Study of ephemeral rock pools on Domboshawa Mountain, Zimbabwe

By

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Abstract

Five ephemeral rock pools were sampled weekly from December 2006 to May 2007 on the Domboshawa Mountain. Physical variables, which included temperature, pH, dissolved oxygen, phosphorus, nitrogen, conductivity and pool morphometry (depth, total wetted surface and volume), were measured. The ecological variables measured were primary production, diversity and doubling time for the phytoplankton community. Geology and catchment characteristics affected variables such as nitrogen and conductivity. Pool morphometry is the main physical factor that structured these habitats. The pools were frequently flushed out. On a weekly average, the deepest pool (P1) was flushed out 73.61 times whilst the shallowest pool was flushed out 248.34 times. The shallowest pool (P3) had higher diurnal temperature variations than the deepest pool (P1). Both the minimum and maximum temperatures of 14.7°C and 33.6°C respectively were recorded in the shallowest pool (P3). Nevertheless, there was no significant difference (χ^2, $p > 0.05$) in the ranges of temperatures experienced in the shallowest and the deepest pool. Deeper pools stratified whilst the shallow ones did not. Pool morphometry has an effect on doubling time in phytoplankton populations. In the deepest pool it took 19 days whilst in the shallowest pool it took 43 days for the *Microcystis aeruginosa* population to double. The larger pools were more diverse in species composition than the smaller pools. Temporal variation in the phytoplankton community was observed. The blue green algae, *M. aeruginosa*, increased in abundance towards the end of the rain season whilst the green algae, *Spirogyra rhizobrachiales*, decreased in abundance as the season progressed. Pool morphometry, catchment characteristics, temporal variation in temperature and the high weekly rates of flushing out were the main factors that affected these habitats.

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1.0 INTRODUCTION

1.1 Background

There are many definitions, which describe an ephemeral rain-pool. McLachlan (1983) described an ephemeral pool as a temporary water body supported mainly by rainfall, which collects in a depression. Hammer and Martens (1998), state that ephemeral rain-pools are small depressions on boulders or on sandstone plateaus. Dodson (1987) described rain-filled rock pools as ephemeral aquatic habitats found wherever flat areas of rock are exposed. Where the rain collects in depressions on rock, the pools may persist for weeks or months. They may then develop a particular community, which illustrates features of a simple standing water system (Moss, 1988).

McLachlan and Cantrell (1980) studied such pools in Malawi. They form on depressions on the tops of the rocky outcrops during the rain season between November and March. The depressions are generally bare at the start of the rainy season, though perhaps with some dried remains of sediment from a previous wet phase. Ephemeral pools create an environment that is a host to a unique assemblage of organisms when they fill up each summer. Protozoa, Rotifers and Cladocera usually occur in these pools. They survive by feeding on algae and bacteria. Amphibians lay eggs in these pools. The tadpoles feed on the algal populations in the pools (Osborne and McLachlan, 1985). As the pools begin to dry, tree frogs migrate away from the pools and aestivate for the long dry seasons in burrows, crevices and old logs. Plants, invertebrates and amphibians have to complete their life cycle before the pool dries up (McLachlan, 1985). The pools provide a habitat for many organisms such as toads, which rely on the pool's warm waters for breeding. The warmer the water, the faster the tadpoles develop, an adaptation to the short life that many of the pools have (McLachlan, 1983).

1.2 Justification

Study of the faunal and floral composition of temporary environments broadens our knowledge of the biodiversity of these habitats. It is one of the most important factors taken into consideration when establishing preservation criteria (Ramsar Convention Bureau, 1992). Temporary habitats represent convenient systems in which to study ecological concepts, as they are amenable to experimental manipulation (Blaustein, 1990). Ephemeral habitats also provide a useful model system for studying life history patterns, which enable populations to persist despite high environmental variation (Beardall et al, 2001; Ripley et al, 2004). It is therefore important to consider the combined action of spatial, temporal and environmental variables in explaining ecological systems (Debrey et al, 1991; Borcard et al, 1992). No research has been done on ephemeral rock pools in Zimbabwe; hence the present study on Domboshawa Mountain will provide a baseline for further studies. It will also contribute to understanding the factors that structure ephemeral pool communities

1.3 Research questions

The main objective of this study was to investigate the temporal and spatial factors influencing biodiversity in ephemeral pools. The study sought to address the following questions:

- What are the physical factors that affect ephemeral rock pool communities?
- How does the chemical composition of the pools vary?

2.0 LITERATURE REVIEW

2.1 The rock pool environment

The ephemeral rock pools are filled mainly by rainfall (McLachlan, 1983) though, in some cases water draining from the catchment may fill them up as well. The pool environment is unstable with large unpredictable hydro cycles that vary in space and in time. Shallow pools can fill with water, dry up and then refill again several times during a rain season. Chemical and biological changes, both cyclic and irreversible occur very rapidly in these pools (Moss, 1988; Graham, 1995; Podrabsky et al, 1998). Large diurnal fluctuations occur in temperature and dissolved oxygen concentration while pH and conductivity values exhibit a high degree of variation. The communities may be exposed to extremes in temperature, and dissolved oxygen concentration and pH values at the beginning, mid and end of the rain season. The duration of the habitat also determines which taxa are capable of surviving and reproducing in a pool of a particular duration (Schneider and Frost, 1996; Boix et al, 2001).

2.2 Effects of pool flooding and drying

Rock pools are generally shallow; hence they are very prone to flooding and drying throughout the duration of the rain season (De Vries, 1996). The flood effects can vary with depth, time and floodwater quality. Floods are associated with a pulse of nutrients imported from the catchment by floodwater (Jeffries, 1994; Nielsen et al. 1999). The pulse of nutrients immediately after flooding drives the increases in primary production and a proliferation of the phytoplankton community. Diatoms are associated with flooding and become dominant in the phytoplankton community at this time (Moss, 1988).

Most literature on the drying of rock pools states evaporation as the dominant process (Talling, 1992). As the pools dry up, a number of changes occur, which are; reduced nitrogen inputs, higher pH, greater deoxygenating rates and a proliferation of large motile flagellates (Moss, 1988; Talling, 1992;

Jeffries, 1994). The absence of flushing out results in increase in algal abundance and changes in algal species composition. Another feature is that biotic interactions such as competition and predation increase (Schneider and Frost, 1996), because of declining habitat and increase in the proportion of predatory taxa respectively. When the pool dries up, drought resistant propagules of micro invertebrates and plants remain within the sediments.

2.3 Water physicochemical variables of ephemeral rock pools

Rainfall frequency, amount, pattern and evaporation balance are important factors which characterise the type of habitat and its physicochemical features which its biota will have to endure (Williams, 2006). The rock pools usually hold water with low levels of electrical conductivity (Hammer and Martens, 1998). Conductivity is the ability of water to conduct an electric current and depends on the concentration of ions in the solution. In the 90 pools surveyed in the Drakensburg Mountain in South Africa, the conductivity of the water ranged between 3-70 μScm^{-1} (Hammer and Martens, 1998). At Korannaberg, the average conductivity of eight pools over a period of 32 weeks varied between about 20 and 200 μScm^{-1}. The variation depended on the size of the pool and the stage during the hydro cycle. In Southeastern Botswana, 30 pools from two rock sites (Thamaga and Kgale Siding near Gaborone) were monitored in two rainy seasons of 1997 and 1998, and the average conductivity of the pools ranged between 12 and 43 μScm^{-1} in 1997 and between 27 and 140 μScm^{-1} in 1998 (Brendonck et al, 1998).

Water temperature affects water chemistry parameters such as dissolved oxygen concentration, pH and primary production. Most rock pools are shallow; hence water temperatures closely follow the ambient air temperature and show high diurnal variations (De Vries, 1996). Temperature is crucial to the survival of many temporary water species as it provides essential cues that regulate the timing of life cycles, emergence from and entry into diapause, flight periodicities and colonisation dynamics (Williams, 2006).

2.4 Biological communities in ephemeral rock pools

Presence or absence of some phytoplankton species in a pool depends on random dispersal of propagules through wind or animals (Maguire, 1963; Moore and Faust, 1972; Daborn, 1976). Physicochemical conditions and biotic interactions during each wet cycle determine establishment and maintenance of viable populations (Maguire, 1963; Proctor, 1964; Daborn, 1976). In Malawi mostly algae, insect larvae and tadpoles colonize small temporary rain–filled rock pools (McLachlan, 1985). Community composition varies spatially among pools and temporarily in the same pools (Prophet, 1963).

Four major groups of organisms (protozoa, rotifera, cladocera and copepoda) dominate the freshwater zooplankton (Lane, 1978; Williams, 1997). Temporary pools give shelter to large branchiopod crustaceans (Brendonck et al, 2000; Brendonck et al, 2002). Many branchiopod species can withstand oxygen concentration of less than $5mgl^{-1}$. Nearly all cladocera species are found at a pH ranging from 6.5 to 8.5 (Pennak, 1989). The ephemeral nature of the pools excludes fish, except *Gnathobranchius* species. The most important invertebrate predators in temporal pools on rock substrate are turbellarians. When the turbellarians are present in large densities, they reduce the zooplankton densities drastically, sometimes with total extinction of the active population (Blaustein, 1990). Predation of zooplankton by both amphibians and various invertebrates may be an important biotic mechanism regulating temporary pool communities (Spureles, 1972; Lane, 1978: Williams, 1997; Blaustein, 1990).

Overflows that occur between shallow rock pools disperse floating eggs. This is an effective means of short-range dispersal (Venable and Brown, 1988; Brendonck et al, 1998). Passive transfer by waterfowl, aquatic insects and in wind blown dust explains the extensive distribution of some of the species. Some species are restricted to very small geographic areas, sometimes a single pond. It is difficult to account for their distribution since few direct measurements have been made in any zooplankton groups (Pennak, 1989; Brendonck et al, 1998).

Freshwater cyclopoid copepods bridge unfavourable dry periods by means of resting eggs (Proctor, 1964; Williams, 1975; Lane, 1978; Brendonck et al, 2002). The resistant resting eggs synchronize their life cycle with favourable habitat phases. They form egg banks to buffer against catastrophic population crashes due to the early drying of pools. They enter diapause in the late copepodid stage, and can survive for several years in the dry sediments of temporary ponds (Pennak, 1989; Hairston, 1996). The cyclopoida produce resting eggs, but resistant copepodid cysts are the most common. Passive dispersal is brought about in this stage, where first cyclopoids to appear in dried mud cultures are in the copepodid stage (Pennak, 1989). Many copepods are found every year in temporary pools, which are completely dried up during the greater part of the year. Resting eggs and cysts in the dry mud carry the species over. The larvae of flies dominate the invertebrate community of ephemeral water bodies. They feed on the sediment, particularly its contained bacteria. *Chironomus imicola* and *Polypedilum vanderplanki*, larvae of two midge species (Chironomidae) occurs in rainwater pools on rock surfaces at high densities (Hinton, 1968). A reduction in the duration of aquatic stages increases the chances of an individual emerging as a fly before the pool it inhabits dries. *Chironomus imicola* completes its life cycle from egg to adult in twelve days. It favours larger pools which allow time for development of larger larvae and adults. *Polypedilum vanderplanki* survive interrupted conditions as its pool dries between rainstorms and refills. Its life cycle is completed in 35-43 days and can survive in much smaller pools than *Chironomus imicola* (Hinton, 1968). The larvae remain viable for many years in an almost completely desiccated state. Tadpoles of the Savanna ridge frog, *Ptychadena anchiaetae* (Moss, 1988) hatch from eggs laid in the pools. The eggs are not drought resistant, so the tadpoles have to complete their life history before the pool dries out. If they do not complete it, their dried carcasses may be later scavenged by *Chironomus imicola* (Moss, 1988).

Phytoplankton quickly develops in temporary rock pools. This comes from inocula, which are readily dispersed as dry cysts or spores by wind (Reynolds, 1984; Osborne and McLachlan, 1985). If the rainfall is heavy and storms follow each other quickly, the pools may be flushed out so rapidly that algal populations do not have time to form (Osborne and McLachlan, 1985). However, motile algal species such as *Euglena* and *Chlamydomonas* species, which can use their flagella to remain suspended in the water, can withstand being flushed out. Major inorganic nutrients that are required by phytoplankton are nitrogen and phosphorus. Algal growth is limited by phosphorus such that presence of additional phosphorus compounds can stimulate algal productivity and enhance eutrophication processes (Lean and Pick 1981; Bartram and Ballance, 1996). In surface water, nitrate is the nutrient taken up by plants and assimilated into cell protein. It is relatively a soluble ion and is easily leached so it usually available in water, though it may limit algal growth at times (Osborne and McLachlan, 1985). The productivity of any aquatic environment depends on the primary producers (phytoplankton) and the environmental conditions that affect them. Each species of phytoplankton has a particular response to different concentrations of limiting nutrients and each has a maximum growth rate.

Phytoplankton growth in ephemeral rock pools is influenced by variations in water chemistry, irradiance, nutrient supply, presence of tadpoles, temperature and the washout rate (McLachlan, 1983; Osborne and McLachlan, 1985; Moss, 1988). Reynolds (1986) also states that variation in the chemical composition of natural waters might be important in regulating the abundance, composition and the geographical and periodic distribution of phytoplankton. However the ephemeral nature of the pools excludes some organisms such that only organisms that can aestivate, avoid desiccation and have very rapid rates of development during the wet phase can live in these environments (Williams, 1997).

3.0 MATERIALS AND METHODS

3.1 The study area

Domboshawa Mountain is 25km to the north of Harare, (31^o 10` E, $17^o$ 35` N) in the Mashonaland East Province. The mountain's elevation is 1638m. Domboshawa lies in the Chinamora porphyritic granite complex, which covers an area of $600km^2$. The Chinamora granite is exposed in bare dome shaped hills and steep walled dwalas that characterize the Domboshawa- Chinamora uplands (Baldock, 1999).

The Domboshawa Mountain is a mushroom shaped intrusive, with a broad domed top formed from exfoliated Chinamora pophyritic granite (Baldock, 1999). The soils are sandy, often with shiny feldspar grains and support a sparse broom of resurrection plants (*Myrothamnus flabellifolios*) and grassland vegetation. Most of the rock surface is covered by lichens and mosses (Baldock, 1999). The Domboshawa Mountain area falls under Natural region 2 (Nyamapfene, 1991). The rain season starts from October/November to April when most of the rain falls as sporadic heavy convectional storms with intermittent showers followed by a dry season from May to September. The seasonal rainfall at Domboshawa ranges between 400 and 1150mm (Nyamapfene, 1991).

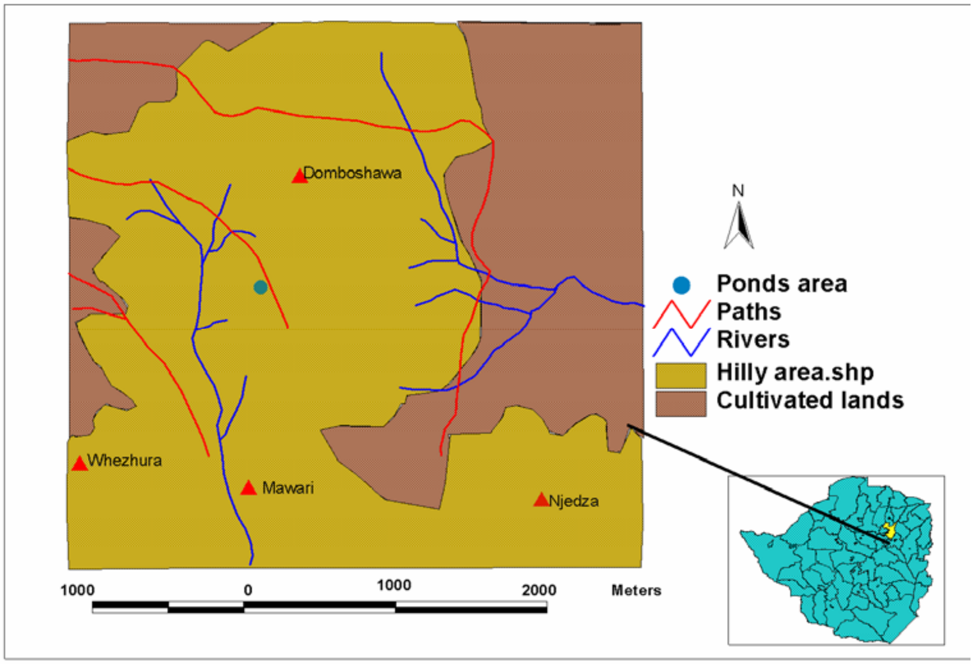


Figure 3.1. Location of Domboshawa Mountain in Zimbabwe and an expanded view of the area.

3.2 Sampling sites

Five pools occur as a series on the granite rock surface (Fig3.2). A Global Positioning System (GPS) was used to mark the five pools. Their positions are given in Table 3.1.

Table 3.1. Global positioning system coordinates and elevation for the five pools.

