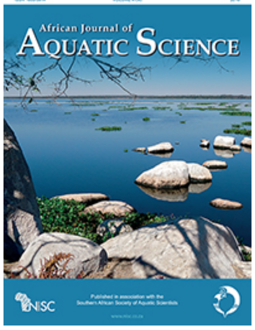

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Short Note

Macroinvertebrate communities associated with duckweed (Lemnaceae) in two Eastern Cape rivers, South Africa

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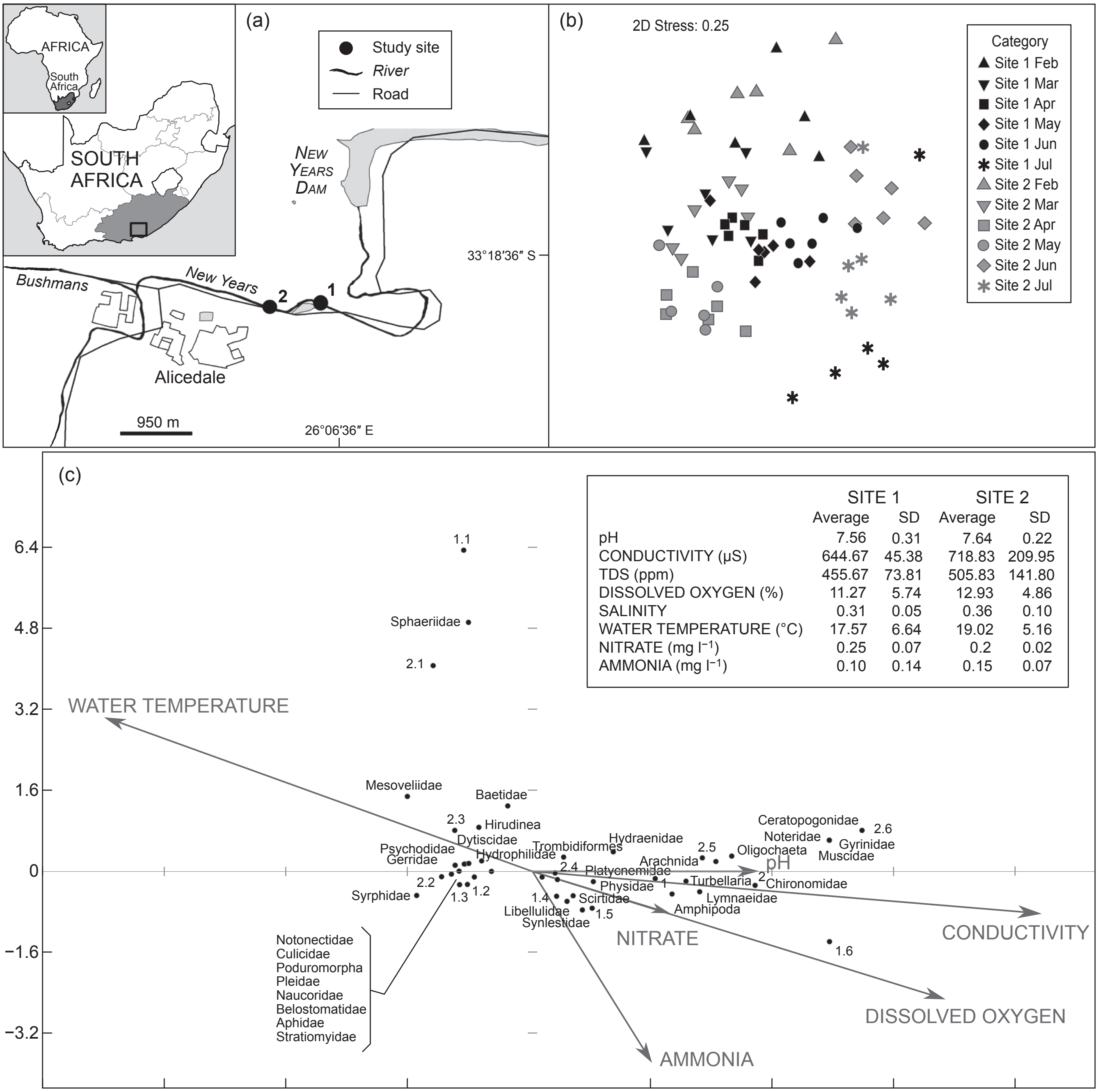
The functional feeding groups and diversity of macroinvertebrate communities associated with duckweed mats in the New Years River (two sites) and Bloukrans River (two sites), Eastern Cape province, South Africa, were assessed. Duckweed (Lemnaceae) is a ubiquitous family of floating macrophytes. A total of 41 macroinvertebrate families were collected monthly over a six-month period from February to July 2014. Duckweed biomass in both rivers was highly variable both temporally and spatially. The majority of identified macroinvertebrate taxa were predators and detritivores, with a small percentage of herbivores. An average of approximately 26% of the macroinvertebrate taxa found were from families that include species from more than one functional feeding group. Although overall measures of diversity and ecosystem health (Fisher's α and Simpson's index) remained constant over time in the New Years River, significant differences in macroinvertebrate community structure were seen between sites and months on both rivers, with dissimilarity being driven by a larger number of species in the New Years River. This high variability within macroinvertebrate assemblages probably reflects a combination of heterogeneous duckweed distribution, variation in physico-chemistry, opportunistic behaviours of macroinvertebrate predators and/or successional colonisation of duckweed mats.

