgL^{-1})	Turbidity (NTU)
11	January	28.5	9
	February	12.5	7
	March	32	2
	April	23	**8**
	May	5.5	1
	June	35.5	7
	July	10.5	2
	August	34	9
	September	27	13
	October	16	6
	November	24.5	10
	December	18.5	8
12	January	13	2
	February	4	6
	March	25.5	3
	April	18	4
	May	14	1
	June	54.5	1.3
	July	17	6
	August	7.5	1
	September	17	3
	October	12.5	3
	November	24.5	2
	December	18.5	8

Appendix 2.7a: The *in situ* physico-chemical parameters measured at the three rivers sites during the period September 2009 to April 2011 in Lake Nandoni (IA refers to sites that were not accessible).

Survey period	Site 13	Site 14	Site 15
pH			
Sept	7.33	7.84	7.71
Oct	7.14	7.74	7.98
Nov	6.67	6.8	7.06
Dec	6.69	7.19	7.33
Jan	8.75	8.1	8.1
Feb	IA	7.3	7.71
March	7.03	7.25	7.75
April	7.31	7.22	7.38
May	6.6	6.67	6.79
June	7.45	7.2	7.63
July	7.33	7.59	7.51
August	7.01	7.75	7.48
September	7.63	8.39	8.31
October	7.06	7.72	8.19
November	7.08	7.34	7.16
December	7.02	7.15	7.43
April	6.65	6.47	6.42
Electrical Conductivity (mgL^{-1})			
Sept	330	137.2	133.5
Oct	359	150.3	148.4
Nov	382	156.8	157.1
Dec	176.3	119.6	120.3
Jan	138.6	107	114.1
Feb	IA	94.2	104.7
March	182.7	85.5	94.5
April	135.5	101.6	112.3
June	190.7	101.4	110.0
July	194.8	112.4	115.5
August	183.5	115.4	116.1
September	246.0	121.1	121.3
October	310.0	123.6	140.0
November	291.0	146.2	150.3
December	239.0	132.7	131.3
April	186.7	127.6	123.7

Appendix 2.7b: The *in situ* physico-chemical parameters measured at the three rivers sites during the period September 2009 to April 2011 (IA refers to sites that were not accessible).

Temperature (^{o}C)			
Survey period	**Site 13**	**Site 14**	**Site 15**
Sept	18.6	18.3	20.2
Oct	22.1	21.3	23.2
Nov	21.3	20.4	21.7
Dec	24.2	24.7	26.6
Jan	28.9	23.3	27.3
Feb	IA	24	28.9
March	27.9	23.9	29.6
April	25.3	23.1	25.1
May	21	20.1	20.9
June	16.1	16.8	16.9
July	14.6	14.7	15.1
August	15.4	15.2	15.3
September	19.4	19.5	21.9
October	23.8	23.9	25.8
November	24.1	23.6	25.5
December	22.3	21.9	23.8
April	20.4	20.8	21.8
Dissolved oxygen saturation (%)			
Sept	7.1	100.2	92.4
Oct	0	84.5	86.0
Nov	35.5	99.6	103.1
Dec	79.4	94.6	92.9
Jan	58	101.7	97.7
Feb	IA	87.4	96.6
March	71.8	90.1	101.4
April	89.2	86.7	96.2
May	95.6	98.8	101.7
June	92.8	101.1	98.4
July	84.2	98.9	96.2
August	91.2	110.9	110.1
September	82.6	119.7	105.9
October	96.5	117.2	108.3
November	86.6	80.2	103.2
December	70.5	82.8	82.3
April	82.5	96.3	94.3

Appendix 2.7 c: The *in situ* physico-chemical parameters measured at the three rivers sites during the period September 2009 to April 2011 (IA refers to sites that were not accessible).

Dissolved oxygen concentration (mgL^{-1})			
Survey period	**Site 13**	**Site 14**	**Site 15**
Sept	0.69	9.28	8.04
Oct	0	7.43	6.92
Nov	3.1	9.25	9.3
Dec	6.75	7.64	7.5
Jan	7.21	7.71	7.22
Feb	IA	6.28	6.66
March	5.73	7.03	7.73
April	7.22	7.21	7.78
May	8.13	8.23	9.18
June	8.1	9.35	8.91
July	8.15	9.71	9.28
August	9.36	11.0	10.7
September	7.49	10.33	8.65
October	8.05	9.0	8.9
November	7.14	7.0	8.2
December	6.10	7.21	6.92
April	7.36	8.49	8.26
TDS (ppm)			
Sept	164	68.2	67.1
Oct	179	74.6	74.2
Nov	151	78.4	70.1
Dec	88.2	60.3	60.3
Jan	69.1	53.6	57.4
Feb	IA	32.6	52.3
March	91.6	45	57.9
April	67.8	50.6	56.1
June	95.6	50.9	54.8
July	97.3	56.2	57.6
August	91.8	57.7	57.9
September	123.0	60.4	60.5
October	156.0	62.1	70.1
November	145.0	73.2	57.4
December	120.0	66.4	66.9
April	93.3	63.4	62.2

Appendix 3.1a: Phytoplankton diversity and abundance as observed in December 2009 at sites 2 to and 10 to 12 in Lake Nandoni.

