

**COMPLEMENTARITY BETWEEN TWO METRICS WHICH
USE INVERTEBRATES TO ASSESS RIPARIAN CONDITIONS
OF RIVERS**

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I declare that this thesis is my own work. It is being submitted for the Degree of Master of Science at the University of KwaZulu Natal, Pietermaritzburg. It has not been submitted before for any degree or examination at any other University.

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First day of March 2005

S. E. P. P.

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ABSTRACT

Conservation of streams involves an understanding of their physical, chemical and biological entities. SASS5 is a biomonitoring method developed to monitor the habitat quality of a water body. It is based on differential scores attributed to various macroinvertebrate families with varying degrees of sensitivity to anthropogenic impact. This method, however, does not assess impacts on particular species.

Odonata are good candidates for study at the species level as they are well researched and males are easily identified. As adults, they are known to be sensitive indicators of both riparian and river conditions. Yet Odonata cannot be an umbrella taxon for all other taxa. Therefore, the main aim of this study is to determine the complementarity of the two metrics (Odonata assemblages and SASS5), establishing whether Odonata assemblages offer additional information on, or insight into, riverine habitat quality as portrayed by SASS5.

To accomplish this, certain objectives were addressed. 1) The variation of SASS5 scores and 2) Odonata assemblages between river systems, structural habitat types (open or closed canopies) and compositional habitat types (indigenous or alien vegetation). 3) Whether SASS5 scores vary to the same extent, and, 4) on the same spatial scale (river system and point localities) as Odonata abundance and species richness.

The relationship between these two metrics was determined along three rivers in the Pietermaritzburg basin. Sampling units (SUs) with extremes in vegetation structure (sunlight and shaded SUs) and vegetation composition (alien or indigenous) were selected. Using this range of environmental conditions placed environmental extremes on the macroinvertebrate populations at point localities and having three different river systems added the dimension of variation over a broader scale, thus stretching the two metrics to investigate whether both responded similarly or in different ways.

Results indicated that both metrics provide a similar portrait of overall river conditions. At the smaller spatial scale, the Odonata assemblage, unlike SASS, was highly sensitive to the riparian vegetation. Odonata species were less sensitive to vegetation composition but differentially sensitive to vegetation structure. However, landscape context is also important, with point localities being affected by the neighboring dominant habitat type. Larval Odonata alone did not provide this information. Overall, aquatic macroinvertebrates and adult Odonata provide a highly complementary pair of metrics that together provide large spatial scale (river system) and small spatial scale (point localities) information on the level of impact of stressors such as riparian invasive alien trees.

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Complementarity between two metrics which use invertebrates to assess riparian conditions of rivers

INTRODUCTION

Water monitoring

Water monitoring worldwide

With increasing anthropogenic impact on the landscape, the water quality of rivers throughout the world is deteriorating (Clark & Samways 1996; Richter et al. 1997; Smith et al. 1999), with stream biotas being altered in numerous ways (Uys et al. 1996; Samways & Taylor 2004). Yet, aquatic ecosystems are highly complex, and consist of interactions between physical, chemical and biological entities. This makes them difficult and expensive to monitor using traditional physico-chemical monitoring. One reason for this is that the intermittent nature of measurements often results in pulsed releases of effluents remaining unrecorded. The sensitivity of this monitoring method may also be insufficient to detect pollutants of low concentrations. This is problematic when these substances are bio-accumulative. Furthermore, there is a large number and variety of toxic compounds and other anthropogenic impacts that could affect the water quality, and testing for the full range of these compounds is costly (Dallas 2002). Thus, a more effective use of techniques to assess rivers as well as a more integrated approach to the protection of water resources worldwide is required (Dallas 1997; Norris & Thoms 1999). However, it is important that techniques be integrated, as no single measure is an acceptable surrogate for monitoring the biological state of a river.

Aquatic organisms reflect the effects of chemical and physical impacts on their habitats, and are sensitive to impacts occurring over extended periods of time (Cook et al. 2001). Macroinvertebrates are fairly immobile in their aquatic phase and are thus usually representative of the general location being sampled. Also, different organisms react differently to the stresses that they experience. The various

invertebrate taxa have different sensitivities to changes in flow regimes, deterioration in water quality, habitat alteration and changes in the chemical conditions of the river system (Uys et al. 1996). Taxa most affected by a disturbance on the river would be regarded as being most sensitive. Other taxa may not be affected, and may even benefit from the absence of the more sensitive species or change in physical conditions. Organisms, being biological endpoints, are therefore good indicators of river quality and reflect the overall ecological integrity of their environment. By using them, decision-making is improved, money is saved and our ability to protect the health of rivers is increased. Therefore, biological techniques for the assessment of aquatic ecosystems have been adopted (Rosenberg & Resh 1993, Metcalf-Smith 1994). The proliferation of techniques has been stimulated by regulatory authorities who see bioassessment data as valuable for the management of aquatic ecosystems (Karr 1991; Norris & Norris 1995).

Bioassessment integrates the affects of water quantity and quality on habitat and biotic integrity. Bioassessment may be defined as the utilization of one or more component of the biota to assess the effect of a change in another component such as water quality (Dallas 2002). The ultimate goal of bioassessment is to provide a cost efficient, accurate measure of the biotic integrity of aquatic ecosystems that can be easily interpreted by managers and policy makers who may have little biological training (Schindler 1987; Karr 1991).

The leading universal approach concerning freshwater bioassessment has probably been the River Invertebrate Prediction and Classification System (RIVPACS). This method was developed by Wright et al. (1984) and has been successfully used on a national scale in the United Kingdom (Armitage et al. 1987). With slight adaptations, it has been implemented in Australia (Smith et al. 1999). Compared to previous methods, RIVPACS is cheaper, the results are more easily understood, and a more holistic assessment of anthropogenic effects on rivers can be made (Norris & Thoms 1999). These are the primary criteria that rapid biological assessments are designed to fulfil (Resh & Jackson 1993).

History of water monitoring in South Africa

In South Africa, bioassessment began with the development of a Biotic index by Chutter (1972). This index was highly labour intensive and was not widely used. A more effective method based on that of the Biological Monitoring Working Party's (BMWP) was developed (Wright et al. 1984; Walley & Hawkes 1996). This method was originally developed in the United Kingdom and thus needed to be adapted for South Africa's specific needs. The result was the SASS (South African Scoring System) method, which has subsequently undergone several upgrades (Chutter 1994, 1998). SASS may be used to 1) assess the ecological state of aquatic ecosystems, 2) assess the spatial and temporal trends in ecological state, 3) assess emerging problems, 4) set objectives for rivers, and 5) assess the impact of developments and predict changes in the ecosystem due to these developments. This method is now widely used in southern Africa, and is the mainstay of the National River Health Programme (NRHP) (Uys et al. 1996; Roux 1997). It is also widely used by many institutions such as Umgeni Water, The Council for Scientific and Industrial Research (CSIR) and the Department of Water Affairs and Forestry (DWAF) (Dickens & Graham 2002) and has undergone extensive testing, particularly by Dallas (1995, 1997, 2000a, b, 2002).

The advantages of SASS are that it is a quick method that is easy to use in the field. Also, very little equipment and expertise is required, thus costs are low (Brown 2001). SASS allows for comparisons between sites and river systems, as well as monitoring of long-term trends. Sampling for SASS is also largely non-destructive, so no further damage is inflicted on the environment. Disadvantages include the fact that SASS only becomes increasingly reliable as the number of available biotopes increase, which can be problematic when a river has low biotope diversity. Furthermore, SASS is especially reliant on the stones-in-current biotope, which is often absent at many sites in the lower reaches of rivers. Also, SASS identifies most invertebrates only to family or even higher taxon level, which limits the interpretation of processes occurring at finer taxonomic levels. Lastly, this method does not include any information on the invertebrates themselves. Information on for example the life

histories of the macroinvertebrates would provide more detailed information for interpreting the state of the water body and its environment.

The latest version of SASS is SASS5 (Dickens & Graham 2002), which is a revision of SASS4 and has addressed some of the deficiencies of SASS4 that came to light. SASS5 is designed for low or moderate flow hydrology and works best when the diversity of biotopes is wide and includes riffles or rapids (Dickens & Graham 2002). Macroinvertebrate families, and some higher taxa, are scored according to their sensitivity to deterioration in water quality. SASS scores range from 0 to 15. Highly pollution-tolerant species score low, and intolerant or highly-sensitive species score high. These scores have been shown to relate directly to water quality and are especially sensitive to organic pollution (Uys et al. 1996). The SASS score is considerably influenced by the number of biotopes from which the organisms are collected (Chutter 1998). The more pollution-tolerant a taxon, the more biotopes in which it generally occurs (Uys et al. 1996). Thus, polluted sites tend not to be influenced by biotope diversity. However, where water quality is more natural, SASS scores tend to be extremely sensitive to biotope diversity (Chutter 1998). ASPT (Average score per taxon) scores however are less influenced by biotope (Chutter 1998). Certain guidelines are available for the interpretation of SASS5 and ASPT scores (Table 1) (Uys et al. 1996). These guidelines apply to all rivers in South Africa except Western Cape rivers with pH < 6.

Table 1. Guidelines for the interpretation of SASS5 and ASPT (Average score per taxon) scores.

SASS 5	ASPT	Water Condition
>100	>6	Water quality natural, biotope diversity high
<100	>6	Water quality natural, biotope diversity reduced
>100	<6	Borderline case between natural water quality and some deterioration in water quality. Interpretation should be based on the extent to which SASS 5 exceeds 100 and ASPT is < 6.
50-100	<6	Some deterioration in water quality
<50	variable	Major deterioration in water quality

There are five major classes of environmental factors that may affect the ecological condition or integrity of aquatic ecosystems: chemical variables, flow regime, habitat structure, biotic interactions and energy source. A biological field assessment of macroinvertebrate assemblages such as SASS provides an integrated measurement of environmental problems and aids in the management of water resources.

Value of Odonata species as indicator taxa

Value of adult Odonata males

Odonata species are important components of freshwater ecosystems. They are top predators and, as an assemblage, are able to occupy the entire spectrum of aquatic habitats, with both larval and adult stages generally being relatively biotope-specific (Corbet 1962; Clark 1992; Samways 1993). They are widespread throughout Africa (Samways 1992) where they depend mostly on structurally specific aquatic and terrestrial microhabitats (Samways 1993). This dependence results in their sensitivity to changes in water quality and to landscape disturbance within these habitats, and thus they reflect to some extent the ecological condition of their habitats (Samways & Steytler 1996; Chovanec & Waringer 2001). Odonata are well studied, and adult taxonomy, together with the behaviour and ecology of a large number of species, is fairly well known in comparison with other freshwater invertebrate taxa (Samways 2002a, 2002b, Chovanec & Waringer 2001). There is a sufficient number of species to give variety and yet not an unmanageable number of unnamed species which would result in many difficult-to-recognize morphospecies (Samways 1993). Adults are large and conspicuous, and most South African species are easily identified in the field (Osborn & Samways 1996). These characteristics of Odonata suggest that they are valuable environmental indicators. Furthermore, their long ontogenetic development meets the requirements for medium or long term monitoring (Chovanec & Waringer 2001).

Adult males are most useful in biomonitoring programmes as they usually display distinctive species colouration and patterning and are generally highly biotope-specific (Samways 1993). In contrast, teneral males and females are more cryptically coloured, with females often only visiting the water to mate and oviposit (Corbet 1962). The larvae are also cryptic, and are therefore difficult to identify to species level. Large numbers of them remain undescribed in Africa and thus their potential as ecological indicators is limited (Samways 1993; Stewart & Samways 1998).

South African Odonata

Adult Odonata have been widely studied in South Africa, and they are useful in many different conservation programmes and management strategies (Clark & Samways 1996; Samways & Taylor 2004). It is their requirements for particular microhabitats that render them useful as indicators of disturbances in biotopes or biotope quality. A broad knowledge of their taxonomy allows them to be used in congruence studies with other taxa (Samways 1993). This is when the data from several representative taxa are geographically overlaid to give a meaningful picture of biodiversity across an area. Odonata can be used as a representative taxon in the location of high value biodiversity areas, which may also be areas with high conservation requirements (Samways 1993; Samways 2002). Odonata were also used to test the IUCN categories and criteria of threat, and to provide guidelines that could be used for red-listing other invertebrate taxa (Samways 2002a). They have also been used in the design of conservation ponds (Samways et al. 1996; Suh & Samways 2001).

Single species versus assemblage structures

Biomonitoring programmes aim to assess ecosystem changes, either structural or functional, using indicator species or species assemblages (Kremen et al. 1993).

Single species may be useful in gaining certain information that cannot be duplicated in ecosystem-level tests. A single species may, for example, be a specialist and require particular habitat conditions. Information on this gives a more complete

picture of overall landscape integrity. However, single-species tests generally cannot be used to predict responses at higher levels of organization (Kimbell & Levin 1985). Nevertheless, a sensitive sublethal parameter of response can be monitored in a sensitive species, and a response may be detected at a lower concentration of toxicant than could be detected at the ecosystem level (Weis 1985). A study by Samways et al. (1996) used single species of Odonata as indicators of habitat change and noted that species restricted to a narrower range of conditions were better indicators of change than species that were able to breed in a wide variety of habitats. They deduced that stenotopic species (habitat-restricted, geographically narrow-range species) were better indicators than eurytopic ones (habitat-tolerant, geographically-widespread species) as they were more likely to be affected by changing conditions. Thus common species could be used to identify the type of biotope and rarer species could be indicative of relict or undisturbed or disturbed conditions and used to rate the importance of any site within its biotope group (Eyre et al. 1986). However, a major difficulty with this approach is that the categorisation of sensitivity may be a subjective choice, therefore multispecies testing provides additional information (Cairns 1986).

Studies of biotic composition in Britain (Wong et al. 2003), Australia (Sheldon et al. 2002) and the USA (Boyle & Fraleigh 2003) suggest that stream invertebrate assemblages in different parts of the world are highly structured by environmental filters and are not random assemblages. Changes in an assemblage structure may result from shifts in the competitive ability or fecundity of invertebrates forming that assemblage, and are not necessarily dependent on the deaths of organisms. Therefore the use of assemblage data is useful as anthropogenic effects are often subtle, affecting the growth and reproduction of organisms (Marcucella & Abramson 1978). As a subset, Odonata assemblages have become valuable tools for the ecological assessment of aquatic ecosystems (Samways & Steytler 1996). The specific biotope requirements and preference of Odonata governs their presence or absence, as well as abundance, and thus assemblage composition along specific environmental gradients (Osborn & Samways 1996). As many Odonata species are stenotopic, there is a strong relationship between biotope and Odonata assemblages. However, the presence of Odonata at a particular site is probably due to a particular suite of environmental conditions (Clark & Samways 1996; Stewart & Samways 1998). Thus

knowing which species occur under which sets of biotope conditions facilitates the interpretation of changes in species assemblages as a result of changes in biotope features such as vegetation coverage and water quality. River managers are then able to classify biotopes quickly and assess changes in physical conditions through a change in assemblage patterns (Clark & Samways 1996). The difficulty lies in knowing which biotope features are being altered, as a number of biotope variables are usually responsible for Odonata assemblage patterns. Odonata assemblages are clear biotic manifestations of a suite of physical conditions (Stewart & Samways 1998) and are reliable indicators for evaluating the quality of land-water ecotones, habitat heterogeneity and the hydrological dynamics of water bodies, i.e. ecological health (Chovanec & Waringer 2001). This is the ability of an aquatic ecosystem to support and maintain a balanced, integrated, adaptive assemblage of organisms having a species composition, diversity and functional organisation comparable to that of the natural habitats within a region (Karr & Dudley 1981).

Odonata endemism in South Africa

To date there are 158 South African Odonata species (Samways & Taylor 2004). The endemics make up 18% of the total (14% Zygoptera; 4% Anisoptera) (Samways 1992). Within southern Africa, South Africa has the highest number of endemic Odonata species. The proportion of endemic versus widespread species can be used to make conservation decisions on whether conservation is for rarity, localization and endemism, or for typicalness (Samways 1993)

South Africa also has the highest proportion of globally red-listed species (Samways 2002 a,b). In recent years, conservation status assessments of South African Odonata has led to the discovery of some new species and new national records. Many areas of the country have not yet been thoroughly explored, and the concern is that there might be more local extinctions of populations and species than is generally realized. The point being that endemics have considerable value for being incorporated into customized monitoring programmes for South Africa.

The search for complementarity among indicator metrics

Bioassessment in South Africa has thus led to the development of SASS which has reached version 5. It allows for comparisons between sites and river systems as well as monitoring long term trends. SASS5 however, is a coarse method, as it is intended to be a rapid bioassessment method that is field based to reduce the time needed to process samples. Furthermore, the taxonomic resolution of these samples is limited to the family level (Dallas 2002; Dickens & Graham 2002). SASS5 does not focus down to the species level and therefore would not be able to give any information of conservation issues of concern at this level. In particular, as named species are not used, SASS5 does not generate assessments of how endemic species are being affected vis-à-vis more geographically widespread species. In other words, SASS5 does not provide a measure of ecological integrity at the species level.

In turn, using only Odonata as indicators of ecological integrity, does not offer a fully representative sample on which to base sound biological conservation decisions (Samways 1993). They are only a single taxon and may not expose what is happening at higher levels of organisation. Yet all taxa could not be monitored at the species level as this would be too time consuming, labour intensive and expensive. As no single indicator can give a full picture of a particular environmental state, it is necessary to look for complementarity amongst indicator metrics, and to identify indicators of change in structural, functional and compositional diversity at a range of scales and levels of organization for rivers (Rogers & Biggs 1999). A solution would be to combine SASS5, a measure of ecosystem health, with the Odonata, a measure of ecological integrity at the species level. This would possibly give a more meaningful and comprehensive picture of river health and conservation value. It would also provide information on water quality as well as on biodiversity value.

Aims of this study

The main aim of this study is to determine the complementarity of two metrics (Odonata assemblages and SASS5), establishing whether Odonata assemblages offer

additional information on, or insight into, riverine habitat quality as portrayed by SASS5. This study was not concerned with the detection of pollution.

To accomplish this, the following objectives were addressed:

- 1) How **SASS5 scores** (including macroinvertebrate abundance (see text) and macroinvertebrate family or higher taxon richness) vary between river systems, between structural habitat types (open or closed canopies) and between different compositional habitat types (indigenous or alien vegetation). Three groups of null hypotheses were therefore tested. Firstly, that there is no variation between (a) SASS5 scores, (b) macroinvertebrate abundance and (c) macroinvertebrate family richness across different river systems.
- 2) How **Odonata assemblages** (Odonata abundance and species richness) vary between river systems, between structural habitat types (open or closed canopies) and between different compositional habitat types (indigenous or alien vegetation). Three groups of null hypotheses were therefore tested. Firstly, that there is no variation among Odonata assemblages (Odonata abundance and species richness) across different river systems. If this hypothesis is rejected then variation among Odonata assemblages exist and statistical tests will be carried out to examine where variation exists between river systems. Secondly, that Odonata assemblages are not affected by the structure of the riparian vegetation (i.e. whether the canopy is open or closed), and, thirdly, that Odonata are not affected by the composition of the habitat (i.e. whether the vegetation is indigenous or alien).
- 3) Whether SASS5 scores vary in the same way and to the same extent as Odonata abundance and species richness and weighted Odonata scores (see text). Here I test the null hypothesis that SASS5 does not vary in the same way as Odonata species richness and abundance and weighted scores.
- 4) Whether the spatial scale of variation (river system and point localities) of the Odonata indices and the SASS5 score is the same. Here I test the null hypothesis that the spatial scale of variation is not the same. If this hypothesis is accepted, the spatial scale relating to the Odonata and that relating to SASS5 score would be investigated by identifying the components of the variation.

This will be done by isolating:

- A) The macroinvertebrate taxonomic groups (families) responsible for the variation in the SASS5 scores.
- B) The Odonata taxonomic groups (species) responsible for variation in the Odonata assemblages.
- C) The components of the Odonata assemblages affected most; the eurytopic species (habitat tolerant and/or widespread species) or the stenotopic species (habitat specialists and/or narrow range/specialist species).

The results then determine the merits of using both metrics or either metric for determining the effects of vegetation change upon the stream fauna and to provide guidelines for assessing the impacts of alien vegetation upon the fauna.

METHODS

Study area

Three permanent rivers (Msunduzi, Dorpspruit and Townbush) in the Pietermaritzburg basin, 30°20'E, 29°36'S, were chosen as the study area (Fig. 1). The reaches studied were similar in elevation (660 – 690 m.a.s.l.) thus avoiding influences that changes in elevation might have on species composition (Heino 2002). A range of sampling units (SUs) were chosen along each river based on as much vegetal canopy variation as possible. This provided extremes in both shaded versus sunlit SUs, and in compositional diversity i.e. alien plants versus indigenous plants. Using such a range of environmental conditions placed environmental extremes on the invertebrate populations at point localities. Having three different river systems added the dimension of variation over a broader scale. This was done to 'stretch' the two metrics as far as possible, and to see whether they both responded in the same or in different ways to the spectrum of environmental conditions.