Keywords: detritivores, herbivores, *Landoltia*, *Lemna*, predators, *Wolffia*

Lemnaceae (duckweed) is a cosmopolitan family of free-floating macrophytes (Les et al. 1997) that are found throughout the world (Hillman 1961). They are one of the fastest growing groups of angiosperms, with a doubling time of ~28 hours under optimal conditions (Kutschera and Niklas 2015). They proliferate in fresh-, slow-moving or still water, growing on top of or just below the water surface, sometimes creating large dense mats (Hillman 1961; Parr et al. 2002; Kutschera and Niklas 2015). These mats are often temporally and spatially patchy in distribution (McLay 1974; Demars et al. 2014; Kutschera and Niklas 2015). They are also potentially important habitats and sources of nutrients for macroinvertebrate assemblages (Harper and Bolen 1996) that are central to the functioning of aquatic ecosystems, particularly with respect to their role in nutrient cycling (Houser et al. 2013). Despite the importance of duckweed mats, few studies have investigated the macroinvertebrate diversity and community composition associated with them (e.g. Scotland 1940; Harper and Bolen 1996), with no work completed in the Southern Hemisphere. Scotland (1940) reported a complex community of macroinvertebrates found in association with duckweed in ponds and other areas of slow moving water near Ithaca, New York, USA, comprising numerous predaceous species, detritivores and generalists, as well as specialist herbivores (Scotland 1940). Harper and Bolen (1996) also found a prevalence of predaceous insects, namely Coenagrionidae and Libellulidae, and minimal numbers of herbivores and detritivores, with a total of 32 families of invertebrates associated with duckweed in wetlands of North Carolina, USA. In South Africa, where duckweed can range from being a nuisance to an invasive species (Henderson 2010), very little is known about its associated macroinvertebrate communities. A better understanding of the macroinvertebrate diversity and community structure associated with duckweed mats will help to inform management plans for aquatic ecosystem health, particularly in areas where duckweed has become problematic.

This study aimed to investigate the functional feeding groups and diversity of the macroinvertebrate assemblages associated with duckweed mats in the Bloukrans and New Years river systems, Eastern Cape province, over a six-month time period. We hypothesised that (1) a taxonomically rich community would be associated with South African duckweed mats, dominated by predators, because it is likely that duckweed occupies a comparable ecological niche in austral regions; and (2) that the spatially and temporally heterogeneous nature of duckweed mat abundance and distribution would lead to differences in macroinvertebrate community structure between sites and months.