December 2009	Site 1		Site 2		Site 3		Site 4		Site 10		Site 12	
	Cells/ ml	% comp	Cells/ ml	% comp	Cells/ ml	% comp	Cells/ ml	% comp	Cells/ ml	% comp	Cells/ ml	% comp
CYANOPHYCEAE												
Anabaena sp.									592	29.1	420	19.0
Microcystis aeruginosa	23	2.8			100	7.8	194	10.3				
Microcystis flos-aquae							372	19.7	403	19.8		
Pseudanabaena sp.	615	75.4	1032	70.8	1078	83.8	1181	62.5	955	47.0	1645	74.2
BACILLARIOPHYCEAE												
Aulacoseira granulata	20	2.5	43	2.9	29	2.2	23	1.2	51	2.5	54	2.5
Cocconeis pediculus			11	0.8					3	0.1		
Cyclotella meneghiniana									3	0.1		
Fragilaria sp.			194	13.3	3	0.2	29	1.5	6	0.3	3	0.1
Gomphonema spp.							3	0.2				
Navicula spp.	3	0.4	9	0.6	3	0.2						
Nitzschia palea			11	0.8								
CHLOROPHYCEAE												
Carteria sp.	3	0.4	6	0.4			3	0.2				
Chlamydomonas sp.	37	4.6	29	2.0	9	0.7	31	1.7				
Chlorococcum infusionum									3	0.1		
Coelastrum pseudomicroporum							23	1.2				
Monoraphidium sp.	3	0.4			9	0.7	3	0.2				
Oocystis lacustris	11	1.4										
Pediastrum duplex	46	5.6										
Pediastrum simplex			20	1.4								
Scenedesmus disciformis	29	3.5	46	3.1			11	0.6	11	0.6	11	0.5
Staurastrum sp.			23	1.6	3	0.2	11	0.6	3	0.1		
Tetraedron planctonica	17	2.1	6	0.4	3	0.2						
DINOPHYCEAE												
Ceratium hirundinella			17	1.2	51	4.0					74	3.4
Peridinium sp.	3	0.4	9	0.6			6	0.3				
EUGLENOPHYCEAE												
Strombomonas vermicosa	3	0.4										
Trachelomonas intermedia	3	0.4	3	0.2					3	0.1	9	0.4
-												
Total Cyanophyceae	638	78.2	1032	70.8	1178	91.6	1747	92.4	1951	95.9	2065	93.2
Total Bacillariophyceae	23	2.8	269	18.4	34	2.7	54	2.9	63	3.1	57	2.6
Total Chlorophyceae	146	17.9	129	8.8	23	1.8	83	4.4	17	0.8	11	0.5
Total Dinophyceae	3	0.4	26	1.8	51	4.0	6	0.3	0	0.0	74	3.4
Total Euglenophyceae	6	0.7	3	0.2	0	0.0	0	0.0	3	0.1	9	0.4
TOTAL CELLS/ML	**815**	**100.0**	**1459**	**100.0**	**1287**	**100.0**	**1890**	**100.0**	**2033**	**100.0**	**2217**	**100.0**

Appendix 3.1b: Phytoplankton diversity and abundance as observed in February 2010 at sites 2 to 5 and 10 to 12 in Lake Nandoni.

February 2010	Site 1		Site 2		Ste 3		Site 4		Site 5		Site 10		Site 11		Site 12	
	Cells/ml	% comp	Cells/ml	% comp	Cells/ml	% comp	Cells/ml	% comp	Cells/ml	% comp	Cells/ml	% comp	Cells/ml	% comp	Cells/ml	% comp
CYANOPHYCEAE																
Anabaena sp.											63	6.5	408	9.4	119	3.3
Microcystis aeruginosa	123	9.8									289	30.1	308	7.1	157	4.4
Pseudanabaena sp.	744	59.4	114	26.3	789	65.2			257	44.3	492	51.2	3337	77.0	2632	73.2
BACILLARIOPHYCEAE																
Achnanthes minutissima									40	6.9					29	0.8
Aulacoseira granulata					29	2.4			17	3.0	17	1.8	72	1.7	67	1.9
Cocconeis pediculus	3	0.2									6	0.6	7	0.2	10	0.3
Cyclotella meneghiniana			9	2.0					6	1.0	3	0.3				
Cyclotella sp.													36	0.8	29	0.8
Cymbella spp.							3	0.6								
Fragilaria sp.	72	5.7	49	11.2	154	12.8			46	7.9						
Melosira varians															10	0.3
Navicula spp.							3	0.6	20	3.4					19	0.5
CHLOROPHYCEAE																
Carteria sp.			3	0.7			3	0.6								
Chlamydomonas sp.	37	3.0	3	0.7	17	1.4	3	0.6	11	2.0	3	0.3			29	0.8
Chlorella sp.	49	3.9	117	27.0												
Chlorococcum infusionum							6	1.2								
Closterium cornu													7	0.2		
Closterium sp.	9	0.7	6	1.3												
Coelastrum sp.	23	1.8	46	10.5												
Eudorina elegans									46	7.9						
Gonatozygon sp.													36	0.8	67	1.9
Monoraphidium minutum									6	1.0	3	0.3				
Monoraphidium sp.	20	1.6														
Oocystis lacustris											11	1.2	7	0.2		
Pediastrum simplex											46	4.8				
Scenedesmus acuminatus	11	0.9														
Scenedesmus disciformis	103	8.2	46	10.5	97	8.0	23	4.9	51	8.9			57	1.3	38	1.1
Scenedesmus quadricauda															19	0.5
Staurastrum sp.	23	1.8	14	3.3	29	2.4	3	0.6	9	1.5			7	0.2	24	0.7
Tetraedron minimum									6	1.0						
Tetraedron planctonica			3	0.7												
Tetrastrum sp.					11	0.9										

Appendix 3.1b (cont.)