Pools	Coordinates	Elevation (meters)
P1	17^o36.498\`S, $031^o$10.168\`E	1550
P2	17^o36.516\`S, $031^o$10.177\`E	1558
P3	17^o36.521\`S, $031^o$10.183\`E	1560
P4	17^o36.525\`S, $031^o$10.186\`E	1558
P5	17^o36.536\`S, $031^o$10.197\`E	1563

No aquatic macrophytes grew in any of the pools. When it rained the pools were frequently filled to overflowing, and overflows between neighbouring pools were frequently observed. Two of the pools (P2 and P3) were sampled fourteen times, during which they dried up after thirteen weeks of the study, refilled during the fifteenth week and then dried again. Another pool (P4) was sampled seventeen times, during which it dried up after the sixteenth week, refilled during the nineteenth week and then dried up again. Two pools (P5 and P1) did not dry up throughout the study period. They dried up prematurely by the 6th of May after livestock from the surrounding communal area drank up the water.

Figure 3.2. Google satellite image showing the sampling sites on Domboshawa Mountain

3.3 Sampling

The pools were sampled once every week from 16 December 2006 to 5 May 2007. The deepest pool (P1) was 15.4m^2 in wetted total surface area with a maximum depth of 0.78m (Table 3.2), whilst the shallowest pool (P3) was 8m^2 in wetted total surface area with maximum depth 0.24m. The pool basins` maximum depths range from 0.24 to 0.78 cm for the shallowest and deepest pool respectively.

Table 3.2.The pools` morphometric features

Pool morphometry	P1	P2	P3	P4	P5
Maximum depth (m)	0.78	0.30	0.24	0.36	0.74
Area (wetted surface m^2)	15.40	7.10	8.00	11.90	16.60
Maximum volume (m^3)	3.61	0.99	1.07	1.46	3.47
Catchment area (m^2)	2368.70	2762.80	2848.10	3242.80	2314.80
Total catchment area (m^2)	13537.20				

The pool's total wetted area was determined by layering transects at 1 metre intervals across the pool's surface. Area was calculated for each trapezium and summed up to give total wetted surface area using the formula (Anton and Rorres, 1987);

$$\frac{(a+b)\times h}{2}$$

Where;

a and b are lengths of the transects

h was the interval between the transects (1m)

Mean depth was determined by measuring the depth at 20 centimetre intervals along the transect and averaged. Volume was determined by multiplying area and mean depth. The volume for each trapezium was added and summed up to give the pool's volume. Flush out rates for the pools were calculated by multiplying weekly total precipitation and total catchment area then the product divided by each pool's maximum capacity using the formula (Anton and Rorres, 1987);

$$\frac{CA \times P}{V}$$

Where;

CA is Catchment area

P is weekly total precipitation

V is maximum volume of the pool.

3.3 Sample collection and analysis

Samples of water were collected in 750ml polythene bottles and kept in the refrigerator at $4^{o}C$ for preservation before analysis (Mackereth, 1978). The TNT Persulfate Digestion Method 10072 as described in HACH (1996-2000) was used to determine total phosphorus. The TNT Phosver 3 Persulfate Digestion Method as described in HACH (1996-2000) was used to determine total nitrogen. Dissolved oxygen concentration, water temperature, conductivity and pH were measured on site. Dissolved oxygen concentration and water temperature were measured using a digital Oxygen meter model WTW Oxi 330. Conductivity was measured using a conductivity meter model WTW LF340. pH was read with a pH meter model WTW pH 330. A 24-hour study to determine the oxygen levels and temperature in surface and bottom water was carried out on 9 April 2007.

Plankton was collected using plankton nets of mesh size 20um and 64um for phytoplankton and zooplankton respectively. The phytoplankton and zooplankton samples were fixed on site with 10% Formalin for later microscopic examination (Bartram and Balance, 1996). The plankton composition was determined quantitatively by pouring a 1ml sample into a counting chamber, identifying, and counting under the microscope according to Prescott (1970).

Aquatic insects and benthic macro invertebrate samples were collected using a hand net, mesh size 500um. The net was held vertically against the pool bottom disturbing the substrate, and swept through the water column to the surface (Bartram and Balance, 1996). The composition was examined quantitatively by pouring the sample through a three tiered sieve system .The organisms were washed into a 250ml bottle with 70% alcohol for preservation. Identification and counting was carried out according to (Jacobs, 1986).

Primary production was measured using the light and dark bottles method (Marra, 2002). Clear and dark bottles were incubated in the pools for six hours from 9AM to 3PM. Gross primary production was estimated as the difference between dissolved oxygen concentration in clear and dark bottles Photosynthesis was determined using the formula (Marra, 2002);

$$mgC\,/\mathrm{m}^3/\mathrm{h} = \frac{(LB - DB) \times 1000 \times 0.375}{(PQ) \times t}$$

Where;

LB is light bottle dissolved oxygen concentration in mgl^{-1}

DB is dark bottle dissolved oxygen concentration in mgl^{-1}

PQ (0.5) is molecules of oxygen liberated during photosynthesis divided by molecules of carbon dioxide assimilated.

t is the incubation period in hours

0.375 converts mass of oxygen to mass of carbon. It is the ratio of molecules of carbon to molecules of oxygen ($12mgC/32mgO_2$)

1000 converts L to m^3 ($1L = 1000cm^3$).

3.4 Determination of catchment area

The catchment area was determined by mapping the area using a hand held Global Positioning System (GPS), Garmin 45 model. The coordinates were used to plot the area. The area of the catchment was then determined by dividing the scaled map of the catchment area into small squares of known area and summing up (Fig. 3.1).The area of the squares was derived from the scaled satellite image (Fig.3.2.).

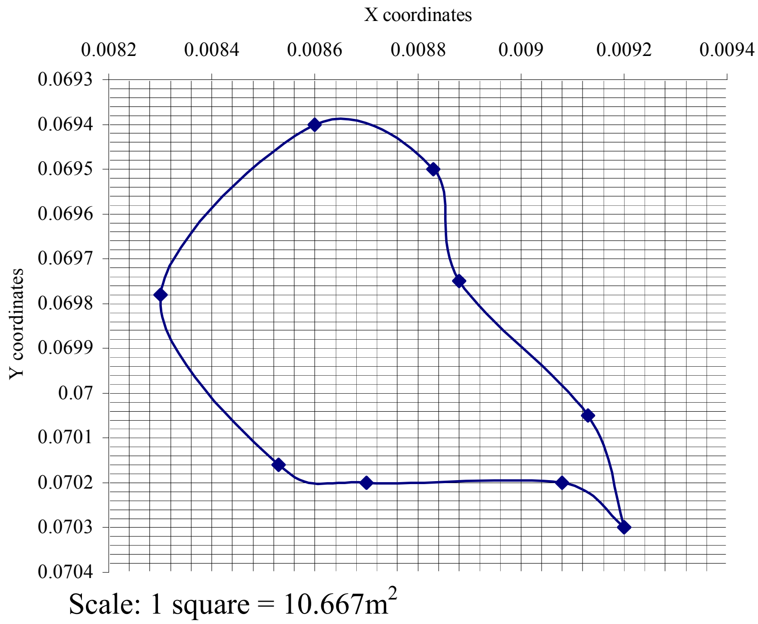


Figure 3.3. Total catchment area for the five pools.

3.5 Data analysis

Principal Component Analysis was used to explore the relationship between the environmental variables and the biological communities of macro invertebrates, phytoplankton and zooplankton. Cluster analysis was performed on physicochemical variables and diversity indices to explore similarities among the pools. Paired two-tailed T-tests were used to ascertain if there was a significant difference in the diurnal bottom and surface temperature and oxygen concentration for the shallowest and the deepest pools. A Chi-square test was performed to determine if the shallowest and deepest pools offered significantly different habitats in terms of the minimum and maximum range of temperature the pool experiences. Correlation analysis was used to determine the relationships between environmental variables. Values for two pools (P1 and P5) were used interchangeably to plot the graphs basing on their high correlation values which clearly illustrated the trend. Time series regression analysis was used to explore temporal variation in the phytoplankton community, which had enough data to perform the analysis. STASTICA Version 7.0 package was used to perform these analyses. The doubling time for the phytoplankton species *Microcystis aeruginosa* was calculated using the formula (Anton and Rorres, 1987);

$$\frac{\ln 2 \times t}{X}$$

Where;

$\ln$ is the natural logarithm

t is time in days (7)

X is the exponential growth function

The Shannon-Wiener index ($\overline{H}$) was used to measure species diversity in each pool using the equation (Shannon and Wiener, 1949);

$$\overline{H} = -\sum p_i \ln p_i$$

Where;

$\overline{H}$ is index of diversity,

ln is the natural logarithm.

p_i is proportion of the *i*th species to the total count

4.0 RESULTS

4.1 Precipitation

A total of 113.0mm of rain occurred in December, whilst the highest amount of 258.0mm occurred in January. The amount decreased progressively to 27.1mm by mid April. Afterwards, no precipitation occurred (Table 4.1). The pools flooded and flushed out every time it rained. The flush out rates were higher in shallow pools (P2, P3 and P4) than in the two deeper pools (P1and P5) (Fig. 4.1.).

Table 4.1. Weekly total precipitation preceding each sampling date

Year	Month	Date of sampling	Precipitation (mm)	Total (mm)
2006	December	16	58.0	113.0
		23	28.0	
		30	27.0	
2007	January	06	49.0	258.0
		13	32.5	
		20	88.0	
		27	74.5	
	February	03	37.0	95.5
		10	25.0	
		17	9.5	
		24	0.0	
	March	03	24.5	26.4
		10	14.3	
		17	4.6	
		24	0.0	
		31	20.0	
	April	07	0.0	27.1
		14	5.6	
		21	0.8	
		28	20.7	
		05	0.0	

Source: Meteorological Services Department, Harare, 2007.

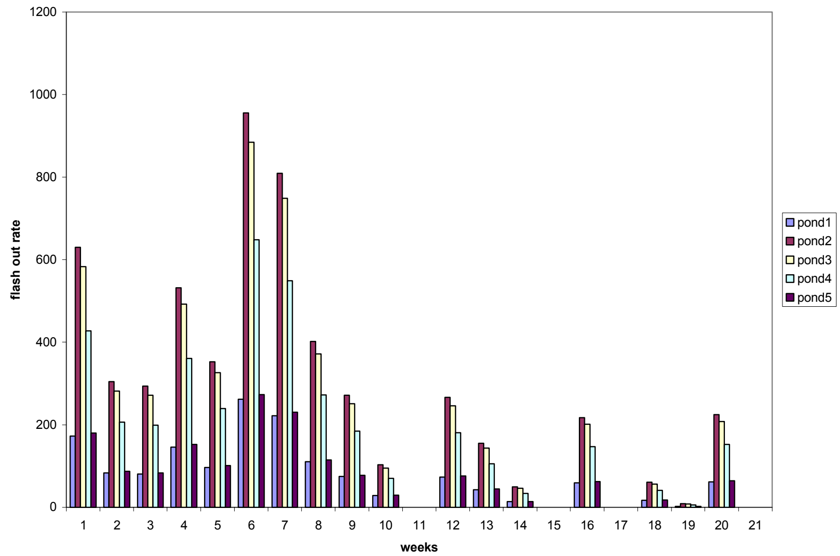


Figure 4.1. Weekly rate of flushing out for the five pools.

4.2 Temporal variation

Physicochemical variables (Figs 4.2 - 4.7), primary production and biodiversity showed temporal variation. Dissolved oxygen, conductivity, pH and primary production decreased when the amount of precipitation received per week increased. Total nitrogen and species diversity increased when precipitation increased (Fig 4.2-7.). Correlations between the environmental variables with precipitation are given in Table 4.2.

Table 4.2 Correlation values between environmental variables and precipitation.

	P1	P2	P3	P4	P5	All pools
Conductivity	-0.24	-0.08	-0.14	0.18	-0.47	-0.11
Primary production	-0.38	0.45	0.40	-0.12	-0.12	-0.17
Oxygen	-0.26	-0.46	-0.45	-0.19	-0.50	-0.26
pH	-0.23	-0.15	-0.12	-0.21	-0.25	-0.32
Total Nitrogen	0.39	0.72	0.41	-0.32	0.51	0.48
Total Phosphorus	-0.19	-0.01	0.05	0.03	0.64	-0.12
Temperature	-0.17	0.07	0.16	-0.12	-0.18	-0.28
Species Diversity	0.43	0.42	0.51	-0.27	0.56	0.40

Dissolved oxygen was lower during the first nine weeks of the study, became higher after week twelve and then fell after the twentieth week (Fig.4.2).

Figure 4.2.Temporal variation in dissolved oxygen and precipitation.

Conductivity was low during the first twelve weeks (Fig.4.3) they rose after week thirteen. The conductivity levels increased with decrease in precipitation.

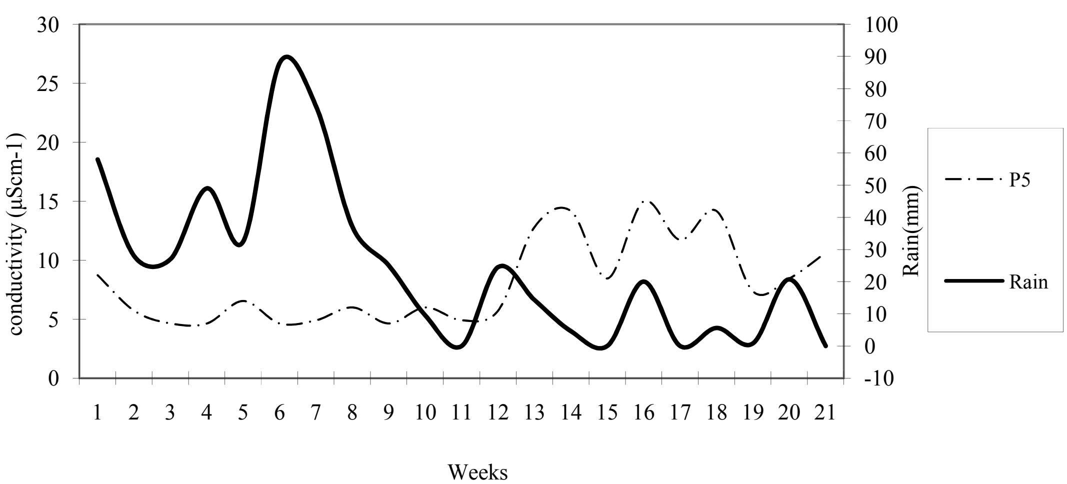


Figure 4.3. Temporal variation in conductivity and precipitation.

Total nitrogen levels were higher during the first thirteen weeks, but fell afterwards (Fig 4.4). The trend was that total nitrogen levels rose when precipitation increased and fell when precipitation decreased (Fig 4.4.).

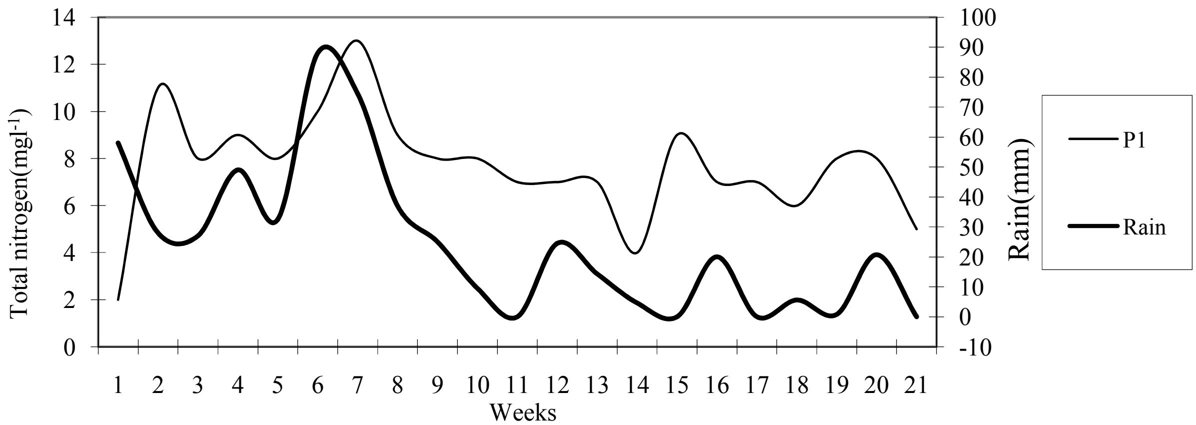


Figure 4.4. Temporal variation in total nitrogen and precipitation.

The general trend among the pools was that pH levels increased with decrease in precipitation (Fig 4.5.).