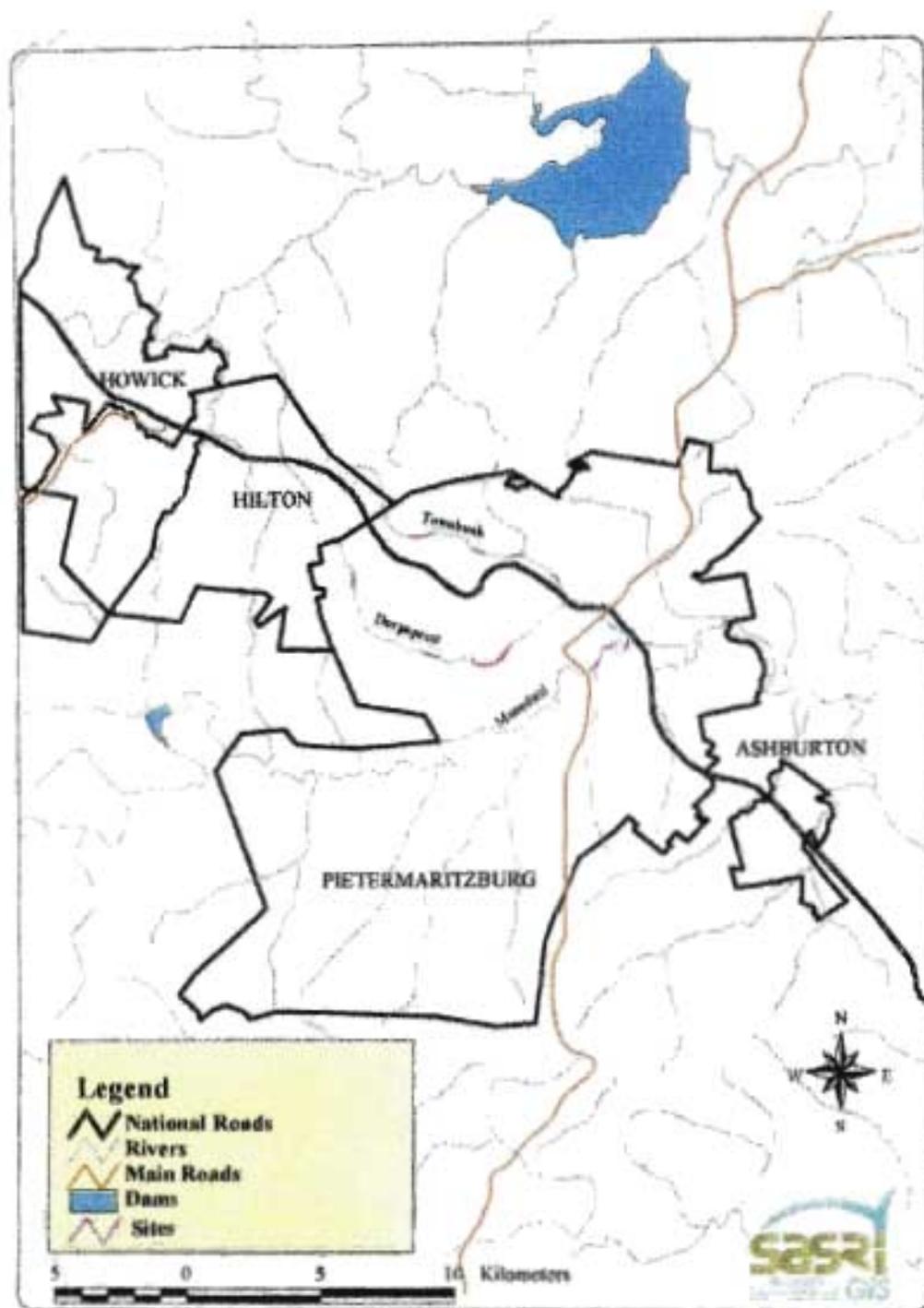


Fig. 1: A map of the Pietermaritzburg basin showing the areas along the river where the study took place

Fourteen SUs were along the Msunduzi (Table 2) and 28 SUs along the Townbush (Table 3) and 28 SUs along the Dorpspruit (Table 4) streams, giving 70 SUs in all. Each SU was divided into four categories according to a combination of vegetation structure and composition. Vegetation structure was divided into either an open (< 30% of river bank with tree canopy) or a closed (> 70% of river bank with tree canopy) canopy, and vegetation composition into SUs with either principally indigenous or alien vegetation along the rivers bank. Shaded SUs had little undergrowth so when classifying their vegetation composition, the trees and vegetation forming the canopy was examined. Open sites had little canopy cover and thus the ground vegetation was examined in order to classify the SUs vegetation composition.

However, as a result of the natural variation within each river it was not possible to achieve equality in vegetation structure and composition. Along the Msunduzi, there was little alien vegetation and few SUs with closed canopies, therefore 14 SUs with open canopies and indigenous vegetation were selected. Along the Townbush stream, 14 SUs with closed canopies and alien vegetation, seven SUs with open canopies and indigenous vegetation, and seven SUs with open canopies and alien vegetation were selected. SUs along the Dorpspruit were divided into two with open canopies and alien vegetation, twelve with open canopies and indigenous vegetation, twelve with closed canopies and alien vegetation and two SUs with closed canopies and indigenous vegetation.

SUs were chosen to include the different type and density of canopy cover, and to include all SASS5 biotopes in each SU. A SU included a measured 10 m stretch of stream together with the 1 m wide strip of vegetation on either side of the stream (i.e. a 10 m × 1 m × 2 transect). Within each 10 m stretch was a glide and a riffle to ensure that all biotopes were included, minimizing variation (Dickens & Graham 2002). River depth was never greater than 0.75 m.

Table 2: Sampling units (SUs) along the Msunduzi river. Canopy cover = the percentage of sky above the SU that was blocked by vegetation. Veg on bank = the percentage of the left and right bank along the SU that was covered with vegetation (indigenous and alien). O = SUs with a completely open, or predominantly open, tree canopy (< 30% of canopy covered with vegetation). I = SUs with dominantly indigenous vegetation along the river bank. Rapid refers to a strong flow of water over rocks. Riffle refers to a weaker flow of water over rocks and smaller stones.

SU	Classification	River width (m)	Canopy cover (%)	Veg on bank (%)	Flow	Dominant vegetation type
1	OI	6	0	70	Rapid into flat. Strong flow at all sites	<i>Pennisetum</i> sp., <i>Ischaemum fasciculatum</i>
2	OI	4.5	0	20	Riffle into glide	<i>Ischaemum fasciculatum</i> , <i>Cyperus</i> sp.
3	OI	4.5	0	80	Riffle into glide	<i>Pennisetum</i> sp., <i>Ischaemum fasciculatum</i> , <i>Paspalum urvillei</i>
4	OI	5	0	50	Riffle into glide	<i>Pennisetum</i> sp., <i>Cardiospermum grandiflora</i>
5	OI	4	0	40	Flat into riffle	<i>Pennisetum</i> sp., <i>Ischaemum fasciculatum</i> , <i>Cyperus</i> sp.
6	OI	5	0	30	A few rocks in flat flow	<i>Pennisetum</i> sp., <i>Typha capensis</i> , <i>Sorghum</i> sp.
7	OI	4.5	0	60	Rapid into glide	<i>Ischaemum fasciculatum</i> , <i>Cyperus</i> sp.
8	OI	5	0	60	Rapid into glide	<i>Cyperus</i> sp.
9	OI	5	5	70	Strong flow around and over large rocks	<i>Paspalum urvillei</i> , <i>Pennisetum</i> sp.
10	OI	5	0	60	Glide into	<i>Pennisetum</i> sp.,

					rapid	<i>Ischaemum fasciculatum</i>
11	OI	4	0	90	Flow around vegetation island	<i>Ischaemum fasciculatum</i> , <i>Typha capensis</i> , <i>Juncus</i> sp.
12	OI	6	0	70	Riffle into glide	<i>Pennisetum</i> sp., <i>Cyperus</i> sp., <i>Sorghum</i> sp.
13	OI	4	0	70	Mostly rapid	<i>Cyperus textiles</i> , <i>Pennisetum</i> sp.
14	OI	5.5	0	60	Glide, pebble island	<i>Cyperus</i> sp., <i>Sorghum</i> sp.

Table 3: Sampling units (SUs) along the Townbush river. Canopy cover = the percentage of sky above the SU that was blocked by vegetation. Veg on bank = the percentage of the left and right bank along the SU that was covered with vegetation (indigenous or alien). O = SUs with a completely open or dominantly open tree canopy (< 30% of canopy covered with vegetation). C = SUs with a closed or dominantly closed tree canopy cover (> 30% of canopy covered with vegetation). I = SUs with dominantly indigenous vegetation. A = SUs with dominantly alien vegetation. Rapid refers to a strong flow of water over rocks. Riffle refers to a weaker flow of water over rocks and smaller stones.

SU	Classification	River width (m)	Canopy cover (%)	Veg on bank (%)	Flow	Dominant vegetation type
15	CA	1.5	80	20	Mostly rapid	<i>Bambusa</i> sp., <i>Hedychium gardnerianum</i>
16	CA	1.5	80	10	Rapid into glide	<i>Eucalyptus grandis</i> , <i>Hedychium gardnerianum</i>
17	CA	1.5	70	70	Mostly rapid	<i>Hedychium gardnerianum</i> , <i>Eucalyptus grandis</i>

18	CA	2	70	50	Glide into rapid	<i>Eucalyptus grandis</i> , <i>Setaria megaphylla</i>
19	CA	2	80	10	Mostly rapid	<i>Hedychium gardnerianum</i> , <i>Ficus</i> sp.
20	CA	1.5	70	30	Mostly rapid	<i>Hedychium gardnerianum</i> , <i>Quercus</i> sp.
21	CA	1.5	80	30	Riffle into glide	<i>Hedychium gardnerianum</i> , <i>Tricalysia lanceolata</i> .
22	CA	1.5	80	10	Rapid into glide	<i>Bambusa</i> sp., <i>Hedychium gardnerianum</i>
23	CA	1.5	90	5	Ripples	<i>Bambusa</i> sp., <i>Hedychium gardnerianum</i>
24	CA	1.5	70	60	Mostly rapid	<i>Ficus</i> sp., <i>Hedychium gardnerianum</i>
25	CA	1.5	80	20	Mostly rapid	<i>Hedychium gardnerianum</i> , <i>Ficus</i> sp.
26	CA	1.5	70	10	Riffle into glide	<i>Hedychium gardnerianum</i> , <i>Lantana camara</i> , <i>Citrus</i> sp.
27	CA	1.5	70	50	Glide into rapid	<i>Tricalysia lanceolata</i>
28	CA	2	80	20	Glide into riffle	<i>Eucalyptus grandis</i> , <i>Setaria</i> sp., <i>Lantana camara</i> .
29	OI	1.5	20	10	Glide into rapid	<i>Setaria</i> sp., <i>Lantana camara</i>
30	OI	2	10	30	Rapid into glide	<i>Setaria</i> sp., <i>Bambusa</i> sp., <i>Hedychium gardnerianum</i>
31	OA	1	0	80	Glide with riffles	Mowed mixed grass

32	OI	2	10	60	Glide into rapid	<i>Setaria megaphylla</i> , <i>Hedychium gardnerianum</i>
33	OA	1.5	10	60	Riffles	Mowed mixed grass
34	OI	1.5	10	40	Mostly rapid	<i>Setaria megaphylla</i> , <i>Hedychium gardnerianum</i>
35	OA	1.5	20	50	Glide into rapid	<i>Lantana camara</i> , <i>Hedychium gardnerianum</i>
36	OI	1.5	10	20	Glide into rapid	<i>Setaria</i> sp., <i>Hedychium gardnerianum</i>
37	OA	2	20	70	Rapid into glide	<i>Solanum mauritianum</i> , <i>Lantana camara</i>
38	OI	2	10	60	Glide into rapid	<i>Setaria megaphylla</i> , <i>Hedychium gardnerianum</i>
39	OA	2.5	20	40	Glide into rapid	Mowed mixed grass, <i>Hedychium gardnerianum</i>
40	OA	2	10	20	Glide into rapid	Mowed mixed grass
41	OI	1.5	20	50	Glide into rapid	<i>Setaria</i> sp., <i>Setaria megaphylla</i> , <i>Hedychium gardnerianum</i>
42	OA	2.5	10	40	Rapid into glide	<i>Hedychium gardnerianum</i> , <i>Lantana camara</i>

Table 4: Sampling units (SUs) along the Dorpspruit river. Canopy cover = the percentage of sky above the SU that was blocked by vegetation. Veg on bank = the percentage of the left and right bank along the SU that was covered with vegetation (indigenous or alien). O = SUs with a completely open or dominantly open tree canopy (< 30% of canopy covered with vegetation). C = SUs with a closed or dominantly closed tree canopy cover (< 30% of canopy covered with vegetation). I = SUs with dominantly indigenous vegetation. A = SUs with dominantly alien vegetation. Rapid refers to a strong flow of water over rocks. Riffle refers to a weaker flow of water over rocks and smaller stones.

SU	Classification	River width (m)	Canopy cover (%)	Veg on bank (%)	Flow	Dominant vegetation type
43	OI	2	20	80	Glide into rapid	<i>Setaria</i> sp. & <i>Ischaemum fasciculatum</i>
44	OI	1	30	80	Glide into rapid	<i>Ischaemum fasciculatum</i>
45	OI	1.5	30	80	Rapid into glide	<i>Setaria</i> sp. & <i>Ischaemum fasciculatum</i>
46	OI	1.5	20	70	Riffle into glide	<i>Ischaemum fasciculatum</i>
47	OI	1.5	10	60	Glide log in water	<i>Ischaemum fasciculatum</i>
48	OI	2	30	30	Rapid into glide	<i>Setaria</i> sp., <i>Ischaemum fasciculatum</i>
49	OI	2	30	20	Glide into rapid	<i>Setaria</i> sp.
50	CI	1.5	80	20	Glide	<i>Rolhmannia globosa</i>
51	CI	2	80	30	Rapid into glide	<i>Rapaneamela nophloes</i> , <i>Ilex mitis</i>
52	CA	2	80	20	Rapid into glide	<i>Duranta</i> sp.
53	CA	2	70	30	Glide	<i>Morus alba</i>
54	CA	2	80	40	Rapid into glide	<i>Duranta</i> sp.
55	CA	2	80	30	Riffle into glide	<i>Bambusa</i> sp., <i>Hedychium gardnerianum</i>
56	CA	1.5	80	30	Rapid into glide	<i>Bambusa</i> sp., <i>Syzigium</i>

57	OA	1.5	10	50	Mostly rapid	<i>australe</i> <i>Hedychium gardnerianum</i>
58	OI	2	20	40	Rapid into glide	<i>Setaria</i> sp.
59	OI	1.5	20	40	Mostly rapid	<i>Setaria</i> sp.
60	OI	1.5	10	80	Glide into rapid	<i>Setaria</i> sp.
61	OA	1.5	10	90	Rapid into glide	<i>Lantana camara</i> , <i>Setaria</i> sp.
62	OI	1.5	5	70	Mostly rapid	<i>Setaria</i> sp.
63	OI	2	5	70	Rocky	<i>Setaria</i> sp.
64	CA	2	70	20	Glide into rapid	<i>Solanum mauritianum</i> , <i>Jacaranda mimosifolia</i>
65	CA	1.5	70	20	Rapid into glide	<i>Eriobotrya japonica</i> , <i>Setaria</i> sp.
66	CA	2	70	30	Glide into rapid	<i>Morus alba</i> , <i>Setaria</i> sp.
67	CA	1	70	30	Glide into rapid	<i>Hedychium gardnerianum</i>
68	CA	1.5	80	40	Glide into rapid	<i>Pinus</i> sp., <i>Hedychium gardnerianum</i>
69	CA	1.5	70	30	Rapid into glide	<i>Pinus</i> sp., <i>Hedychium gardnerianum</i>
70	CA	2	70	20	Riffles	<i>Cinnamomum camphora</i> , <i>Solanum mauritianum</i> , <i>Dodocarpus</i>

Sampling

Sampling began in February 2002 until early May 2002, which is the height of the season for adult Odonata in the area (Suh & Samways 2004). Sampling was seasonally limited to this period to avoid major changes and fluctuations in flow rates, which otherwise affect Odonata population levels and SASS5 scores (Dallas 1997, Stewart and Samways 1998, Hawkins et al. 2000).

Odonata were sampled by walking slowly along the 10 m stretch of each SU, recording all adult male Odonata individuals that were present within 1 m either side of the waters' edge. Sampling was not limited to a certain time period as it was limited to a certain space (Moore 1991). Sampling was before midday on hot sunny days when most territorial males are active (Steytler & Samways 1995). Close-focus binoculars, 7 x 25, were used to identify Odonata species on the wing. Unidentified species were caught in a net and brought into the laboratory for identification.

Sampling of the benthic invertebrates was according to the SASS5 technique (Dickens & Graham 2002). Within each SU different biotopes were identified and then sampled separately. Biotopes included three categories. These categories were 1) stones, 2) gravel, sand and mud, and 3) aquatic vegetation. A sample of each biotope within each SU was collected over a wide area to ensure that the full spatial variability of the biotope was sampled. Where possible, the sample was collected across the full width and length of the SU.

Stones, including bedrock and any other solid object, were divided into those that were in a current where the movement of the water prevented the settling of fine silt and those that were out of the current. Vegetation included both emergent marginal and submerged vegetation. A SASS5 net (1 mm mesh on 30 cm² frame attached to strong handle) and waders were used for sampling (Dickens & Graham 2002). Stones, bedrock and any other solid object in the current, were rubbed and kicked with the waders and turned over where possible to dislodge any biota present. The net was held close to and downstream of the stones being kicked. Dislodged biota drifted into the net while coarse sediments that were also dislodged, sank to the bottom of the

river before reaching the net. Stones were kicked for about 2 minutes depending on how difficult they were to move. It also provided a standard across SUs so that sites could be compared. Stones, bedrock and any other solid object out of the current were sampled by kicking, turning or scraping them while sweeping the net through the disturbed area. This was carried out for 1 minute. Samples collected both in and out of the current were combined into a single 'stones biotope' sample.

Sweeping the net forwards into the vegetation and immediately bringing it back through the same area sampled vegetation hanging into or growing at the edge of the stream. This sampling was done for 2 min. Gravel sand and mud was sampled for 30 sec by stirring the substrate with the feet while sweeping the net over the disturbed area. Gravel is made up of small stones less than two cm in diameter. Visual observation was conducted for 1 min to detect specimens that may have been missed during sampling. Sampling effort was restricted to the mentioned time intervals, to avoid an inflated SASS5 score. Each of the above three samples were individually washed down in the net then placed in a white 30 X 40 cm tray. Samples were left for about 5 min to encourage organisms to emerge from any debris in the tray. Debris were carefully checked for any organisms and then removed from the tray when found to be free. Samples were never collected a day or so after heavy rain as the debris in the water made it difficult to separate out the macroinvertebrates.

Data recording

Adult male Odonata abundance and species richness were recorded in every SU. Macroinvertebrates were identified to family level, while for the Baetidae and Hydropsychidae the number of species within each family was recorded. Identification of the macroinvertebrates in the trays was for < 15 min (Gerber & Gabriel). However, if no new organisms were found within five min, identification was ended. Samples were then returned to the river. Recordings were made on SASS5 score sheets, issued by the River Health Programme, Department of Water

Affairs and Forestry, together with the date, SU code, weather conditions and water temperature. This resulted in three separate biotope scores for each family. These scores were combined in a single total column. The abundance of organisms within each taxon was estimated as follows: a single individual was recorded as '1', two to ten organisms were allocated an 'A' and 10 - 100 organisms were allocated a 'B'. Each family was allocated a sensitivity score between one and 15 (Dickens & Graham 2002), as assigned on the scoring sheet according to their sensitivities to anthropogenic impacts. These scores from the total column were then used to calculate the three principal indices of SASS. Firstly, the scores were summed to provide the SASS5 score. Secondly, the total number of taxa found was summed, and thirdly, the ASPT (Average Score Per Taxon) score was calculated by dividing the SASS score by the number of taxa found (Dickens & Graham 2002). Even though the number of species within each family of Baetidae and Hydropsychidae were recorded, they were each only counted as one taxon, irrespective of how many species were found. From these scores, three indices were used to represent the macroinvertebrate data recorded. The SASS5 score, the number of taxa found which represented the macroinvertebrate family richness and the macroinvertebrate abundance. The abundance estimation (see above) at each SU was used to calculate abundance. '1' was left as 1, 'A' was replaced by a two and 'B' was replaced by a three. These allocated scores were then summed and a total abundance for each SU was obtained. The two indices, SASS5 score and macroinvertebrate family richness, are dependent on each other. Macroinvertebrate family richness was used to supplement the SASS5 score.

Data analyses

Assemblage variation and co-variation

The non-parametric Kruskal-Wallis test (Minitab ver. 14.10 (Minitab inc. 2003)) along with a pairwise comparison (Orlich 2002), was used for comparing differences in Odonata abundance and species richness, SASS5 scores and macroinvertebrate abundance and family richness, between the three river systems. Bar graphs

indicating the differences in the means of these indices between the river systems were plotted.

Canonical Correspondence Analysis (CCA) (Ter Braak 1986) from CANOCO version 2.1 was used to illustrate the response of Odonata adults, Odonata larvae and macroinvertebrate families to the structure (open or closed canopy cover) and composition (indigenous or alien) of the vegetation (Palmer 1993). Odonata assemblages were represented by species abundance and richness indices and macroinvertebrates by family abundance and richness indices. CCA is a multivariate direct gradient analysis which relates patterns in community composition to variation in environmental variables. Statistical significances of the effects of environmental variables was done using Monte Carlo tests (Ter Braak 1986).

These data were further analyzed using cluster analysis (PRIMER-E Ltd 2001), which analyzed the similarities between SUs in terms of both adult Odonata assemblages (abundance and species richness) and macroinvertebrate assemblages (abundance (see above) and family richness). A Bray-Curtis coefficient was used as the similarity measure (Bray & Curtis 1957). Prior to the cluster analysis, the data were log transformed to down-weight the more abundant species and allow the rarer species to exert some influence on the similarity calculation (Clarke & Warwick 2001). Throughout this study all dendrograms were constructed using either the data collected from the Odonata or the macroinvertebrate assemblages as pointed out in the figure legends. The y-axis labels of the dendrograms were then substituted to denote either open or closed canopy or, alien or indigenous vegetation. These figures were then inspected for similarity clustering in order to ascertain any relationship between the assemblages (Odonata and macroinvertebrate) and the vegetation (structure and composition). An inevitable corollary of this is that the topology of some dendrograms is exactly the same, however, for the purpose of analysis it is the clustering according to the y-axis labels that is significant.

Also cluster analysis was carried out to determine the effect of vegetation structure and composition on the similarity of SUs as to macroinvertebrates and their different sensitivity scores using the methods outlined above.

To deduce whether Odonata abundance and species richness vary in the same direction and to the same extent as SASS5 scores, a regression analysis was performed using Minitab ver. 14.10 (Minitab inc. 2003).

A similar comparison was done by regressing weighted Odonata scores against SASS5 scores. Odonata were weighted using a rating that gave an indication of their abundance and conservation status. This rating is given in Samways (1999). The abundance gives an indication of overall regional abundance and is the number of known localities (at the arbitrary distance of at least 5 km) in South Africa for each species up to 31 July 1997. 1 - 5 records scores 5; 6 - 10 records scores 4; 11 - 20 records scores 3; 21 - 30 records scores 2; 41+ records scores 1. The criteria used for the degree of endemism scores were the largest areas for all records combined: recorded from < 1000 km² scores 5; from < 10 000 km² scores 4; from < 100 000 km² scores 3; from < 1 000 000 km² scores 2; from southern Africa scores 1; pan-African, and possibly also European and/or Asiatic scores 0. For the purpose of this study, these scores were reversed (i.e.: 5 = 0; 4 = 1; 3 = 2; 2 = 3; 1 = 4; 0 = 5) so that integers increased positively with size of area.