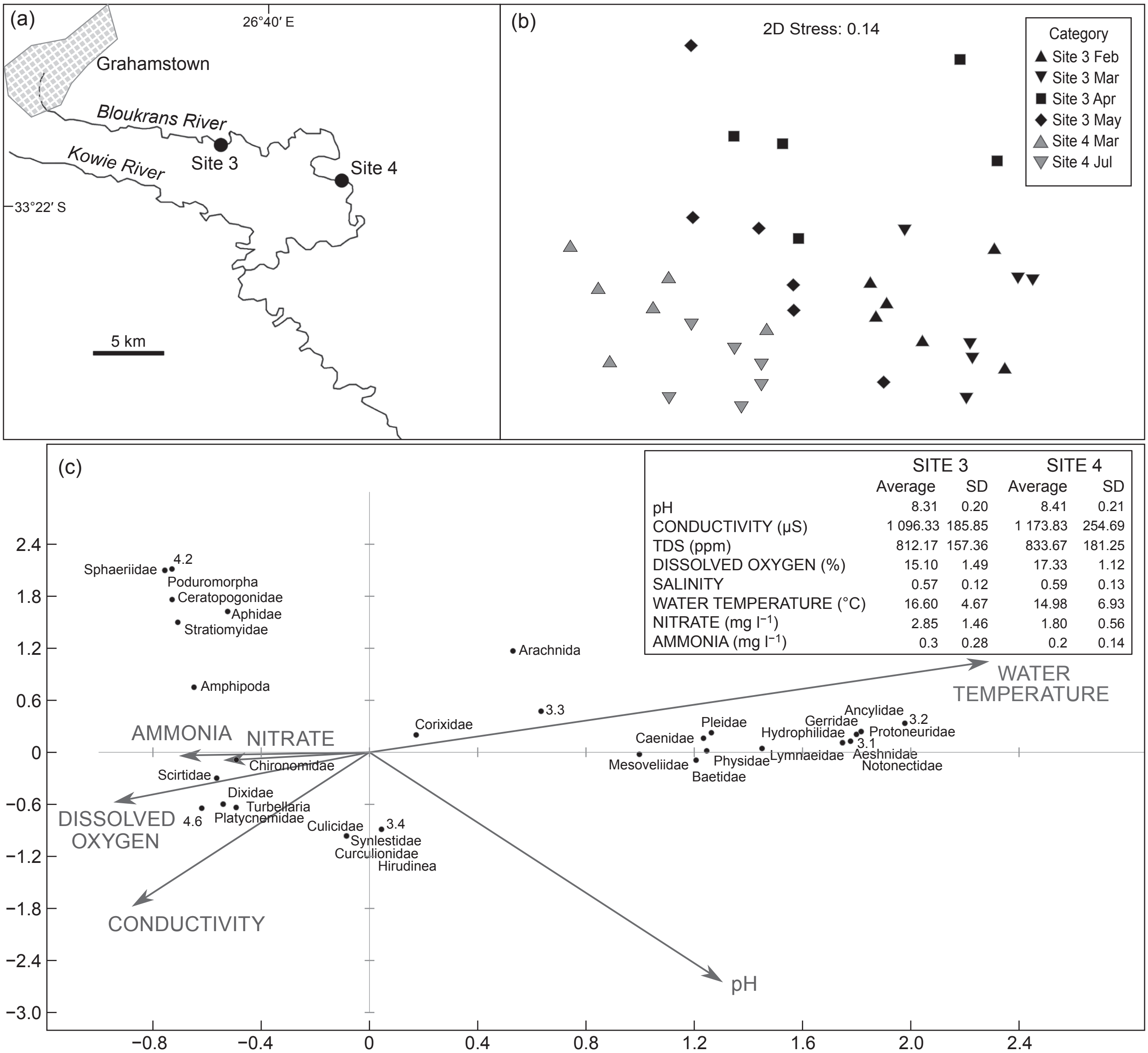
Four study sites, maximum 2 m depth, were chosen: two on the New Years River (Site 1: 33°18′54″ S, 26°06′25″ E and Site 2: 33°18′58″ S, 26°06′05″ E, Figure 1a) and two on the Bloukrans River (Site 3: 33°19′24″ S, 26°36′01″ E



