EFFECT OF INVASION AND CLEARING OF ALIEN RIPARIAN VEGETATION ON BENTHIC MACROINVERTEBRATE AND ADULT ODONATA ASSEMBLAGES IN SOUTPANSBERG RIVERS

by

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DECLARATION

The work described in this thesis was carried out in the Soutpansberg area (Sheefeera, Piesanghoek and Entabeni forest plantations), Limpopo Province, South Africa and in the Department of Entomology and Centre for Agricultural Biodiversity, University of Stellenbosch, Stellenbosch. The study was conducted from February 2004 to May 2005, under the supervision of Professor Michael J. Samways.

I, the undersigned, hereby declare that the work contained in this thesis is my own original work and that I have not previously, in its entirety or in part, submitted it at any university for a degree. Where use has been made of the work of others it is duly acknowledged in the text.

Signature: ______________________________ Date: ____________________

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ABSTRACT

Benthic macroinvertebrates (sampled using South African Scoring System, SASS5) and adult male Odonata (sampled with close-focus binoculars) were recorded on two streams and a river of Soutpansberg, with the aim of determining the effect of invasion and removal of alien riparian vegetation on their assemblages. A secondary aim was to establish the importance of dragonflies as indicators of degree of disturbance in rivers. Forty two aquatic macroinvertebrate families and 33 adult Odonata species were recorded at a total of 71 sampling units. Three distinct riparian vegetation types were selected (natural, alien and cleared). Cleared vegetation refers to clearing of invasive alien trees, allowing regrowth of natural vegetation. Natural and cleared vegetation supported more benthic macroinvertebrate families compared to alien vegetation. Certain families that were lost to alien vegetation were recorded from natural vegetation. The highest SASS5 score was recorded from natural vegetation, followed by cleared vegetation, and the lowest was from alien vegetation. The highest number of adult Odonata was recorded at cleared vegetation, with alien and natural vegetation supporting the least number of Odonata species. Vegetation type, stream flow and microhabitats were statistically identified as the most influential variables for benthic macroinvertebrate assemblages. For adult Odonata assemblages, vegetation type, shade and temperature were the most important environmental variables. Species assemblages of adult Odonata can be used as indicators of environmental condition of rivers. The clearing of alien riparian vegetation clearly benefits the indigenous benthic macroinvertebrates as conditions are restored to their natural state. It also benefits dragonfly species richness, but if natural succession proceeds to a shaded tree canopy, the effect becomes similar to that of habitat shaded by alien vegetation. The impact of alien vegetation is to reduce sun-loving invertebrate species, especially dragonflies, with lesser impact on shade-loving species.

ALGEMENE OPSOMMING

Bentiese makroinvertebrate (verkry deur gebruik te maak van "South African Scoring System" SASS5) en volwasse manlike Odonata (verkry deur gebruik te maak van naby fokus verkykers) was gemonitor op twee stroompies en 'n rivier van die Soutpansberg, met die doel om die effek van infestasie en verwydering van eksotiese rivierbank vegetasie geboseer op hul samedromming. 'n Sekondêre doel was om vas te stel die belangrikheid van Odonata as indikators van versteurings graad in riviere. Twee en veertig akwatiese makroinvertebraat families en 33 volwasse Odonata spesies was gemonitor by 'n total van 71 monsternemings eenhede. Drie unieke rivierbank vegetasie tipes was geselekteer (natuurlik, eksotiese of verwyder). Die verwyderde vegetasie verwys na areas waar eksotiese vegetasie verwyder is om herstel van natuurlike vegetasie kans te gee. Natuurlike en verwyderde vegetasie onderhou meer bentiese makroinvertebraat families in vergelyking met eksotiese vegetasie. Sekere families wat verlore was in areas van eksotiese was gemonitor in natuurlike vegetasie. Die hoogte SASS5 waardes was gemonitor van die natuurlike vegetasie, op gevolg deur die verwyderde vegetasie area. Die hoogte getal volwasse Odonata was gemonitor in die verwyderde vegetasie. Vegetasie tipe, stroom vloei en mikrohabitat was statisties geïdentifiseerd as die faktore wat die bentiese makroinvertebrates getalle meeste beïnvloed. Vir die volwasse Odonata getalle, vegetasie tipes, skadu en temperatuur was die mees belangrike omgewings faktore. Spesies getalle van volwasse Odonata kan gebruik word as indikator van omgewings kondisies van 'n rivier. Die verwydering van eksotiese rivierbank vegetasie is duidelik voordelig vir die inheemse bentiese macroinvertebrate weens kondisies herstel word na hul natuurlike toestand. Dis ook voordelig dat Odonata spesies rykheid, meer as natuurlike opvolging voortgaan tot skadu ryke bome, die effek sal eenders wees as die skaduryke habitat van die eksotiese vegetasie. Die invloed van eksotiese vegetasie is om son-liewende invertebraat spesies, veral Odonata, met skadu liewende spesies.

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CHAPTER 1

INTRODUCTION

Background

South Africa is a country which is rich in natural resources, of which the most important and among the scarcest is water. Davies *et al.* (1993) estimated that there would be insufficient water for national domestic use, industry and agriculture by the year 2025. Additionally, with an average annual rainfall of less than 500 mm, South African Rivers are under threat of pollution and degradation. Therefore, Rivers demand care of not only the Riverbed but the adjacent soil, as part of an overall ecosystem conservation plan. The complexity of interactions between land, water and atmosphere must be recognized to protect and restore Rivers (McCully 1996). Removal of dense stands of invasive alien plants increases available water (surface and underground), especially when removed from riparian areas (Macdonald 2004). Constitutionally, the Republic of South Africa has the regulations promulgated in terms of the Conservation of Agricultural Resources Act (CARA) which categorizes invasive plants and stipulates what needs to be done with respect to their management and control (Zimmermann *et al.* 2004). All other parts will eventually be affected by disrupting any part of the system.

It is necessary to assess and monitor the environmental condition of Rivers in a reliable scientific manner in order to achieve sustainable utilization, conservation and effective management. In South Africa, biological assessment or bioassessment has become an important method for rapid monitoring of Rivers, forming the backbone of the National River Health Programme (Uys *et al*. 1996), and also forms part of South African National Water Act (1998). Ecological status or the number and severity of anthropogenic perturbations on a River and their effects on the system must be determined. These disturbances include biotic factors, such as the presence of alien plants and animals. For example, the invasion of the riparian vegetation and the instream areas by the alien tree *Nerium oleander* (Versveld *et al.* 1998) was the most important factor affecting the ecological status of the Doring River.

King (1992) accorded the weightings to the abiotic and biotic perturbations that were regarded as the primary causes of the degradation of the River ecosystem. The highest weighting was given to the presence of plantations, orchards and cultivated land along Riverbank, followed by the removal of indigenous riparian vegetation as well as encroachment by alien riparian vegetation. The quality and abundance of the riparian vegetation affects the aquatic invertebrate assemblages (Richardson and Van Wilgen 2004). This is concerning because riparian zones have become the most invaded areas. Versveld *et al.* (1998) estimated that the current degree of invasion of riparian zones, notably in Limpopo, Mpumalanga and the Western Cape are likely to increase by at least 50% in the next 10 years, and to double in the next 20 years, if nothing is done to correct the situation. The Soutpansberg Region in the Limpopo Province has favourable conditions for alien plants with its warm climatic conditions and high annual rainfall. Invasion of riparian areas are rapid, especially by species such as *Acacia mearnsii* (Versveld *et al.* 1998). As riparian vegetation has direct access to water and can use it at substantial rates, it is therefore important to control and minimize invasion.

Alien vegetation as a threat to biodiversity

Invasive alien plants (IAPs) are considered to be a serious threat to biodiversity, like direct human transformation of the natural habitats and production of greenhouse gases (Le Maitre *et al.* 2004). Not only trees, but grasses also, reduce the biodiversity of indigenous communities, and their control is complicated by abundant seed production and persistent seed banks (Milton 2004). Nearly one tenth of the surface area of South Africa is infested with invasive alien plants (Water Research Commission 2001). These include waterways, riparian zones and grassland. Invasion by alien plants is the second most serious threat to biodiversity following direct habitat destruction. They may lead to a greatest continuing threat to biodiversity, especially to rare species, if allowed to persist and spread to their greater extent (Latimer *et al.* 2004).

Infestations are high in River beds and along banks of Rivers, with some River systems being extremely infested (Richardson and Van Wilgen 2004). IAPs compete with indigenous species for water, space, sunlight and other resources resulting in them dominating the area. They lead to the reduction in the structural diversity of the vegetation and disrupt the functioning of the ecosystem, which can influence the number and type of animal species that can be supported by the vegetation in that habitat (Water Research Commission 2001). In short, alien species are a threat to ecosystems, habitats and to indigenous species (Zimmermann *et al.* 2004).

Invasion by alien plants alters the abundance and composition of indigenous ant communities associated with seed dispersal function of indigenous plants, and bird habitats are changed, leading to reduced species richness and abundance (Richardson and Van Wilgen 2004). Most invasive species (e.g. *Eucalyptus camaldulensis*, *Acacia. mearnsii, Arundo donax,* and *Lantana camara*) form closed-canopy stands along Rivers (Richardson and Van Wilgen 2004). Plantations of eucalypts (bluegum trees), most of which are indigenous to Australia are major problem in the Soutpansberg. In Mpumalanga Province, the afforestation of catchments with eucalypt plantations causes complete drying up of streams within 6-12 years after planting (Forsyth *et al.* 2004). In contrast, removal of dense stands of *Acacia. mearnsii* along riparian areas increases streamflow (Dye and Jarmain 2004). Alien plant invasions are becoming more widespread and serious throughout the world (Richardson *et al*. 2004). Such invasions may lead cause extinction of over 1000 plants and animal species (Calder 1999). In response, South Africa developed the Working for Water Programme, which was launched by the national Department of Water Affairs and Forestry in 1995 aiming at controlling the distribution of alien invasive plants, with the primary goal of increasing water supplies (Macdonald 2004). Several methods are being used to fight the problem of aliens:

1. Biological control (species-specific insects and fungi).
2. Chemical control (environmentally safe herbicides).
3. Manual clearing (removing or burning).

Bioassessment

Bioassessment is a process whereby one or more components of the biota are used to assess the effect of change in other components such as water quality (Hawkins and Norris 2000). Roux (1997) also points out that such a biomonitoring method might also be used for the assessment of ecological state of the aquatic ecosystems, emerging problems, the impacts of development, and the spatial and temporal trends in ecological state. It can be used to predict changes in an ecosystem due to urban development, to set objectives for River remediation, and to guide management of an ecological reserve (South African National Water Act 1998). With more extensive work being done by the Working for Water Programme throughout South Africa, there is now a need to assess the success of the Programme in terms of biodiversity recovery. Assessment can be done using the South African Scoring system (SASS), but the resolution of SASS scores is at invertebrate family level (i.e. morphospecies in families), implying that changes in species level composition of some invertebrate communities in response to the clearing of alien riparian vegetation may not be detected. However, major changes in abundance of invertebrate taxa may be significant in this respect. Much is known that a particular species respond in particular ways. As it is difficult to name immature aquatic insects (larvae), yet much easier to name adult dragonflies, it means that dragonflies may be used to complement SASS for evaluating the local success of the programme. SASS is sensitive for comparing different Rivers but less sensitive for specific sites (Natural, Alien and Cleared vegetation), here called "NAC vegetation types," whereas dragonflies are sensitive (Smith 2005).

In South Africa, SASS was originally developed by Chutter (1972). It has been recommended for the rapid assessment of water quality and River condition, with the most recent refinement being SASS version 5 (SASS5). The method is rapid, simple and cost effective and has undergone several iterations and modification through inputs from practitioners before it became a standard method for rapid bioassessment in South Africa (Dickens and Graham 2002). It involves sampling of aquatic macroinvertebrates among the submerged marginal vegetation as well as the streambed, and scores are assigned to each family according to its sensitivity or tolerance to disturbance or pollution (Dallas 1995). High scores are allocated to the most sensitive taxa, and lowest scores to those that are least susceptible to pollution. The sum of the scores is called the SASS5 score, and it gives an index of River health, while the average score per taxon (ASPT) is the most standardized measure. ASPT score is the SASS5 score divided by the number of sampled taxa.

SASS5 is used by several organizations, such as the Cape Metropolitan Council, the South African Department of Water Affairs and Forestry, Umgeni Water, and CSIR amongst others. SASS5 is relevant for the assessment of River quality and River health (Dickens and Graham 2002). When the SASS5 method is used, it is essential to interpret data in relation to habitat quality, availability and diversity. It is necessary to collate a wide diversity of biotopes to include riffles, glides and deposition zones (Dickens and Graham 2002).

Bioassessment can be used to characterize the response of an ecosystem to various forms of disturbance, and is known as instream biological response monitoring (Roux *et al.* 1994). Disturbance is an event that disrupts ecosystem, assemblage or population structure, and changes resources, substratum availability, or the physical environment. Bioassessment has been found to be a more sensitive and reliable measure of environmental conditions than physical and chemical measurements, because it considers the effects of number of environmental variables (Warren

1971). Also, the biota is a useful indicator of disturbance of an ecosystem (Rosenberg and Resh 1993). Bioassessment analyses are usually limited to non-toxic determinants such as temperature, conductivity, total alkalinity and nutrient concentrations although some potential toxic compounds (e.g. trace metals, and biocides) that could affect water quality are also considered (Dallas 2002).

The most often recommended taxonomic groups for the use in assessments of water quality are algae and macroinvertebrates, with macroinvertebrates being the most commonly used group in South Africa (WRC 2001) because they are sensitive to many alterations to the water body in which they live. Different species react differently to a particular given environmental stress. Being relatively non-mobile in their aquatic phase, macroinvertebrates are thus a reflection of the population of the location sampled that allows effective spatial analyses of disturbance (Dallas 2002). Also, they are easily sampled and relatively abundant. The biota serves as an indicator of the general ecological condition of the aquatic ecosystem through continuous reflection of the water conditions in which they live (Hawkes 1979). When focusing solely on physico-chemical monitoring, other impacts that can alter River flow, loss of habitat area and diversity, obstruction to passage along streams, and riparian degradation can be overlooked (Harris 1995). This has meant that traditional physico-chemical monitoring system of water quality has been largely inadequate (Warren 1971). On the other hand, the heterogeneous distribution and patchiness of macroinvertebrate assemblages leads to spatial and temporal variability, which is the major limitation to the use of macroinvertebrates in bioassessment (Dickens and Graham 2002). Furthermore, the causes of the heterogeneity and hence spatial and temporal variability are not always known in lotic systems (Dallas 2002).

Time and financial constraints have led to rapid bioassessment methods, such as the Australian SIGNAL biotic index (Stream Invertebrate Grade Number Average Level; Chessman 1995), the British BMWP system (Biological Monitoring Working Party; Walley and Hawkes 1996), as well as SASS. The methods have been widely recommended, as they simplify data collection and interpretation by limiting the extent of collection through fixed count methods (SIGNAL), or by restricting taxonomic resolution to family level or higher taxa (SASS and SIGNAL).

Irrespective of simple data collection, biotic indices have proved to be highly effective in reflecting human impacts on River ecosystems. Using biotic indices, disturbance effects such as insecticides (Wallace *et al.* 1996), agriculture and afforestation (Quinn *et al.* 1997), wastewater discharge (Dickens and Graham 1998) and organic pollution (Cao *et al*. 1997) such as the trout farm effluent (Brown 1997) have been detected. These results have led to biotic indices being more widely used in conservation, pollution control, River management and biological monitoring.

Adult Odonata (dragonflies) as indicators

The presence of a wide range of indigenous dragonflies is an indication of a healthy system (Corbet 1999). Adult dragonflies inhabit a wide range of aquatic habitats and have been observed to react rapidly to changes in physical conditions (Samways 1989b, Steytler and Samways 1995) as such they have been used as potential indicators at the species level in several studies (e.g. Bulánková 1997, Clark and Samways 1996, Schmidt 1985, Stewart and Samways 1998). Furthermore, the residency status of most species can be determined from teneral adults and repeated localized observations (Samways 1989a). The assemblages of Odonata change continuously along a River, which reflects subtle changes in habitat variables (Hawking and New 1999). When different insect taxa were ranked, according to suitability as indicators, the Odonata was ranked in the top 20% (Brown 1991).

Schmidt (1985) suggested that relative abundance of Odonata species changes as a result of human impact, with the most sensitive species disappearing locally altogether. Stewart and Samways (1998), working in South Africa, also classified biotopes according to the assemblages of Odonata species for the purpose of assessing biotope quality. Even though tenerals spent some time away from water, dragonflies nevertheless return to water bodies to reproduce when they are sexually mature (Angelibert and Giani 2003).

Aims and objectives

This study tested the null hypothesis that removal of invasive alien riparian vegetation will not restore the aquatic macroinvertebrate communities by improving both water conditions and riparian habitats. The main aim of this study was to determine the effect of invasion and removal of alien riparian vegetation on the benthic macroinvertebrate and the adult Odonata assemblages. A secondary aim was to establish the importance of dragonflies as indicators of degree of disturbance in Rivers. The following specific questions were addressed:

A) Effects on the benthic macroinvertebrates:

1. How are SASS5 scores affected by invasive alien plants and their clearing? Do SASS5 scores indicate a decline in overall River health when alien plants are present, but improvement when they are removed?
2. Do changes in environmental variables (e.g. temperature, pH, electrical conductivity and oxygen) occur between sites and do these changes correlate with changes in SASS5 scores?
3. Which taxa are absent from, or unique to, Natural, Alien and Cleared (NAC) vegetation types?
4. Are there changes in the relative abundance of major SASS indicator taxa (Ephemeroptera, Plecoptera, Trichoptera, and Odonata (EPTO))?
5. Is the taxon richness lower in cleared or infested areas?

B) Effects on adult Odonata:

1. How do Odonata species composition change between NAC vegetation types?
2. How are Odonata communities spatially distributed, and what is the variation in population densities between these sites?
3. Which Odonata species are characteristic of NAC vegetation types?
4. Can any Odonata species be used as indicators or detectors of change (for monitoring purposes)?
5. Are the measured environmental variables important determinants of the abundance of Odonata species?

CHAPTER 2

SITES, MATERIALS AND METHODS

SITES

Study area

The study area is the Soutpansberg of the Limpopo Province in South Africa. It is the second-most invaded Province, with the invasive alien plant problem having been described as "huge" (Versveld *et al.* 1998). Vegetation is mainly savanna (Low and Rebelo 1996). Most invasive species have been mapped from savanna, 294 species in 653 quarter-degree squares (Richardson and Van Wilgen 2004). More than 80 species have been mapped as invaders in the Limpopo Province (Versveld *et al.* 1998), with the Soutpansberg being the most invaded region, and with its high rainfall catchments, wide range of environments and warm, sub-tropical climate.

Mean precipitation is 610 mm per year, and the annual runoff is 52 mm. Annual rainfall can reach 2000 mm (Entabeni) in the middle of Soutpansberg, and yet elsewhere, can be as low as 340 mm. Mist precipitation has been measured at an average of 1366 mm per annum (State of Rivers Report 2001).

Site characteristics

In this study, the ideal aim was to have three sites with distinct riparian vegetation types along the same River: (1) Natural vegetation; (2); Alien vegetation and (3) Cleared invasive alien plants (IAPs) vegetation "NAC vegetation types". However, the chances were low that such a trio of sites, be easily found along any one River in the Soutpansberg. So, a different sampling approach was taken. Two streams and one River were sampled in the commercial forestry areas with similar weather conditions. The sites were located at the same region and it was assumed that they are similar but differ with vegetation type (i.e. natural, alien and cleared) only. So any different in macroinvertebrate community assemblage was attributed to vagetation type (directly or indirectly) . Replicates were chosen on a priori basis, and multivariate statistics were used to effectively sort them. Each sampling unit (SU) was categorized in terms of 1) natural, or 2) alien, or 3) cleared vegetation type and percentage (%) canopy cover. Natural vegetation was defined as riparian vegetation with less than 15% IAPs, while alien was considered to be a riparian vegetation with greater than 75% IAPs. Cleared vegetation has alien plants removed sometime before sampling. Canopy cover was categorized as closed (above 75% cover over the stream/ River), medium (50-60% cover) or open (less than 15% cover over the stream/ River). Spatial replication was 23 sampling units (SUs) in each of the natural and alien vegetation types, and 25 SUs from cleared vegetation. All SUs were selected from the headwater zones, a typical mountain stream. Each SU was a 10 m stretch of a River with a 2 m wide strip of vegetation on both banks. Each SU was at least 5 m apart. A variety of microhabitats (i.e. riffles, run, aquatic macrophytes etc.) were included in each SU to minimize variation between the sites (Dickens and Graham 2002).

Distribution of sampling units (SUs)

Table 2.1: Distribution of sampling units across plantations

Land Owner	Plantation	SUs
Steven Lumber Mills	Shefeera	A02 – A06
	Piesanghoek	A07 – N47
Komatiland	Entabeni	C48 – C72

The details for a specific sampling unit are given in Appendix 2.

Sheefera plantation

The SUs (A02-A05) were on the tributary of Luvuvhu River. SU A01 was located in a seasonal stream closer to Louis-Trichardt town (Fig. 2.1), and therefore excluded from the analysis. The riparian vegetation at Sheefera is dominated by severe alien plants, mostly *Caesalpinia decapetala* (mauritius thorn) and *Solanum mauritianum* (bugweed). Biocontrol agents have been released prior 2001 at this site but have had little impact.

Piesanghoek plantation

A stream passing through Piesanghoek is a tributary of Luvuvhu River. It was selected for its severe infestation on the one hand and indigenous riparian vegetation on the other. SUs A06 – A23 were of alien riparian vegetation, whereas N24 –N47 were of natural vegetation. Alien vegetation is dominated mostly by *Solanum mauritianum*, *Acacia mearnsii, Pinus patula Caesalpinia decapetala* and *Eucalyptus gomphocephala* species.

Entabeni plantation

Lutanandwa River with its cleared vegetation along the riparian zone flows through Entabeni plantation. During the sampling period, alien plants along the watercourse were being cleared for the third time. All SUs (C48 – C72) with IAPs removed along the riparian vegetation were selected from Lutanandwa River, between Entabeni Plantation offices and Timbadola Sawmill. The Lutanandwa River is also a tributary of Luvuvhu River which flows into the Limpopo River.

Table 2.1: Exotic plant species mentioned in the text

FAMILY AND SPECIES NAMES	Common names	Growth form
FABACEAE		
* *Acacia mearnsii* De Wild.	black wattle	Tree
**Caesalpinia decapetala* (Roth) Alston	mauritius thorn	Shrub
VERBENACEAE		
**Lantana camara* L.	cherry-pie; lantana	Shrub
APOCYNACEAE		
Nerium oleander L.	selonsroos	Shrub
MYRTACEAE		
Eucalyptus camaldulensis Dehnh.	murray red gum	Tree
* *Eucalyptus gomphocephala* A. DC.	bluegum tree	Tree
SOLANACEAE		
**Solanum mauritianum* Scop.	bugweed	Shrub
POACEAE		
Arundo donax L.	giant reed	Perennial herb
PINACEAE		
**Pinus patula* Schlechtd & Cham.	patula pine	Tree

* Species recorded during the study.

Scientific names according to Henderson L (1995). Plant Invaders of Southern Africa: A pocket field guide to the identification of 161 of the most important and potentially important alien species. Agricultural Research Council, Pretoria.

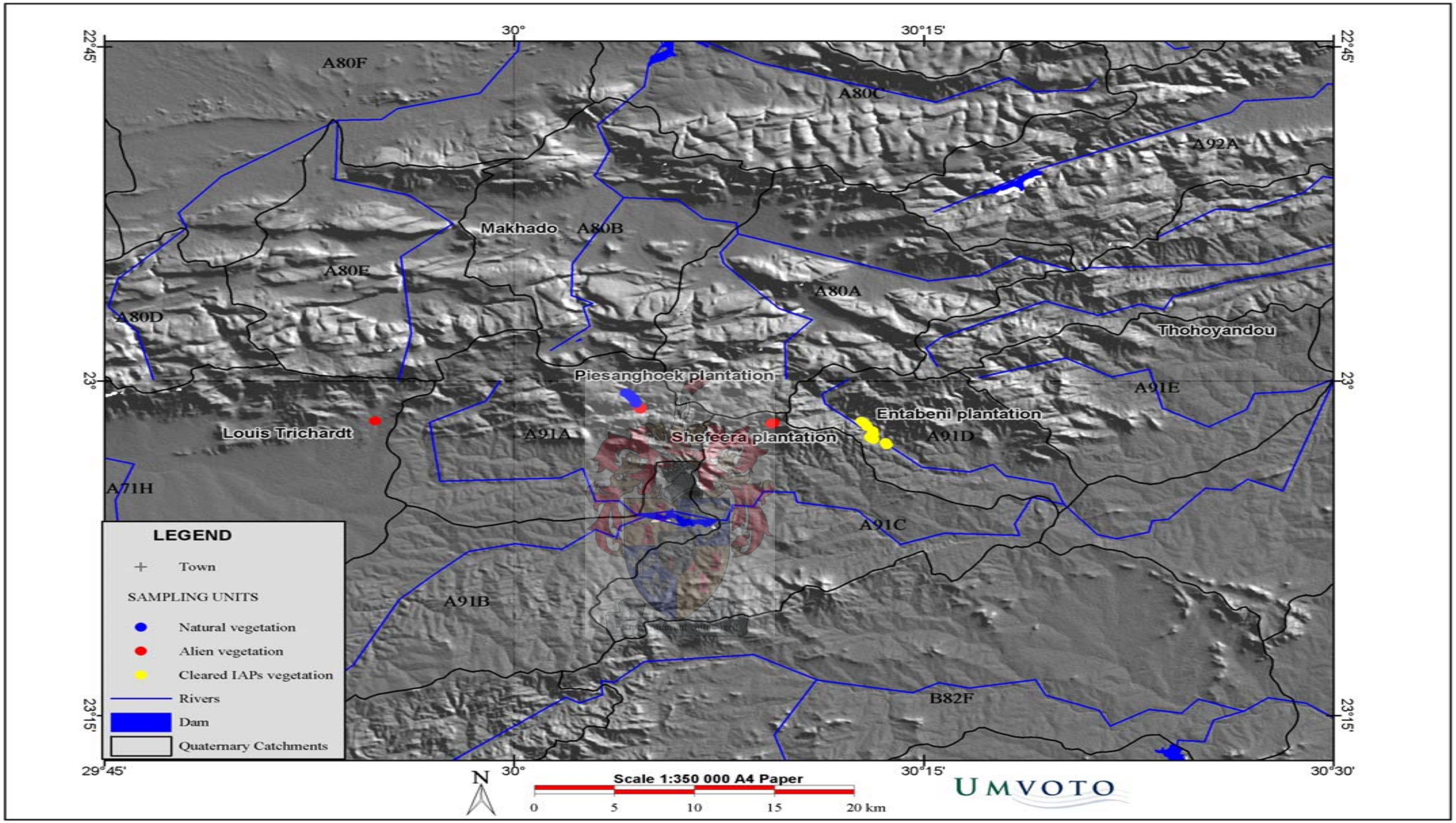

Figure 2.1: The Soutpansberg Region, showing Piesanghoek, Shefeera and Entabeni plantations along the Rivers where the study took place.

Figure 2. 2: Piesanghoek plantation, showing the stream in the distance.

Figure 2.3: Sampling unit (N41), showing natural vegetation in Piesanghoek plantation.

Figure 2.4: Sampling unit (A20) in alien vegetation, showing the spreading of plantation (*Pinus* spp.) into the edge of the stream in Piesanghoek.

Figure 2.5: Alien vegetation in Piesanghoek, showing the most dominated IAPs (*Pinus* spp., *Caesalpinia decapetala, Solanum mauritianum*, and *A. mearnsii*).

Figure 2.6: Cleared vegetation in Entabeni plantation, showing cleared *Solanum mauritianum* species along the Lutanandwa

SAMPLING

Benthic macroinvertebrates

The benthic macroinvertebrate samples at each sampling unit (SU) were collected during September and October 2004, using the standardized SASS5 method (Dickens and Graham 2002). No floods were experienced prior to the sampling period, ensuring fair representation of the biota at the sites. All microhabitats available were sampled: stones, both in and out of current, vegetation (marginal and aquatic vegetation) and gravel, sand and mud (referred to as GSM) (Dickens and Graham 2002). Hand picking and visual observation were carried out during sampling for missed specimens during sampling procedure. Depending on how movable the stones were, they were kicked continuously for two to five minutes. All microhabitats available within a SU were sampled together, giving one sample per SU. A soft 950 µm mesh kick net on a 30 cm square frame on a stout handle was held immediately downstream of the sampled area. The vegetation was sampled by sweeping about two meters through vegetation in different flow velocities. The net was placed below the water level moving it backwards and forwards. Loose substrata were agitated for approximately 30 sec, dislodging macroinvertebrates. While in the net, the samples were washed until they were cleaned and then tipped into the sorting tray and identified to family level with the exception of Baetidae and Hydropsychidae, which were identified to species level and their abundances were recorded. Time limit for identification was restricted to 15 min per sample. SASS5 is not meant to identify all the inhabitants of the River, as this would then need increased sampling time and hence give statistically incomparable results (Dickens and Graham 2002). The field guide by Gerber and Gabriel (2002) was used for identification. National River Health Programme SASS data sheets were used to record results, and the sensitivity score of each family was assigned as indicated on the sheet. According to the families present in the Riverbed and the marginal vegetation, SASS5 score, number of taxa, and ASPT (Average Score Per Taxon) were then calculated and compared between natural, alien and cleared vegetation types.

Adult Odonata

Odonata were observed visually, and sometimes with close-focus binoculars (Lutz and Pittman 1970). Identification to species level was made from keys derived from field guides (Tarboton and Tarboton 2002, Samways unpubl.). Voucher specimens were collected to verify identification. Sampling effort was limited to 30 min observation period in each SU and conducted during December 2004 and January 2005, a peak season for adult Odonata. Observation was done from 10h00 to 15h00 and restricted to sunny, windless days to ensure maximum Odonata activity. Some ecological factors such as light intensity, temperature and time of the day determined the pattern of adult Odonata activity (Lutz and Pittman 1970). Only male dragonflies were counted and matched to the particular habitats (Clark and Samways 1996), because the females are most of the time not associated with water (Samways *et al.* 1996).

Sampling unit variables

The following physical/chemical variables were measured simultaneously at each sampling unit using YSI 556 MPS (Multi Probe System):

- Dissolved oxygen
- pH
- Water temperature
- Electrical conductivity

Measured habitat variables at each SU

- Flow rate using Gerber and Gabriel (2002) classification
- Mean width and depth of the River
- Vegetation type (natural, alien and cleared) and canopy cover
- Elevation
- Number of years since first clearing (where invasive alien plants have been cleared)

There were two measurements taken of each variable in each sampling unit, one during benthic macroinvertebrates sampling and the other during adult Odonata sampling period. Habitat diversity was assessed using the Integrated Habitat Assessment System also called IHAS (McMillan 1998), together with SASS scores. It considers the stream width and depth, presence of algae, and riparian vegetation type. Plant species were classified as broad plant types e.g. aquatic vegetation (plants in the stream channel, partly or fully submerged), marginal vegetation (grasses, reeds, shrubs and sedges on the waters edge), and algae (isolated and also in stones) according to the Gerber and Gabriel (2002) classification.

Microhabitats in each sampling unit were divided into six categories according to particle size using the categories of Dickens and Graham (2002): 1) Silt (< 0.06 mm), 2) Sand (0.06 - 2 mm), 3) Gravel (2 - 20 mm), 4) Stones (2 - 30 cm), 5) Boulders (> 30 cm) and 6) Bedrock (Slabs of rock).

Following Gerber and Gabriel (2002), three classes of water flow which have an important influence on aquatic macroinvertebrates and the dragonfly assemblage composition were identified.1) Riffles (very fast-flowing, broken water on the surface), 2) Runs (flows with no broken water) and 3) Pools (water flows more slowly).

DATA ANALYSIS

Data collected from all Rivers was pooled for each of the three vegetation types (i.e. natural, alien and cleared). Analysis was divided into benthic macroinvertebrates and into adult Odonata components.

Benthic macroinvertebrates

Selected individual metrics: taxon richness, South African Scoring System version 5 (SASS5) and Average score per taxon (ASPT) were calculated and compared for all three vegetation types.

The PRIMER v5 software (Clarke and Warwick 2001) was used for comparing all three vegetation types for taxon richness and abundance. Cluster analysis from PRIMER v5 was used to determine the similarity of sampling units (SUs) in terms of major SASS5 indicator taxa; Ephemeroptera, Plecoptera, Trichoptera, and Odonata (EPTO).

Total number of taxa, SASS5 and ASPT scores were illustrated graphically to indicate the differences between sampling units and all three vegetation types. The taxon richness, SASS5 and ASPT scores in cleared-IAPs site from the year 2001 were also illustrated graphically, recording any improvement in biodiversity after clearing of IAPs.

The program CANOCO, an acronym for Canonical Community Ordinations (Ter Braak and Šmilauer 2002) was used to ordinate the data. Canonical Correspondence Analysis (CCA) was used for the integrated analysis of the two overall data sets: (1) benthic macroinvertebrate community structure (families and abundance) and (2) a set of physical and environmental variables.