February 2010	Site 1		Site 2		Ste 3		Site 4		Site 5		Site 10		Site 11		Site 12	
	Cells/ml	% comp	Cells/ml	% comp	Cells/ml	% comp	Cells/ml	% comp	Cells/ml	% comp	Cells/ml	% comp	Cells/ml	% comp	Cells/ml	% comp
CRYPTOPHYCEAE																
Cryptomonas major													14	0.3		
DINOPHYCEAE																
Ceratium hirundinella	17	1.4	9	2.0	60	5.0	3	0.6	40	6.9			7	0.2	309	8.6
Peridinium sp.	3	0.2			3	0.2	3	0.6								
Sphaerodinium sp.											14	1.5	7	0.2		
EUGLENOPHYCEAE																
Euglena pusilla									3	0.5						
Euglena sp.			3	0.7												
Trachelomonas intermedia	17	1.4	14	3.3	9	0.7			14	2.5					5	0.1
Trachelomonas volvocina					11	0.9	415	89.5	9	1.5	14	1.5	21	0.5	33	0.9
Total Cyanophyceae	867	69.2	114	26.3	789	65.2	0	0.0	257	44.3	844	87.8	4053	93.6	2908	80.9
Total Bacillariophyceae	74	5.9	57	13.2	183	15.1	6	1.2	129	22.2	26	2.7	115	2.6	162	4.5
Total Chlorophyceae	275	21.9	237	54.6	154	12.8	37	8.0	129	22.2	63	6.5	115	2.6	176	4.9
Total Cryptophyceae	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	14	0.3	0	0.0
Total Dinophyceae	20	1.6	9	2.0	63	5.2	6	1.2	40	6.9	14	1.5	14	0.3	309	8.6
Total Euglenophyceae	17	1.4	17	3.9	20	1.7	415	89.5	26	4.4	14	1.5	21	0.5	38	1.1
TOTAL CELLS/ML	**1253**	**100.0**	**435**	**100.0**	**1210**	**100.0**	**463**	**100.0**	**581**	**100.0**	**961**	**100.0**	**4332**	**100.0**	**3594**	**100.0**

Appendix 3.1c: Phytoplankton diversity and abundance as observed in April 2010 at sites 2 to 5 and 10 to 12 in Lake Nandoni.

April 2010	Site 2		Site 3		Site 4		Site 5		Site 10		Site 11		Site 12	
	Cells/ml	% comp	Cells/ml	% comp	Cells/ml	% comp	Cells/ml	% comp	Cells/ml	% comp	Cells/ml	% comp	Cells/ml	% comp
CYANOPHYCEAE														
Microcystis aeruginosa	988	25.3	1042	30.9	809	17.9	275	14.5	801	52.9			422	9.0
Pseudanabaena sp.	1274	32.6	843	25.0	2169	48.0	626	33.1	386	25.5	664	57.6	2456	52.6
BACILLARIOPHYCEAE														
Achnanthes minutissima	129	3.3	14	0.4	100	2.2	14	0.8	40	2.6	29	2.5	193	4.1
Aulacoseira granulata	14	0.4	24	0.7	43	1.0	6	0.3	20	1.3	9	0.7		
Cocconeis pediculus	21	0.5	10	0.3	29	0.6	3	0.2	3	0.2	11	1.0	7	0.2
Cyclotella meneghiniana	122	3.1	19	0.6										
Cyclotella sp.			67	2.0	172	3.8	57	3.0	6	0.4	17	1.5	29	0.6
Fragilaria ulna	215	5.5	181	5.4	558	12.4	323	17.1	26	1.7				
Navicula spp.	7	0.2			7	0.2	3	0.2			3	0.2	7	0.2
Nitzschia spp.											26	2.2	115	2.5
Synedra ulna											11	1.0	36	0.8
CHLOROPHYCEAE														
Chlamydomonas sp.	36	0.9					11	0.6	31	2.1	9	0.7		
Chlorococcum infusionum	7	0.2			14	0.3								
Closterium cornu	14	0.4					11	0.6	6	0.4	9	0.7	7	0.2
Cosmarium sp.					14	0.3					3	0.2	7	0.2
Crucigenia tetrapedia	107	2.7	152	4.5	143	3.2	46	2.4						
Crucigeniella rectangularis	143	3.7	343	10.2	86	1.9	80	4.2	11	0.8	80	6.9		
Gonatozygon sp.	21	0.5							6	0.4				
Kirchneriella sp.			76	2.3										
Monoraphidium minutum	115	2.9	10	0.3	7	0.2	23	1.2	9	0.6				
Monoraphidium sp.	21	0.5									6	0.5	50	1.1
Oocystis lacustris			19	0.6							26	2.2		
Pandorina morum			76	2.3										
Pediastrum simplex					57	1.3							115	2.5
Pediastrum tetras													57	1.2
Pteromonas angulosa			19	0.6			9	0.5						
Scenedesmus disciformis	258	6.6	228	6.8	29	0.6	166	8.8	43	2.8	92	7.9	200	4.3
Scenedesmus quadricauda											6	0.5		
Sphaerocystis sp.													93	2.0
Staurastrum sp.	379	9.7	148	4.4	200	4.4	74	3.9	31	2.1	49	4.2	200	4.3
Tetraedron minimum					7	0.2	6	0.3						
Tetrastrum sp.											11	1.0		
CHRYSOPHYCEAE														
Dinobryon sertularia					7	0.2								
DINOPHYCEAE														
Ceratium hirundinella	21	0.5	81	2.4	64	1.4	143	7.6	77	5.1	92	7.9	644	13.8
Sphaerodinium sp.							3	0.2						
EUGLENOPHYCEAE														
Euglena sp.	7	0.2							6	0.4				
Trachelomonas intermedia	7	0.2	19	0.6			9	0.5	3	0.2	3	0.2		
Trachelomonas volvocina			5	0.1			3	0.2	9	0.6			29	0.6
Total Cyanophyceae	2263	57.9	1885	55.9	2979	65.9	901	47.7	1187	78.4	664	57.6	2878	61.7
Total Bacillariophyceae	508	13.0	314	9.3	909	20.1	406	21.5	94	6.2	106	9.2	387	8.3
Total Chlorophyceae	1103	28.2	1071	31.7	558	12.4	426	22.5	137	9.1	289	25.1	730	15.6
Total Chrysophyceae	0	0.0	0	0.0	7	0.2	0	0.0	0	0.0	0	0.0	0	0.0
Total Dinophyceae	21	0.5	81	2.4	64	1.4	146	7.7	77	5.1	92	7.9	644	13.8
Total Euglenophyceae	14	0.4	24	0.7	0	0.0	11	0.6	17	1.1	3	0.2	29	0.6
TOTAL CELLS/ML	**3909**	**100.0**	**3375**	**100.0**	**4518**	**100.0**	**1890**	**100.0**	**1513**	**100.0**	**1153**	**100.0**	**4668**	**100.0**

Appendix 3.1d: Phytoplankton diversity and abundance as observed in May 2010 at sites 2 to 5 and 10 to 12 in Lake Nandoni.