	SITE 1		SITE 2	
	Average	SD	Average	SD
pH	7.56	0.31	7.64	0.22
CONDUCTIVITY (µS)	644.67	45.38	718.83	209.95
TDS (ppm)	455.67	73.81	505.83	141.80
DISSOLVED OXYGEN (%)	11.27	5.74	12.93	4.86
SALINITY	0.31	0.05	0.36	0.10
WATER TEMPERATURE (°C)	17.57	6.64	19.02	5.16
NITRATE (mg l^{-1})	0.25	0.07	0.2	0.02
AMMONIA (mg l^{-1})	0.10	0.14	0.15	0.07

Figure 1: (a) Map of the New Years River showing locations of sampling Sites 1 and 2; (b) NMDS plot comparing the community composition of the macroinvertebrate assemblages collected in association with duckweed mats on the New Years River system; (c) canonical correspondence analysis (CCA) of the physico-chemical parameters driving macroinvertebrate assemblages associated with duckweed mats on the New Years River and table of the six-month physico-chemical averages for Sites 1 and 2

and Site 4: 33°21′13″ S, 26°43′14″ E; Figure 2a), because of the semi-permanent duckweed mats found at these sites on these rivers. All sites were situated in river headwaters, with minimal flow and occurred within the Albany Thicket biome, which is found at an altitude of between 430 and 500 m above sea level and has an annual rainfall of 340–650 mm (Hoare et al. 2006). The area is also known for clayey soils, as well as for sandstone and shale formations (Hoare et al. 2006). The duckweed mats were made up of a combination of four duckweed species: *Landoltia punctata* (G.Mey) Les and D.J.Crawford, *Lemna minor* L., *Lemna gibba* L. and *Wolffia arrhiza* L., specimens of which were identified at the Selmar Schonland Herbarium (GRA), Albany Museum, Grahamstown.



	SITE 3 Average	SITE 3 SD	SITE 4 Average	SITE 4 SD
pH	8.31	0.20	8.41	0.21
CONDUCTIVITY (µS)	1 096.33	185.85	1 173.83	254.69
TDS (ppm)	812.17	157.36	833.67	181.25
DISSOLVED OXYGEN (%)	15.10	1.49	17.33	1.12
SALINITY	0.57	0.12	0.59	0.13
WATER TEMPERATURE (°C)	16.60	4.67	14.98	6.93
NITRATE (mg l^{-1})	2.85	1.46	1.80	0.56
AMMONIA (mg l^{-1})	0.3	0.28	0.2	0.14

Figure 2: (a) Map of the Bloukrans River showing locations of sampling Sites 3 and 4; (b) NMDS plot comparing the community composition of the macroinvertebrate assemblages collected in association with duckweed mats on the Bloukrans River system; (c) canonical correspondence analysis (CCA) of the physico-chemical parameters driving macroinvertebrate assemblages associated with duckweed mats on the Bloukrans River (South Africa) and table of the six-month physico-chemical averages for Sites 3 and 4

Six replicate duckweed samples were collected at each site, a minimum of 5 m apart within an area of 150 m^2, once a month for six months from February until July 2014. Duckweed samples were collected as described by Hill (1998). Samples were collected at each site using a rectangular plastic container (height 92 mm, width 145 mm × length 209 mm) converted into a sieve by removing the bottom of the container and replacing it with 500-µm mesh. For increased leverage, the rectangular plastic container was placed into a metal frame and connected to a wooden pole (1.5 m). The sieve was placed below the duckweed mat and levered steadily upwards to take each sample. Excess water was allowed to drain from each sample before all plant matter was placed into a large *Ziploc*® bag and stored on ice.

In situ physico-chemical measures were recorded at each site on each sampling occasion. The pH, salinity, water temperature, total dissolved solids (TDS) and electrical conductivity were measured using a Eutech PCTEST35 multiparameter pen, dissolved oxygen was measured using a Sper Scientific 850045 DO pen and [NH_4^+] (mg l^{-1}) and [NO_3^-] (mg l^{-1}) were measured with Vernier ion-specific electrodes (ISE) and LabQuest 2 interface.