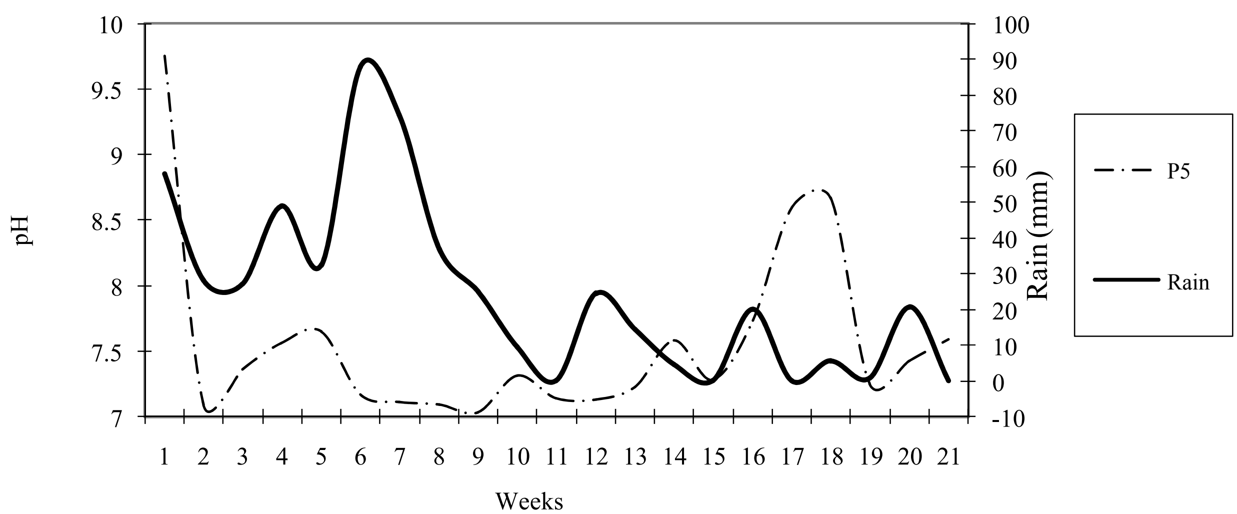


Figure 4.5. Temporal variation in pH and precipitation.

High primary production rates were recorded after week twelve (Fig 4.6).The trend among the pools was that primary production increased with decrease in precipitation.

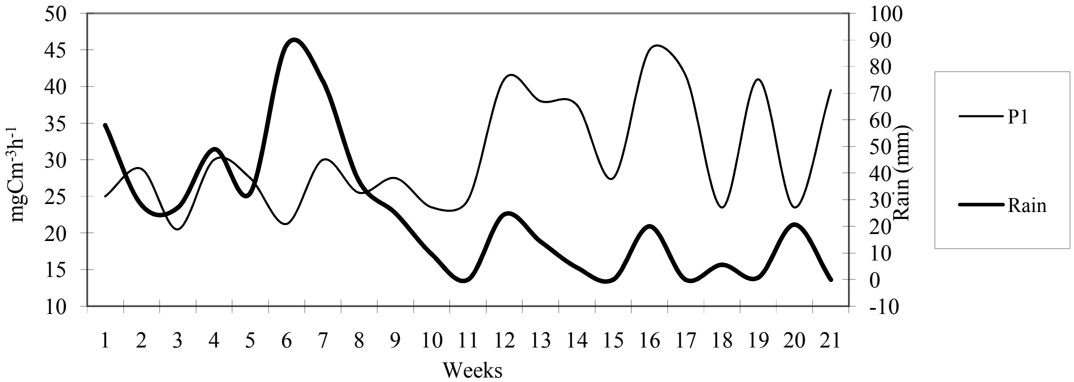


Figure 4.6. Temporal variation in primary production and precipitation.

The trend among the pools was that species diversity increased with increase in precipitation (Fig 4.7.).

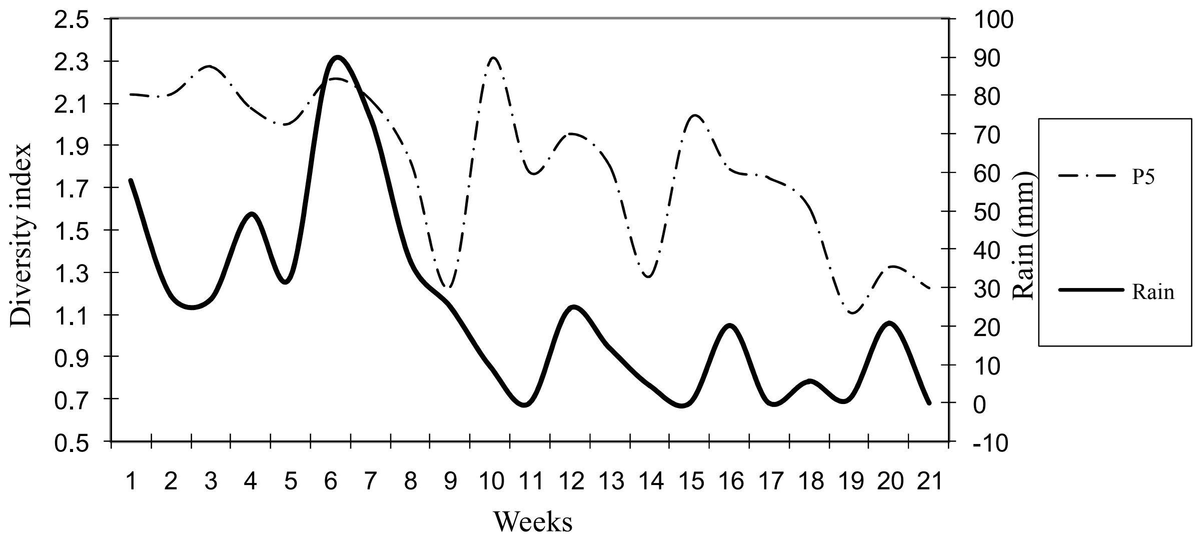


Figure 4.7.Temporal variation in species diversity and precipitation.

4.3 Indirect gradient analysis

Principal Components Analysis of 12 environmental variables show factor 1 accounting for 32.36% of the variance (Fig.4.8). Days on which there was no rain, conductivity, and dissolved oxygen are on one end of the gradient while precipitation, flush out rate and total nitrogen are associated with the other end of the gradient. This principal component therefore represents a precipitation gradient.

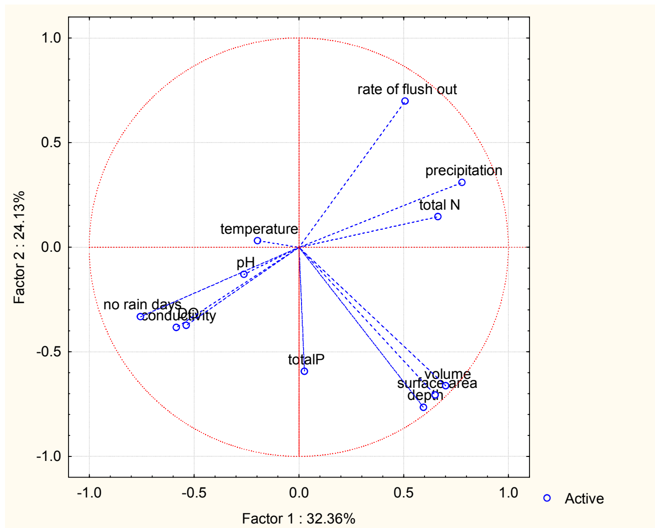


Figure 4.8. Projection of environmental variables on Axes 1 and 2.

4.4 Temperature and dissolved oxygen profiles (24 March 2007)

4.4.1 Temperature profile

Temperature increased below the surface at 0.05m depth then decreased as depth increased. Stratification occurred in the two deepest pools (P1 and P5) at depth 0.15 to 0.30 and 0.15m to 0.20m respectively (Fig. 4.9.).

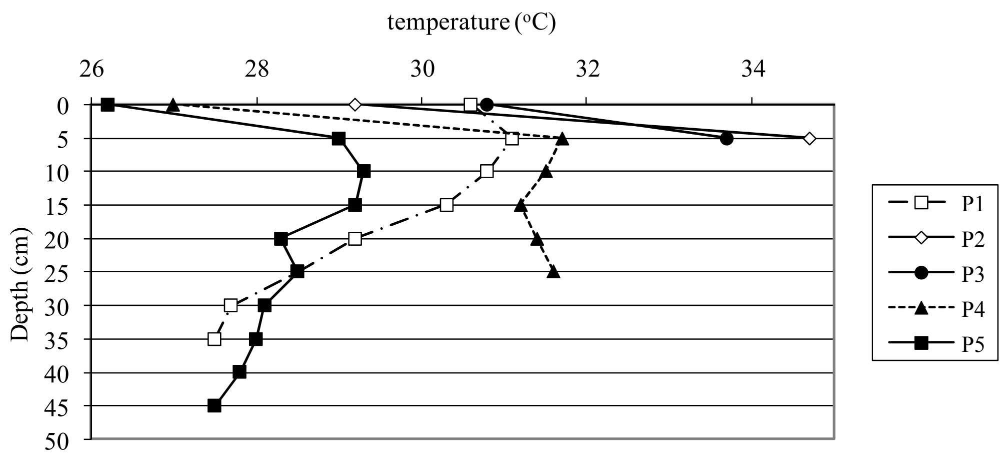


Figure 4.9. Temperature change in relation to depth in the five pools.

4.4.2 Dissolved oxygen profile

The dissolved oxygen decreased below the surface at 0.05m depth in all the pools (Fig. 4.10.).

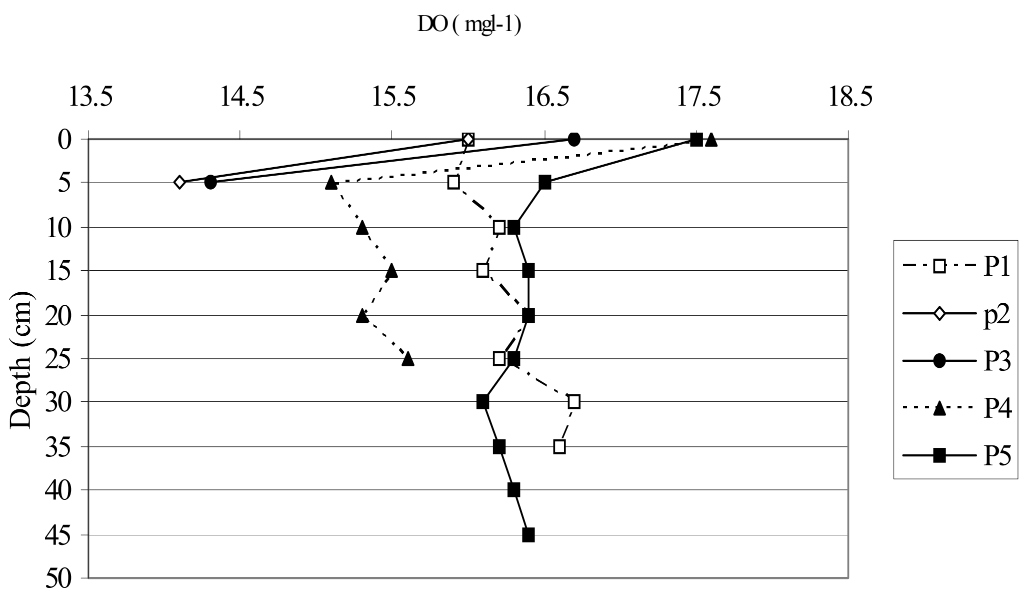


Figure 4.10. Dissolved oxygen in relation to depth in the five pools.

4.5 Diurnal variation (9 April 2007)

4.5.1 Diurnal temperature variation

There was a sharp decrease in temperature in the shallowest pool at noon (Fig 4.11). The diurnal temperature trends were the same both pools. The surface and bottom temperatures increased throughout the day, then decreased gradually throughout the night, then rose again after 6AM (Fig 4.11.). After 5 PM and through the night, bottom temperatures in both pools were warmer than those at the surface, and then surface temperature became warmer again after 7AM. The shallow pool (P1) had the highest temperature at 34°C at 2Pm as well as the lowest of 14°C at 6AM.

Paired T-tests were performed to test whether diurnal temperature between surface and bottom temperature was the same within the pools and between the pools. There was no significant difference ($p > 0.05$) for both pools (P1 and P3) in their surface and bottom temperatures. However, there was a significant difference ($p < 0.05$) between the two pools in their surface and bottom temperatures

There was no significant difference (χ^2, $p > 0.05$) on the minimum and maximum surface and bottom temperature ranges for the deepest and the shallowest pool (P1 and P3).

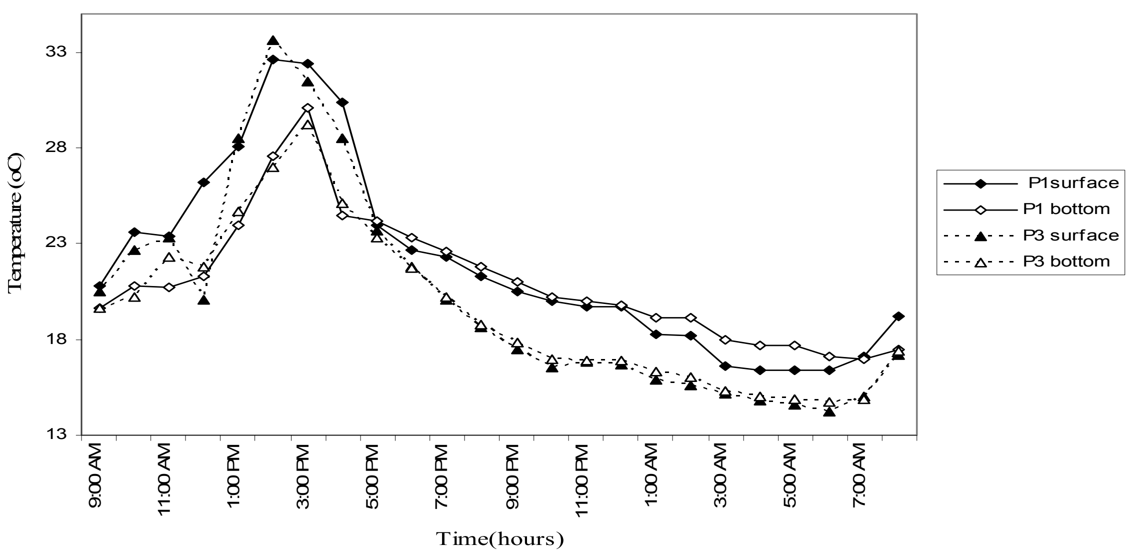


Figure 4.11. Diurnal temperature variation at the surface and bottom of the smallest and the largest pool.

4.5.2 Diurnal oxygen variation

Dissolved oxygen trend for the deepest (P1) and shallowest (P3) pools showed an increase in the morning, a decrease mid afternoon (12PM -I PM), then a gradual increase up to 4 PM, followed by a gradual decrease throughout the night, then an increase again after 6 AM onwards (Fig. 4.12.). Throughout the night, bottom oxygen concentration levels were higher than the surface levels. For P3, this trend started after 4 PM, whilst it was after 10 PM for P1. T-tests were performed to test whether the diurnal dissolved oxygen concentration variation between surface and bottom waters was the same within the pools and between the pools, P1 and P3. There was no significant difference ($p > 0.05$) in the surface and bottom dissolved oxygen for both the pools. However, there was a significant difference ($p < 0.05$) between the two pools in the dissolved oxygen concentration at surface and bottom waters (Fig 4.12.).

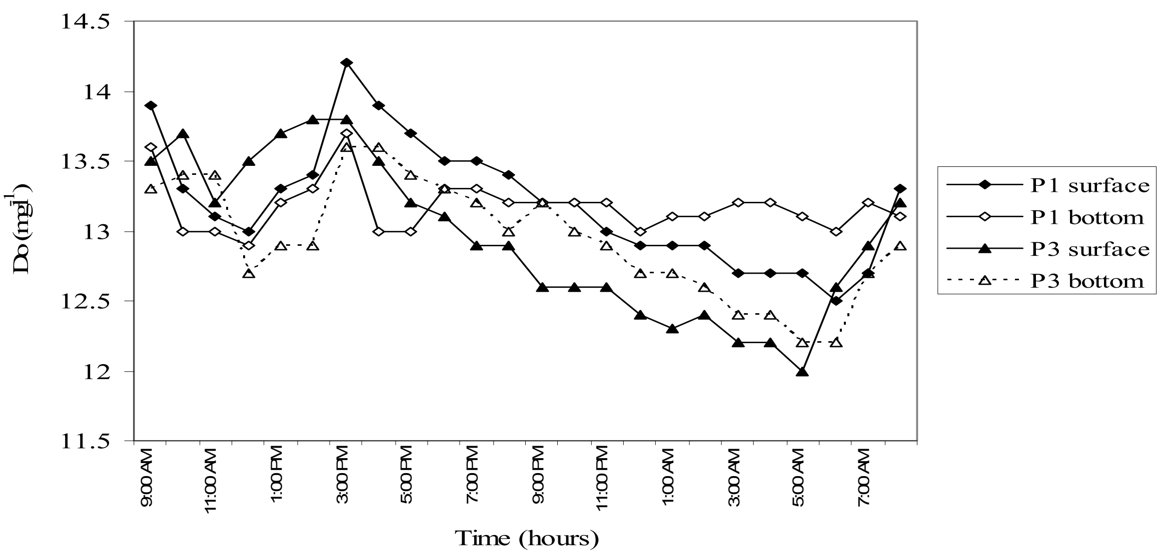


Figure 4.12. Diurnal dissolved oxygen variation in the deepest (P1) and shallowest (P3) pools.

The pools were supersaturated (Fig. 4.13) throughout day and night. The pools were highly saturated from mid to late afternoon, reaching a peak at 3 PM and then fell gradually during the night. The levels rose up again after 5 AM (Fig.4.13).