May 2010	Site 1		Site 2		Site 3		Site 4		Site 5		Site 10		Site 11		Site 12	
	Cells/ml	% comp	Cells/ml	% comp	Cells/ml	% comp	Cells/ml	% comp	Cells/ml	% comp	Cells/ml	% comp	Cells/ml	% comp	Cells/ml	% comp
CYANOPHYCEAE																
Anabaena sp.															72	4.1
Merismopedia minima	92	7.2														
Microcystis aeruginosa			123	13.1	106	7.6	149	9.9			1117	30.4			51	2.9
Microcystis wesenbergii					49	3.5										
Oscillatoria sp.							72	4.8								
Pseudanabaena sp.	20	1.6	72	7.6	349	25.2	183	12.2	146	11.9	86	2.3	20	1.7	23	1.3
BACILLARIOPHYCEAE																
Achnanthes minutissima	57	4.5	26	2.7	34	2.5	11	0.8	46	3.7	14	0.4	3	0.2	3	0.2
Aulacoseira granulate	29	2.3							11	0.9	7	0.2				
Cocconeis pediculus	6	0.5	6	0.6							14	0.4				
Cyclotella sp.	174	13.8	94	10.1	114	8.3	60	4.0	83	6.8	100	2.7	23	1.9	20	1.1
Cymbella spp.											7	0.2				
Fragilaria ulna	521	41.2	403	43.0	106	7.6	746	49.6	106	8.7	100	2.7	9	0.7	72	4.1
Gyrosigma sp.											14	0.4				
Navicula spp.											7	0.2			11	0.7
Nitzschia spp.					3	0.2			3	0.2						
Synedra ulna	3	0.2											9	0.7		
CHLOROPHYCEAE																
Carteria sp.			3	0.3			3	0.2								
Chlamydomonas sp.	74	5.9	3	0.3	20	1.4	6	0.4			7	0.2	14	1.2	6	0.3
Closterium cornu			23	2.4	11	0.8	23	1.5	26	2.1	29	0.8	29	2.4	9	0.5
Cosmarium sp.					3	0.2										
Crucigenia tetrapedia	23	1.8	23	2.4			23	1.5	46	3.7						
Crucigeniella rectangularis	80	6.3	46	4.9	149	10.7	57	3.8	252	20.6	301	8.2	92	7.7	114	6.5
Monoraphidium minutum	11	0.9	11	1.2	3	0.2			20	1.6					3	0.2
Monoraphidium sp.			6	0.6	3	0.2	14	1.0	26	2.1			6	0.5	11	0.7
Oocystis lacustris							11	0.8			29	0.8	17	1.4		
Pandorina morum											229	6.2				
Pediastrum simplex					46	3.3										
Pediastrum tetras			11	1.2												
Pteromonas angulosa	3	0.2														
Scenedesmus disciformis	69	5.4	23	2.4			11	0.8	57	4.7	57	1.6	34	2.9		
Sphaerocystis sp.									69	5.6						
Staurastrum sp.	57	4.5	34	3.7	100	7.2	54	3.6	66	5.4	36	1.0	29	2.4	11	0.7
Tetraedron minimum	3	0.2			3	0.2	11	0.8	3	0.2	7	0.2	9	0.7	6	0.3
CHRYSOPHYCEAE																
Dinobryon sertularia	11	0.9	3	0.3			6	0.4	14	1.2						
DINOPHYCEAE																
Ceratium hirundinella	17	1.4	3	0.3	255	18.4	23	1.5	206	16.9	1317	35.9	798	67.2	1261	71.8
Peridinium sp.			11	1.2	3	0.2	14	1.0	20	1.6					3	0.2
Sphaerodinium sp.	3	0.2	9	0.9			14	1.0			7	0.2			6	0.3

Appendix 3.1d (cont.)

May 2010	Site 1		Site 2		Site 3		Site 4		Site 5		Site 10			Site 11		Site 12	
	Cells/ml	% comp	Cells/ml	% comp	Cells/ml	% comp	Cells/ml	% comp	Cells/ml	% comp	Cells/ml	% comp		Cells/ml	% comp	Cells/ml	% comp
EUGLENOPHYCEAE																	
Euglena sp.								3	0.2			7	0.2				
Trachelomonas hispida														3	0.2		
Trachelomonas intermedia	3	0.2			9	0.6	6	0.4	17	1.4	21	0.6	17	1.4	6	0.3	
Trachelomonas scabra											7	0.2					
Trachelomonas volvocina	9	0.7	6	0.6	20	1.4	3	0.2	6	0.5	150	4.1	77	6.5	69	3.9	
Total Cyanophyceae	112	8.8	194	20.7	503	36.4	403	26.8	146	11.9	1203	32.7	20	1.7	146	8.3	
Total Bacillariophyceae	789	62.4	529	56.4	257	18.6	818	54.4	249	20.4	265	7.2	43	3.6	106	6.0	
Total Chlorophyceae	320	25.3	183	19.5	337	24.4	215	14.3	563	46.1	695	18.9	229	19.3	160	9.1	
Total Chrysophyceae	11	0.9	3	0.3	0	0.0	6	0.4	14	1.2	0	0.0	0	0.0	0	0.0	
Total Dinophyceae	20	1.6	23	2.4	257	18.6	51	3.4	226	18.5	1325	36.1	798	67.2	1270	72.3	
Total Euglenophyceae	11	0.9	6	0.6	29	2.1	11	0.8	23	1.9	186	5.1	97	8.2	74	4.2	
TOTAL CELLS/ML	**1264**	**100.0**	**938**	**100.0**	**1384**	**100.0**	**1504**	**100.0**	**1221**	**100.0**	**3673**	**100.0**	**1187**	**100.0**	**1756**	**100.0**	

Appendix 3.1e: Phytoplankton diversity and abundance as observed in June 2010 at sites 2 to 5 and 10 to 12 in Lake Nandoni.