In the laboratory, each macroinvertebrate sample was sorted and preserved in 70% ethanol within 72 hours of collection. Before removing the macroinvertebrates from each sample, the duckweed was carefully checked for any feeding scars or damage, which would be indicative of the presence of herbivorous insects. All macroinvertebrates (>500 μm) were removed from each sample and preserved in 70% ethanol for later identification to family level using the 'Guides to the Freshwater Invertebrates of Southern Africa' (Day et al. 2003; de Moor et al. 2003a, 2003b; Stals and de Moor. 2007) and grouped into functional feeding groups. Once all macroinvertebrates had been removed, each duckweed sample was dried to a constant weight at 50 °C. The dry weight of each duckweed sample was used to calculate the number of macroinvertebrates per kilogram dry weight of duckweed, to account for the spatial variations in the density of duckweed mat cover within and between sites and provide an indication of biomass.

The macroinvertebrate community composition of duckweed mats was compared visually in each river using non-metric multidimensional scaling (NMDS) plots. This was followed by a permutational multivariate analysis of variance (PERMANOVA; Anderson 2001; McArdle and Anderson 2001; site and month as factors; 999 permutations of residuals under a reduced model), which is reasonably robust to heterogeneous dispersion (PERMDISP test for homogeneous variances yielded $p < 0.05$). Sampling occasions on the Bloukrans River where duckweed mats were absent were excluded from the NMDS and PERMANOVA analysis, resulting in four months of data for Site 3 and two for Site 4 on the Bloukrans River. Both analyses were based on Bray–Curtis similarities, using $\log(x + 1)$ transformed data to test for differences in community structure between sites and months within each river. Where there were significant differences, a similarities percentages procedure (SIMPER) was used to identify the taxa driving the dissimilarities (Clarke 1999). All analyses were performed in Primer v. 6 (Clarke and Gorley 2006). Using the macroinvertebrate count data, a canonical correspondence analysis (CCA) in PARTITION (v. 3.0; Veech and Crist 2009) was completed for each river to investigate the physio-chemical drivers (salinity and TDS were omitted, because of their high correlation coefficients with conductivity; all ≥0.98) of macroinvertebrate community structure and composition in each river. Macroinvertebrate family level diversity was assessed for the New Years River system by calculating the Simpson's index (D), the Shannon–Wiener index (H') and Fisher's α (Karlson et al. 2004; Magurran 2004; Keylock 2005) to provide a basic indication of ecosystem health (e.g. Reynoldson and Metcalfe-Smith 1992) in order to ensure comparability of community composition across space and time. A repeated measures ANOVA (Statistica v. 13.0) was then performed on $\log(x + 1)$ transformed calculated diversity data (to meet the assumptions of normality and homogeneity of variance required for parametric tests), with month and sites as categorical factors, to test for differences in diversity amongst sites and months and followed by Tukey's HSD *post hoc* tests where significant differences were found. No analysis of comparative diversity was possible for the Bloukrans River, due to some months with absent duckweed mats (see above).