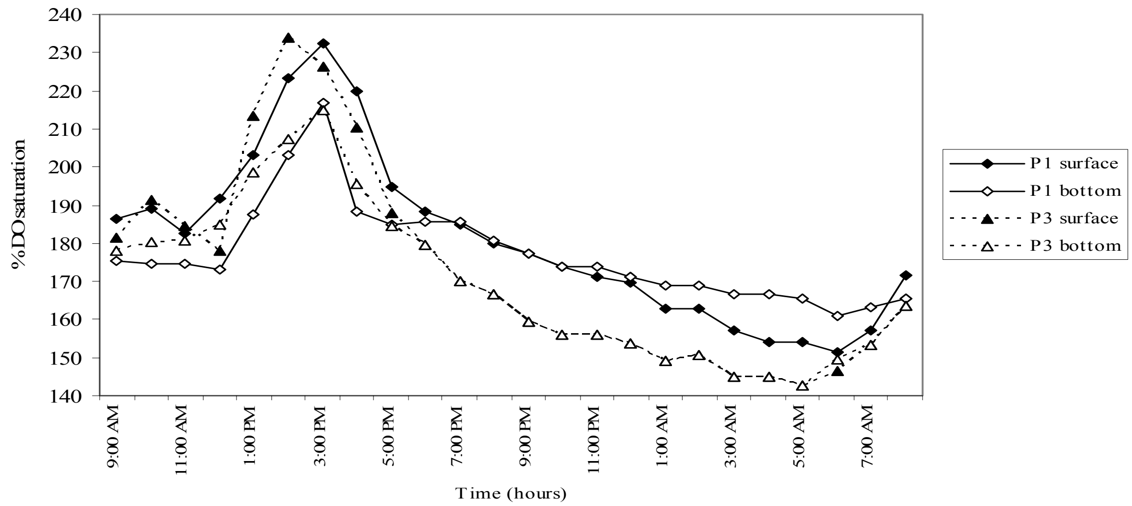


Figure 4.13. Diurnal oxygen percentage saturation in the deepest and shallowest pools.

4.6 Biological communities

4.6.1 Species-environment relationship

The results of the PCA technique indicate that axis 1 accounts for 16.07% of the variance whilst axis 2 accounts for 10.62% (Fig 4.14.). The analysis shows the grouping of species with corresponding environmental variables. *Microcystis aeruginosa (9), Synecchocystis aquatilis (10)*, conductivity and dissolved oxygen are negatively correlated with the axis 1. These species and variables are also positively correlated with days on which there was no rain. These environmental variables and species are in a gradient which represents decreasing precipitation. Total nitrogen, *Spirogyra rhizobrachiales (12)*, *Cylindrocystis labrynthoides(11)* and dytiscidae *(8)* are positively correlated with axis 1. These species and the environmental variable are in a gradient which represents increase in precipitation.

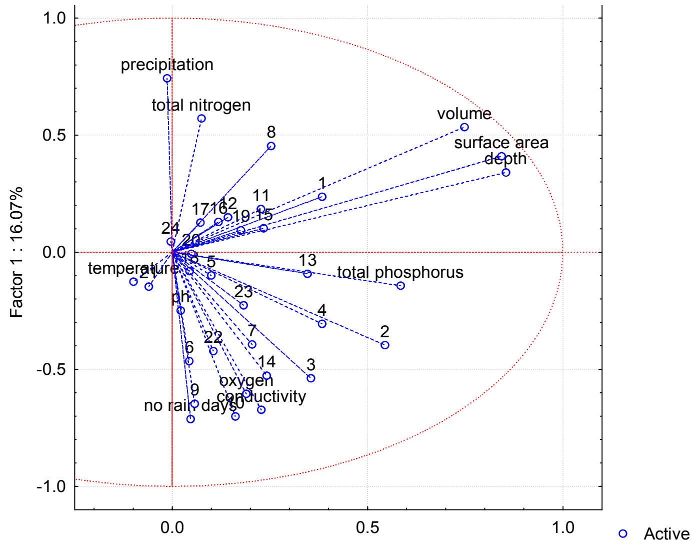


Figure 4.14. Projection of biological communities and environmental variables on Axes 1 and 2. (Species codes are given in Appendix 2).

4.6.2 Phytoplankton growth

Doubling time (Table 4.20) for *Microcystis aeruginosa* population was longer in the three pools (P2, P3 and P4) than in the other two pools (P1 and P5).

Table 4.3 *M. aeruginosa* population doubling time and pools average flushing rates.

Pools	Exponential growth function	Doubling time (days)	Weekly flushing rate
P1	0.2515	19	73.61
P2	0.1067	45	268.41
P3	0.1128	43	248.34
P4	0.1415	34	182.01
P5	0.2505	19	76.58

M. aeruginosa increased with time (Fig 4.15.), whilst *Spirogyra rhizobrachiales* decreased with time (Fig 4.17).Values from the deepest and the shallowest pools (P1 and P3) respectively, were used to illustrate the trend. In the shallow pool (P3), the increase was punctuated by flush outs, then the population recovered again (Fig 4.16.).

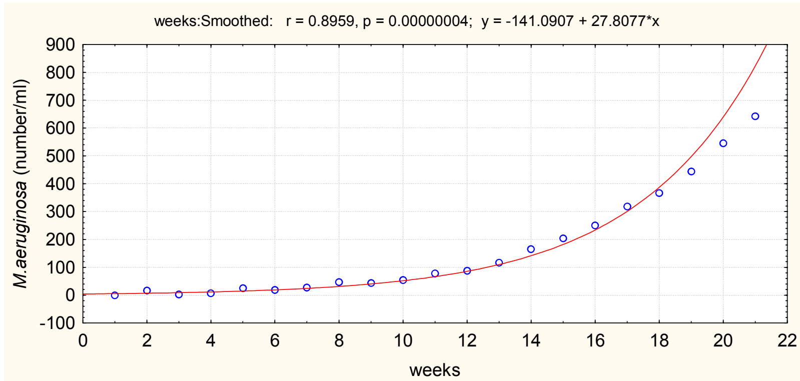


Figure 4.15. *Microcystis aeruginosa* increase with time in the deepest pool (P1).

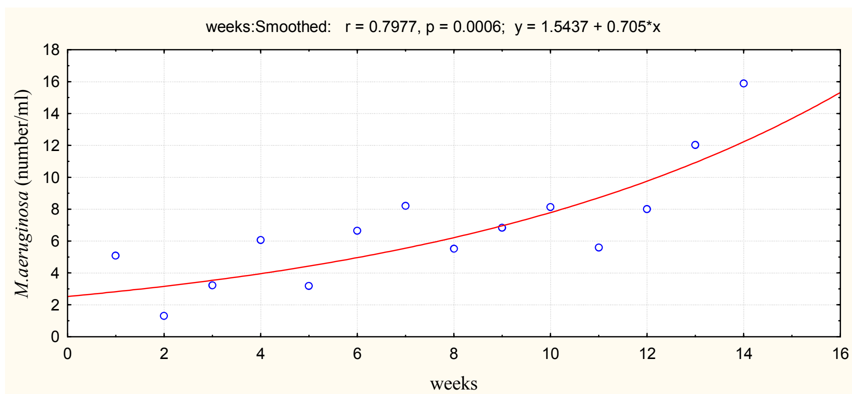


Figure 4.16. *Microcystis aeruginosa* increase with time in the shallowest pool (P3).

Spirogyra rhizobrachiales abundance decreased during the first five weeks in both pools P1 and P3 (Fig. 4.17). However, after the sixth week, the trend was punctuated by series of increases and then decreases, indicating the population recovering from the pool`s flushing outs.

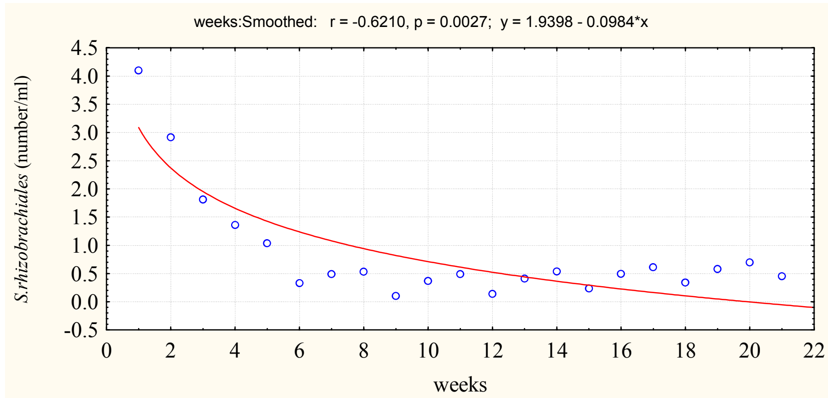


Figure 4.17. *Spirogyra rhizobrachiales* decrease with time in the deepest pool (P1).

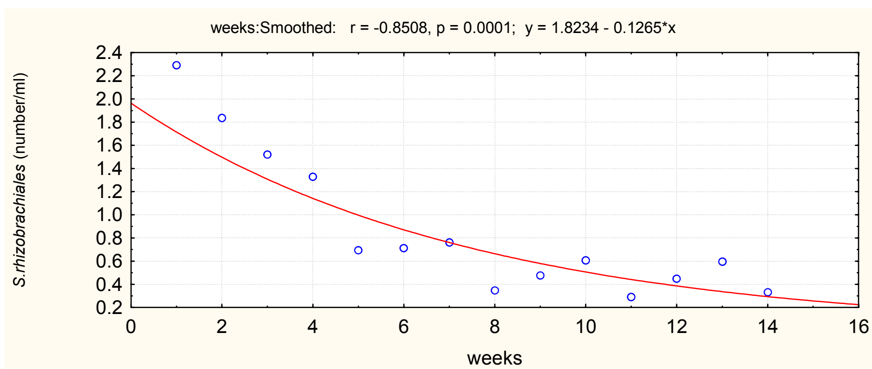
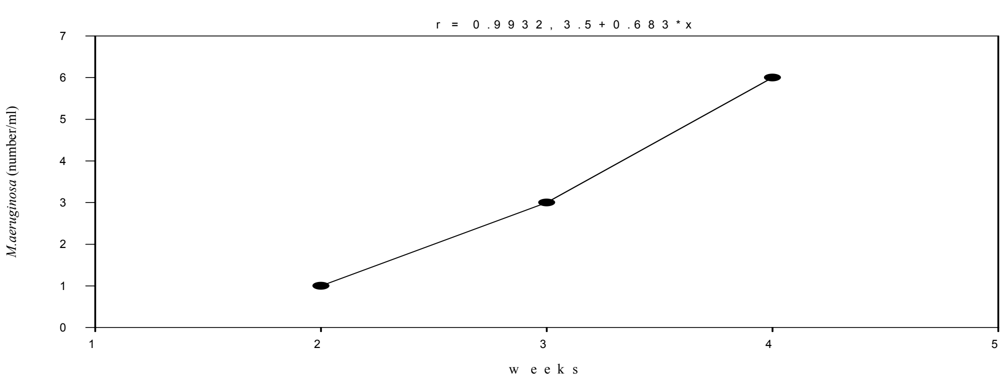


Figure 4.18. *Spirogyra rhizobrachiales* decrease with time in the shallowest pool (P3).

M. aeruginosa populations showed series of increases which were punctuated by flush outs (Fig. 4.19). (Fig 4.16) was used to produce the graphs below.

(a)



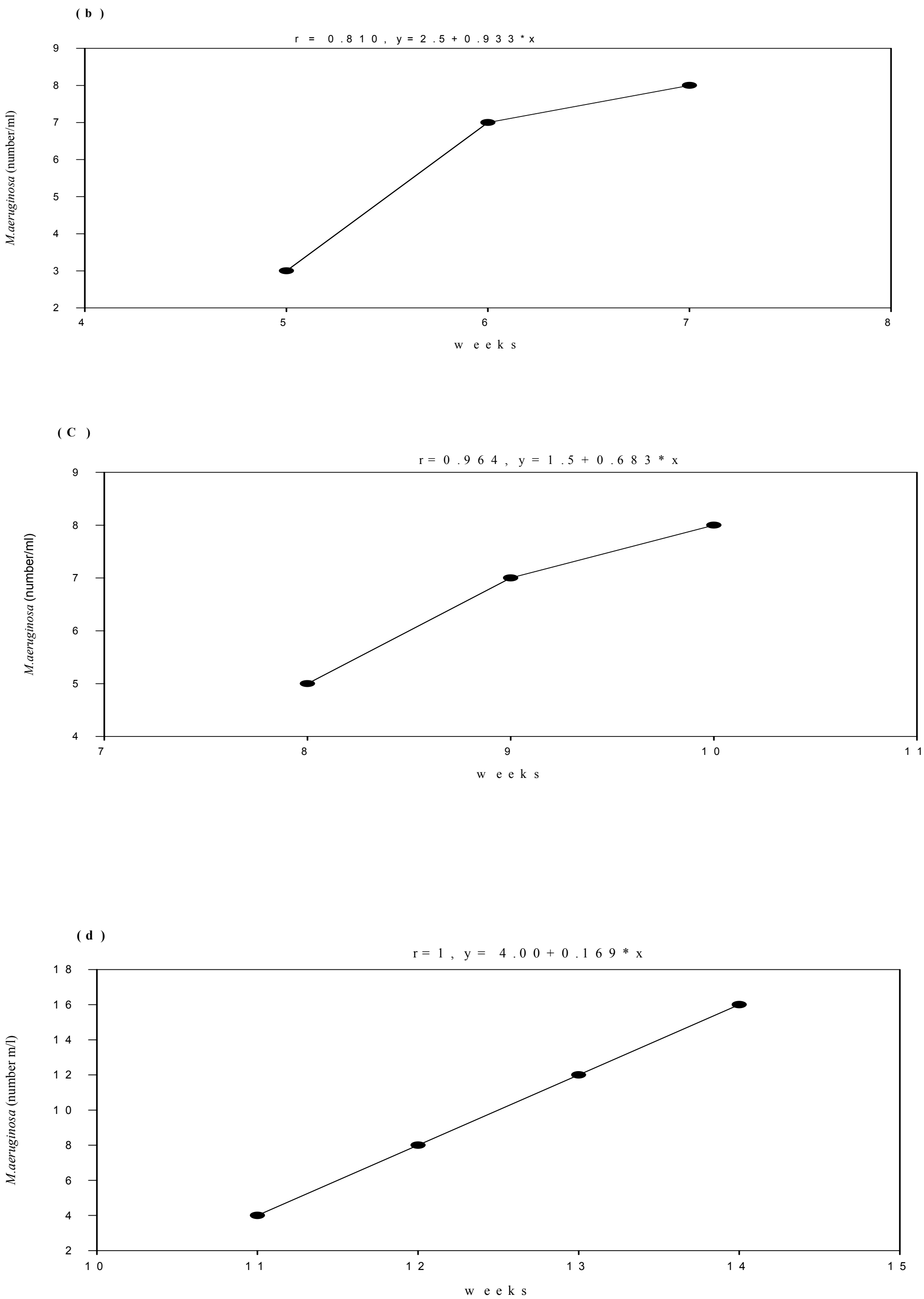


Figure 4.19. *M.aeruginosa* populations recovering after flushing outs in the shallow pool (P3).

4.6.3 Structure of the pools` biological communities

Results from (Figs.4.19 to 4.23) revealed some marked differences in the plankton and macro invertebrate communities of the pools (Species list is given in Appendix 3). P1, P4 and P5 had 7 macroinvertebrates with abundances above 10, whilst P2 and P3 had lesser species. Aeshnids, Notonectids and Naucorids were the three most abundant macro invertebrates in the mentioned three pools whilst P2 and P3 had only Chironomids and Naucorids, respectively, as the most abundant taxa. For the zooplankton species; P1, P4 and P5 had 3 species with abundance above 10 whilst P2 and P3 did not have any. Cyclopoid nauplii was the most abundant in P1 whilst *Asplanchina girodii* was the most abundant in P4 and P5. However, *Asplanchna girodii*, was the most abundant in the four pools except in P1 where cyclopoid nauplii were the most abundant. For the phytoplankton community, P1, P4 and P5 also had 2 species each with abundances above 100 whilst P2 and P3 had none. *Microcystis aeruginosa* and *Synechocystis aquatilis* were the most abundant phytoplankton species in all the five pools (Figs 4.19-.23). The ranks and abundance (total counts) and missing species on the curves are given in Appendix 5. Table 4.4 below summarises the importance curves information.

Table 4.4. Number of species with abundances >10 for the five pools.