RESULTS

Odonata and Macroinvertebrate assemblages recorded

749 individual Odonata adults were recorded within the 70 sampling units (SUs) along the three river systems. These individuals comprised seven different families and 17 species (Table 5). Among the Odonata larvae that could be identified to species level, four families and nine species were recorded. The Odonata larvae were a subset of the 51 macroinvertebrate families (or other higher taxon) recorded within these SUs (Table 6).

Table 5: Species list of Odonata adults (A) and larvae (L) found at the three rivers.

	Msunduzi river		Townbush river		Dorpspruit river	
Zygoptera						
Synlestidae						
<i>Chlorolestes tessellatus</i> (Burmeister, 1839)			A		A	
Platycnemididae						
<i>Allocnemis leucosticta</i> Sélys, 1836			A		A	
Coenagrionidae						
<i>Ceriagrion glabrum</i> (Burmeister, 1839)		L	A			L
<i>Pseudagrion hageni</i> Karsch, 1893		L			A	
<i>Pseudagrion kersteni</i> (Gerstäcker, 1869)	A	L	A		A	L
<i>Pseudagrion salisburyense</i> Ris, 1921	A	L	A	L	A	L
<i>Pseudagrion sublacteum</i> (Karsch, 1893)	A					
<i>Ischnura senegalensis</i> (Rambur, 1842)					A	

Chlorocyphidae					
<i>Platycypha caligata</i> (Sélys, 1853)	A		A		A
Anisoptera					
Gomphidae					
<i>Crenigomphus hartmanni</i> (Förster, 1898)	A				
<i>Paragomphus cognatus</i> (Rambur, 1842)		L	A		A L
Aeshnidae					
<i>Anax imperator</i> Leach, 1815		L			
<i>Anax speratus</i> Hagen, 1867	A				
Libellulidae					
<i>Orthetrum julia</i> Kirby, 1900	A		A		A
<i>Crocothemis erythraea</i> (Brullé, 1832)	A	L			A
<i>Trithemis arteriosa</i> (Burmeister, 1839)	A				
<i>Trithemis dorsalis</i> (Rambur, 1842)		L			
<i>Trithemis furva</i> Karsch, 1899	A		A		A
<i>Trithemis stictica</i> (Burmeister, 1839)		L			
<i>Zygonyx natalensis</i> (Martin, 1900)	A				

Table 6: Macroinvertebrate taxa found in the three rivers.

	Msunduzi river	Townbush river	Dorpspruit river
Coelenterata			√
Turbellaria	√	√	√
Annelida			
Oligochaeta	√	√	√
Hirudinea	√		
Crustacea			
Amphipoda		√	√
Potamonautidae	√	√	√
Atyidae	√	√	√
Palaemonidae	√		
Hydracarina	√		
Plecoptera			
Perlidae	√	√	
Ephemeroptera			
Baetidae	√	√	√
Caenidae	√	√	√
Heptageniidae	√		
Leptophlebiidae		√	√
Oligoneuridae	√		
Tricorythidae	√	√	√
Odonata			
Chlorocyphidae	√	√	
Synlestidae	√	√	√
Coenagrionidae	√	√	√
Platycnemidae		√	√
Aeshnidae	√	√	√
Corduliidae	√		
Gomphidae	√	√	√
Libellulidae	√	√	√
Hemiptera			
Belostomatidae	√		
Corixidae	√	√	√
Gerridae	√	√	√
Naucoridae	√	√	√
Nepidae		√	√
Notonectidae	√		√
Pleidae	√		
Veliidae	√	√	√
Megaloptera			
Corydalidae	√	√	
Trichoptera			
Hydropsychidae	√	√	√
Philopotamidae	√	√	

Hydroptilidae		√	
Leptoceridae	√	√	√
Pisuliidae		√	√
Coleoptera			
Dytiscidae		√	
Elmidae	√	√	√
Gyrinidae	√	√	√
Hydraenidae		√	
Hydrophilidae			√
Diptera			
Athericidae	√	√	√
Ceratopogonidae	√	√	√
Chironomidae	√	√	√
Culicidae	√		
Muscidae	√		√
Simuliidae	√	√	√
Tabanidae	√		
Tipulidae	√	√	√

Assemblage variation and co-variation

Variation of SASS5 scores, macroinvertebrate abundance and macroinvertebrate family richness between river systems

The mean SASS5 scores, the mean macroinvertebrate abundance and the mean macroinvertebrate family richness per SU across the three different river systems are shown as Table 7. These data are represented graphically as Figs 1, 2 and 3.

Table 7: Mean SASS5 score, macroinvertebrate abundance and macroinvertebrate family richness per SU, including their standard errors (SE), across the three different river systems.

	Mean	±SE	Mean invert	±SE	Mean invert	±SE
	SASS5 score		abundance		family richness	
Msunduzi	124.21	2.57	40.00	0.94	20.71	0.40
Townbush	77.64	4.74	24.50	1.34	13.42	0.74
Dorpspruit	78.89	2.91	28.79	1.20	14.14	0.53

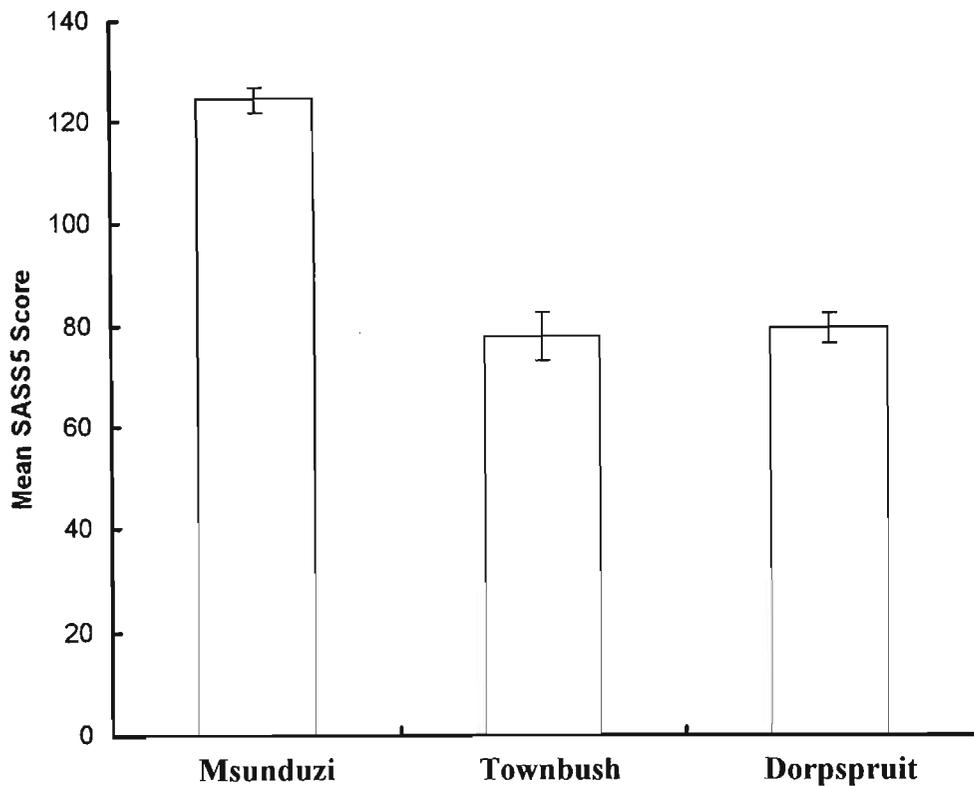


Fig. 2: Differences in the mean ($\pm 1SE$) SASS5 scores across the three river systems.

A significant statistical difference exists between the SASS5 scores across the three river systems (Kruskal-Wallis test; $H = 31.92$ (adjusted for ties), $df = 2$, $p < 0.05$). Therefore the hypothesis that there is no variation between SASS5 scores across different river systems is rejected. A pairwise comparison (Orlich 2002) of these scores was carried out to examine where the variation between the river systems exists. Significant differences in the SASS5 score between the Msunduzi and the Dorpspruit SUs ($Z = 5.23$, $df = 2$, $p < 0.05$) and between the Msunduzi and the Townbush SUs ($Z = 5.08$, $df = 2$, $p < 0.05$) were found, although no significant difference exists for the SASS5 score between the Townbush and the Dorpspruit SUs ($Z = 0.19$, $df = 2$).

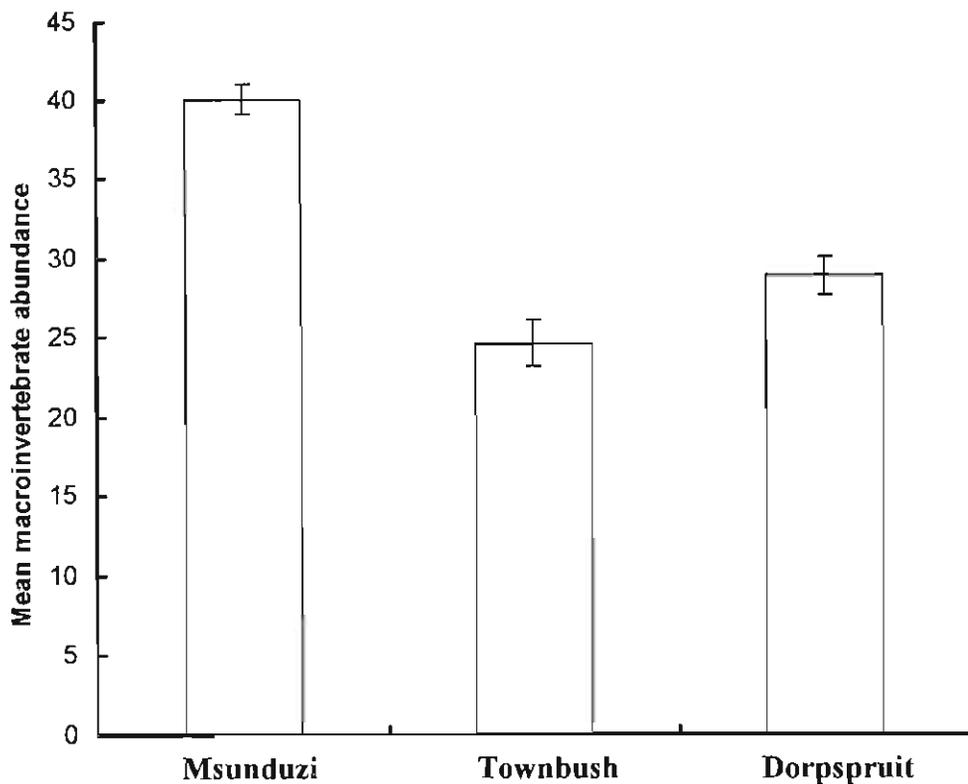


Fig. 3: Differences in mean ($\pm 1SE$) macroinvertebrate abundance across the three river systems

A Kruskal-Wallis test revealed also a significant statistical difference between the macroinvertebrate abundance across the three river systems ($H = 31.84$ (adjusted for ties), $df = 2$, $p < 0.05$). Therefore the hypothesis that there is no variation of macroinvertebrate abundance across the three different river systems is rejected. A pairwise comparison (Orlich 2002) of these scores reveals significant differences in the macroinvertebrate abundance between the Msunduzi and the Townbush SUs ($Z = 5.63$, $df = 2$, $p < 0.05$) and between the Msunduzi and the Dorpspruit SUs ($Z = 4.05$, $df = 2$, $p < 0.05$). Again no significant difference exists for the macroinvertebrate abundance between the Townbush and the Dorpspruit SUs ($Z = 1.93$, $df = 2$).

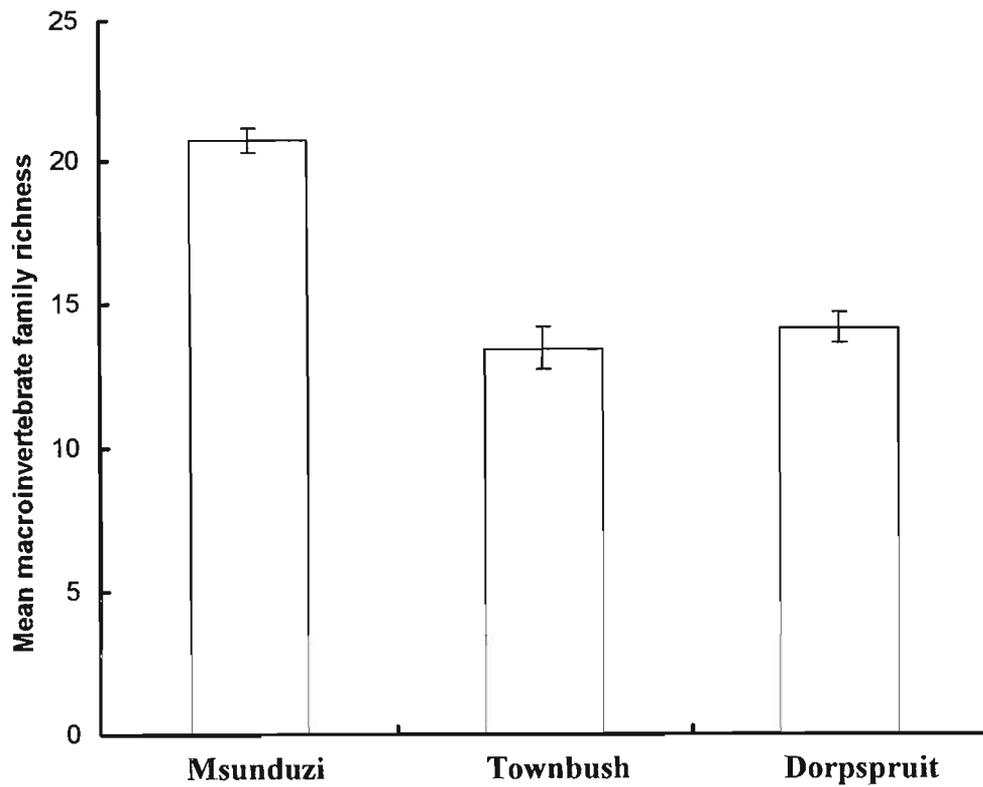


Fig. 4: Differences in the mean ($\pm 1SE$) macroinvertebrate family richness across the three river systems.

A Kruskal-Wallis test revealed a significant statistical difference between the macroinvertebrate family richness across the three river systems ($H = 31.73$ (adjusted for ties), $df = 2$, $p < 0.05$). Therefore the hypothesis that there is no variation of macroinvertebrate family richness across the three different river systems is rejected. A pairwise comparison (Orlich 2002) of these scores reveals significant differences in the macroinvertebrate family richness between the Msunduzi and the Townbush SUs ($Z = 5.29$, $df = 2$, $p < 0.05$) and between the Msunduzi and the Dorpspruit SUs ($Z = 4.98$, $df = 2$, $p < 0.05$). Again, no significant difference exists for the macroinvertebrate family richness between the Townbush and the Dorpspruit SUs ($Z = 0.38$, $df = 2$).

Therefore in terms of the three criteria used, SASS5, macroinvertebrate abundance and macroinvertebrate family richness, the Msunduzi river system is statistically significantly different from the Townbush and Dorpspruit. Statistically no significant difference was found between these last two river systems.

Variation in macroinvertebrate assemblages (macroinvertebrate abundance and family richness) between different structural and compositional habitat types

Environmental variables (vegetation structure and composition) affected macroinvertebrate assemblages, with the Monte Carlo test of the CCA indicating that the vegetation composition (indigenous or alien) of a SU significantly accounts for variation in the assemblages (abundance and family richness) ($F = 3.00, p = 0.005$). Thus, the hypothesis that macroinvertebrate assemblages are not affected by vegetation composition is rejected. Vegetation structure (open or closed canopy cover) did not significantly account for the variation among the macroinvertebrate assemblages ($F = 0.81, p = 0.77$). Thus, the hypothesis that vegetation structure does not affect macroinvertebrate assemblages is accepted. SASS5 scores along a particular river system were similar at each SU (Standard errors of the mean were minimal) (Table 7). Thus we can conclude that within a particular river system the water quality was similar and was not considered as a variable. Therefore the vegetation structure and composition between SUs could be compared.

Similarities between the SUs in terms of macroinvertebrate assemblages (abundance and family richness) were investigated using cluster analysis. A cluster was Msunduzi SUs clustered together, with a similarity of approximately 65% (Fig. 5). Townbush SUs clustered into two separate groups, with 45% similarity. The larger cluster T25 – T38 has a 55% similarity and the smaller cluster T22 – T30 has a 50% similarity. Msunduzi, Dorpspruit and half of the Townbush SUs cluster together with a 54% similarity,

however, T22 – T30 are dissimilar from this large cluster. These SUs, except for T34 and T28 are all found along the highest stretch of the Townbush river studied. Thus SUs that are closest together possibly have the most similar macroinvertebrate assemblages.

The Dorpspruit SUs clustered with a similarity of approximately 60%. There were however, three Dorpspruit SUs (D49, D50 and D51) that clustered with SUs from other river systems (Fig. 5). The macroinvertebrate assemblages at these SUs differed from the other Dorpspruit SUs in that no Oligochaetae were found and except for D51 where one specimen was found. No Tricorythidae were found. These two families were abundant at most of the other Dorpspruit SUs. Looking at the geography of these SUs, D49 had an open canopy, but was sandwiched between two closed canopy SUs, possibly resulting in unique environmental conditions. D50 was the only SU where no riffle occurred. This would have affected the macroinvertebrate assemblages as their diversity is directly affected by the diversity of the habitats available to them (Dickens & Graham 2002). Furthermore, D50 and D51 were the only two SUs with a closed canopy of dominantly indigenous vegetation. Thus, compared to other Dorpspruit SUs, environmental conditions differed and consequently the macroinvertebrate assemblages found here seem to be more similar to those assemblages at SUs along the other river systems.

Msunduzi, Dorpspruit and half of the Townbush SUs cluster together with a 54% similarity, however, T22 – T30 are dissimilar from this large cluster. These SUs, except for T34 and T28 are from the highest stretch of river studied. Thus SUs that are closest together possibly have the most similar macroinvertebrate assemblages.

The cluster analysis indicates a 57% similarity between Msunduzi and Dorpspruit SUs and a much lower similarity between the Msunduzi and the two clusters of Townbush SUs (53% and 45% similarity) (Fig. 5). Yet the Kruskal-Wallis test shows no significant difference between the Townbush and Dorpspruit SUs. Macroinvertebrate abundance and family richness was however on average, lower along the Townbush and this difference is noticeable in the cluster analysis.

Y-axis labels of figure 5 were substituted to denote vegetation structure (open or closed canopy cover) (Fig. 6). This dendrogram was then inspected for similarity clustering in order to ascertain any relationship between macroinvertebrate assemblages and vegetation structure.

SUs with similar vegetation structure did not clearly cluster (Fig. 6). The open canopy SUs of the Msunduzi clustered at a similarity of approximately 65%. This represents the most similar of the clusters in this analysis. There were two other smaller clusters of SUs, T38 – D58 with a 55% similarity and D56 – D52 with a 60% similarity (Fig. 6). Other open and closed canopy SUs were dispersed among each other. SUs with the highest percentage similarity (D61(0) and D58(0); M11(0) and M5(0); D67(1) and D45(0); D66(1) and D60(0); T42(0) and T18(1)) had different canopy cover combinations (Fig. 6). Thus SUs had similar macroinvertebrate assemblages, even though vegetation structure differed, indicating that vegetation structure has a minimal effect on these assemblages. All Msunduzi SUs had similar vegetation structures so environmental variation was minimal. However, there are two dissimilar clusters of Townbush SUs which are not dependent on vegetation structure. Both clusters, T22 – T30 and T35 – T38 consist of SUs with different vegetation structures. There is a mechanism other than the environmental variable, vegetation structure that is resulting in certain SUs having similar macroinvertebrate assemblages. The most common factor among the Townbush SUs, T22 – T30, is their close position along the river.

This cluster analysis also indicates that Msunduzi SUs are similar to Dorpspruit SUs, despite differences in vegetation structure. Again there is a mechanism which has a stronger effect on macroinvertebrate assemblages at individual SUs than vegetation structure. This is possibly the position of each SU along the stream. Macroinvertebrates are not very mobile and assemblages nearest to each other would probably be most similar. Thus position along the river may be more important in determining macroinvertebrate assemblages, than vegetation structure.

Vegetation structure does however, have some effect on macroinvertebrate assemblages as is seen by the fact that Msunduzi SUs which have similar vegetation structures are most similar, and the three Dorpspruit SUs, which have different environmental variables from other Dorpspruit SUs, do not cluster with them.

To further investigate the role of vegetation structure on macroinvertebrate assemblages, separate dendrograms for the Townbush and Dorpspruit rivers were constructed. The Msunduzi SUs were not further investigated as they all had similar vegetation structures (open canopies).

No clear pattern of the response of macroinvertebrate assemblages to a change in the vegetation structure along the Townbush was discernable, although two small clusters were apparent. One, T41 – T37, with 60% similarity, was characterized by open canopy cover, whilst the other T25 – T20, with 72% similarity, was characterized by closed canopy cover (Fig. 7).

There seems to be no biological or physical reason for the lack of clusters of open or closed canopies. It is concluded that as far as these results show, vegetation structure is not important in determining the similarities between SUs in terms of macroinvertebrate assemblages.