June 2010	Site 1		Site 2		Site 4		Site 5		Site 10		Site 11		Site 12	
	Cells/ml	% comp	Cells/ml	% comp	Cells/ml	% comp	Cells/ml	% comp	Cells/ml	% comp	Cells/ml	% comp	Cells/ml	% comp
CYANOPHYCEAE														
Merismopedia minima	29	1.1												
Microcystis aeruginosa	2252	83.0					80	10.6	243	24.6				
Microcystis wesenbergii			280	44.5	80	10.4								
Pseudanabaena sp.					14	1.9	89	11.7						
BACILLARIOPHYCEAE														
Achnanthes minutissima	7	0.3	11	1.8	43	5.6	43	5.7	3	0.3			7	0.1
Aulacoseira granulate							17	2.3						
Cocconeis pediculus			3	0.5	3	0.4								
Cyclotella sp.	68	2.5	57	9.1	100	13.1	57	7.6	20	2.0	54	2.4	7	0.1
Fragilaria ulna			54	8.6	117	15.3	11	1.5	29	2.9				
Navicula spp.							3	0.4	9	0.9	11	0.5		
Nitzschia palea													7	0.1
Pleurosigma sp.									3	0.3				
CHLOROPHYCEAE														
Carteria sp.			11	1.8										
Chlamydomonas sp.			9	1.4			11	1.5						
Closterium cornu	4	0.1	6	0.9	29	3.7	40	5.3			11	0.5		
Crucigenia tetrapedia	29	1.1			80	10.4	34	4.5						
Crucigeniella rectangularis	129	4.7	92	14.5	103	13.4	126	16.7	123	12.4	136	6.2	86	1.6
Monoraphidium minutum	14	0.5			23	3.0	6	0.8	3	0.3				
Monoraphidium sp.	29	1.1			29	3.7								
Oocystis lacustris									11	1.2	14	0.7	29	0.5
Oocystis marsonii													29	0.5
Pandorina morum											115	5.2	401	7.7
Pteromonas angulosa			3	0.5										
Scenedesmus disciformis	43	1.6	57	9.1	103	13.4	137	18.2	40	4.0	186	8.5	57	1.1
Scenedesmus lefevrii	7	0.3												
Staurastrum sp.	29	1.1	17	2.7	23	3.0	29	3.8	3	0.3	7	0.3	7	0.1
Tetraedron minimum	4	0.1	6	0.9	9	1.1	9	1.1	3	0.3	25	1.1		
Tetrastrum sp.							11	1.5						
CHRYSOPHYCEAE														
Dinobryon sertularia					3	0.4			3	0.3	4	0.2		
DINOPHYCEAE														
Ceratium hirundinella	47	1.7	20	3.2	3	0.4	29	3.8	449	45.4	1568	71.3	4475	85.5
Peridinium sp.					6	0.7			9	0.9	7	0.3	43	0.8
EUGLENOPHYCEAE														
Euglena sp.	4	0.1					6	0.8						
Trachelomonas intermedia	7	0.3					3	0.4	6	0.6	11	0.5	7	0.1
Trachelomonas volvocina	14	0.5	3	0.5			14	1.9	34	3.5	50	2.3	79	1.5
Total Cyanophyceae	2280	84.0	280	44.5	94	12.3	169	22.3	243	24.6	0	0.0	0	0.0
Total Bacillariophyceae	75	2.8	126	20.0	263	34.3	132	17.4	63	6.4	64	2.9	21	0.4
Total Chlorophyceae	286	10.6	200	31.8	398	51.9	403	53.4	183	18.5	494	22.5	609	11.6
Total Chrysophyceae	0	0.0	0	0.0	3	0.4	0	0.0	3	0.3	4	0.2	0	0.0
Total Dinophyceae	47	1.7	20	3.2	9	1.1	29	3.8	458	46.2	1575	71.7	4518	86.3
Total Euglenophyceae	25	0.9	3	0.5	0	0.0	23	3.0	40	4.0	61	2.8	86	1.6
TOTAL CELLS/ML	**2714**	**100.0**	**629**	**100.0**	**766**	**100.0**	**755**	**100.0**	**990**	**100.0**	**2198**	**100.0**	**5234**	**100.0**

Appendix 3.1f: Phytoplankton diversity and abundance as observed in July 2010 at sites 2 to 5 and 10 to 12 in Lake Nandoni.

July 2010	**Site 2**		**Site 3**		**Site 5**		**Site 10**		**Site 11**		**Site 12**	
	Cells/ml	% comp	Cells/ml	% comp	Cells/ml	% comp	Cells/ml	% comp	Cells/ml	% comp	Cells/ml	% comp
CYANOPHYCEAE												
Microcystis aeruginosa	100	21.0										
Microcystis wesenbergii					320	47.7						
BACILLARIOPHYCEAE												
Achnanthes minutissima					3	0.4						
Cocconeis pediculus			9	1.7	6	0.9						
Cyclotella sp.	31	6.6	37	7.4	17	2.6	14	0.6	14	0.8	7	0.1
Fragilaria ulna	194	40.7	120	23.9	80	11.9	162	6.3	14	0.8	7	0.1
Gomphonema spp.									4	0.2		
Melosira varians			23	4.5	6	0.9						
Navicula spp.	3	0.6							4	0.2		
Nitzschia palea	3	0.6			3	0.4						
Nitzschia spp.									4	0.2		
Pleurosigma sp.							10	0.4				
Synedra ulna							5	0.2	4	0.2		
CHLOROPHYCEAE												
Carteria sp.			3	0.6	3	0.4	10	0.4				
Chlamydomonas sp.	6	1.2			3	0.4						
Closterium cornu	6	1.2	17	3.4			5	0.2				
Coelastrum pseudomicroporum					46	6.8						
Coelastrum sp.											115	2.2
Crucigeniella rectangularis			11	2.3					14	0.8		
Monoraphidium minutum			9	1.7	17	2.6					7	0.1
Monoraphidium sp.			34	6.8	23	3.4	5	0.2				
Oocystis lacustris	23	4.8	34	6.8			5	0.2	4	0.2		
Scenedesmus disciformis	69	14.4	57	11.4	46	6.8						
Staurastrum sp.	29	6.0	37	7.4	9	1.3	10	0.4	7	0.4		
Tetraedron minimum	3	0.6	6	1.1	26	3.8						
CHRYSOPHYCEAE												
Dinobryon sertularia	3	0.6	9	1.7								
DINOPHYCEAE												
Ceratium hirundinella	9	1.8	77	15.3	57	8.5	2332	90.6	1618	94.8	5127	96.4
Peridinium sp.			11	2.3	6	0.9	10	0.4	4	0.2	21	0.4
EUGLENOPHYCEAE												
Trachelomonas hispida			3	0.6								
Trachelomonas volvocina			6	1.1	3	0.4	10	0.4	18	1.0	36	0.7
Total Cyanophyceae	100	21.0	0	0.0	320	47.7	0	0.0	0	0.0	0	0.0
Total Bacillariophyceae	232	48.5	189	37.5	114	17.0	190	7.4	43	2.5	14	0.3
Total Chlorophyceae	134	28.1	209	41.5	172	25.5	33	1.3	25	1.5	122	2.3
Total Chrysophyceae	3	0.6	9	1.7	0	0.0	0	0.0	0	0.0	0	0.0
Total Dinophyceae	9	1.8	89	17.6	63	9.4	2342	90.9	1622	95.0	5148	96.8
Total Euglenophyceae	0	0.0	9	1.7	3	0.4	10	0.4	18	1.0	36	0.7
TOTAL CELLS/ML	**478**	**100.0**	**503**	**100.0**	**672**	**100.0**	**2575**	**100.0**	**1708**	**100.0**	**5320**	**100.0**

