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# Zooplankton and diatoms of temporary and permanent freshwater pans in the Mpumalanga Highveld region, South Africa

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This paper provides a description of the zooplankton and epiphytic diatom communities of permanent and temporary freshwater pans in the Mpumalanga Highveld region of South Africa. Few studies have investigated the biota of pans in this area, which is seriously threatened by mining and agricultural development. Nineteen pan sites within a 20 km radius covering a wide range of water chemistries were sampled once for zooplankton, epiphytic diatoms and water physico-chemical data in 2009. Collected zooplankton and diatom samples were identified to species or genus level. Many of the zooplankton taxa reported in this study were not recorded in similar pan studies in South Africa and southern Africa. The study revealed a difference among the compositions of zooplankton and diatom communities between temporary pans and permanent pans. Zooplankton found exclusively in freshwater temporary pans included cladocerans (*Megafenestra aurita* and *Scapholeberis kingi*), calanoids (*Mesocyclops major* and *Thermodiaptomus mixtus*), a cyclopoid (*Acanthocyclops vernalis*) and a rotifer (*Platylas quadricornis*). Permanent pans were characterized by taxa such as cladocerans (*Ceriodaphnia rigaudi* and *Dunhevedia crassa*), a calanoid (*Metadiaptomus transvaalensis*), cyclopoids (*Paracyclops fimbriatus* and *Eucyclops gibsoni*) and rotifers (*Brachionus dimidiatus* and *Brachionus plicatilis*). The most commonly occurring diatom taxa in temporary pans included taxa indicative of slightly acidic to circumneutral, dystrophic and nutrient-poor waters such as *Nitzschia acidoclinata*, *Gomphonema gracile* and *Eunotia bilunaris*. Permanent pan assemblages were characterized by taxa typical of saline waters, including *Nitzschia frustulum*, *Amphora veneta* and *Planothidium engelbrechtii*. Species of the genera *Pinnularia* and *Eunotia* were almost totally absent from permanent pans.

**Key words:** zooplankton, epiphytic diatoms, pans, wetlands, South Africa.

## INTRODUCTION

There has been a growing awareness of the ecological and socioeconomical importance of isolated depressional wetland systems, particularly in Europe, where isolated wetlands have become a priority habitat under the EU Habitats Directive due to their vulnerability to human activities and climate changes (Céréghino *et al.* 2008). Yet in South Africa, isolated wetlands, which face similar pressures, have largely been ignored. The South African National Water Act (Act No. 36 of 1998) describes the framework which allows for water resource protection and use in a sustainable manner. Within this protection framework provision is made for the assessment of the current ecological integrity or health of a water resource. However the ecological condition of an aquatic habitat

needs to be ascertained for effective implementation of the National Water Act.

Research activity focusing on isolated depressional wetlands particularly on the topic of biodiversity, has mostly been developed in Europe (Oertli *et al.* 2009) and North America (Tiner 2003; Lane *et al.* 2009). In South Africa, such as the Mpumalanga Highveld region, isolated wetlands, locally referred to as pans (the term 'pan' is used hereafter) are exceptionally numerous. However, limnological knowledge of these systems is limited, which is surprising considering their uniqueness in terms of water chemistry, flora and fauna (Hutchinson *et al.* 1932). For this reason the aim of the present study is to investigate the biological communities of pans in the Mpumalanga Highveld area which are increasingly under threat from mining and agricultural activities.

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Various characteristics of pans in South Africa, including their chemistry and biotic features, have been reviewed (Hutchinson *et al.* 1932; Seaman *et al.* 1991; Meintjes *et al.* 1994; Allan *et al.* 1995). Few studies have focused on macroinvertebrate communities (Day *et al.* 2010; Ferreira 2012; Bird 2013) and zooplankton taxa (De Roeck *et al.* 2007; Ferreira 2012) as a tool for biological assessments in temporary and permanent pans in the Western Cape and the Mpumalanga Highveld. Seaman *et al.* (1991) reported on the ecological characteristics of zooplankton in salt pans in the central and western regions of South Africa as well as the Mpumalanga Highveld. However, there is still little known about the zooplankton communities of pans in South Africa and considerably less information available on diatom distribution and diversity in these systems.

Diatoms have a long history of use in the assessment of inland waters internationally as they account for the highest number of species among the primary producers in aquatic systems and respond rapidly to a wide range of toxicants (Pan *et al.* 1999; U.S. EPA 2001). Zooplankton taxa have different preferences for trophic state and water clarity and are known to vary predictably with wetland quality and respond quickly to changes in the environment (Lougheed & Chow-Fraser 2002).

The only comprehensive investigation of depressional wetlands in the Mpumalanga Highveld area, including zooplankton and diatom species, is that by Hutchinson *et al.* (1932) who provided an ecological study of a variety of temporary and permanent pans in the area. Taxonomic identification of diatoms was mostly undetermined. Nevertheless the study highlighted the diversity and complexity of temporary pans, which previous studies have shown to be partly attributable to the variability in length of hydroperiod (Gaiser & Johansen 2000; Dimitriou *et al.* 2009). It is therefore essential to examine the characteristics that define these highly variable systems in order to distinguish changes in biological communities caused by human disturbances from natural variations. This is particularly vital in an area such as the Mpumalanga Highveld where pans are under severe pressure as a result of land cover conversion.

This study has largely been driven by the need for ecological information on South African inland pans in order to assess the ecological status of this type of water body more effectively in accordance with the National Water Act and perhaps provide insight into similar waterbodies internationally.