Pools	P1	P2	P3	P4	P5
Criterion	>10	>10	>10	>10	>10
Macroinvertebrates	9	4	2	8	8
Zooplankton	3	0	0	2	3
Phytoplankton	10	5	3	6	12
Total	22	9	5	16	23

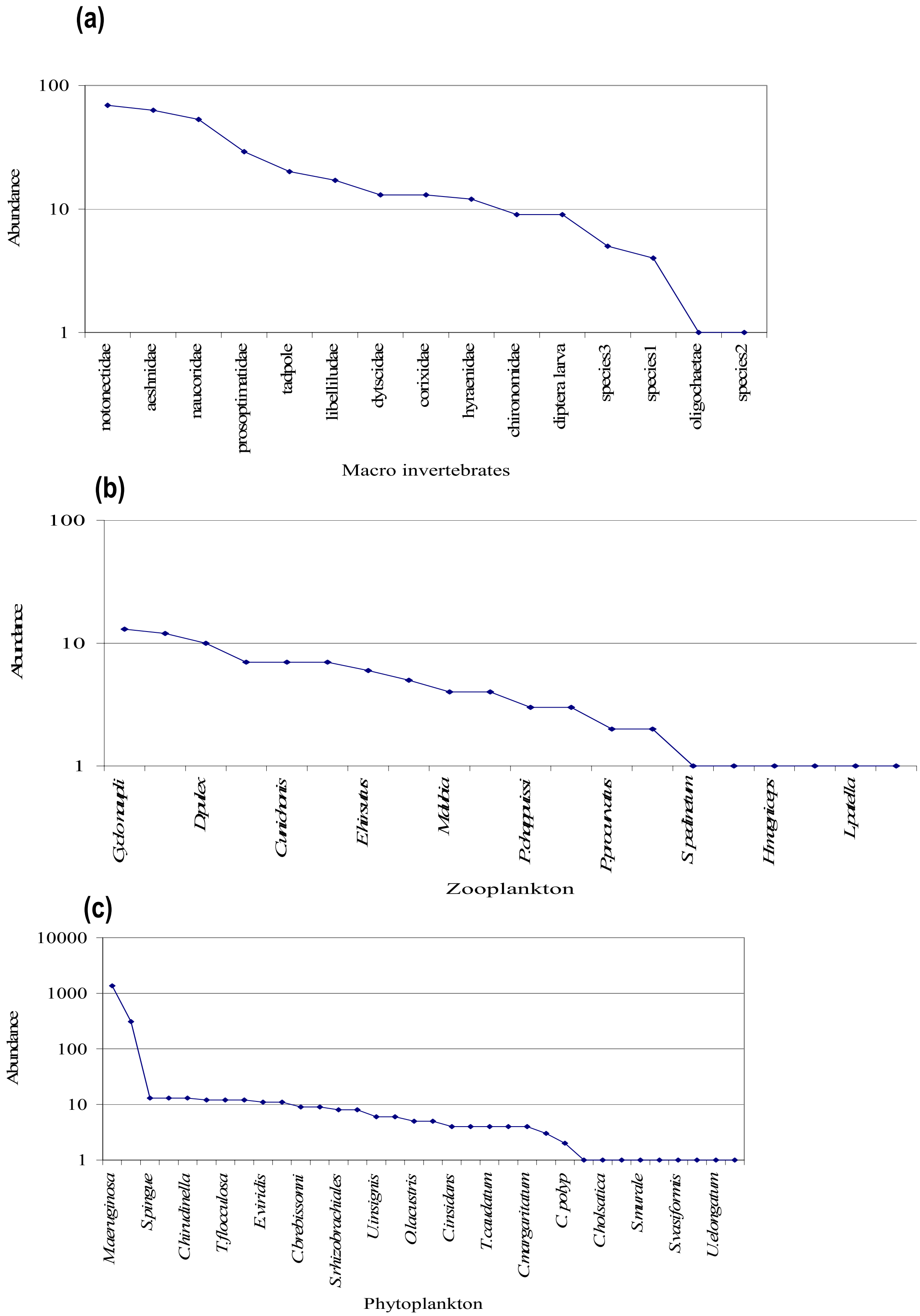


Figure 4.20. Importance curves of biological communities for P1.

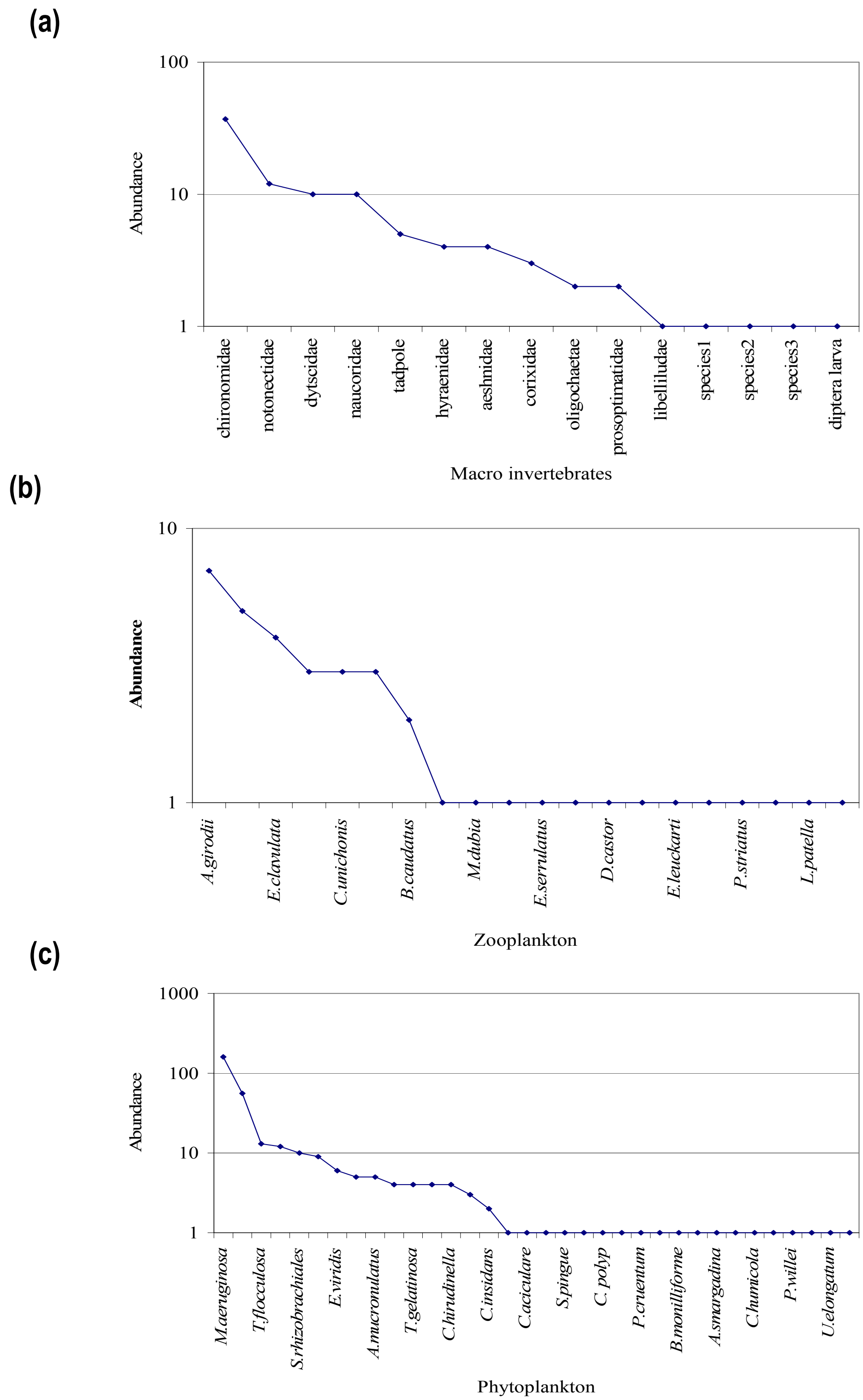


Figure 4.21. Importance curves of biological communities for P2.

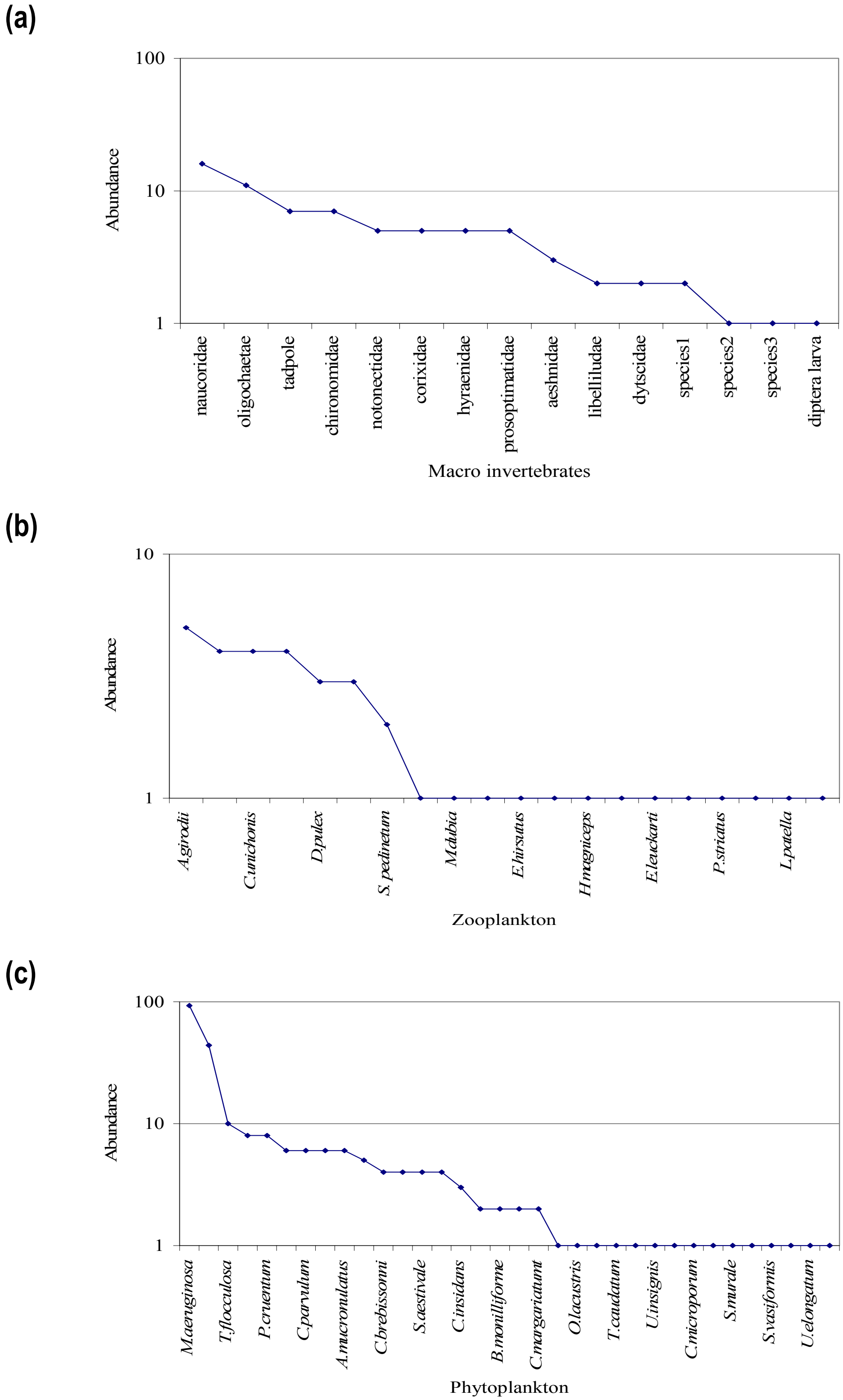


Figure 4.22. Importance curves of biological communities for P3.

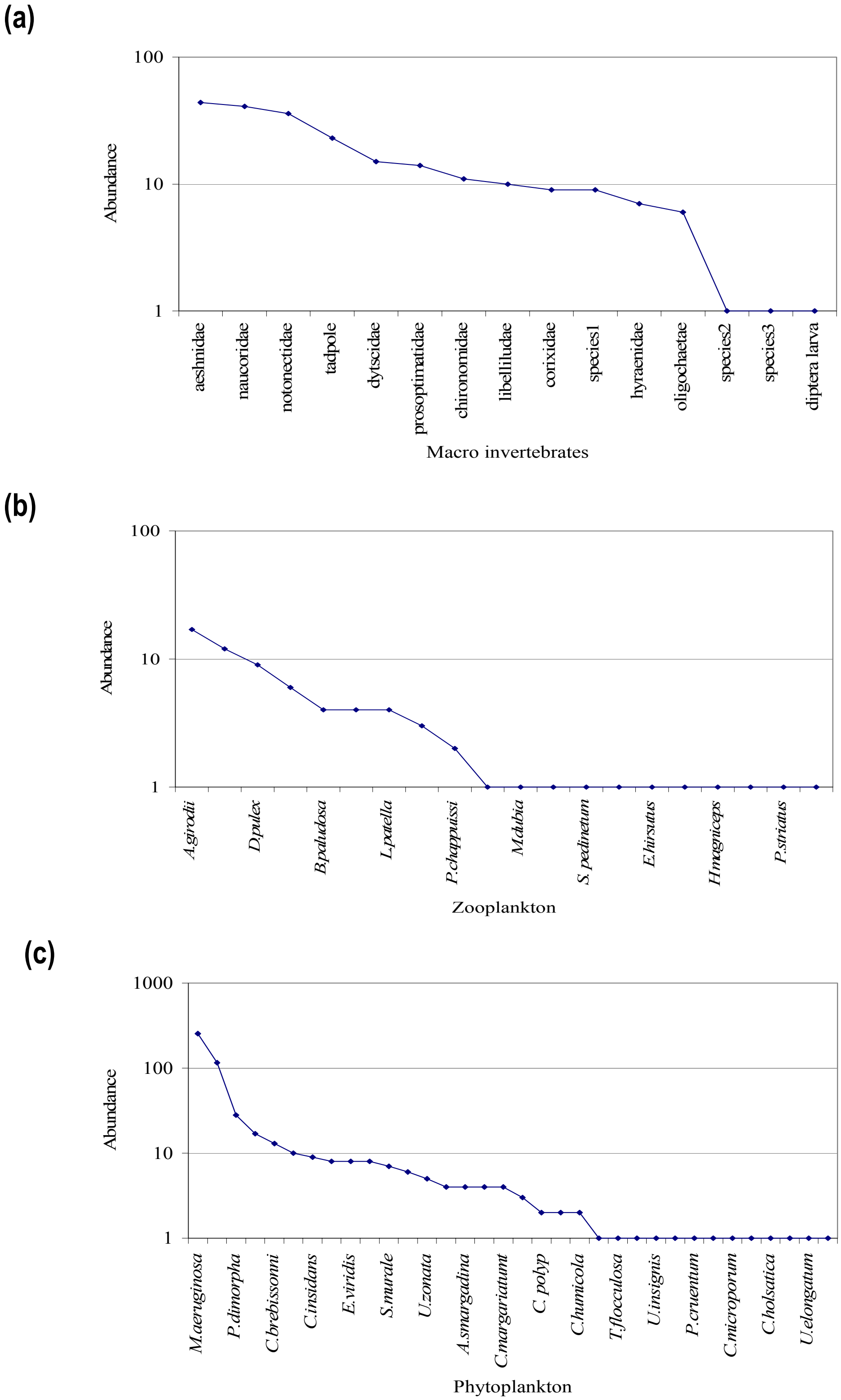
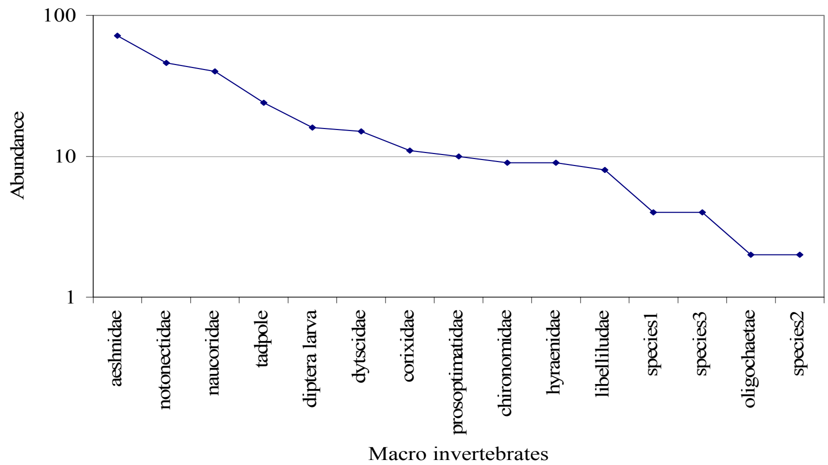
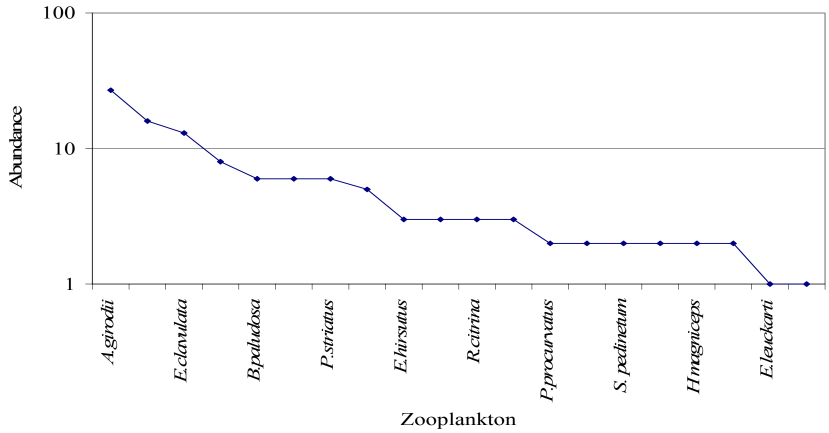


Figure 4.23. Importance curves of biological communities for P4.