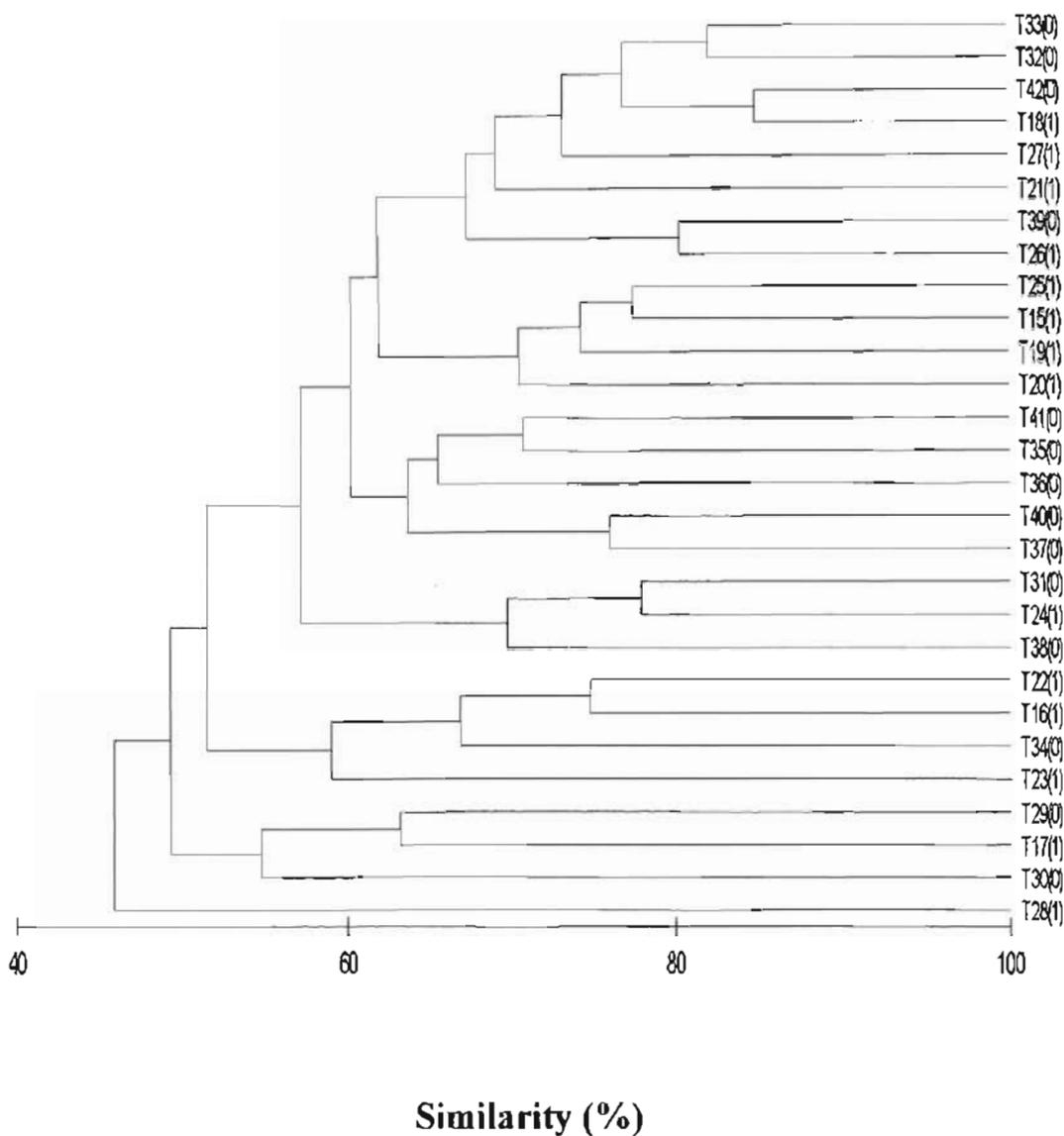


Fig. 7: Dendrogram of the role of vegetation structure (0 = open canopy cover; 1 = closed canopy cover) in determining the similarities between sampling units, in terms of macroinvertebrate assemblages, along the Townbush river (T).

Weak clustering of Dorpspruit SUs also revealed a small response of macroinvertebrate assemblages to a change in vegetation structure. Again two clusters were apparent. A cluster with 55% similarity D56 – D51, which was characterized by closed canopy cover, and the other, D63 – D58, with 70% similarity, was characterized by open canopy cover (Fig. 8).

Again, there seems to be no biological or physical reason for the lack of clusters of open or closed canopies. It can be concluded that vegetation structure (canopy cover) has no discernable effect on macroinvertebrate assemblages in this study, but can affect them to a degree, especially when coupled with other factors such as the location of a SU along the river system.

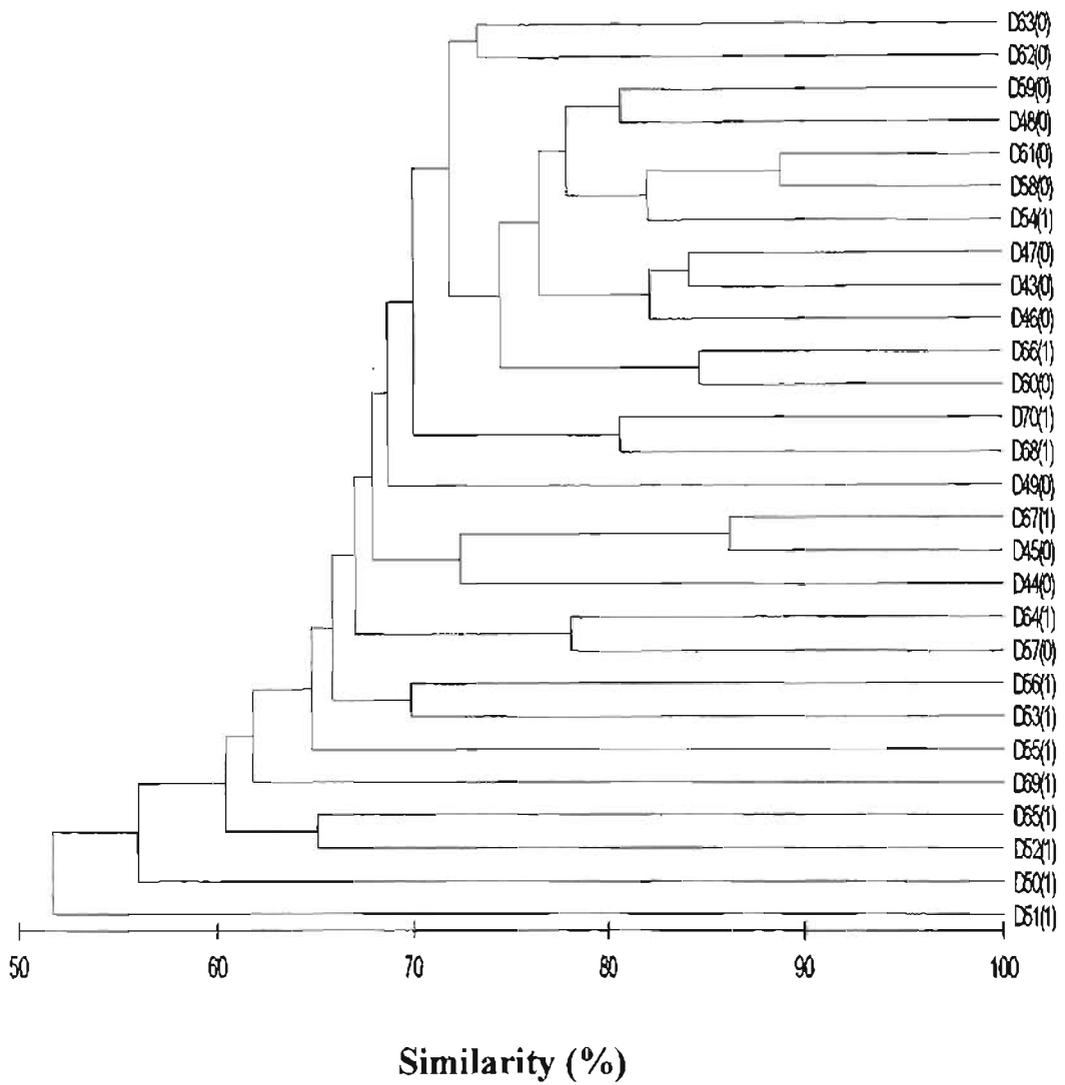


Fig. 8: Dendrogram of the role of vegetation structure (0 = open canopy cover; 1 = closed canopy cover) in determining the similarities between sampling units, in terms of macroinvertebrate assemblages, along the Dorpspruit river (D).

Y-axis labels of figure 4 were substituted to denote vegetation composition (alien or indigenous) (Fig. 9). This dendrogram was then inspected for similarity clustering in order to ascertain any relationship between macroinvertebrate assemblages and vegetation composition. Three small clusters of SUs were evident. The Msunduzi SUs M14 – M12, cluster with a similarity of approximately 65% (Fig. 9). This represents the most similar of the clusters in this analysis. Environmental variation was minimal along these SUs as they all had similar vegetation compositions. But again, the two clusters of Townbush SUs consist of SUs with different vegetation compositions and are thus not dependent on the environmental variable. There is a mechanism other than vegetation composition that is resulting in SUs having similar macroinvertebrate assemblages. The most common factor among the Townbush SUs, T22 – T30, is their position along the river as discussed.

This cluster analysis also indicates that Msunduzi SUs are similar to Dorpspruit SUs, despite differences in vegetation structure. Again there is a mechanism which has a stronger effect on macroinvertebrate assemblages at individual SUs than vegetation composition. This is possibly stream or site location. Macroinvertebrates are not very mobile and assemblages nearest to each other would probably be most similar. Thus position along the river may be more important in determining macroinvertebrate assemblages than is vegetation composition.

The other two clusters were those of the Townbush, T42 – T24, (with a 55% similarity) and characterized by alien vegetation, and the cluster of Dorpspruit SUs, D64 – D52 (with a 60% similarity), characterized by alien vegetation (Fig. 9). The SUs with the highest percentage similarity (D61(0) and D58(0); M11(0) and M5(0); D67(1) and D45(0); D66(1) and D60(0); T42(0) and T18(1)) had different vegetation composition (Fig. 8). Thus SUs had similar macroinvertebrate assemblages, even though vegetation composition differed, indicating that vegetation composition has a minimal effect on these assemblages.

Vegetation composition does however, have some effect on macroinvertebrate assemblages as is seen by the fact that Msunduzi SUs which have similar vegetation composition are most similar and the three Dorpspruit SUs which have different environmental variables from the other Dorpspruit SUs are not similar to them.

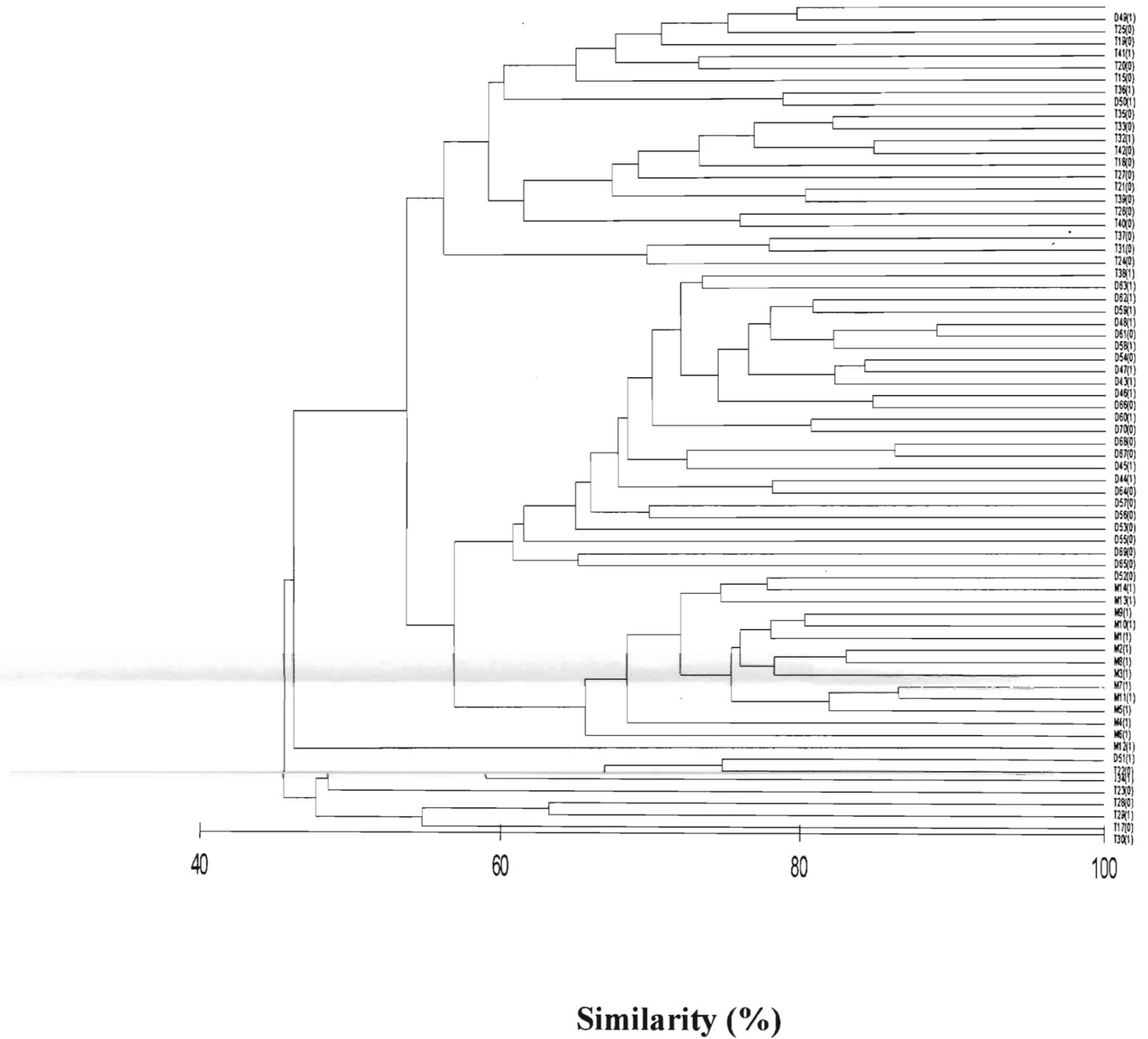


Fig. 9: Dendrogram of the role of vegetation composition (0 = alien vegetation; 1 = indigenous vegetation) in determining the similarities between the 70 sampling units, in terms of macroinvertebrate assemblages in the three different river systems. M = Msunduzi river, T = Townbush river, D = Dorpspruit river.

To further investigate the role of vegetation composition on macroinvertebrate assemblages, separate dendrograms for the Townbush and Dorpspruit were constructed. There was no difference in vegetation composition between the Msunduzi SUs (all SUs were characterized by indigenous vegetation). Therefore, these SUs were excluded from this investigation.

Along the Townbush there was no discernable clustering of SUs with similar vegetation composition. Nevertheless, one cluster of SUs was discernable: T42 – T20 (with a 60% similarity), which were composed of alien vegetation (Fig. 10).

There seems to be no biological or physical reason for the lack of clusters of SUs with similar vegetation composition (i.e. indigenous versus alien vegetation). It is concluded that as far as these results show, vegetation composition is not important in determining the similarities between SUs in terms of macroinvertebrate assemblages.

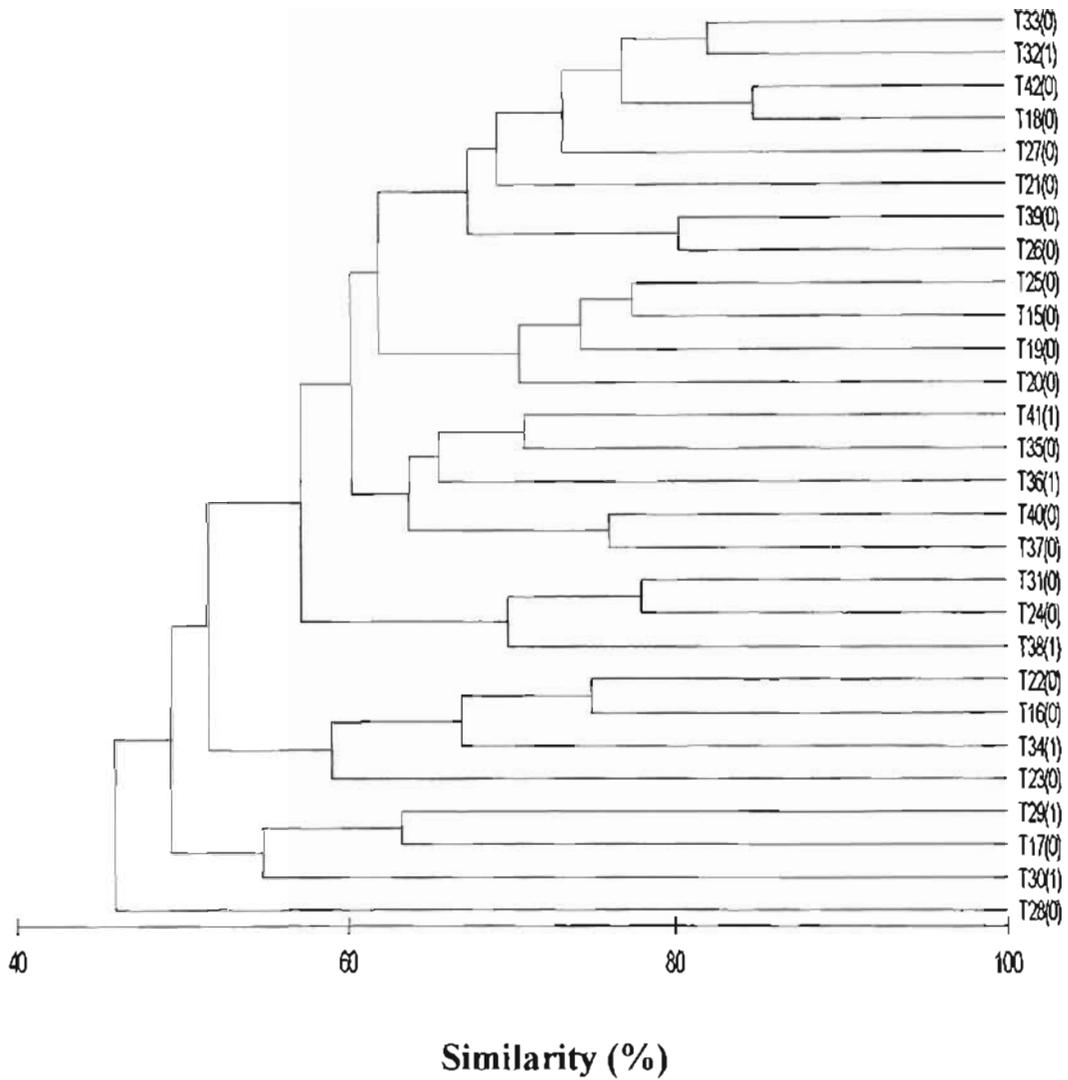


Fig. 10: Dendrogram of the role of vegetation composition (0 = alien vegetation; 1 = indigenous vegetation) in determining the similarities between sampling units, in terms of macroinvertebrate assemblages, along the Townbush river (T).

Along the Dorpspruit there was also little discernable clustering. One cluster, D64 – D52 (with a 60% similarity) composed of alien vegetation was discernable (Fig. 11).

Again there seems to be no biological or physical reason for the lack of clusters of indigenous versus alien vegetation. It can be concluded that vegetation structure (type of canopy cover) has no discernable effect on macroinvertebrate assemblages in this study

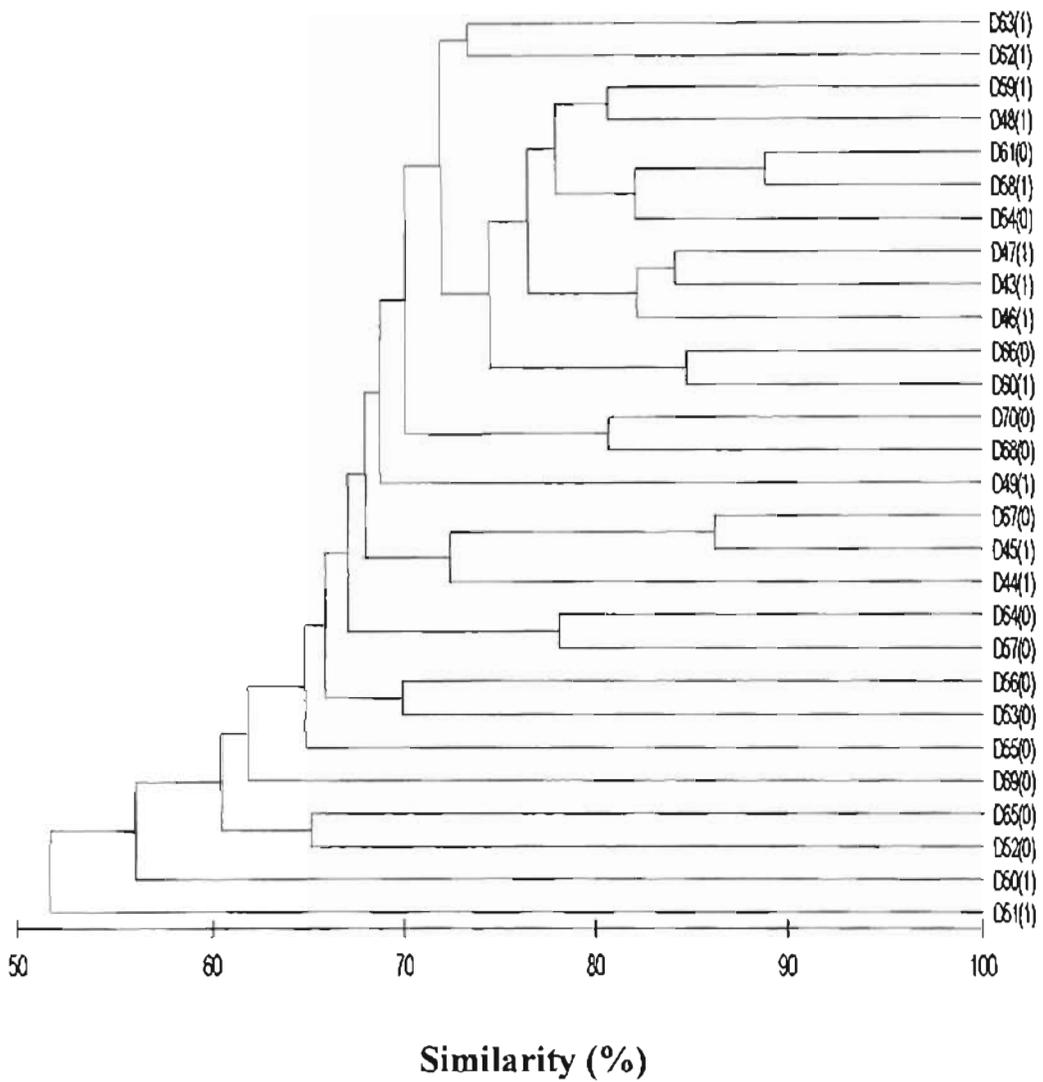


Fig. 11: Dendrogram of the role of vegetation composition (0 = alien vegetation; 1 = indigenous vegetation) in determining the similarities between sampling units, in terms of macroinvertebrate assemblages, along the Dorpspruit river (D).