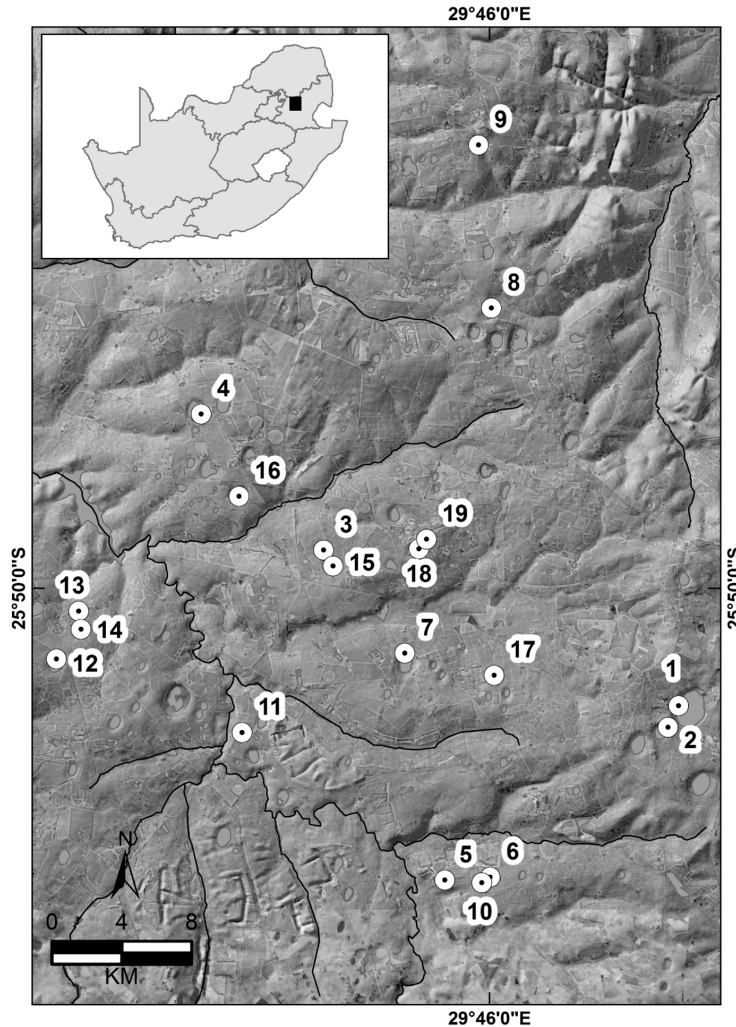
The main purpose of this paper is to report on species of diatoms and zooplankton from pans in the Mpumalanga Highveld region since very little previous taxonomic or ecological records are available on such flora and fauna.

## MATERIALS & METHODS

### *Study area*

The study was carried out in the Highveld region of the Mpumalanga Province, host to one of the densest clusters of pans in South Africa. The region is at an altitude of approximately 1700 m with minimum temperatures below 0°C in the winter and average annual rainfall of *c.* 706 mm. Geology generally consists of weakly cemented sandstones and fissile shales of the Karoo Supergroup with some intrusion by highly resistant dolerite sills and dykes (Tooth & McCarthy 2007). In the grasslands of Mpumalanga, pans typically receive direct rainfall as well as generally diffuse flow entering the pans through seepage through the surrounding soil mass, and/or groundwater (Tooth & McCarthy 2007). These depressions are shallow, and even when fully inundated, are usually less than 3 m deep. These are usually circular to oval in shape (Goudie & Thomas 1985), and where two or more depressions have spread and combined, they form characteristically kidney-shaped or lobed wetlands. These systems are highly variable in terms of vegetation, size and above all water chemistry whilst being in close proximity to one another. The pans vary from permanently inundated reed pans characterized by a central, emergent *Phragmites australis* reedbed, surrounded by a ring of open water underlain with submergent macrophytes, such as *Lagarosiphon* sp. and *Potamogeton* sp., to temporarily inundated grass pans covered by grasses and sedges, often dominated by floating mats of *Leersia hexandra* (Allan *et al.* 1995). Typically found on the outermost margins are crops of maize and occasionally a few alien tree species (*Eucalyptus* sp., *Salix* sp., *Acacia* sp.).

Over a period of two days in May 2009, 11 temporary and eight permanent pans (range = 6–213 ha, Fig. 1) were sampled in a 20 km radius once for zooplankton, epiphytic diatoms and water chemistry where feasible. Further site information is given in Table 1. All sites are situated in a heavily transformed landscape which has been subject to strong alterations due to land use conversions, namely mining and agriculture. Sites



**Fig. 1.** Study area and location of sampling sites.

were randomly selected using 1:50 000 scale South African topographical maps and GIS software, and later ground-truthed to establish the wetland type in terms of hydrological regime (temporary or permanently inundated wetlands).

#### *Sample collection, preparation and analysis*

Zooplankton samples were collected using a plankton net (150  $\mu\text{m}$  mesh size) to make horizontal tows of 10 m length from the margin of the pan to the centre. Captured zooplankton were preserved in 70% ethanol and identified using the highest taxonomic resolution possible (usually species or genus). The cladocerans were identified to species level according to Day *et al.* (1999). Ostracods and copepods were identified using