CCA is designed to test for the significance of association between environmental variables with the variation in community structure, using a Monte Carlo permutation test included in CANOCO for Windows (Ter Braak and Šmilauer 2002).

Five CCA ordinations were performed, one for each of the three vegetation types, one for all the riparian vegetation together and the one for all the riparian vegetation types but considering major SASS5 indicator taxa (EPTO). The option to log transform data was selected for all the ordinations because the sampling units were randomly selected, resulting in high variation in number of individuals within sampling units. Outlying species were excluded from the analysis where necessary.

The main reason for separate ordinations was to compare the broad differences between the NAC vegetation types. Each riparian vegetation site had its own characteristic set of environmental variables and therefore the use of CCA to determine the effect of environmental variables was justified.

A regression analysis using STATISTICA software package (Statsoft Inc. 2003) was carried out at 95% confidence level within all three vegetation types, determining if ASPT scores and SASS5 scores varied in the same direction.

Analysis of Variance (ANOVA) using the STATISTICA program was carried out to assess the variance between all three vegetation types. Three separate ANOVA's were performed: for benthic macroinvertebrate taxa richness, for SASS5 and for ASPT scores. ANOVA is a more efficient method than multiple two-group studies analyzed via t-tests, and more information can be gained with fewer observations (Statsoft Inc. 2003). Each factor can be tested while controlling others, making ANOVA more statistically powerful than the simple t-test.

Adult Odonata

Total number of species was illustrated graphically to indicate the differences between SUs and in all the three vegetation types.

Multivariate analysis of Odonata abundance data was done with PRIMER v5 software (Clarke and Warwick 2001). Cluster analysis was used to examine the relationship between SUs and NAC riparian vegetation sites using group averaging and Bray Curtis similarity measures. The sampling units with similar biota were placed together in habitat clusters representing community patterns. Spearman Rank Correlation Coefficient was used to test any correlation between riparian vegetation sites.

Four CCA ordinations were performed, one for each of the three separate riparian vegetation sites and one for the combined riparian vegetation sites. Ordination analysis in this study was based on unimodal, direct analysis using the CANOCO for Windows program (Ter Braak and Šmilauer 2003). Monte Carlo Permutation tests for significance of the relation among adult Odonata with environmental variables.

Three regression analyses were carried out to determine the direction of variance within factors. Adult Odonata species richness was regressed against benthic macroinvertebrate taxa richness, SASS5 and ASPT scores.

ANOVA was also carried out to ascertain if there was significant variation between NAC vegetation types in terms of adult Odonata species richness.

CHAPTER 3

RESULTS

BENTHIC MACROINVERTEBRATES

Benthic macroinvertebrate taxa

Forty-two benthic macroinvertebrate families including Odonata larvae were recorded at a total of 71 sampling units (SUs) across natural, alien and cleared (NAC) vegetation types. These benthic macroinvertebrate families are presented in Table 3.1.1.

Table 3.1.1: Benthic macroinvertebrate taxa sampled in 71 sampling units from natural, alien and cleared vegetation types

		Vegetation types		
Taxon	**Sensitivity score**	Natural	Alien	Cleared
ANNELIDA				
Oligochaeta	1	√	√	√
CRUSTACEA				
Potamonautidae	3	√	√	√
Paleomonidae	10			√
PLECOPTERA				
Perlidae	12	√		√
EPHEMEROPTERA				
Baetidae 2 spp.	6		√	
Baetidae >2 spp.	12	√		√
Caenidae	6	√	√	√
Heptageniidae	13	√	√	√
Leptophlebiidae	9	√	√	√
Oligoneuridae	15	√	√	
Tricorythidae	9	√	√	√
ODONATA				
Chlorocyphidae	10	√	√	√
Synlestidae	8	√	√	√

Taxon	Sensitivity score	Vegetation types		
		Natural	Alien	Cleared
Coenagrionidae	4	√	√	√
Lestidae	8	√	√	√
Platycnemididae	10	√	√	√
Protoneuridae	8	√		√
Aeshnidae	8	√	√	√
Gomphidae	6	√	√	√
Libellulidae	4	√	√	√
HEMIPTERA				
Corixidae	3	√		
Gerridae	5	√	√	√
Notonectidae	3		√	
Veliidae	5	√	√	√
TRICHOPTERA				
Hydropsychidae 2 spp.	6		√	
Hydropsychidae >2 spp.	12	√		√
Psychomyiidae	8		√	
Leptoceridae	6	√		
COLEOPTERA				
Dytiscidae	5	√	√	√
Elmidae	8	√		√
Gyrinidae	5	√	√	√
Helodidae	12	√	√	√
Hydrophilidae	5			√
Psephenidae	10	√	√	
DIPTERA				
Athericidae	10	√	√	√
Chironomidae	2	√		√
Dixidae	10		√	
Ephydridae	3			√
Psychodidae	1		√	√
Simulidae	5		√	

		Vegetation types		
Taxon	**Sensitivity score**	Natural	Alien	Cleared
Tabanidae	5		√	
Tipulidae	5	√	√	√
GASTROPODA			√	√
Ancylidae	6	√		
Planorbinae	3			√

Cluster analysis for Ephemeroptera, Plecoptera, Trichoptera and Odonata taxa

Fig. 3.1.1 shows similarity between 71 SUs in terms of EPTO taxa richness and abundance. The dendrogram was examined for similarity clustering with the aim of detecting any correlation between EPTO taxa richness and vegetation type.

There was no clear clustering of SUs with similar vegetation structure (Fig. 3.1.1). The large cluster was for alien riparian vegetation site SUs, A08-A09 with 45% similarity. There were other smaller clusters of SUs, C55-C58 with 80% similarity; A14-A10 with 70% similarity and A18-A12 with 75% similarity which are dependent mainly on vegetation structure. Clusters, N43-N46, N31-C71 and N34-C72 consist of SUs with different vegetation structures. SUs with the highest similarity percentage (N43-N44; C56-C57; A18 and A21) had similar vegetation structure combinations. Thus vegetation type had a minimal effect on the benthic macroinvertebrate assemblages. SUs in close proximity, N43 and N44; N45 and N46; C56 and C57; A04 and A05; A11 and A12 had similar benthic macroinvertebrate assemblages, indicating that their adjacent positions along the River is a major determinant for their assemblages.

EPTO taxa

A total of nineteen EPTO families were recorded from 71 SUs. Eighteen of them were present in natural riparian vegetation SUs. Sixteen were recorded at each of the alien and cleared IAPs vegetation sites (Fig. 3.1.2). More than two Baetidae species were recorded from natural and cleared IAPs riparian vegetation, with only two recorded from alien vegetation (Table 3.1.2).

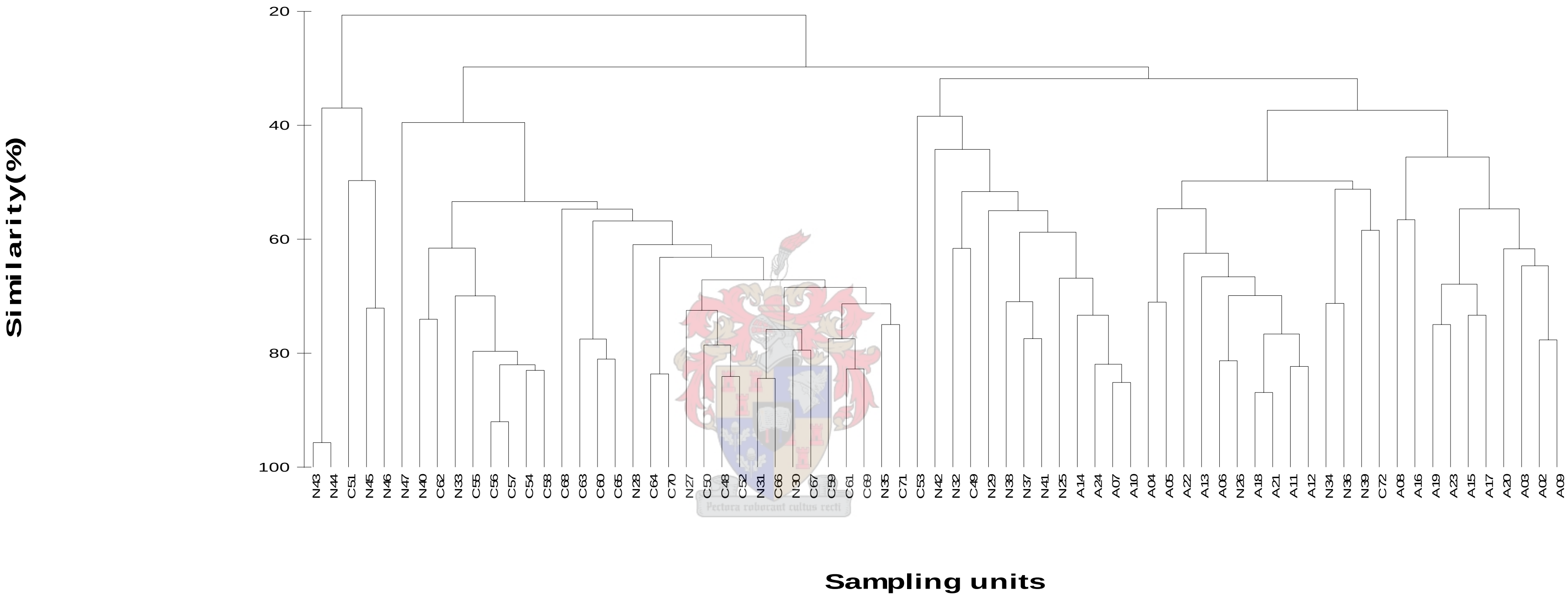

Figure 3.1.1: Clustering of the 71 sampling units in terms of major SASS5 indicator taxa (Ephemeroptera, Plecoptera, Trichoptera and Odonata) richness and abundance. Vegetation types: N = Natural, A = Alien, C = Cleared.

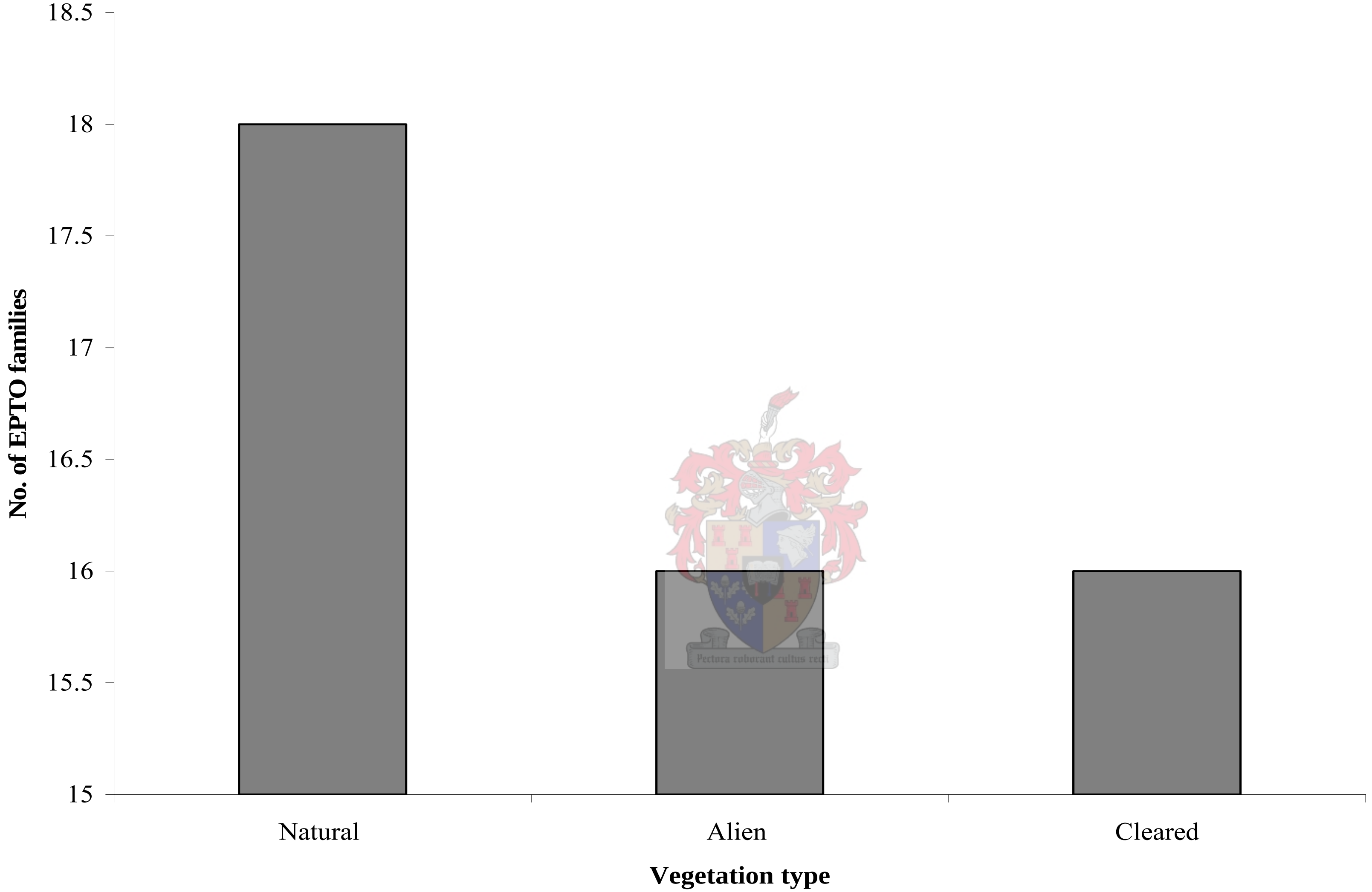

Figure 3.1.2: Number of Ephemeroptera, Plecoptera, Trichoptera and Odonata (EPTO) families recorded in 71 sampling units.

Table 3.1.2: Abundance of major SASS5 indicator taxa: Ephemeroptera, Plecoptera, Trichoptera and Odonata (EPTO) in all three vegetation types

	Vegetation types		
Taxon	Natural	Alien	Cleared
EPHEMEROPTERA			
Baetidae 2 spp.		318	
Baetidae >2 spp.	95		224
Caenidae	26	57	3
Heptageniidae	2	2	1
Leptophlebiidae	5	50	6
Oligoneuridae	2	25	
Tricorythidae	188	344	262
PLECOPTERA			
Perlidae	2		2
TRICHOPTERA			
Hydropsychidae 2 spp.		339	
Hydropsychidae >2 spp.	333		519
Psychomyiidae		7	
Leptoceridae	5		
ODONATA (larvae)			
Chlorocyphidae	7	8	50
Synlestidae	14	27	1
Coenagrionidae	5	49	16
Lestidae	2	1	2
Platycnemididae	9	19	12
Protoneuridae	4		9
Aeshnidae	9	118	12
Gomphidae	162	78	93
Libellulidae	1	1	14

High abundance of family Trichorithidae, Caenidae, Aeshnidae and Coenagrionidae was from alien riparian vegetation (Table 3.1.2). Natural vegetation supported many EPTO taxa.

Clustering of sampling units in terms of overall benthic macroinvertebrates

When SUs were clustered in terms of overall benthic macroinvertebrate taxa richness and abundance, there were no clear clusters with similar vegetation structure (Fig. 3.1.3). However there were small clusters of SUs with similar vegetation structure: A16-A09 with 43% similarity, N39-N36 with 45% similarity, N47-N46 with 46% similarity, C68-C55 with 60% similarity and N33-N28 with 63% similarity.

Benthic macroinvertebrate taxa richness, SASS5 and ASPT scores

Different number of taxa, SASS5 scores and average score per taxon (ASPT) were recorded from sampling units (SUs) at similar riparian vegetation structure (Figs 3.1.4, 3.1.5, 3.1.6, 3.1.7, 3.1.8 and 3.1.9). Depending on the microhabitats available within the SU, number of taxa was also different even at SUs in close proximity.

The highest number of taxa (18) was recorded at SU A12, located in alien riparian vegetation site (Fig. 3.1.6). However, the highest ASPT score was at SU C65 (Fig. 3.1.8). An ASPT score of 8.5 was recorded, with SU supporting few but more sensitive taxa. SU A12 from alien riparian vegetation had a highest SASS5 score with its large number of taxa (Fig. 3.1.7). Its ASPT was lower than that of SU C65 (Fig. 3.1.8), because it had many less-sensitive taxa.

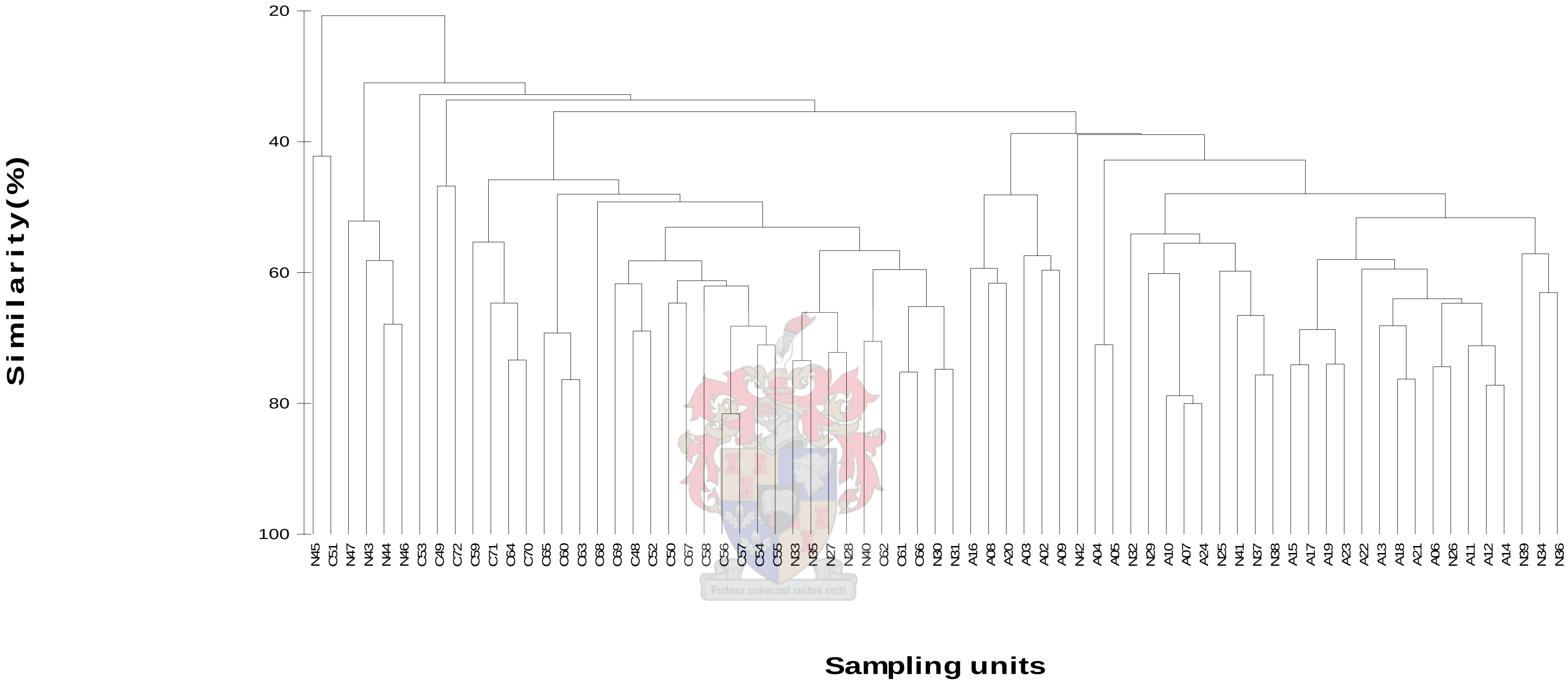

Figure 3.1.3: Clustering of the 71 sampling units in terms of overall benthic macroinvertebrate taxon richness and abundance. Vegetation types: N=Natural, A = Alien, C = Cleared.

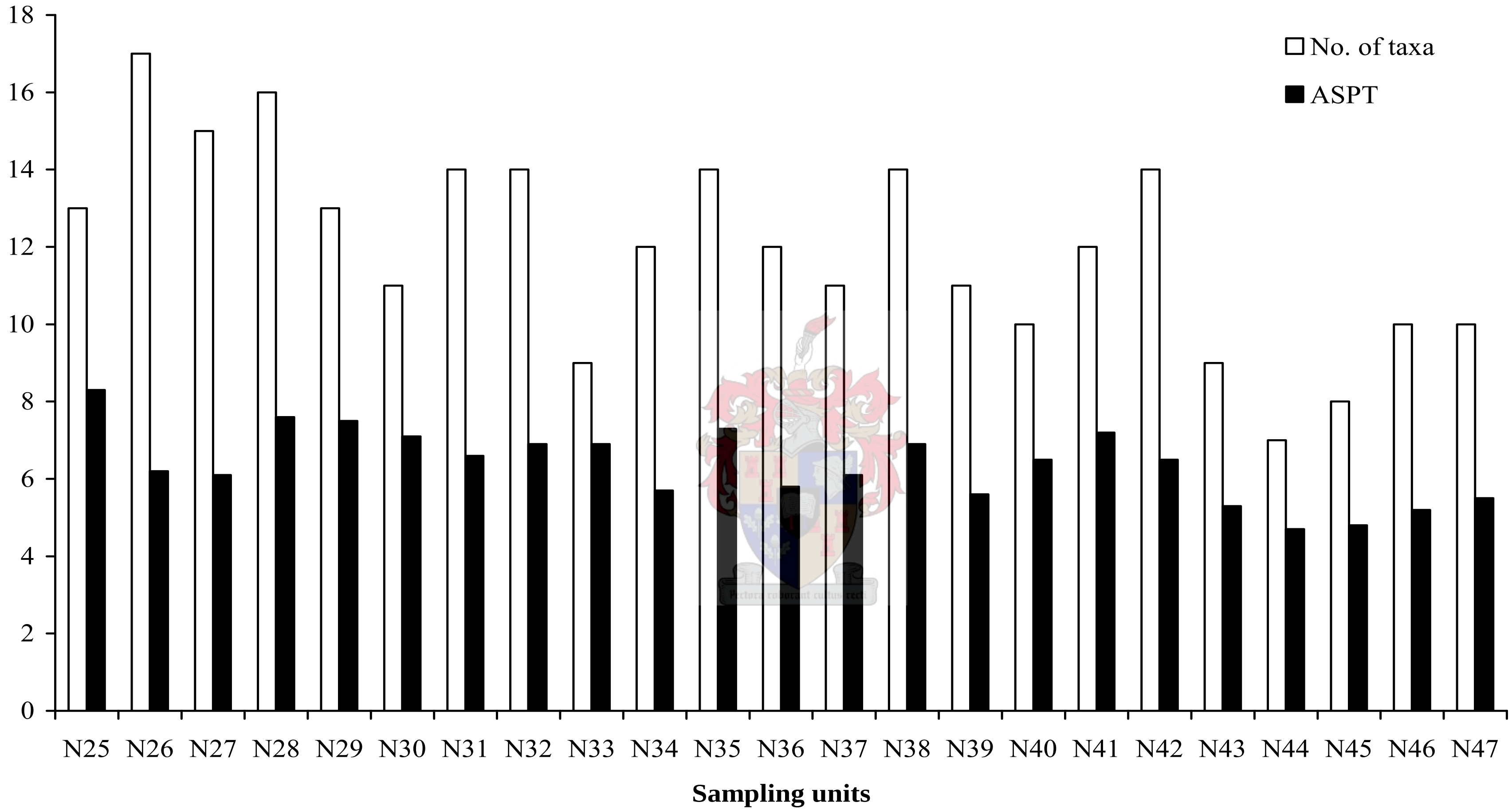

Figure 3.1.4: Benthic macroinvertebrate taxa and average score per taxon (ASPT) in natural vegetation.

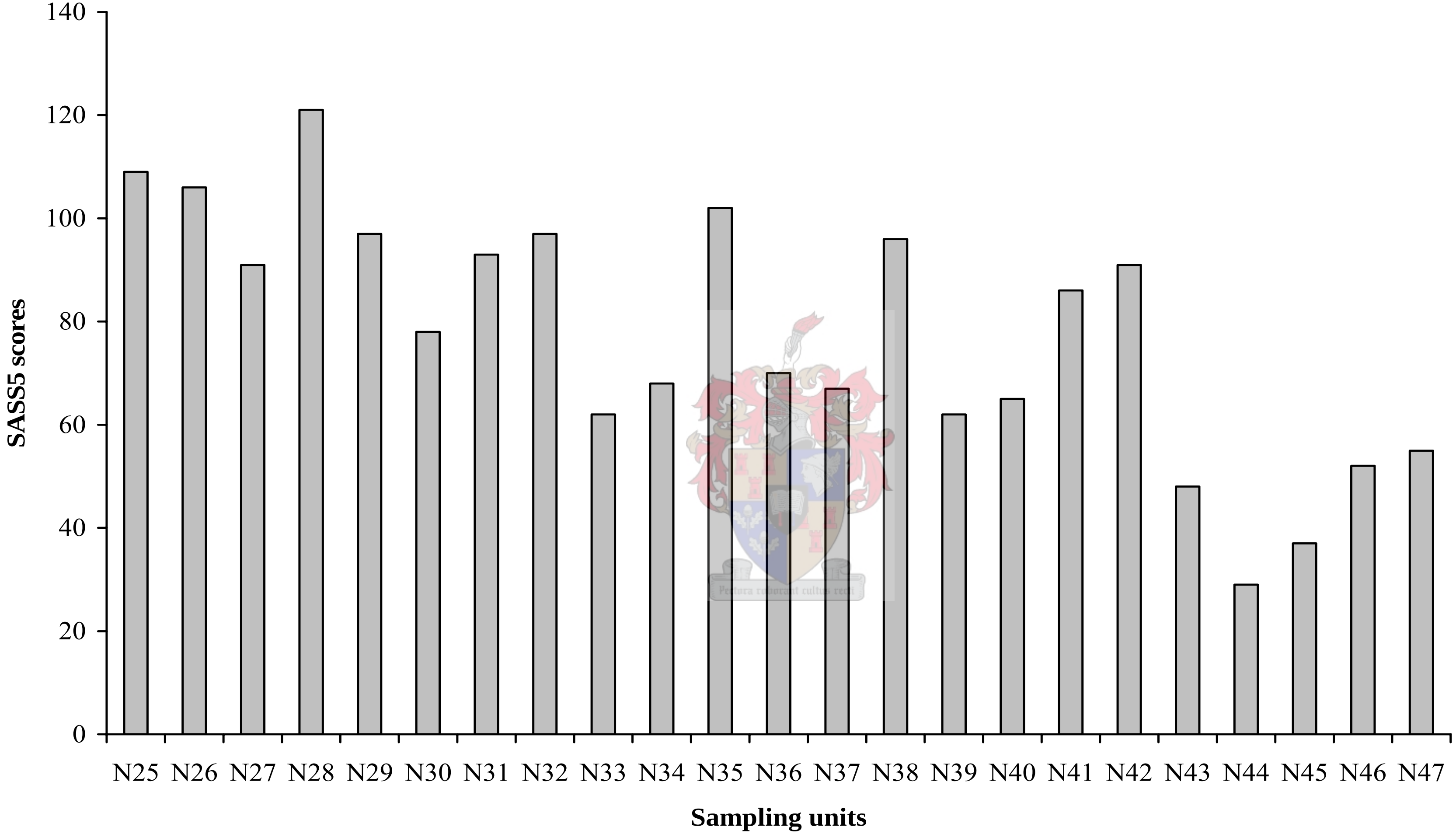

Figure 3.1.5: SASS5 scores in natural vegetation.

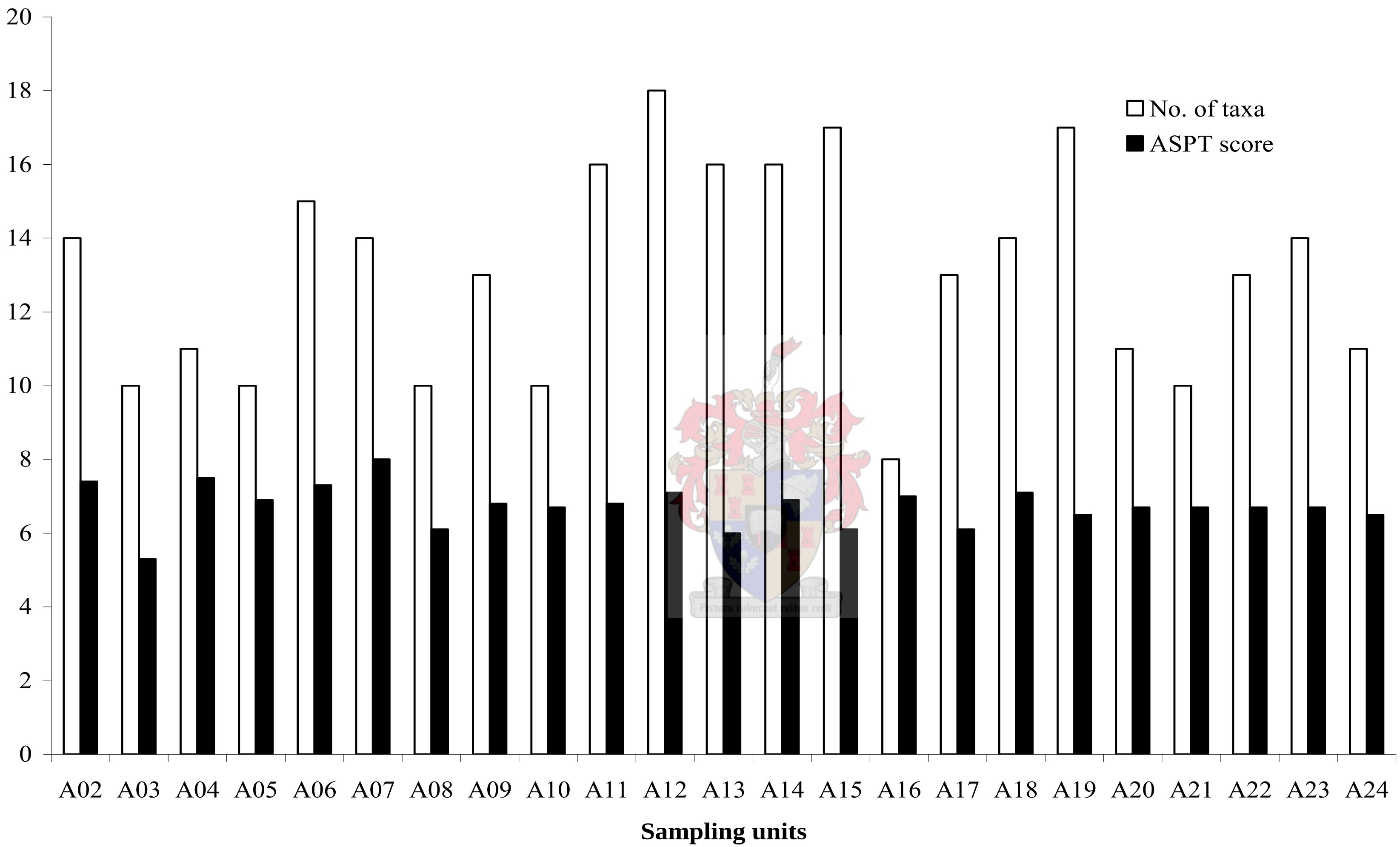

Figure 3.1.6: Benthic macroinvertebrate taxa and average score per taxon (ASPT) scores in alien vegetation.