Variation of macroinvertebrates with different sensitivity scores between different structural and compositional habitat types

The effect of vegetation structure and composition on macroinvertebrates with different sensitivity scores was investigated using cluster analysis. The most discernable trend in these data was the clustering of SUs belonging to the same river system. One was the Msunduzi SUs, which clustered with a 65% similarity, another was T39 – T23 clustering with a 35% similarity, and the other was D46 – D56 clustering with a 60% similarity. Townbush SUs were least similar. This cluster was also least similar to the clusters of SUs along the other river systems (35% similarity), which were approximately 57% similar to each other. Msunduzi SUs clustered with the highest similarity. There was no discernable clustering of SUs with similar vegetation structure (Fig. 12) or vegetation composition (Fig. 13). It appears that macroinvertebrates with similar sensitivity scores occur along similar river systems and not at SUs with similar environmental variables (vegetation structure and composition). This conclusion could be made as the rivers were a locked variable. The aim of this study was not to compare rivers, rather to compare the effect of vegetation (structure and composition) along the river on the macroinvertebrate assemblages. It was thus a study in impact of riparian cover and not a water quality study per se.

Outliers occurred among these clusters. T35 clustered with Dorpspruit SUs and D52, D51, and D49 clustered among Townbush SUs (Fig. 12 and 13). D51 and D52 were different in that they were the only two SUs with a closed canopy and indigenous vegetation. D49 was the open canopy SU, sandwiched between two SUs with a closed canopy, resulting in unique environmental conditions and possibly unique macroinvertebrate assemblages. T35 did not appear to be unique in any way. Thus environmental variables (vegetation structure and composition) do have a small effect on macroinvertebrates with different sensitivity scores and how they assemble, but not as great an affect as the river system in which they occur.

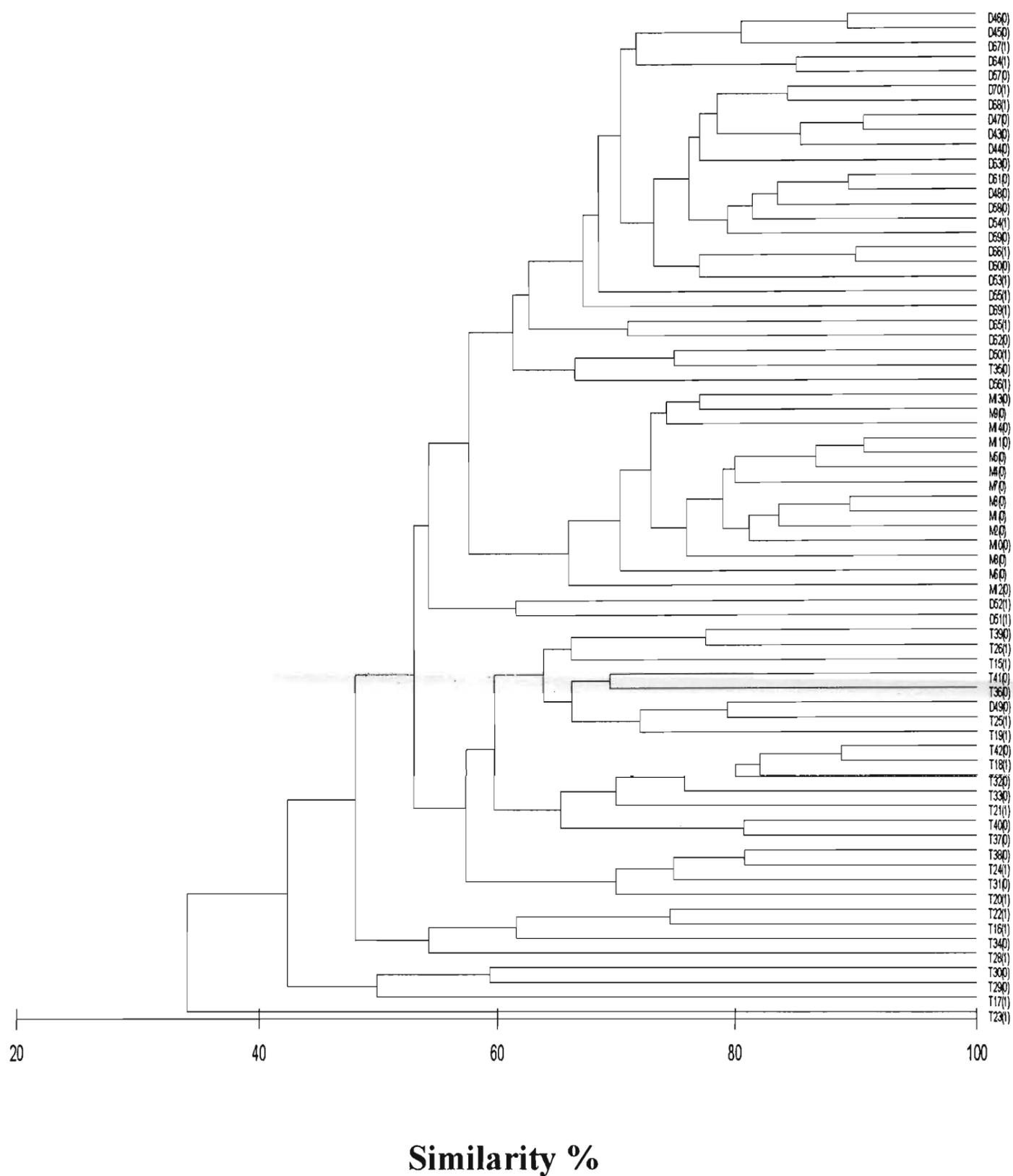


Fig. 12: Dendrogram of the role of vegetation structure (0 = open canopy cover; 1 = closed canopy cover) in determining the similarities between the 70 sampling units, in terms of macroinvertebrates with different sensitivity scores in the three different river systems. M = Msunduzi river, T = Townbush river, D = Dorpspruit river.

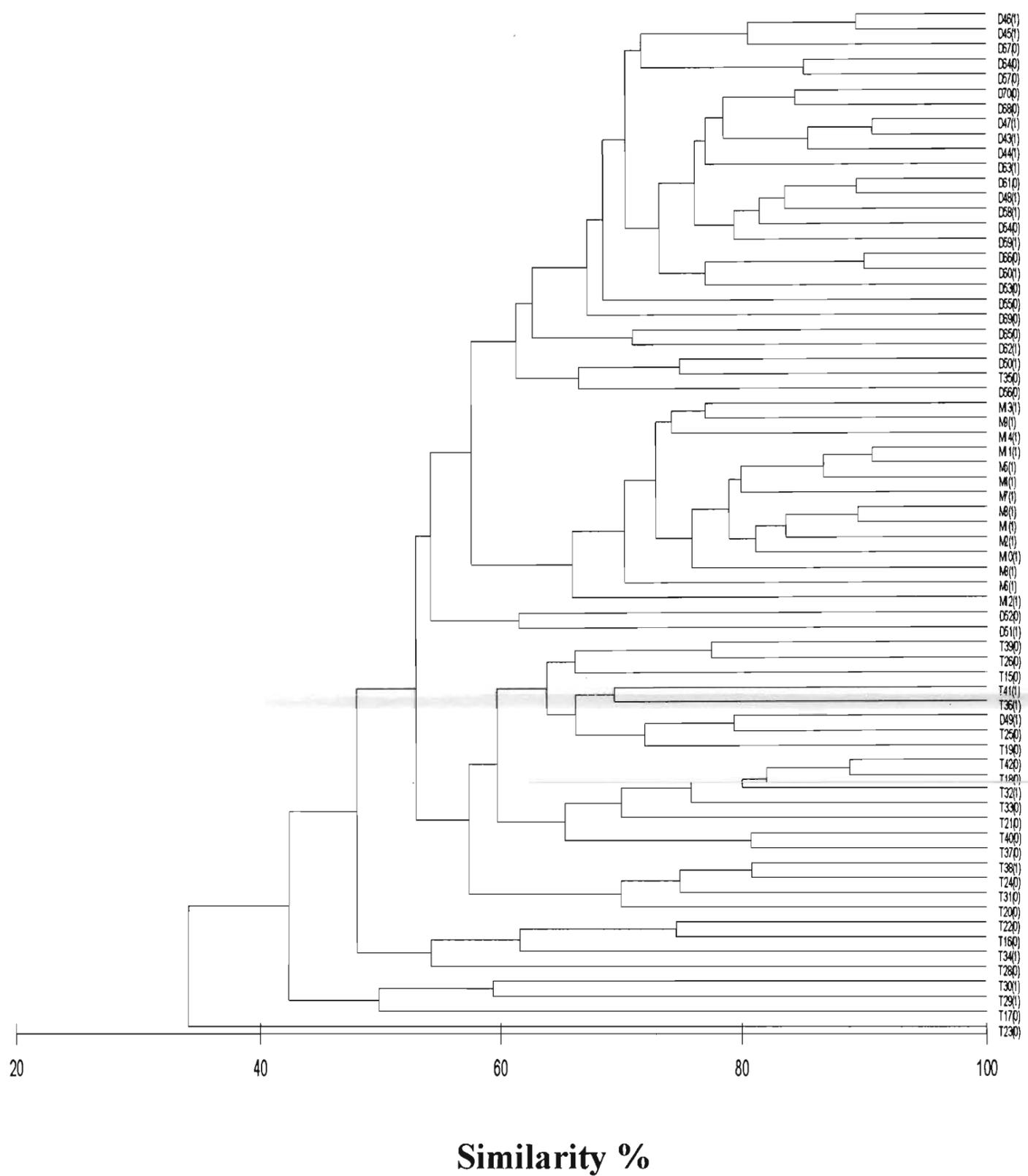


Fig. 13: Dendrogram of the role of vegetation composition (0 =alien vegetation; 1 = indigenous vegetation) in determining the similarities between the 70 sampling units, in terms of macroinvertebrates with different sensitivity scores in the three different river systems. M = Msunduzi river, T = Townbush river, D = Dorpspruit river.

Variation in Odonata assemblages

Variation in Odonata assemblages (abundance and species richness) between river systems

Mean Odonata abundance per SU and the mean Odonata species richness per SU across the three different river systems are shown as Table 8. These data are represented graphically in Figs 14 and 15.

Table 8: Mean Odonata abundance and species richness per SU, including their standard errors (\pm SE), across the three different river systems.

River system	Mean Odonata abundance	\pm SE	Mean Odonata spp. richness	\pm SE
Msunduzi	21.86	1.76	6.07	0.35
Townbush	7.57	0.83	2.46	0.18
Dorpspruit	8.14	0.97	3.21	0.25

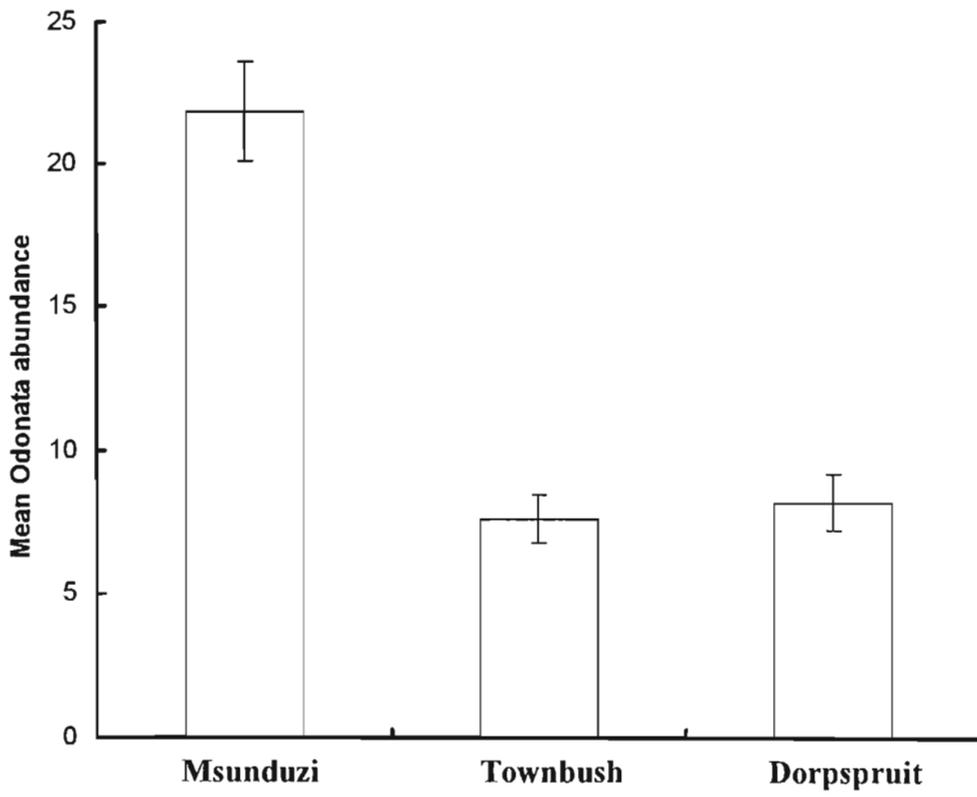


Fig. 14: Mean ($\pm 1SE$) Odonata abundance per sampling unit across the three river systems.

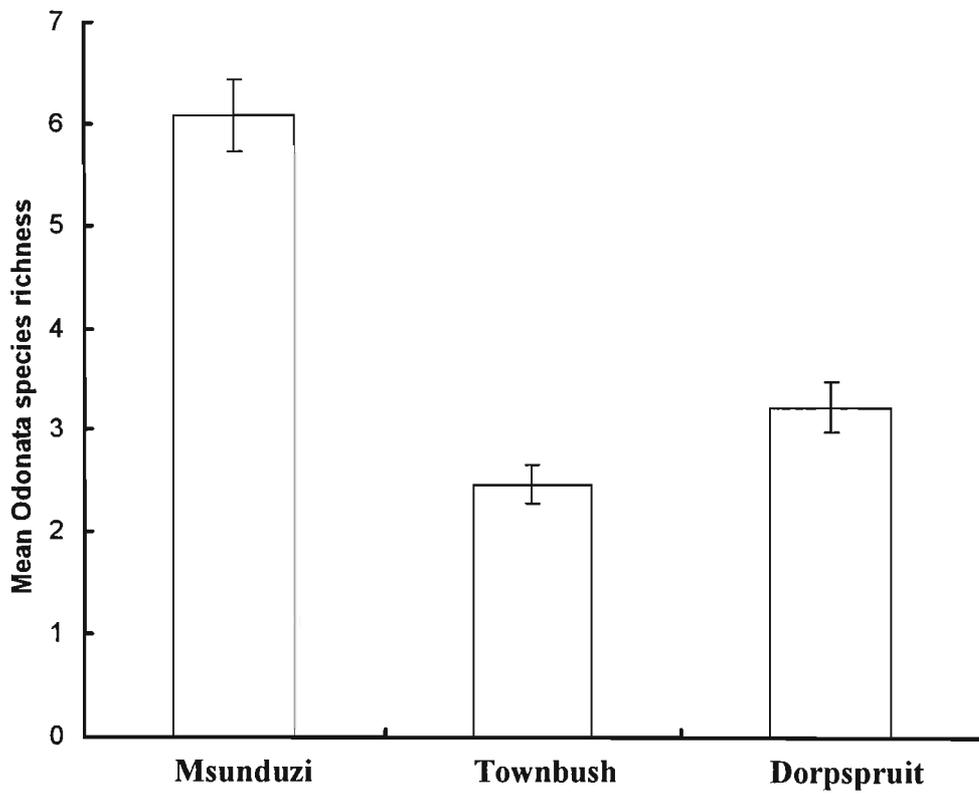


Fig. 15: Mean ($\pm 1SE$) Odonata species richness per sampling unit across the three river systems.

There was a significant statistical difference between the mean Odonata abundance (per SU) between the three river systems (Kruskal-Wallis test; $H = 30.45$ (adjusted for ties), $df = 2$, $p < 0.05$). Thus the hypothesis that there is no variation among Odonata assemblages across different river systems is rejected. A pairwise comparison (Orlich 2002) of these scores was carried out to examine where the variation between the river systems existed. Significant differences in the mean Odonata abundance between the Msunduzi and the Townbush SUs ($Z = 5.17$, $df = 2$, $p < 0.05$) and between the Msunduzi and the Dorpspruit SUs ($Z = 4.89$, $df = 2$, $p < 0.05$) exists, although no significant difference exists in Odonata abundance between the Townbush and the Dorpspruit SUs ($Z = 0.34$, $df = 2$).

A Kruskal-Wallis test also revealed a significant statistical difference between the mean Odonata species richness between the three river systems ($H = 33.25$ (adjusted for ties), $df = 2$, $p < 0.05$). Therefore, the hypothesis that there is no variation among Odonata assemblages across different river systems is rejected. A pairwise comparison of these scores reveals significant differences in the Odonata species richness between the Msunduzi and the Townbush SUs ($Z = 5.74$, $df = 2$, $p < 0.05$) and between the Msunduzi and the Dorpspruit SU ($Z = 4.25$, $df = 2$, $p < 0.05$). Again no significant difference exists for the Odonata species richness between the Townbush and the Dorpspruit SUs ($Z = 1.82$, $df = 2$).

Therefore, in terms of the two criteria used, Odonata abundance and species richness, the Msunduzi river system is statistically significantly different from the Townbush and Dorpspruit. Statistically no significant difference was found between these last two river systems. These results are similar to those found for the SASS5 scores, macroinvertebrate abundance and macroinvertebrate family richness between the three river systems. It can be concluded that macroinvertebrate and Odonata assemblages respond similarly to the large scale environmental conditions along a particular river system.

Variation in Odonata assemblages between different structural and compositional habitat types

To determine whether vegetation structure and/or composition had an effect on Odonata adult and larval assemblages, a CCA was performed. The Monte Carlo test from the CCA indicated that the vegetation structure (open or closed canopy) significantly accounted for most of the variation among Odonata adult assemblages (abundance and species richness) between SUs ($F = 10.53$, $p \leq 0.005$). Thus, the null hypothesis that Odonata assemblages are not affected by the structure of the vegetation is rejected and it can be concluded that vegetation structure is more important in accounting for similarities in Odonata assemblages than is the river system or position of a SU along a river system.

The vegetation composition (indigenous versus alien) at the SU was also significant in accounting for variation among the Odonata adult assemblages (abundance and species richness) between the SUs ($F = 3.59$, $p \leq 0.005$). Thus, the hypothesis that Odonata assemblages are not affected by the composition of the vegetation is rejected. Vegetation composition is, however, not as important in accounting for variation in the Odonata assemblages as is vegetation structure.

For the Odonata larvae, no definitive results are available, as only 10% of the Odonata larvae species could be identified to species level, the rest being too young. Thus, insufficient data were available to perform statistical tests.

Similarities between the SUs in terms of adult Odonata assemblages (abundance and species richness) were investigated using cluster analysis. Msunduzi SUs clustered together, M6 being the exception, with a similarity of approximately 45% (Fig. 16). M6 was one of the SUs with the least vegetation along its bank and it did not have a riffle or rapid as did other Msunduzi SUs. Conditions for Odonata species were less favorable. The species richness at M6 was low and the Odonata abundance was lowest compared to other Msunduzi SUs. Townbush and Dorpspruit SUs were interspersed among each other. Three Townbush SUs (T22, T16 and T23) stood out, they were approximately

95% dissimilar from the rest of the SUs (Fig. 16). These SUs were geographically isolated from other Townbush SUs in a relatively forested area. Another cluster, D55 – D50 were 85% dissimilar from the rest of the SUs (Fig. 16). These SUs were found next to each other on the same stretch of river, D50 being the exception, it was found a little lower along the river.

It can be concluded that the river system, and the position of SUs in relation to each other, is marginally important in accounting for Odonata assemblage structures.

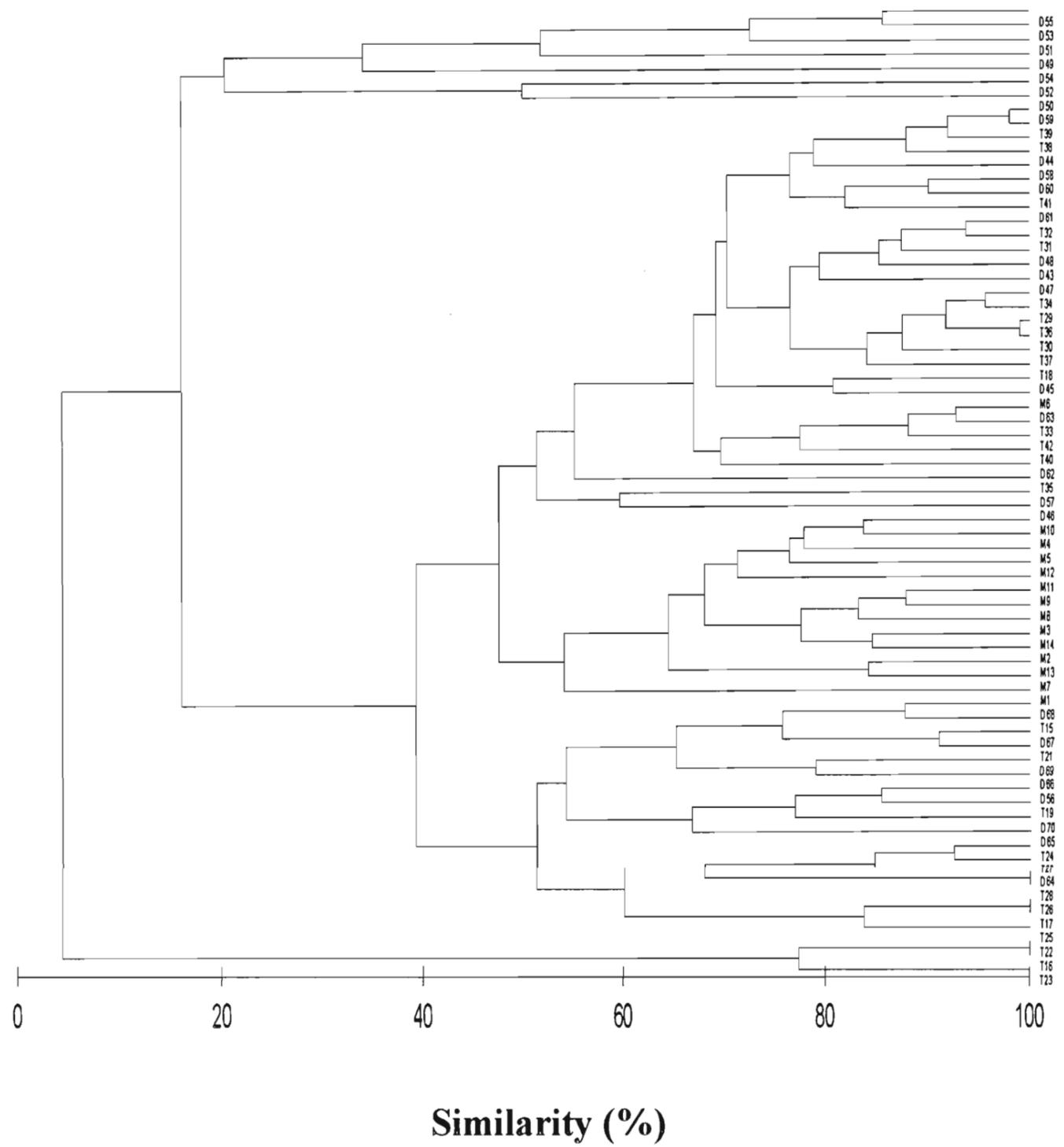


Fig. 16: Dendrogram of similarities between adult Odonata assemblages at all 70 sampling units at all three rivers. M = Msunduzi river, T = Townbush river, D = Dorpspruit river.