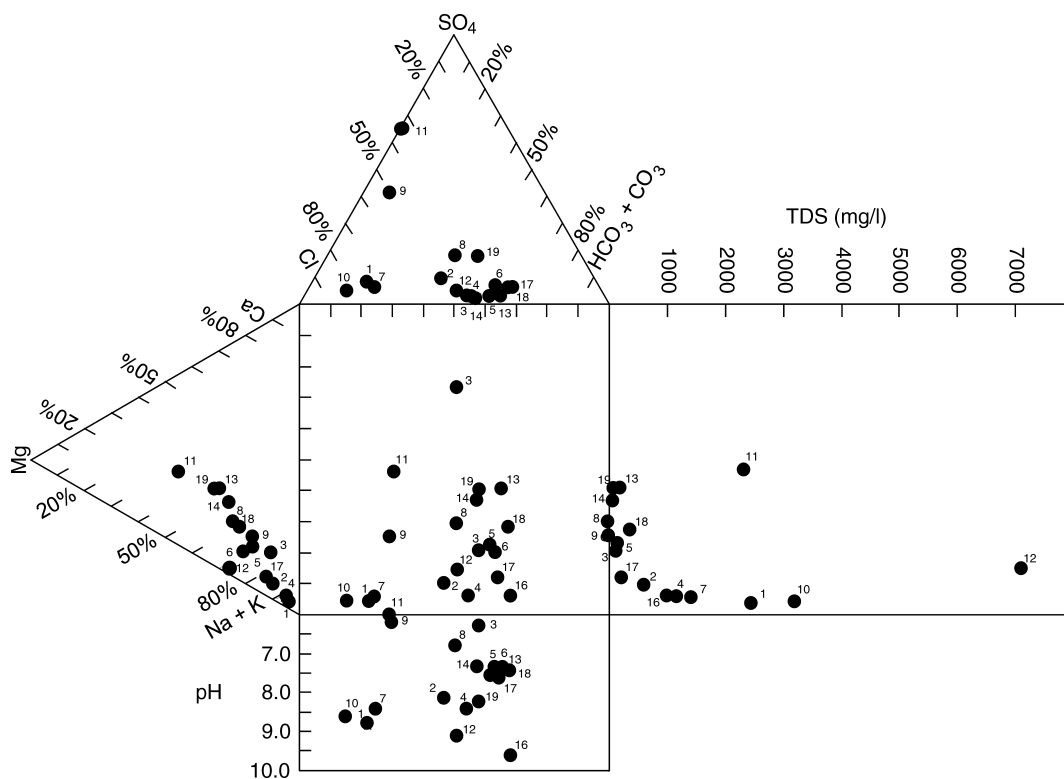
Day *et al.* (2001), and the rotifers according to Ahlstrom (1940), Pennak (1978), Thorp & Covich (1991) and Day & de Moor (2002).

Epiphytic diatoms were sampled by randomly selecting submersed plants from the wetland (water depth <1 m) according to methods described by Lane & Brown (2007). Samples were preserved in ethanol and kept at 4°C until analyses. Water samples were obtained simultaneously with the diatom samples and analysed for conductivity, pH,  $\text{CO}_3^-$ ,  $\text{HCO}_3^-$ ,  $\text{Ca}^{2+}$ ,  $\text{PO}_4^{3-}$ ,  $\text{Mg}^{2+}$ ,  $\text{NO}_3^-$ ,  $\text{NO}_2^-$ ,  $\text{K}^+$ ,  $\text{Na}^+$ ,  $\text{SO}_4^{2-}$ ,  $\text{Cl}^-$  at the Agricultural Research Council's laboratory in Pretoria following standard procedures (APHA 1998).

Diatoms were prepared by oxidizing organic material in samples with hydrochloric acid and

**Table 1.** Physical and chemical characteristics of the 19 study pans, where P = permanent, T = temporary.

Sites	Coordinates	Hydro-period	pH	Conductivity (mS/m)	NO <sub>3</sub> -N/NO <sub>2</sub> -N (mg/l)	Cl <sup>-</sup> (mg/l)	SO <sub>4</sub> <sup>2-</sup> (mg/l)	PO <sub>4</sub> <sup>3-</sup> -P (mg/l)	CO <sub>3</sub> <sup>2-</sup> (mg/l)	HCO <sub>3</sub> <sup>-</sup> (mg/l)	Na <sup>+</sup> (mg/l)	K <sup>+</sup> (mg/l)	Ca <sup>2+</sup> (mg/l)	Mg <sup>2+</sup> (mg/l)
1	25°53'37"S, 29°51'50"E	P	9.0	352	4.7	1075.6	125.2	6.3	15.9	486.8	817.7	20.7	13.6	5.4
2	25°54'17"S, 29°51'31"E	P	8.3	98	0	168.4	36.2	0	0.9	270.9	206.0	19.4	9.8	9.7
3	25°48'48"S, 29°40'52"E	T	6.4	22	0	15.1	0.5	0	0	71.4	21.6	11.2	4.7	1.7
4	25°44'35"S, 29°37'5"E	P	8.6	152	2.0	260.7	9.3	0	7.8	553.9	343.6	27.2	9.5	5.4
5	25°59'0"S, 29°44'37"E	T	7.6	42	0.2	41.6	2.3	0	0	129.3	45.1	10.8	7.9	6.0
6	25°58'54"S, 29°46'1"E	T	7.5	37	0.1	32.7	6.7	0	0	115.9	40.5	9.6	5.4	6.4
7	25°51'59"S, 29°43'22"E	P	8.5	216	0	600.2	55.7	0	5.7	336.1	480.7	23.6	11.4	8.9
8	25°41'19"S, 29°46'3"E	T	6.9	12	0	10.09	5.9	0	0	25.0	7.5	3.7	2.3	1.9
9	25°36'17"S, 29°45'39"E	T	6.3	10	0	10.0	11.0	0	0	9.2	6.2	4.9	1.8	1.1
10	25°59'5"S, 29°45'45"E	P	8.7	456	0	1614.0	95.3	4.4	11.4	484.3	1041.7	23.1	14.8	11.8
11	25°54'26"S, 29°38'21"E	T	6.0	306	2.8	529.2	1233.9	0	0	11.6	283.5	15.5	173.8	195.6
12	25°52'10"S, 29°32'36"E	P	9.2	931	31.3	1682.0	188.0	0	17.1	2848.7	658.1	1499.7	38.5	254.1
13	25°50'41"S, 29°33'18"E	T	7.5	47	0.2	40.4	1.8	0	0	150.7	25.2	18.9	17.1	11.7
14	25°51'15"S, 29°33'22"E	T	7.5	31	0.4	32.8	0.7	0	0	87.8	20.2	11.9	10.4	6.8
15	25°49'18"S, 29°41'9"E	T	-	-	-	-	-	-	-	-	-	-	-	-
16	25°47'8"S, 29°38'15"E	P	9.7	129	1.5	165.8	29.9	0	54.6	521.6	294.7	19.2	9.5	2.9
17	25°52'40"S, 29°46'8"E	T	7.7	54	0.7	51.8	3.3	0	0	185.4	80.1	16.5	5.7	4.3
18	25°48'46"S, 29°43'49"E	T	7.6	63	0.7	62.3	13.4	0	0	270.8	76.7	10.4	18.4	14.1
19	25°48'28"S, 29°44'3"E	P	8.4	27	0.7	30.9	21.2	0	15.6	70.2	17.1	6.6	9.3	7.1