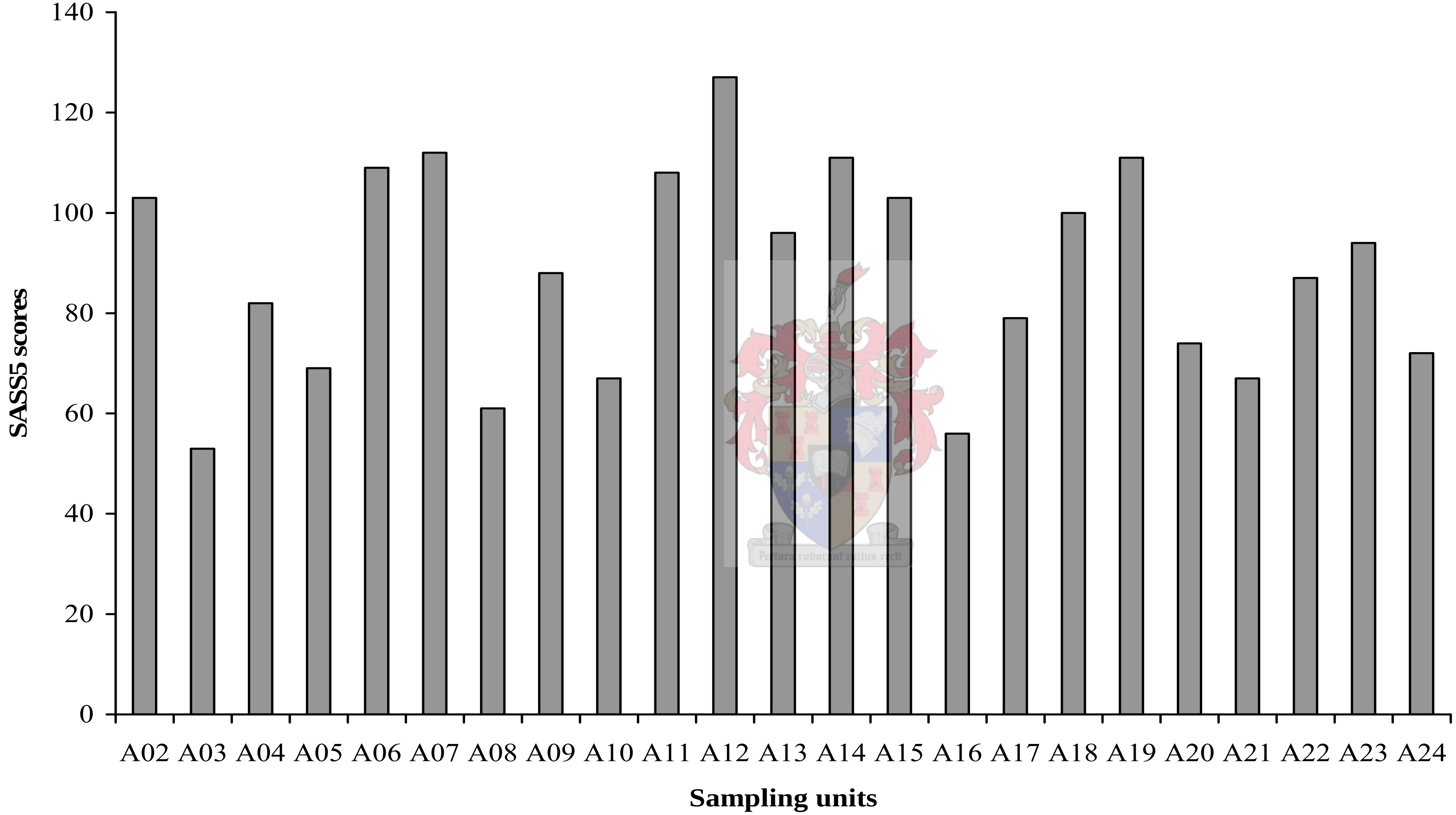

Figure 3.1.7: SASS5 scores in alien vegetation.

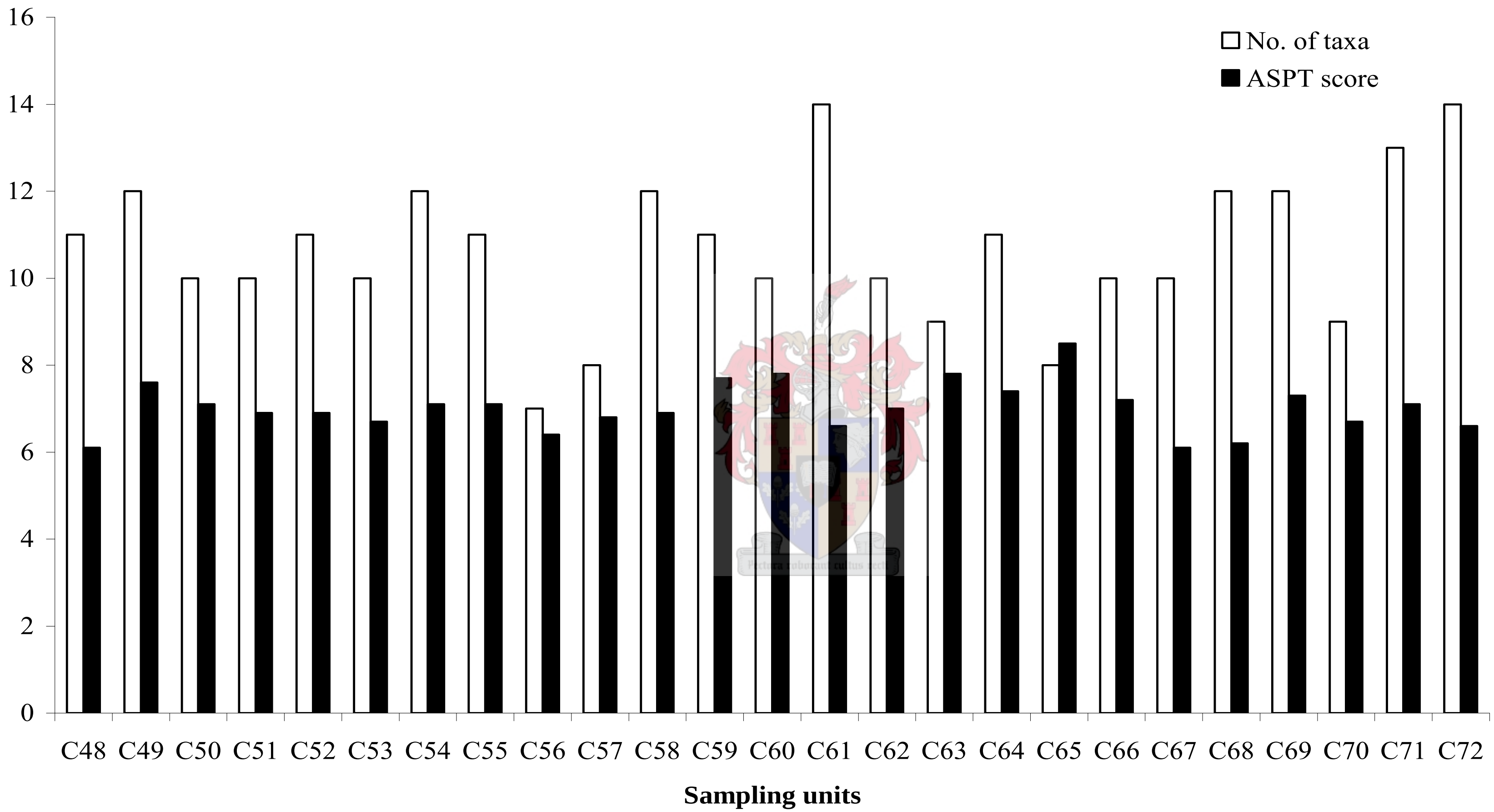

Figure 3.1.8: Benthic macroinvertebrate taxa and average score per taxon (ASPT) scores in cleared vegetation.

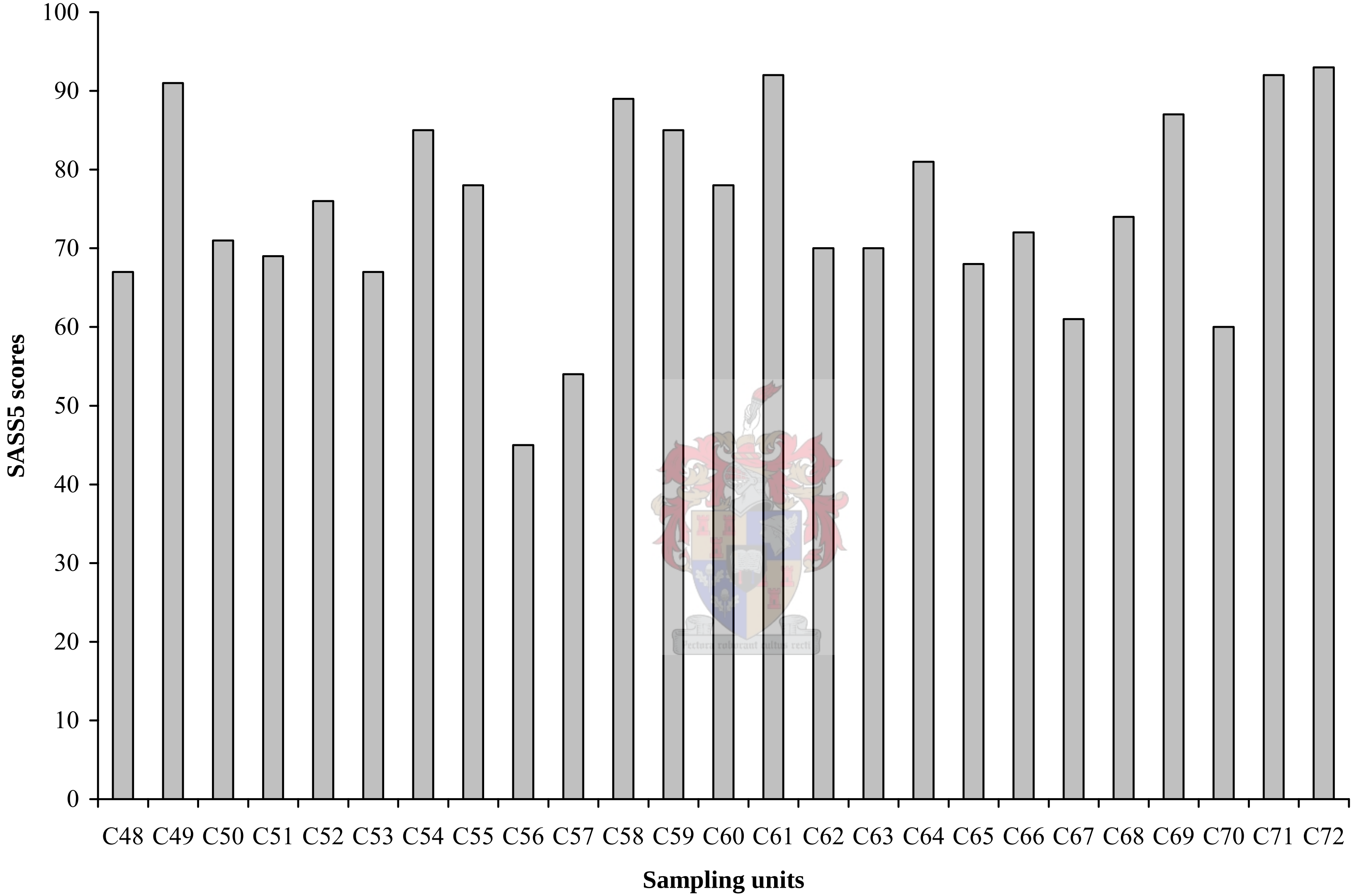

Figure 3.1.9: SASS5 scores in cleared vegetation.

Taxon richness, ASPT and SASS5 scores

To further investigate the role of riparian vegetation type on benthic macroinvertebrate assemblages, number of taxa, ASPT and SASS5 scores were illustrated (Figs 3.1.10 and 3.1.11). Natural and cleared invasive alien plants (IAPs) vegetation types supported more benthic macroinvertebrate families compared to alien vegetation (Fig. 3.1.11). Thirty-three families were recorded at each of the natural and cleared IAPs sites. Only 31 families were supported by alien vegetation. Most families that were lost to alien vegetation were present in natural riparian vegetation.

The highest SASS5 score was obtained from natural vegetation, followed by cleared and alien vegetation sites respectively (Fig. 3.1.10). There is a clear pattern of response of benthic macroinvertebrate assemblages to a change in the vegetation type. SASS5 score was reduced in alien vegetation but shows an increase in cleared vegetation site.

Although natural and cleared vegetations shared equal number of taxa, natural vegetation had higher ASPT score (Fig. 3.1.11). Natural vegetation had ASPT score of 7.4 compared to 6.9 at each of the alien and cleared vegetation. Natural vegetation supported many highly-sensitive taxa than cleared vegetation and hence high ASPT score.

SASS5 and ASPT score in natural vegetation show an impaired system, with ASPT score in each of the alien and cleared vegetation indicating a slightly impoverished system (Table 3.1.3). These results show that vegetation type is important in determining the similarity between different sites in terms of macroinvertebrate assemblages.

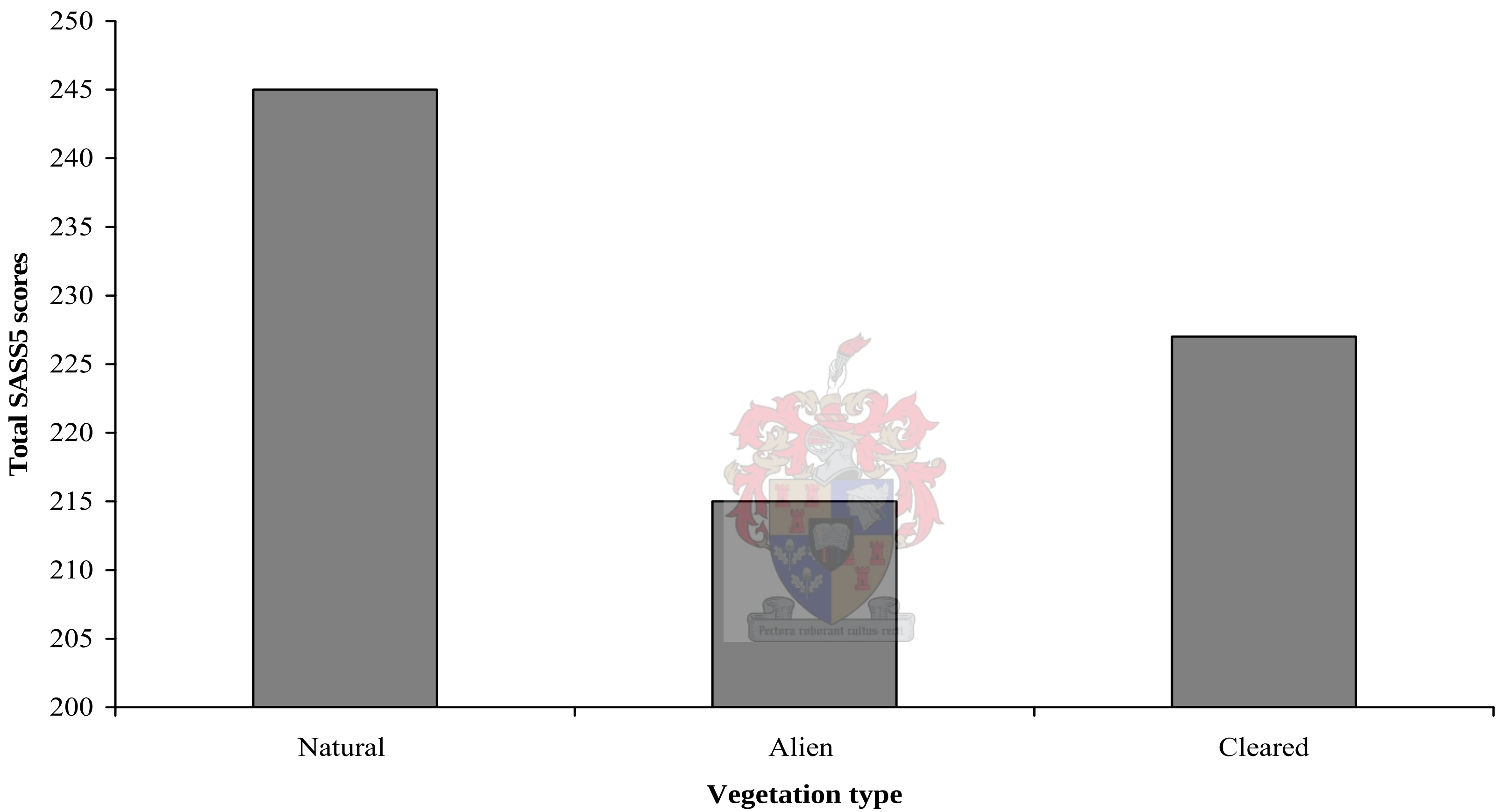

Figure 3.1.10: Overall SASS5 scores in natural, alien and cleared vegetation types.

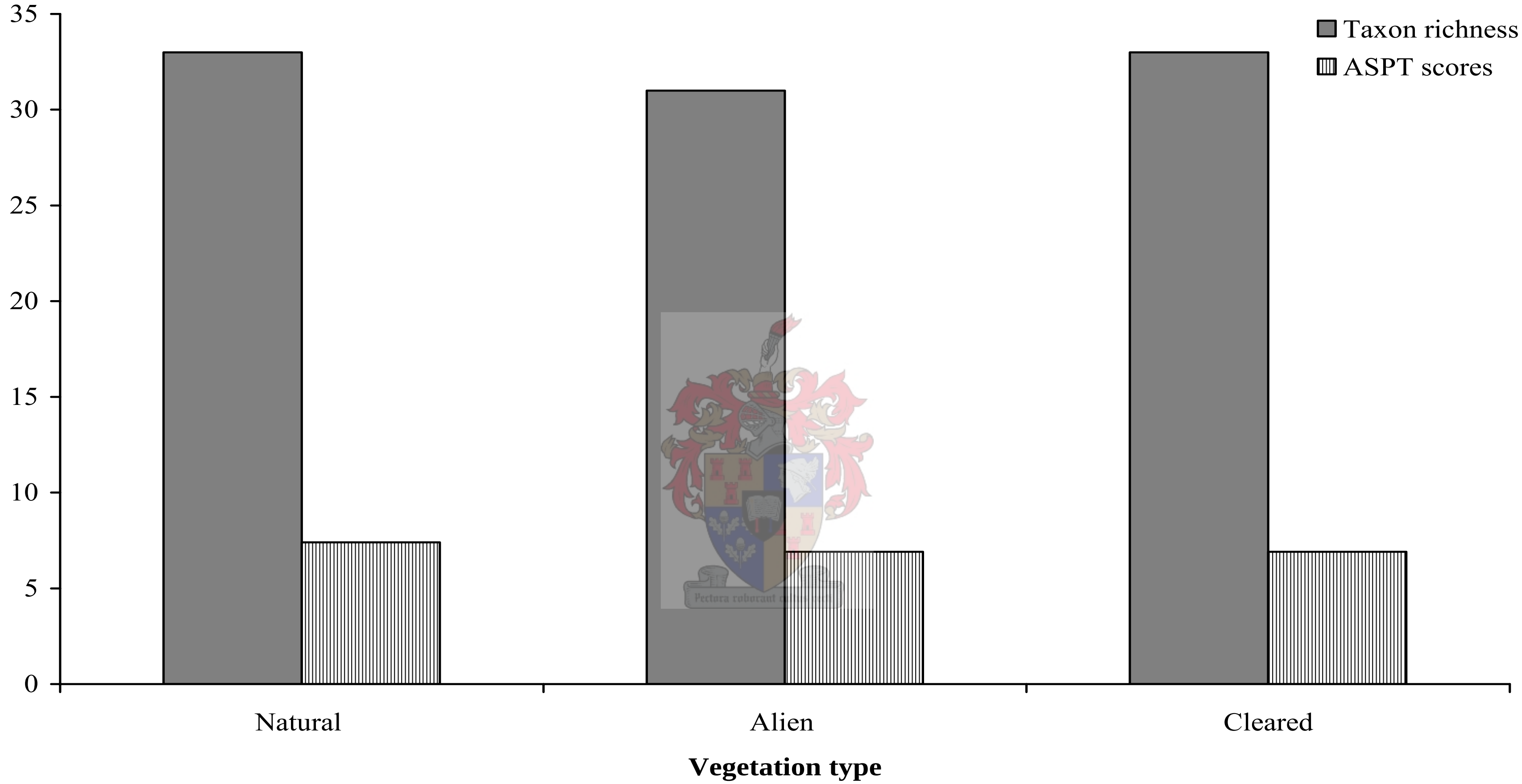

Figure 3.1.11: Benthic macroinvertebrate taxon richness and average score per taxon (ASPT) in all the three vegetation types.

Table 3.1.3: Reference ecological conditions of River based on Water Research Commission classification. SASS5 = South African Scoring System version 5, ASPT = Average Score Per Taxon

Class	Description	SASS5 Score	ASPT score
A	Unimpacted. High taxa diversity with numerous sensitive taxa	>180	>7
B	Slightly impacted. High taxa diversity but with fewer sensitive taxa	180-160	6.9-6.0
C	Moderately impacted. Moderate diversity of taxa	160-120	5.9-5.0
D	Considerably impacted. Most tolerant taxa present	120-51	<5
E	Severely impacted. Only tolerant taxa present	<51	Variable

Table 3.1.4: Spearman Rank order Correlation Coefficients for natural, alien and cleared vegetation types in terms of taxon richness, SASS5 and ASPT scores. MD pairwise deleted. Marked correlations are significant at p <.05

VEGETATION TYPES	Natural	Alien	Cleared
Natural		0.130	0.296 #
Alien	0.130		0.102
Cleared	0.296 #	0.102	

Clustering of vegetation types based on taxon richness, SASS5 and ASPT scores

Natural and cleared vegetation types were clustered together with 87% similarity. The two were later clustered with alien vegetation site with 79% similarity (Fig. 3.1.12). It is indicated that natural vegetation and cleared vegetation are more similar. The clearing of invasive aliens benefitted the site to such an extent that it was comparable to the natural site in terms of benthic macroinvertebrate assemblages.

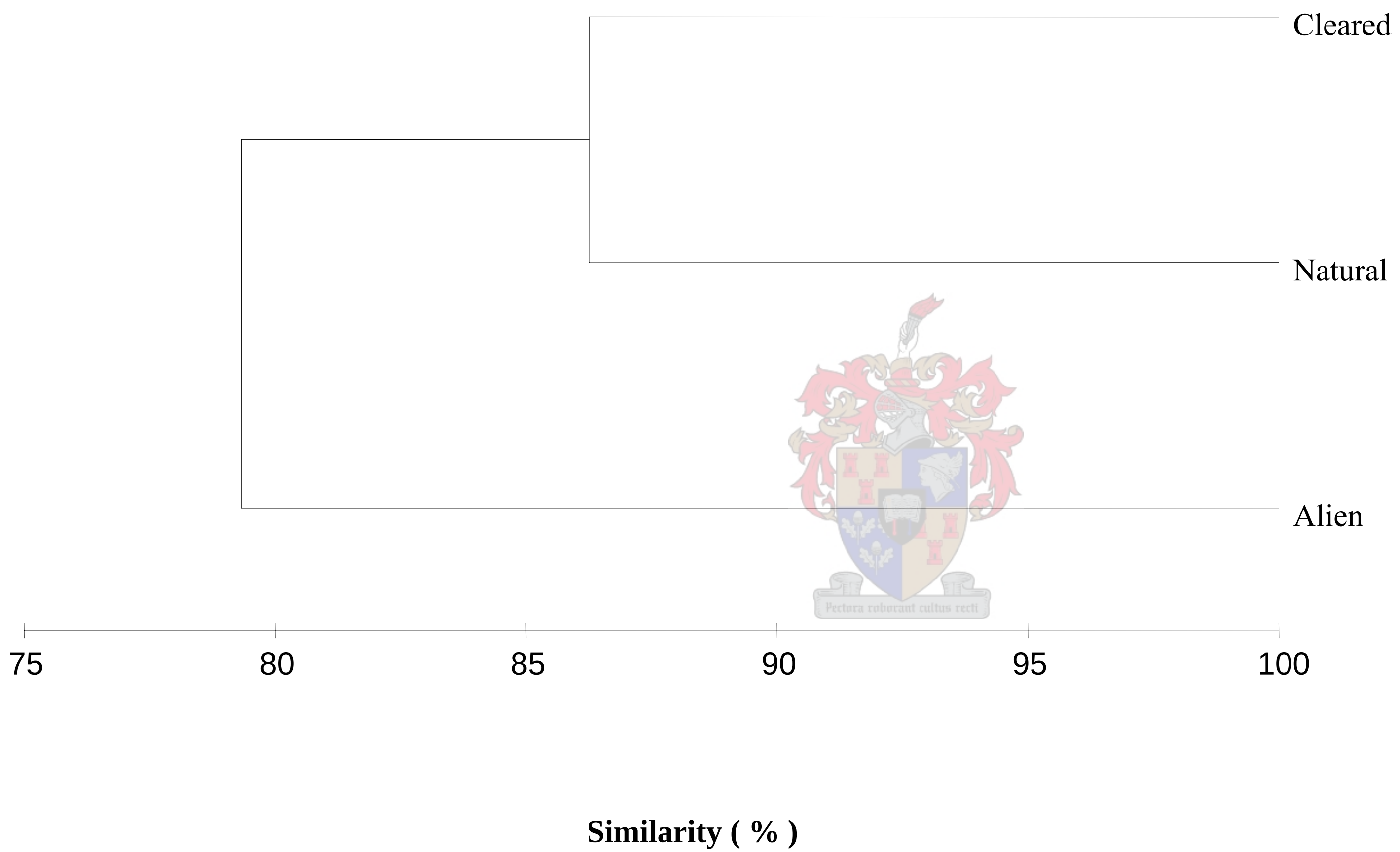

Figure 3.1.12: Clustering of natural, alien, and cleared vegetation types in terms of taxon richness, South African Scoring System version 5 (SASS5) and average score per taxon (ASPT).

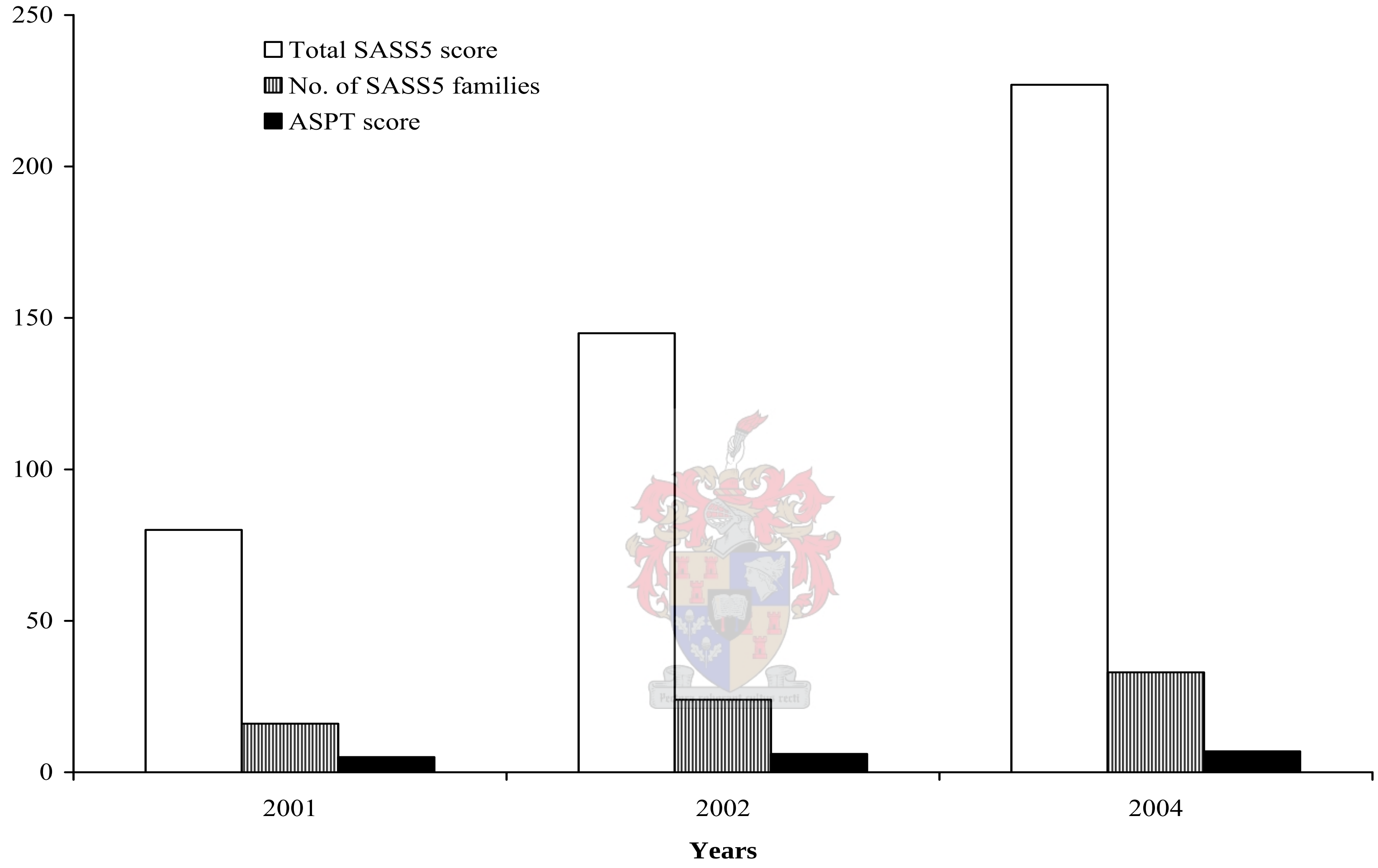

Figure 3.1.13: SASS5 scores and families, and ASPT scores, for the years 2001, 2002 and 2004 recorded from Lutanandwa River (cleared vegetation in Entabeni plantation).

Biodiversity improvement in cleared IAPs site

Fig. 3.1.13 compares SASS5 results obtained from Entabeni plantation in 2001, 2002 and 2004, illustrating recovery of benthic macroinvertebrate diversity after clearing of invasive alien plants (IAPs) which started in 1999. SASS scores from the Lutanandwa River in 2001 and 2002 (Diedericks 2002) were pooled for comparison with current results. No SASS5 was conducted during 2003. There is a clear pattern of recovery of benthic macroinvertebrate over these few years.

The River had an ASPT score of 5.0 during 2001 but improved to 6.0 and 6.9 during 2002 and 2004 respectively. Only 16 families were recorded in 2001, with 24 and 33 recorded in 2002 and 2004 respectively. These results show that clearing of IAPs clearly benefitted the benthic macroinvertebrate assemblages.

Table 3.1.5: Average values for measured environmental variables during the benthic macroinvertebrates sampling period

	Vegetation types		
Environmental variables	Natural	Alien	Cleared
Elevation (m)	999.6	1006.3	728.8
Temperature (°C)	16.5	18.07	18.96
Conductivity (mS/cm)	0.12	0.11	0.076
Dissolved Oxygen (mg/L)	7.42	7.40	8.57
pH	7.77	7.13	7.70

Environmental variables and benthic macroinvertebrate assemblages

CCA ordination diagrams are presented in Figs 3.1.14 and 3.1.15. Fig. 3.1.14 shows the arrangement of macroinvertebrate taxa in natural vegetation, relative to their environmental variables in Fig. 3.1.15. The Monte Carlo tests resulted in axes which are significant for this ordination (F = 1.510, p = 0.028 with 499 permutations). Benthic macroinvertebrates–environmental variables correlation is fairly high, with shade accounting for most of the variation in benthic macroinvertebrate in natural vegetation (F = 3.210, p =

0.002). Therefore, the null hypothesis that environmental variables had no effect on benthic macroinvertebrate assemblages is rejected. Environmental variables were accounted for 43% variability in benthic macroinvertebrate assemblages, with shade alone accounting for 32% of the variation (Fig. 3.1.15).

Fig. 3.1.16 is a triplot showing the ordinations of benthic macroinvertebrate taxa, environmental variables and SUs at which species were recorded in alien vegetation site. The Monte Carlo test showed that all axes are not significant, accepting the null hypothesis that environmental variables had no effect in benthic macroinvertebrate assemblages ($F = 1.272$, $p = 0.058$). Conductivity ($F = 2.311$, $p = 0.010$), pH ($F = 2.193$, $p = 0.002$) and micro habitats ($F = 2.124$, $p = 0.032$) account for 24%, 23%, and 22% in total variation respectively, which are too low for significant variation among benthic macroinvertebrates in invaded areas.

The benthic macroinvertebrate taxa in cleared vegetation site are given in the CCA ordination (Fig. 3.1.17). Environmental variables influencing them are given in Fig. 3.1.18. A summary of Monte Carlo permutation tests indicates that the effects of environmental variables are highly significant ($F = 1.734$, $p = 0.002$), accounting for 77.4% variation. Microhabitats ($F = 3.073$, $p = 0.010$) accounted for most of the variation (25%), and the shade cover ($F = 1.683$, $p = 0.036$) accounted for 15% of the total variation in benthic macroinvertebrate assemblages. Dissolved Oxygen ($F = 1.100$, $p = 0.324$), Flow ($F = 1.046$, $p = 0.414$), elevation ($F = 1.029$, $p = 0.456$), temperature ($F = 0.997$, $p = 0.446$), pH ($F = 0.948$, $p = 0.510$) and conductivity ($F = 0.821$, $p = 0.706$) had no significant effect on the macroinvertebrate assemblages in cleared areas.