Appendix 3.1g: Phytoplankton diversity and abundance as observed in August 2010 at sites 2 to 5 and 10 to 12 in Lake Nandoni.

August 2010	Site 1		Site 2		Site 3		Site 4		Site 10		Site 11		Site 12	
	Cells/ml	% comp	Cells/ml	% comp	Cells/ml	% comp	Cells/ml	% comp	Cells/ml	% comp	Cells/ml	% comp	Cells/ml	% comp
CYANOPHYCEAE														
Merismopedia minima			1403	23.1										
BACILLARIOPHYCEAE														
Achnanthes minutissima	3	0.2			7	0.2								
Aulacoseira granulate									10	0.3			7	0.3
Cocconeis pediculus	20	1.1	21	0.4			19	0.5			5	0.1		
Cyclotella sp.	77	4.4	136	2.2	50	1.1	76	2.0	14	0.5	5	0.1	7	0.3
Cymbella spp.					7	0.2			10	0.3				
Fragilaria ulna	1155	66.2	3895	64.0	3902	87.1	3461	89.1	243	8.0	57	1.6	240	10.2
Gyrosigma sp.			7	0.1										
Melosira varians							19	0.5						
Navicula spp.							10	0.2	10	0.3	5	0.1	4	0.2
Nitzschia spp.	3	0.2												
Synedra ulna											5	0.1	7	0.3
CHLOROPHYCEAE														
Carteria sp.	3	0.2												
Chlamydomonas sp.	14	0.8	43	0.7	14	0.3			5	0.2	5	0.1		
Chlorella sp.							29	0.7						
Closterium cornu	11	0.7											4	0.2
Coelastrum pseudomicroporum			115	1.9	57	1.3								
Crucigenia tetrapedia	46	2.6	115	1.9	115	2.6								
Crucigeniella rectangularis	146	8.4	57	0.9	115	2.6			38	1.3				
Eudorina elegans											152	4.4	115	4.9
Monoraphidium minutum	20	1.1					5	0.1						
Monoraphidium sp.	34	2.0	86	1.4	14	0.3	48	1.2	5	0.2				
Oocystis lacustris							10	0.2						
Pandorina morum									152	5.0				
Pediastrum simplex	46	2.6												
Scenedesmus disciformis	80	4.6	86	1.4	29	0.6	57	1.5						
Staurastrum sp.	20	1.1	29	0.5	7	0.2	29	0.7	5	0.2				
Tetraedron minimum	11	0.7												
CRYPTOPHYCEAE														
Cryptomonas major											10	0.3		
CHRYSOPHYCEAE														
Dinobryon sertularia	26	1.5					10	0.2	5	0.2				
DINOPHYCEAE														
Ceratium hirundinella	6	0.3	43	0.7	107	2.4	90	2.3	2432	80.5	3170	90.9	1862	78.9
Peridinium sp.			21	0.4	57	1.3	14	0.4	62	2.0	29	0.8	64	2.7
Sphaerodinium sp.	3	0.2	14	0.2					10	0.3	24	0.7		
EUGLENOPHYCEAE														
Euglena sp.			7	0.1										
Trachelomonas volvocina	20	1.1	7	0.1			10	0.2	24	0.8	24	0.7	50	2.1

Appendix 3.1 h: Phytoplankton diversity and abundance as observed in September 2010 at sites 2 to 5 and 10 to 12 in Lake Nandoni.