**Fig. 2.** Durov diagram showing ionic composition, pH and total dissolved solids for the Mpumalanga Highveld pan dataset.

potassium permanganate. Clean diatom frustules were mounted in a synthetic resin with high refraction index (1.73) and at least 400 valves were counted and identified to the lowest taxonomic level possible (usually species) using a light microscope with  $\times 1000$  magnification. The main diatom floras used for taxonomic identification were Archibald (1966), Gasse (1986) and Krammer & Lange-Bertalot (1986–1991). All diatom materials are housed in the South African Diatom Collection (SADC) of the Research Unit for Environmental Sciences and Management, North-West University, South Africa. Zooplankton voucher specimens are deposited in the Life Sciences Museum and Biodiversity Centre, University of the Witwatersrand.

## RESULTS & DISCUSSION

### Environmental characteristics of sites

The 18 pan sites analysed for water chemistry cover a large environmental gradient. Results are summarized in Table 1. At the time of sampling there was less than 1 cm of water at Site 15, there-

fore it was not feasible to collect a water sample for chemical analysis. Fig. 2 shows the distribution of pans based on their ionic composition, pH and total dissolved solids. With the exception of sites 11 and 12, the pan dataset are of either sodium-chloride or sodium-bicarbonate composition, ranging in conductivity from 10 mS/m to 931 mS/m. High sodium and chloride concentrations may reflect the marine origins of the bedrocks. The pans are composed of almost equal amounts of calcium and magnesium, reflecting the dolomitic origin of the water with pH ranges from 6.0 to 9.7. High pH values may reflect the dolomitic character of the groundwater. Low pH values may reflect acidic impacts of anthropogenic origin. Clear outliers in the dataset are Site 11 dominated by sulphate ions and Site 12 by potassium ions whose chemical composition is clearly different from the other pans in the dataset and are thought to reflect impacts from mining and intensive agricultural practices.

### Species composition of zooplankton

Zooplankton was sampled from 12 pan sites.

Of these sites five are temporary water bodies, while seven are permanent systems. A total of 34 zooplankton species belonging to 21 genera were identified (Appendix 1). The highest diversity recorded amongst pans in the current study was found at Site 17 (17 taxa) and 18 (15) which are both freshwater temporary pans (conductivities <100 mS/m) of sodium-bicarbonate type. The lowest diversity was found at sites 1 (3) and 10 (4) which are highly saline, permanent pans of sodium-chloride type impacted by nutrients from intensive agriculture in the area as shown in Table 1. Species tolerant of such high salinities included *Lovenula falcifera* and *Metadiaptomus transvaalensis*. These taxa have previously been described as the most common copepods in southern African salt pans (up to ~7800 mg/l Na, ~ 9000 mg/l Cl) but have also been reported in a variety of only slightly saline to quite fresh water-bodies (Seaman *et al.* 1991).

Taxa that were found exclusively in temporary freshwater pans were the Cladocera species *Megafenestra aurita*, *Scapholeberis kingi*, *Daphnia laevis* and *Daphnia pulex*, the Calanoida species *Mesocyclops major* and *Thermodiaptomus mixtus*, the Cyclopoida *Acanthocyclops vernalis*, Type A and G Cyprididae and the Rotifera *Platyias quadricornis* and a *Mytilina* sp.

A large number of the species present were found in a range of freshwater to very saline conditions. The cosmopolitan Cyclopoida species *Ectocyclops phaleratus* was found most commonly at 10 of the 12 sites. It occurs in small pans, is acid-sensitive and does not occur in waters with pH below 6 (Haney 2013). The most common of the Calanoida species was *Metadiaptomus transvaalensis* found at 9 of the 12 sites and the Cladocera species which occurred most frequently was *Simocephalus vetulus*, a cosmopolitan species known from littoral habitats.

Species that can tolerate highly saline conditions, as were found at Site 12, are the Cladocera species, *Ceriodaphnia rigaudi*, an *Alona* sp., *Dunhevedia crassa* and *Macrothrix spinosa*, the Calanoida, *Metadiaptomus transvaalensis* and the Cyclopoida, *Paracyclops fimbriatus*, *Eucyclops gibsoni* and *Ectocyclops phaleratus*. The Rotifera found under very saline conditions were *Brachionus dimidiatus* and *Brachionus plicatilis*. *B. plicatilis* was reported in salt pans in the Free State and Tswaing Crater (formerly known as Pretoria Salt Pan) as well as inland saline waters across southern Africa (Seaman *et al.* 1991).

Many of the zooplankton taxa reported in this

study were not recorded in similar pan studies in southern Africa. There was little compositional overlap between the zooplankton species recorded in the permanent pans in this study and that of various permanent pans sampled in the same region by Hutchinson *et al.* (1932) and Ferreira *et al.* (2012). The species which were comparable included *Ceriodaphnia reticulata*, *Ceriodaphnia rigaudi*, *Daphnia laevis*, *Lovenula falcifera*, *Metadiaptomus transvaalensis*, *Platyias quadricornis*, *Pseudocycpris expansa*, *Pseudocycpris spinosa* and *Simocephalus vetulus*. *Platyias quadricornis*, *Ceriodaphnia rigaudi*, *Lovenula falcifera* and *Pseudocycpris expansa* were also recorded in temporary pans located east of the Mpumalanga Highveld area in the Gauteng Province (Hutchinson *et al.* 1932). Other similar species present in the temporary pans in this study and those studied by Hutchinson *et al.* (1932) included *Brachionus quadridentatus*, *Chydoris sphaericus* and *Daphnia barbata*.