(a)



(b)



(c)

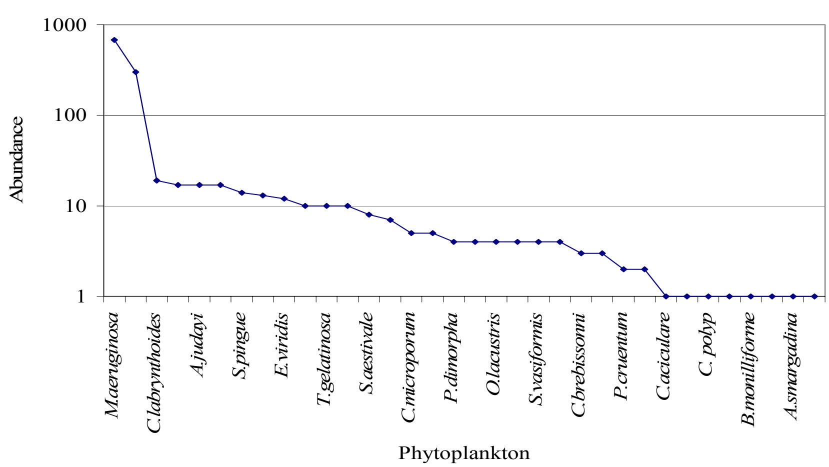


Figure 4.24. Importance curves of biological communities for P5.

Analysis of the species curve data showed that there was a relationship between flushing rate, pool size and the number of species which were frequent in the different pools (Fig 4.25).

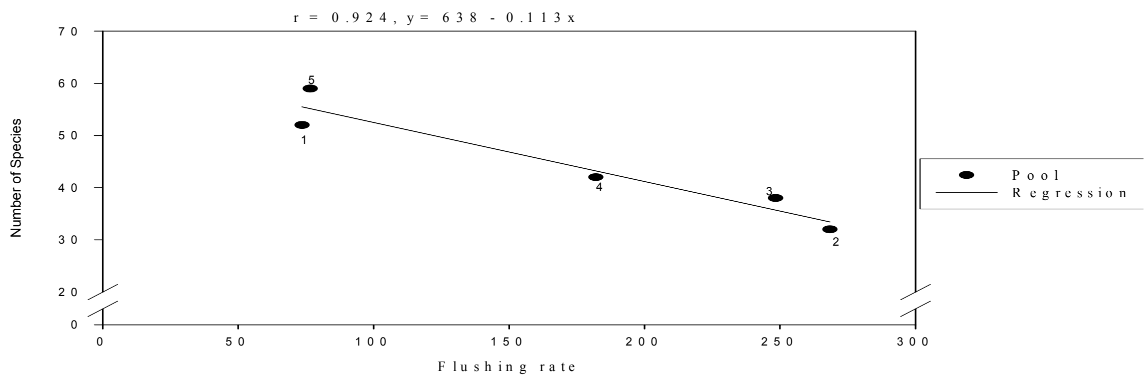


Figure 4.25. Relationship between flushing rate, pool size and number of frequent species.

4.6.4 Cluster analysis

Using species diversity and environmental variables the five pools were clustered into two groups, P2 and P3 formed one group, whilst P1, P4 and P5 formed the second group. These results show that the pools were grouped according to similarity in their morphometric features (Fig 4.26).

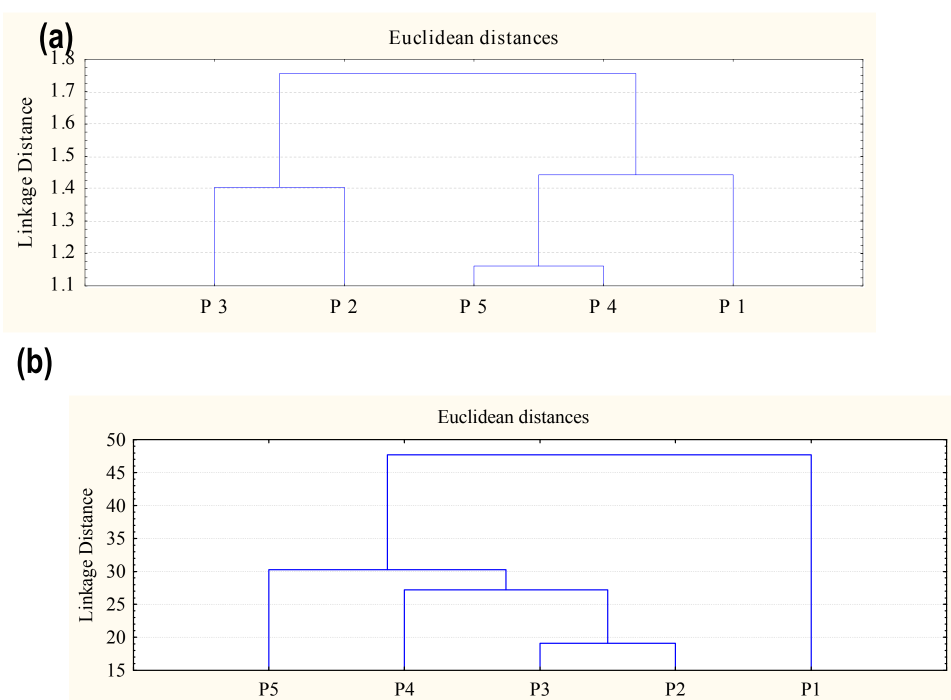


Figure 4.26. Cluster analysis using (a) Diversity indices, (b) environmental variables.

5.0 DISCUSSION AND CONCLUSION

5.1Temporal variation

5.1.1 Ecological variables

Some of the pools dried up, then refilled again during the rainy season. Primary production varied temporarily. Higher rates of production were measured towards the end of the rainy season. This might be attributed to increase in habitat duration due to infrequent flushing outs, which meant that populations became established. A comparable shift of species composition in the phytoplankton community was observed. Some phytoplankton species such as *Cylindrocystis brebissonnii* and *Perone dimorpha* that were present at the start of the research were absent towards the end, yet other species such as *M. aeruginosa* and *S. aquatilis* persisted as major components of the system for the duration of the rain season. These observations concur with Borcard *et al* (1992) findings which they attributed to environmental limits characteristic to each species such as temperature as well as interspecific competition. *M. aeruginosa*, and *S aquatilis* which are blue green algae increased in abundance whilst *Spirogyra rhizobrachiales*, a green algae, decreased in abundance towards the end of the rainy season. Algal blooms are largely a result of increase nutrients such as nitrogen and phosphorus. However, the trend observed in this study might have been influenced by temperature. The temperatures measured towards the end of the rain season could be a contributing factor to the dominance of blue green algae. This observation is supported by the work of (Pliński and Jóźwiak, 1999; Sibanda, 2003) who established the role of temperature in blooms of blue green algae. The observed successional sequence might also be explained by residence times. This is supported by Wetzel (2001) who states that green algae and diatoms are dominant during periods of short residence times, while blue green algae develop abundantly when water residence times are longer. In this research, short residence times were characterised by the early weeks when high rates of flushing out meant short residence times while longer residence times were characterised by the later weeks when flushing out was less frequent. Dytiscids were positively correlated with precipitation. They were more abundant during the start of the rain season than towards the end. Macan (1963) similarly found these results and attributed this to the lower temperatures which occur when it rains. Dytiscid larvae fail to develop after a temperature range of 27^{o}C, hence the association with precipitation. Species diversity showed temporal variation. High species diversity was measured early to mid rainy season (December to February), while low species diversity was measured towards the end of the season (March and April). These results might be attributed to decrease in occurrence of precipitation which meant reduced cysts and spore inputs (Maguire, 1963). High precipitation at the start of the rain reason also meant frequent disturbance, which created new niches (Wetzel, 2001). The end of the season was also characterised by profusion of species such as *M. eruginosa* and *S. aquatilis* which might have caused shading; an unfavourable condition for other species.

5.1.2 Environmental variables

Environmental variables such as total nitrogen, dissolved oxygen, and pH varied considerably throughout the rainy season. Total nitrogen levels decreased towards the end of the rainy season. This observation is similar to Kalff (2000) findings, which he attributed to denitrification, which rises with increasing water residence time and decreasing water depth. Rainwater itself may account for all nitrogen in surface waters (Visser, 1974; Payne, 1986), hence this might also explain the observed high levels at the start of the season when precipitation was high. Dissolved oxygen and pH levels increased towards the end of the rainy season. This observation concurs with Schneider and Frost (1996) and Williams (1997).The rise was attributed to increase in habitat duration, which meant establishment of the phytoplankton community as pond washout decreased. Considerable daily photosynthesis in the ponds results in increased oxygen levels. It also depletes available carbon dioxide, causing the pH rise. Conductivity was low during the start of the rain season but increased towards the end. This might be attributed to extended periods of evaporation towards the end of the rain season, which concentrates the ions. However the conductivity levels in the pools were low when compared with levels in other tropical water bodies such as Lake Chivero which have levels above $200\mu Scm^{-1}$ (Sibanda, 2005). These low levels might be attributed to the fact that the water drained an igneous catchment, which contains few ions (Payne, 1986).

5.2 Diurnal variation

5.2.1 Temperature

The pools are shallow; hence they are subject to rapid heating from solar radiation and cooling from the wind. The water temperature was high immediately below the surface, and decreased with increasing depth. This observation may be attributed to evaporative cooling at the surface waters which lowers the temperature, resulting in a warmer layer immediately beneath the surface (Williams, 2006). The sun is the source of heat that warms most waters (Macan, 1963) hence the temperature fell during the night. Stratification was observed in the two deeper pools. Stratification in water bodies occurs when surface warming increases the temperature difference and resulting density difference to the point where resistance to mixing becomes greater than the mixing power of the wind-induced (Macan, 1963; Kalff, 2002). Stratification is usually short lived in shallow water bodies (Kalff, 2002). However, stratification was recorded once in this study; hence the duration needs further investigation. During the night, bottom waters were warmer than surface waters. This might have been a result of surface waters losing heat faster than bottom waters due to wind action on the surface waters (Williams, 2006). The shallow pool had a greater diurnal fluctuation than the deeper pool. This observation is consistent with (Macan, 1963; Williams, 2006) who established that the more the water to be heated, the slower is the heating process. Therefore, the smaller the volume of water, the greater is its diurnal temperature fluctuation and the higher the minimum and maximum that it is likely to reach. However, the Chi-square result showed that there was no significant difference in the temperature ranges experienced in the two habitats.

5.2.2 Dissolved oxygen

There was a sharp decrease in dissolved oxygen at depth immediately below the surface, a depth which corresponded sharp increase in temperature (Figs.4.10 -4.11). This observation is similar to Kalff (2000) who attributed the decrease to elevated temperatures which reduce the absolute solubility of oxygen, lowering dissolved oxygen levels. Dissolved oxygen was high during the day, but fell gradually during the night. Similarly, the study of diurnal variation of oxygen in two shallow ponds in India showed that the levels varied between 4.5 and 9.9 ppm, being maximal at 5.30pm and minimal at 5.30am (Whitney, 1942). These increases were attributed to photosynthesis during the day, taking place at a higher rate than respiration resulting in surplus oxygen, whilst at night respiration depletes the oxygen (Whitney, 1942; Macan, 1963). During the night, dissolved oxygen at the bottom was higher than at the surface. Moss (1988) found similar results and attributed them to higher respiration rates at the surface at night than at the bottom because zooplankters often go through diurnal vertical migrations reaching the water surface by night and moving down by day. In the smaller pool (Fig.4.14) the changes in the oxygen content were sudden, an observation which is consistent with (Macan, 1963) findings that the smaller the volume of water the more sudden are fluctuations in oxygen content. The thermal stratification which takes a year may be completed in twenty-four hours in a pond, emphasising the highly variable nature of the environment (Young and Zimmerman, 1956).

The pools were supersaturated with oxygen throughout the day and night. Podrabsky et al, (1998) similarly measured oxygen maxima of 256% saturation in mid to late afternoon in rainwater pools in Venezuela. They attributed the result to considerable algal photosynthesis which may produce supersaturation during the day, whilst wind induced turbulence, which facilitates a gradient of oxygen diffusion maintained the supersaturated state at night. In a separate study, Macan (1963) found similar results in moderately unproductive lakes and attributed them to being a result of the clearness of the water and absence of decomposing matter. However the oxygen values measured in this research were exceptionally high and could not be explained, though the oxygen meter used gave consistent results when tap water was measured. The super saturation status of the pools therefore needs further investigation.

5.3 Structure of biological communities

Despite ephemeral habitats being unstable environments with unpredictable hydro cycles, they enable populations to persist. Decreasing water volume has been shown to induce accelerated development in females of the mosquito Aedes triseriatus which breeds in shallow pools. This indicates an adaptation mechanism to escape the deteriorating environment (Menge and Sutherland, 1976). Aquatic beetles are active in shallow ponds whose temperatures may on occasion approach $40^{o}C$ in the afternoon (Young and Zimmerman, 1956). Similarly high temperatures ($35^{o}C$) were recorded in this research in the shallowest pool (Fig4.10). Under these high temperatures, the insects do not stay near the surface but congregate at the bottom. They return to the surface at night and in the early morning to forage, when the water is cooler. This observation concurs with Williams (1997) who states that organisms that can aestivate, avoid desiccation and have very rapid rates of development during the wet phase can live in ephemeral rock pools.

New phytoplankton species continuously colonised the pools, while some previous colonisers were being lost from the community. This might be attributed to higher disturbance frequencies such as rapid changes in the water levels and high flushing rates in the pools. These observations are supported by Wetzel (2001) who states that new species always colonise shallow reservoirs which are disrupted often. The results (Fig 4.25) show that as flushing rates increases and the pool is small, the total number of species decreases. These results can be explained by the Intermediate Disturbance Hypothesis (Townsend *et al,* 2003) which states that as the disturbance frequency increases, species diversity decreases. The smaller pools were more frequently flushed out than the larger pools; hence they had lesser species as compared to the larger pools. It took longer for the phytoplankton population to double in comparison with between 3-5 days in lakes (Wetzel 2001). This might be attributed to the high rates of flushing out in the pools which decimated phytoplankton populations. The highly variable nature of the ephemeral pools might also explain the low rates of primary production as compared with tropical shallow lakes which have an average primary production rate of 83.3mgC$m^{-2}h^{-1}$ (Wetzel, 2001). The doubling time for *M. aeruginosa* population in the pools was longer in comparison with larger water bodies such as lakes which take between three to five days (Wetzel, 2000). This might be attributed to the higher rates of flushing out, hence the population took longer to establish.

Species diversity within the pools increased with increasing precipitation (Fig. 4.9), though increased precipitation was a severe disturbance to the communities through increased rates of flushing out. This observation concurs with Wetzel, (2001) who states that phytoplankton communities of shallow reservoirs are disrupted often, creating new niches, which leads to increased diversity. Biodiversity varied spatially among the pools (Fifs.4.16-4.19). The three larger pools were more diverse in species composition than the smaller pools. Meintjes (1996) similarly found that larger pans supported more species than smaller pans whilst working on crustacean-dominated pans of South Africa. The results were explained by the theory of island biogeography, which state that as the size of the geographical area increases, so do species. Different types of habitats are included and habitat diversity captured when area increase (MacAurthur and Wilson, 1967; Browne, 1981).

Species abundance was also high in the three pools (Table 4.6).The three larger pools also had highest abundances as compared to the two smaller pools (Table 4.6). They had similar biological communities, with Aeshnids, Notonectids and Naucorides being the most abundant macro invertebrates. These organisms favour larger pools which allow time for development of larger larvae and adults (Hinton, 1968). *Asplanchna girodii* were the most abundant zooplankton species in all the pools. This observation might be attributed to their short development (Macan, 1963). However, cyclopoid nauplii were the most abundant zooplankton forms in the largest pool (P1) (Fig.4.20b).The development stages of the species are long; hence this deepest pool was favoured as it ensured development into adults before drying out. *M. aeruginosa* was the most abundant species phytoplankton species in all the five pools. This observation might be attributed to the cosmopolitan nature of the species (Wetzel, 2001). Cluster analysis using species diversity indices also showed the grouping of the three larger pools (P1, P4 and P5) into one group, whilst the other two smaller pools formed the other group. However, using environmental variables, two groups were formed. P2 and P3 formed one group, P4 and P5 the second, whilst P1 was on its own. These groupings can therefore be attributed to having been influenced by pool morphometry.

5.4 Conclusion

The study has shown that catchment characteristics and the geology of the area influenced the water physicho-chemical variables of the pools. The catchment is characterised by an igneous parent rock with thin soils which supports vegetation such as resurrection plants, mosses and lichens. These characteristics influenced the nitrogen concentration and conductivity in these pools. Precipitation was found to be the most important factor that structures the biological communities in these habitats. Frequent flooding and flushing out meant the phytoplankton populations in the pools had long doubling times as compared to other water bodies such as lakes. Temporal variation in temperature determined temporal succession in the biological communities. The size of the pool determined diurnal variation and biodiversity. The deeper pools stratified, as does large water bodies such as lakes. The larger pools were more diverse in species composition and had similar biological communities. Therefore, pool morphometry, catchment characteristics, temporal variation in temperature and precipitation and the high rates of flushing out were the main factors that were found to affect ephemeral rock pools.

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Personal communication

Mr Mupungu. The Chief Meteorologist, Meteorological Service Department, Harare, 2007.