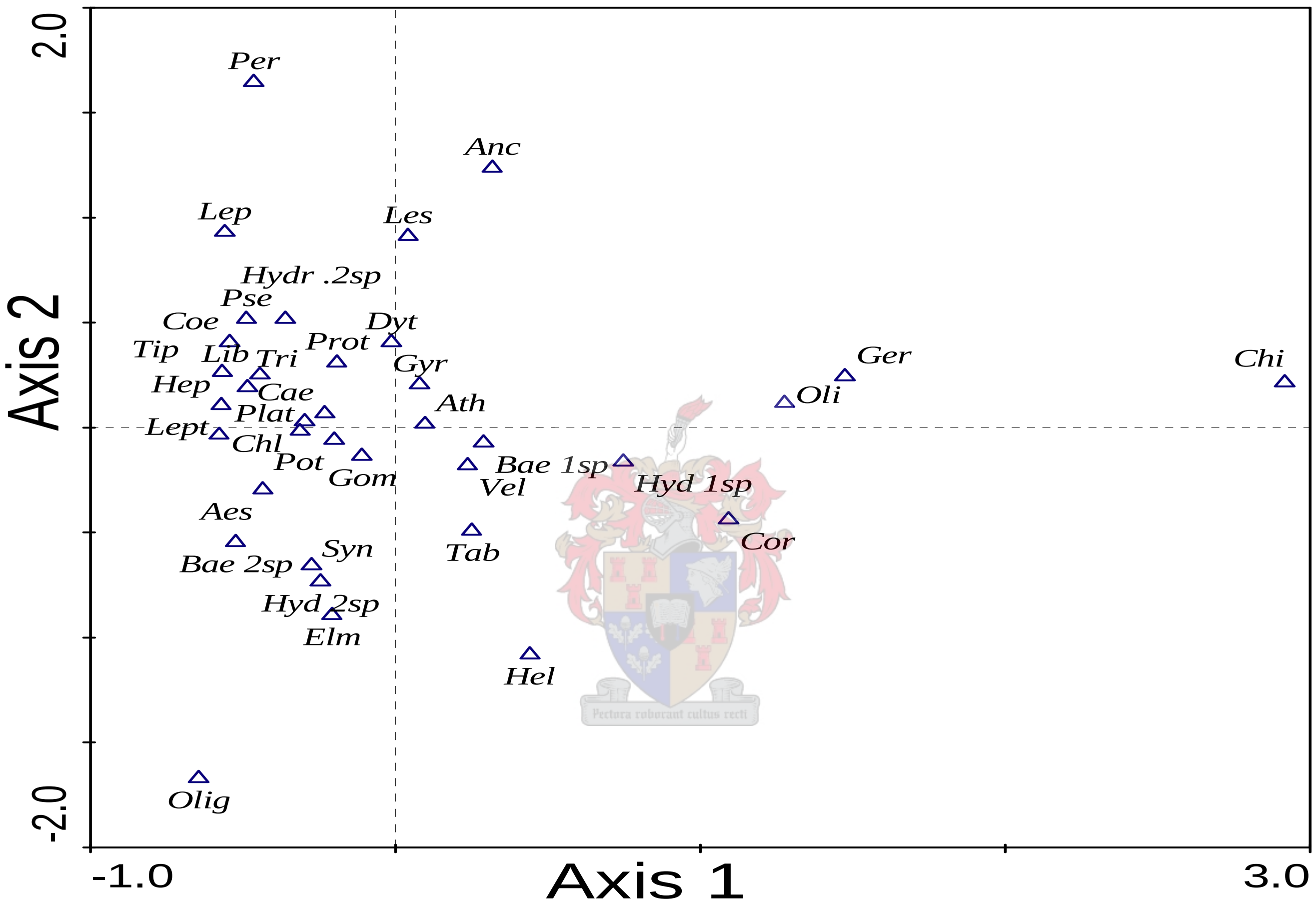

Figure 3.1.14: Canonical Correspondence Analysis (CCA) ordination diagram with benthic macroinvertebrate families in natural vegetation. The arrangement of families can be related to the environmental variables in Fig. 3.1.15. Full family names are given in Appendix 1.

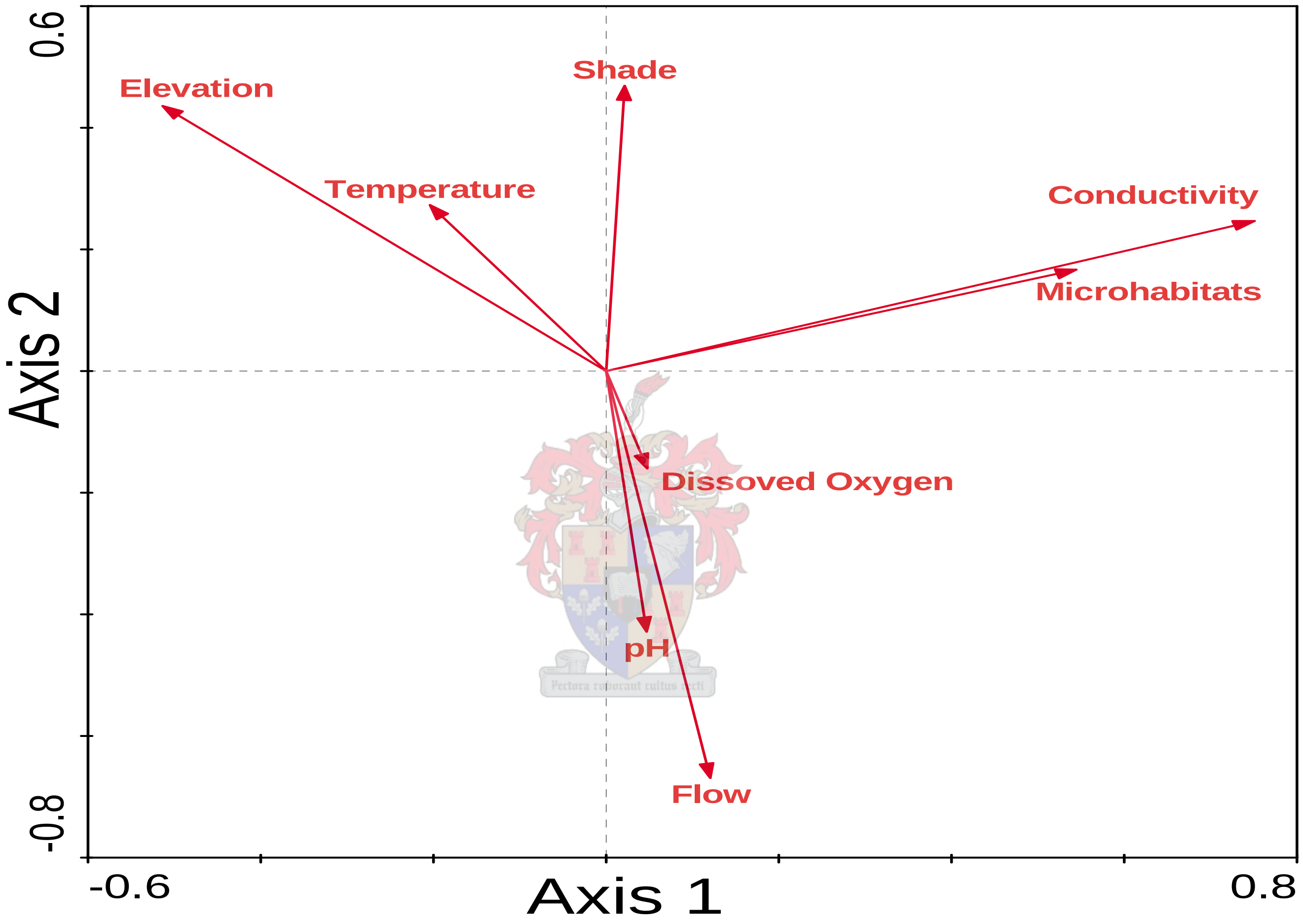

Figure 3.1.15: Canonical Correspondence Analysis (CCA) ordination diagram with environmental variables at natural vegetation.

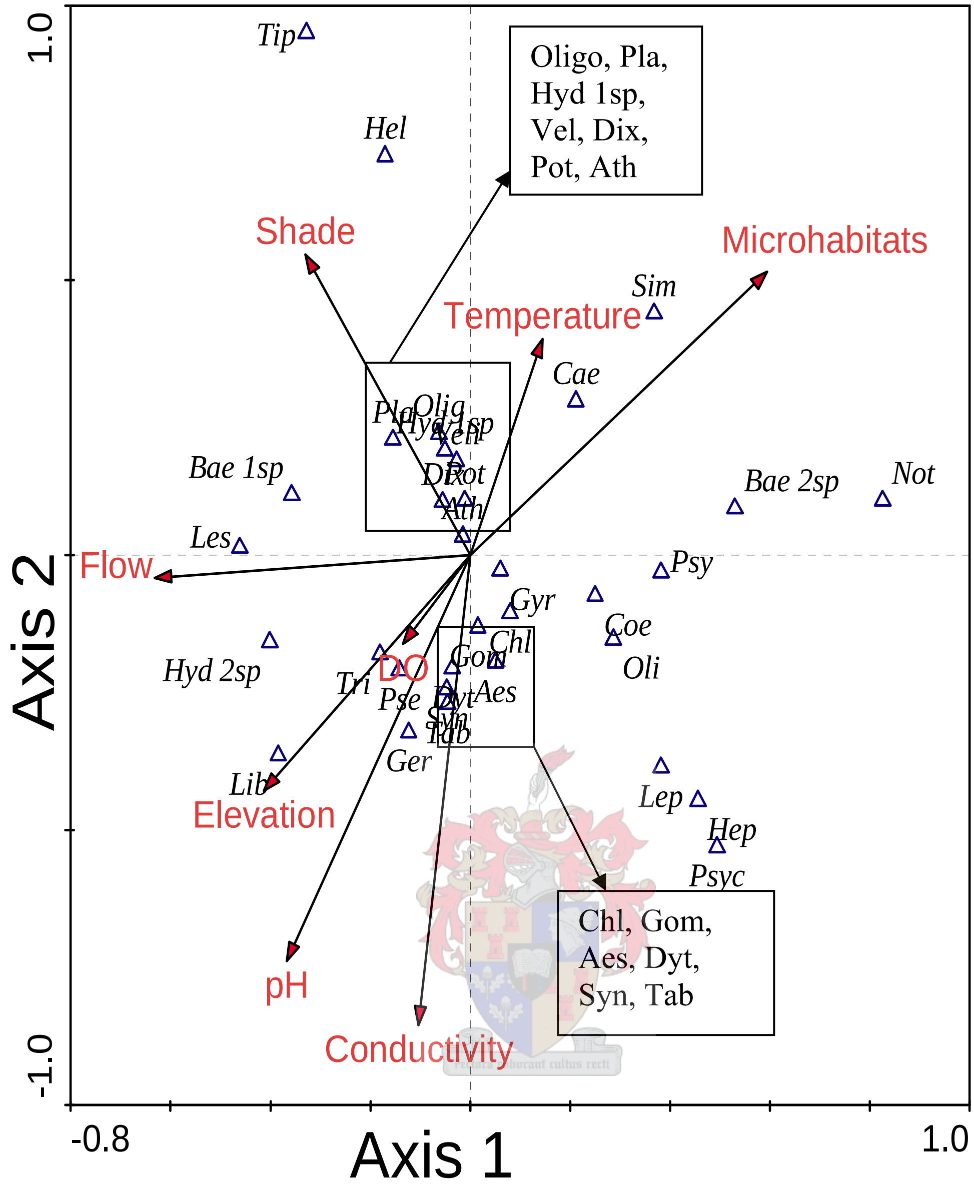

Figure 3.1.16: Canonical Correspondence Analysis (CCA) ordination diagram with benthic macroinvertebrate families (light abbreviations) and environmental variables (bold names) in alien vegetation. Environmental variable: DO = Dissolved Oxygen. Full family names are presented in Appendix 1.

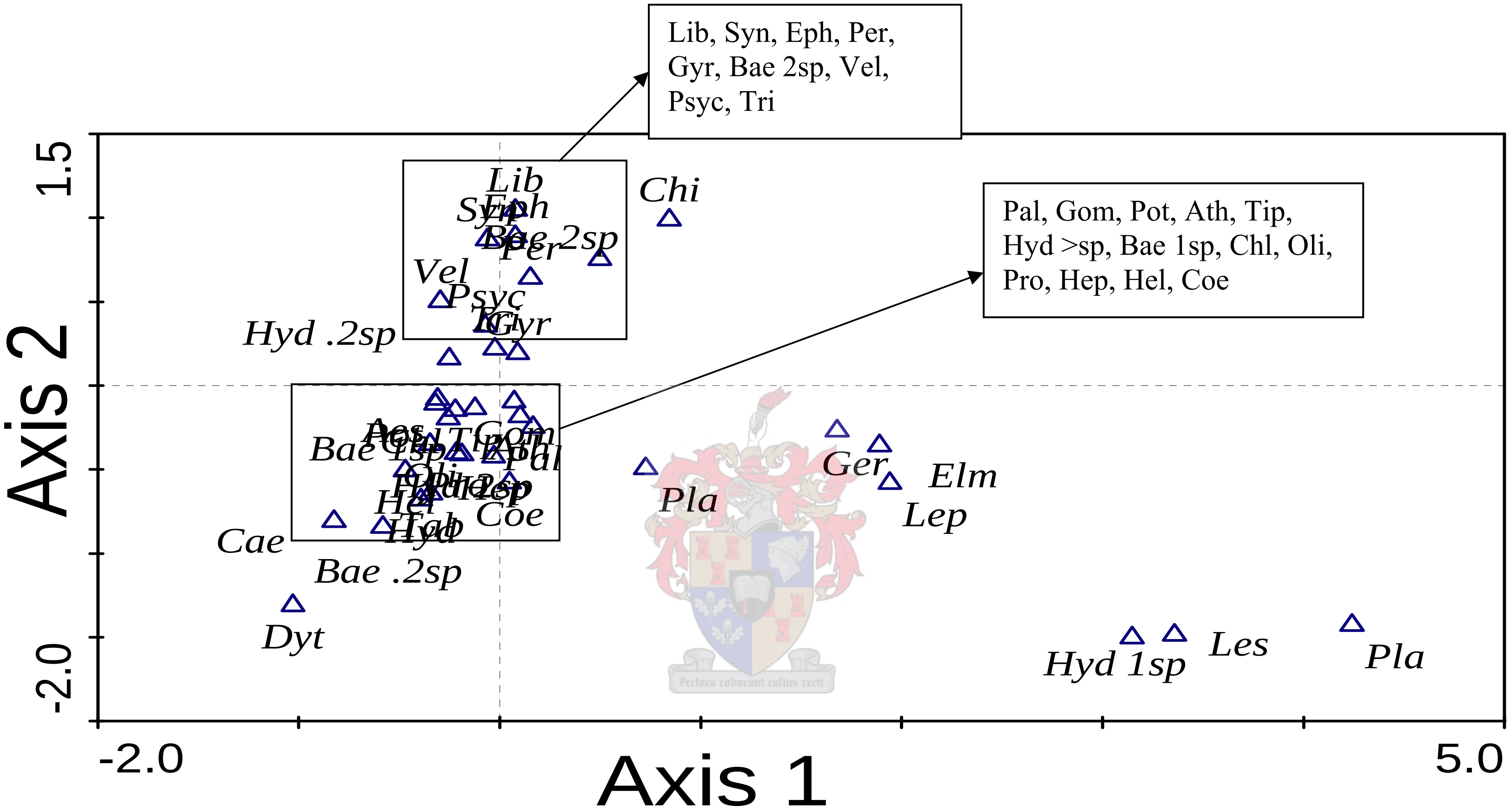

Figure 3.1.17: Canonical Correspondence Analysis (CCA) ordination diagram with benthic macroinvertebrate taxa at cleared vegetation. The arrangement of families can be related to the environmental variables in Fig. 3.1.18. Full family names are presented in Appendix 1.

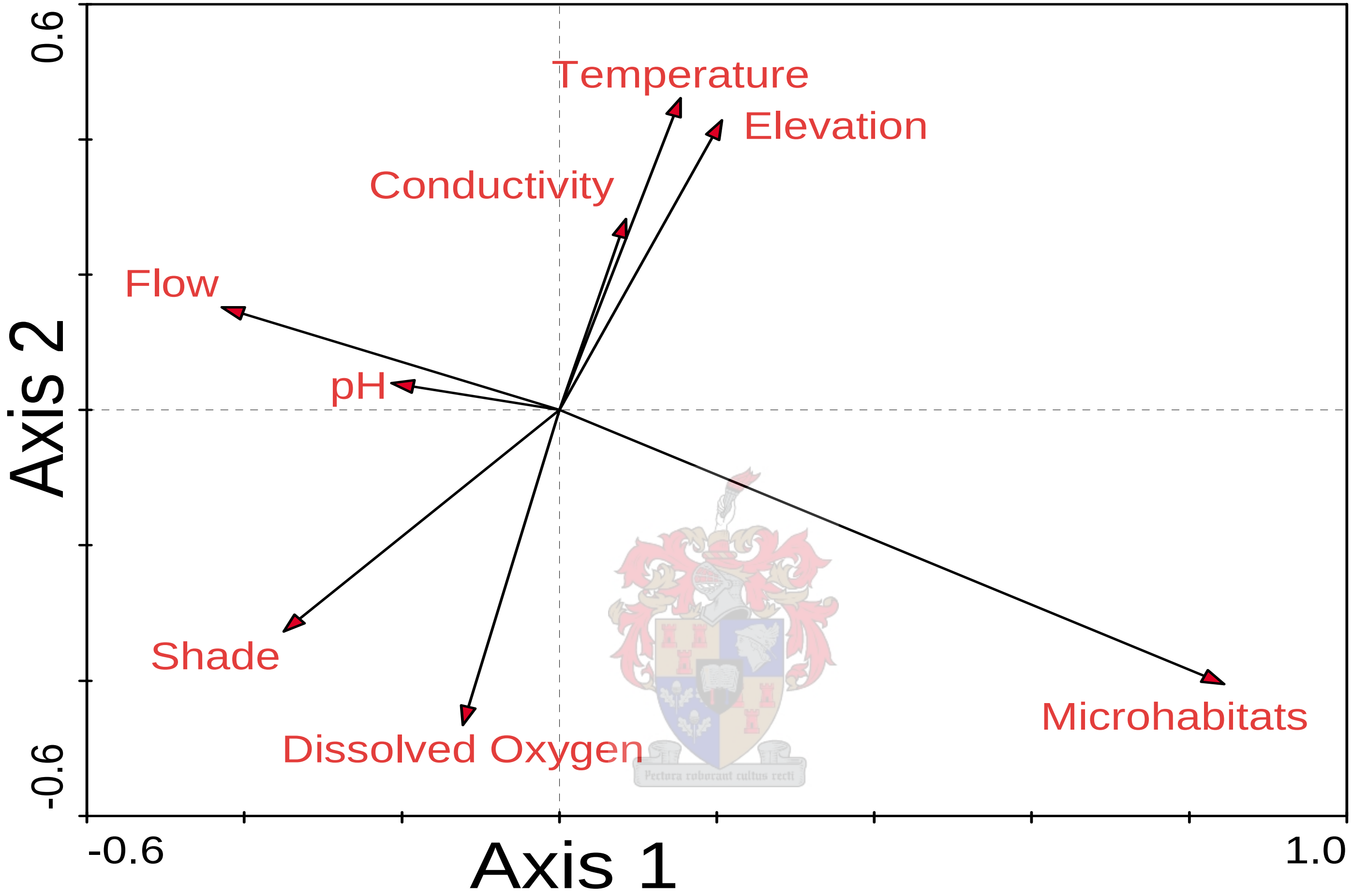

Figure 3.1.18: Canonical Correspondence Analysis (CCA) ordination diagram with environmental variables influencing macroinvertebrate assemblages at cleared vegetation.

Fig. 3.1.19 shows arrangement of EPTO families in all the three vegetation types (i.e. natural, alien and cleared) with the environmental variables that are accounted for the variation in assemblages. Environmental variables altogether account for 54.2% in the variability of EPTO taxa in all the three vegetation types. The effects of environmental variables are highly significant ($F = 2.614$, $p = 0.002$). Therefore, the null hypothesis that environmental variables had no effect in EPTO taxa assemblages is rejected.

A CCA ordination of overall benthic macroinvertebrate taxa with environmental variables is given in Fig. 3.1.20. Monte Carlo permutation test showed that environmental variables had a significant effect ($F = 2.746$, $p = 0.002$) in the variability of benthic macroinvertebrate assemblages. Therefore, the null hypothesis that environmental variables had no effect in benthic macroinvertebrate assemblages is rejected. Vegetation structure had no significant effect in the CCA ordination of individual vegetation type (Figs 3.1.15, 3.1.16 and 3.1.18), but had a significant effect ($F= 5.237$, $p = 0.002$) in the CCA ordination of overall vegetation types data (Figs 3.1.19 and 3.1.20).

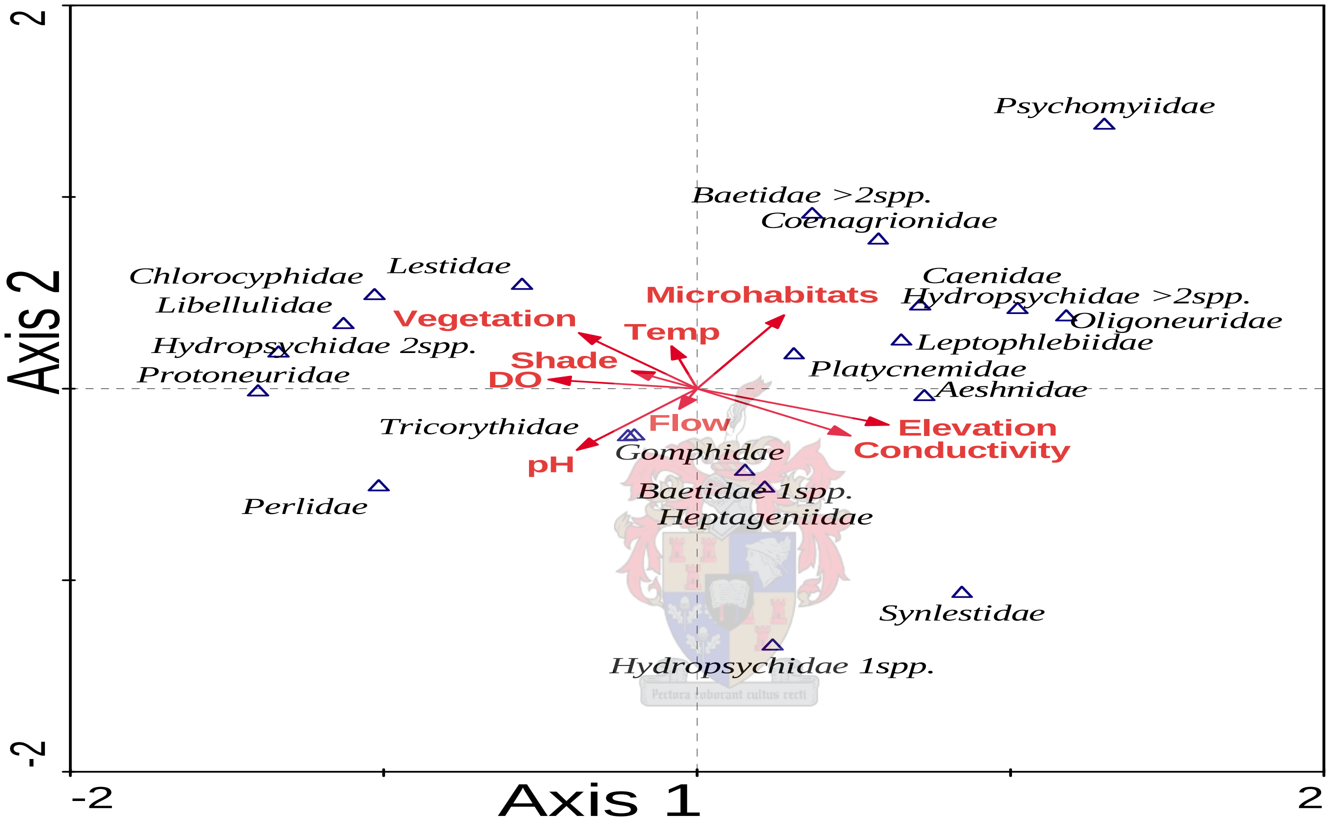

Figure 3.1.19: Canonical Correspondence Analysis (CCA) ordination diagram with Ephemeroptera, Plecoptera, Trichoptera and Odonata (EPTO) taxa and environmental variables influencing their assemblages at natural, alien and cleared vegetation sites.

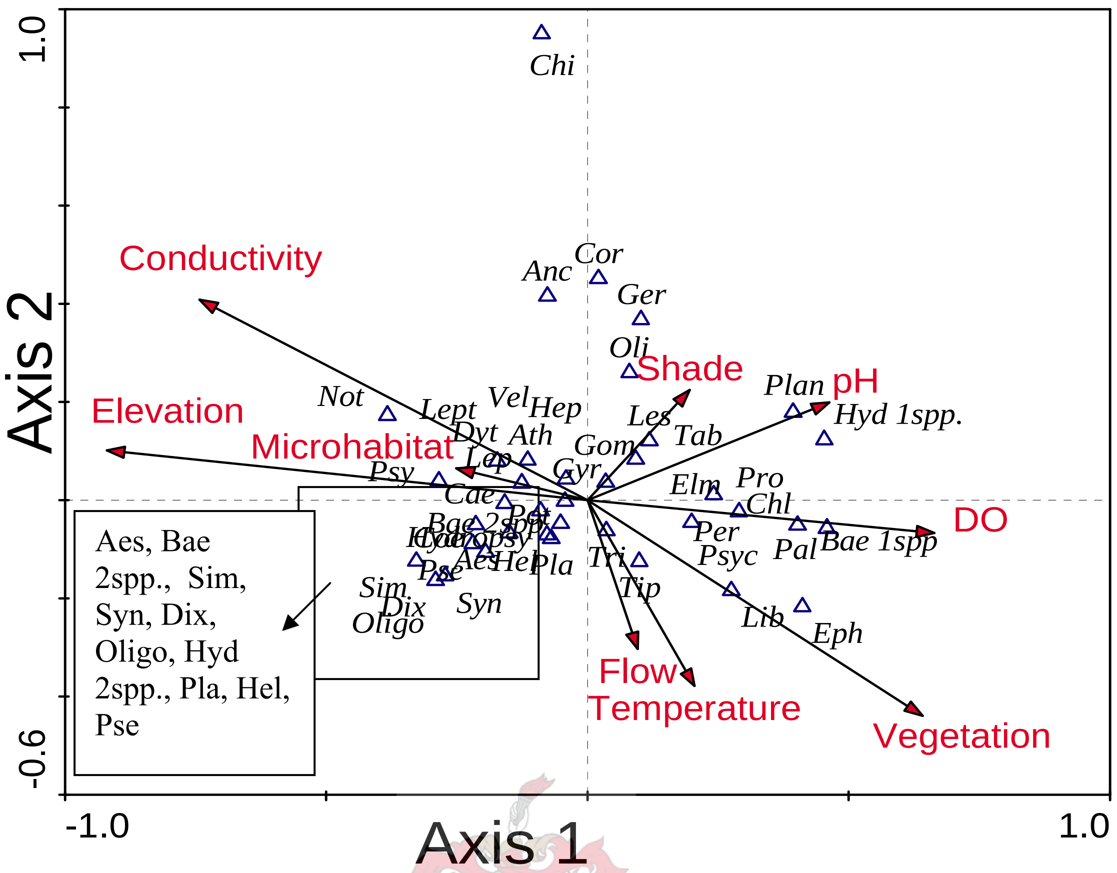

Figure 3.1.20: Canonical Correspondence Analysis (CCA) ordination diagram with overall environmental variables (bold names) influencing benthic macroinvertebrate assemblages at natural, alien and cleared vegetation sites. DO = Dissolved Oxygen. Full family names are presented in Appendix 1.

Variations between ASPT and SASS5 score

Using regression analysis to evaluate the relationship between SASS5 and ASPT scores at all SUs, it was found that the SASS5 score was positive and significantly correlated with the ASPT score (F = 28.03, p < 0.001, r^2 = 0.289, y = 5.105 + 0.0201x) (Fig. 3.1.21).

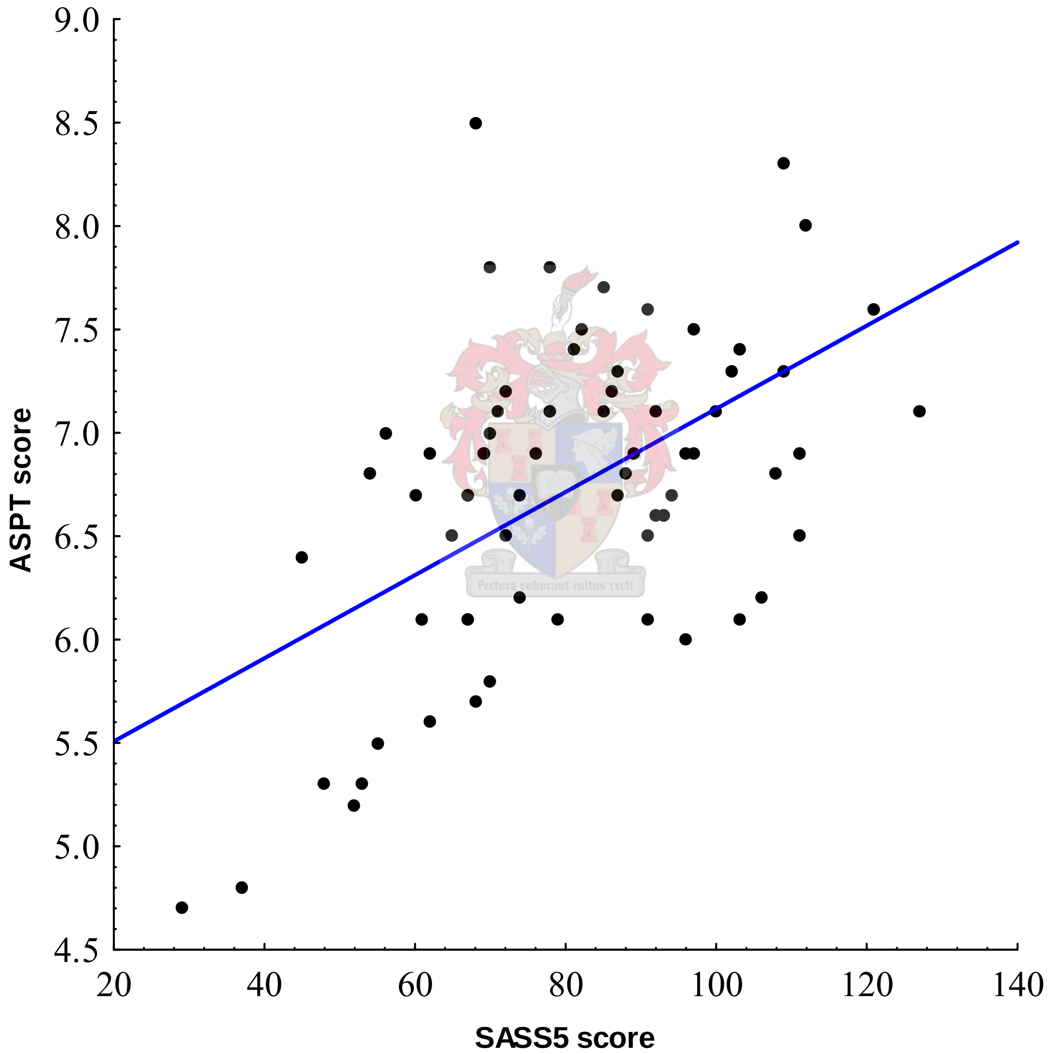

Figure 3.1.21: Linear regression of ASPT score against SASS5 score at each sampling unit. y = 5.105 + 0.0201x.

Analysis of variance (ANOVA) between sampling units at natural, alien and cleared (NAC) vegetation types

Using ANOVA, Fig. 3.1.22 shows significant statistical variation between the three types of vegetations in terms of benthic macroinvertebrate taxon richness. Therefore, the null hypothesis that there is no variation in benthic macroinvertebrate taxa richness among the three types of site is rejected. A significant statistical variation exists between alien and cleared vegetation sites (F= 12.911, p = 0.001) and between natural and cleared vegetation sites (F = 4. 375, p = 0.042).

Fig. 3.1.23 shows no significant statistical variation in SASS5 scores between the three types of site altogether, although a less significant statistical variation between alien and cleared sites exists (F = 7.247, p = 0.010). Thus the null hypothesis that there is no variation among SASS5 scores between NAC riparian vegetation is accepted.