Few species overlapped with the zooplankton taxa recorded from various saline waters in South Africa and southern Africa reported by Seaman *et al.* (1991), those being *Lovenula falcifera*, *Metadiaptomus transvaalensis* and *Brachionus plicatilis*. These results highlight the large variation of zooplankton communities amongst temporary and permanent pans and underline the need for further studies on the diversity and distribution of pan zooplankton communities locally and throughout southern Africa.

### Diatom distribution

A total of 140 species of epiphytic diatoms belonging to 37 main zoological groups were identified (Appendix 2). Of these, 61 taxa were unique to one site and 24 taxa found at only two sites. The genus *Nitzschia* contained the rarest taxa (19). Genera represented by the greatest number of taxa were *Nitzschia* (32), *Navicula* (17), *Gomphonema* (11) and *Eunotia* (11). Some of the taxa were widespread (7 taxa were found in >50% of sites) namely *Gomphonema parvulum* (16 sites), *Nitzschia frustulum* (12 sites), *Nitzschia palea* (12 sites), *Gomphonema gracile* (11 sites), *Eunotia bilunaris* (11 sites), *Nitzschia acidoclinata* (11 sites) and *Nitzschia palea* var. *debilis* (10 sites). The diatom assemblages resemble those in a study by Lane and Brown (2007) who investigated the epiphytic assemblage composition in numerous pans in Florida, U.S.A. *Gomphonema parvulum* and *Nitzschia palea* are considered eutrophic indicators (Van Dam *et al.* 1994; McCormick & Stevenson

1998) and it is therefore not surprising that these taxa were prevalent throughout the study pans which receive high nutrient and organic inputs as a result of intensive agricultural practices.

The most commonly occurring taxa in temporary pans (except for Site 11 which was sulphate-contaminated), included taxa indicative of slightly acidic to circumneutral, dystrophic and nutrient-poor waters such as *Nitzschia acidoclinata*, *Gomphonema gracile* and *Eunotia bilunaris*. These seasonally inundated systems prone to episodic drying also contained a diverse assemblage of aerophilic taxa such as *Pinnularia borealis*, *Pinnularia subcapitata*, *Luticola mutica* and *Hantzschia amphioxys*. Such taxa can grow in, or endure drought-prone, low-moisture environments (Lowe & Collins 1973). In contrast, frequent taxa occurring in permanent pans comprised *Nitzschia frustulum*, *Amphora veneta* and *Planorhynchium engelbrechtii*, taxa often associated with saline waterbodies (Cholnoky 1955; Krammer & Lange-Bertalot 1986; 1988). Species of the genera *Pinnularia* and *Eunotia* were almost totally absent from permanent pans.

This study provides a checklist of freshwater zooplankton and diatoms sampled within a variety of pans which encompass a broad range of hydrologic characteristics. The results contribute to a better knowledge of the richness and composition of zooplankton and epiphytic diatom species in pans in the Mpumalanga Highveld region. This is particularly vital in an area where pans are little studied and under serious threat as a result of environmental modifications and land cover conversion. Future research is required to identify zooplankton and diatom community indicators useful to evaluate the effect of anthropogenic impacts on freshwater pans in the Mpumalanga Highveld region.

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**Appendix 1.** List of freshwater zooplankton species collected at pan sites in the Mpumalanga Highveld region with their respective voucher number.\* Indicates too few or too immature to identify.

Taxon name	1		2		3		4		5		7		10		12		14		16		17		18		
	WITS PL-1	WITS PL-2	WITS PL-3	WITS PL-4	WITS PL-5	WITS PL-7	WITS PL-10	WITS PL-12	WITS PL-14	WITS PL-16	WITS PL-17	WITS PL-17	WITS PL-17	WITS PL-17	WITS PL-17	WITS PL-17	WITS PL-17	WITS PL-17	WITS PL-17	WITS PL-17	WITS PL-17	WITS PL-17	WITS PL-17	WITS PL-17	WITS PL-17
<b>CLADOCERA</b>																									
<b>Daphniidae</b>																									
<i>Ceriodaphnia reticulata</i> Jurine, 1820			X		X											X				X					X
<i>Ceriodaphnia rigaudi</i> Richard, 1894				X	X												X			X					X
<i>Megafenestra aurita</i> Fischer, 1849		X																X							
<i>Scapholeberis kingi</i> Sars, 1888																									
<i>Simocephalus vetulus</i> Müller, 1776					X					X								X		X					X
<i>Daphnia barbata</i> Weltner, 1898							X																		X
<i>Daphnia laevis</i> Birge, 1878																									
<i>Daphnia pulex</i> Leydig, 1860			X																						
<b>Chydoridae</b>																									
<i>Alona</i> sp.1																									
<i>Chydoris sphaericus</i> Müller, 1785	X											X						X							X
<i>Dunhevedia crassa</i> King, 1853				X	X						X							X							X
Macrothricidae																									
<i>Macrothrix spinosa</i> King, 1852				X																					X
<b>CALANOIDA</b>																									
<b>Diaploimidae</b>																									
<i>Lovenula falcifera</i> Lovén, 1845	X	X																X							X
<i>Metadiaptomus transvaalensis</i> Methuen, 1910	X	X		X														X							X
<i>Mesocyclops major</i> Sars, 1927										X															
<i>Paracyclops fimbriatus</i> Fischer, 1853										X															
<i>Thermodiaptomus mixtus</i> Sars, 1909				X						X															X
<b>CYCLOPOIDA</b>																									
<i>Acanthocyclops vernalis</i> Fischer, 1853																		X							X
<i>Eucyclops gibsoni</i> Brady, 1904			X	X	X													X							X
<i>Ectocyclops phaleratus</i> Koch, 1838		X	X	X	X						X							X							X
<b>OSTRACODA</b>																									
<b>Cyprididae</b>																									
<i>Pseudocypripis expansa</i> Sars, 1924							X																		X
<i>Pseudocypripis spinosa</i> Methuen, 1910				X																					X
*Type A (Large green)																									
*Type B (Brown)																									X