APPENDICES

Appendix 1

Correlation matrices for environmental variables for all pools

Correlations are significant at p < .05000 N=105

	pH	cond	prima prod	0xy	total N	totalP	temp	depth	tsa	volume	precipitation	norain
pH	1.00	0.59	0.79	0.98	0.71	0.48	0.94	0.57	0.65	0.45	-0.32	-0.30
cond	0.59	1.00	0.47	0.58	0.13	0.41	0.55	0.30	0.28	0.14	-0.11	0.15
prima prod	0.79	0.47	1.00	0.79	0.60	0.43	0.78	0.40	0.47	0.28	-0.17	-0.19
0xy	0.98	0.58	0.79	1.00	0.72	0.52	0.93	0.56	0.65	0.43	-0.26	-0.25
total N	0.71	0.13	0.60	0.72	1.00	0.36	0.67	0.56	0.63	0.52	0.48	-0.54
totalP	0.48	0.41	0.43	0.52	0.36	1.00	0.44	0.51	0.54	0.45	-0.12	-0.08
temp	0.94	0.55	0.78	0.93	0.67	0.44	1.00	0.53	0.61	0.41	-0.28	-0.27
depth	0.57	0.30	0.40	0.56	0.56	0.51	0.53	1.00	0.96	0.96	0.36	-0.32
tsa	0.65	0.28	0.47	0.65	0.63	0.54	0.61	0.96	1.00	0.92	0.41	-0.37
volume	0.45	0.14	0.28	0.43	0.52	0.45	0.41	0.96	0.92	1.00	0.44	-0.38
precipitation	0.32	-0.11	0.17	0.26	0.48	0.12	0.28	0.36	0.41	0.44	1.00	-0.71
noraindays	-0.30	0.15	-0.19	-0.25	-0.54	-0.08	-0.27	-0.32	-0.37	-0.38	-0.71	1.00
S -W Index	0.83	0.36	0.66	0.83	0.68	0.54	0.80	0.64	0.76	0.59	0.40	-0.33

Appendix 2

Species codes

Code	Species
1	Tadpole
2	Aeshnidae
3	Notonectidae
4	Naucoridae
5	Diptera larvae
6	Prosoptimatidae
7	Corixidae
8	Dytiscidae
9	*Microcystis aeruginosa*
10	*Synecchocystis aquatilis*
11	*Chlamydomyxa labrynthoides*
12	*Spirogyra rhizobrachiales*
13	*Ankyra judayi*
14	*Ceratium hirudinella*
15	*Staurastrum pingue*
16	*Peridinium willei*
17	*Euglena viridis*
18	*Ulothrix zonata*
19	*Tetraspora gelatinosa*
20	*Arthrodesmus mucronulatus*
21	*Uronema elongatum*
22	*Asplanchna girodii*
23	*Conochilus unichornis*
24	*Epiphanes clavulata*

Appendix 3

Macroinvertebrates, zooplankton and phytoplankton composition in the pools.

Macro invertebrate composition in the five pools through the study period

	P1	P2	P3	P4	P5
Diptera larva	+	-	-	-	+
Chironomidae	+	+	+	+	+
Corixidae	+	+	+	+	+
Tadpole	+	+	+	+	+
Oligochaetae	-	+	+	+	+
Dytiscidae	+	+	+	+	+
Notonectidae	+	+	+	+	+
Hyraenidae	+	+	+	+	+
Prosoptimatidae	+	+	+	+	+
Unidentified 1	+	-	+	+	+
Unidentified 2	-	-	-	-	+
Unidentified 3	+	-	-	-	+
Naucoridae	+	+	+	+	+
Aeshnidae	+	+	+	+	+
Libelliludae	+	-	+	+	+

(+) present, (-) absent

Zooplankton composition in the five pools through the study period

	P1	P2	P3	P4	P5
Cladocera					
Daphnia pulex	+	+	+	+	+
Chyodorus gibbus	+	-	-	-	+
Moina dubia	+	-	-	-	+
Pleuroxus chappuissi	+	-	-	+	-
Pleuroxus procurvatus	+	-	-	-	-
Copepoda					
Diaptomus castor	-	-	-	-	+
Cyclopoida					
Cyclopoid naupilii	+	-	+	+	+
Eucyclops serrulatus	+	-	-	-	+
Eucyclops leuckarti	+	-	-	-	-
Ectocyclops hirsutus	+	-	-	-	+
Halicyclops magniceps	-	-	-	-	+
Rotifera					
Epiphanes clavulata	+	+	+	+	+
Asplanchna girodii	+	+	+	+	+
Conochilus unichornis	+	+	+	-	+
Brachionus caudatus	+	+	-	+	+
Lepadella patella	-	-	-	+	+
R otaria citrina	+	-	-	+	+
Synchaeta pedineta	-	+	+	-	+
Branchionus paludosa	+	+	+	+	+

Phytoplankton composition in the five pools throughout the study period

	P1	P3	P2	P4	P5
Cylindrocystis brebissonnii	+	+	+	+	+
Chrysarachnian insidans	+	+	+	+	+
Spirogyra rhizobrachiales	+	+	-	+	+
Perone dimorpha	+	-	-	+	+
Closterium aciculare	+	-	-	-	-
Tabellaria flocculosa	+	+	+	-	+
Euglena viridis	+	+	+	+	+
Oocystis lacustris	+	-	-	+	+
Staurastrum pingue	+	-	-	+	+
Synecchcystis aquatilis	+	+	+	+	+
Tetraedron caudatum	+	-	-	-	-
Chlamydomonas polypyredenium	+	-	-	+	-
Microcystis aeruginosa	+	+	+	+	+
Stigochlonium aestivale	+	+	+	+	+
Ulothrix zonata	+	+	+	+	+
Urococcus insiginis	+	-	-	-	-
Tetraspora gelatinosa	+	+	+	+	+
Closterium parvulum	+	+	+	-	+
Poriphyridium cruentum	+	-	+	-	+
Ankyra judayi	+	+	+	+	+
Chlamydomyxa labrynthoides	+	+	+	+	+
Arthrodesmus mucronulatus	+	+	+	+	+
Ceratium hirudinella	+	+	-	-	+
Coelastrum microporum	+	-	-	-	+
Batrachospermum monilliforme	-	-	+	-	+
Chladophora holsatica	-	-	+	-	-
Asterocystis smaragdina	-	-	-	+	-
Schizogonium murale	-	-	-	+	-
Chlorococcum humicola	-	-	-	+	-
Stipitococcus vasiformis	-	-	-	+	+
Peridinium willei	-	-	-	-	+
Cosmarium magaritatum	+	-	+	+	+
Uronema elongatum	-	-	-	-	+
Trachelomonas lafvrei	-	-	-	-	+

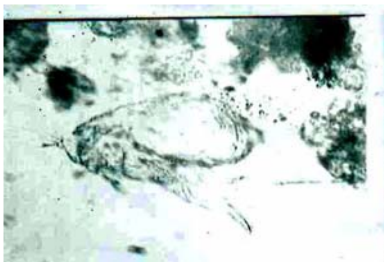
(+) present, (-) absent

Appendix 4

Plankton species in the pools

Some of the zooplankton species found in the pools.

1



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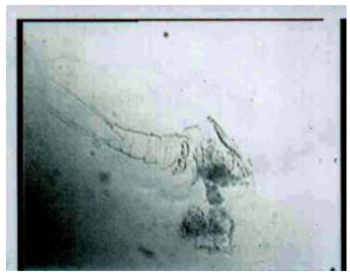

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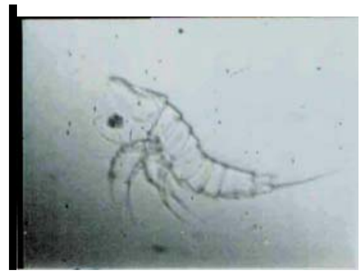

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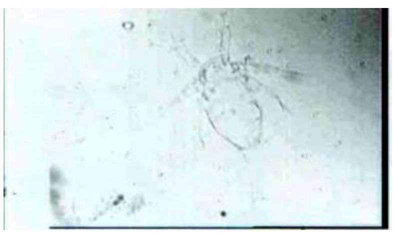

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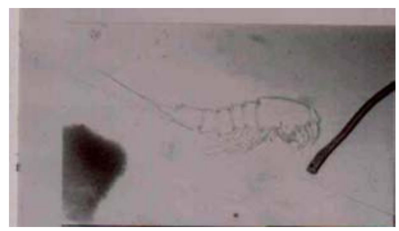

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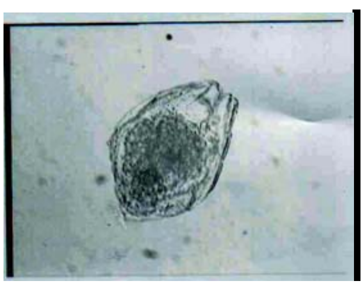

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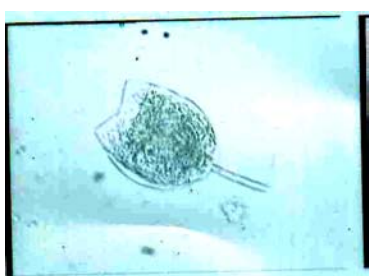

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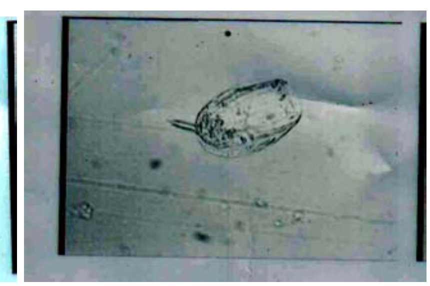

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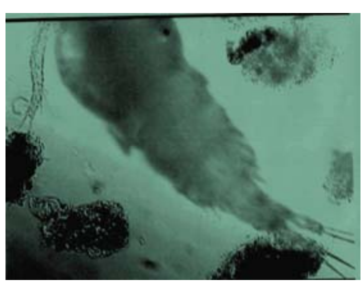

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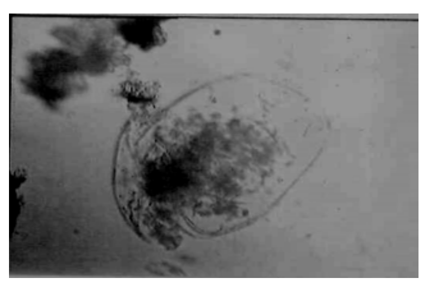
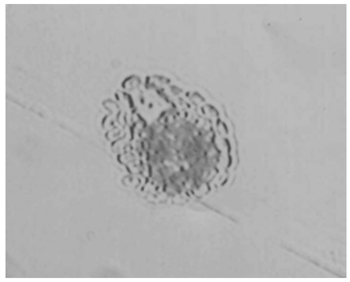


Plate 1. Some of the zooplankton species from the pools, (1) *Pleuroxus chappuissi*, (2) *Halicyclops magniceps*, (3) *Eucyclops leukarti* (4) Cyclopoid naupilus, (5) copepodid stage, (6) Herpaticoida sp, (7) *Asplanchna girodii*, (8) *Conochilus unicornis*, (9) *Epiphanes clavulata*, (10) *Diaptomus castor*, (11) *Ectocyclops hirsutus*, (12) *Chydorus gibbus*

1

2



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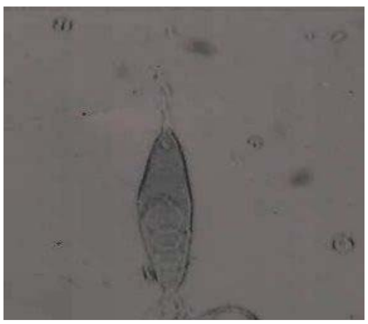

5

Plate 2. Some of the phytoplankton species from the ponds, (1) *Cosmarium margaritatum*, (2) *Coelospharium microporum*, (3) *Uronema elongatum*, (4) Euglena sp, (5) *Cylindrocystis brebissonni*,

1

2

Plate 4.3. (1) One of the pools with water, (2) One of the pools when it dried up.

Appendix 5

Total counts and ranks for species used to plot importance curves

Pool 1 macroinverts	Total counts	Rank
notonectidae	69	1
aeshnidae	63	2
naucoridae	53	3
prosoptimatidae	29	4
tadpole	20	5
libelliludae	17	6
dytscidae	13	7
corixidae	13	8
hyraenidae	12	9
chironomidae	9	10
diptera larva	9	11
species3	5	12
species1	4	13
oligochaetae	1	14
species2	1	15

phytoplankton	Total counts	rank
M.aeruginosa	1362	1
S.aquatilis	310	2
S.pingue	13	3
S.aestivale	13	4
C.hirudinella	13	5
P.dimorpha	12	6
T.flocculosa	12	7
A.judayi	12	8
E.viridis	11	9
C.parvulum	11	10
C.brebissonnii	9	11
T.gelatinosa	9	12
S.rhizobrachiales	8	13
U.zonata	8	14
U.insignis	6	15
A.mucronulatus	6	16
O.lacustris	5	17
C.labrynthoides	5	18
C.insidans	4	19
C.aciculare	4	20
T.caudatum	4	21
P.cruentum	4	22
C.margaritatum	4	23
C.microporum	3	24
C. polyp	2	25
B.monilliforme	1	26
C.holsatica	1	27
A.smargadina	1	28
S.murale	1	29
C.humicola	1	30
S.vasiformis	1	31
P.willei	1	32
U.elongatum	1	33
T.lafvrei	1	34

zooplankton	Total counts	rank
Cyclo naupli	13	1
A.girodii	12	2
D.pulex	10	3
E.clavulata	7	4
C.unichonis	7	5
B.caudatus	7	6
E.hirsutus	6	7
B.paludosa	5	8
M.dubia	4	9
E.serrulatus	4	10
P.chappuissi	3	11
R.citrina	3	12
P.procurvatus	2	13
E.leuckarti	2	14
S. pedinetum	1	15
D.castor	1	16
H magniceps	1	17
P.striatus	1	18
L.patella	1	19
C.gibbus	1	20

Pool 2 macroinvertebrates	Total counts	rank	phytoplankton	Total counts	Rank	zooplankton	Total counts	rank
chironomidae	37	1	*M.aeruginosa*	160	1	*A.girodii*	7	1
notonectidae	12	2	*S.aquatilis*	56	2	*D.pulex*	5	2
dytscidae	10	3	*T.flocculosa*	13	3	*E.clavulata*	4	3
naucoridae	10	4	*C.parvulum*	12	4	*B.paludosa*	3	4
tadpole	5	5	*S.rhizobrachiales*	10	5	*C.unichonis*	3	5
hyraenidae	4	6	*A.judayi*	9	6	*S. pedinetum*	3	6
aeshnidae	4	7	*E.viridis*	6	7	*B.caudatus*	2	7
corixidae	3	8	*C.brebissonni*	5	8	*P.procurvatus*	1	8
oligochaetae	2	9	*A.mucronulatus*	5	9	*M.dubia*	1	9
prosoptimatidae	2	10	*U.zonata*	4	10	*Cyclopoid nauplii*	1	10
libelliludae	1	11	*T.gelatinosa*	4	11	*E.serrulatus*	1	11
species1	1	12	*C.labrynthoides*	4	12	*E.hirsutus*	1	12
species2	1	13	*C.hirudinella*	4	13	*D.castor*	1	13
species3	1	14	*S.aestivale*	3	14	*H magniceps*	1	14
diptera larva	1	15	*C.insidans*	2	15	*E.leuckarti*	1	15
			P.dimorpha	1	16	*P.chappuissi*	1	16
			C.aciculare	1	17	*P.striatus*	1	17
			O.lacustris	1	18	*R.citrina*	1	18
			S.pingue	1	19	*L.patella*	1	19
			T.caudatum	1	20	*C.gibbus*	1	20
			C. polyp	1	21			
			U.insignis	1	22			
			P.cruentum	1	23			
			C.microporum	1	24			
			B.monilliforme	1	25			
			C.holsatica	1	26			
			A.smargadina	1	27			
			S.murale	1	28			
			C.humicola	1	29			
			S.vasiformis	1	30			
			P.willei	1	31			
			C.margariatumt	1	32			
			U.elongatum	1	33			
			T.lafvrei	1	34			

Pool3
rank

macroinvertebrate	Total counts	rank
naucoridae	16	1
oligochaetae	11	2
tadpole	7	3
chironomidae	7	4
notonectidae	5	5
corixidae	5	6
hyraenidae	5	7
prosoptimatidae	5	8
aeshnidae	3	9
libelliludae	2	10
dytscidae	2	11
species1	2	12
species2	1	13
species3	1	14
diptera larva	1	15

phytoplankton	Total counts	rank
M.aeruginosa	93	1
S.aquatilis	44	2
T.flocculosa	10	3
T.gelatinosa	8	4
P.cruentum	8	5
U.zonata	6	6
C.parvulum	6	7
A.judayi	6	8
A.mucronulatus	6	9
E.viridis	5	10
C.brebissonni	4	11
S.rhizobrachiales	4	12
S.aestivale	4	13
C.labrynthoides	4	14
C.insidans	3	15
P.dimorpha	2	16
B.monilliforme	2	17
C.holsatica	2	18
C.margariatumt	2	19
C.aciculare	1	20
O.lacustris	1	21
S.pingue	1	22
T.caudatum	1	23
C. polyp	1	24
U.insignis	1	25
C.hirudinella	1	26
C.microporum	1	27
A.smargadina	1	28
S.murale	1	29
C.humicola	1	30
S.vasiformis	1	31
P.willei	1	32
U.elongatum	1	33
T.lafvrei	1	34

zooplankton	total counts	
A.girodii	5	1
E.clavulata	4	2
C.unichonis	4	3
Cyclopoid nauplii	4	4
D.pulex	3	5
B.paludosa	3	6
S. pedinetum	2	7
P.procurvatus	1	8
M.dubia	1	9
E.serrulatus	1	10
E.hirsutus	1	11
D.castor	1	12
H magniceps	1	13
B.caudatus	1	14
E.leuckarti	1	15
P.chappuissi	1	16
P.striatus	1	17
R.citrina	1	18
L.patella	1	19
C.gibbus	1	20