September 2010	Site 1		Site 3		Site 4		Site 5		Site 10		Site 11	
	Cells/ml	% comp	Cells/ml	% comp	Cells/ml	% comp	Cells/ml	% comp	Cells/ml	% comp	Cells/ml	% comp
CYANOPHYCEAE												
Microcystis aeruginosa	132	7.3	23	1.5	23	2.0	34	2.2			23	3.8
BACILLARIOPHYCEAE												
Achnanthes minutissima					3	0.3						
Cocconeis pediculus			3	0.2			9	0.5	25	1.0	17	2.8
Cyclotella sp.	89	4.9	29	1.9	60	5.3	20	1.3	4	0.1		
Cymbella spp.											3	0.5
Diatoma vulgaris					3	0.3						
Fragilaria ulna	1084	59.9	515	34.4	649	57.3	821	52.0			14	2.3
Gomphonema spp.											6	0.9
Navicula spp.	3	0.2	3	0.2	20	1.8	9	0.5	29	1.2	34	5.6
Nitzschia palea									7	0.3	20	3.3
Pleurosigma sp.			6	0.4					7	0.3	9	1.4
Surirella sp.	9	0.5	3	0.2			6	0.4			3	0.5
Synedra ulna			3	0.2								
CHLOROPHYCEAE												
Chlamydomonas sp.	9	0.5	9	0.6	26	2.3			7	0.3	6	0.9
Closterium cornu	9	0.5	6	0.4	9	0.8	6	0.4				
Crucigenia tetrapedia	11	0.6			34	3.0	11	0.7				
Crucigeniella rectangularis	34	1.9			57	5.1						
Eudorina elegans									115	4.8		
Lagerheimia sp.	3	0.2	3	0.2	3	0.3						
Monoraphidium minutum	3	0.2	3	0.2	6	0.5					6	0.9
Monoraphidium sp.	154	8.5	34	2.3	31	2.8	6	0.4				
Oocystis lacustris	57	3.2	57	3.8	11	1.0	23	1.4				
Scenedesmus disciformis	57	3.2	57	3.8	57	5.1	114	7.2	57	2.4	57	9.4
Staurastrum sp.	26	1.4	26	1.7	6	0.5					3	0.5
Tetraedron minimum	11	0.6	9	0.6	6	0.5	3	0.2				
DINOPHYCEAE												
Ceratium hirundinella	92	5.1	681	45.5	117	10.4	509	32.2	2134	89.1	403	66.2
Peridinium sp.	29	1.6	11	0.8	9	0.8			7	0.3	3	0.5
EUGLENOPHYCEAE												
Trachelomonas intermedia							9	0.5				
Trachelomonas volvocina			17	1.1	3	0.3			4	0.1	3	0.5
Total Cyanophyceae	132	7.3	23	1.5	23	2.0	34	2.2	0	0.0	23	3.8
Total Bacillariophyceae	1184	65.4	561	37.5	735	64.9	864	54.7	72	3.0	106	17.4
Total Chlorophyceae	375	20.7	203	13.6	246	21.7	163	10.3	179	7.5	72	11.7
Total Dinophyceae	120	6.6	692	46.3	126	11.1	509	32.2	2141	89.4	406	66.7
Total Euglenophyceae	0	0.0	17	1.1	3	0.3	9	0.5	4	0.1	3	0.5
TOTAL CELLS/ML	**1810**	**100.0**	**1496**	**100.0**	**1133**	**100.0**	**1579**	**100.0**	**2395**	**100.0**	**609**	**100.0**

Appendix 3.2 a: The zooplankton diversity and abundance observed at the sites 1, 2 and 3 in the Lake Nandoni for the period September 2009 to September 2010 (Crustacean abundance reported as number of individuals per 100 ml and Rotifera as individuals per 1 ml).

			Copepoda			
Site number	**Date**	**Cladocera abundance**	**Copepod abundance**	**Calanoid abundance**	**Cyclopoid abundance**	**Rotifera abundance**
1	September	15	80	77	3	N
	October	10	130	126	4	N
	November	9	72	66	6	N
	December	20	42	36	6	N
	January	4	28	25	3	N
	February	22	71	51	20	0
	March	5	64	52	8	0
	April	13	56	43	13	3
	May	11	69	438	26	1
	June	45	46	93	3	1
	July	9	14	9	5	4
	August	11	8	5	3	0
	September	52	57	45	12	0
2	September	24	36	36	0	N
	October	6	22	20	3	N
	November	12	106	88	18	N
	December	29	57	47	10	N
	January	5	44	40	4	N
	February	14	111	82	20	1
	March	3	49	45	4	0
	April	45	103	92	11	2
	May	21	54	181	13	0
	June	60	96	127	16	2
	July	118	109	87	20	2
	August	85	118	90	28	0
	September	43	25	20	5	0
3	September	6	48	33	15	N
	October	9	44	41	3	N
	November	20	67	66	1	N
	December	23	106	92	4	N
	January	8	32	30	2	N
	February	26	69	58	11	4
	March	33	100	93	7	1
	April	96	8	6	2	1
	May	27	67	137	20	1
	June	13	69	400	16	2
	July	63	47	36	9	0
	August	323	167	116	22	0
	September	27	7	4	3	2

Appendix 3.2b: The zooplankton diversity and abundance observed at the sites 4 and 5 in the Lake Nandoni for the period September 2009 to September 2010 (Crustacean Abundance reported as number of individuals per 100 ml and Rotifera as individuals per 1 ml).

			Copepoda			
Site number	**Date**	**Cladocera abundance**	**Copepod abundance**	**Calanoid abundance**	**Cyclopoid abundance**	**Rotifera abundance**
4	September	11	86	74	12	N
	October	9	187	176	11	N
	November	9	59	39	20	N
	December	58	130	118	12	N
	January	10	20	15	5	N
	February	20	6	0	0	2
	March	0	89	77	12	0
	April	35	5	4	1	0
	May	28	76	200	16	0
	June	71	58	61	17	0
	July	76	70	58	12	0
	August	339	95	85	10	2
	September	17	48	35	13	0
5	September	34	64	56	8	N
	October	10	165	141	24	N
	November	11	52	48	4	N
	December	35	99	83	16	N
	January	9	24	19	15	N
	February	11	50	44	14	1
	March	10	110	82	28	0
	April	40	17	15	2	1
	May	55	65	80	15	2
	June	33	33	74	9	0
	July	125	48	34	14	0
	August	84	47	40	7	0
	September	2	2	2	0	0

Appendix 3.3: The zooplankton diversity and abundance observed at the sites 10, 11 and 12 in the Lake Nandoni for the period September 2009 to September 2010 (Crustacean abundance reported as number of individuals per 100 ml and Rotifera as individuals per 1 ml).