Over the six-month sampling period, 41 macroinvertebrate families were collected in association with duckweed mats from the New Years and Bloukrans rivers (Table 1). Community composition in both systems was similar, with predators accounting for 42.9% and 37.9%, detritivores for 25.7% and 27.6%, herbivores for 5.7% and 6.9% and families with species that fitted into more than one functional feeding group accounting for 25.7% and 27.6% of macroinvertebrates in the New Years and Bloukrans rivers, respectively (Table 1). The high number of predators (e.g. Odonata) associated with the duckweed mats supported the findings of Scotland (1940) and Harper and Bolen (1996), suggesting that duckweed is important as habitat and refuge for predaceous aquatic organisms. Additionally, species from the family Mesoveliidae, which are known to use duckweed as oviposition sites (Scotland 1940; Lanciani 1987), were commonly found in our samples (Table 1). Chironomidae, which include herbivorous, detritivorous and predaceous species (Day et al. 2003), were a frequent component of the sampled macroinvertebrate communities (Table 1). Some species of Chironomidae are known to damage aquatic plants by using leaves to create cases (Schutz 2008); however, no visible feeding damage or casemaking was evident on the duckweed samples collected during this study. Because many species of Chironomidae are detritivores or predators (Day et al. 2003) it is probable that they were using duckweed mats to forage rather than feeding directly on living plants. In comparison, however, the waterlily aphid *Rhopalosiphum nymphaeae* L. was the most frequently found macroinvertebrate in the sampled duckweed mats, because they are strictly herbivorous (Picker et al. 2004). It can therefore be assumed that they were feeding on the duckweed, despite the lack of visible damage. Herbivorous macroinvertebrates made up only a small percentage of the families associated with the duckweed samples, probably indicating that duckweed mats do not play a substantial role as a direct food source for the majority of the associated macroinvertebrate community, with the exception of *R. nymphaeae.* However, 29% of the collected macroinvertebrates were detritivores, indicating that duckweed might play a role in these systems as an indirect food source.

There was no significant difference recorded in Fisher's α and Simpson's index between sites and months in the New Years River ($F_{(5,50)} = 2.31$, $p = 0.06$ and $F_{(5,50)} = 0.89$, $p = 0.50$, respectively). The Shannon–Wiener index (H') was the only index that showed a significant difference between sites during April and July ($F_{(5,50)} = 8.76$, $p < 0.001$), but is known to be the most unstable diversity index of the three used here (Magurran 2004). Fisher's α and Simpson's index (D) are regarded as more stable and independent of sample size (Karlson et al. 2004), suggesting that there is enough evidence to indicate no meaningful differences in macroinvertebrate diversity between the sites and months on the New Years River. Consequently, river condition can be assumed to have remained stable over the studied spatial and temporal scales.

Visual inspection of the macroinvertebrate community in both the New Years and Bloukrans river systems showed distinct groupings associated with site and month, with

Table 1: Taxa, functional feeding groups, mean abundances (individuals/kg duckweed dry weight) and frequency of occurrence (Dominant = >50%, Frequent = between 50% and 25%, Occasional = between 25% and 5% and Rare = <5%) of macroinvertebrates collected in association with duckweed mats on the New Years and Bloukrans rivers, South Africa

Class	Order	Family	Functional feeding group	Bushmans	Bloukrans	Bushmans frequency	Bloukrans frequency
Collembola	Poduromorpha		Detritivore	4	14	Rare	Rare
Insecta	Ephemeroptera	Baetidae	Herbivore (microphytes), detritivore	150	465	Occasional	Occasional
		Caenidae	Detritivore	0	6	Not found	Occasional
	Odonata	Synlestidae	Predator	0	0	Rare	Rare
		Protoneuridae	Predator	0	2	Not found	Rare
		Platycnemidae	Predator	1	6	Occasional	Occasional
		Aeshnidae	Predator	0	0	Not found	Rare
		Libellulidae	Predator	3	0	Occasional	Not found
	Hemiptera	Mesoveliidae (*Mesovelia vittigera*)	Predator	5	58	Occasional	Frequent
		Gerridae	Predator	139	152	Rare	Occasional
		Corixidae	Detritivore	0	6	Not found	Rare
		Notonectidae	Predator	4	3	Rare	Rare
		Pleidae	Predator	19	11	Frequent	Occasional
		Naucoridae	Predator	1	0	Rare	Not found
		Belostomatidae	Predator	0	0	Rare	Not found
		Aphidae (*Rhopalosiphum nymphaeae* Linn.)	Herbivore	506	9	Dominant	Rare
	Coleoptera	Gyrinidae	Predator	0	0	Rare	Not found
		Dytiscidae	Predator	5	0	Occasional	Not found
		Curculionidae	Herbivore	0	0	Not found	Rare
		Hydraenidae	Detritivore	0	0	Occasional	Not found
		Hydrophilidae	Predator	17	0	Frequent	Rare
		Scirtidae	Herbivore, detritivore	4	10	Occasional	Occasional
		Noteridae	Herbivore, detritivore	0	0	Rare	Not found
	Diptera	Psychodidae	Detritivore	0	0	Rare	Not found
		Culicidae	Predator, detritivore	5	0	Occasional	Rare
		Dixidae	Detritivore	0	0	Not found	Rare
		Chironomidae	Herbivore (macrophytes), detritivore or predator	8	778	Occasional	Frequent
		Ceratopogonidae	Predator	0	8	Rare	Occasional
		Stratiomyidae	Detritivore	16	4	Frequent	Occasional
		Syrphidae	Detritivore	0	0	Rare	Not found
		Muscidae	Herbivore (microphytes), detritivore	0	0	Rare	Not found
Crustacea	Amphipoda		Detritivore	4	9	Occasional	Occasional
Arachnida	Trombidiformes	Unidentified family 1	Predator	3	0	Occasional	Not found
		Unidentified family 2	Predator	1	0	Occasional	Rare
Platyhelminthes	Turbellaria		Detritivore	5	1	Frequent	Rare
Annelida	Oligochaeta		Detritivore	14	0	Occasional	Not found
	Hirudinea		Predator, parasite	13	0	Occasional	Rare
Mollusca	Bivalvia	Sphaeriidae	Detritivore	6	5	Occasional	Rare
	Gastropoda	Physidae	Herbivore (microphytes), detritivore	13	888	Frequent	Frequent
		Lymnaeidae	Herbivore (microphytes), detritivore	2	5	Occasional	Occasional
		Ancylidae	Herbivore (microphytes), detritivore	0	0	Not found	Rare