Pool 4 macroinvertebrates	Total counts	rank
aeshnidae	44	1
naucoridae	41	2
notonectidae	36	3
tadpole	23	4
dytscidae	15	5
prosoptimatidae	14	6
chironomidae	11	7
libelliludae	10	8
corixidae	9	9
species1	9	10
hyraenidae	7	11
oligochaetae	6	12
species2	1	13
species3	1	14
diptera larva	1	15

Zooplankton species	Total counts	Rank
A.girodii	17	1
E.clavulata	12	2
D.pulex	9	3
Cyclopoid nauplii	6	4
B.paludosa	4	5
R.citrina	4	6
L.patella	4	7
B.caudatus	3	8
P.chappuissi	2	9
P.procurvatus	1	10
M.dubia	1	11
C.unichonis	1	12
S. pedinetum	1	13
E.serrulatus	1	14
E.hirsutus	1	15
D.castor	1	16
H magniceps	1	17
E.leuckarti	1	18
P.striatus	1	19
C.gibbus	1	20

phytoplankton	Total counts	rank
M.aeruginosa	93	1
S.aquatilis	44	2
T.flocculosa	10	3
T.gelatinosa	8	4
P.cruentum	8	5
U.zonata	6	6
C.parvulum	6	7
A.judayi	6	8
A.mucronulatus	6	9
E.viridis	5	10
C.brebissonni	4	11
S.rhizobrachiales	4	12
S.aestivale	4	13
C.labrynthoides	4	14
C.insidans	3	15
P.dimorpha	2	16
B.monilliforme	2	17
C.holsatica	2	18
C.margariatumt	2	19
C.aciculare	1	20
O.lacustris	1	21
S.pingue	1	22
T.caudatum	1	23
C. polyp	1	24
U.insignis	1	25

C.hirudinella	1	26
C.microporum	1	27
A.smargadina	1	28
S.murale	1	29
C.humicola	1	30
S.vasiformis	1	31
P.willei	1	32
U.elongatum	1	33
T.lafvrei	1	34

Pool 5 macroinvertebrates	**Total counts**	**rank**
aeshnidae	72	1
notonectidae	46	2
naucoridae	40	3
tadpole	24	4
diptera larva	16	5
dytscidae	15	6
corixidae	11	7
prosoptimatidae	10	8
chironomidae	9	9
hyraenidae	9	10
libelliludae	8	11
species1	4	12
species3	4	13
oligochaetae	2	14
species2	2	15

phytoplankton	**Total counts**	**rank**
M.aeruginosa	680	1
S.aquatilis	300	2
C.labrynthoides	19	3
S.rhizobrachiales	17	4
A.judayi	17	5
C.hirudinella	17	6
S.pingue	14	7
P.willei	13	8
E.viridis	12	9
U.zonata	10	10
T.gelatinosa	10	11
A.mucronulatus	10	12
S.aestivale	8	13
C.insidans	7	14
C.microporum	5	15
C.margariatumt	5	16
P.dimorpha	4	17
T.flocculosa	4	18
O.lacustris	4	19
C.humicola	4	20
S.vasiformis	4	21
T.lafvrei	4	22
C.brebissonni	3	23
C.parvulum	3	24
P.cruentum	2	25
U.elongatum	2	26
C.aciculare	1	27
T.caudatum	1	28
C. polypy	1	29
U.insignis	1	30
B.monilliforme	1	31
C.holsatica	1	32
A.smargadina	1	33
S.murale	1	34

zooplankton	**Total counts**	**rank**
A.girodii	27	1
C.unichonis	16	2
E.clavulata	13	3

Cyclopoid nauplii	8	4
B.paludosa	6	5
E.serrulatus	6	6
P.striatus	6	7
D.pulex	5	8
E.hirsutus	3	9
B.caudatus	3	10
R.citrina	3	11
C.gibbus	3	12
P.procurvatus	2	13
M.dubia	2	14
S. pedinetum	2	15
D.castor	2	16
H magniceps	2	17
L.patella	2	18
E.leuckarti	1	19
P.chappuissi	1	20

Appendix 6

Raw data measured from the five pools.

pool	week	pH	cond μScm^{-1}	PP $mgC^{-1}cm^{-3}h^{-1}$	0xy mgl^{-1}	totalN mgl^{-1}	totalP mgl^{-1}	temp ^{o}C	depth m	tsa m^2	volume m^3	rain mm	noraindays number	S-W H`	flashoutrate weekly
1	1	10.1	38	25.00	13.6	2	0.42	32.0	0.78	15.4	3.61	58.0	5	1.73	172.75
1	2	7.39	14	28.75	13.3	11	0.02	22.7	0.69	14.8	3.14	28.0	6	2.24	83.40
1	3	7.27	7	20.50	13.1	8	0.41	31.8	0.78	15.4	3.61	27.0	6	2.29	80.42
1	4	7.87	9	30.00	13.7	9	0.27	22.3	0.78	15.4	3.61	49.0	3	1.78	145.94
1	5	7.96	38	27.50	12.4	8	0.15	31.3	0.71	14.6	3.18	32.5	5	1.89	96.79
1	6	7.24	8	21.25	13.2	10	0.23	23.9	0.78	15.4	3.61	88.0	2	1.67	262.09
1	7	7.19	10	30.00	13.7	13	0.23	31.8	0.78	15.4	3.61	74.5	2	1.87	221.89
1	8	7.11	39	25.50	12.5	9	0.11	29.7	0.78	15.4	3.61	37.0	2	1.46	110.20
1	9	7.06	9	27.50	13.9	8	0.24	21.8	0.78	15.4	3.61	25.0	6	1.29	74.46
1	10	7.31	14	23.50	13.8	8	0.02	29.1	0.73	14.9	3.14	9.5	5	2.19	28.29
1	11	7.86	10	24.50	13.3	7	0.27	28.1	0.64	13.2	2.43	0.0	5	0.89	0
1	12	7.23	23	41.00	14.1	7	0.16	22.7	0.73	14.2	2.64	24.5	4	1.42	72.97
1	13	7.11	17	38.00	14.7	7	0.53	31.3	0.60	12.6	1.25	14.3	6	1.46	42.59
1	14	7.88	23	37.50	16.0	4	0.36	30.6	0.38	8.1	0.74	4.6	7	1.10	13.70
1	15	7.3	20	27.50	13.9	9	0.71	27.3	0.69	14.8	2.38	0.0	6	1.66	0
1	16	7.73	50	45.00	14.3	7	0.7	26.4	0.56	11.7	0.86	20.0	7	1.87	59.57
1	17	8.7	32	41.50	14.6	7	0.63	20.8	0.33	7.5	0.49	0.0	5	1.32	0
1	18	8.79	42	23.50	13.6	6	0.34	29.6	0.23	4.4	0.18	5.6	5	1.18	16.68
1	19	7.25	21	41.00	13.6	8	0.18	31.6	0.56	11.7	0.86	0.8	6	1.18	2.38
1	20	7.3	23	23.50	13.3	8	0.03	31.3	0.37	8.1	0.71	20.7	7	0.69	61.65
1	21	7.39	37	39.50	12.6	5	0.13	30.7	0.26	4.5	0.19	0.0	7	0.58	0
2	1	7.31	15	62.50	12.7	9	0.5	32.2	0.30	7.1	0.99	58.0	5	2.09	629.92
2	2	7.03	14	37.00	13.8	6	0.12	22.3	0.11	4.2	0.38	28.0	6	1.61	304.09
2	3	7.52	7	40.5	13.4	8	0.31	31.3	0.30	7.1	0.90	27.0	6	1.33	293.24
2	4	7.55	9	27.5	13.0	10	-0.0	22.1	0.30	7.1	0.90	49.0	3	1.50	532.17
2	5	7.59	11	66	11.7	9	-0.0	31.3	0.13	3.2	0.42	32.5	5	1.26	352.97
2	6	7.73	7	42.5	13.6	12	-0.0	23.3	0.30	7.1	0.99	88.0	2	0.87	955.73
2	7	7.62	9	27.5	13.0	11	0.07	31.3	0.30	7.1	0.99	74.5	2	1.33	809.12
2	8	7.43	13	43.5	12.1	14	-0.0	30.6	0.30	7.1	0.99	37.0	2	1.31	401.84
2	9	7.39	9	21.5	13.4	10	0.03	21.3	0.30	7.1	0.99	25.0	6	1.53	271.52
2	10	7.89	14	36.5	13.9	7	0.11	30.5	0.13	4.5	0.38	9.5	5	1.63	103.18
2	11	7.31	9	44.5	13.7	7	-0.0	29.1	0.09	3.3	0.13	0.0	5	1.34	0
2	12	7.16	13	23	14.6	9	0.21	23.1	0.13	4.5	0.38	24.5	4	1.63	266.08
2	13	7.93	38	47.5	14.9	5	0.72	31.7	0.09	2.2	0.19	14.3	6	0.89	155.37
2	14														
2	15	7.71	28	37.5	14.6	3	0.54	26.7	0.11	4.2	0.38	0.0	6	1.58	0
2	16														
2	17														
2	18														
2	19														
2	20														
2	21														
3	1	7.64	16	12.5	12.9	1	0.22	32.3	0.24	8.0	1.07	58.0	5	2.19	582.82
3	2	7.31	12	41.3	13.5	4	0.39	23.9	0.09	3.0	0.27	28.0	6	1.49	281.37
3	3	7.55	8	29.8	12.9	8	0.23	31.4	0.24	8.0	1.07	27.0	6	1.86	271.31
3	4	7.93	7	35.0	12.9	8	0.18	22.1	0.24	8.0	1.07	49.0	3	1.93	492.38
3	5	7.98	10	39.5	11.5	4	-0.0	30.0	0.10	3.1	0.31	32.5	5	1.52	326.58
3	6	7.47	8	30.0	13.0	7	0.11	23.0	0.24	80	1.07	88.0	2	1.84	884.28
3	7	7.41	7	35.0	13.0	9	0.16	31.3	0.24	8.0	1.07	74.5	2	1.15	748.62
3	8	7.36	9	28.5	12.1	9	-0.0	30.6	0.24	8.0	1.07	37.0	2	0.95	371.80
3	9	7.23	6	32.5	13.1	10	0.13	21.4	0.24	8.0	1.07	25.0	6	1.31	251.25
3	10	7.43	13	39.0	13.7	8	0.36	30.4	0.11	3.6	0.28	9.5	5	1.63	95.46
3	11	7.13	8	33.0	13.7	8	-0.0	29.4	0.06	2.6	0.07	0.0	5	1.32	0
3	12	7.19	10	11.5	14.3	8	0.23	23.3	0.11	3.6	0.28	24.5	4	1.17	246.19
3	13	7.47	27	31.0	14.9	6	0.34	31.9	0.06	1.7	0.03	14.3	6	0.68	143.69
3	14														
3	15	7.35	24	29.5	14.4	5	0.61	26.9	0.09	3.0	0.29	0.0	6	1.60	0
3	16														
3	17														
3	18														

3	19														
3	20														
3	21														
4	2	7.3	13	48.0	13.27	12	0.34	22.1	0.28	10.7	1.03	28.0	6	2.18	206.20
4	3	7.28	10	21.5	13.04	5	0.29	31.0	0.36	11.9	1.46	27.0	6	2.18	198.84
4	4	7.46	9	17.5	13.12	9	0.23	21.7	0.36	11.9	1.46	49.0	3	1.42	360.86
4	5	7.46	10	23.0	11.03	4	0.14	31.2	0.27	9.8	1.05	32.5	5	1.69	239.34
4	6	7.23	9	23.8	13.06	9	0.17	22.9	0.36	11.9	1.46	88.0	2	1.96	648.07
4	7	7.13	9	17.5	13.16	10	0.21	31.0	0.36	11.9	1.46	74.5	2	1.91	548.65
4	8	7.11	9	39.0	12.01	9	0.21	30.5	0.36	11.9	1.46	37.0	2	2.20	272.48
4	9	7.11	8	14.3	13.17	11	0.19	21.7	0.36	11.9	1.46	25.0	6	1.72	184.11
4	10	7.29	12	21.5	13.50	6	0.38	30.2	0.31	10.1	1.03	9.5	5	2.21	69.96
4	11	7.48	7	57.5	13.40	6	0.26	28.4	0.26	9.2	0.51	0.0	5	1.73	0
4	12	7.28	10	33.5	14.10	7	0.43	23.1	0.31	10.1	1.03	24.5	4	1.77	180.43
4	13	7.19	19	27.5	14.50	7	0.28	31.6	0.26	9.2	0.43	14.3	6	1.91	105.31
4	14	7.91	23	17.5	15.10	7	0.17	27.0	0.11	3.7	0.36	4.6	7	1.47	33.88
4	15	7.28	19	43.0	15.20	8	0.34	26.7	0.28	10.7	0.93	0.0	6	1.82	0
4	16	7.34	23	37.5	14.80	7	0.62	27.4	0.10	3.9	0.06	20.0	7	1.83	147.29
4	17														
4	18														
4	19	7.32	11	30.5	14.40	11	0.24	31.6	0.10	3.93	0.06	0.8	6	2.14	5.89
4	20														
4	21														
5	1	9.75	22	37.5	13.60	6	0.42	30.9	0.74	16.6	3.47	58.0	5	2.14	179.72
5	2	7.09	11	41.3	13.88	9	0.39	22.7	0.67	15.4	2.97	28. 0	6	2.14	86.76
5	3	7.36	7	28.5	13.19	6	0.4	31.8	0.74	16.6	3.47	27.0	6	2.27	83.66
5	4	7.56	7	27.5	13.11	13	0.88	22.4	0.74	16.6	3.47	49.0	3	2.08	151.83
5	5	7.65	14	39.5	12.61	7	0.22	31.2	0.69	15.7	2.99	32.5	5	2.00	100.70
5	6	7.17	7	30.0	13.27	9	0.79	22.9	0.74	16.6	3.47	88.0	2	2.21	272.67
5	7	7.11	8	27.5	13.09	12	1.13	30.7	0.74	16.6	3.47	74.5	2	2.12	230.84
5	8	7.09	12	36.5	12.46	13	0.83	28.3	0.74	16.6	3.47	37.0	2	1.83	114.65
5	9	7.03	7	22.5	13.26	11	0.69	21.7	0.74	16.6	3.47	25.0	6	1.23	77.46
5	10	7.31	12	45.0	13.70	8	0.36	28.6	0.68	15.9	2.97	9.5	5	2.30	29.44
5	11	7.14	8	37.5	13.70	8	0.19	28.3	0.63	14.7	2.17	0.0	5	1.78	0
5	12	7.13	11	46.0	14.20	4	0.49	22.9	0.68	15.9	2.97	24.5	4	1.95	75.91
5	13	7.23	37	36.5	14.30	2	0.49	31.3	0.57	13.9	2.28	14.3	6	1.80	44.31
5	14	7.58	42	27.5	16.30	8	0.77	26.5	0.67	15.4	2.67	0.0	6	2.02	0
5	16	7.73	45	47.5	14.90	6	0.39	25.7	0.53	11.4	2.02	20.0	7	1.79	61.97
5	17	8.6	33	33.5	14.70	4	0.27	20.3	0.31	8.9	0.68	0.0	5	1.75	0
5	18	8.67	42	21.5	13.30	4	0.23	29.1	0.20	5.1	0.21	5.6	5	1.61	17.35
5	19	7.25	17	42.5	14.90	9	0.37	30.8	0.53	11.4	2.02	0.8	6	1.11	2.48
5	20	7.43	21	34.5	13.70	5	0.19	31.3	0.34	9.8	1.02	20.7	7	1.32	64.14
5	21	7.59	29	30.0	13.70	2	0.31	30.3	0.24	5.0	0.28	0.0	7	1.23	0

*Blank spaces indicate when the pools were dry.

Appendix 7

Field recording sheet/form

Name..

Date……………………………………………………Time………………………………………..

Pool……………………………………………GPS coordinates…………….........……………….

Precipitation (mm)……………………………………

Temperature (^{o}C)……………………………………..

pH…………………………………………………….

Conductivity (μScm^{-1})………………………………….

Dissolved oxygen (mg^{-1})…………………………….....

Volume (m^3)…………………………………………...

Total wetted surface area (m^2)…………………………

Mean depth (m)………………………………………...

Total nitrogen (mg^{-1})…………………………………...

Total phosphorus (mg^{-1})………………………………..

Flushing rates…………………………………………...

Notes………………………………………………………………………………………………

………………………………………………………………………………………………

…………………………………………………………………………………………….....