Y-axis labels of figure 16 were substituted to denote vegetation structure (open or closed canopy cover) (Fig. 17). This dendrogram was then inspected for similarity clustering in order to ascertain any relationship between Odonata assemblages and vegetation structure.

Adult Odonata assemblages along the three river systems were clearly affected by vegetation structure (Fig. 17). Three tight clusters of SUs were apparent. D55 – D50 (with a 25% similarity) were all composed of a closed canopies, D59 – M1 (with a 50% similarity), were all composed of an open canopies and D68 – T23 (with a 50% similarity, when ignoring the three dissimilar Townbush SUs, T22, T16, and T23), were all composed of closed canopies. These three dissimilar and isolated Townbush SUs had similar canopy covers. All the SUs with open canopies were clustered together, however the SUs with closed canopy covers were divided into two groups which were less than 20% similar when ignoring the three Townbush SUs, T22, T16 and T23. The cluster of dissimilar Dorpspruit SUs (D55 –D50) were all characterized by closed canopy covers, except for the outlier D49 which was positioned between these SUs (Fig. 17). This shows that vegetation structure is more important in affecting Odonata assemblages, than is the river system.

Two SUs D49, an open canopy SU and T18, a closed canopy SU were outliers. They clustered with SUs of different vegetation structure. D49 was sandwiched between closed canopy SUs and seemed to reflect their characteristics. A few SUs (T22 and T16; T26 and T17; D64 and T28) were found to be 100% similar. Each pair had the same vegetation structure (Fig. 17). Thus it can be concluded that vegetation structure has a strong effect on Odonata assemblages.

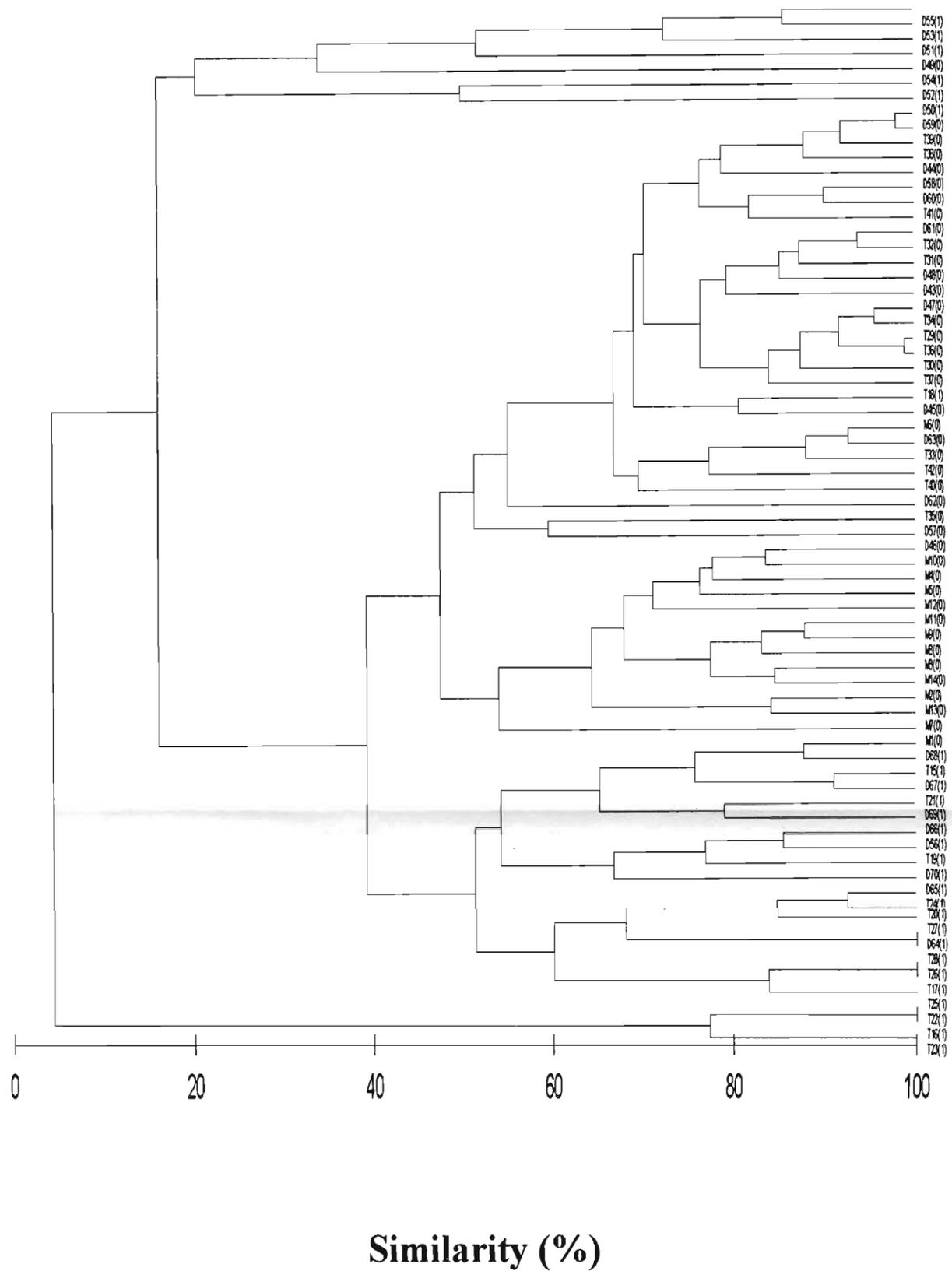


Fig. 17: Dendrogram of vegetation structure (0 = open canopy cover; 1 = closed canopy cover) in determining the similarities between the 70 sampling units in terms of adult Odonata assemblages, in the three different river systems. M = Msunduzi river, T = Townbush river, D = Dorpspruit river.

To further investigate the role of vegetation structure on Odonata assemblages, individual dendrograms for the Townbush and Dorpspruit rivers were constructed. Msunduzi SUs were excluded from this investigation, as all the SUs had the same vegetation structure.

The effect of vegetation structure on Odonata assemblages along the Townbush river was apparent as SUs with similar canopy covers clustered tightly together. Cluster, T34 – T35 has a similarity of 55%, and is composed of open canopy SUs. Cluster T24 – T23 has a similarity of 60%, when excluding the three dissimilar SUs, T22, T16 and T23, and is composed of closed canopy SUs. These Townbush SUs are again dissimilar, despite their similar vegetation structures, to other SUs along the Townbush river. The isolation of these three SUs in a relatively forested area results in them having different Odonata assemblages, even though environmental variables seem to be similar to other SUs. This is possibly due to little movement by Odonata along the riparian zone. Thus it is not simply the local vegetational character of a SU that is important, but also its context. Most of the shaded SUs had sunny areas fairly close to them allowing local generalist species to penetrate the shaded SUs. However SUs T22, T16 and T23 were surrounded by much forest, preventing certain species from penetrating them and resulting in their Odonata assemblages being very different. The two clusters of open and closed canopy SUs were about 50% similar. Two closed canopy SUs, T18 and T19, were outliers and were clustered among the open canopy SUs (Fig. 18). Species found at these two SUs were generalist species and possibly reflect different environmental conditions not noticeable.

It can be concluded that vegetation structure has a discernable effect on Odonata assemblages. However, certain areas, even though they may be environmentally suitable, or similar, may be inaccessible to Odonata adults.

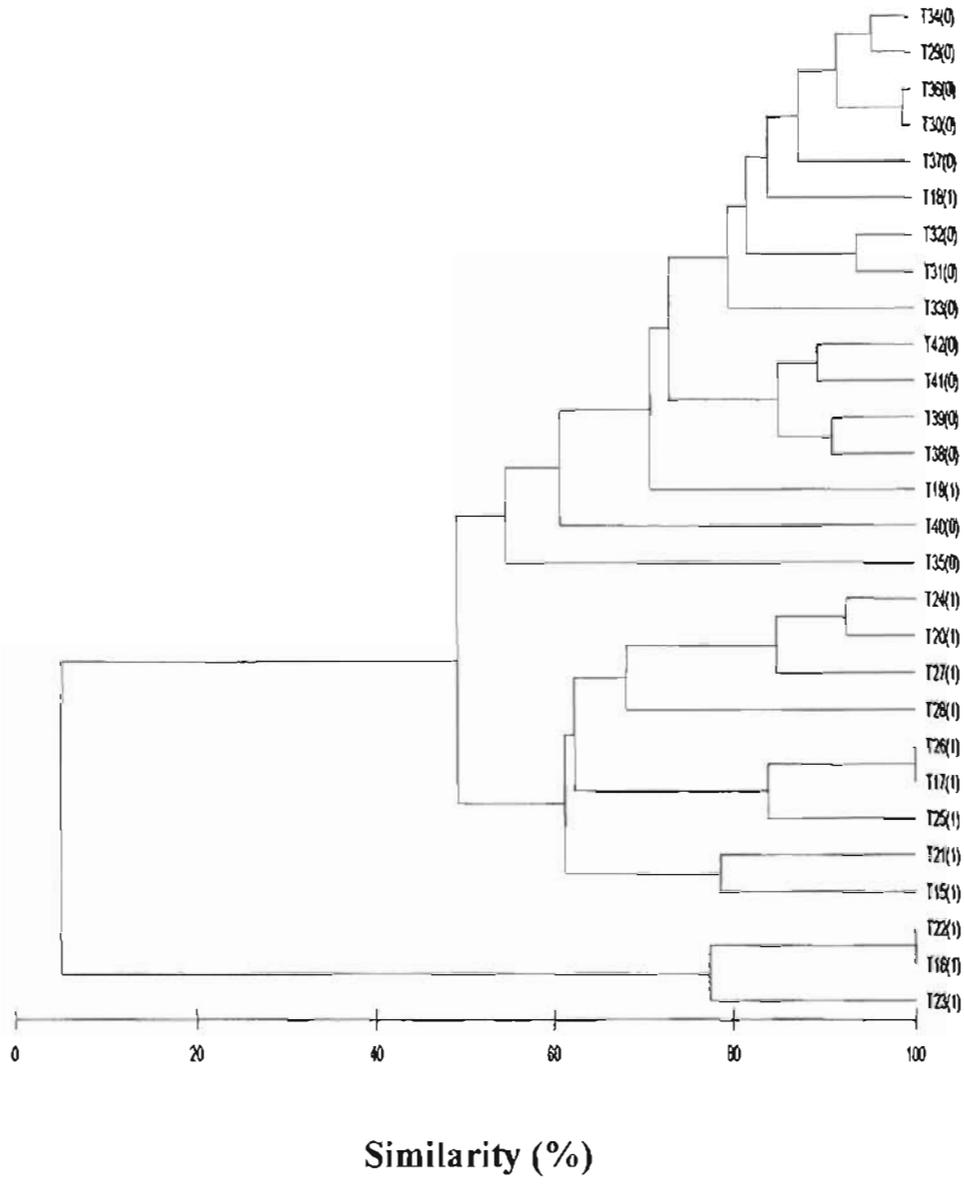


Fig. 18: Dendrogram of the role of vegetation structure (0 = open canopy cover; 1 = closed canopy cover) in determining the similarities between sampling units, in terms of Odonata assemblages, along the Townbush river (T).

Along the Dorpspruit, the effect of vegetation structure on adult Odonata assemblages was again apparent as SUs grouped into three clusters, D69 – D65 (with 50% similarity) which were composed of closed canopies, D64 – D50 (with 20% similarity) which were composed of closed canopies and D57 – D58 (with a 55% similarity) which were composed of open canopies. The two clusters of closed canopy SUs had a similarity of less than 20%. These clusters clearly consisted of SUs from the upper and lower stretch of the river. SU D49, composed of an open canopy, was an outlier. It was sandwiched between two closed canopy SUs and had Odonata assemblages similar to these closed canopy SUs (Fig. 19).

It can be concluded that vegetation structure is important in determining Odonata assemblages, as open canopy SUs cluster together as partially do closed canopy SUs. Position along the stream also has an affect on Odonata assemblages, but to a much lesser extent.

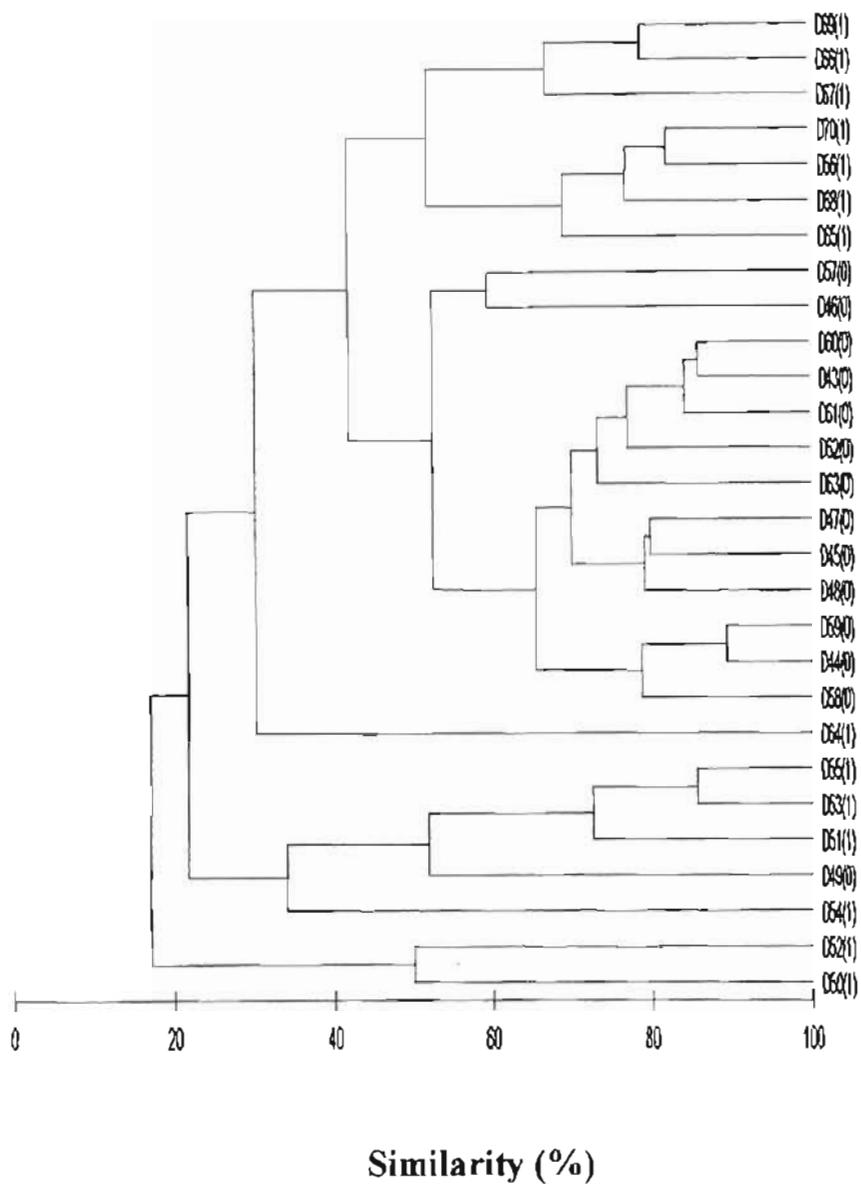


Fig. 19: Dendrogram of the role of vegetation structure (0 = open canopy cover; 1 = closed canopy cover) in determining the similarities between sampling units, in terms of adult Odonata assemblages, along the Dorpspruit river (D)

Y-axis labels of figure 16 were then substituted to denote vegetation composition (alien or indigenous) (Fig. 20). This dendrogram was then inspected for similarity clustering in order to ascertain any relationship between Odonata assemblages and vegetation composition.

No clear pattern of the response of Odonata assemblages to a change in the vegetation composition was discernable, although two clusters were apparent (Fig. 20). One was D68 – T23, with 50% similarity when ignoring the three dissimilar Townbush SUs, T22, T16 and T23, and composed of alien vegetation, and the other the Msunduzi SUs, with a 50% similarity and composed of indigenous vegetation. Msunduzi SUs all have similar vegetation structures, so this is possibly the underlying reason why they cluster together. The cluster of SUs characterized by alien vegetation, also all have similar vegetation structures, so again this is probably the reason these SUs cluster together (Fig. 17). A few SUs were 100% similar (T22 and T16; T26 and T17; D64 and T28). These pairs all had the same vegetation composition (Fig. 20). The cluster of dissimilar Dorpspruit SUs (D55 – D50) were characterized by different vegetation compositions. However, the cluster of dissimilar Townbush SUs was characterized by similar vegetation compositions.

It can be concluded that vegetation composition does have a small affect on Odonata assemblages, but not as strong an effect as vegetation structure. These results confirm those of the Kruskal-Wallis test.

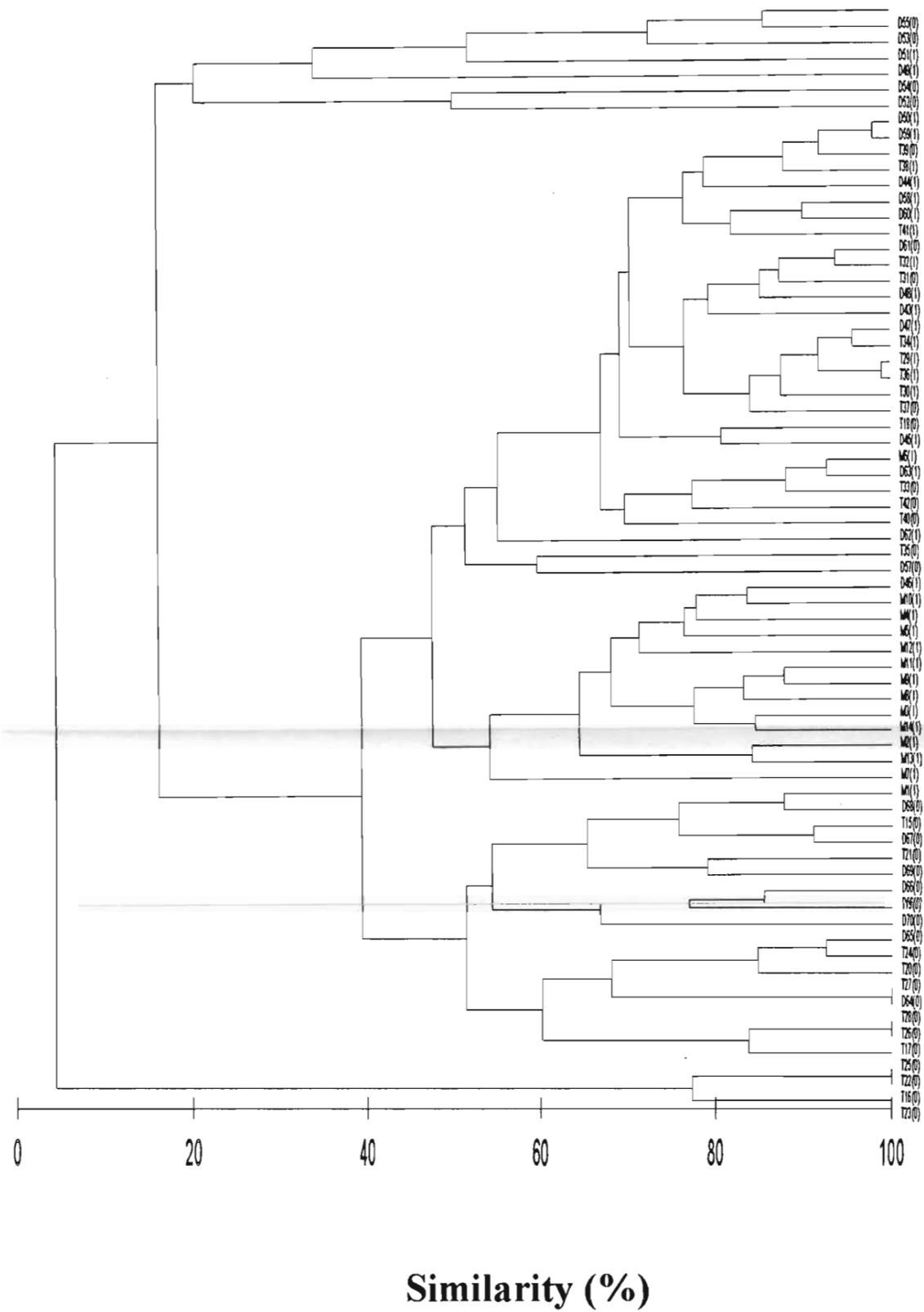


Fig. 20: Dendrogram of the role of vegetation composition (0 = alien vegetation; 1 = indigenous vegetation) in determining the similarities between the 70 sampling units, in terms of adult Odonata assemblages, along the three different river systems. M = Msunduzi river, T = Townbush river, D = Dorpspruit river.

To further investigate the role of vegetation composition on adult Odonata assemblages separate dendrograms for the Townbush and Dorpspruit rivers were constructed. Msunduzi SUs were not further studied as they all had similar vegetation compositions.

Along the Townbush a cluster of SUs, T19 – T23, with a 50% similarity, when ignoring the three dissimilar SUs, T22, T16 and T23 and characterized by alien vegetation was apparent (Fig. 21). These SUs are again dissimilar from the rest of the cluster (95% dissimilar), despite their similarity in vegetation composition to other SUs clustered with them. Thus even though environmental variables seem to be most important in influencing Odonata assemblages, certain areas are still inaccessible to them.