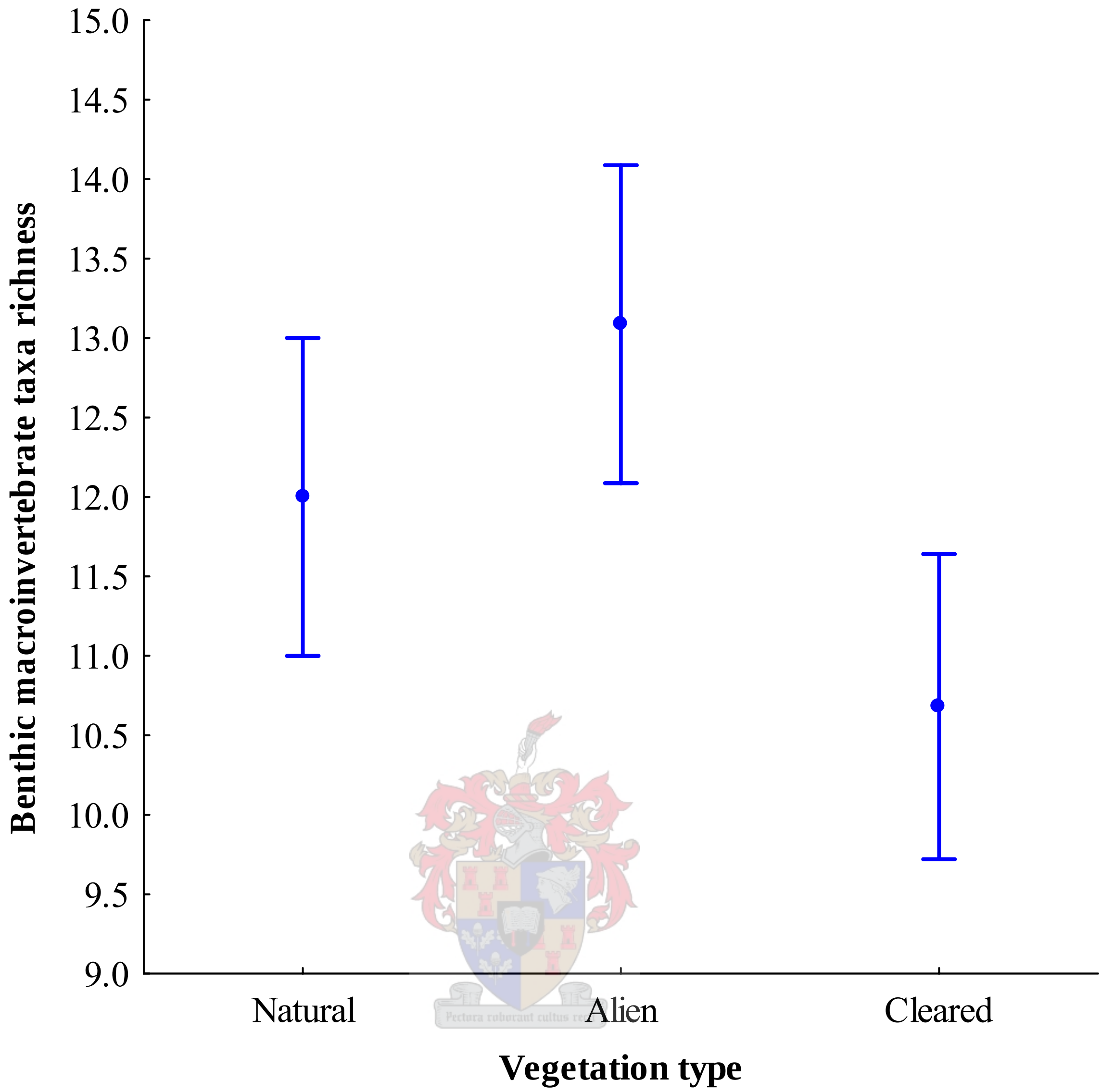

Figure 3.1.22: Analysis of variance between all three site types in terms of benthic macroinvertebrate taxon richness ($F = 6.037$, $p = 0.004$).

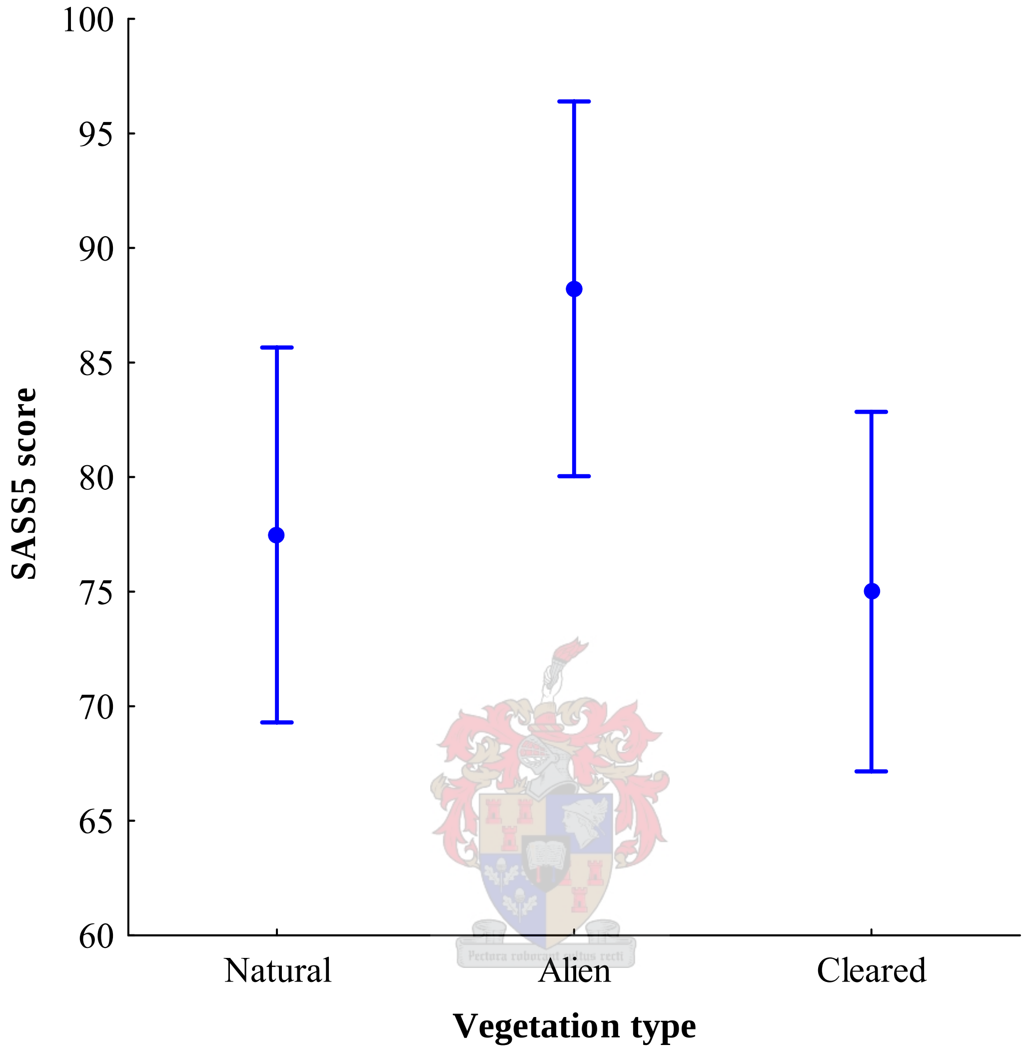

Figure 3.1.23: Analysis of variance between the three types of site in terms of South African Scoring System version 5 (SASS5) scores (F = 3.007, p = 0.056).

ANOVA showed significant statistical variation among ASPT scores between all the three types of site (Fig. 3.1.24). Therefore, the null hypothesis that there is no variation among ASPT scores between the three types of site is rejected. Significant differences exist in the ASPT scores between natural and alien sites ($F = 2.633$, $p = 0.011$) and between natural and cleared sites ($F = 8.818$, $p = 0.005$). There was however, no significant statistical variation in ASPT scores between alien and cleared sites ($F = 3.041$, $p = 0.088$).

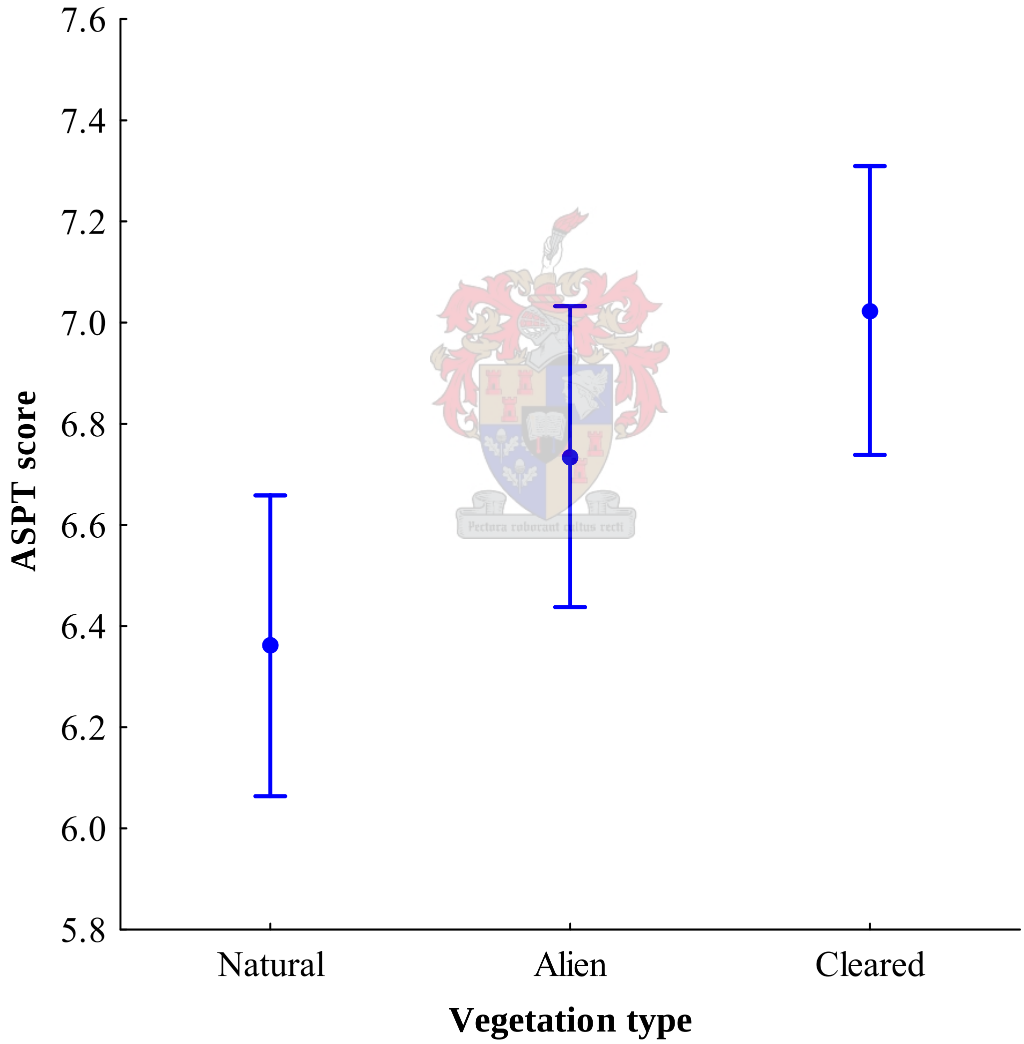

Figure 3.1.24: Analysis of variance between all the three types of site in terms of average score per taxon (ASPT) scores ($F = 5.166$, $p = 0.008$).

ADULT ODONATA

Adult Odonata species

Thirty-three adult Odonata species were recorded in 71 SUs (Table 3.2.1). Figs 3.2.1, 3.2.2 and 3.2.3 show the variation in the total number of adult Odonata species between SUs. 1506 adult Odonata individuals in total were recorded from natural, alien and cleared site combined (Fig. 3.2.4), with more individuals in cleared site followed by natural site and then alien site. SU C62 in cleared site had the highest number (10) of adult Odonata species (Fig. 3.2.3), with N26 of natural site supporting seven adult Odonata species (Fig. 3.2.1). Alien site sampling units supported minimal number of adult Odonata species, with only six species being the highest count per SU (Fig. 3.2.2).

The adult Odonata species comprised 25 Anisoptera and eight Zygoptera (Table 3.2.1). A total of eight families were recorded at all sites combined. Twenty-eight adult Odonata species comprising eight families were recorded from cleared site, while 14 and 15 adult Odonata species were recorded in natural and alien sites respectively. *Aeshna subpupillata* was recorded only at natural site whereas *Orthetrum trinacria, Trithemis dorsalis* and *Trithemis stictica* were localized in alien site. Twelve adult Odonata species were restricted to cleared site.

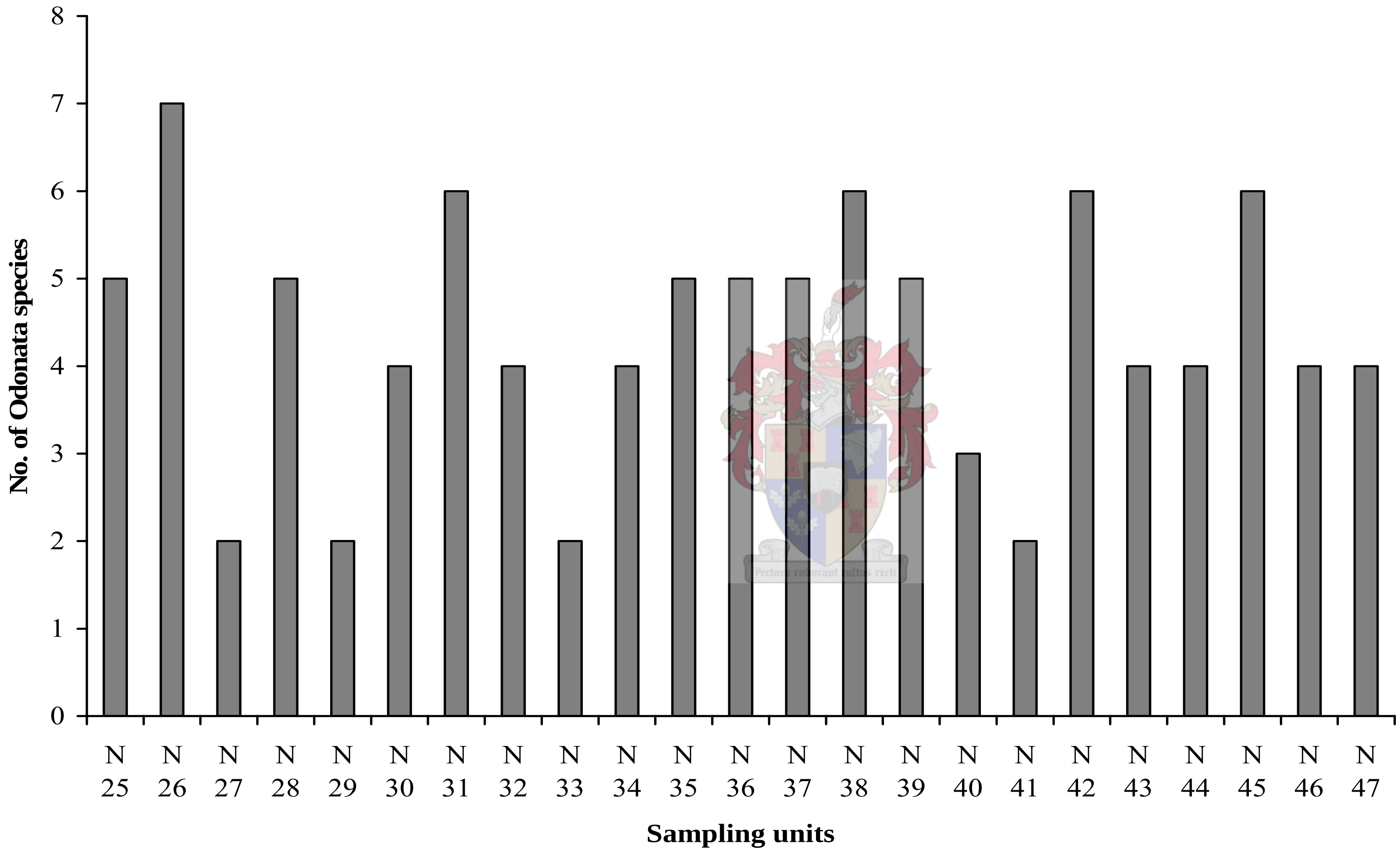

Figure 3.2.1: Adult Odonata species richness in natural vegetation.

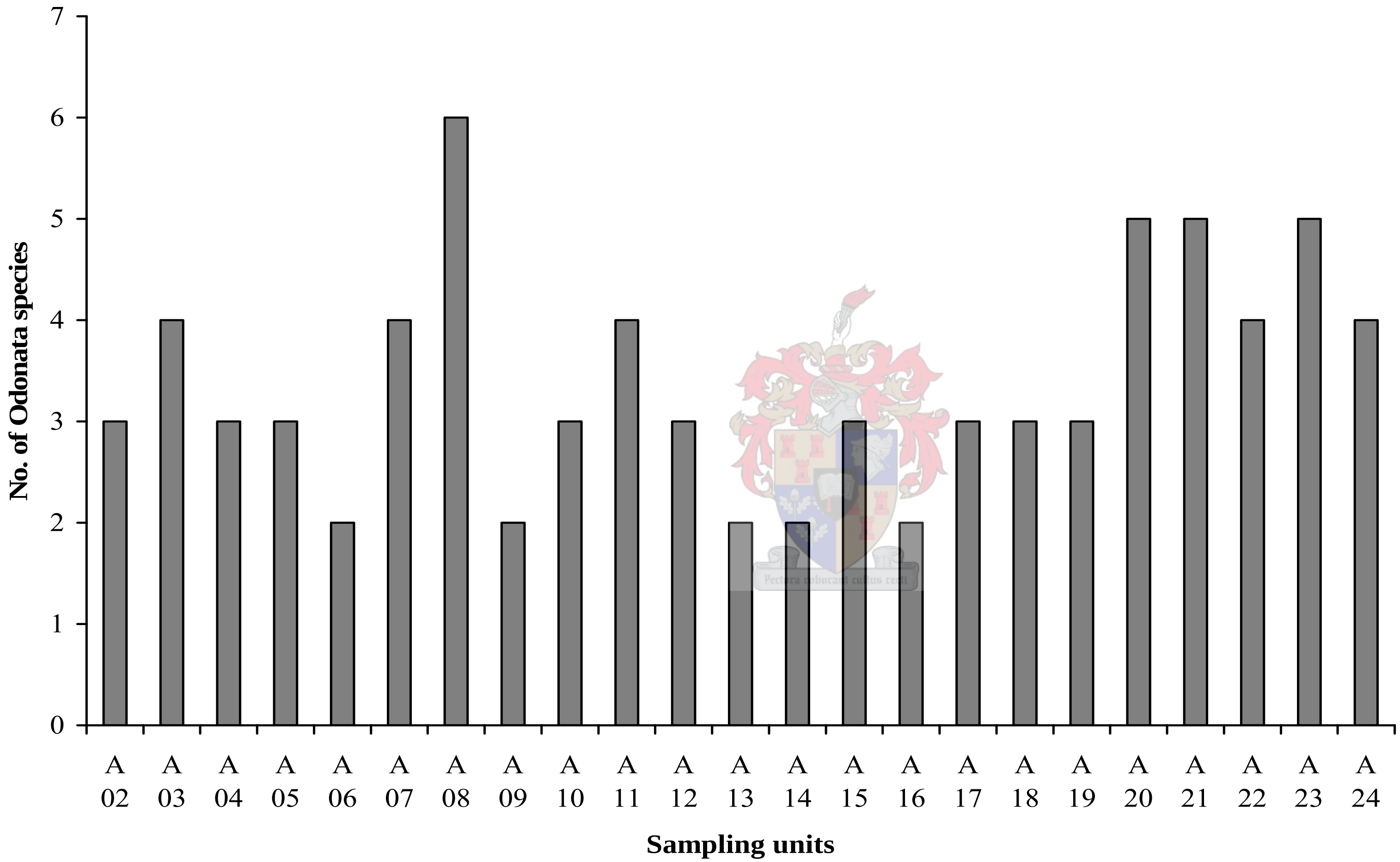

Figure 3.2.2: Adult Odonata species richness in alien vegetation.

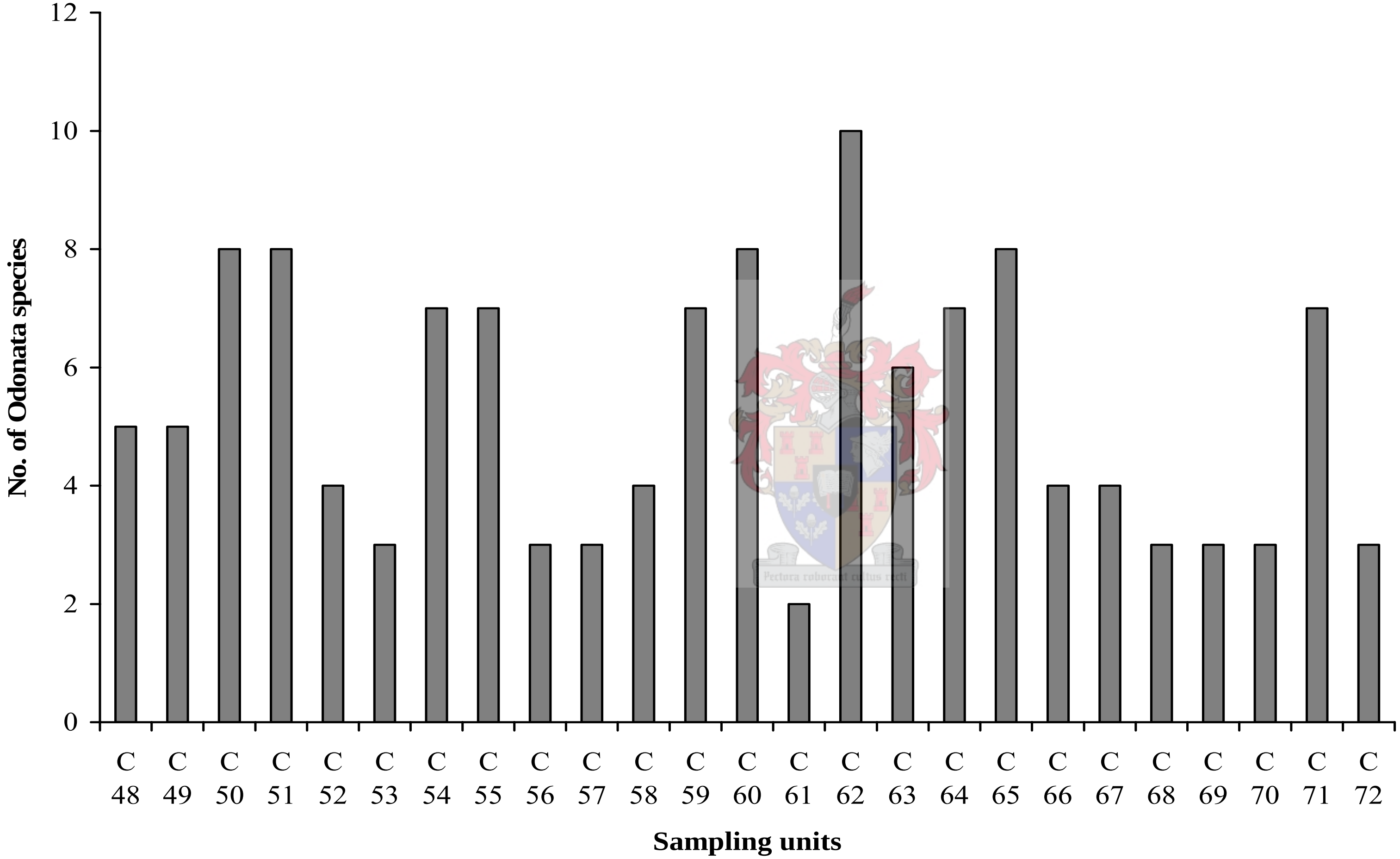

Figure 3.2.3: Adult Odonata species richness in cleared vegetation.

Table 3.2.1: Adult Odonata species sampled in 71 sampling units across all vegetation types

	Vegetation types		
	Natural	Alien	Cleared
SUBORDER ANISOPTERA			
Family Aeshnidae			
1. *Aeshna subpupillata* McLachlan, 1896	√		
2. *Anax speratus* Hagen, 1867	√		√
Family Gomphidae			
3. *Ictinogomphus ferox* (Rambur, 1842)	√		√
4. *Paragomphus cognatus* (Rambur, 1842)		√	√
Family Corduliidae			
5. *Phyllomacromia picta* (Sélys, 1871)	√		√
Family Libellulidae			
6. *Nesciothemis farinosa* (Förster, 1898)			√
7. *Orthetrum abbotti* Calvert, 1892			√
8. *Orthetrum caffrum* (Burmeister, 1839)		√	√
9. *Orthetrum chrysostigma* (Burmeister, 1839)	√		√
10. *Orthetrum icteromelas* Ris, 1910			√
11. *Orthetrum julia falsum* Longfield, 1955	√	√	√
12. *Orthetrum machadoi* Longfield, 1955	√	√	√
13. *Orthetrum trinacria* (Sélys, 1841)		√	
14. *Palpopleura portia* (Drury, 1773)		√	√
15. *Pantala flavescens* (Fabricius, 1798)			√
16. *Sympetrum fonscolombii* (Sélys, 1840)			√
17. *Trithemis arteriosa* (Burmeister, 1839)			√
18. *Trithemis donaldsoni* (Calvert, 1899)			√
19. *Trithemis dorsalis* (Rambur, 1842)		√	
20. *Trithemis furva* Karsch, 1899			√
21. *Trithemis kirbyi* Sélys, 1891			√
22. *Trithemis pluvialis* Frostier, 1906		√	√
23. *Trithemis stictica* (Burmeister, 1839)		√	
24. *Crocothemis erythraea* (Brullé, 1832)			√
25. *Crocothemis sanguinolenta (*Burmeister, 1839)			√
SUBORDER ZYGOPTERA			
Family Coenagrionidae			
26. *Africallagma elongatum* (Martin, 1907)	√		√
27. *Africallagma glaucum* (Burmeister, 1839)	√	√	√
28. *Pseudagrion hageni tropicanum* Pinhey, 1966	√	√	√
29. *Pseudagrion kersteni* (Gerstäcker, 1869)	√	√	√
30. *Pseudagrion salisburyense* Ris, 1921			√

	Vegetation types		
	Natural	Alien	Cleared
SUBORDER ANISOPTERA			
Family Platycnemididae			
31. *Allocnemis leucosticta* Sélys, 1863	√	√	
Family Protoneuridae			
32. *Elattoneura glauca* (Sélys, 1860)	√	√	√
Family Chlorocyphidae			
33. *Platycypha caligata* (Sélys, 1853)	√	√	√

Table 3.2.2: Average values for measured environmental variables during adult Odonata sampling period

	Vegetation types		
Environmental variables	Natural	Alien	Cleared
Temperature (°C)	21.25	24.40	27.25
Conductivity (mS/cm)	0.14	0.13	0.09
Dissolved Oxygen (mg/L)	7.27	7.15	7.012
pH	6.86	6.74	6.72
Elevation (m)	999.6	1006.3	727.8

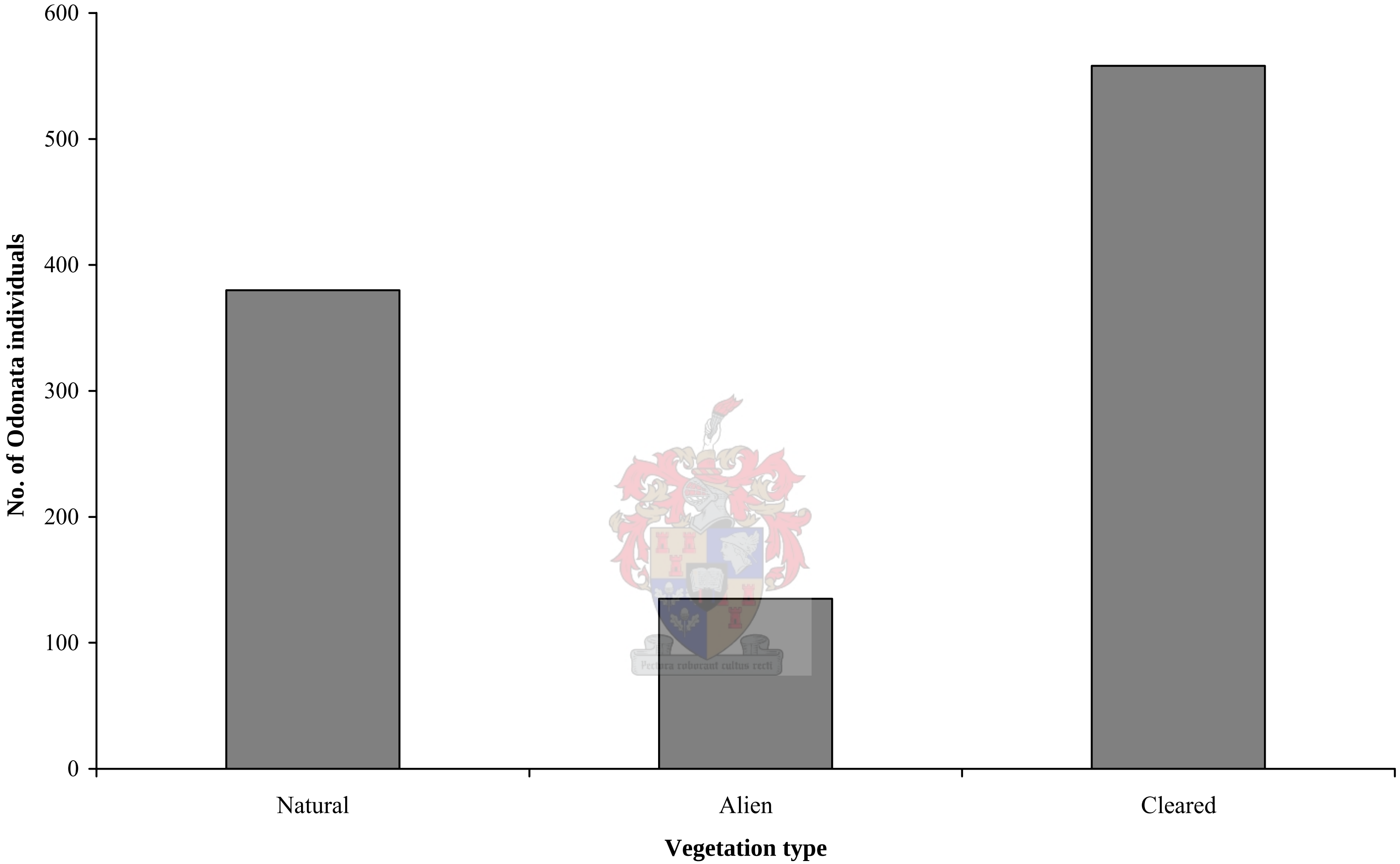

Figure 3.2.4: Total adult Odonata individuals recorded in natural, alien and cleared (NAC) riparian vegetation sites.

Figure 3.2.5: *Allocnemis leucosticta*, shade-loving species with no record at cleared vegetation type.

Figure 3.2.6: *Platycypha caligata*, usually associated with riffles.

Figure 3.2.7: *Orthetrum julia falsum,* consistently recorded across all three vegetation types.

Environmental variables and adult Odonata species assemblages

CCA ordination of adult Odonata species and environmental variables in natural site is given in (Fig. 3.2.8). A Monte Carlo test indicated that environmental variables had a significant effect (F = 1.510, p = 0.028) on the variability of adult Odonata assemblages in natural areas. Therefore, the null hypothesis that environmental variables had no significant effect in the adult Odonata assemblages is rejected. Environmental variables explained 43% of the total variability in Odonata assemblages, with shade cover alone explains 32% of the total variability (Fig. 3.2.8). Adult Odonata-shade correlations were highly significant (F = 3.210, p = 0.002 with 499 permutations).

Fig. 3.2.9 is a CCA ordination diagram showing an arrangement of adult Odonata species in relation to their environmental variables in alien vegetation. Environmental variables had a significant effect on adult Odonata species assemblages in this vegetation type (F = 1.144, p = 0.026 with 499 permutations). Therefore, the null hypothesis that environmental variables had no significant effect on adult Odonata assemblages in alien vegetation is rejected. Environmental variables altogether, explained 40% of the total variability in adult Odonata assemblages. Shade (F = 2.096, p = 0.018) and temperature (F = 1.89, p = 0.048) had significant effects, and accounted for most of the variation in adult Odonata assemblages in alien site. Alone, shade explained 23% of the total variation in adult Odonata assemblages in alien site, with temperature explaining 21% of the total variability.

Fig. 3.2.10 is a CCA ordination with adult Odonata species and environmental variables at cleared site. The effects of environmental variables are highly significant (F = 1.610, p = 0.002 with 499 permutations). Overall environmental variables explain 79% of the total variability of adult Odonata assemblages. Only elevation (p = 0.720) and flow (p = 0.844) had no significant effect on adult Odonata assemblages.