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## Appendix 1 (continued)

Taxon name	1	2	3	4	5	7	10	12	14	16	17	18
	WITS PL-1	WITS PL-2	WITS PL-3	WITS PL-4	WITS PL-5	WITS PL-7	WITS PL-10	WITS PL-12	WITS PL-14	WITS PL-16	WITS PL-17	WITS PL-18
*Type C (Small white)		X			X	X				X	X	X
*Type D (Transparent large white)						X	X			X	X	X
*Type E (Medium green)				X								
*Type F (Small white transparent)	X											
*Type G (Round white globular)												X
<b>ROTIFERA</b>												
<b>Brachionidae</b>												
<i>Brachionus dimidiatus</i> Bryce, 1931								X				
<i>Brachionus quadridentatus</i> Hermann, 1783										X		
<i>Brachionus plicatilis</i> Müller, 1786								X				
<i>Platylas quadricornis</i> Ehrenberg, 1832									X			
<b>Mytilinidae</b>												
<i>Mytilina</i> sp. 1									X		X	

Appendix 2. List of diatom species collected at pan sites in the Mpumalanga Highveld region with their respective voucher number.

Taxon name	1 09-139	2 09-140	3 09-142	4 09-143	5 09-144	6 09-145	7 09-146	8 09-148	9 09-149	10 09-134	11 09-135	12 09-136	13 09-137	14 09-138	15 09-130	16 09-131	17 09-132	18 09-124	19 09-127
<i>Achnanthes exigua</i> Grunow	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-
<i>Achnanthes minutissima</i> var. <i>macrocephala</i> (Kützing) Hustedt	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-
<i>Achnanthes minutissima</i> var. <i>minutissima</i> Kützing	-	-	-	-	-	X	X	X	-	-	-	-	X	X	-	-	X	-	X
<i>Achnanthes minutissima</i> var. <i>saprophila</i> (Kützing) Kobayasi & Mayama	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Amphora coffeaeformis</i> (Agardh) Kützing	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-
<i>Amphora pediculus</i> (Kützing) Grunow	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-
<i>Amphora veneta</i> Kützing	X	X	X	X	-	-	X	-	-	X	-	-	-	-	-	X	-	-	X
<i>Anomooneis sphaerophora</i> (Ehrenberg) Pflzer	X	X	-	X	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-
<i>Aulacoseira granulata</i> var. <i>angustissima</i> (O.M.) Simonsen	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-
<i>Brachysira neoexilis</i> Lange-Bertalot	-	-	-	-	-	X	-	X	-	-	-	X	X	-	-	-	X	X	-
<i>Caloneis hyalina</i> Hustedt	-	-	-	-	-	-	-	X	X	-	-	-	-	-	-	-	-	-	-
<i>Caloneis</i> sp. 1	-	-	X	-	-	-	X	-	-	-	X	-	-	-	-	-	-	-	-
<i>Cavinula varicostriata</i> (Kraske) Mann & Slicke	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-
<i>Chamaepinnularia medioicris</i> (Kraske) Lange-Bertalot	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-
<i>Chamaepinnularia</i> sp. 1	-	-	-	-	-	-	-	X	-	-	-	-	-	-	X	-	-	-	-
<i>Cocconeis placentula</i> Ehrenberg	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Cocconeis placentula</i> var. <i>lineata</i> (Ehrenberg) Van Heurck	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X
<i>Craticula buderi</i> (Hustedt) Lange-Bertalot	-	-	-	X	X	-	X	-	-	X	-	-	X	X	-	X	X	-	X
<i>Craticula molesiformis</i> (Hustedt) Lange-Bertalot	X	X	-	X	-	-	X	-	-	-	-	-	-	-	-	X	-	-	X
<i>Cyclotella mnerghiniana</i> Kützing	X	X	-	X	-	-	-	-	-	-	X	-	-	-	-	-	-	-	X
<i>Diadisma contenta</i> (Grunow) Mann D.G. Mann	-	-	-	-	X	X	-	-	-	X	-	-	X	-	-	-	-	-	-
<i>Ecyonema minutum</i> (Hilse) D.G. Mann	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Ecyonema neogracile</i> Krammer	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-
<i>Ecyonopsis microcephala</i> (Grunow) Krammer	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Ecyonopsis subminuta</i> Krammer & Reichardt	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Eolimna minima</i> (Grunow) Lange-Bertalot	X	-	X	X	-	-	X	-	-	X	-	-	-	-	-	X	-	-	X