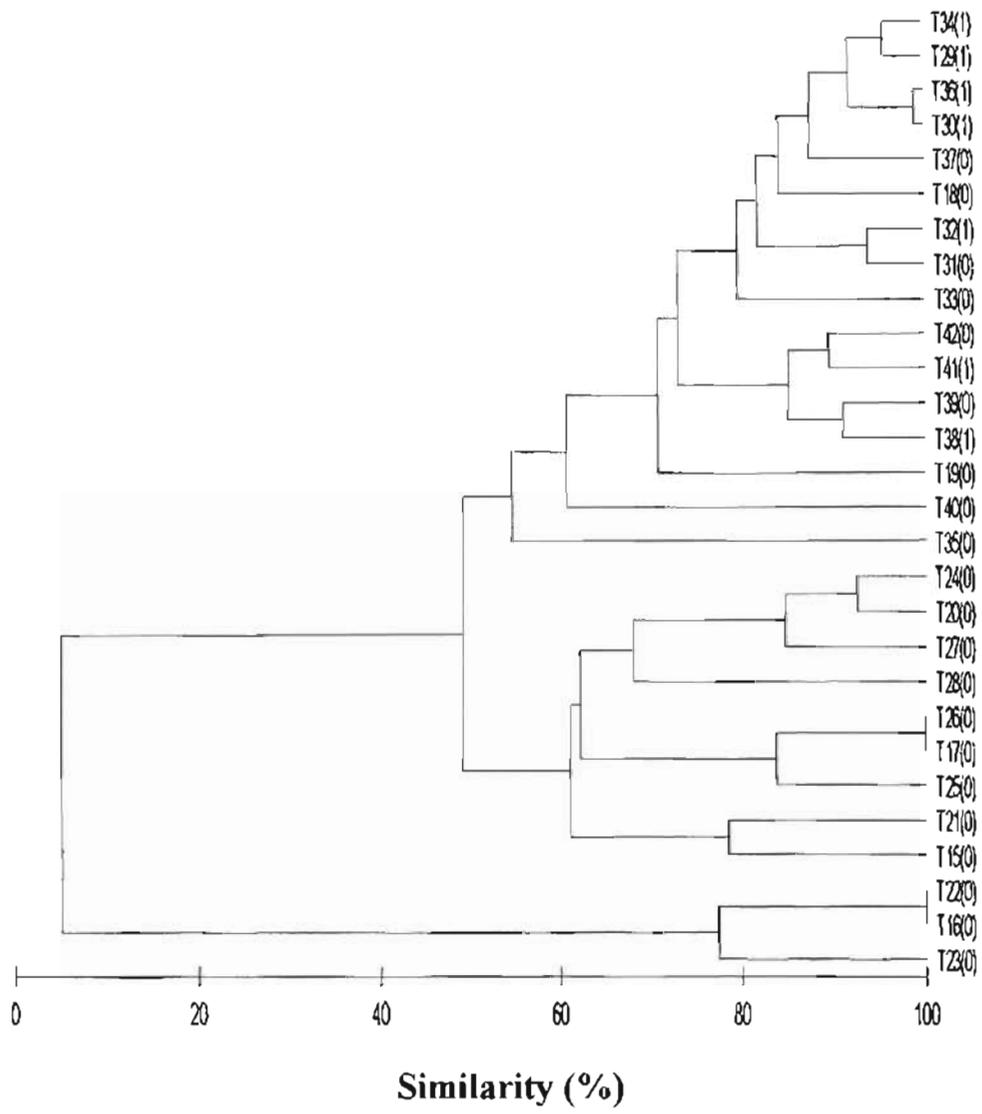


Fig. 21: Dendrogram of the role of vegetation composition (0 = alien vegetation; 1 = indigenous vegetation) in determining the similarities between sampling = Townbush river (T).

There was some clustering of SUs with similar vegetation composition along the Dorpspruit river. One cluster was D69 –D65, with 50% similarity and composed of alien vegetation, and another D60 – D58, with 65% similarity and composed of indigenous vegetation (Fig. 22).

Thus it can be concluded that vegetation composition has some affect on Odonata assemblages, but not as large an affect as vegetation structure. Odonata are thus more tolerant of different vegetation compositions i.e. alien or indigenous vegetation than they are of different vegetation structures i.e. open or closed canopy SUs. They have specific sunlight or shade requirements.

All conditions, river system, vegetation structure and vegetation composition, are linked together to affect macroinvertebrate and Odonata assemblages. It appears therefore, that the river system is most important in accounting for variation in macroinvertebrate assemblages, and that vegetation structure is most important in accounting for variation in Odonata assemblages.

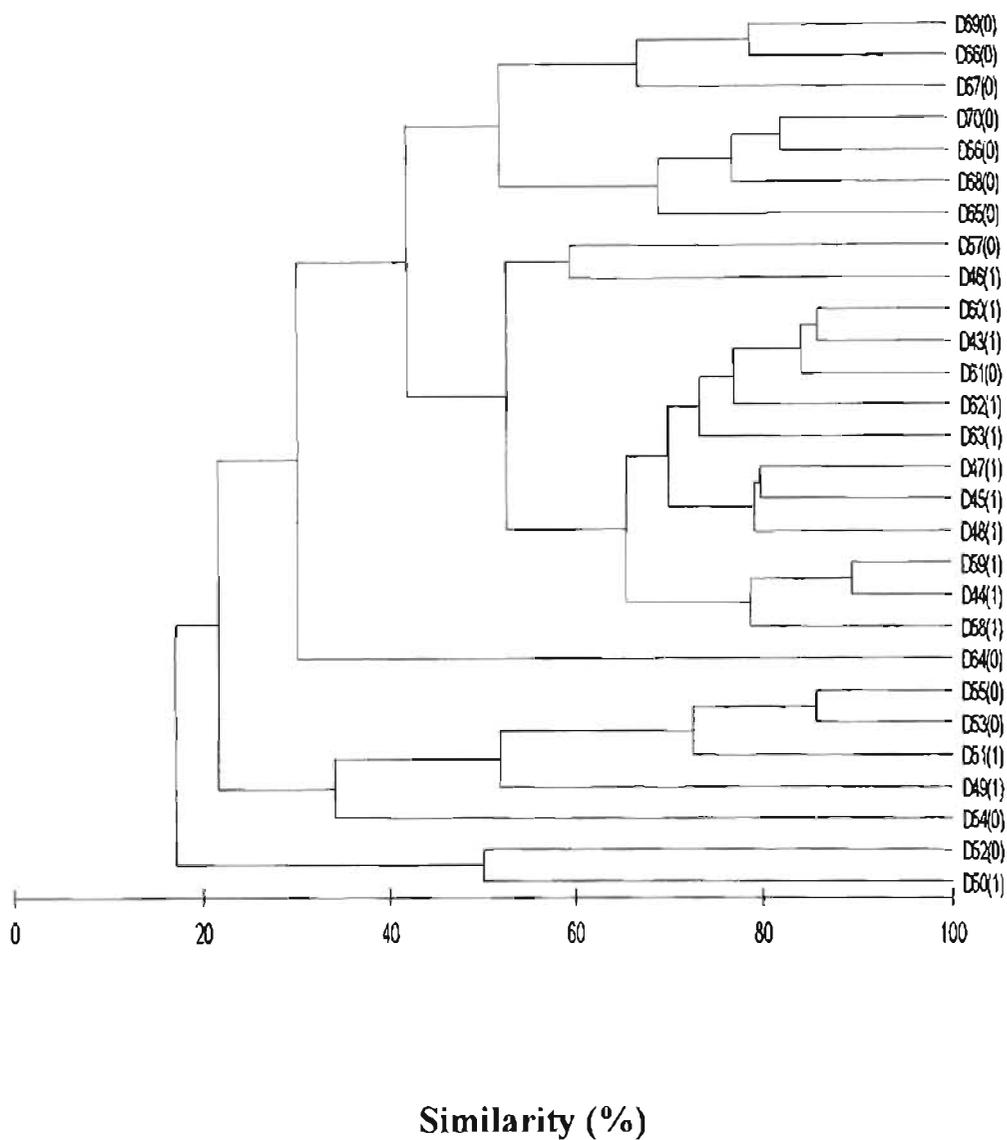


Fig. 22: Dendrogram of the role of vegetation composition (0 = alien vegetation; 1 = indigenous vegetation) in determining the similarities between sampling units, in terms of adult Odonata assemblages, along the Dorpspruit river (D).

How does SASS5 vary in relation to Odonata abundance and species richness?

Using regression analysis to evaluate the relationship between the two metrics assessing the riparian conditions of these rivers it was found that SASS5 scores were positively and highly significantly correlated with Odonata abundance ($r^2 = 0.486$, $df = 68$, $p < 0.005$) (Fig. 23) and with Odonata species richness ($r^2 = 0.402$, $df = 68$, $p < 0.005$) (Fig. 24). Variation in SASS5 scores was in a similar direction to that of the Odonata indices. Thus SASS5 and Odonata indices are responding in a similar way to changes in vegetation structure and composition along the river system in which they are found. Thus the hypothesis that SASS5 does not vary in the same way as Odonata abundance and species richness is rejected.

Abundance drops are usually a sign of stress as found for Odonata in Stellenbosch (Norma Sharratt, pers. Comm) and for grasshoppers in the Karoo (Gebeyehu & Samways, 2003). Drops in SASS score should therefore correlate with drops in Odonata abundance.

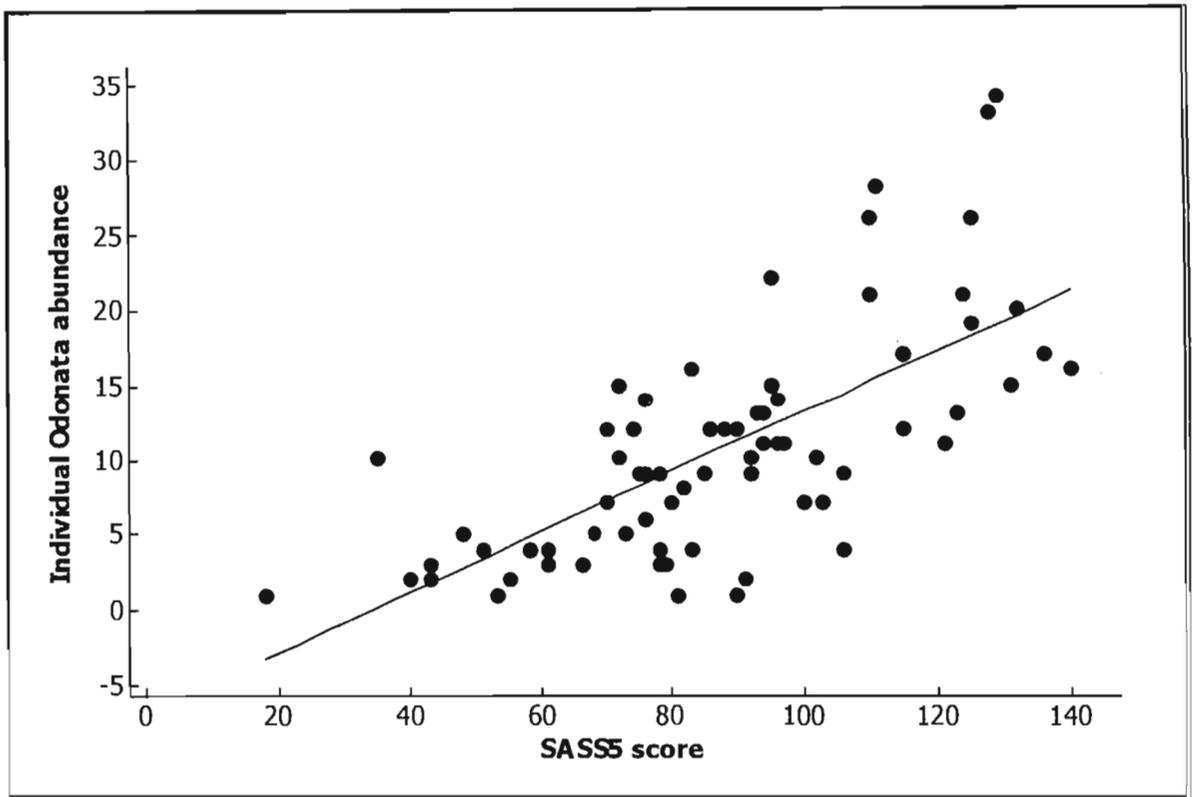


Fig. 23: Linear regression of the Odonata abundance at each sampling unit against SASS5 scores. $y = -6.850 + 0.2002 \text{ SASS5}$

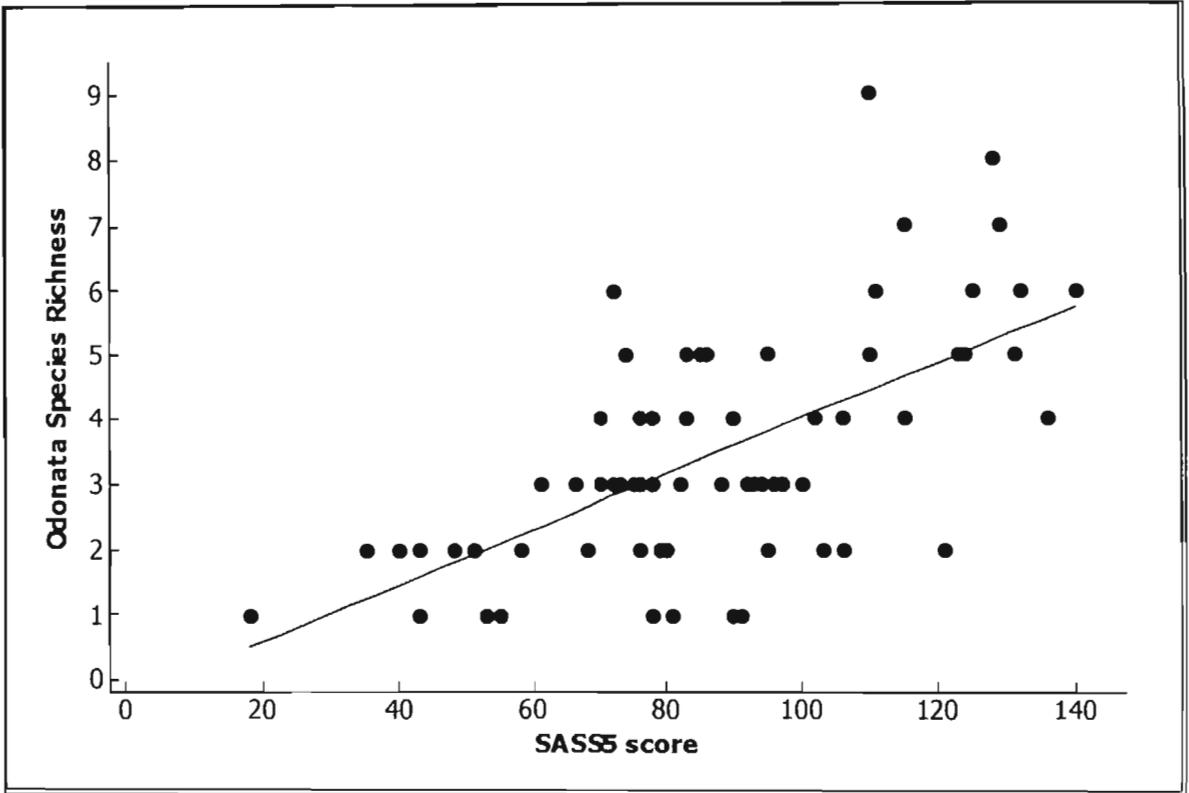


Fig. 24: Linear regression of the Odonata species richness at each sampling unit against SASS5 score. $y = -0.2639 + 0.4287SASS5$

How does SASS5 vary in relation to weighted Odonata abundance and endemism?

Using regression analysis to evaluate the relationship between SASS5 and weighted Odonata abundance and endemism it was found that SASS5 scores were positively and highly significantly correlated with weighted Odonata abundance ($r^2 = 0.373$, $df = 68$, $p < 0.005$) (Fig. 25), weighted Odonata endemism ($r^2 = 0.409$, $df = 68$, $p < 0.005$) (Fig. 26) and with the total of these two scores ($r^2 = 0.393$, $df = 68$, $p < 0.005$) (Fig. 27). These correlation coefficients were rather low. Variation in SASS5 scores were in a similar direction to that of the weighted Odonata indices showing again, that they respond in a similar way to changes in vegetation structure and composition along the river system in which they are found. Therefore, the hypothesis that SASS5 does not vary in the same way as weighted Odonata indices is rejected.

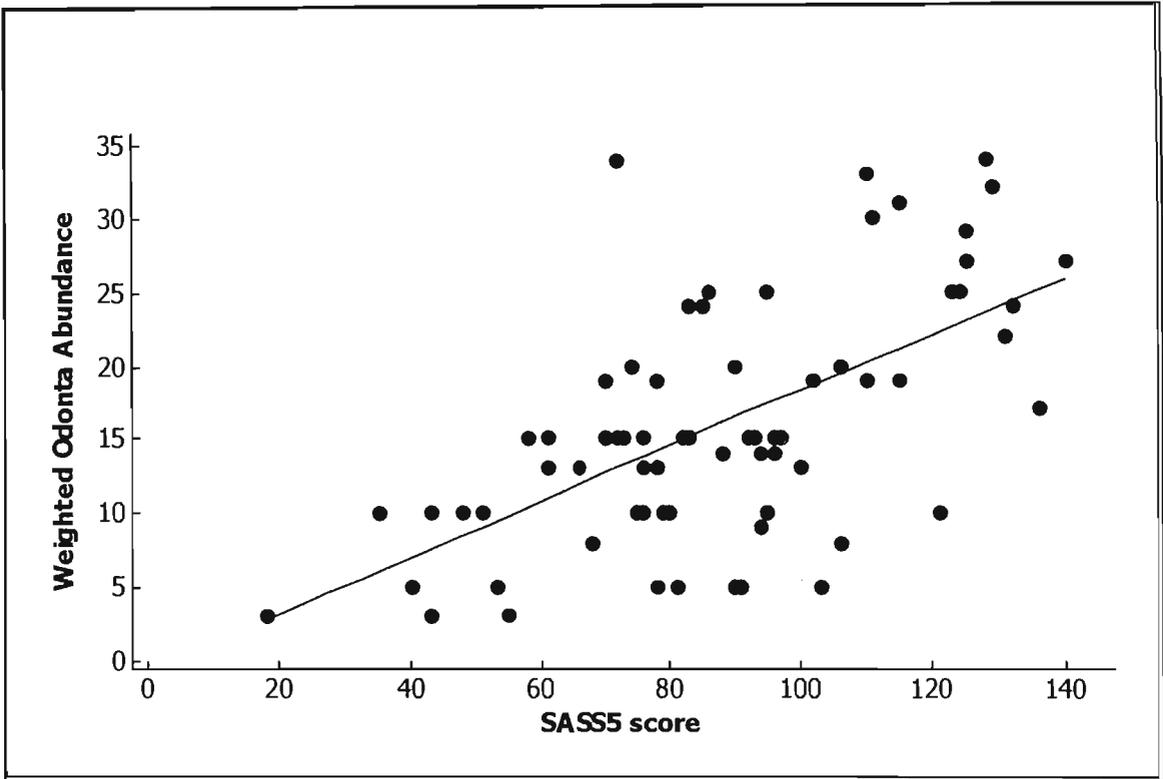


Fig. 25: Linear regression of the weighted Odonata abundance at each sampling unit against SASS5 score. $y = 0.608 + 0.1889 \text{ SASS5}$

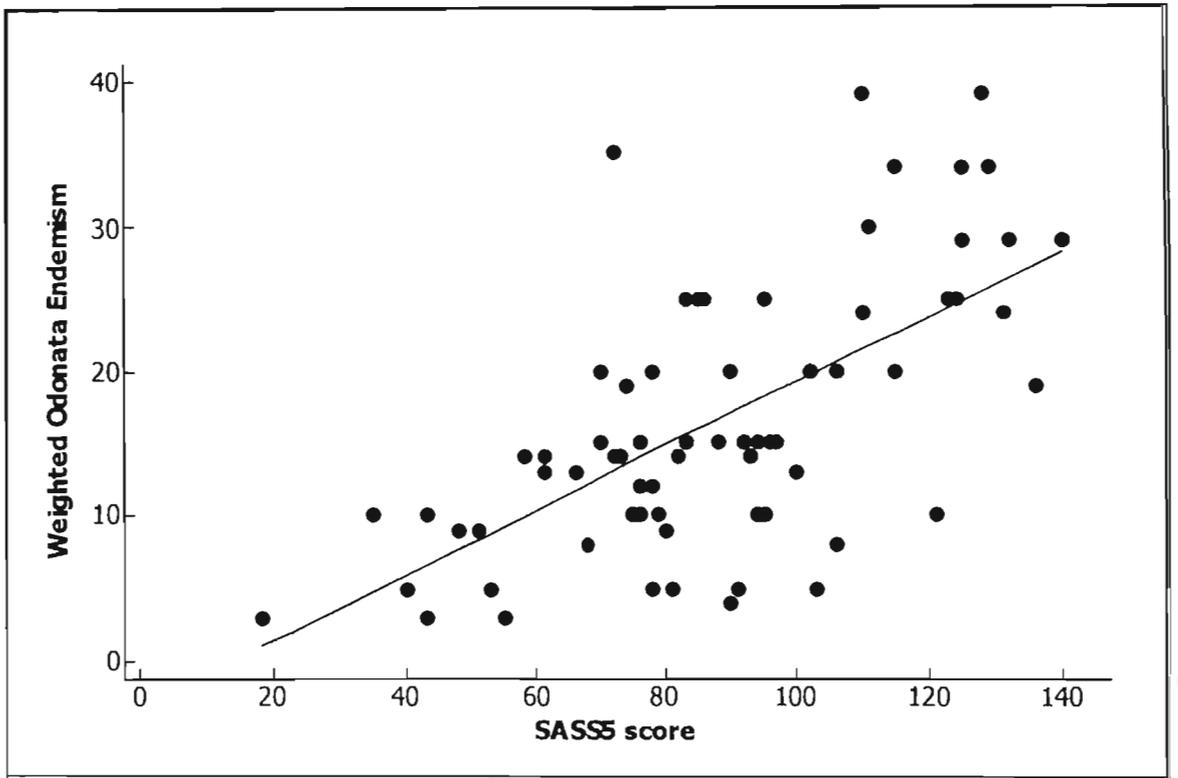


Fig. 26: Linear regression of weighted Odonata endemism at each sampling unit against SASS5 score. $y = -2.984 + 0.2221 \text{ SASS5}$