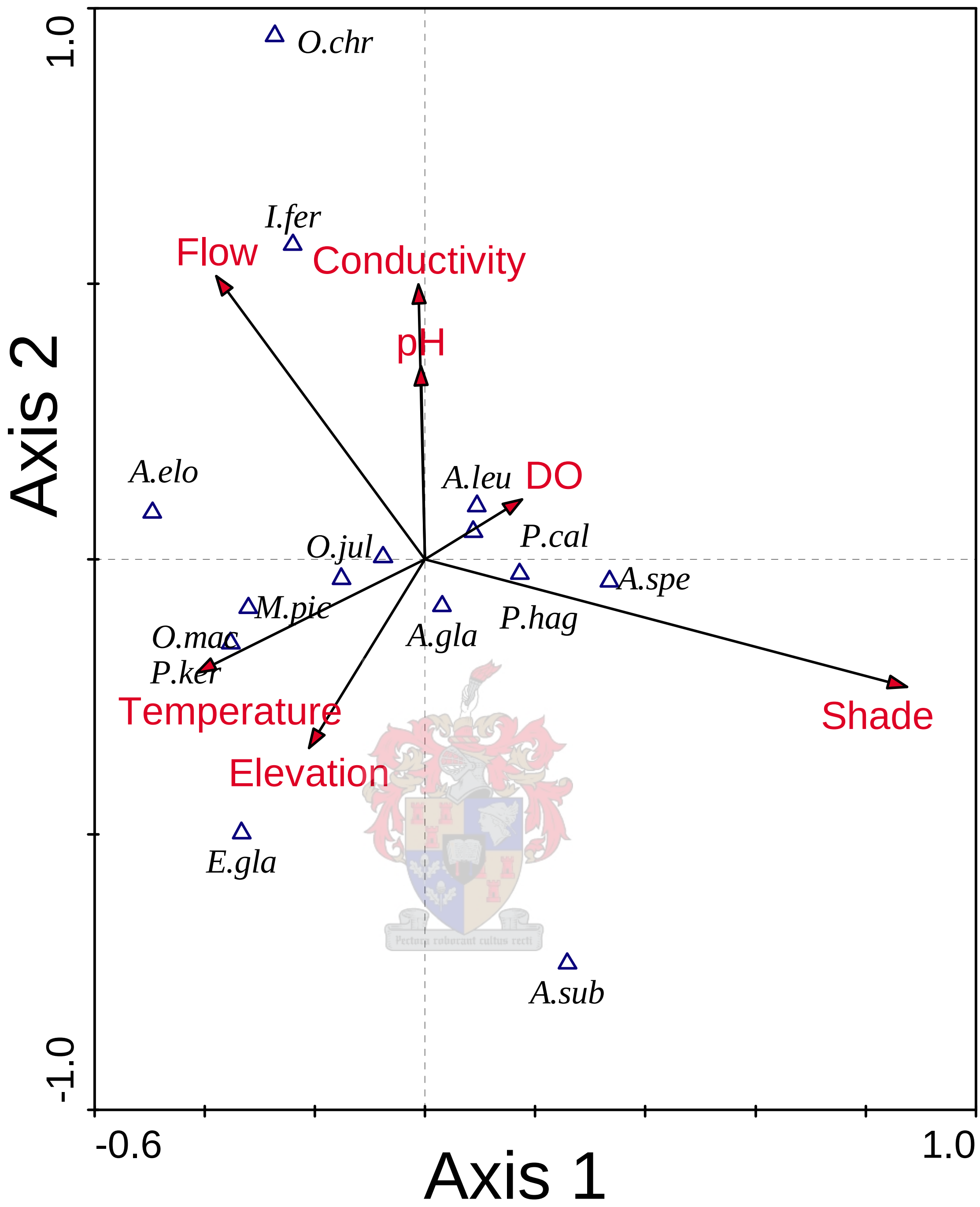

Figure 3.2.8: Canonical Correspondence Analysis (CCA) ordination of adult Odonata species with environmental variables (bold names) in natural vegetation. Full species names are given in Appendix 3.

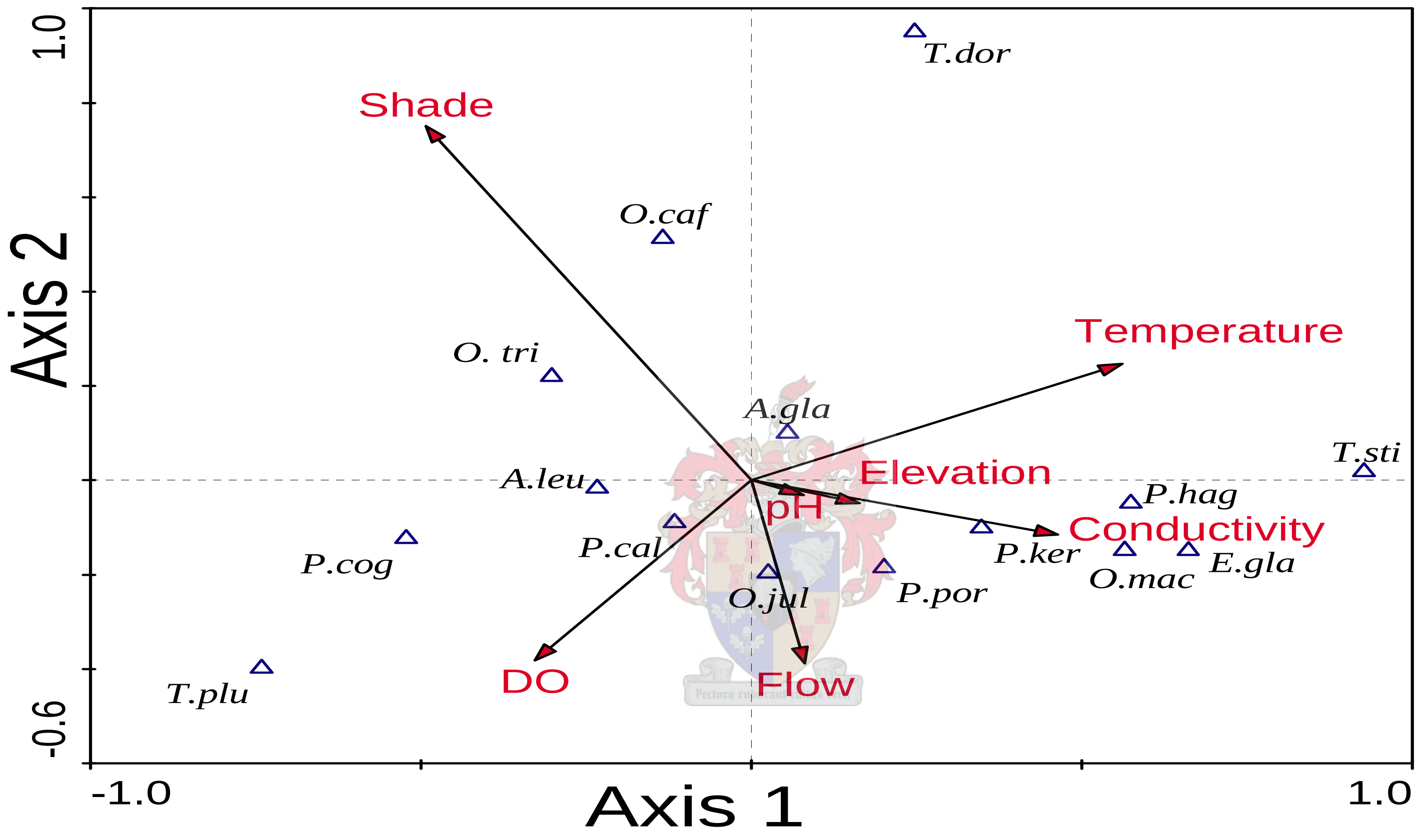

Figure 3.2.9: Canonical Correspondence Analysis (CCA) ordination with adult Odonata species and environmental variables (bold names) at alien vegetation. DO = Dissolved Oxygen. Full species names are given in appendix 3.

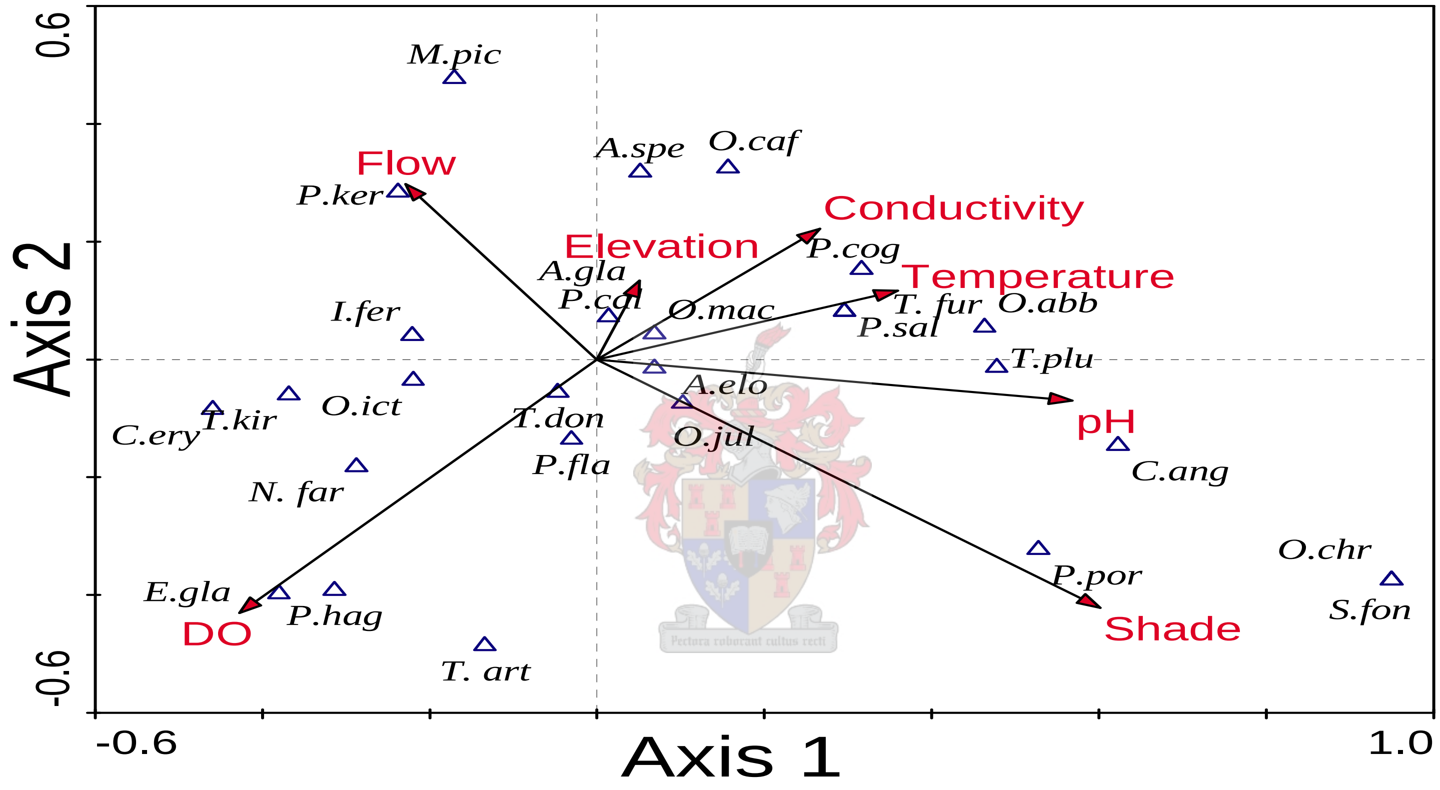

Figure 3.2.10: Canonical Correspondence Analysis (CCA) Ordination of adult Odonata species with environmental variables (bold names) in cleared vegetation. Full species names are given in Appendix 3.

Fig. 3.2.11 is a CCA ordination diagram showing arrangement of adult Odonata species in relation to their environmental variables in all the three vegetation types**.** A Monte Carlo test showed a highly significant effects of environmental variables on the variability of adult Odonata assemblages (F = 2.82, p = 0.002). The environmental variables altogether account for 51.5% of the total variability of adult Odonata. Vegetation type alone, accounted for 43% of the total variation. Only pH (F = 1.176, p = 0.278) had no significant effect in the variability of adult Odonata assemblages in the three vegetation types combined.

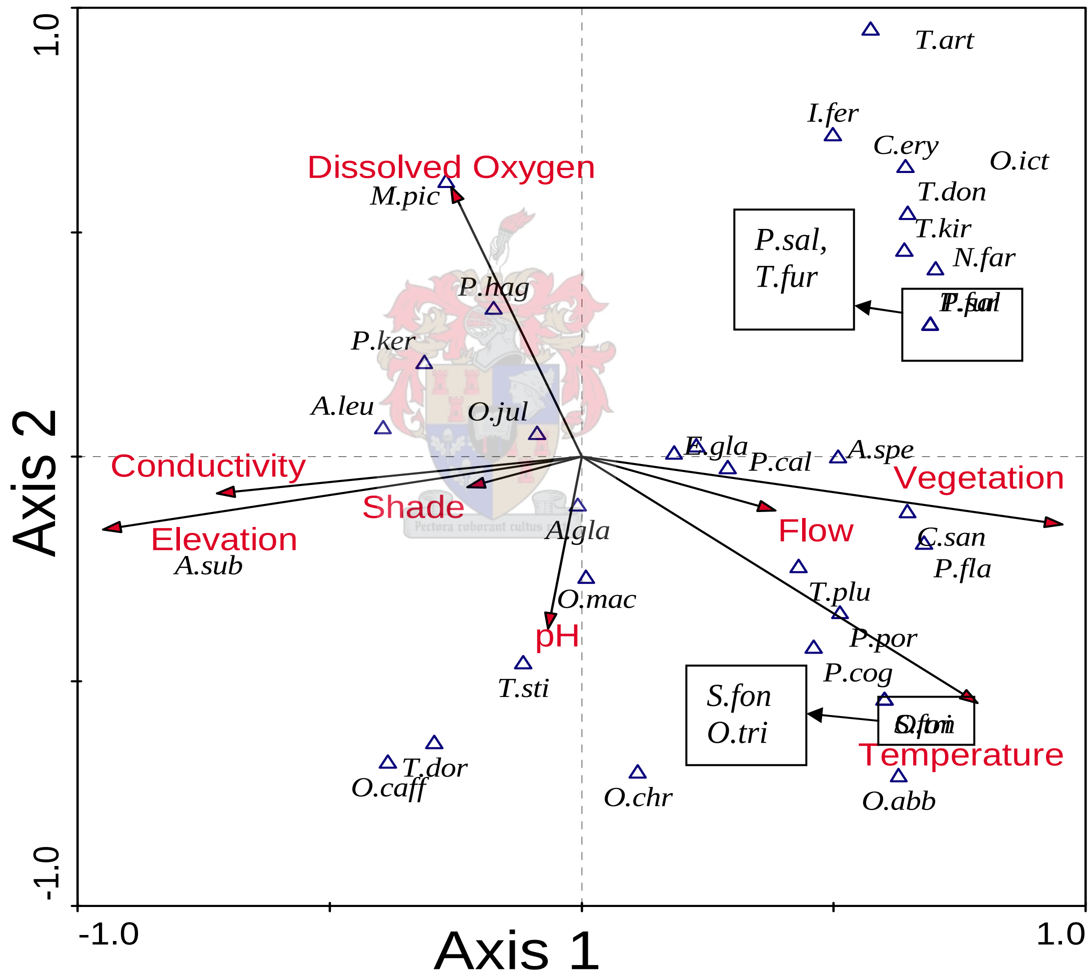

Figure 3.2.11: CCA ordination of environmental variables (bold names) with adult Odonata species (light names) in natural, alien and cleared vegetation type combined. Full species names are presented in Appendix 3.

Adult Odonata responses in different vegetation types

Fig. 3.2.12 shows the responses of *Allocnemis leucosticta* and *Orthetrum julia falsum* towards the three vegetation types. *A. leucosticta* abundance was lower in alien than in natural vegetation, with it absent in cleared vegetation type (Fig. 3.2.12). Thus the hypothesis that adult Odonata species does not occurs across different riparian vegetation types is accepted. Nevertheless, *O. julia falsum* was recorded consistently across all three vegetation types.

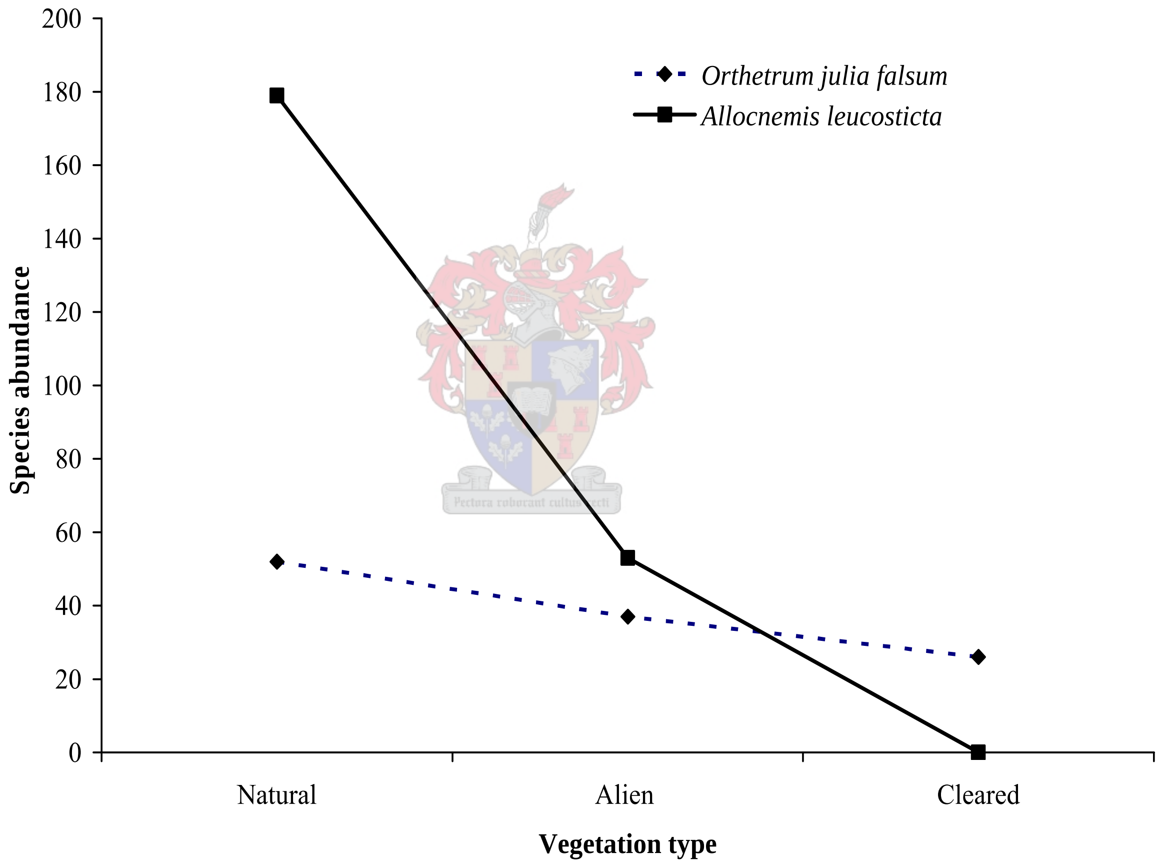

Figure 3.2.12: *Allocnemis leucosticta* and *Orthetrum julia falsum* species responses to natural, alien and cleared vegetation types.

Clustering of sampling units in terms of adult Odonata assemblages

Fig. 3.2.13 showed clustering of all 71 sampling units (SUs) in terms of adult Odonata species assemblages. Natural and alien vegetation SUs are clustered close to each other, showing most similarity. Cleared vegetation SUs had their own separate cluster. Therefore, cleared vegetation is much less related to natural and alien vegetation types in terms of adult Odonata assemblages.

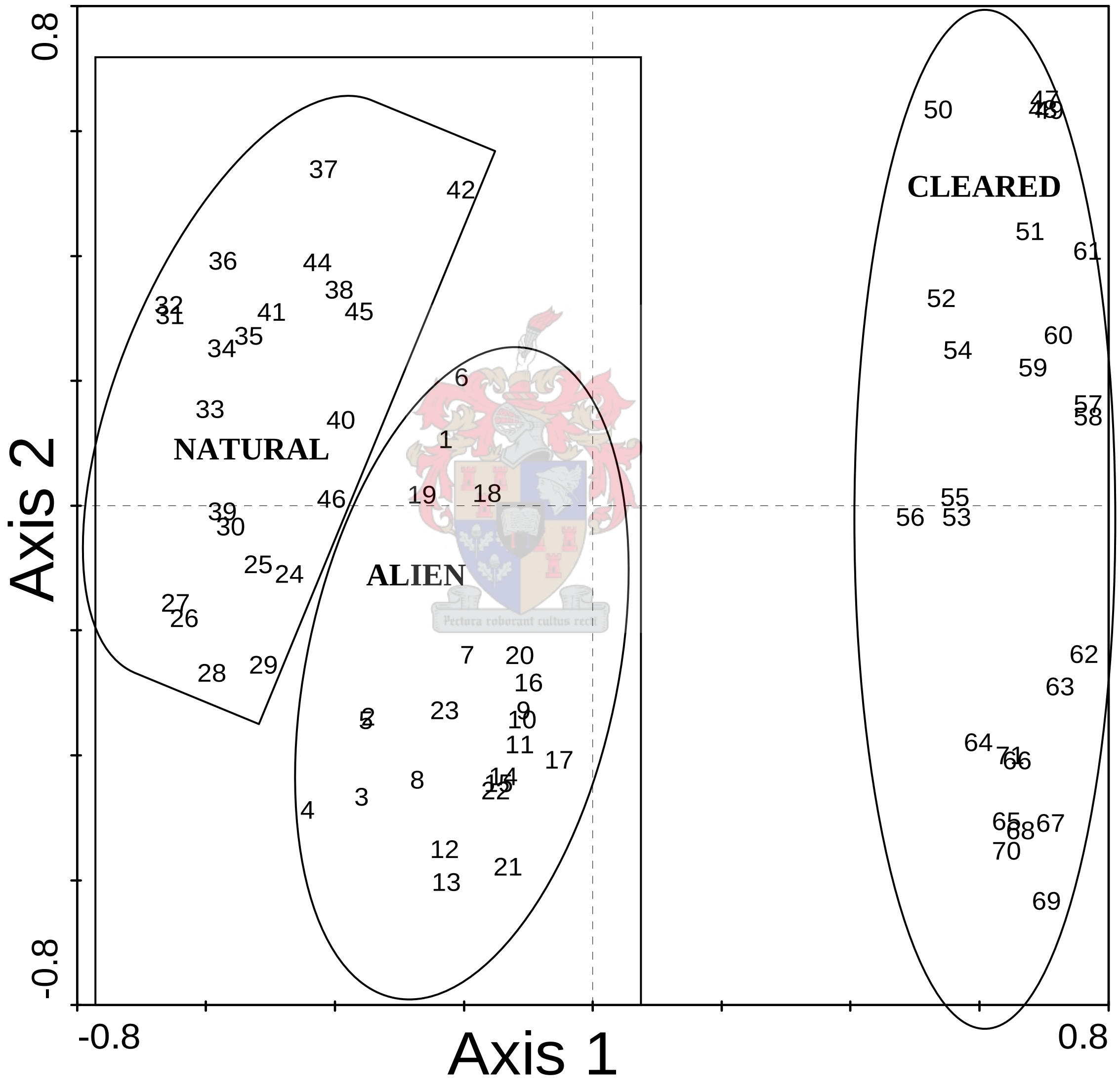

Figure 3.2.13: Canonical Correspondence Analysis (CCA) ordination diagram with sampling units in all three vegetation types based on adult Odonata species assemblages. Descriptions for sampling units are given in appendix 2.

Odonata species richness in all three vegetation types

There was significant variation in adult Odonata species richness across the three vegetation types (Fig. 3.2.14). Thus the hypothesis that there is no variation in adult Odonata species richness across the three vegetation types is rejected. There was significant variation in adult Odonata species richness between natural and alien vegetation (F = 6.368, p = 0.015) and between alien and cleared vegetation (F = 13.24, p = 0.001), although there was not between natural and cleared vegetation (F = 2.88, p = 0.096).

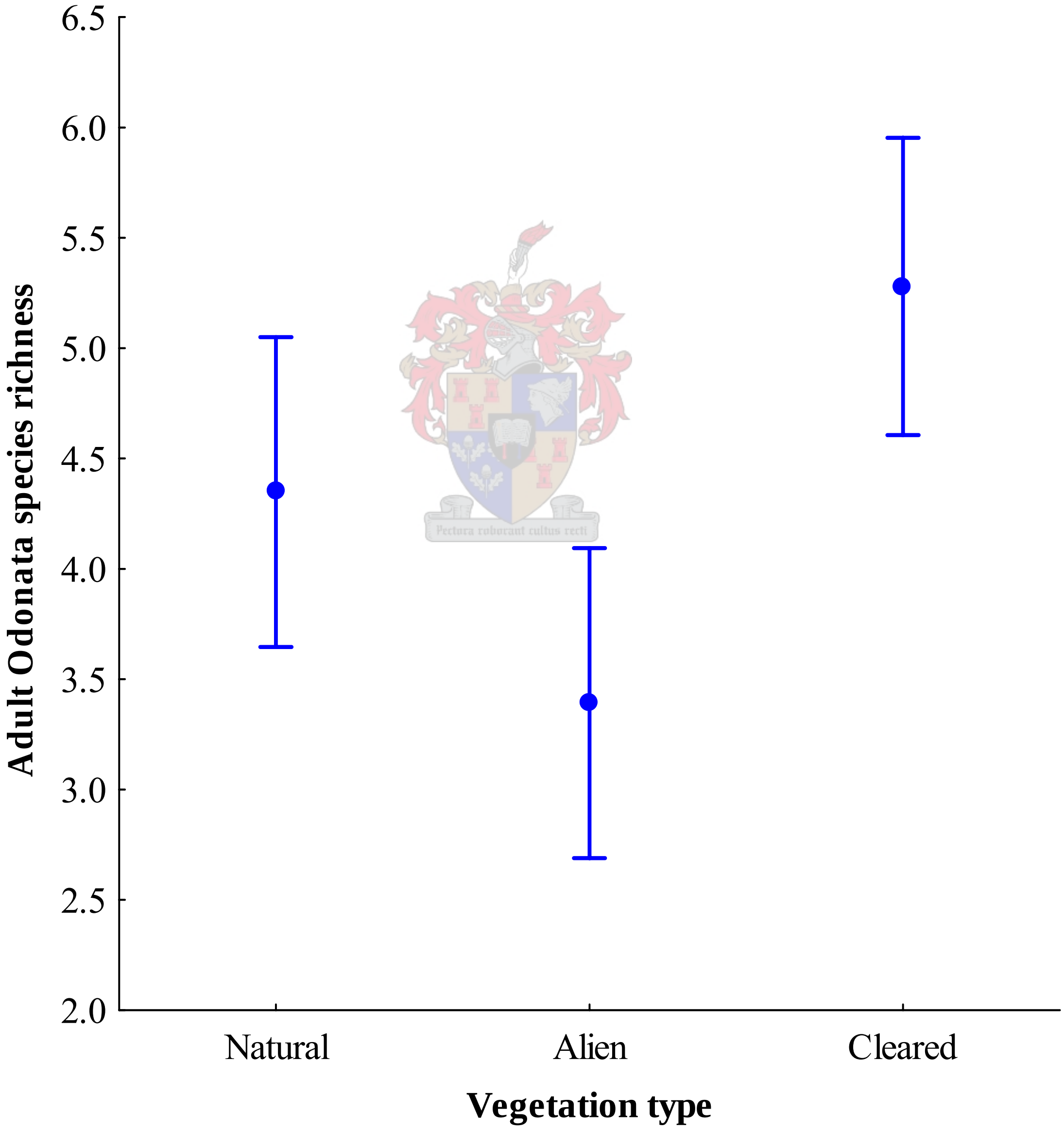

Figure 3.2.14: Analysis of variance of Odonata species richness at all three vegetation types (F = 7.501, p = 0.001).

Adult Odonata species richness and benthic macroinvertebrate correlations

When the total number of adult Odonata species was compared with the total number of benthic macroinvertebrate taxa across all three vegetation types (Fig. 3.2.15), the highest number of adult Odonata species was recorded from cleared vegetation. Natural and cleared vegetation had nearly equal effect on adult Odonata species assemblages, with only 14 and 15 adult Odonata recorded from natural and alien vegetation respectively. Cleared vegetation supported both high number of adult Odonata species and benthic macroinvertebrate taxa. The total number of benthic macroinvertebrate taxa was slightly reduced in alien compared with natural and cleared vegetation (Fig. 3.2.15).

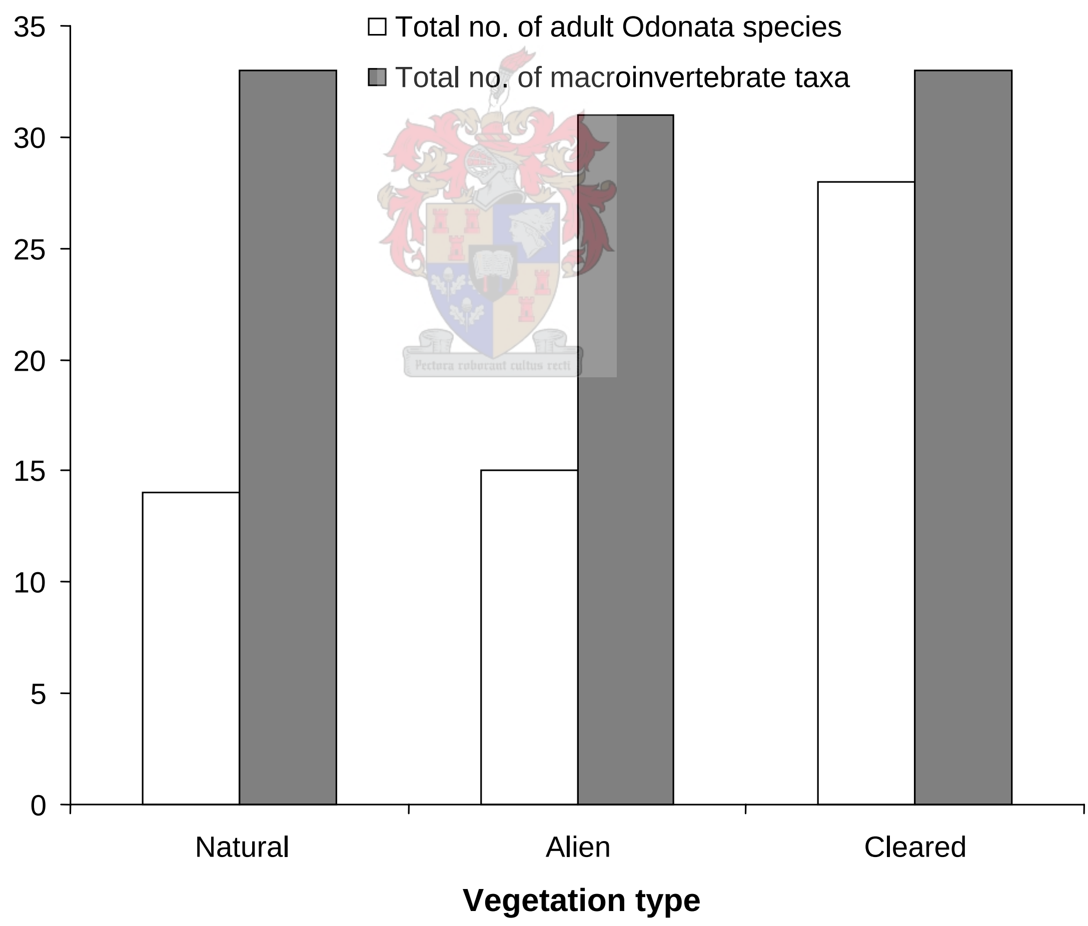

Figure 3.2.15: Total number of adult Odonata species and benthic macroinvertebrate taxa in all three vegetation types.

Fig. 3.2.16 shows no significant correlation between adult Odonata species richness and benthic macroinvertebrate taxa richness (F = 2.956, p = 0.901), and that they responded differently to changes in vegetation types along the River system. Therefore, the hypothesis that adult Odonata species richness does not respond to changes in vegetation, in the same way as benthic macroinvertebrate taxa richness is accepted.

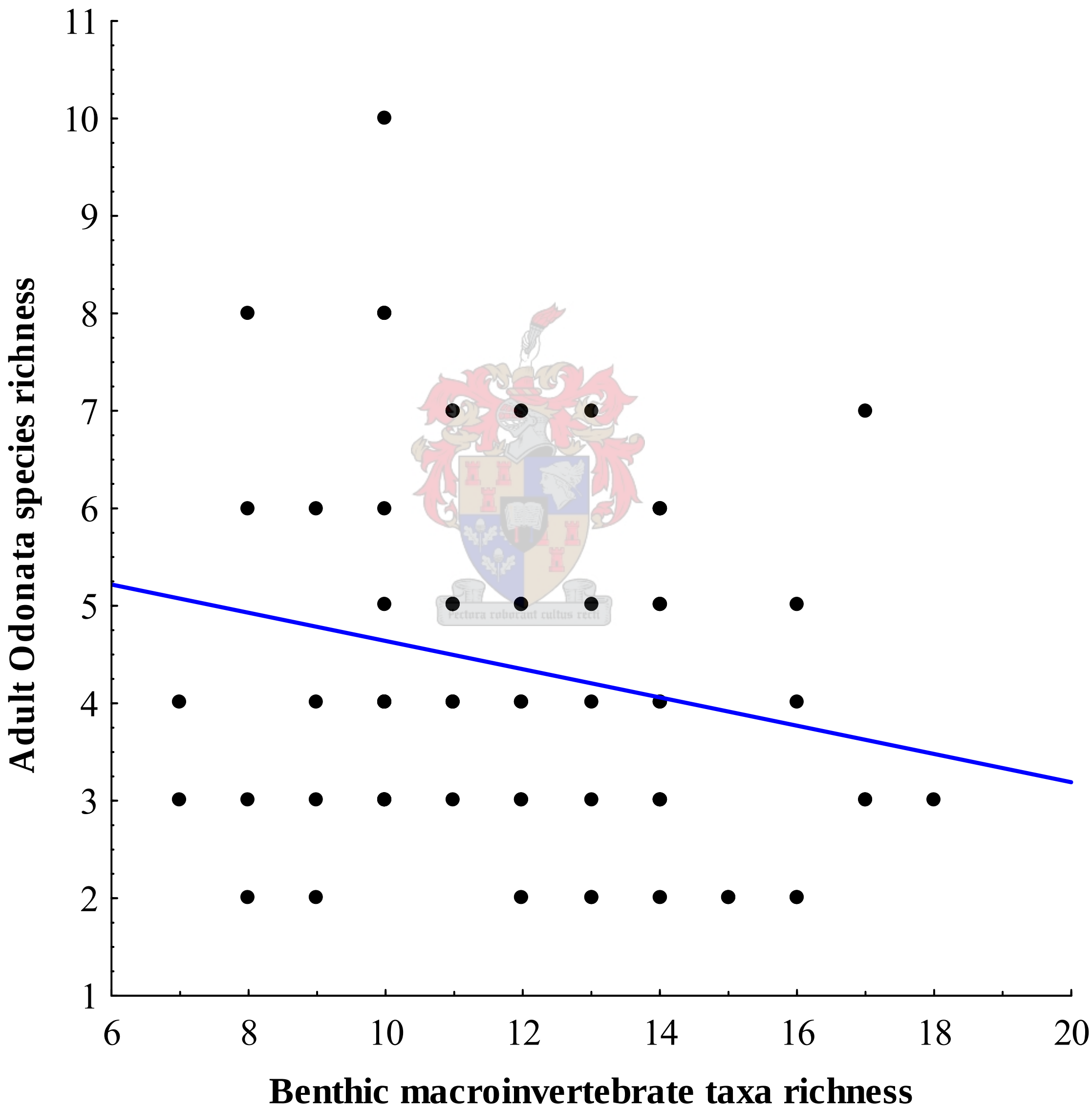

Figure 3.2.16: Linear regression of adult Odonata species richness against benthic macroinvertebrate taxa richness at all sampling units. y = 6.0878 - 0.1448x.