Continued on p. 124

## Appendix 2 (continued)

Taxon name	1 09-139	2 09-140	3 09-142	4 09-143	5 09-144	6 09-145	7 09-146	8 09-148	9 09-149	10 09-134	11 09-135	12 09-136	13 09-137	14 09-138	15 09-130	16 09-131	17 09-132	18 09-124	19 09-127
<i>Eolima subminuscula</i> (Manguin)	X	X	-	-	-	-	X	-	-	X	-	-	-	-	-	X	-	-	-
Moser Lange-Bertalot & Metzlin																			
<i>Epithemia sorex</i> Kützing	-	-	X	X	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-
<i>Eunotia bilunaris</i> (Ehrenberg) Mills	-	X	-	-	-	X	-	X	X	-	-	-	X	X	X	X	X	X	X
<i>Eunotia exigua</i> (Brébisson ex Kützing)	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-
Rabenhorst																			
<i>Eunotia flexuosa</i> (Brébisson) Kützing	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Eunotia formica</i> Ehrenberg	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Eunotia mesiana</i> Choinoky	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-
<i>Eunotia minor</i> (Kützing) Grunow	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	X	-
<i>Eunotia naegefi</i> Migula	-	-	X	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-
<i>Eunotia paludosa</i> Grunow	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-
<i>Eunotia pectinalis</i> var. <i>undulata</i> (Raifs)	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Rabenhorst																			
<i>Eunotia</i> sp. 1	-	-	-	-	-	X	-	-	X	-	-	-	-	-	-	-	-	-	-
<i>Eunotia</i> sp. 2	-	X	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Fistulifera saprophila</i> (Lange-Bertalot & Bonik) Lange-Bertalot	-	X	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-
<i>Fragilaria biceps</i> (Kützing) Lange-Bertalot	X	X	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-
<i>Fragilaria nanana</i> Lange-Bertalot	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-
<i>Fragilaria tenera</i> (W. Smith) Lange-Bertalot	-	X	-	-	X	-	-	-	-	-	-	-	-	X	-	-	-	-	-
<i>Fragilaria ulna</i> (Nitzsch.) Lange-Bertalot	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Fragilaria ulna</i> var. <i>acus</i> (Kützing) Lange-Bertalot	X	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Frustulia crassinervia</i> (Brébisson) Lange-Bertalot & Krammer	-	-	X	-	-	-	-	X	X	X	-	-	-	-	X	-	-	-	-
<i>Frustulia vulgaris</i> (Thwaites) De Toni	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-
<i>Gomphonema auritum</i> A. Braun ex Kützing	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X
<i>Gomphonema constrictum</i> Ehrenberg	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-
<i>Gomphonema exilissimum</i> (Grunow) Lange-Bertalot & Reichardt	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	X
<i>Gomphonema gracile</i> Ehrenberg	X	-	X	-	X	X	-	X	-	-	-	-	X	X	X	X	X	X	X
<i>Gomphonema lagenula</i> Kützing	-	-	-	-	-	-	-	-	-	-	-	-	X	X	-	-	-	-	X
<i>Gomphonema</i> aff. <i>lagenula</i> Kützing	-	-	-	-	-	-	-	-	-	-	-	-	X	X	-	-	-	-	-
<i>Gomphonema parvulus</i> Lange-Bertalot & Reichardt	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	X
<i>Gomphonema parvulum</i> Kützing	X	X	X	X	X	X	X	X	-	X	X	X	X	X	-	X	X	X	X

Continued on p. 125

Appendix 2 (continued)

Taxon name	1 09-139	2 09-140	3 09-142	4 09-143	5 09-144	6 09-145	7 09-146	8 09-148	9 09-149	10 09-134	11 09-135	12 09-136	13 09-137	14 09-138	15 09-130	16 09-131	17 09-132	18 09-124	19 09-127		
<i>Gomphonema parvulum</i> var. <i>parvulum</i> f. <i>saprophilum</i> Lange-Bertalot & Reichardt	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	X	
<i>Gomphonema pseudoaegur</i> Lange-Bertalot	X	-	X	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	X
<i>Gomphonema turris</i> Ehrenberg	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Hantzschia abundans</i> Lange-Bertalot	-	-	X	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-
<i>Hantzschia amphioxys</i> (Ehrenberg) Grunow	-	X	-	-	X	X	X	X	X	-	X	X	X	X	-	-	-	-	-	-	-
<i>Lernicola hungarica</i> (Grunow) Round & Basson	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Luticola mullica</i> (Kützing) D.G. Mann	-	-	X	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Luticola mullica</i> (aff. <i>mullica</i> )	-	-	X	-	-	X	-	-	-	-	X	-	-	-	X	-	-	-	-	-	-
<i>Luticola nivalis</i> (Ehrenberg) D.G. Mann	-	-	-	-	-	-	-	-	-	X	X	-	-	-	X	-	-	-	-	-	-
<i>Mayamaea agrestis</i> (Hustedt) Lange-Bertalot	-	-	-	-	-	-	-	-	-	X	X	-	-	-	-	-	-	-	-	-	-
<i>Mayamaea atomus</i> (Kützing) Lange-Bertalot	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Mayamaea atomus</i> var. <i>permitis</i> (Hustedt) Lange-Bertalot	X	X	-	-	-	-	X	-	-	X	-	X	-	-	-	X	-	-	-	-	-
<i>Microcostatus shoemarii</i> Taylor	-	-	-	-	-	-	-	X	-	-	X	-	-	-	-	-	-	-	-	-	-
<i>Levanetis Bianco</i> & Ector	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Navicula arvensis</i> var. <i>maior</i> Lange-Bertalot	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Navicula cincta</i> (Ehrenberg) Ralits in Pritchard	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Navicula cryptocephala</i> Kützing	-	-	-	X	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-
<i>Navicula joubaudii</i> Germain	-	-	X	-	-	X	-	-	-	X	-	-	-	-	X	-	-	-	-	-	X
<i>Navicula lepidula</i> Grunow	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Navicula longicephala</i> Hustedt	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-
<i>Navicula notha</i> Wallace	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Navicula radiosa</i> Kützing	-	-	-	-	X	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-
<i>Navicula recens</i> Lange-Bertalot	-	-	-	-	-	-	X	-	-	-	-	X	-	-	-	X	-	-	-	-	-
<i>Navicula riediana</i> Lange-Bertalot & Rummich	X	-	-	-	X	-	X	-	-	X	X	-	-	-	-	X	-	-	-	-	-
<i>Navicula rostellata</i> Kützing	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Navicula symmetrica</i> Patrick	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Navicula tridentula</i> Kraske	-	-	X	-	-	-	-	X	-	-	-	-	X	-	-	-	-	-	-	-	-
<i>Navicula veretia</i> Kützing	X	X	X	X	X	X	X	-	-	-	-	X	-	-	-	X	-	-	-	-	-
<i>Navicula viaplantii</i> Lange-Bertalot & Sabater	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-

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## Appendix 2 (continued)