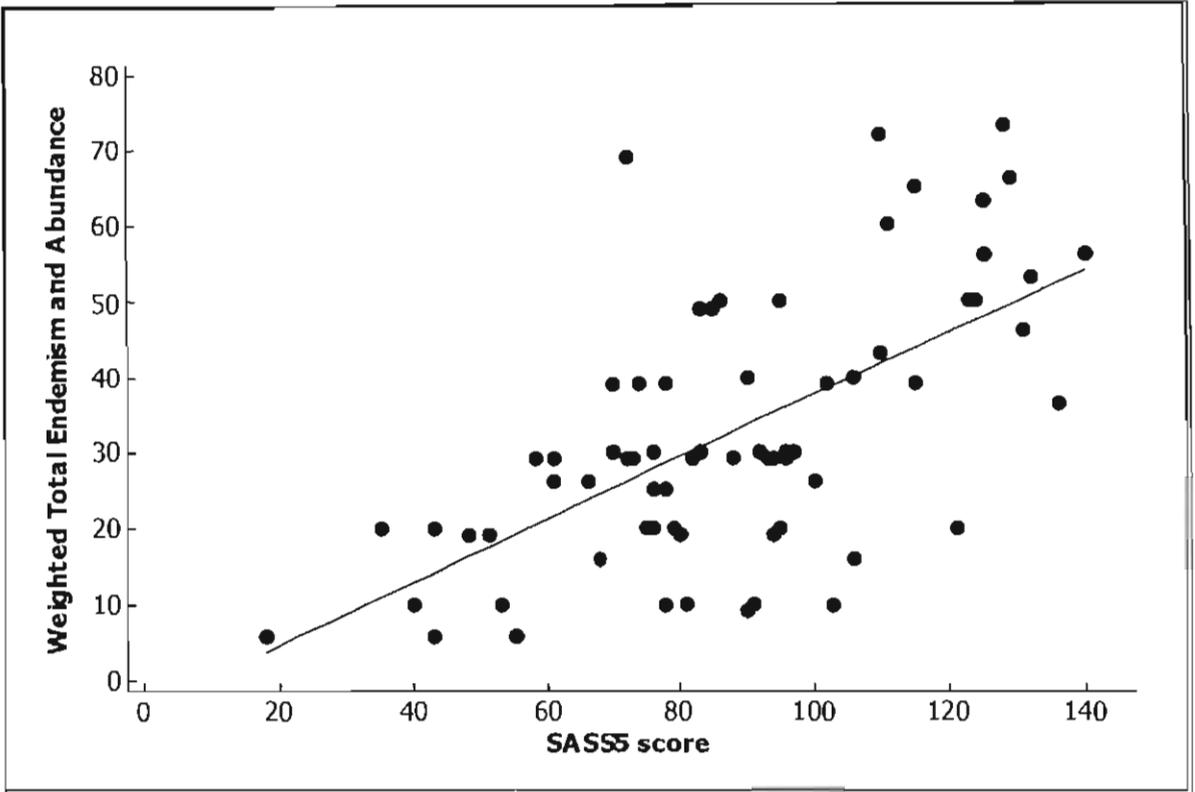


Fig. 27: Linear regression of the total weighted Odonata endemism and abundance at each sampling unit against SASS5 score. $y = -3.592 + 0.4110 \text{ SASS5}$

Components of variation

Taxonomic groups responsible for variation in SASS5 scores

SASS5 scores were varied across the three river systems. They were significantly higher along the Msunduzi river. Of the 51 macroinvertebrate families in the three different river systems, 41 of these were in the Msunduzi river, 37 in the Townbush and 35 in the Dorpspruit. Ten of the 51 families were unique to the Msunduzi river (Table 6). Five of these ten families had high sensitivity scores (Palaemonidae (10); Hydracarina (8); Heptageniidae (13); Oligoneuridae (15) & Cordulidae (8)), the other five had low sensitivity scores (Leeches (3); Belastomatidae (3); Pleidae (4); Culicidae (1) and Tabaenidae (5)). Three of the families were unique to the Townbush river (Table 6). These families (Hydroptilidae (6); Dyticidae (5); Hydraenidae (8)) had average to low sensitivity scores. Only, two of the families were unique to the Dorpspruit river (Table 6). These families included Coelenterata (1) and Hydrophilidae (5) which had low sensitivity scores. SASS5 scores were high along the Msunduzi river, because of greater number of families present at each SU (Fig. 3) and because certain families (Perlidae, Heptageniidae, and Chlorocyphidae) with very high sensitivity scores (≥ 10) were common at SUs, whereas along the Townbush and Dorpspruit rivers, families with very high sensitivity scores (≥ 10) were found at few SUs (Table 9).

Heptageniidae, (found at 85.7% of the SUs) were only found along the Msunduzi river. Perlidae (found at 85.7% of the SUs along the Msunduzi) and Chlorocyphidae (found at 78.6% of the SUs along the Msunduzi) were also found along the Townbush river but at very few of the SUs (3.6% and 25.0% respectively). The Msunduzi sites were all characterized by open canopies and indigenous vegetation. Perlidae were at one Townbush SU, which had a closed canopy and alien vegetation. Chlorocyphidae, along the Townbush river, was at two SUs with open canopies and indigenous vegetation, two SUs with open canopies and alien vegetation and three SUs with closed canopies and alien vegetation.

Table 9: Percentage of SUs along the three different rivers, where macroinvertebrates with very high (≥ 10) sensitivity scores, occurred.

Taxon	Msunduzi river	Townbush river	Dorpspruit river
Amphipoda(13)	-	21.4	3.6
Palaemonidae(10)	7.1	-	-
Perlidae(12)	85.7	3.6	-
Heptageniidae(13)	85.7	-	-
Oligoneuridae(15)	7.1	-	-
Chlorocyphidae(10)	78.6	25.0	-
Platynemididae(10)	-	28.6	10.7
Philopotamidae(10)	21.4	32.1	-
Pisulidae(10)	-	3.6	3.6
Athericidae(10)	14.3	32.1	35.7

Taxonomic groups responsible for variation in Odonata assemblages

Odonata assemblages (abundance and species richness) varied significantly between river systems. Mean abundance and species richness per SU were both higher along the Msunduzi river (Table 8). Seventeen Odonata species were found along the three river systems. Of these 17 species, eleven were along the Msunduzi river (*Pseudagrion sublacteam*, *Crenigomphus hartmanni*, *Anax speratus*, *Trithemis arteriosa* and *Zygonyx natalensis* were unique to the Msunduzi river), nine species were found along the Townbush river (*Ceriagrion glabrum* being the only species unique to the Townbush) and 11 species were found along the Dorpspruit river (*P. hageni* and *Ischnura senegalensis* were the two species unique to the Dorpspruit) (Table 5). All three rivers had similar numbers of species resident along their banks, even though the species composition differed.

The difference in abundance and species richness scores between the rivers was because of the frequency at which the species were found at each SU along these rivers. Most species along the Msunduzi river occurred at most of the SUs, whereas along the other two river systems most of the species occurred at few SUs (Table 12). *P. kersteni*, *Platycypha caligata* and *T. furva*, were found at most of the Msunduzi SUs. At the SUs along the Townbush and Dorpspruit rivers, *P. kersteni* was the most common species (Table 10).

Of the 47 SUs along the Townbush and Dorpspruit rivers where *P. kersteni* was found, 19 had closed canopies and alien vegetation, nine had open canopies and alien vegetation and 19 had open canopies and indigenous vegetation. *P. kersteni* is an African species that is fairly common throughout South Africa (Samways 2002a).

P. caligata was found at seventeen SUs along the Townbush and Dorpspruit rivers. Seven of these had closed canopies and alien vegetation, six had open canopies and alien vegetation and four had open canopies and indigenous vegetation. *P. caligata* is also an African species that is fairly common throughout South Africa (Samways 2002a).

T. furva was found along the Msunduzi river only. SUs here were all composed of open canopies and indigenous vegetation. This species is also an African species that is common (Samways 2002a).

Chlorolestes tessellatus and *Allocnemis leucosticta*, both of which are South African endemics, were along both the Townbush and the Dorpspruit rivers, but not along the Msunduzi river. *C. tessellatus* was only found at SUs with closed canopies where there was never more than two other species present. *A. leucosticta* occurred at thirteen SUs along these two rivers. Two of these thirteen SUs had open canopies, the others were all composed of closed canopies and all but two of these had two or less other species present.

Table 10: The percentage of SUs along the three different river systems where the relevant Odonata species occurred.

Odonata species	Msunduzi river	Townbush river	Dorpspruit river
<i>Chlorolestes tessellatus</i>		25.0	14.3
<i>Allocnemis leucosticta</i>		10.7	35.7
<i>Ceriagrion glabrum</i>		3.6	
<i>Pseudagrion hageni</i>			28.6
<i>Pseudagrion kersteni</i>	100	89.3	78.6
<i>Pseudagrion salisburyense</i>	64.3	3.6	10.7
<i>Pseudagrion sublacteum</i>	78.6		
<i>Ischnura senegalensis</i>			7.1
<i>Platycypha caligata</i>	85.7	17.9	50.0
<i>Crenigomphus hartmanni</i>	28.6		
<i>Paragomphus cognatus</i>		17.9	
<i>Anax speratus</i>	14.3		
<i>Orthetrum julia</i>	78.6	71.4	46.4
<i>Crocothemis erythraea</i>	7.1		3.6
<i>Trithemis arteriosa</i>	35.7		
<i>Trithemis furva</i>	92.9	7.1	25.0
<i>Zygonyx natalensis</i>	7.1		

DISCUSSION

Large spatial scale: variation between river systems

A biological monitoring technique should reveal whether any anthropogenic impact is causing deterioration in water quality. It should provide some indication of the severity of this impact. To do this, the technique should be able to detect any subtle changes in response to increasing distance from the impact (Brown 2001).

Use of several different techniques would enhance the interpretation of data collected as part of a biological monitoring programme. It is unlikely that any single technique will fulfill all the above criteria on its own (Brown 2001).

This study aimed to assess complementarity or not between two metrics so as to assess the ecological state of a river system and its surrounding environment. Adult Odonata are well known to respond to particular environmental variables, but this does not necessarily reflect the response of other taxa. In other words, Odonata cannot be assumed as surrogates for other taxa. In contrast, the SASS5 method is efficient in assessing the health of a river system, although it is not necessarily sensitive to the vegetation structure on the banks.

This study revealed that the spatial scale (river system versus point localities) was a significant variable for both the SASS5 and Odonata indices. At the level of a river, macroinvertebrate abundance and taxon richness and Odonata abundance and species richness responded similarly to the different river systems. All indices were significantly higher along the Msunduzi river, yet had similar values for the Townbush and Dorpspruit rivers. Individual values at sites along the Dorpspruit river were always slightly higher than those along the Townbush river. The Msunduzi river was the largest of the three river systems, with highest habitat heterogeneity, and corresponding high taxon richness, and overall abundance (Dallas 1997; Kinvig & Samways 2000; Vaun McArthur & Voelz 2000). When looking at the Average Score Per Taxon (ASPT) values (which is a more

constant value than the SASS5 score and less affected by the number of biotopes (Dallas 1997)) for each river system, this stretch of the Msunduzi river seems to have a natural water quality with possibly some deterioration, but nevertheless high biotope diversity. The Townbush and Dorpspruit rivers, according to the ASPT values, had some deterioration in water quality. It is known that habitat quantity, quality and diversity all affect SASS5 scores (Dickens & Graham 2002), with Odonata species richness and abundance affected similarly. Odonata indices may have been high along the Msunduzi due to the absence of shaded sites, and where species richness seems to be lower, especially as adult Odonata are known to have strong and species-specific sunlight versus shade preferences (Clark & Samways 1996; Stewart & Samways 1998). Most South African Anisoptera and Zygoptera species do not enter closed-canopy riparian vegetation (Pinhey 1984; Kinvig & Samways 2000). Consequently, the shaded sites along the Townbush and Dorpspruit generally had lower species richness than sites along the Msunduzi.

Small spatial scale: variation in vegetation structure and composition

Odonata adults and macroinvertebrates were found here to respond differently to certain environmental variables (vegetation structure and composition). These particular variables which act at point localities for Odonata resulted in little variation in the macroinvertebrate assemblages at this spatial scale. There was however, one telling exception. SU D49 was one of two SUs that did not group with SUs of similar vegetation structure. D49 had an open canopy, yet it had an Odonata assemblage similar to the SUs on either side with closed canopies. Movement of sun-loving Odonata into D49 was inhibited by shade, yet it also provided sunlight which the shade-loving species (e.g. *Allocnemis leucosticta*) nevertheless still need at times.

Msunduzi SUs were the most uniform with regards to vegetation structure and composition, and in macroinvertebrate assemblages. Townbush SUs separated into two clusters. One cluster, which consisted of eight SUs which were all included in the eleven-SUs with the lowest SASS5 scores. Thus SUs, with similar SASS5 scores appear

to have similar resident macroinvertebrate assemblages (similar macroinvertebrate family richness and abundance). This suggests that macroinvertebrates with similar sensitivities group together.

In terms of SASS5, only three SUs from the Dorpspruit were found not to cluster with other SUs from the same river system. They were D49, which was composed of an open canopy, and was found sandwiched between SUs with closed canopies, D50, which was the only SU with no rapid, and D51 which together with D50, were the only two SUs in the study with a closed canopy of indigenous vegetation. These two SUs were included in the three sites with the lowest SASS5 score. It seems, as with the Odonata, that the macroinvertebrate assemblages were responding to neighbouring SUs.

The Townbush river SUs had the lowest similarity in terms of macroinvertebrate assemblages. These SUs had the largest range of SASS5 scores (18 – 121). The Msunduzi SUs, which were also similar to each other, had the smallest range of SASS5 scores (110 – 140) while the Dorpspruit SUs were intermediate in SASS5 scores between the other two rivers (48 – 106). This indicates that SASS5 is very sensitive to overall river system rather than to individual SU changes. Although, as the SASS score for the river system is calculated using each individual SU, SASS5 can be considered as responding to average SU character (i.e. riparian zone vegetation) as well as water quality.

The structural and compositional type of SU along the river system was very important in determining particular Odonata assemblages. When viewing the three river systems separately, clustering showed that SUs which were closest together, particularly along the Townbush and the Dorpspruit rivers, were most similar, suggesting movement of Odonata along the rivers. Dorpspruit SUs were divided into two groups based on the Odonata assemblages: those from the top stretch of the river system, and those from the bottom stretch. They differed from a vegetational point of view in that along the bottom stretch of river SUs with open canopies were separate from those with closed canopies, whereas along the top stretch of river these SUs were interspersed.

Viewing the Odonata of the three river systems together, Townbush and Dorpspruit SUs were clustered among each other, as a result of similar vegetation structure, and possibly even some movement of individuals between rivers. In terms of Odonata, the Msunduzi SUs were relatively different from the SUs of the other two rivers, as a result of this being a bigger river with many sunny biotopes. Nevertheless, there were three Townbush SUs (T16; T2 and T23) which were very different from the rest of the SUs, apparently as a result of being isolated in a relatively forested area. This again emphasizes that it is not just simply the local vegetational character of a site that is important, but also its context.

Complementarity between metrics

The results show strong complementarity between the two metrics. They vary in a similar way to environmental conditions, although with emphasis on different spatial scales. Macroinvertebrates which are less vagile are mostly affected by the overall canopy cover, the quality of the water body, and in turn, reflect the health of the river system. In contrast, Odonata adults, are highly sensitive to local environmental conditions, and respond rapidly using flight to seek suitable habitat (Samways et al. 1996). Thus, these vagile insects reflect the immediate, proximal structure of the environment along the river, as well as the general condition of the river. Similarly Brown (1991) commented that family-level data provided a good indication of the effects of overall anthropogenic impact on the system, while species data seemed to reflect specific patterns in environmental variables thought to otherwise take time to reflect an impact.

Macroinvertebrate assemblages here were similar along whole river systems, with little response to closed versus open and alien versus indigenous vegetation. Therefore, SASS5 can be considered as responding to average habitat character (i.e. riparian zone vegetation) as well as water quality. Odonata assemblages, in contrast, were sensitive to vegetation changes, particularly structure over composition. Nevertheless, for Odonata, the context still mattered at individual point localities, where there was high contrast in

vegetation structure. Where closed canopy dominated, with only short stretches of river with open canopy, the Odonata assemblage was largely of the closed canopy type, even in an open patch such as D49.

These two indices together provide a more comprehensive synthesis of the biological condition of a particular river system (or SU at the smaller spatial scale). Using these biological endpoints will improve decision making in stream protection and restoration and save money (Karr & Chu 1999). These metrics, however can be used on another dimension, by breaking them down to derive potentially diagnostic information from each of the component metrics (Karr et al. 1986). This type of knowledge can guide diagnosis of site specific causes of degradation (Yoder & Rankin 1995).

Resident Odonata species as indicators

There is value in knowing which adult male Odonata species are resident, to characterize a habitat in terms of the species that occur there in the highest numbers and breeding there regularly (Hawking & New 2002). Furthermore, resident adults would be more affected by changes in the immediate environment than would tourist species, and would therefore be of the greatest value as indicators. In this study, most Odonata larvae were too young to identify to species level, meaning that resident status could not be categorically determined. However, by inference, at the familial and generic levels, the species encountered here were all likely to be resident. Along the Msunduzi, *P. kersteni* and *P. salisburyense* were in high numbers, and larval representatives of this genus were present, indicating that they are most probably resident species. *P. kersteni* is also most probably a resident species along the Dorpspruit where it occurs in large numbers and where larval representatives of the genus are also abundant. Other species along the Msunduzi, and represented by larvae at higher taxonomic levels were *P. sublacteum*, *Platycypha caligata* and *Orthetrum julia*. Along the Townbush river this was also the case with *P. kersteni* and *O. julia*.

Monitoring abundant resident species may be important for detecting early decline of the habitat (Hawking & New 2002). However, monitoring rare species is also important as they can be indicative of relict or undisturbed conditions and used to rate the importance of any site within its biotope groups (Eyre et al. 1986). Species which occurred in very low numbers along the Msunduzi included *Crocothemis erythraea*, *Zygonyx natalensis* and *Anax speratus*. Along the Townbush, rare species included *Ceriagrion glabrum*, *P. salisburyense* and *Trithemis furva*, and along the Dorpspruit *C. erythraea* and *Ischnura senegalensis* were locally rare. It is also important to identify species that are restricted to a narrow range of conditions as they may be good indicators of change. *Chlorolestes tessellatus* and *Allocnemis leucosticta* are sensitive indicators largely restricted to shade areas (Samways et al. 1996). Here, they were positively sensitive to natural forest conditions.

The habitat requirements of Odonata species are important in governing the presence or absence and abundance of species along environmental gradients (Osborn & Samways 1996). This information allows the development of characteristic assemblages of Odonata species which would be used to monitor changes in the environment (Clark & Samways 1996). Environmental disturbances alter these Odonata assemblages, both in species composition and abundance. If the habitat preferences of certain species are known, a change in that species composition would be an indication of a type of disturbance. Species with more specific habitat preferences would be more susceptible to certain types of disturbance (Clarke & Samways 1996). In this regard, rare and threatened sun-loving species are likely to be very indicative of invasion by alien woody plants.

SASS5 and individual Odonata species

This study highlighted the difficulty of using Odonata larvae at the species level. Furthermore, Hawking and New (2002) found that the diversity and abundance of larvae varies considerably, even on consecutive dates. This shortcoming is partly overcome by the SASS5 method which specifies the habitats to be sampled, so that there is no 'chance'

sampling of different substrates. Nevertheless, it is still important to be aware that larvae sampled from a single sample, may not be a true representation of the full spectrum of local species.

It would be useful to know more about the life histories of the macroinvertebrates used in the SASS5 method, which would provide more detailed information for interpreting the state of the water body and its environment. This was suggested by this study, where families with high sensitivity scores were more numerous along the Msunduzi, yet poorer in the other two river systems. This compares with taxa with low sensitivity scores which were more common in these two other rivers, suggesting perhaps some degradation of these two systems. This degradation was probably mostly due to alien trees shading the habitat. A cautionary note, which parallels the findings of Kinvig & Samways (2000) is that it is essential to compare like with like. When alien trees invade there is 'degradation' of Odonata assemblages, but this 'degradation converges on assemblage structures found under indigenous tree canopies. However, when the invasive alien canopy becomes very thick and blocks out sunlight, sun-loving endemic species can be locally extirpated (Samways & Taylor 2004).

RECOMMENDATIONS

It would be advisable to monitor the rivers regularly and to take note of which macroinvertebrate families are present in each individual sample. Sensitivity scores of these macroinvertebrates should also be recorded. This could be an early indicator as to whether rivers and their canopies are changing or not in quality. Along streams in the Puget Sound basin, early signs of degradation were shown in the loss of intolerant (these species would have high sensitivity scores) and long-lived taxa. This was followed by an overall decrease in taxa richness. Heavily affected sites were dominated by a few, highly-tolerant taxa (Morley & Karr 2002). It is important to take note of the composition of macroinvertebrate assemblages in each sample, as SASS5 scores could still be relatively high if many highly-tolerant taxa are still present in a SU, despite the actual degradation of the stream. It is important therefore, to also include the ASPT score, to give a more accurate picture of the true health of the river (Dickens & Graham 2002).

Individual macroinvertebrate families and their life histories are also capable of telling us more specifically where a disturbance is coming from. For example, Morley and Karr (2002) found that the number of stonefly taxa at a site was more closely related to local land cover, whereas the number of long-lived taxa was a better indication of sub-basin land-cover. With a better understanding of the life histories of macroinvertebrates and their responses to specific stressors, the diagnosis of causes of degradation, and not just the warning of degradation, might be possible. This will greatly aid in restoration and conservation efforts.

The biotope requirements of Odonata species are important in governing the presence or absence and abundance of species along environmental gradients (Osborn & Samways 1996). This information allows the development of characteristic assemblages of Odonata species which could be used to monitor changes in the environment (Clark & Samways 1996). Environmental disturbances alter these Odonata assemblages, both in species composition and species abundances. If the biotope preferences of certain

species are known, a change in that species composition would be an indication of a type of disturbance. Species with more specific biotope preferences would be more susceptible to certain types of disturbance (Clark & Samways 1996). In this regard rare and threatened sun-loving species are likely to be very indicative by invasive alien woody plants.

Another advantage would be to use SASS5 to raise public awareness as to how invertebrates can be invaluable in conserving our environment. It is well known that invertebrates are relatively neglected in comparison with plants and vertebrates in conservation action (Horwitz et al. 1999). The public will always be more willing to protect something that is beneficial to them. Furthermore, protecting our environment as best we can is an essential long-term investment.

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