Adult Odonata species richness and SASS5 scores

Adult Odonata species richness was not significantly correlated with SASS5 scores ($F = 0.805$, $p = 0.373$, y = 5. 1481 - 0.0098x) (Fig. 3.2.17). The variation between the two was not in the same direction and they responded differently to changes in vegetation types along the River system.

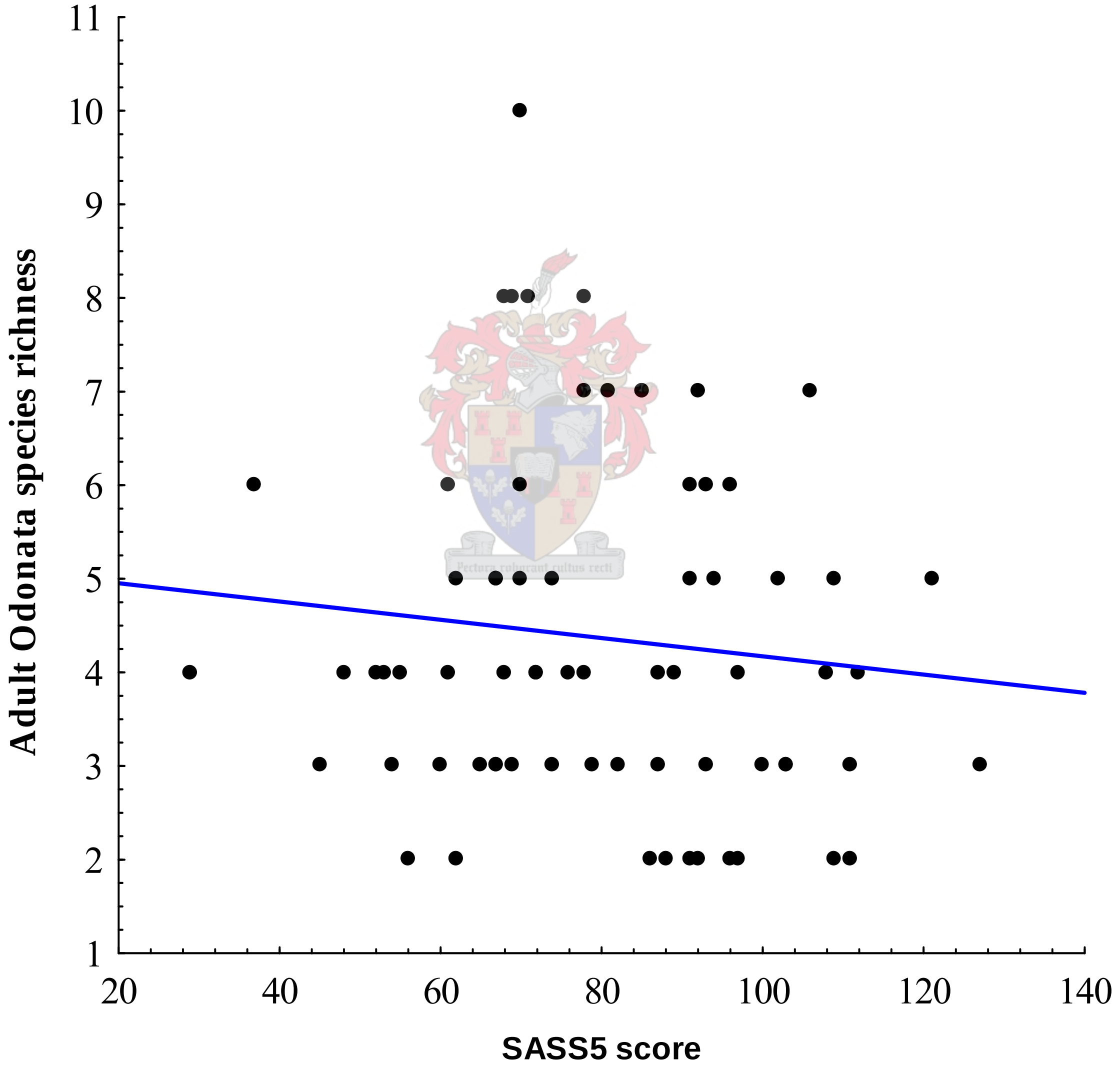

Figure 3.2.17: Linear regression of adult Odonata species richness at each sampling unit against SASS5 score. y = 5. 1481 - 0.0098x.

Adult Odonata species richness and ASPT scores

There was a significant and positive correlation between adult Odonata species richness and ASPT scores across all three vegetation types ($F = 2.198$, $p = 0.008$, $r = 0.176$). The variation in adult Odonata species richness was in similar direction to that of ASPT scores (Fig. 3.2.18). This shows that both measures respond in a similar way to the changes in vegetation type. Thus the hypothesis that adult Odonata species richness does not vary in the in the same way as ASPT scores is rejected.

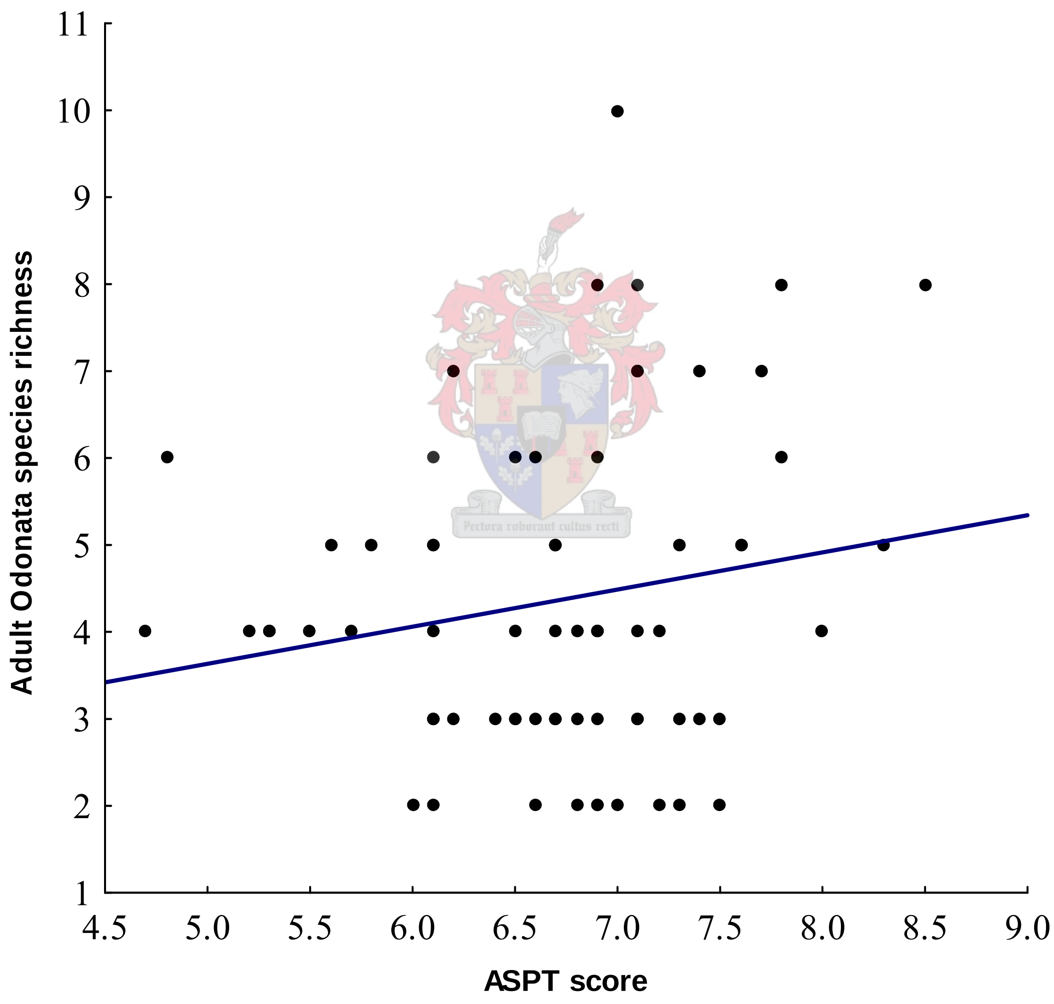

Figure 3.2.18: Linear regression of adult Odonata species richness at each sampling unit against ASPT score. y = 1.4982 + 0.42708x. Correlation: r = 0.176.

CHAPTER 4

DISCUSSION

BENTHIC MACROINVERTEBRATES

Invasive alien plants and their clearing on SASS5 and ASPT scores

Fig. 3.1.10 illustrates that the SASS5 score indicates a decline in overall River health when alien plants were present but improvement when they were removed. There is a major difference in SASS5 scores between natural and alien vegetation types. Most benthic macroinvertebrate sensitive taxa prefer natural vegetation rather than alien vegetation. Natural vegetation had high SASS5 scores, indicating good stream condition. The SASS5 scores in the natural vegetation was also the highest recorded in all three vegetation types. The lower SASS5 scores in alien vegetation were due to loss of a number of sensitive taxa, especially Paleomonidae, Perlidae and Protoneuridae. Therefore, invasive alien plants reduce SASS5 scores by reducing the number of highly sensitive taxa while supporting the number of less sensitive taxa.

SASS5 scores for 2001, 2002 and 2004 of cleared vegetation in Entabeni plantation

The SASS5 and ASPT scores improved in the 2004 surveys compared to the 2002 surveys with more SASS5 families encountered during the 2004 than during the 2002 survey. The lowest number of families was recorded during the 2001 survey, when the River was beginning to recover from infestation. The severe flood of 2000 may have had an impact on SASS5 results during 2001 because it is known that in the nearby Kruger National Park two species of nationally threatened species were literally washed out of the country (Samways 2005). Low SASS5 scores at this site during the 2001 and the 2002 surveys may be attributed to both flood damage and infestations along the riparian zone. The question is, which had the most important influence, floods or invasive alien plants? Floods or no floods, the high diversity of benthic macroinvertebrates can be altered due to competition and predation that become important regulating factors (Ward and Stanford 1983a) and the recovery of Odonata is remarkably rapid following flooding

(Samways 1989b). Diversity is altered in systems with severe or frequent organic loading (Watson *et al.* 1982). This loading may be in the form of dead leaves falling from dense alien vegetation along the riparian zone. So the clearing of invasive alien plants along the Lutanandwa River in Entabeni, reduced organic loading and hence benefitted the benthic macroinvertebrate assemblage. The fact that there were fewer taxa during the 2001 and 2002 surveys, confirms that infestations with alien plants caused damage to the stable instream habitat mainly as a result of increasing sediments. In general, River conditions deteriorate as invasion by alien plants progresses.

Abundance of major SASS5 indicator taxa (EPTO)

Alien vegetation supported fewer EPTO taxa compared to natural vegetation. Baetidae, Tricorythidae, and Hydropsychidae families were abundant in all three vegetation types. However, alien vegetation supported fewer Baetidae and Hydropsychidae species. Similarly, Odonata species (larvae) in natural vegetation were also in cleared vegetation. There was a remarkable drop of Gomphidae abundance in alien vegetation, which improved considerably in cleared vegetation. It is more likely that alien vegetation does not suit the habitat requirements for the most sensitive taxa such as Perlidae.

Environmental variables and benthic macroinvertebrate assemblages

Monte Carlo permutation test showed that environmental variables (Fig. 3.1.20) had a significant effect on the variability of benthic macroinvertebrate assemblages in all three vegetation types. Microhabitat type, flow rate, vegetation type, elevation, shade, temperature and conductivity accounted for most of the variation of benthic macroinvertebrate assemblages.

Microhabitats

The availability of microhabitats is important especially in savanna conditions where environmental conditions are unpredictable and extreme (Stewart 1993). Different benthic macroinvertebrates prefer different microhabitats. Natural vegetation, with its high number of sampling units with marginal and aquatic vegetation, had high species richness. Also, the highest numbers of Gomphidae individuals were recorded from sampling units with natural marginal and aquatic vegetation. Clark (1991) reported that the sites with macrophytes had significantly higher species abundances and total numbers of individuals by providing good oviposition sites for adults as well as perching sites, especially for the smaller Zygoptera. Moore and Chutter (1988) observed dragonfly larvae occurring in high abundance amongst marginal vegetation in the major Rivers of the Kruger National Park. Marginal vegetation provided microhabitats for avoiding predation. Athericidae were mainly in the vegetation surrounding the edge of the stream and on rocks in River beds. Therefore, marginal vegetation increases benthic macroinvertebrates diversity. It is more likely that for some species, lack or presence of logs, vegetation, or other microhabitats determines their presence.

Flow rate

Flow rate had a significant effect in the variability of benthic macroinvertebrate in all three vegetation types. Most species preferred pools and runs which allows for gravel, aquatic and marginal vegetation (good sites for hatching and escaping predation). The climbers, bottom sprawlers and burrowers are usually associated with pools or backwaters of the streams while the clingers are associated with fast riffles, where they cling to rocks or any other submerged substrate (Gerber and Gabriel 2002). Oligoneuridae, Tricorythidae, Notonemouridae, Small minnow flies (family Baetidae), Heptageniidae, Perlidae and Paleomonidae were associated with runs (moderately fast flowing water) while Veliidae were linked to riffles (very fast flowing water). Caddisflies were typically associated with moderate flows. Benthic macroinvertebrates were strongly influenced by flow rate, with most of the families being flow specific.

Vegetation type

Alien vegetation can exclude indigenous plants and reduce soil surface coverage. This in turn can influence the SASS5 results in that the high surface run-off in sparsely vegetated catchments results in high-sediment input (lowering the ASPT score). In the Piesanghoek plantation, where *Pinus* species were growing along the edge of the stream, there was further impact on bank stability. Invasions also lead to changes in the quality of natural allochthonous organic matter input and reduced the diversity of microhabitats (Dallas 2000).

Benthic macroinvertebrate taxon richness was higher in natural and cleared vegetation when compared to alien vegetation. Natural forests play an important role in preventing excessive run-off which otherwise leads to serious erosion and therefore high siltation (reduced water clarity). Siltation causes loss of habitat through blanketing or smothering and as a consequence of reduction in light penetration (increased turbidity), loss of sight and to some extent death of non-tolerant species. Although alien vegetation supported a high number of taxa, most taxa are not well suited to live there. Most of the sensitive taxa recorded in natural vegetation were not recorded in alien vegetation resulting in lower SASS5 scores. A clear indication of biodiversity recovery was that of cleared vegetation with equal number of taxa as in natural vegetation.

Pinus, *Acacia* and *Eucalyptus* species are of major commercial importance in South Africa, but they are also a serious threat to water supplies and biodiversity in major conservation areas (Wittenberg and Cock 2001). Alien vegetation is a major problem, reducing exposed soil cover, particularly in the steep, mountainous areas, thereby causing high amounts of erosion during harvesting, mostly because of the lack of understorey vegetation cover (Hirji *et al.* 2002). Unnaturally high sediment depositions are a serious threat to benthic macroinvertebrates that are less tolerant of highly silted conditions (Diedericks 2002). Sedimentation refers to the combined processes of soil erosion, entrainment, transportation, deposition and compaction of sediment (Hirji *et al.* 2002). Sedimentation results in changes in dissolved oxygen, pH, and conductivity of the water, and water quality, therefore impacting on the use of such water (Miller 1998, Hirji *et al.* 2002). All benthic macroinvertebrates that need to attach themselves to stable substrates such as bedrock, boulders and cobbles or that hide among these substrates are severely affected (Diedericks 2002). Loss of aquatic habitats is one of the most serious consequences of sedimentation. Thus it is not surprising that alien vegetation supported less taxa compared with natural vegetation. However, alien vegetation provides good breeding environment for some invertebrates, especially Gyrinidae (Appendix 1b).

Elevation

Elevation had a major effect on the variability of benthic macroinvertebrates in all three vegetation types. However, taxon richness at lower elevations (natural vegetation at Piesanghoek and Cleared vegetation at Entabeni) was higher compared to alien vegetation. Taxon richness was lower in alien vegetation, although it had higher elevation compared with alien and cleared vegetation. An increase in elevation level resulted in the reduction of species richness. So, elevation did not clearly correlate with benthic macroinvertebrate taxon richness.

Shade, temperature and oxygen

Vegetation type was an important influence on controlling shading and temperature of the stream. There were clear relationships between both shade and temperature with vegetation type. However, here both shade and temperature counted little towards variation in benthic macroinvertebrates in all three vegetation types combined. Natural vegetation had the greatest shade effect on the stream in terms of lowered temperature. Highest temperatures were recorded in cleared vegetation with little or no shading of the stream. Alien vegetation only partly shaded the stream and resulted in moderate temperatures. Both high and lower temperature supported equal number of taxa, with most of the highly sensitive taxa being recorded at lower temperatures. Few taxa were recorded at moderate temperatures (i.e. alien vegetation).

Increase in temperature had negative impact on the survival of many sensitive invertebrates that require cool, oxygenated water. Notonemouridae (stoneflies) are highly sensitive to higher temperature and low oxygen level (Dallas *et al.* 1998). However, an increase in temperature may have a positive impact on benthic macroinvertebrates. Both the abundances, number of Ephemeroptera and Trichoptera taxa, the total number of taxa, the average number of taxa per stone and ASPT, all increased as temperature increases (Palmer 1997). Grazers are inhibited at >23°C through lower ingestion rate (Rutherford *et al.* 2000), and some families (e.g. Chironomidae) are adapted to low concentrations of dissolved oxygen (DO). Most Leptophlebiidae mayflies seem to require emergent large cobbles in pools with relatively high oxygen. So, reduced oxygen may lead to the reduction in such invertebrates that have high oxygen demand. The maintenance of adequate DO concentrations is critical for the survival and functioning of the benthic macroinvertebrates because DO is needed for the respiration of all aerobic organisms.

Conductivity

Conductivity is a measure of the ability of water to conduct an electrical current. This results from an increase in salts. An increase in water conductivity may have a major impact on the survival of certain sensitive benthic macroinvertebrates that have a specific range of conductivities in which they live. Study on *Tricorythus* species in the Sabie River showed that an increase in salinity level greater than 15% from about 15 mS/m can have a chronic effect on populations of this species (Goetsch and Palmer 1997). An increased water conductivity in natural vegetation benefitted Leptoceridae species (cased caddisflies) which prefer higher water conductivity. There was no record of this family in both alien and cleared vegetation with low conductivity.

Unique benthic macroinvertebrates

There were unique benthic macroinvertebrate families to each vegetation type (Table 3.1.1). Unique families are defined as families that were encountered in one vegetation type. For example, Paleomonidae was only in cleared vegetation. In turn, Perlidae was recorded only in natural and cleared vegetation types. Alien vegetation does not offer suitable microhabitats for this family which apparently needs natural vegetation. However, Dixidae and Simuliidae families were recorded only in alien vegetation. This indicated that alien vegetation may be important for the conservation of some indigenous species.

ADULT ODONATA SPECIES

Species composition and population densities

The recorded species richness of 33 adult Odonata species is unlikely to be complete for this area, considering sampling did not include high-flying and crepuscular species. Nevertheless, the records gave clear, comparative results.

There were significant differences between vegetation types, with the highest Odonata species richness and density being recorded in the cleared vegetation. Interestingly, almost equal number of Odonata species was recorded in both natural and alien vegetation. Some species, such as *Orthetrum julia falsum*, *Africallagma glaucum*, and *Elattoneura glauca*, were remarkably tolerant of vegetation type, being common across all three types.

Odonata as environmental indicators

Some Odonata species were very sensitive to vegetation type. *Allocnemis leucosticta*, for example, was abundant only in highly shaded natural vegetation. Other species such as *Nesciothemis farinosa*, *Orthetrum abbotti* and *Pantala flavescens* were locally abundant in cleared vegetation, but not in alien or naturally shaded conditions. They clearly benefitted from clearing of invasive alien plants.

Adult Odonata assemblages have the potential to indicate water quality. However, certain species are more sensitive than others (Watson 1982). Multispecies assemblages here were good ecological indicators for natural and alien vegetation types. *P. flavescens*, *N. farinosa*, *Crocothemis erythraea* and *O. abbotti* were indicators of cleared vegetation while *Orthetrum trinacria*, *Trithemis dorsalis* and *Trithemis stictica* were indicators of alien vegetation.

The proportions of sun-to shade-loving species are mainly controlled by the type of vegetation. Natural and alien vegetation are the most important for shade-loving species, whereas cleared vegetation supported sun-loving species. Shade-loving species, such as *A. leucosticta* were associated with natural and alien vegetation types only. Sun-loving species, such as *N. farinosa*, *O. abbotti*, *Sympetrum fonscolombii*, *Trithemis arteriosa*, *T. donaldsoni*, *T. furva*, *T. kirbyi*, *Crocothemis erythraea*, *C. sanguinolenta* and *Pseudagrion salisburyense* were associated with cleared vegetation. Steytler and Samways (1995) found that *T. arteriosa*, *T. stictica*, *T. dorsalis/furva*, *N. farinosa*, *O. julia falsum*, *O. trinacria*, *I. senegalensis* and *Agriocnemis* species were negatively correlated with shade, suggesting an affinity with sunshine.

Environmental variables and adult Odonata species

Canonical Correspondence Analysis (CCA) ordination showed that several environmental variables are important determinants of adult Odonata assemblages, with vegetation type having the largest effect.

Vegetation type and temperature

Temperature fluctuated primarily between vegetation types, rather than between sampling units, with a general trend of higher temperatures being recorded from cleared, open vegetation than alien, closed vegetation type. Slight differences between sampling units may be interpreted mainly due to differences in time of the day at which each sampling unit was sampled. CCA ordination with Odonata species and environmental variables showed positive correlation between vegetation type and stream temperature. Lower stream temperature was recorded in natural and alien vegetation types respectively, with higher temperature recorded in cleared vegetation. Natural, alien and cleared vegetation types accounted for most variation in adult Odonata. This was principally because each vegetation type had a series of microhabitats suitable or not for particular adult Odonata species. Few species were able to tolerate the conditions imposed by invasive alien trees, which supports findings elsewhere (Samways and Taylor 2004).

Temperature drops from cleared, through alien to natural vegetation respectively, illustrating the degree of cover from dense stands along the streams. Species richness can increase with stream temperature. Lutz and Pittman (1970) found that some ecological factors such as light intensity and ambient temperature had an influence on adult Odonata assemblages. Cleared vegetation with its moderately high temperature had the highest number of Odonata species. In fact, it doubled that of natural vegetation, which was one species less than that in alien vegetation (Fig. 3.2.15). In general, however, the data here show that water temperature may be used as reasonable surrogate for vegetation type. Clearing of IAPs clearly benefited adult Odonata species assemblages by creating more microhabitats and allowing sunlight to penetrate in open areas.

Elevation

An increase in elevation resulted in fewer adult Odonata species, and elsewhere in South Africa (Samways 1989a) and in Australia (Hawking and New 1999). Cleared vegetation of low elevation supported large number of Odonata species when compared to alien and natural vegetation of higher elevations. Many Odonata species (e.g. *N. farinosa*, *O. abbotti*, *P. salisburyense*, and *C. sanguinolenta*) were recorded only at lower elevation showing preference for certain elevations. Therefore, elevation is of great importance in determining the assemblages of adult Odonata along the Rivers.

Flow rate

Flow rate had a significant effect on the Odonate assemblage. *Platycypha caligata* was associated mainly with riffles. Steytler and Samways (1995) found that some species are associated with fast flowing water in South Africa. A replacement of riffle may result in possible replacement of adult Odonata species associated with or tolerant of conditions in current. Coenagrionidae larvae were often recorded in vegetation in backwaters or in pools. It is possible that very few if any adult Coenagrionidae will be found in a River without pools, at these sites. A declining flow level may increase biomass of diatoms or algae which could lead to an initial increase in grazers, detritus feeders and therefore Odonata (predators). Flow rate is of great importance in determining the assemblages of some Odonata species. Gomphidae larvae were often recorded in sandy substrates where they burrow under sand. However, libellulids have been recorded in stony habitats, both in- and out-of-current.

Complementarity between SASS5 and adult Odonata on River health assessment

Regression analysis of adult Odonata species richness against average score per taxon (ASPT) at each sampling unit showed that the two are significant and positively correlated, suggesting that adult Odonata can complement ASPT scores in River health assessment. This means that there is both a species level and a higher taxon level measure of disturbance. Complementarities between SASS5 method and adult Odonata species assemblages are useful in that aquatic larvae are not easily identified up to species level and as a result, a meaningful ecological conclusion on River conditions, both at species and family level can be drawn.

Although there was significant variation among macroinvertebrates for ASPT scores for the three vegetation types, there was no significant statistical variation between all three vegetation types combined in terms of SASS5 scores. SASS5 scores are good for comparing different Rivers but not different sites along the same River. Smith (2005) found that SASS5 scores were highly positive and significantly correlated with Odonata abundance and species richness between three Rivers in another region in South Africa. However, it should be considered that SASS5 scores are positively correlated with Odonata species richness only when compared sites had been selected from different River system. Here, a significant statistical variation was obtained between alien vegetation and cleared vegetation which were situated at different Rivers but not between natural and alien vegetation at the same River system.

Regression analysis also showed that SASS5 scores are not influenced to the same extent as adult Odonata species richness in all three vegetation types combined. Therefore, the use of ASPT scores and adult Odonata species as complementary metrics for measuring impact of IAPs on streams is justified.

CHAPTER 5

CONCLUSION AND MANAGEMENT RECOMMENDATIONS

Conclusion

The presence of invasive alien plants (IAPs) along the riparian zones reduced the SASS5 score. However, proper clearing of these IAPs greatly increased SASS5 scores by creating more suitable microhabitats for the most sensitive taxa that were lost to alien vegetation. Vegetation type, flow rate and microhabitats were the most important determinants of benthic macroinvertebrate assemblages.

Some benthic macroinvertebrate families (e.g. Leptoceridae and Ancylidae) were restricted to a particular vegetation type and were strongly affected by changes in vegetation type due to invasion by alien plants. However, some families were generalist and common across natural, alien and cleared vegetation types (e.g. Baetidae, Heptageniidae, Synlestidae and Athericidae). Nevertheless, there were changes in relative abundance of the major SASS5 indicator taxa, Ephemeroptera, Plecoptera, Trichoptera and Odonata (EPTO) across the three vegetation types. Alien vegetation supported few number of EPTO taxa compared with natural vegetation. Indeed, alien vegetation supported less benthic macroinvertebrate families than did natural or cleared vegetation. The equal number of families in natural and cleared vegetation was attributed to the recovery of certain taxa when vegetation is cleared. This indicates that clearing of IAPs restores stream fauna integrity remarkably quickly. This appears to have come about through improvement of both water quality and microhabitat diversity for this essentially sun-loving community.

Vegetation type, elevation, temperature, water conductivity, dissolved oxygen, shade and flow rate were important determinants of the abundance of adult Odonata species in all three vegetation types combined. It was whether vegetation was natural, alien or cleared that drove adult Odonata species richness and assemblage composition. Cleared vegetation, with its open areas, supported a higher number of adult Odonata than did natural or alien vegetation types. The low number of Odonata species in natural and alien vegetation was principally attributed to shade. Groups of Odonata species, and to some extent, individual species, can be used as indicators of alien vegetation disturbance along the River system.

Both benthic macroinvertebrate and adult Odonata population levels and assemblage changes are strongly affected by vegetation type. The clearing of invasive alien riparian vegetation clearly benefits the indigenous benthic macroinvertebrates, including Odonata, but if aliens are allowed to dominate and create a shaded tree canopy, the effect is one of loss of habitat. Alien riparian vegetation reduces sun-loving invertebrate species, especially dragonflies. Although this would appear to benefit the few endemic forest species (e.g. *Allocnemis leucosticta*), this is not the case in reality. As most rare species in South Africa prefer sunny habitats, aliens effectively bias the assemblage away from the natural status to one of widespread generalists. As it is difficult to name immature aquatic insects (larvae), yet much easier to name adult dragonflies, it means that dragonflies may be used to complement SASS for evaluating the local success of the Working for Water Programme, and River health condition.

A null hypothesis that the removal of invasive alien riparian vegetation will not restore the aquatic macroinvertebrate communities by improving both water conditions and riparian habitats was then rejected as more species were recorded after clearing of invasive alien plants. The effect of invasion of alien riparian vegetation is to reduce biodiversity of sun-loving species wheras clearing of these invasive alien plants improves the biodiversity of macroinvertebrates, such as Odonata. Odonata were found to be a good indicator of the degree of disturbance (i.e. invasion of IAPs) in rivers. It is hypothesised that sediment deposition in rivers can have a detrimental effect on benthic macroinvertebrate community, particularly the Odonata.

Management Recommendations

Clearance of invasive alien riparian vegetation, as along the Lutanandwa River at Entabeni plantation, results in intermediate disturbance that enhances species diversity of both benthic macroinvertebrates families and adult dragonfly species. However, initial clearing of invasive alien plants (IAPs) requires follow up clearance for the long-term benefit of stream biodiversity.

If the invasive alien plants along the streams in Sheefera and Piesanghoek plantations were successfully controlled, there is likely to be an increase in both benthic macroinvertebrates and adult Odonata species richness. The most sound management approach for the protection of moderately impacted systems such as Sheefera and Piesanghoek would be the limitation of further encroachment by IAPs along the riparian vegetation.

Streams at Sheefera, Piesanghoek and Entabeni plantations are subject to silt deposition by their location in steep, mountainous areas. Therefore, well-buffered riparian zones must be maintained at all the times.

Pines and eucalypts, which are spreading into the edge of the stream, as the case in Piesanghoek, should be cleared before the stream is severely invaded and suffers reduced biodiversity. This suggests that spreading of plantation forest should be monitored on a regular basis to avoid an encroachment problem.

Streams within the plantations are important for the conservation of stream biodiversity. They can serve as conservation areas for biodiversity when the riparian zones are well managed.

Long-term biomonitoring at selected sampling units within the plantations is recommended. It provides useful insights into natural ecosystem dynamics, and is essential for obtaining a greater understanding of ecosystem processes and change.

Groups of Odonata species rather than individual species are recommended for use as indicators because individual species are constrained by physical environmental variables unrelated to the desired conditions or by specific microhabitat requirements.

SASS5, complemented with adult Odonata, can be used to evaluate distribution or restoration changes on the stream during plantation management. Good management will improve stream conditions and maintain irreplaceable biodiversity, which in turn becomes an indicator of such good management.

It is suggested that future research should investigate the sources, fates and management significance of deposited sediments in the Rivers of Soutpansberg. Particular attention should be given to their effects on benthic macroinvertebrates, particularly the Odonata.

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APPENDICES

Appendix 1: Recorded benthic macroinvertebrate families with their abbreviated names.