			Copepoda			Rotifera
Site number	**Date**	**Cladocera abundance**	**Copepod abundance**	**Calanoid abundance**	**Cyclopoid abundance**	
10	September	2	139	123	16	N
	November	2	7	6	1	N
	October	17	6	6	0	N
	December	32	40	35	5	N
	January	19	13	10	3	N
	February	106	57	42	15	0
	March	95	21	13	8	0
	April	17	49	38	11	1
	May	127	211	134	77	2
	June	174	96	77	19	2
	July	95	27	23	4	4
	August	10	25	20	5	8
	September	8	64	49	15	0
11	September	1	44	32	12	N
	October	25	125	100	25	N
	December	13	10	10	0	N
	January	14	13	13	0	N
	February	25	64	60	4	3
	March	28	27	13	14	0
	April	50	44	32	8	0
	May	112	105	68	37	2
	June	277	82	39	43	2
	July	48	26	20	6	6
	August	274	218	194	24	2
	September	15	10	5	5	0
12	September	9	98	90	8	N
	October	1	67	62	5	N
	November	7	66	64	2	N
	December	19	43	36	7	N
	January	6	14	12	2	N
	February	38	22	18	4	0
	March	37	41	34	7	1
	April	71	71	57	14	1
	May	97	133	83	40	1
	June	267	104	73	31	2
	July	89	56	48	8	8
	August	224	95	78	17	2
	September	54	74	46	28	0

Appendix 3.4 : Size distribution of the fish specimens collected in Lake Nandoni for stomach content analyses.

Body length classes(mm)	Species				
	Oreochromis mossambicus	***Labeobarbus marequensis***	***Schilbe intermedius***	***Tilapia rendalli***	***Marcusenius macrolepidotus***
111-120				5	
121-130				1	
131-140				1	
141-150					
151-160				1	
161-170					
171-180					2
181-190			3		2
191-200	1		7		
201-210	1		13	1	2
211-220			23		
221-230	4	2	10	1	1
231-240	1		4		
241-250	2		7		
251-260	1		6		
261-270	2	2	4		
271-280			3		
281-290			3		
291-300	1		5		
301-310			2		
311-320					
321-330		1			
331-340	1	1			
341-350					
351-360		1			
361-370					
371-380	1				
381-390					
391-400					
401-410		1			
Total	**15**	**8**	**90**	**10**	**7**

Appendix 3.5: Diversity of stomach content of the five fish species collected in Lake Nandoni Dam. (P = Present).

	Species				
Food items	***Orechromis mossambicus***	***Tilapia rendalli***	***Schilbe intermedius***	***Marcusenius macrolepidotus***	***Labeobarbus marequensis***
Insects					
Baetidae			P		
Ceratopogonidae				P	
Chaoboridae (Larvae)		P	P	P	
Chaoboridae (Pupae)			P		
Chironomidae				P	
Coleoptera			P		
Diptera			P		
Ecnomidae				P	
Hymenoptera			P		
Libelludae				P	
Orthoptera			P		
Polymitarcyidae			P		
Trichoptera (Pupae)			P	P	
Pyralidae			P		
Unidentifiable	P	P			
Other animal groups					
Crustacea	P				
Hirudenea				P	
Oligochaeta				P	
Mollusca		P			
Fish			P		
Araneae			P		
Plant related					
Algae	P	P	P	P	P
Plant Material	P	P	P	P	
Seeds				P	
Sand particles/detritus					
	P	P	P	P	

Appendix 3.6: Stomach content analyses of the size classes of *S. intermedius* in Lake Nandoni in the period January 2010 to April 2011.

Fork length size classes	Number	Percentage of stomach with food	Percentage volume of food	Algae	Plant	Insect	Fish	Sand
181-190	3	100	23.8			100		
191-200	7	100	23.5			100		
201-210	13	84.6	31.5		2.9	93.7	3.5	
211-220	23	95.6	52.6		38.0	49.8		12.2
221-230	10	100	33.1		23.6	60.0		12.4
231-240	4	100	70	7.7	51.4	40.9		
241-250	7	100	38.2	9.4	23.3	65.2		2.1
251-260	6	100	28.4		5.6	94.4		
261-270	4	100	24.9			100		
271-280	3	100	43.8		63.9	36.1		
281-290	3	100	94.6	13.2	32.8	40.3		13.7
291-300	5	100	29.5			100		
301-310	2	100	54.2		8.3	40.0	51.7	

Appendix 3.7: Means and standard deviations (in parenthesis) of the *in situ* physico-chemical parameters measured in Lake Nandoni during the period October 2009 to December 2010.

Sample size	Survey date	Electrical conductivity (μScm^{-1})	Total Dissolved Solids (mgL^{-1})	Temperature (^oC)
20	Oct-09	164.41 (3.47)	82.45 (1.72)	19.63 (1.43)
20	Nov-09	168.92 (6.09)	84.26 (1.64)	21.45 (2.59)
15	Dec-09	164.47 (5.31)	81.83 (2.33)	23.70 (3.35)
20	Jan-10	167.14 (12.03)	83.49 (6.09)	23.35 (2.45)
20	Feb-10	170.23 (14.74)	85.06 (7.30)	23.52 (2.97)
20	Mar-10	166.76 (22.04	83.58 (11.01)	24.69 (2.07)
20	Apr-10	167.15 (23.35)	83.66 (11.74)	23.91 (2.69)
20	May-10	162.61 (29.15)	81.31 (14.58)	21.06 (0.75)
20	Jun-10	160.40 (30.14)	80.11(15.01)	19.99 (0.39)
20	Jul-10	137.91 (0.98)	68.93 (0.43)	17.65 (0.17)
20	Aug-10	136.18 (4.09)	68.19 (1.97)	17.37 (0.14)
20	Sep-10	140.69 (1.21)	70.15 (0.55)	19.16 (1.19)
20	Oct-10	141.25 (3.68)	70.77 (1.81)	20.15 (1.29)
20	Nov-10	143.57 (5.37)	71.98 (2.71)	18.80 (0.16)
20	Dec-10	145.49 (6.99)	72.79 (3.51)	21.27 (2.19)
Average (SD)		155.81 (13.02)	77.90 (6.48)	21.05 (2.36)