Table 2: Effect of site and month, using PERMANOVA, on macroinvertebrate community structure in the New Years and Bloukrans river systems (PERMANOVA results). Values in bold indicate significant differences; – denotes that Site × Month interaction calculation was not possible for Bloukrans, because of missing data in some months

	Bushmans River				Bloukrans River			
	df	MS	*p*	Pseudo-*F*	df	MS	*p*	Pseudo-*F*
Site	1	9 112.5	**0.001**	4.43	1	18 392.0	**0.001**	14.59
Month	5	15 447.0	**0.001**	7.51	4	5 672.1	**0.001**	4.500
Site × Month	5	7 055.7	**0.001**	3.43	0	–	–	–
Residuals	60	2 055.6			29	1 260.4		
Total	71				34			

some degree of overlap in certain cases (Figures 1b and 2b). PERMANOVA confirmed significant differences between sites and months in both river systems (Table 2) and a significant Site × Month interaction in the New Years River, indicating that the magnitude of difference between sites varied significantly among the different months sampled, and vice versa. *Post hoc* comparisons revealed that there were significant differences between sites on the New Years River in all months (all $p < 0.05$), with the exception of February and March. Site × Month interactions could not be calculated for the Bloukrans River, because of a lack of duckweed in some months; however, *post hoc* comparisons indicated that macroinvertebrate community structure was significantly different between all month combinations (all $p < 0.05$), with the exception of between April and May. The structure of macroinvertebrate assemblages associated with duckweed appear to frequently change, which could have implications for duckweed's role as a food resource and refuge in aquatic ecosystems.

The SIMPER analysis identified Baetidae, Libellulidae, Mesoveliidae, Pleidae, Aphidae, Scirtidae, Hirudinea, Sphaeriidae, Physidae, Oligochaeta, Stratiomyidae, Turbellaria, Amphipoda, Lymnaeidae and Chironomidae as primary contributors to the cumulative percentage (50%) contribution to between-group differences between sites and months in the New Years River, whereas Mesoveliidae, Platycnemidae, Physidae, Chironomidae, Amphipoda and Baetidae accounted for the cumulative percentage (50%) contribution to between-group differences between the sites and months in the Bloukrans River.