Taxon	Abbreviations used in analyses
ANNELIDA	
Oligochaeta	Oli
CRUSTACEA	
Potamonautidae*	Pot
Paleomonidae	Pal
PLECOPTERA	
Perlidae	Per
EPHEMEROPTERA	
Baetidae 1 spp.	Bae 1sp
Baetidae 2 spp.	Bae 2sp
Baetidae >2 spp.	Bae >sp
Caenidae	Cae
Heptageniidae	Hep
Leptophlebiidae	Lep
Oligoneuridae	Oligo
Tricorythidae	Tri
ODONATA	
Chlorocyphidae	Chl
Synlestidae	Syn
Coenagrionidae	Coe
Lestidae	Les
Platycnemididae	Pla
Protoneuridae	Pro
Aeshnidae	Aes
Gomphidae	Gom
Libellulidae	Lib
HEMIPTERA	
Corixidae*	Cor
Gerridae*	Ger
Notonectidae*	Not
Veliidae/M.veliidae*	Vel
TRICHOPTERA	
Hydropsychidae 1spp.	Hyd 1sp
Hydropsychidae 2 spp.	Hyd 2sp
Hydropsychidae >2 spp.	Hyd >2sp

Taxon	Abbreviations used in analyses
Psychomyiidae	Psy
Leptoceridae	Lept
COLEOPTERA	
Dytiscidae*	Dyt
Elmidae	Elm
Gyrinidae*	Gyr
Helodidae*	Hel
Hydrophilidae*	Hydro
Psephenidae	Pse
DIPTERA	
Athericidae	Ath
Chironomidae	Chi
Dixidae*	Dix
Ephydridae	Eph
Psychodidae	Psyc
Simulidae	Sim
Tabanidae	Tab
Tipulidae	Tip
GASTROPODA	
Ancylidae	Anc
Planorbinae*	Plan

* Air breathers

Appendix 1a: Benthic macroinvertebrate taxon richness and abundance in natural (N) vegetation sampling units. Full family names are presented in Appendix 1.

Taxon	Sampling Units																							Total
	N 25	N 26	N 27	N 28	N 29	N 30	N 31	N 32	N 33	N 34	N 35	N 36	N 37	N 38	N 39	N 40	N 41	N 42	N 43	N 44	N 45	N 46	N 47	
ANNELIDA																								
Oli							2								1			1	1	1	1		1	8
CRUSTACEA																								
Pot	6	5	5	4	5	5	7	3	5	7	8	6	6	8	8	4	7	4			1	2		106
PLECOPTERA																								
Per			1	1																				2
EPHEMEROPTERA																								
Bae 1sp		9	3	4	3		2			1	1	4	1	3	2		13		4	3		1	2	56
Bae 2sp	10					6			7							10		6						39
Cae		6	1	5					3		2	1	1		2		4	1						26
Hep					2																			2
Lep		1	1	1	1			1																5
Olig	2																							2
Tri	38	7	29	21	39	12	13	7	7	6	2	2	2	1			2							188
ODONATA																								
Chl		1		1	1						1						1	2						7
Syn	2		2											2				8						14
Coe		2		1		1					1													5
Les				1											1									2
Plat	1	1	1				1	1			1			2	1									9
Prot								1								2							1	4
Aes	2			1		1	1			1		1	1	1										9
Gom	4	15	4		1	9	8	12	4	13	5	25	7	19	6	10	10	3			4	3		162
Lib										1														1
HEMIPTERA																								
Cor																							1	1
Ger							1			1				2	7			1	1	16	4	19		52

Taxon	Sampling Units																							
	N 25	**N 26**	**N 27**	**N 28**	**N 29**	**N 30**	**N 31**	**N 32**	**N 33**	**N 34**	**N 35**	**N 36**	**N 37**	**N 38**	**N 39**	**N 40**	**N 41**	**N 42**	**N 43**	**N 44**	**N 45**	**N 46**	**N 47**	**Total**
Vel	1	4	1					1	2		1	2	1			1	3	8		3		9	2	39
TRICHOPTERA																								
Hyd 1sp			19								1		4			11				2	2	1	3	43
Hyd 2sp	30				14			6					28	33			27	18						156
Hydr >2sp			10	17		31	25		9		14					19							9	134
Lept		1			4																			5
COLEOPTERA																								
Dyt			1		1			1			1				1								2	7
Elm																		1						1
Gyr		18	12	32	3	7	16	18	34	48	28	4	14	21	18	6		5	13	11		17	14	339
Hel	1													1			1	1	1					5
Pse		2	1	1	3	1	2	3			2						1							16
DIPTERA																								
Ath	3		2	3	7	5	2	5	1	2	2	2	1	1	2	6	4	1	7		1	4	1	62
Chi																			5		7		1	13
Tab	3	2				3	1	1				6	3	3		1	3		3	1		3	2	35
Tip		1						2		1		1				1								6
GASTROPODA																								
Anc				1	1	1			1													1		5

Appendix 1b: Benthic macroinvertebrate taxon richness and abundance in alien (A) vegetation sampling units. Full family names are given in Appendix 1.

	Sampling Units																							
Taxon	**A 02**	**A 03**	**A 04**	**A 05**	**A 06**	**A 07**	**A 08**	**A 09**	**A 10**	**A 11**	**A 12**	**A 13**	**A 14**	**A 15**	**A 16**	**A 17**	**A 18**	**A 19**	**A 20**	**A 21**	**A 22**	**A 23**	**A 24**	**Total**
ANNELIDA																								
Oli							1											1						2
CRUSTACEA																								
Pot	3	6	8	4	4	8	9			4	3	3	3	4	4	3	4	5	3	5	3	6	3	95
EPHEMEROPTERA																								
Bae 1sp			27	11	14	9			13	10	16	10	11				9			7	6		7	150
Bae 2sp	21	30					11	32						15	13	13		8	10			15		168
Cae	5	11	4		3			4			3	1	3			2		1	5		15			57
Hep															2									2
Lep					1									18	24		3	1	1	2				50
Olig	1		2	1	3	1		4		2	4		5				2							25
Tri	1				8	43		1	43	7	9	54	28	2		6	14	11	1	34	15	36	31	344
ODONATA																								
Chl					1	3						1							3					8
Syn			1								1	1		6	3	5	1	1			3	2	3	27
Coe	1	4			1	1	10	1	3	4	4		3	2	5	4	1	1	3	1				49
Les																					1			1
Pla	1	3	1		2	1			1	1	2		4									1	2	19
Aes	2					5	11		2	18	6	1	6	10	8	6	9	4	4	8	11	2	5	118
Gom	1			1	2	1	2	7	2	3	8	5	9	6		12	3	2		6		7	1	78
Lib												1												1
HEMIPTERA																								
Ger														1								1		2

Appendix 1b continue

	Sampling Units																							
Taxon	**A02**	**A03**	**A04**	**A05**	**A06**	**A07**	**A08**	**A09**	**A10**	**A11**	**A12**	**A13**	**A14**	**A15**	**A16**	**A17**	**A18**	**A19**	**A20**	**A21**	**A22**	**A23**	**A24**	**Total**
Not								1																1
Veli		5		2	2					1	1	1	3	1		1		3				1	1	22
TRICHOPTERA																								
Hyd 1sp	3	23	18	19	17			5		17	11	8		7		1	14	15	2	15	14	26		215
Hyd 2sp						43			33				11										37	124
Psy							7																	7
COLEOPTERA																								
Dyt								1	1	2				1							1			6
Elm																								
Gyr	2	25	6	2	19	17	29	40	23	30	6	12	32	15	18	18	19	8	41		12	11	26	411
Hel	2		2	2	1	1												1			1			10
Pse						3	1	1	1	5	18	5	15	2			10	3		3		4	4	75
DIPTERA																								
Ath			1	6	5	1	4	1			2	2	1	2		4	5	1	2	4	2	3		46
Dix	1									4	1													6
Psyc														1										1
Sim	1	4						1		1	1		2											10
Tab										4	1	1	1	2		2	3	1			1	1		17
Tip		1	2	1								1												5

Appendix 1c: Benthic macroinvertebrate taxon richness and abundance in cleared (C) vegetation sampling units. Full family names are given in appendix 1.

	Sampling Units																									
Taxon	**C 48**	**C 49**	**C 50**	**C 51**	**C 52**	**C 53**	**C 54**	**C 55**	**C 56**	**C 57**	**C 58**	**C 59**	**C 60**	**C 61**	**C 62**	**C 63**	**C 64**	**C 65**	**C 66**	**C 67**	**C 68**	**C 69**	**C 70**	**C 71**	**C 72**	**Total**
ANNELIDA																										
Oli	2					1								2				2								7
CRUSTACEA																										
Pot			6			3	2	2			4		2	2	4	4	1		3	1	4		3	4		45
Pal		14		2		2		4			1			9	9		7		4		14	2	4	1	12	85
PLECOPTERA																										
Per			1				1																			2
EPHEMEROPTERA																										
Bae 1sp	8		2		3							6		4			2		2			3	12	6	1	49
Bae 2sp		5		5			7	14	10	10	6				9											66
Bae >2sp						19							26			16		48								109
Cae			1										1											1		3
Hep												1														1
Lep				3																		3				6
Tri	28	4	21		29	10	14	8	21	16	27	10	5	5		25	1	4	11	10	2	7		1	3	262
ODONATA																										
Chl		11	2		3		2	1			4	1	1	7		2	2	3	3	1		3	2	1	1	50
Syn																					1					1
Coe		1										3		2						1	1	1		4	3	16
Les				1																					1	2
Pla		1						1										4							6	12
Pro		3				4								1								1				9
Aes											1				1	1			2	3	3			1		12
Gom	3	6	6	5	2		2	4	2		1	4	1	10	1	6	2	3	9	3	6	5	2	7	3	93
Lib	1		4				2	1	3	2	1															14
HEMIPTERA																										
Ger				14	2		14					8													2	40
Vel	1									1					1							1	1			5
TRICHOPTERA																										
Hyd 1sp				2																					5	7
Hyd 2sp		21				10																				31
Hyd >2sp	25		27		21		17	22	40	37	33	12	27	11	13	37	17	28	13	30	7	22	14	28		481

Appendix 1c

	Sampling Units																									
Taxon	**C 48**	**C 49**	**C 50**	**C 51**	**C 52**	**C 53**	**C 54**	**C 55**	**C 56**	**C 57**	**C 58**	**C 59**	**C 60**	**C 61**	**C 62**	**C 63**	**C 64**	**C 65**	**C 66**	**C 67**	**C 68**	**C 69**	**C 70**	**C 71**	**C 72**	**Total**
COLEOPTERA																										
Dyt																	2									2
Elm	1			1	1																				1	4
Gyr	3	1	3		12	9	1	3	5	18	30	1	2	6	17	2			8	4	18	18			14	175
Hel		2										1					1									4
Hyd														1												1
DIPTERA																										
Ath	3			1	1	4	1			2			2	3	2									1		20
Chi					1																					1
Eph	3					3	5	3	3	10										2	10	5				44
Psyc																				1	1					2
Tab											8	9	2	3	3	3	3	2	3				5	13	4	58
Tip		1			2						2						1				1		5	1	1	14
GASTROPODA																										
Pla				1																						1

Appendix 2: Measured variables and descriptions at each sampling unit (SU) during benthic macroinvertebrates sampling period.

SU no.	Latitude (°South)	Longitude (°East)	Elevation (m)	Water Temperature (°C)	Conductivity (mS/cm)	Dissolved Oxygen (mg/L)	pH	Shade cover	Microhabitats	Flow rate
A 02	23.02959	29.91512	892	18.67	0.071	7.06	6.37	close	av/mv/sooc/m	run
A 03	23.03176	30.15697	984	19.23	0.071	7.37	6.1	open	mv/sic/g/m	run
A 04	23.03121	30.15725	997	19.94	0.073	6.95	6.58	medium	sic/sooc/av/mv	riffle
A 05	23.03127	30.15729	1006	19.3	0.075	7.14	5.44	close	sooc/mv/g/m	run
A 06	23.03134	30.15834	972	15.67	0.115	7.9	7.33	close	sic/mv/m/a	riffle
A 07	23.0209	30.07706	1020	18.11	0.117	7.89	7.34	medium	sic/g/m/av/mv/a	riffle
A 08	23.0207	30.07702	1030	19.3	0.12	7.64	6.82	open	sic/sooc/av/mv/m/a	run
A 09	23.02053	30.07711	1035	20.09	0.122	7.25	6.25	open	sic/sooc/s/m/av/mv/a	run
A 10	23.02036	30.07693	1014	14.3	0.107	8.11	6.94	open	sic/g/s/m/av/mv/a	riffle
A 11	23.02008	30.07683	1012	15.02	0.108	8.35	7.16	open	sic/sooc/av/mv/a	riffle
A 12	23.01964	30.07701	1015	16.15	0.11	8.21	7.24	open	sic/sooc/g/s/av/mv/a	riffle
A 13	23.01973	30.07654	1024	17.29	0.113	7.81	7.61	open	sic/sooc/mv/g/s/a	run
A 14	23.01964	30.07637	1029	19.41	0.118	7.7	7.37	open	sic/sooc/mv/av/a	run
A 15	23.01939	30.07609	990	16.16	0.111	7.48	7.46	open	sooc/mv/av/a	run
A 16	23.01924	30.07598	993	16.81	0.113	7.71	7.11	open	sic/sooc/mv/av/a	run
A 17	23.01906	30.07586	997	17.14	0.114	7.61	7.07	open	sic/sooc/mv/av/a	run
A 18	23.01893	30.07574	1005	17.89	0.115	7.29	7.22	open	sic/sooc/g/s/av/mv/a	riffle
A 19	23.01865	30.07563	1011	18.65	0.116	7.08	7.43	open	sic/sooc/mv/av/a	riffle
A 20	23.01851	30.07541	1015	18.48	0.118	6.71	7.17	open	sooc/av/mv	pool
A 21	23.01841	30.07532	1017	20.58	0.123	6.94	8.11	open	sic/av/mv/si	riffle
A 22	23.01797	30.07513	1026	19.61	0.121	6.91	7.78	medium	sic/sooc/mv/si	riffle
A 23	23.01787	30.07493	1029	19.05	0.12	6.88	8.05	medium	sic/sooc/mv/a	riffle
A 24	23.0177	30.07484	1032	18.69	0.119	6.29	7.95	medium	sic/sooc/mv	run
N 25	23.01655	30.07437	1004	14.02	0.108	7.88	7.73	open	sic/sooc/mv/av	riffle
N 26	23.01628	30.07427	1005	14.36	0.108	7.9	7.74	open	sic/sooc/mv	run
N 27	23.01591	30.07407	1007	15.03	0.11	7.92	7.79	open	sic/sooc/mv/m/s	pool
N 28	23.01517	30.07385	1012	15.98	0.112	7.75	7.74	close	sic/sooc/g/s/m	pool
N 29	23.0151	30.07382	1016	16.51	0.114	7.41	7.54	open	sic/sooc/mv	run
N 30	23.01466	30.07371	1018	17.27	0.115	7.69	7.78	medium	sic/av/mv/g/s	riffle

SU no.	Latitude (°South)	Longitude (°East)	Elevation (m)	Water Temperature (°C)	Conductivity (mS/cm)	Dissolved Oxygen (mg/L)	pH	Shade cover	Microhabitats	Flow rate
N 31	23.01445	30.07358	1026	18.04	0.117	7.69	7.65	open	sic/sooc/g/s/m/mv	run
N 32	23.01411	30.07332	1033	18.51	0.119	7.35	7.62	close	sic/sooc/mv/g/s/m	run
N 33	23.01385	30.07317	1016	19.38	0.122	5.73	7.62	close	sic/sooc/mv	pool
N 34	23.01369	30.07299	1017	19.44	0.122	6.14	7.49	close	sic/sooc/mv/g/s/m	run
N 35	23.01328	30.07296	1019	19	0.121	6.72	7.44	medium	sic/sooc/mv/g/s/m	run
N 36	23.01298	30.07259	1016	18.8	0.121	6.99	7.74	medium	sic/sooc/mv/g/m	riffle
N 37	23.01278	30.07235	1018	18.96	0.121	6.73	7.85	open	sic/sooc/av/mv/g/s/m/a	riffle
N 38	23.01251	30.07226	968	14.63	0.108	7.82	7.87	open	sic/sooc/av/mv/m	run
N 39	23.01217	30.0719	940	14.82	0.108	7.82	7.93	medium	sic/sooc/mv/g/s/m	run
N 40	23.01176	30.0716	1009	15.01	0.109	7.85	8.1	close	sic/sooc/g	run
N 41	23.01161	30.07158	949	16.16	0.109	7.99	8.06	medium	sic/sooc/g/s/m	riffle
N 42	23.01132	30.07107	990	15.32	0.11	7.78	7.98	open	sic/sooc/mv/g/s/m/a	run
N 43	23.00996	30.0705	984	15.69	0.143	7.51	7.84	open	sic/sooc/g/s/m/si	riffle
N 44	23.00961	30.06971	985	16.03	0.144	7.92	7.55	open	sic/sooc/mv/g/s/m	riffle
N 45	23.00932	30.06903	988	15.89	0.143	6.8	7.25	close	sooc/mv/g/s/m/a	pool
N 46	23.00925	30.06873	985	15.84	0.127	7.5	8.09	close	sic/mv/g/s/m/a	run
N 47	23.00905	30.06828	986	15.31	0.124	7.8	8.28	medium	sic/sooc/mv/g/s/m/a	run
C 48	23.04759	30.22754	721	16.03	0.065	9.15	7.51	open	sic/sooc/g/s/m/a	riffle
C 49	23.0473	30.22732	722	16.22	0.066	9.11	7.54	open	sic/sooc/mv/g/si	riffle
C 50	23.04709	30.22721	720	16.37	0.066	9.1	7.58	open	sic/sooc/g/s/m	riffle
C 51	23.04659	30.22704	728	17.48	0.068	9.14	7.53	open	sooc/mv/g/s/m/si	pool
C 52	23.04591	30.22683	732	18.11	0.069	8.83	7.24	open	sic/g/s/m/si	riffle
C 53	23.04356	30.21941	757	19.76	0.072	8.86	7.73	medium	sic/sooc/mv/g/s/m/a	run
C 54	23.04307	30.21846	772	21.58	0.074	8.27	7.72	medium	sic sooc/mv/g/s/m/si/b	riffle
C 55	23.04282	30.21804	756	21.73	0.074	7.94	7.71	open	sic/sooc/mv/g/s/m/si	run
C 56	23.04214	30.21741	772	22.09	0.075	7.84	7.71	open	sic/sooc/g/s/m/a	riffle
C 57	23.0418	30.21709	769	22.06	0.075	7.66	7.8	medium	sic/sooc/g/s/m/si/a	run
C 58	23.04147	30.21759	677	15.51	0.067	9.06	7.5	medium	sic/mv/si/a	riffle
C 59	23.04132	30.21802	678	15.6	0.067	9.3	7.54	medium	sic/mv/g/s/m	riffle
C 60	23.04122	30.21899	712	15.59	0.067	9.09	7.51	close	sic/sooc/mv/g	riffle
C 61	23.03974	30.21924	695	15.73	0.067	9.15	7.57	close	sic/mv/g/s/b	riffle

Appendix 2 continue

SU no.	Latitude (°South)	Longitude (°East)	Elevation (m)	Water Temperature (°C)	Conductivity (mS/cm)	Dissolved Oxygen (mg/L)	pH	Shade cover	Microhabitats	Flow rate
C 62	23.03884	30.21884	685	15.85	0.067	9.13	7.65	medium	sic/mv/g/s/m	riffle
C 63	23.03836	30.21883	699	16.11	0.067	9.2	7.64	medium	sic/g/s	riffle
C 64	23.03716	30.21886	717	16.54	0.068	9.1	7.72	medium	sic/sooc/mv/g/s	riffle
C 65	23.03387	30.2154	735	18.22	0.07	8.6	7.9	close	sic/mv/g/s/m/si	run
C 66	23.03342	30.21522	724	19.12	0.072	8.54	7.8	medium	sic/sooc/mv/g/s/m	run
C 67	23.03258	30.21491	727	20.76	0.075	8.45	7.86	open	sic/sooc/mv/g/s/m/a	run
C 68	23.03221	30.21432	730	21.14	0.075	8.22	7.92	open	sic/mv/g/s/m/a	riffle
C 69	23.03156	30.21357	737	21.38	0.076	8.06	7.82	open	sic/sooc/mv/g	run
C 70	23.03125	30.21312	743	21.42	0.076	8.06	7.92	open	sic/mv/g/s/m	riffle
C 71	23.03017	30.21237	745	20.85	0.076	8.19	7.81	open	sic/mv/g/s/m	run
C 72	23.03002	30.21182	743	20.39	0.075	7.94	7.74	open	sooc/mv/g/s/m/a	run

SU: A = Alien, N =Natural, C = Cleared vegetation
Habitats: sic= stones in current, sooc= stones out of current, av= aquatic vegetation, mv= marginal vegetation, g= gravel, s= sand, m= mud, si= silt, a= algae, b= boulder.

Appendix 3: Recorded adult Odonata species with their abbreviated names.

Scientific Name	Abbreviations used in analysis	Common name
SUBORDER ANISOPTERA		**DRAGONFLIES**
Family Aeshnidae		**Hawkers**
1. *Aeshna subpupillata* McLachlan, 1896	*A.sub*	Stream Hawker
2. *Anax speratus* Hagen, 1867	*A.spe*	Orange Emperor
Family Gomphidae		**Clubtails**
3. *Ictinogomphus ferox* Rambur, 1842	*I.fer*	Common Tigertail
4. *Paragomphus cognatus* (Rambur, 1842)	*P.cog*	Boulder Hooktail
Family Corduliidae		**Emeralds**
5. *Phyllomacromia picta* (Sélys, 1871)	*M.pic*	Darting Cruiser
Family Libellulidae		**Skimmers**
6. *Crocothemis erythraea* (Brullé, 1832)	*C.ery*	Broad Scarlet
7. *Crocothemis sanguinolenta (*Burmeister,1839)	*C.san*	Small Scarlet
8. *Nesciothemis farinosa* (Förster, 1898)	*N.far*	Black-pointed Skimmer
9. *Orthetrum abbotti* Calvert, 1892	*O.abb*	Little Skimmer
10. *Orthetrum caffrum* (Burmeister, 1839)	*O.caff*	White-lined Skimmer
11. *Orthetrum chrysostigma* (Burmeister, 1839)	*O.chr*	Epaulet Skimmer
12. *Orthetrum icteromelas* Ris, 1910	*O.ict*	Spectacled Skimmer
13. *Orthetrum julia falsum* Longfield, 1955	*O.jul*	Julia Skimmer
14. *Orthetrum machadoi* Longfield, 1955	*O.mac*	Swamp Skimmer
15. *Orthetrum trinacria* (Sélys, 1841)	*O.tri*	Long Skimmer
16. *Palpopleura portia* (Drury, 1773)	*P.por*	St Lucia Widow
17. *Pantala flavescens* (Fabricius, 1798)	*P.fla*	Wandering Glider
18. *Sympetrum fonscolombii* (Sélys, 1840)	*S.fon*	Red-veined Darter
19. *Trithemis arteriosa* (Burmeister, 1839)	*T.art*	Red-veined Drawing
20. *Trithemis donaldsoni* (Calvert, 1899)	*T.don*	Denim Dropwing
21. *Trithemis dorsalis* (Rambur, 1842)	*T.dor*	Lakeside Dropwing
22. *Trithemis furva* Karsch, 1899	*T.fur*	Dark Dropwing
23. *Trithemis kirbyi* Sélys, 1891	*T.kir*	Rock Dropwing
24. *Trithemis pluvialis* Förster, 1906	*T.plu*	Riffle Dropwing
25. *Trithemis stictica* (Burmeister, 1839)	*T.sti*	Jaunty Dropwing
SUBORDER ZYGOPTERA		**DAMSELFLIES**
Family Coenagrionidae		**Pond Damsels**
26. *Pseudagrion hageni tropicanum* Pinhey, 1966	*P.hag*	Painted Sprite
27. *Pseudagrion kersteni* (Gerstäcker, 1869)	*P.ker*	Kersten's Sprite
28. *Pseudagrion salisburyense* Ris, 1921	*P.sal*	Slate Sprite
29. *Africallagma elongatum* (Martin, 1907)	*A.elo*	Slender Bluet
30. *Africallagma glaucum* (Burmeister, 1839)	*A.gla*	Swamp Bluet
Family Platycnemididae		
31. *Allocnemis leucosticta* Sélys, 1863	*A.leu*	Goldtail
Family Protoneuridae		**Threadtails**
32. *Elattoneura glauca* (Sélys, 1860)	*E.gla*	Grey Threadtail
Family Chlorocyphidae		**Jewels**
33. *Platycypha caligata* (Sélys, 1853)	*P.cal*	Dancing Jewel

Appendix 3a: List of adult Odonata species recorded in natural (N) vegetation.

	Sampling Units																							
Species Name	N 25	N 26	N 27	N 28	N 29	N 30	N 31	N 32	N 33	N 34	N 35	N 36	N 37	N 38	N 39	N 40	N 41	N 42	N 43	N 44	N 45	N 46	N 47	**Total**
SUBORDER ANISOPTERA																								
Family Aeshnidae																								
A.. subpupillata				1																				1
A. speratus																					1			1
Family Gomphidae																								
I. ferox																		1	2					3
Family Corduliidae																								
P. picta												1	4											5
Family Libellulidae																								
O. chrysostigma																				4				4
O. julia-falsum	3	4		1			2	1		1	6		9	1	2			5		4	6	2	5	52
O. machadoi						1	1						3											5
SUBORDER ZYGOPTERA																								
Family Coenagrionidae																								
A. .elongatum	4	1					4												4					13
A.. glaucum	8	13	11	6	8	14	18	13	3	6	9	9	19	14	7	17	2	7		7	13	4	14	222
P. hageni tropicanum		1		1				4		3	9	3		1	4			4			8	3		41
P. kersteni	1	3					5				1			3				2						15
Family Platycnemididae																								
A. leucosticta		4				1	6	7	4	5	14	16	3	11	9	24	12	15	8	8	14	5	13	179
Family Protoneuridae																								
E. glauca	1	1		1																				3
Family Chlorocyphidae																								
P. caligata			1		2	4						4		2	2	3			3		2		2	25

Appendix 3b: List of adult Odonata species recorded in alien (A) vegetation.

Species Name	Sampling units A 02	A 03	A 04	A 05	A 06	A 07	A 08	A 09	A 10	A 11	A 12	A 13	A 14	A 15	A 16	A 17	A 18	A 19	A 20	A 21	A 22	A 23	A 24	Total
SUBORDER ANISOPTERA																								
Family Gomphidae																								
P. cognatus																						1		1
Family Libellulidae																								
O. caffrum															3									3
O. chrysostigma																								
O. icteromelas																								
O. julia-falsum	3			1		5	3			5	1					3		7	1	2	1	3	2	37
O. machadoi							2		4	2							1			1				10
O. trinacria			3																					3
P. portia							1																	1
P. flavescens																								
T .dorsalis								1																1
T .pluvialis		1																						1
T. stictica									1															1
SUBORDER ZYGOPTERA																								
Family Coenagrionidae																								
A.. glaucum	5	5	6	3	3	5	6	12	13	14	16	19	13	14	13	15	3	13	13	17	16	7	6	237
P. hageni tropicanum										1									1					2
P. kersteni																			1					1
Family Platycnemididae																								
A. leucosticta	3	3	3	1	4	4	2						2	5				3	2	5	4	7	5	53
Family Protoneuridae																								
E. glauca																1								1
Family Chlorocyphidae																								
P. caligata		2				2	2				3	1		3			1			4	3	2	4	27

Appendix 3c: List of adult Odonata species recorded in cleared (C) vegetation.

	Sampling units																									
Species Name	C 48	C 49	C 50	C 51	C 52	C 53	C 54	C 55	C 56	C 57	C 58	C 59	C 60	C 61	C 62	C 63	C 64	C 65	C 66	C 67	C 68	C 69	C 70	C 71	C 72	**Total**
SUBORDER ANISOPTERA																										
Family Aeshnidae																										
A. speratus		2														1							1	1		5
Family Gomphidae																										
I. ferox	5	4	1	4			3								3											20
P. cognatus													1						1	1						3
Family Corduliidae																										
P. picta		1																								1
Family Libellulidae																										
C. erythraea			1					1																		2
C. sanguinolenta													1					1								2
N. farinosa	1		2	1			4	2			8	3			5											26
O. abbotti																		1						2		3
O. caffrum																								1		1
O. chrysostigma																		13								13
O. icteromelas															2											2
O. julia-falsum			1	3	3					2	6		1		1		2	5	1						1	26
O. machadoi												1					2			1	1					5
P. portia												1					1	5								7
P. flavescens							1	1				1	1			1	1					1		1		8
S. fonscolombii																		2								2
T. arteriosa				3																						3
T. donaldsoni	1		1	1		3	2								1		1									10
T. furva													1													1
T. kirbyi					3			1																		4
T. pluvialis			1															2	1							4

Appendix 3c continue

	Samplingunits																								
Species Name	C 48	C 49	C 50	C 51	C 52	C 53	C 54	C 55	C 56	C 57	C 58	C 59	C 60	C 61	C 62	C 63	C 64	C 65	C 66	C 67	C 68	C 69	C 70	C 71	C 72	**Total**
SUBORDER ZYGOPTERA																										
Family Coenagrionidae																										
A.. elonatum															14	13								4		31
A. .glaucum	4	6	9	8	17	12	9	13	3	3		9	12	5	8	8	14		4	6	22	14	14	16	7	223
P. hageni tropicanum				1				8			5				1	1										16
P. kersteni									1						1											2
P. salisburyense													1													1
Family Protoneuridae																										
E. glauca							3	3				2														8
Family Chlorocyphidae																										
P. caligata	3	3	3	6	11	8	11		4	6	13	17	7	6	1	2	2	3	2	3	4	3	4	3	3	128

Appendix 4: Measured variables at each sampling unit (SU) during adult Odonata sampling period. Same sampling units as in benthic macroinvertebrates were used.

SU no.	Water Temperature (°C)	Conductivity (mS/cm)	Dissolved Oxygen (mg/L)	pH
A 02	21.93	0.078	7.53	4.59
A 03	22.76	0.079	7.32	7.29
A 04	22.7	0.077	7.27	5.13
A 05	22.29	0.079	7.08	5.13
A 06	22.35	0.081	7.27	3.83
A 07	22.02	0.138	7.65	5.16
A 08	24.83	0.143	7.22	7.55
A 09	25.62	0.146	7.36	6.34
A 10	25.75	0.147	7.05	6.44
A 11	25.99	0.146	7.19	6.67
A 12	26.17	0.146	7.26	7.07
A 13	25.85	0.145	7.15	7.41
A 14	25.65	0.145	6.96	7.76
A 15	25	0.143	6.82	7.51
A 16	25.01	0.143	6.82	7.51
A 17	24.65	0.142	6.46	7.5
A 18	24.34	0.142	6.19	7.33
A 19	24.02	0.14	7.68	6.45
A 20	24.62	0.142	7.41	7.36
A 21	24.83	0.143	7.42	7.47
A 22	25.27	0.144	6.85	8.06
A 23	25.05	0.144	7.3	7.93
A 24	24.46	0.14	7.26	7.61
N 25	22.99	0.139	7.05	6.05
N 26	22.82	0.139	6.58	5.89
N 27	22.98	0.139	7.02	6.37
N 28	22.73	0.138	7.14	6.51
N 29	22.55	0.138	7.01	6.58
N 30	22.24	0.137	6.91	6.71
N 31	22.3	0.137	7.06	7.16
N 32	18.73	0.127	7.83	6.58
N 33	19.02	0.128	7.47	6.93
N 34	19.52	0.13	7.38	7.11
N 35	19.51	0.13	7.36	7.12
N 36	19.75	0.129	8.01	7.17
N 37	19.95	0.128	7.88	7.32
N 38	20.03	0.129	7.87	7.42
N 39	20.33	0.13	7.17	7.32
N 40	20.35	0.13	7.14	7.32
N 41	20.96	0.131	7.64	7.58
N 42	20.98	0.131	7.63	7.57
N 43	21.4	0.178	7.2	7.24
N 44	21.41	0.177	7.18	7.24
N 45	22.25	0.181	6.75	5.43
N 46	22.27	0.181	6.77	5.43
N 47	23.57	0.161	7.16	7.79
C 48	23.37	0.083	7.55	6.09

Appendix 4 continue

SU no.	Water Temperature (°C)	Conductivity (mS/cm)	Dissolved Oxygen (mg/L)	pH
C 49	23.4	0.083	7.47	5.95
C 50	23.43	0.084	7.41	5.94
C 51	24.6	0.085	7.49	6.54
C 52	24.64	0.085	7.47	6.46
C 53	24.67	0.085	7.44	6.47
C 54	26.58	0.09	7.47	6.58
C 55	26.61	0.09	7.49	6.63
C 56	27.61	0.091	7.25	5.08
C 57	27.65	0.091	7.25	5.38
C 58	27.72	0.091	7.22	5.8
C 59	27.77	0.091	7.2	5.91
C 60	25.18	0.088	7.19	5.86
C 61	25.21	0.088	7.21	5.89
C 62	25.24	0.088	7.22	5.93
C 63	28.14	0.091	6.93	8.23
C 64	28.17	0.092	6.93	8.23
C 65	28.2	0.091	6.92	8.24
C 66	30.49	0.097	6.46	7.24
C 67	30.48	0.097	6.46	7.27
C 68	30.48	0.097	6.46	7.3
C 69	30.62	0.1	6.25	8.01
C 70	30.61	0.099	6.26	8.01
C 71	30.6	0.099	6.24	8.01
C 72	29.66	0.1	6.05	6.92

SU: A = Alien, N = Natural, C = Cleared vegetation