Taxon name	1 09-139	2 09-140	3 09-142	4 09-143	5 09-144	6 09-145	7 09-146	8 09-148	9 09-149	10 09-134	11 09-135	12 09-136	13 09-137	14 09-138	15 09-130	16 09-131	17 09-132	18 09-124	19 09-127
<i>Navicula viridula</i> (Kützing) Ehrenberg	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Navicula zaroni</i> Hustedt	-	-	-	-	X	-	-	-	-	-	-	-	-	X	-	-	-	-	-
<i>Neidium</i> sp. 1	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-
<i>Nitzschia acidoclinata</i> Lange-Bertalot	X	-	X	-	X	-	-	X	-	-	-	-	X	-	-	-	X	-	-
<i>Nitzschia agnita</i> Hustedt	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Nitzschia amphibia</i> Grunow	-	X	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Nitzschia archibaldi</i> Lange-Bertalot	-	-	-	X	-	X	-	-	-	X	-	-	X	-	-	-	-	-	-
<i>Nitzschia calida</i> Grunow in Cleve & Grunow	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-
<i>Nitzschia capiteolata</i> Hustedt	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-
<i>Nitzschia clausii</i> Hantzsch	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-
<i>Nitzschia debilis</i> (Arnott) Grunow	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-
<i>Nitzschia dravelliensis</i> Coste & Ricard	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-
<i>Nitzschia fonticola</i> Grunow in Cleve & Möller	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-
<i>Nitzschia frustulum</i> (Kützing) Grunow	X	X	X	X	X	X	X	-	-	X	X	X	-	-	-	X	-	-	-
<i>Nitzschia gracilis</i> Hantzsch	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Nitzschia intermedia</i> Hantzsch	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Nitzschia lacuum</i> Lange-Bertalot	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Nitzschia larceolata</i> W.M. Smith	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-
<i>Nitzschia lange-bertalotii</i> Coste & Ricard	-	-	X	-	-	X	-	-	-	X	-	-	-	-	-	-	-	-	-
<i>Nitzschia liebethuthii</i> Rabenhorst	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-
<i>Nitzschia linearis</i> (Agardh) W.M. Smith	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Nitzschia microcephala</i> Grunow	-	-	X	-	-	-	X	-	-	X	X	-	-	X	-	-	X	-	-
<i>Nitzschia nana</i> Grunow	-	X	-	-	X	-	-	-	-	X	X	-	-	X	-	-	-	-	-
<i>Nitzschia palea</i> (Kützing) W. Smith	X	X	-	-	X	-	X	-	X	X	-	-	X	-	X	X	X	X	X
<i>Nitzschia palea</i> var. <i>debilis</i> (Kützing) Grunow	-	-	X	-	-	-	X	-	X	X	-	-	X	-	X	X	X	X	X
<i>Nitzschia paleacea</i> Grunow	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X
<i>Nitzschia pseudofonticola</i> Hustedt	-	-	-	-	-	-	-	-	-	X	X	-	-	X	-	-	-	-	-
<i>Nitzschia pura</i> Hustedt	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-
<i>Nitzschia pusilla</i> (Kützing) Grunow	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-
<i>Nitzschia radicola</i> Hustedt	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Nitzschia sigma</i> (Kützing) W.M. Smith	X	X	-	X	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-
<i>Nitzschia subacicularis</i> Hustedt	-	X	-	X	-	X	-	-	-	-	-	-	X	X	X	X	X	-	-
<i>Nitzschia supralitorea</i> Lange-Bertalot	X	X	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Nitzschia terrestris</i> (Petersen) Hustedt	-	-	X	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-
<i>Nitzschia vitrea</i> var. <i>salmarium</i> Grunow	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-

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Appendix 2 (continued)

Taxon name	1 09-139	2 09-140	3 09-142	4 09-143	5 09-144	6 09-145	7 09-146	8 09-148	9 09-149	10 09-134	11 09-135	12 09-136	13 09-137	14 09-138	15 09-130	16 09-131	17 09-132	18 09-124	19 09-127
<i>Pinnularia acrospheria</i> W. Smith	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-
<i>Pinnularia borealis</i> Ehrenberg	-	-	X	-	-	X	-	X	X	-	X	-	-	X	-	-	-	X	-
<i>Pinnularia divergens</i> W.M. Smith	-	-	X	-	-	-	-	-	-	-	X	-	-	-	X	-	-	-	-
<i>Pinnularia gibba</i> Ehrenberg	-	-	X	-	X	X	-	-	-	-	-	-	X	X	-	-	-	-	-
<i>Pinnularia subbrevistriata</i> Krammer	-	-	X	-	X	X	X	X	X	X	X	-	-	-	-	-	X	-	X
<i>Pinnularia subcapitata</i> Gregory	-	-	X	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-
<i>Pinnularia subcapitata</i> var. <i>subrostrata</i> (Gregory) Krammer	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	X	-
<i>Pinnularia viridis</i> (Nitzsch) Ehrenberg	-	-	X	-	-	-	-	X	X	-	X	-	-	-	-	-	X	-	-
<i>Planothidium engelbrechtii</i> (Cholnoky) Round & Bukhtyarova	X	X	X	X	-	-	X	-	-	X	X	-	-	-	-	X	-	-	-
<i>Rhopalodia gibba</i> (Ehrenberg) O. Müller	X	-	-	X	X	-	-	-	-	-	-	-	-	X	-	X	-	-	-
<i>Rhopalodia operculata</i> (Agardh) Hakansson	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	X	-	-	-
<i>Sellaphora seminulum</i> (Grunow) D. G. Mann	-	X	X	X	X	-	X	-	-	-	X	-	X	-	X	-	-	-	-
<i>Sellaphora</i> sp. 1	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-
<i>Stauroneis nana</i> Hustedt	-	-	-	X	-	X	-	-	-	-	X	-	-	-	-	-	-	-	-
<i>Stauroneis obtusa</i> Lagerstedt	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-
<i>Stauroneis</i> sp. 1	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-
<i>Stenopterobia curvula</i> (W. Smith) Krammer	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-
<i>Stenopterobia delicatissima</i> (Lewis) Brébisson	-	-	-	-	-	-	-	X	X	-	-	-	-	-	X	-	-	-	-
<i>Stenopterobia</i> sp. 1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-
<i>Surirella ovalis</i> Brébisson	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Thalassiosira duostrata</i> Pienaar	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-