Physico-chemical parameters at Sites 1 and 2 on the New Years River were similar over the six-month period, with the exception of strong variability in water temperature. The majority of the macroinvertebrates associated with duckweed here grouped together in the centre of the ordination plot (Figure 1c), suggesting that the measured physico-chemical parameters did not strongly affect community structure, however, increased pH, $[NO_3^-]$ and to some extent conductivity, could have had some effect. There were a few exceptions, however, where physico-chemistry clearly drove taxa abundance, with Sphaeriidae associating strongly with lower $[NH_4^+]$ and Mesoveliidae clearly preferring warmer water (Figure 1c).

Macroinvertebrates from duckweed mats at Sites 3 and 4 on the Bloukrans River had clearer groupings, with increased temperature, lower pH and higher values of conductivity and dissolved oxygen correlated to specific macroinvertebrate taxa (Figure 2c). There were also high numbers of Chironomidae found in the Bloukrans samples, which appeared to be associated with increased $[NO_3^-]$ and $[NH_4^+]$, probably a result of sewage run-off (Barber-James et al. 2003) and because many species of chironomids are known to be pollution-tolerant (Calle-Martínez and Casas 2006; Carew et al. 2007; Senderovich and Halpern 2013). Although physico-chemistry might be partially responsible for the differences in macroinvertebrate community structure seen between sites and months, particularly on the Bloukrans River, duckweed mats are also highly temporally variable and their biomass can be strongly affected by rainfall and subsequent flow rate (Hillman 1961; Demars et al. 2014; Kutschera and Niklas 2015), providing patchy refuge and habitat access (McLay 1974; Kutschera and Niklas 2015). Consequently it is possible that the changes in macroinvertebrate assemblages might also simply reflect opportunistic colonising behaviour, particularly by predators. The biomass of duckweed collected on each sampling occasion with a standardised collection volume indicated large variability on both a temporal and spatial scale (Figure 3), underlining the heterogeneous nature of duckweed mat distribution. The effects of succession in macroinvertebrate assemblages upon the appearance of patchy duckweed mats should also be considered in future studies (e.g. Moorehead et al. 1998; Landeiro et al. 2010; Fontanarrosa et al. 2013).

The macroinvertebrate functional feeding groups associated with the duckweed mats in both the New Years and Bloukrans rivers were similar to those found in the Northern Hemisphere by Scotland (1940) and Harper and Bolen (1996), with predators and detritivores as the dominant functional feeding groups, but with little evidence of specialist herbivores. Differences in macroinvertebrate community structure were observed between sites and months on both rivers; potentially attributable to variation in physico-chemistry or patchiness in duckweed availability, but might also reflect opportunistic colonisation by macroinvertebrate predators or patterns in macroinvertebrate succession of duckweed mats. The macroinvertebrate diversity remained similar across sites and times in the New Years River. However, the New Years River had a larger number of taxa driving differences in community structure (16 species; SIMPER c. 50%) when compared with the Bloukrans (6 species; SIMPER c. 50%), suggesting that taxonomically rich systems are more robust to spatially and temporally changing heterogeneous environments, such as that of a duckweed mat.

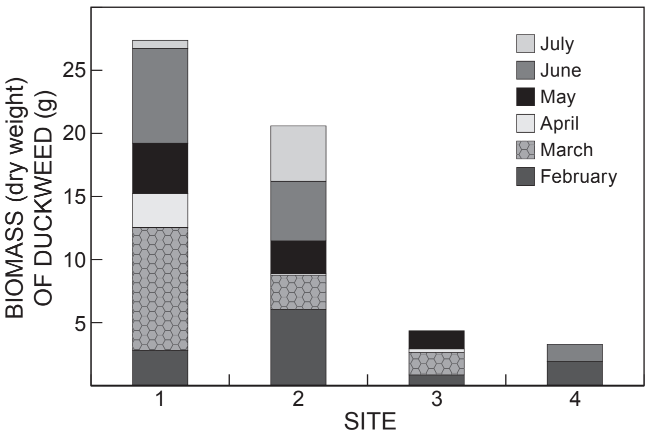


Figure 3: Average dry weight biomass of duckweed samples collected with a standardised container at all sites on the New Years (Sites 1 and 2) and Bloukrans (Sites 3 and 4) rivers from April to July 2014

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